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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 39-1/1

“Synthetic Aperture Radar”
(«РЛ система с синтезированной апертурой»)

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"An Interpolated Phase Adjustment by Contrast Enhancement Algorithm for SAR"

Phase adjustment by contrast enhancement (PACE) is an autofocus algorithm that is capable of performance that is unattainable by conventional techniques. It is a nonparametric method that requires no constraints on the type of phase error to be measured. The algorithm does not require special data culling techniques or the presence of isolated scatterers. However, the drawback of PACE algorithm is that the number of estimated variables is very large; it leads to a long computational time. The azimuth sampling frequency is commonly much bigger than the bandwidth of phase error in SAR image so that we can estimate part of the phase error variables and then obtain the whole variables by interpolation; this induces the interpolated phase adjustment by contrast enhancement (IPACE) algorithm. The IPACE algorithm can remarkably reduce the computational time while maintaining the accuracy. This letter has derived the detailed processing of IPACE, and the results of the experiments using real SAR data are presented to show the validity of the proposed algorithm. [J1]

"Physical Limitations on Detecting Tunnels Using Underground-Focusing Spotlight Synthetic Aperture Radar"

This paper examines the feasibility of underground-focusing spotlight synthetic aperture radar (UF-SL-SAR) systems for tunnel detection applications. A general formulation is reviewed for generating UF-SL-SAR imaging by using multiple frequencies across a wide band and by focusing in space to subsurface points using well-known ray refraction at the nominal ground surface. A full-wave finite-difference frequency-domain model is used to consider wave propagation in realistic soil with loss- and frequency-dependent dielectric constant and a randomly rough ground surface, both of which serve to obscure and distort the returned tunnel target signal. Imaging results are presented for two representative soil scenarios: dry sand and moist clay loam. Considering the ground surface ray refraction for focusing greatly improves the SAR image relative to conventional SAR focusing at the ground surface. Using UF-SL-SAR, a small shallow tunnel is reasonably imaged for the sand case, despite the roughness of the ground interface. However, for higher conductivity moist clay loam, the clutter from the rough surface overwhelms the significantly attenuated target signal, which must propagate through the lossy intervening soil. It is demonstrated that, despite ideal focusing, the tunnel is successfully imaged only for the sand case. [J2]

"Building Detection From One Orthophoto and High-Resolution InSAR Data Using Conditional Random Fields"

Today's airborne SAR sensors provide geometric resolution in the order well below half a meter. Many features of urban objects become visible in such data. However, layover and occlusion issues inevitably arise in urban areas complicating automated object detection. In order to support interpretation, SAR data may be analyzed using complementary information from maps or optical imagery. In this paper, an approach for building detection in urban areas based on object features extracted from high-resolution interferometric SAR (InSAR) data and one orthophoto is presented. Features describing local evidence as well as context information are used. Buildings are detected by classification of those feature vectors within a Conditional Random Field (CRF) framework. Although as graphical model similar to Markov Random Fields (MRF), CRFs have the advantage of incorporating global context information, of relaxing the conditional independence assumption between features, and of a more general integration of observations. We show that, first, CRFs perform well in comparison to Maximum Likelihood classifiers and MRFs. Second, the combined use of optical and InSAR features may improve detection results. [J3]

"Exploration of Subsidence Estimation by Persistent Scatterer InSAR on Time Series of High Resolution TerraSAR-X Images"

Ground subsidence is a major concern for land use planning and engineering risk assessment. This paper explores subsidence detection by the persistent scatterer (PS) interferometric synthetic aperture radar (InSAR)

technique using the multitemporal high resolution spaceborne SAR images. We first describe the mathematical models and the data reduction procedures of the PS solution. The experiments of subsidence detection are then carried out over the Jinghai County in Tianjin (China) which has been sinking due to overuse of groundwater. The time series of high resolution SAR images collected by the X-band radar sensor onboard the satellite TerraSAR-X (TSX) are utilized for the PS detection, PS networking and subsidence estimation. The experimental results demonstrate that the high resolution of TSX SAR images can dramatically increase the PSs' density and coverage extent, especially in the built-up areas. Subsidence values can be extracted on the individual objects like buildings, street lamps and manhole covers, and on the linear engineering structures like the Jinghu high-speed railway. The PS InSAR with short radar wavelength (3.1 cm) is quite sensitive to ground displacement in the radar line-of-sight direction, and the derived subsidence measurements are in good agreement with the in situ data taken by optical leveling. [J4]

"Polarimetric Decomposition Over Glacier Ice Using Long-Wavelength Airborne PolSAR"

In recent years, there has been increased interest in using synthetic aperture radar (SAR) to study and monitor glaciers and ice sheets for glaciological and climate change research. However, due to the medium's complexity, SAR backscattering from ice remains poorly understood, including the relative importance of scattering from surface and volume layers and also dependences on frequency and glacier zone. Extreme weather conditions can result in quickly changing surface conditions influencing backscatter signatures while leaving the underlying volume of interest unchanged. Surface and volume components must thus be separated in order to infer information regarding the properties of the ice volume. This paper describes a three-component scattering model to decompose polarimetric SAR (PolSAR) images of glacier ice. Total backscatter is modeled as the incoherent summation of surface, volume, and sastrugi (wind-induced feature) components. The proposed model adapts and extends the Freeman and Durden decomposition for an ice volume scenario in which the volume is a dielectric medium. Forms of the model for both random and oriented volumes are considered, and a new oriented sastrugi component is introduced which is able to explain backscatter behavior between different winter scenes. Validation is performed with airborne PolSAR data at L- and P-band collected using the E-SAR system of the German Aerospace Center over the Austfonna ice cap in Svalbard, Norway, as part of the ICESAR campaign. [J5]

"SPEC Method-A Fine Coregistration Method for SAR Interferometry"

There is increasing demand for landscape acquisition using interferometric synthetic aperture radar for frequent Earth observation. Making an accurate digital elevation model (DEM) from an interferogram is often seriously affected by a mass of singular points (SPs) included in the interferogram. The origin of a type of SPs lies in inaccurate coregistration in making the interferogram. However, there have not been any method more effective than affine transformation based on cross correlation. Numerous research works have aimed at how to process the SPs resulting in the coregistration. In this paper, contrarily, we propose an additional method of local and nonlinear coregistration which employs the number of SPs as the evaluation criterion. This method provides us with an interferogram to generate a more accurate DEM. Experiments demonstrate that, with the proposed method, we can obtain a DEM having higher signal-to-noise ratios. [J6]

"Ground Moving Targets Imaging Algorithm for Synthetic Aperture Radar"

It is well known that the motion of a target induces range migration, especially for high-resolution synthetic aperture radar (SAR) systems. Ground moving target imaging necessitates the correction of the unknown range migration. To finely refocus a moving target, one must accurately obtain the motion parameters for compensating the target trajectory. However, in practice, these parameters usually cannot be precisely estimated. This paper proposes a new imaging approach for ground moving targets without a priori knowledge of their motion parameters. In the devised method, the azimuth compression function is constructed in range frequency domain, which can eliminate the coupling effect between range and azimuth. Theoretical analysis confirms that the methodology can precisely focus targets without interpolation procedure. The effectiveness of the proposed imaging technique is demonstrated by both simulated and real airborne SAR data. [J7]

"A Cluster-Analysis-Based Efficient Multibaseline Phase-Unwrapping Algorithm"

Multibaseline phase unwrapping is a critical processing procedure of multibaseline synthetic aperture radar interferometry (InSAR). It has an advantage over single-baseline phase unwrapping in discontinuous-terrain-height estimation. In this paper, the pixels' combination information of multiple InSAR interferograms with different baseline lengths is deeply investigated, and the term ambiguity vector is proposed to represent a pixel's ambiguity number of multiple interferograms. It is also revealed that pixels with the same ambiguity vector have an exclusive pattern among them. A fast cluster-analysis (CA)-based method is proposed for multibaseline

phase unwrapping. In this method, all pixels are first clustered into different groups according to their patterns, and then, information of the cluster center is used to unwrap the phases of pixels group by group. Simulation results are shown to verify the effectiveness, efficiency, and noise robustness of CA multibaseline phase-unwrapping method. [J8]

"Rice Crop Monitoring in South China With RADARSAT-2 Quad-Polarization SAR Data"

This letter presents preliminary results of an attempt to monitor rice crop growth using RADARSAT-2 quad polarization synthetic aperture radar (SAR) data. Three RADARSAT-2 quad-polarization SAR images are collected from transplanting to rice crop harvesting. Ground truth data, such as rice height and biomass, are measured during RADARSAT-2 data acquisition in Hainan Province, South China. The correlation between backscattering coefficient and rice growth parameters is analyzed, and then, a rice field mapping method with quad polarization SAR image is developed. Experiments show that an HV or VH image backscattering coefficient exhibits the best correlation with rice age after transplantation. Furthermore, the HV or VH image is also more suitable for retrieving rice growth parameters, such as rice height and dry biomass, for FQ4 RADARSAT-2 SAR data. The ratio image of HH/VV possesses high separability required to distinguish rice crop from banana, forest, and river. Results indicate that RADARSAT-2 quad polarization SAR data presented enormous potential for monitoring rice crop growth. [J9]

"Multiregion Image Segmentation by Parametric Kernel Graph Cuts"

The purpose of this study is to investigate multiregion graph cut image partitioning via kernel mapping of the image data. The image data is transformed implicitly by a kernel function so that the piecewise constant model of the graph cut formulation becomes applicable. The objective function contains an original data term to evaluate the deviation of the transformed data, within each segmentation region, from the piecewise constant model, and a smoothness, boundary preserving regularization term. The method affords an effective alternative to complex modeling of the original image data while taking advantage of the computational benefits of graph cuts. Using a common kernel function, energy minimization typically consists of iterating image partitioning by graph cut iterations and evaluations of region parameters via fixed point computation. A quantitative and comparative performance assessment is carried out over a large number of experiments using synthetic grey level data as well as natural images from the Berkeley database. The effectiveness of the method is also demonstrated through a set of experiments with real images of a variety of types such as medical, synthetic aperture radar, and motion maps. [J10]

"Three-Dimensional SAR Focusing From Multipass Signals Using Compressive Sampling"

Three-dimensional synthetic aperture radar (SAR) image formation provides the scene reflectivity estimation along azimuth, range, and elevation coordinates. It is based on multipass SAR data obtained usually by nonuniformly spaced acquisition orbits. A common 3-D SAR focusing approach is Fourier-based SAR tomography, but this technique brings about image quality problems because of the low number of acquisitions and their not regular spacing. Moreover, attained resolution in elevation is limited by the overall acquisitions baseline extent. In this paper, a novel 3-D SAR data imaging based on Compressive Sampling theory is presented. It is shown that since the image to be focused has usually a sparse representation along the elevation direction (i.e., only few scatterers with different elevation are present in the same range-azimuth resolution cell), it suffices to have a small number of measurements to construct the 3-D image. Furthermore, the method allows super-resolution imaging, overcoming the limitation imposed by the overall baseline span. Tomographic imaging is performed by solving an optimization problem which enforces sparsity through $\ell 1$-norm minimization. Numerical results on simulated and real data validate the method and have been compared with the truncated singular value decomposition technique. [J11]

"Coherence, Polarization, and Statistical Independence in Cloude-Pottier's Radar Polarimetry"

The Cloude-Pottier radar polarimetry paradigm, which is understood as the spectral decomposition theorem of the target coherency matrix plus the classification technique based on the triad of parameters given by entropy, alpha angle, and anisotropy, has become a very well-established methodology for treating high-resolution polarimetric radar images, particularly those obtained with synthetic aperture radar (SAR) sensors. This methodology is revisited here from the standpoint of the coherence and polarization theory and their mutual relationship, in the light of the interest aroused once again after Wolf's article on this subject in 2003. Despite its success in terms of acceptance by the SAR community, the Cloude-Pottier paradigm relies on the arguable assumption that different scattering mechanisms can be separated by diagonalizing the aforementioned coherency matrix and then assigning each corresponding eigenvector to one of the independent scattering mechanisms. Our main statement in this paper is that the coherency matrix illustrates the behavior of the target

from the point of view of polarization and not of full coherence, which would justify this assumption, even if only partially. Therefore, it is not rigorous to identify each eigenvector of this decomposition with a distinct scattering mechanism. Cloude and Pottier argue that the eigendecomposition of the coherency matrix outperforms other target decomposition theorems due to its uniqueness. It is also suggested that this very uniqueness, together with the orthogonality of the eigenvectors, supports the injective mapping between scattering mechanisms and eigenvectors that was first assumed based on statistical independence. With the aim of providing a comprehensive overview of the problem, we discuss some important concepts with regard to both field and target coherency matrices. In addition, we revise the concepts of entropy, alpha angle, and anisotropy as defined by the aforementioned authors, which are-- also a central part of this paradigm and which have played an important role in SAR image classification since its introduction. Again, some disagreement is found with the meaning of these parameters as they have been discussed so far. [J12]

"A Gaussian Mixture Filter for Range-Only Tracking"

Range-only tracking problems arise in extended data collection for inverse synthetic radar applications, robotics, navigation and other areas. For such problems, the conditional density of the state variable given the measurement history is multi-modal or exhibits curvature, even in seemingly benign scenarios. For this reason, the use of extended Kalman filter (EKF) and other nonlinear filtering techniques based on Gaussian approximations can result in inaccurate estimates. We introduce a new filter for such tracking problems in two dimensions called the Gaussian mixture range-only filter (GMROF), which generates Gaussian mixture approximations to the conditional densities. The filter equations are derived by analytic techniques based on the specific nonlinearities of range-only tracking. A slight modification of the standard measurement process model, "noise before nonlinearity," is used to simplify the moment calculations. Implementation requires, at each step, the fitting of a low order Gaussian mixture to a simple exponentiated trigonometric function of a scalar variable. Simulations involving scenarios from earlier comparative studies indicate that the GMROF consistently outperformed the EKF, and achieved the accuracy of particle filters while significantly reducing the computational cost. [J13]

"Experimental Study on Radiometric Performance of Synthetic Aperture Radiometer HUT-2D-Measurements of Natural Targets"

This paper describes the analysis of L-band radiometric measurement data gathered with the synthetic aperture radiometer HUT-2D during several ground-based and airborne measurement campaigns. The radiometric data are analyzed from the instrument's performance point of view, aiming to verify the theoretical performance of an instrument of this kind and to assess the performance of the HUT-2D radiometer system in particular. The data sets considered for the study consist of measurements of well-known natural targets, such as cosmic background radiation, and measurements of pure water scenes, the brightness temperature of which is possible to model based on in situ measurements. We define four figures of merit, which are applicable for synthetic aperture radiometers. These are radiometric resolution, image bias, pixel-to-pixel random error, and temporal stability. Then, we use the selected data sets to assess these in the case of HUT-2D. The experimental results are discussed and compared to the theoretical values, where applicable. Also, we discuss possibilities to improve the presented performance. The main results of this paper are the consolidated performance parameters of the HUT-2D instrument. We study and discuss the properties of the error components related to the technology in a general level, and study the scalability of the errors as a function of the measured targets. In particular, the stability of the direction-dependent error component is pointed out, and a mitigation guideline is proposed. [J14]

"A Foreground/Background Separation Framework for Interpreting Polarimetric SAR Images"

In this letter, we present a novel foreground/background separation (FBS) framework for interpreting polarimetric synthetic aperture radar (PolSAR) images. The FBS framework takes the spatial relations between pixels into consideration and incorporates the advantages of pairwise dissimilarity-based grouping schemes. The FBS method can separate specific targets and objects from the background, which is essential in an interpretation system. Multiple FBS operations can be integrated to interpret PolSAR images, flexibly fusing various inherent features of PolSAR data. Several PolSAR data sets are used to verify the proposed approach. [J15]

"Cross-Range Scaling Algorithm for ISAR Images Using 2-D Fourier Transform and Polar Mapping"

This paper proposes a new method that solves the problem of inverse synthetic aperture radar image cross-range scaling by estimating the rotational velocity (RV) using the expansion-rotation-scale relationship between two range-Doppler (RD) images. This method is composed of three steps. The first step is preprocessing to construct 2-D Fourier transform images and initial polar-mapped images. In this step, two RD images are 2-D

Fourier transformed to avoid the necessity of finding the rotation center; then, the transformed images are polar mapped with identical polar grids to convert rotation into translation in the θ-direction only. The second step is a coarse search that finds the angular shift that provides the maximum correlation between two polar images. The angular shift found is used as the initial relative rotation angle (RA), and the initial relative scaling factor (RSF) is calculated using the RV which is equal to the angular shift divided by the time delay between the images. The third step is the optimization of the relative RA using the Nelder-Mead approach, with the RSF updated using the relative RA derived during each iteration. In simulations using a Mig-25 aircraft, composed of ideal point scatterers, and the measured data from a Boeing 747-400, the targets were properly rescaled in the range-cross-range domain due to the accurate estimation of the RV. [J16]

"Multitemporal Image Change Detection Using Undecimated Discrete Wavelet Transform and Active Contours"

In this paper, an unsupervised change detection method for satellite images is proposed. Owing to its robustness against noise, the undecimated discrete wavelet transform is exploited to obtain a multiresolution representation of the difference image, which is obtained from two satellite images acquired from the same geographical area but at different time instances. A region-based active contour model is then applied to the multiresolution representation of the difference image for segmenting the difference image into the "changed" and "unchanged" regions. The proposed change detection method has been conducted on two types of image data sets, i.e., the synthetic aperture radar images and the optical images. The change detection results are compared with several state-of-the-art techniques. The extensive simulation results clearly show that the proposed change detection method consistently yields superior performance. [J17]

"Instrumental CWLFM High-Range Resolution Radar in Millimeter Waveband for ISAR Imaging"

This paper shows a High-Range Resolution (HRR) Radar prototype development, transmitting in millimeter-wave band. The waveform selected to be used is the continuous-wave linear frequency modulation (CWLFM), which allows, at the same time, good range resolution, moderate unambiguous doppler range and reasonable operational range taking into account that high-frequency band is used. The radar prototype looks for High-Range Resolution (HRR) characteristics as well as flexibility, in order to obtain the best Inverse Synthetic Aperture Radar (ISAR) images possible depending on the applications and targets involved. That is, depending on the speed and target's trajectories, some radar features, such as transmitted bandwidth, modulator frequency or sampling frequency, play a key role in obtaining the best possible results while using lowest electrical requirements. [J18]

"Pattern-Based Accuracy Assessment of an Urban Footprint Classification Using TerraSAR-X Data"

Assessing the accuracy of land-cover classifications is a major challenge in remote sensing. This is mostly due to the absence of geometrically and thematically highly resolved, reliable, area wide, and up-to-date reference data. This study focuses on a multifaceted accuracy assessment of an urban footprint classification derived from a single-polarized TerraSAR-X image in stripmap mode for the city of Padang in Indonesia. For this purpose, a pixel-based approach was used to identify the urbanized and nonurbanized areas. As reference, a geometrically and thematically highly resolved, accurate, and detailed 3-D city model is available. Based on this data, the classification result is assessed by basic methodologies-square measures and error matrix. Beyond that, the accuracy of the urban footprint classification is analyzed in dependence of the physical structure of the complex urban landscape-defined by built-up density and building volumes. Results reveal that the accuracy of classification results varies in dependence of the structural characteristics of the particular urban environment. Furthermore, the study shows what is thematically mapped by an urban footprint classification. [J19]

"On the Generation of Late ERS Deformation Time Series Through Small Doppler and Baseline Subsets Differential SAR Interferograms"

In this letter, we investigate the potential of the small baseline subset (SBAS) differential synthetic aperture radar interferometry (DInSAR) technique to produce consistent deformation time series by using data sets of SAR images with high Doppler centroid (DC) frequencies. To cope with this issue properly, we exploited an archive of SAR scenes acquired by the European Remote Sensing 2 (ERS-2) sensor after the February 2000 three-gyroscope navigation mode failure. Our approach is oriented toward the long-term investigation of large-scale displacements with low spatial resolution (about 100 Ч 100 m) by processing sets of SAR images without discarding scenes depending on their DC values. Our analysis involves a set of descending SAR data frames from 1992 to 2007 relevant to the Napoli (Italy) bay area. Comparison with contemporaneous Global Positioning System measurements clearly confirms the effectiveness of the proposed approach. [J20]

"Multilevel Local Pattern Histogram for SAR Image Classification"

In this letter, we propose a theoretically and computationally simple feature for synthetic aperture radar (SAR) image classification, the multilevel local pattern histogram (MLPH). The MLPH describes the size distributions of bright, dark, and homogenous patterns appearing in a moving window at various contrasts; these patterns are the elementary properties of SAR image texture. The MLPH is a very powerful descriptor of SAR images because it captures both local and global structural information. Additionally, it is robust to speckle noise. Experiments on a TerraSAR-X data set demonstrate that MLPH significantly outperforms four other widely used features in SAR image classification. [J21]

"The Glacier and Land Ice Surface Topography Interferometer: An Airborne Proof-of-Concept Demonstration of High-Precision Ka-Band Single-Pass Elevation Mapping"

As part of the NASA International Polar Year activities, a Ka-band cross-track interferometric synthetic aperture radar (SAR) recently demonstrated high-precision elevation swath mapping capability. This proof-of-concept instrument was achieved by interfacing two Ka-band slotted-waveguide antennas in a cross-track geometry and Ka-band electronics with the Jet Propulsion Laboratory's L-band uninhabited aerial vehicle SAR. Deployed on the NASA Gulfstream III, initial engineering flights in March and April 2009 marked the first airborne demonstration of single-pass cross-track interferometry at Ka-band. Results of a preliminary interferometric assessment indicate height precisions that, for a 3 m Ч 3 m posting, range from 30 cm in the near range to 3 m in the far range and greater than 5 km of swath over the urban areas imaged. The engineering flights were followed by a comprehensive campaign to Greenland in May 2009 for ice-surface topography mapping assessment. Toward that end, coordinated flights with the NASA Wallops Airborne Topographic Mapper lidar were conducted in addition to establishing ground calibration sites at both the Summit Station of the National Science Foundation and the Swiss Camp of the Cooperative Institute for Research in the Environmental Sciences. Comparisons of the radar-derived elevation measurements with both in situ and lidar data are planned for a subsequent paper; however, at this stage, a single data example over rugged ice cover produced a swath up to 7 km with the desired height precision as estimated from interferometric correlation data. While a systematic calibration, including assessment and modeling of biases, due to penetration of the electromagnetic waves into the snow cover has not yet been addressed, these initial results indicate that we will exceed our system requirements. [J22]

"Imaging Geodesy-Toward Centimeter-Level Ranging Accuracy With TerraSAR-X"

In this paper, we report on experiments to measure large-scale Earth surface displacements, such as those caused by solid Earth tides, with centimeter-level accuracy using TerraSAR-X radar images. With two totally different approaches, corner reflectors and image correlation techniques, we show the clear interrelation between the radar range measurements and the projection of the solid Earth tide motion vector onto the radar line of sight. Pixel location accuracies of up to 2.6-cm standard deviation can be achieved after a single calibration. We further demonstrate that solid Earth tides and tropospheric water vapor variations are the largest sources of ranging error if not compensated for. Alternatively, tropospheric water vapor can be estimated with centimeter accuracy using our proposed technique of synthetic aperture radar (SAR) image correlation and solid Earth motion compensation by the existing models. We also consider ionospheric delays which improve the results marginally in the X-band. Our results show the best ranging accuracies so far reported for spaceborne radar amplitude images and make TerraSAR-X-together with our simple compensation methodology-suitable for the imaging of centimeter-level Earth displacements. Absolute measurements of volcanoes or glaciers are possible without the use of ground equipment and without the use of SAR interferometry, thus avoiding the associated problems of phase ambiguity, phase unwrapping, and reference points. [J23]

"Hierarchical Segmentation of Polarimetric SAR Images Using Heterogeneous Clutter Models"

In this paper, heterogeneous clutter models are used to describe polarimetric synthetic aperture radar (PolSAR) data. The KummerU distribution is introduced to model the PolSAR clutter. Then, a detailed analysis is carried out to evaluate the potential of this new multivariate distribution. It is implemented in a hierarchical maximum likelihood segmentation algorithm. The segmentation results are shown on both synthetic and high-resolution PolSAR data at the X- and L-bands. Finally, some methods are examined to determine automatically the "optimal" number of segments in the final partition. [J24]

"Possibilistic Soil Roughness Identification for Uncertainty Reduction on SAR-Retrieved Soil Moisture"

Soil roughness plays an essential role in the reflection of the incoming radar signal at the soil surface and is,

therefore, highly important in the retrieval of the soil moisture information from the backscattered radar signal. However, soil roughness, generally described by means of the root mean square (rms) height and the correlation length, remains difficult to measure correctly and is, furthermore, found to be highly variable. In order to overcome these difficulties, Verhoest et al. suggested the use of possibility distributions to reflect possible values of roughness parameters for a given roughness state of an agricultural field. These distributions were then further used to retrieve the soil moisture information. Nevertheless, as they estimated the possibility distributions by brute force, without taking into account any interactivity between the roughness parameters, rather wide distributions of retrieved soil moisture content were obtained. This paper first tries to independently estimate the possibility distributions for both roughness parameters on the basis of a synthetically generated roughness data set. Next, the interactivity between the rms height and the correlation length is taken into account through the identification of a joint possibility distribution by means of a possibilistic clustering algorithm. When applied to actual synthetic aperture radar data, the results show that a narrower, i.e., more specific, possibility distribution of the soil moisture content is obtained when the possibilistic retrieval procedure is performed based on the joint possibility distributions. [J25]

"Exploiting MIMO SAR Potentialities With Efficient Cross-Track Constellation Configurations for Improved Range Resolution"

In this paper, an innovative technique is presented for synthetic aperture radar (SAR) ground range resolution improvement using multiple transmit and receive platforms with adequate cross-track displacement. Using orthogonal waveforms, which occupy the same bandwidth in the range frequency domain, for the different platforms of the constellation, a multiple-input-multiple-output SAR system is configured. The proposed technique allows one to achieve a maximum theoretical range resolution improvement factor that is significantly greater than the number of operating SAR sensors by jointly exploiting both mono- and bistatic acquisitions. This can be exploited to obtain a ground range resolution that is much higher than the resolution corresponding to the frequency bandwidth transmitted by the single platform. After illustrating the proposed technique and its system requirements, a simulated data set is used to show the effectiveness of the proposed approach. [J26]

"Seismic Source Quantitative Parameters Retrieval From InSAR Data and Neural Networks"

The basic idea of this paper relies on the concurrent exploitation of the capabilities of neural networks (NNs) and SAR interferometry (InSAR) for the characterization of a seismic source and the estimation of its geometric parameters. When a moderate-to-strong earthquake occurs, we can apply the InSAR technique to compute a differential interferogram. The earthquake is generated by an active seismogenic fault having its own specific geometry. The corresponding differential interferogram contains, in principle, information concerning the geometry of the seismic source that the earthquake comes from. To perform the inversion operation, a novel approach based on NNs is considered. This requires the generation of a statistically significant number of synthetic interferograms necessary for the network training phase. Each of them corresponds to a different combination of fault geometric parameters. After the training, the network is ready to perform, in real time, the inversion on new differential interferograms. This paper illustrates such a methodology and its validation on a set of experimental data. [J27]

"Mapping Three-Dimensional Surface Deformation by Combining Multiple-Aperture Interferometry and Conventional Interferometry: Application to the June 2007 Eruption of Kilauea Volcano, Hawaii"

Surface deformation caused by an intrusion and small eruption during June 17-19, 2007, along the East Rift Zone of Kilauea Volcano, Hawaii, was three-dimensionally reconstructed from radar interferograms acquired by the Advanced Land Observing Satellite (ALOS) phased-array type L-band synthetic aperture radar (SAR) (PALSAR) instrument. To retrieve the 3-D surface deformation, a method that combines multiple-aperture interferometry (MAI) and conventional interferometric SAR (InSAR) techniques was applied to one ascending and one descending ALOS PALSAR interferometric pair. The maximum displacements as a result of the intrusion and eruption are about 0.8, 2, and 0.7 m in the east, north, and up components, respectively. The radar-measured 3-D surface deformation agrees with GPS data from 24 sites on the volcano, and the root-mean-square errors in the east, north, and up components of the displacement are 1.6, 3.6, and 2.1 cm, respectively. Since a horizontal deformation of more than 1 m was dominantly in the north-northwest-south-southeast direction, a significant improvement of the north-south component measurement was achieved by the inclusion of MAI measurements that can reach a standard deviation of 3.6 cm. A 3-D deformation reconstruction through the combination of conventional InSAR and MAI will allow for better modeling, and hence, a more comprehensive understanding, of the source geometry associated with volcanic, seismic, and other processes that are manifested by surface deformation. [J28]

"X-, C-, and L-Band DInSAR Investigation of the April 6, 2009, Abruzzi Earthquake"

This letter compares the coseismic deformation maps obtained from different synthetic aperture radar (SAR) sensors using the well-known differential SAR interferometry technique. In particular, four deformation maps have been obtained from X-, C-, and L-band SAR sensors onboard COSMO-SkyMed, Envisat, and ALOS satellite missions correspondingly. The test case is the April 6,2009, earthquake (Mw= 6.3). This seismic event struck a densely populated region of the Apennines and was felt all over Central Italy. The SAR data set is rather inhomogeneous, since it includes interferograms with three different wavelengths, four acquisition geometries, different spatial resolutions, variable temporal and spatial baselines, and differently emphasized signal noise. However, we find that the detected displacements are highly comparable. The outcome of this work is that, even though such differences have an impact on the properties of the interferograms, the displacements can be measured with an overall discrepancy of about half the value of the shortest wavelength (COSMO-SkyMed) data set. [J29]

"Combination of Direct and Double-Bounce Ground Responses in the Homogeneous Oriented Volume Over Ground Model"

Complex interferometric coherence expressions for the homogeneous (random or oriented) volume-over-ground model are originally derived in a simplified way by neglecting one of the two possible contributions of the ground response: direct return from the ground surface or double-bounce interaction with stems or trunks. The influence of these depends on both system and scene parameters, and in many cases, none of them should be ignored a priori. Therefore, a more general formulation accounting for the simultaneous presence of both ground contributions should be developed. This letter derives this formulation and analyzes the combined effect of both ground returns on the complex coherences. In addition, the implications for a subsequent inversion procedure based on this model are also discussed. [J30]

"Radar Imaging Simulation for Urban Structures"

With the recent advent of very high resolution (VHR) spaceborne synthetic aperture radar (SAR) sensors such as TerraSAR-X and COSMO-SkyMed, the potential to use SAR simulators is increasing. In this letter, we propose a novel radar imaging simulator that is relatively simple to implement and that finds a balance between accuracy and efficiency. The main goal of the proposed method is to obtain a precise simulation of the geometry of objects in SAR images rather than a detailed radiometric simulation. The simulator is based on an extended ray-tracing procedure to determine which surfaces of a generic object contribute to the backscatter. The backscatter contributions are calculated by means of a Lambertian-specular mixture model. The simulator has already been employed successfully in a methodology for 3-D reconstruction of man-made objects from single detected VHR SAR imagery. Here, we illustrate its work on two rather different structures, a rectangular gable-roof building and an Egyptian pyramid. [J31]

"Ocean Wave Integral Parameter Measurements Using Envisat ASAR Wave Mode Data"

An empirical algorithm to retrieve integral ocean wave parameters such as significant wave height (SWH), mean wave period, and wave height of waves with period larger than 12 s (H12) from synthetic aperture radar (SAR) images over sea surface is presented. The algorithm is an extension to the Envisat Advanced SAR (ASAR) wave mode data based on the CWAVE approach developed for ERS-2 SAR wave mode data and is thus called CWAVE_ENV (CWAVE for Envisat). Calibrated ASAR images are used as the only source of input without needing prior information from an ocean wave model (WAM) as the standard algorithms used in weather centers. This algorithm makes SAR an independent instrument measuring integrated wave parameters like SWH and mean wave period to altimeter quality. A global data set of 25 000 pairs of ASAR wave mode images and collocated reanalysis WAM results from the European Centre for Medium-Range Weather Forecasts (ECMWF) is used to tune CWAVE_ENV model coefficients. Validation conducted by comparing the retrieved SWH to in situ buoy measurements shows a scatter index of 0.24 and 0.16 when compared to the ECMWF reanalysis WAM. Two case studies are presented to evaluate the performance of the CWAVE_ENV algorithm for high sea state. A North Atlantic storm during which SWH is above 18 m as observed by SAR and Radar Altimeter simultaneously is analyzed. For an extreme swell case that occurred in the Indian Ocean, the potential of using SWH measurements from ASAR wave mode data derived by the CWAVE_ENV algorithm is demonstrated. [J32]

"Multifunctional Software-Defined Radar Sensor and Data Communication System"

Orthogonal frequency-division multiplexing (OFDM) signal coding and system architecture were implemented to achieve radar and data communication functionalities. The resultant system is a software-defined unit, which can be used for range measurements, radar imaging, and data communications. Range reconstructions were

performed for ranges up to 4 m using trihedral corner reflectors with approximately 203 m of radar cross section at the carrier frequency; range resolution of approximately 0.3 m was demonstrated. Synthetic aperture radar (SAR) image of a single corner reflector was obtained; SAR signal processing specific to OFDM signals is presented. Data communication tests were performed in radar setup, where the signal was reflected by the same target and decoded as communication data; bit error rate of was achieved at 57 Mb/s. The system shows good promise as a multifunctional software-defined sensor which can be used in radar sensor networks. [J33]

"An Internal Calibration Scheme for Polarimetric Synthetic Aperture Radar System"

Two important aspects of internal calibration of polarimetric synthetic aperture radar are discussed, i.e., system gain calibration and individual transmit/receive module (TRM) calibration. System gain variation is measured, utilizing the internal calibration loop. A dual-channel TRM gain and phase calibration is carried out using orthogonal phase coding, where a signal of individual TRM is phase encoded according to a set of orthogonal codes in order to be separated from the composite calibration signal of all TRMs. Calibration results are developed both theoretically and through simulation in the case of TRM failure. Error introduced by phase-shifter toggling inaccuracy is discussed. A cross talk model is used to investigate the effect of imperfect isolation between the two polarization channels of each TRM on the calibration error. [J34]

"Time-Series InSAR Applications Over Urban Areas in China"

In this study, we present the results achieved within the Dragon project, a cooperation program between the European Space Agency (ESA) and the National Remote Sensing Center of China (NRSCC), about monitoring subsidences and landslides in urban areas, analyzing cities growth and measuring the deformation of big man-made structures. Among the processed areas, we report here the main results we obtained in the test sites of Shanghai, Tianjin, Badong, and Three Gorges Dam. The techniques that have been used to process the data are original SAR interferometry (InSAR), Permanent Scatterers (PS-InSAR), Quasi-PS InSAR (QPS-InSAR), and a combination of coherent-uncoherent analysis. The results show that time-series InSAR techniques allow us to extract ground information with high spatial density and thus help us understanding the impact of urban development on terrain movements. [J35]

"Fast Raw-Signal Simulation of Extended Scenes for Missile-Borne SAR With Constant Acceleration"

Fast raw-signal simulation is of considerable value for missile-borne synthetic aperture radar (SAR) algorithm development. On the basis of the two-dimensional (2-D) Fourier simulation method for stripmap SAR, we present a fast echo simulation method suitable for missile-borne SAR diving with constant acceleration. The analytical expression for the 2-D signal spectrum is derived and then converted to a stripmap one. Simulation results for a point target and a real scene demonstrate its validity and effectiveness. [J36]

"The Effect of Orientation Angle Compensation on Coherency Matrix and Polarimetric Target Decompositions"

The polarization orientation angle (OA) of the scattering media affects the polarimetric radar signatures. This paper investigates the effects of orientation compensation on the coherency matrix and the scattering-model-based decompositions by Freeman-Durden and Yamaguchi et al. The Cloude and Pottier decomposition is excluded, because entropy, anisotropy, and alpha angle are roll invariant. We will show that, after orientation compensation, the volume scattering power is consistently decreased, while the double-bounce power has increased. The surface scattering power is relatively unchanged, and the helicity power is roll invariant. All of these characteristics can be explained by the compensation effect on the nine elements of the coherency matrix. In particular, after compensation, the real part of the (HH-VV) · HV* correlation reduces to zero, the intensity of cross-pol |HV| always reduces, and |HH-VV| always increases. This analysis also reveals that the common perception that OA compensation would make a reflection asymmetrical medium completely reflection symmetric is incorrect and that, contrary to the general perception, the four-component decomposition does not use the complete information of the coherency matrix. Only six quantities are included-one more than the Freeman-Durden decomposition, which explicitly assumes reflection symmetry. [J37]

"Semiempirical Calibration of the Integral Equation Model for SAR Data in C-Band and Cross Polarization Using Radar Images and Field Measurements"

The estimation of surface soil parameters (moisture and roughness) from synthetic aperture radar (SAR) images requires the use of well-calibrated backscattering models. The objective of this letter is to extend the semiempirical calibration of the backscattering integral equation model (IEM) initially proposed by Baghdadi for

HH and VV polarizations to HV polarization. The approach consisted in replacing the measured correlation length by a fitting/calibration parameter so that model simulations would closely agree with radar measurements. This calibration in C-band covers radar configurations with incidence angles between 24 and 45.8. Good agreement was found between the backscattering coefficient provided by the SAR and that simulated by the calibrated version of the IEM. [J38]

"InSAR Deformation Time Series Using an -Norm Small-Baseline Approach"

Satellite synthetic aperture radar interferometry (InSAR) is an invaluable tool for land displacement monitoring. Improved access to time series of satellite data has led to the development of several innovative multitemporal algorithms. Small baseline (SB) is one such time-series InSAR method, based on combining and inverting a set of unwrapped interferograms for surface displacement. Two-dimensional unwrapping of sparse data sets is a challenging task, and unwrapping errors can lead to incorrectly estimated deformation time series. It is well known that L1-norm is more robust than L2-norm cost function minimization if the data set has a large number of outlying points. In this paper, we present an L1-norm-based SB method using an iteratively reweighted least squares algorithm. We show that the displacement phase of both synthetic data, as well as a real data set that covers the San Francisco Bay area, is recovered more accurately than with L2-norm solutions. [J39]

"Focusing of Medium-Earth-Orbit SAR With Advanced Nonlinear Chirp Scaling Algorithm"

The signal processing of the medium-Earth-orbit synthetic aperture radar (SAR) is more challenging than that of the current low-Earth-orbit SAR because the imaging geometry is more complicated, and the range and azimuth variances are more severe. This paper deals with these imaging problems in three aspects. First, an advanced hyperbolic range equation (AHRE) is proposed for the first time, which is more precise for a spaceborne SAR than the conventional hyperbolic range equation (CHRE). Second, the point target spectrum based on the AHRE is analytically derived, which is useful for developing efficient SAR processing algorithms. Third, the well-known nonlinear chirp scaling (NLCS) algorithm is modified according to this new spectrum, and the so-called AHRE-based advanced NLCS (A-NLCS) algorithm is established. The simulation results validate the correctness of our method for L-band SAR systems at altitudes from 1000 to 10000 km with an azimuth resolution around 3 m. It is also shown that the A-NLCS algorithm has better performance than the CHRE-based algorithms in longer integration time cases. Therefore, we recommend the A-NLCS algorithm for a spaceborne SAR with a lower frequency, finer resolution, and higher satellite altitude. [J40]

"Comparison of Ocean-Surface Winds Retrieved From QuikSCAT Scatterometer and Radarsat-1 SAR in Offshore Waters of the U.S. West Coast"

In this letter, we generate a temporal/spatial matchup data set between QuikSCAT scatterometer and RADARSAT-1 synthetic aperture radar (SAR) wind products in offshore waters along the U.S. West Coast. Analysis of the resulting three-year database shows that, in general, the wind products from both sensors have characteristics similar to those reported in the literature. Then, we perform an error analysis in the space domain and find that there is significant discrepancy between the two wind products as the matchup points move closer to the coast. The root-mean-square error (rmse) and standard deviation (STD) between the two data sets increases markedly for points matched within about 100 km of the coastline. Beyond 100 km, the rmse, STD, and systematic bias become small and stable. In addition, an empirical relationship between QuikSCAT and SAR winds in coastal region is proposed. Thus, the bias and errors should be taken into account if the standard operational QuikSCAT wind products are used for forcing models in the coastal ocean. [J41]

"Edge Enhancement Algorithm Based on the Wavelet Transform for Automatic Edge Detection in SAR Images"

This paper presents a novel technique for automatic edge enhancement and detection in synthetic aperture radar (SAR) images. The characteristics of SAR images justify the importance of an edge enhancement step prior to edge detection. Therefore, this paper presents a robust and unsupervised edge enhancement algorithm based on a combination of wavelet coefficients at different scales. The performance of the method is first tested on simulated images. Then, in order to complete the automatic detection chain, among the different options for the decision stage, the use of geodesic active contour is proposed. The second part of this paper suggests the extraction of the coastline in SAR images as a particular case of edge detection. Hence, after highlighting its practical interest, the technique that is theoretically presented in the first part of this paper is applied to real scenarios. Finally, the chances of its operational capability are assessed. [J42]

"A New Three-Dimensional Imaging Algorithm for Airborne Forward-Looking SAR"

In this letter, a new 3-D imaging algorithm is proposed for forward-looking synthetic aperture radar based on the imaging geometry and the characteristic of the echo signal. The key point of the proposed algorithm is the introduction of the nonlinear frequency modulation scaling in along-track processing to obtain accurate focusing. As the method needs only Fourier transform and multiplication operations, it is computationally efficient. Simulations with point scatterers are used to validate the method. [J43]

"Unsupervised Extraction of Flood-Induced Backscatter Changes in SAR Data Using Markov Image Modeling on Irregular Graphs"

The near real-time provision of precise information about flood dynamics from synthetic aperture radar (SAR) data is an essential task in disaster management. A novel tile-based parametric thresholding approach under the generalized Gaussian assumption is applied on normalized change index data to automatically solve the three-class change detection problem in large-size images with small class a priori probabilities. The thresholding result is used for the initialization of a hybrid Markov model which integrates scale-dependent and spatiocontextual information into the labeling process by combining hierarchical with noncausal Markov image modeling. Hierarchical maximum a posteriori (HMAP) estimation using the Markov chains in scale, originally developed on quadtrees, is adapted to hierarchical irregular graphs. To reduce the computational effort of the iterative optimization process that is related to noncausal Markov models, a Markov random field (MRF) approach is defined, which is applied on a restricted region of the lowest level of the graph, selected according to the HMAP labeling result. The experiments that were performed on a bitemporal TerraSAR-X StripMap data set from South West England during and after a large-scale flooding in 2007 confirm the effectiveness of the proposed change detection method and show an increased classification accuracy of the hybrid MRF model in comparison to the sole application of the HMAP estimation. Additionally, the impact of the graph structure and the chosen model parameters on the labeling result as well as on the performance is discussed. [J44]

"A Sparse Aperture MIMO-SAR-Based UWB Imaging System for Concealed Weapon Detection"

A high-resolution imaging system based on the combination of ultrawideband (UWB) transmission, multiple-input-multiple-output (MIMO) array, and synthetic aperture radar (SAR) is suggested and studied. Starting from the resolution requirements, spatial sampling criteria for nonmonochromatic waves are investigated. Exploring the decisive influence of the system's fractional bandwidth (instead of previously claimed aperture sparsity) on the imaging capabilities of sparse aperture arrays, a MIMO linear array is designed based on the principle of effective aperture. For the antenna array, an optimized UWB antenna is designed allowing for distortionless impulse radiation with more than 150% fractional bandwidth. By combining the digital beamforming in the MIMO array with the SAR in the orthogonal direction, a high-resolution 3-D volumetric imaging system with a significantly reduced number of antenna elements is proposed. The proposed imaging system is experimentally verified against the conventional 2-D SAR under different conditions, including a typical concealed-weapon-detection scenario. The imaging results confirm the correctness of the proposed system design and show a strong potential of the MIMO-SAR-based UWB system for security applications. [J45]

"Classification of Tropical Vegetation Using Multifrequency Partial SAR Polarimetry"

This letter presents a case study addressing the comparison between different synthetic aperture radar (SAR) partial polarimetric options for tropical-vegetation cartography. These options include compact polarization (CP), dual polarization (DP), and alternating polarization (AP). They are all derived from fully polarimetric (FP) SAR data acquired by the airborne SAR (AIRSAR) sensor over the French Polynesian Tubuai Island. The classification approach is based on the support vector machine algorithm and is further validated by several ground surveys. For a single frequency band, FP data give significantly better results than any other partial polarimetric configuration. Among the partial polarimetric architectures, the CP mode performs best. In addition, the DP mode shows better performance than the AP mode, highlighting the value of the polarimetric differential phase. The combination of different frequency bands (P-, L-, and C-bands) holds the most significant improvement: The multifrequency diversity adds generally more information than the multipolarization diversity. A noticeable result is the major contribution of the C-band at VV polarization (the only polarization available at C-band with the AIRSAR data set used in this letter) to the classification performance, due to its ability to discriminate between Pinus and Falcata. [J46]

"Modeling PSInSAR Time Series Without Phase Unwrapping"

In this paper, we propose a least-squares-based method for multitemporal synthetic aperture radar interferometry that allows one to estimate deformations without the need of phase unwrapping. The method utilizes a series of multimaster wrapped differential interferograms with short baselines and focuses on arcs at which there are no phase ambiguities. An outlier detector is used to identify and remove the arcs with phase

ambiguities, and a pseudoinverse of the variance-covariance matrix is used as the weight matrix of the correlated observations. The deformation rates at coherent points are estimated with a least squares model constrained by reference points. The proposed approach is verified with a set of simulated data. [J47]

"Focusing of Tandem Bistatic-Configuration Data With Range Migration Algorithm"

A bistatic range migration algorithm (RMA) based on an exact analytical bistatic point-target (PT) spectrum in the tandem configuration is proposed in this letter. For the conventional geometry-based bistatic formula method, the derived spectrum is only a quasi-analytical one because a variable called half-quasi-bistatic angle (HQBA) is not exactly analytically expressed. The key step of the proposed algorithm is to deduce an analytical HQBA in the tandem configuration, and thus, an exact analytical closed-form PT spectrum is acquired. Based on this analytical spectrum, a bistatic RMA is presented. It is demonstrated that this algorithm can handle the bistatic tandem configuration with extremely large baseline/range ratio and can also be applied to wide-swath imaging. [J48]

"An Improved Scheme for Target Discrimination in High-Resolution SAR Images"

To design a highly automatic and practical method for target discrimination in synthetic aperture radar images, we propose in this paper an improved scheme consisting of the framework and algorithms for target discrimination. Our main contribution in this scheme comprises four aspects. First, an integrative frame sequentially combining the algorithm based on feature extraction and the knowledge of target group has been presented. Second, three new features for target discrimination have been introduced. Third, a genetic algorithm-based feature-selection algorithm has been presented. The results show that this algorithm can evaluate the goodness-of-feature better. Finally, to improve the accuracy of the discriminator, we have designed a weighted quadratic distance discriminator, which has been observed to improve the performance of target discrimination. We have analyzed the performance of the proposed scheme comprehensively and specifically using some measured data, and carried out comparisons of the existing algorithms. The results show that the proposed scheme could improve the application ability in target discrimination. [J49]

"A New Improved Step Transform Algorithm for Highly Squint SAR Imaging"

In this letter, a new improved step transform (IST) algorithm is developed for highly squint stripmap synthetic aperture radar (SAR) imaging. Different from the previous step transform algorithms, such as the time-varying step transform algorithm, the new algorithm compensates the cubic phase term and the phase term caused by the varying chirp rate using estimation of the target position focused in the coarse-resolution fast Fourier transform, and these undesirable phase terms can be compensated more appropriately. The algorithm can process SAR imaging under a squint angle of up to 75° in X-band. Simulation results show that the IST algorithm is effective. [J50]

"Enhanced Dictionary-Based SAR Amplitude Distribution Estimation and Its Validation With Very High-Resolution Data"

In this letter, we address the problem of estimating the amplitude probability density function (pdf) of single-channel synthetic aperture radar (SAR) images. A novel flexible method is developed to solve this problem, extending the recently proposed dictionary-based stochastic expectation maximization approach (developed for a medium-resolution SAR) to very high-resolution (VHR) satellite imagery, and enhanced by introduction of a novel procedure for estimating the number of mixture components, that permits to reduce appreciably its computational complexity. The specific interest is the estimation of heterogeneous statistics, and the developed method is validated in the case of the VHR SAR imagery, acquired by the last-generation satellite SAR systems, TerraSAR-X and COSMO-SkyMed. This VHR imagery allows the appreciation of various ground materials resulting in highly mixed distributions, thus posing a difficult estimation problem that has not been addressed so far. We also conduct an experimental study of the extended dictionary of state-of-the-art SAR-specific pdf models and consider the dictionary refinements. [J51]

"Electromagnetic Land Surface Classification Through Integration of Optical and Radar Remote Sensing Data"

We present a nonhierarchical electromagnetic (EM) land surface classification method through the integration of satellite multispectral high-resolution optical and polarized radar images of central Alberta near the Saskatchewan border. We implement a conventional supervised land surface classification method and a principal component analysis to a QuickBird image. The EM properties are then assigned to the classified surfaces to produce hierarchical EM land classification maps. To further classify a hierarchical EM surface (i.e.,

dielectric constant), we calculate the root-mean-square surface height with a Shuttle Radar Topography Mission 3-arc-second digital elevation model and the temperatures from a thermal band of a Landsat-5 Thematic Mapper image. We also calculate the backscattering coefficients from the Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar image. Using these estimated values, we calculate the intrinsic weighting factors with the Dubois (1995) model for less vegetated land areas and the Ulaby (1986) model for open water areas. By applying these weighting factors to the hierarchical EM surface, we generate a nonhierarchical higher resolution EM surface map of the study area. [J52]

"Through-Wall Opportunistic Sensing System Utilizing a Low-Cost Flat-Panel Array"

A UWB through-wall imaging system is proposed based on a planar low profile aperture array operating from 0.9 GHz to 2.3 GHz. The goal is to provide a lightweight, fixed array to serve as an alternative to synthetic aperture radars (SAR) that require continuous array movement while collecting data. The proposed system consists of 12 dual-linear printed elements arranged within a triangular lattice, each forming a "flower" shape and backed by a ground plane. The array delivers half-space radiation with wideband performance, necessary for imaging applications. UWB capability is realized by suppressing grating lobes via the introduction of virtual phase centers interwoven within the actual array feeds. The proposed system is demonstrated for through-wall imaging via a non-coherent process. Distinctively, several coherent images are forged from various fixed aperture locations (referred to as "snapshot" locations) and appropriately combined to create a composite scene image. In addition to providing a unique wideband imaging capability (as an alternative to SAR), the system is portable and inexpensive for collecting/storing scattering data. The array design and data collection system is described, and several through-wall images are presented to demonstrate functionality. [J53]

"Sparse representation-based synthetic aperture radar imaging"

There is increasing interest in using synthetic aperture radar (SAR) images in automated target recognition and decision-making tasks. The success of such tasks depends on how well the reconstructed SAR images exhibit certain features of the underlying scene. Based on the observation that typical underlying scenes usually exhibit sparsity in terms of such features, this paper presents an image formation method that formulates the SAR imaging problem as a sparse signal representation problem. For problems of complex-valued nature, such as SAR, a key challenge is how to choose the dictionary and the representation scheme for effective sparse representation. Since features of the SAR reflectivity magnitude are usually of interest, the approach is designed to sparsely represent the magnitude of the complex-valued scattered field. This turns the image reconstruction problem into a joint optimisation problem over the representation of magnitude and phase of the underlying field reflectivities. The authors develop the mathematical framework for this method and propose an iterative solution for the corresponding joint optimisation problem. The experimental results demonstrate the superiority of this method over previous approaches in terms of both producing high-quality SAR images and exhibiting robustness to uncertain or limited data. [J54]

"Broadband waveguide slot array for SAR"

A new kind of wideband waveguide slot array for synthetic aperture radar (SAR) is presented. Elliptical slots are first used for designing the waveguide slot antenna. An eight-element waveguide slot array operating at X-band is designed and measured. Predicted results are compared with measured data and good agreement is reported. The measured bandwidth for VSWR ≤ 1.5 has reached 19.6%. [J55]

"Parametric inverse synthetic aperture radar manoeuvring target motion compensation based on particle swarm optimiser"

Owing to the unknown high-order unstable motion, it is difficult to realise the motion compensation, that is, envelope alignment and phase auto-focusing, for inverse synthetic aperture radar (ISAR) manoeuvring targets. By modelling the envelope shifting and phase modulation into two different high-order polynomial functions against observation time, a novel parametric ISAR motion compensation method is proposed based on polynomial coefficients estimation via particle swarm optimiser (PSO). The average range profile energy and the image contrast are chosen as the fitness functions for envelope alignment and phase auto-focusing, respectively. Furthermore, the polynomial order of phase auto-focusing is chosen higher than that of envelope alignment to meet the accuracy need of phase compensation. Besides, in order to speed up the convergence and ensure that the estimated parameters converge to the global optimisation, a least-square fitting pre-processing is also proposed to determine the target motion order and initialise the best particle at first. Finally, the results based on both numerical experiments and real data are all provided to demonstrate the effectiveness of the proposed PSO-based parametric methods. [J56]

"Multi-baseline phase unwrapping algorithm based on the unscented kalman filter"

A new multi-baseline phase unwrapping algorithm based on the unscented Kalman filter (UKF) for SAR interferometry is proposed. This method is the result of combining a UKF with a path-following strategy and an omni-directional local phase slope estimator. This technology simultaneously performs noise filtering and phase unwrapping by an optimal data fusion approach. In addition, phase slope will be directly estimated from the sample frequency spectrum of the complex interferogram, by which the underestimation of phase slope is overcome. Results obtained with synthetic and real data validate the effectiveness of the proposed method. [J57]

"Strategy of doppler centroid estimation in synthetic aperture radar"

Doppler centroid is an important parameter in synthetic aperture radar (SAR) image processing. Owing to measurement uncertainties, many clutter-lock algorithms are proposed to estimate the Doppler centroid. One of the factors that affect the estimation is `chirp coupling` [linear FM signal is used as transmitting signal in SAR, and this makes echoes of targets from different range bins overlap with each other at the same range bin, which could be called `chirp coupling (CHCO)`]. In broadside or lowly squint mode SAR, CHCO is often ignored. However, with large squint angle, its influence on Doppler centroid estimation will increase and even affect the final image. The azimuth-frequency shift of echoes caused by CHCO is analysed and a method proposed to calculate the threshold angle which is used to judge its influence on Doppler centroid estimation. With the help of the threshold angle, a novel strategy of Doppler centroid estimation is proposed. After theoretic analyses, simulations and experimental results are provided to demonstrate the proposed strategy of Doppler centroid estimation. [J58]

"Adaptive Model-Based Decomposition of Polarimetric SAR Covariance Matrices"

Previous model-based decomposition techniques are applicable to a limited range of vegetation types because of their specific assumptions about the volume scattering component. Furthermore, most of these techniques use the same model, or just a few models, to characterize the volume scattering component in the decomposition for all pixels in an image. In this paper, we extend the model-based decomposition idea by creating an adaptive model-based decomposition technique, allowing us to estimate both the mean orientation angle and a degree of randomness for the canopy scattering for each pixel in an image. No scattering reflection symmetry assumption is required to determine the volume contribution. We examined the usefulness of the proposed decomposition technique by decomposing the covariance matrix using the National Aeronautics and Space Administration/Jet Propulsion Laboratory Airborne Synthetic Aperture Radar data at the C-, L-, and P-bands. The randomness and mean orientation angle maps generated using our adaptive decomposition significantly improve the physical interpretation of the scattering observed at the three different frequencies. [J59]

"Linear Feature Detection in Polarimetric SAR Images"

Recently, the use of linear features for processing remote-sensing images has shown its importance in applications. Unfortunately, traditional linear feature detection methods rely heavily on the image's local information which makes them vulnerable to the presence of noise in the image. This problem becomes particularly difficult for synthetic aperture radar (SAR) image applications where SAR images are corrupted by speckle noise. In order to overcome this problem, we propose a novel method that processes the polarimetric synthetic aperture radar (Pol-SAR) images by combining the multiscale image analysis with polarimetric information in a new fashion. A two-scale approach is adopted here. On a coarse level, the coarse regions of the linear features are extracted by a curvelet transform from a speckle noise reduced image obtained by the polarimetric whitening filter. On a fine level, we develop a fuzzy polarimetric detector to accurately locate the linear features inside the regions. The effectiveness of the proposed method is demonstrated using simulated Pol-SAR data acquired from both EMISAR and Convair-580 systems. [J60]

"Spatial-Range Mean-Shift Filtering and Segmentation Applied to SAR Images"

The mean-shift (MS) algorithm is applied for reducing speckle noise and segmenting synthetic aperture radar (SAR) images. Two coastal images acquired by Envisat's advanced SAR (ASAR) [European Space Agency (ESA)] are used. Studies of the MS parameters are carried out according to the desired product: a speckle filtered image where textures and edges are preserved, or a segmented image, where land and sea are distinguished, as a previous stage for obtaining a land mask and detecting the coastal line. In all cases, Gaussian kernels are used. Speckle filtering results are compared with those obtained using uniform kernels, proving that the former provides better results than the latter. A segmentation approach based on the positions and frequencies at which the MS converges is applied. The use of a combined spatial-range processing and the corresponding bandwidths makes the MS suitable for the two proposed problems. The solid theoretical basis of

this procedure allows designing a guided search of the best parameters according to the desired solution, avoiding a tedious trial-and-error process. Although the used images have different characteristics, results prove that similar sets of parameters can be used, showing some degree of robustness with respect to the image, for a given sensor and image acquisition mode. [J61]

"Interferometric inverse synthetic aperture radar experiment using an interferometric linear frequency modulated continuous wave millimetre-wave radar"

An interferometric linear frequency modulated continuous wave (LFMCW) millimetre-wave radar is presented, along with the results of an experiment conducted to study the feasibility of using it in a future millimetre-wave interferometric inverse synthetic aperture radar (InISAR) system. First, a description of the radar is given. Then, the signal processing chain is described, with special attention to the phase unwrapping technique. The interferometric phase is obtained by unwrapping the prominent target's phase in each antenna using a sliding frame processing technique. Cell migration issues in this method are also addressed. Simulations were carried out to illustrate and assess the processing chain and to show the effects of multipath echoes on the height measurement. In the real experiment, the range, speed and height of a moving target were tracked over consecutive inverse synthetic aperture radar (ISAR) image frames, verifying the performance of the whole system. [J62]

"Active sample-selecting and manifold learning-based relevance feedback method for synthetic aperture radar image retrieval"

Content-based image retrieval (CBIR) provides an effective way to address the increasing need for intelligent data access to synthetic aperture radar (SAR) image repositories. In CBIR, a critical component is relevance feedback (RF), which is used to bridge the `semantic gap`. This study proposes a new RF method with active sample-selecting and manifold learning for CBIR of SAR images. In this method, the authors adopt a modified maximum margin projection with a new neighbourhood estimation criterion to discover both the geometrical structure and discriminant structure of the underlying data manifold. In order to achieve a satisfactory performance with limited feedback samples, the authors also propose an active sample selection strategy with which the diversity of feedback samples can be increased while the redundancy is decreased. The authors test our method on a TerraSAR-X image database and compare it with four other state-of-the-art RF methods. The superiority and validity of the authors` method is proved by the retrieval results and the computing cost is acceptable for image retrieval applications. [J63]

"Pedestal height for sea oil slick observation"

In this study fully polarimetric synthetic aperture radar (SAR) measurements are employed for sea oil slick observation. The co-polarised signature is read in terms of sea surface scattering mechanism with and without surface slicks and it is shown to be sensitive to the presence of sea oil slicks. A model, which relates the pedestal of the polarisation signature to the presence of surface slicks, is developed and successfully tested on L-band ALOS-PALSAR, C-band RADARSAT-2 and C-band SIR-C/X-SAR full-polarimetric SAR data. Experiment results show that polarisation signature, and its pedestal height, can be successfully exploited for both observing sea oil slicks and distinguishing them from weak-damping properties look-alikes. [J64]

"Combining pyramid representation and AdaBoost for urban scene classification using high-resolution synthetic aperture radar images"

This study presents a new algorithm called pyramid representation (PR)-AdaBoost, which combines PR and AdaBoost for urban area classification using high-resolution synthetic aperture radar (SAR) images. PR is used to hierarchically represent local feature sets and AdaBoost is used to choose proper features from the PR vector and effectively discriminate categories. The authors evaluate the proposed algorithm on a data set consisting of high-resolution SAR images of five different categories of scene and on a real TerraSAR-X image. The experimental results have shown that PR-AdaBoost can achieve higher classification accuracy than AdaBoost based on global representation or local representation such as bag-of-features. It also outperforms classical classifiers such as nearest neighbour, boosted distance and support vector machine based on the same representation. [J65]

"Novel range profile synthesis algorithm for linearly stepped-frequency modulated inversed synthetic aperture radar imaging of remote manoeuvring target"

For inversed synthetic aperture radar (ISAR) imaging of remote manoeuvring targets via linearly stepped-frequency modulated waveform, a digital stretch technique and a phase coherence compensation method are

proposed to achieve highresolution range profile (HRRP) synthesis. By using this digital stretch technique, the sampling rate can be dramatically reduced and thus the data amount can be significantly decreased. Since the motion estimation error is inevitable for conventional parameters estimation methods, the residual Doppler will give rise to the phase discontinuity at the juncture between the neighbouring sub-pulses, which may blur the HRRP to some extent. A phase coherence compensation method is proposed to further eliminate the phase difference. Owing to the adaptively and convenience for residual Doppler compensation of the proposed method, a good HRRP can be obtained by means of time-domain sub-pulses synthesis technique. Finally, a well-focused ISAR image can be achieved after the conventional range alignment and autofocusing. Experimental results confirm the effectiveness of the proposed methods. [J66]

"A Ground-Folded Slot Antenna for Imaging Radar Applications"

A ground-folded slot antenna (GFSA) is presented. The antenna geometry is formed by folding the ground of a slot antenna along the slot length to enhance the gain and reduce the backward radiation. Two feeding methods are investigated for use with the GFSA: center feeding and edge feeding. The backward radiation is further reduced by placing a microwave absorber in the backside. The antennas are implemented and measured to show that the antennas operate over a wide bandwidth and have a higher gain and lower backward radiation than a conventional slot antenna. The performance of the proposed antenna as a sensor for an imaging radar is then investigated through a synthetic aperture radar experiment. [J67]

"Improved bilateral filtering for SAR image despeckling"

To effectively preserve edges of synthetic aperture radar (SAR) images while cleanly despeckling, an improved bilateral filtering algorithm (IBF) is proposed. A threshold value is first calculated, which is used to distinguish whether the current pixel and its neighbouring pixels are homogeneous or not. Then, bilateral filtering (BF) is improved by reducing its two parameters to one, which emphasises the contribution of adjacent homogeneous pixels to the approximation of the current pixel. Finally, IBF is applied to remove speckles. The despeckling results for SAR images show that the visual quality and evaluation indexes of IBF outperform those of enhanced Lee filtering (ELF) and BF. [J68]

"Change detection in SAR images by means of grouping connected regions using clone selection algorithm"

Most of the change detection techniques for SAR images based on the analysis of the difference image always generate the result map at the pixel level, which leads to a noisy change detection map, with holes in connected components and jagged boundaries. To attack this problem, a novel technique to generate the result at the region level is proposed, which considers each connected region as an agent and then gives the optimal label combination for all agents through the clone selection algorithm and a new fitness function. The region oriented method can avoid the above problem and improve the change detection performance. Experimental results on the real Radarsat SAR dataset validate the effectiveness of the method on both the quantitative and subjective aspects. [J69]

"Improved ambiguity estimation using a modified fractional radon transform"

Ambiguity estimation is critical for the positioning of a moving target truly. Traditional real-value Radon transform (RRT) has been used to estimate the slope of target??s trajectory such that the ambiguity number can be derived. However, the unknown azimuth velocity of the target makes it difficult to determine the ambiguity number because the quadratic range cell migration (QRCM) caused by the platform velocity reduces the sensitivity of the RRT in the estimation. Also, the RRT does not work well when the signal-to-noise ratio (SNR) is low. Here, a method that uses the second-order Keystone transform (SOKT) to eliminate the QRCM and the modified fractional Radon transform (MFrRT) to estimate the ambiguity number was proposed. The method was simple and applicable in the low-SNR situation. Implementation considerations were presented. Finally, the effectiveness of the method has been shown using simulated and acquired synthetic aperture radar datasets. [J70]

"Adaptive clutter suppression and resolving of velocity ambiguities for an experimental three-channel airborne synthetic aperture radar-ground moving target indication system"

This study investigates practical processing methods aiming at detecting ground moving targets and estimating their motion parameters for an experimental three-channel airborne synthetic aperture radar-ground moving target indication (SARGMTI) system. It focuses on two key points of GMTI processing: adaptive clutter suppression and resolving of velocity ambiguities. Different from the conventional clutter suppression based on

SAR images or in range-Doppler domain of the entire-aperture pulses, the clutter cancellation is proposed to be performed in the Doppler domain of short-aperture pulses to avoid the superposition of clutter echoes from different ground patches in azimuth; meanwhile, the ground moving target signals are focused with the full aperture to maximise the signal-to-noise ratio. To resolve the velocity ambiguity, a joint strategy is proposed that combines the estimates of the along-track interferometric phases and the Doppler spectrum information of a ground moving target according to the Chinese remainder theorem. The implementations of the processing operations are verified with real data from the experimental three-channel airborne SAR-GMTI system. [J71]

"Mapping Soil Moisture Using RADARSAT-2 Data and Local Autocorrelation Statistics"

The purpose of this study is to evaluate the capability of surface radar backscatter models to estimate soil moisture over agricultural fields from fully polarimetric RADARSAT-2 C-band synthetic aperture radar (SAR) responses. For validation purposes, ground measurements over 44 sampling sites in eastern Ontario, Canada were carried out in the spring of 2008 simultaneously with satellite data acquisitions. Soil moisture retrieval was accomplished using two semi-empirical scattering models (Dubois and Oh) and the SAR image backscatter. Discrepancies between measured radar backscatter coefficients and those predicted by the models were previously reported, requiring correction factors to reduce biases associated with these semi-empirical approaches. Soil moisture was estimated by explicitly solving the two backscatter equations of the Dubois model, and using a look-up table (LUT) approach applied to the Oh model. Results showed that the Oh model in a cross-polarization (HH-HV) and Dubois in a co-polarization (HH-VV) inversion scheme provide the best estimates. These model configurations were implemented to produce multi-date soil moisture maps for the eastern Ontario site. To expand the range of validity of these soil moisture estimates, the maps produced by the Dubois and Oh models were uniquely combined. These estimates of absolute soil moisture were then used to derive spatial patterns of near-surface moisture content using the Getis statistic. The Getis statistic maps provide meaningful spatial information, demonstrating the potential of combining the Getis statistic and RADARSAT-2 data in predicting soil moisture conditions. [J72]

"Sandglass transformation for synthetic aperture radar detection and imaging of ship at low signal-to-clutter-plus-noise ratio"

Space/air-borne synthetic aperture radar (SAR) detection and imaging of moving ships at sea are important for ocean reconnaissance and fishery monitoring. A novel algorithm based on sandglass transformation to detect weak ships and form high-quality images under the conditions of low signal-to-clutter-plus-noise ratio is presented here. It requires no prior information about motion parameters of targets. The sandglass transformation can decouple the time and lag time in the instantaneous autocorrelation function of a linear frequency modulated (LFM) signal. Thus the cross-range signals of ship in the approximate form of LFM signals can be integrated coherently via the two-dimensional fast Fourier transformation. The proposed algorithm can not only achieve high-energy accumulation gain, but also suppress the interference of cross terms effectively without loss of resolution. Hence, it is effective to detect weak ships and generate high-resolution images. Numerical and experimental results confirm the effectiveness of the proposed algorithm. [J73]

"Exact analytical two-dimensional spectrum for bistatic synthetic aperture radar in tandem configuration"

An exact analytical solution for the two-dimensional (2-D) point target spectrum is usually difficult to obtain because of the existence of a double-square-root (DSR) term in the bistatic range equation. Some approximate solutions for the 2-D spectrum have been derived and used in order to focus bistatic synthetic aperture data. A geometry-based bistatic formula (GBF) method was used for obtaining a quasi-analytical form of a bistatic 2-D spectrum by Zhang (2007). Although the GBF method cannot completely solve the problem of the DSR term, it provides a novel aspect for dealing with this problem. In this study, based on the quasi-analytical spectrum, the authors change the signal expression space and transform the eight-order polynomial equation in terms of the slow time into the four-order polynomial equation in terms of the half quasi-bistatic angle (HQBA) for the tandem configuration. Then the DSR-term problem is successfully solved and a corresponding exact analytical bistatic 2-D spectrum is obtained. It is proved that the spectra acquired by Rocca's smile operator, Loffeld's bistatic formula (LBF) and the method of series reversion (MSR) are equivalent to this proposed analytical spectrum when certain conditions are met, and that this exact analytical spectrum is the most accurate among them. [J74]

"Unambiguous doppler centroid estimation approach for synthetic aperture radar data based upon compressed signal magnitude"

A new approach to Doppler ambiguity resolution is presented. This approach adopts the fact that the absolute Doppler centroid is a linear function of range frequency. Based on this concept, an alternative azimuth

compression method that is without a prior knowledge about the motion parameters is developed and carried out in range frequency domain to accumulate the target energy along the azimuth. The resulting trajectories become straight lines with the same slope proportional to the unwrapped Doppler centroid. This slope can be well estimated by the azimuth cell walk correction/integration method. Two sets of measured synthetic aperture radar data (airborne and spaceborne radar) show that this approach works well in medium- and high-contrast scenes. [J75]

"3-D Imaging of Vehicles using Wide Aperture Radar"

An image processing procedure is presented to construct a three-dimensional representation of a vehicle from a set of two-dimensional circular synthetic aperture radar (SAR) images. Given a previously generated digital elevation map, a third dimension is inferred from layover and polarization. With high data rates and circular flight paths, SAR scenes may be large relative to the standoff distance. Consequently, variations in elevation angles (with respect to terrain) across the scene become crucial for identifying signatures. The proposed 3D processing inverts elevated point layover to provide partial invariance to elevation angle and produces an unordered set of scattering centers with attributes including an azimuth attribute to preserve anisotropy. The proposed processing is demonstrated on both measured and simulated data. [J76]

"D/A conversion networks for high-resolution SAR A/D converters"

An intermittent-sleeping C-R hybrid structure and a resistor-reusing R-C hybrid structure are presented for high-resolution SAR A/D converters. The switching power of these conversion networks and the matching requirements of their internal passive components are researched based on high-level Matlab modelling. Their applicability to high-resolution SAR ADCs is proven by realisation of two SAR A/D converters with these two novel D/A networks. [J77]

"Focusing Problems of a Buried Point Scatterer using a Low Frequency SAR"

In this paper, we inspect the range and azimuthal defocusing of a buried point scatterer for a low frequency (L or P band) synthetic aperture radar (SAR). Firstly we present the hydraulic electromagnetic and propagation models that allow us to calculate the water content profile in the soil, to deduce the dielectric constant and to simulate the electromagnetic (EM) wave propagation and attenuation. Secondly results of pulse simulation and focusing for several configurations (band polarization, incident angle, point scatterer depth, water content profile) are presented and discussed. The advantages and drawbacks of L and P radars are discussed in the conclusion. [J78]

"Target Recognition by Means of Polarimetric ISAR Images"

Automatic target recognition (ATR) is generally the reason why inverse synthetic aperture radar (ISAR) imaging systems are employed. Moreover, the use of fully polarimetric radar systems in radar imaging applications such as SAR and ISAR has enhanced both image quality and classification capabilities. The authors propose a novel technique for ATR using polarimetric ISAR (Pol-ISAR) images. The proposed method is based on a model matching approach. Results are obtained that show the effectiveness of such a technique. [J79]

"On the Discrimination of Radar Signatures of Atmospheric Gravity Waves and Oceanic Internal Waves on Synthetic Aperture Radar Images of the Sea Surface"

Synthetic aperture radar (SAR) images acquired over the ocean frequently show sea wave-like patterns that have wavelengths well above those of ocean surface waves and that are sea surface signatures of oceanic internal waves (OIWs) or of atmospheric gravity waves (AGWs). However, it is often difficult to decide whether they result from the first or the second kind of waves, which has led many investigators to misinterpret SAR images of the sea surface. Based on solitary wave and radar imaging theories of AGWs and OIWs, we present criteria that help distinguish between them. However, there are cases where these criteria, which are based solely on the shape and structure of the features visible on the SAR images, yield ambiguous results. In these cases, one must resort to additional information on the generation of AGWs and OIWs, which are listed in this paper. [J80]

"On the Use of Anisotropic Covariance Models in Estimating Atmospheric DInSAR Contributions"

Stochastic models are often used to describe the spatial structure of atmospheric phase delays in differential interferometric synthetic aperture radar (DInSAR) data. Synthetic aperture radar interferograms often exhibit anisotropic atmospheric signals. In view of this, the use of anisotropic models for atmospheric phase estimation is increasingly advocated. However, anisotropic models lead to increased computational complexity in estimating

the correlation function parameters with respect to the isotropic case. Moreover, the performance is degraded when dealing with DInSAR techniques involving only a few sparse points usable for computations, as in the case of persistent scatterer interferometry applications, particularly when this estimation has to be done in an automated way on many interferograms. In the present work, we propose some observations about the actual advantage given by anisotropic modeling of atmospheric phase in the case of sparse-grid point-target DInSAR applications. Through analysis of simulated data, we observe that an improvement in the performances of kriging reconstruction approaches can be obtained only when sufficient sampling densities are available. In critical sampling conditions, automated methods with reasonable computational cost may improve their performance if external information on the atmospheric phase screen field is available. [J81]

"Impact of DEM-Assisted Coregistration on High-Resolution SAR Interferometry"

Image alignment is a crucial step in synthetic aperture radar (SAR) interferometry. Interferogram formation requires images to be coregistered with an accuracy of better than a few tenths of a resolution cell to avoid significant loss of phase coherence. In conventional interferometric precise coregistration methods for full-resolution SAR data, a 2-D polynomial of low degree is usually chosen as warp function, and the polynomial parameters are estimated through least squares fit from the shifts measured on image windows. In case of rough topography or long baselines, the polynomial approximation may become inaccurate, leading to local misregistrations. These effects increase with spatial resolution of the sensor. An improved elevation-assisted image-coregistration procedure can be adopted to provide better prediction of the offset vectors. This approach computes pixel by pixel the correspondence between master and slave acquisitions by using the orbital data and a reference digital elevation model (DEM). This paper aims to assess the performance of this procedure w.r.t. the "standard" one based on polynomial approximation. Analytical relationships and simulations are used to evaluate the improvement of the DEM-assisted procedure w.r.t. the polynomial approximation as well as the impact of the finite vertical accuracy of the DEM on the final coregistration precision for different resolutions and baselines. The two approaches are then evaluated experimentally by processing high-resolution SAR data provided by the COnstellation of small Satellites for the Mediterranean basin Observation (COSMO/SkyMed) and TerraSAR-X missions, acquired over mountainous areas in Italy and Tanzania, respectively. Residual-range pixel offsets and interferometric coherence are used as quality figure. [J82]

"Unsupervised Classification of SAR Images Using Markov Random Fields and Model"

This letter deals with synthetic aperture radar (SAR) data classification in an unsupervised way. Many models have been proposed to fit SAR data (K, Weibull, Log-normal, etc.), but none of them are flexible enough to model all kinds of surfaces (particularly when there are urban areas present in the image). Our main contribution is the application of a statistical model G0in a classification process which is shown to be able to model areas with different degrees of heterogeneity. The quality of the classification obtained by mixing this model and a Markovian segmentation is high. We use an iterative conditional estimation method to estimate the parameters of the proposed model. [J83]

"A Novel Imaging Method for Fast Rotating Targets Based on the Segmental Pseudo Keystone Transform"

Fast rotating targets such as gimbaled antennas or propeller blades may cause migration through resolution cells (MTRC) of the high-resolution range profile during the imaging time, which makes the inverse synthetic aperture radar image smeared. To solve this problem, a novel imaging method for fast rotating targets is proposed in this paper. The method is based on the segmental pseudo Keystone transform, which is designed to realize MTRC correction. The fast realization is achieved by employing the discrete match Fourier transform, which makes the algorithm feasible and simple. Experiments with simulated radar data demonstrate the performance of the proposed method. [J84]

"Unsupervised Spatiotemporal Mining of Satellite Image Time Series Using Grouped Frequent Sequential Patterns"

An important aspect of satellite image time series is the simultaneous access to spatial and temporal information. Various tools allow end users to interpret these data without having to browse the whole data set. In this paper, we intend to extract, in an unsupervised way, temporal evolutions at the pixel level and select those covering at least a minimum surface and having a high connectivity measure. To manage the huge amount of data and the large number of potential temporal evolutions, a new approach based on data-mining techniques is presented. We have developed a frequent sequential pattern extraction method adapted to that spatiotemporal context. A successful application to crop monitoring involving optical data is described. Another application to crustal deformation monitoring using synthetic aperture radar images gives an indication about the generic nature of the

proposed approach. [J85]

"An Improved Radon-Transform-Based Scheme of Doppler Centroid Estimation for Bistatic Forward-Looking SAR"

For high-quality synthetic aperture radar (SAR) processing, Doppler centroid estimation is an essential procedure. An incorrect Doppler centroid would cause a loss of SNR, an increase in the azimuth ambiguity level, a shift in the location of the target, etc. An improved Radon-transform-based Doppler centroid estimation scheme of bistatic forward-looking SAR is proposed in this letter. First, this scheme performs edge detection on the range-compressed data and then does the coarse and fine Radon transforms to estimate the Doppler centroid. Simulations and real-data experiments validate the effectiveness of this method. [J86]

"An Improved Quality-Guided Phase-Unwrapping Algorithm Based on Priority Queue"

Phase unwrapping is one of the key problems in reconstructing the elevation map of a scene from interferometric synthetic aperture radar or interferometric synthetic aperture sonar (InSAS) data. In this letter, an improved quality-guided phase-unwrapping algorithm is proposed, which depends on the quality value and its surrounding quality information to guide the path of unwrapping more accurately. In order to design highly efficient quality-guided algorithm, a guided map deduced from the quality map is introduced and taken as the new quality map which the quality-guided algorithm should completely depend on. A quantized quality-guided method is designed, which adopts the quantized new quality map and the priority queue designed to optimize the process of unwrapping. The quantized quality map establishes the relation between the quality values and the indexes of array, which can save the time of inserting one pixel into the priority queue according to its integral quality value. Priority queue keeps all the pixels by their quantized quality in a nondecreasing order by maintaining the doubly linked lists in an increasing order. An optimized strategy is used to accelerate the process of finding the pixel with the highest quality value in the priority queue. Tests performed on real InSAS data and simulated interferograms confirm the accuracy and efficiency of the proposed algorithm, and the improved algorithm is suitable for our real-time processing InSAS system. [J87]

"NL-InSAR: Nonlocal Interferogram Estimation"

Interferometric synthetic aperture radar (SAR) data provide reflectivity, interferometric phase, and coherence images, which are paramount to scene interpretation or low-level processing tasks such as segmentation and 3-D reconstruction. These images are estimated in practice from a Hermitian product on local windows. These windows lead to biases and resolution losses due to the local heterogeneity caused by edges and textures. This paper proposes a nonlocal approach for the joint estimation of the reflectivity, the interferometric phase, and the coherence images from an interferometric pair of coregistered single-look complex (SLC) SAR images. Nonlocal techniques are known to efficiently reduce noise while preserving structures by performing the weighted averaging of similar pixels. Two pixels are considered similar if the surrounding image patches are "resembling." Patch similarity is usually defined as the Euclidean distance between the vectors of graylevels. In this paper, a statistically grounded patch-similarity criterion suitable to SLC images is derived. A weighted maximum likelihood estimation of the SAR interferogram is then computed with weights derived in a data-driven way. Weights are defined from the intensity and interferometric phase and are iteratively refined based both on the similarity between noisy patches and on the similarity of patches from the previous estimate. The efficiency of this new interferogram construction technique is illustrated both qualitatively and quantitatively on synthetic and true data. [J88]

"Polarization Phase Difference Analysis for Selection of Persistent Scatterers in SAR Interferometry"

In this letter, we propose a technique for selecting persistent scatterers (PSs) based on their polarization phase difference (PPD). We analyze a normalized PPD between HH and VV channels averaged over a temporal set of images and select pixels that demonstrate predominantly even or odd bounce scattering properties. We compare selected scatterers to PSs selected by applying an amplitude dispersion threshold as suggested by a standard PS interferometry (PSI) approach and show that both methods are complementary. However, the proposed approach can be potentially used on a small set of synthetic aperture radar (SAR) images, which can be beneficial in the early stage of data acquisition. We apply the proposed technique to produce a deformation map for the San Francisco region from six quad-pol RADARSAT-2 SAR images acquired during 2008-2009. The coverage and the precision of the produced deformation map are higher than if it was calculated with the standard PSI technique applied to the same data set. [J89]

"Ship Surveillance With TerraSAR-X"

Ship detection is an important application of global monitoring of environment and security. In order to overcome the limitations by other systems, surveillance with satellite synthetic aperture radar (SAR) is used because of its possibility to provide ship detection at high resolution over wide swaths and in all weather conditions. A new X-band radar onboard the TerraSAR-X (TS-X) satellite gives access to spatial resolution as fine as 1 m. In this paper, first results on the combined use of TS-X ship detection, automatic identification system (AIS), and satellite AIS (SatAIS) is presented. The AIS system is an effective terrestrial method for tracking vessels in real time typically up to 40 km off the coast. SatAIS, as a space-based system, allows almost global coverage for monitoring of ships since not all ships operate their AIS and smaller ships are not equipped with AIS. The system is considered to be of cooperative nature. In this paper, the quality of TS-X images with respect to ship detection is evaluated, and a first assessment of its performance for ship detection is given. The velocity of a moving ship is estimated using complex TS-X data. As test cases, images were acquired over the North Sea, Baltic Sea, Atlantic Ocean, and Pacific Ocean in Stripmap mode with a resolution of 3 m at a coverage of 30 km 100 km. Simultaneous information on ship positions was available from TS-X and terrestrial as well as SatAIS. First results on the simultaneous superposition of SatAIS and high-resolution radar images are presented. [J90]

"Final TerraSAR-X Calibration Results Based on Novel Efficient Methods"

TerraSAR-X is a satellite mission for scientific and commercial applications operating a highly flexible X-band synthetic aperture radar (SAR) instrument with a multitude of different operation modes. As product quality is of crucial importance, the success or failure of the mission depends essentially on the method of calibrating TerraSAR-X in an efficient way during commissioning the entire system in a restricted time. Only then, product quality and the correct in-orbit operation of the entire SAR system can be ensured. This paper describes the in-orbit calibration method for TerraSAR-X and dedicated activities performed during the commissioning phase as well as final results derived from all calibration procedures. [J91]

"The Importance of Soil Moisture and Soil Structure for InSAR Phase and Backscatter, as Determined by FDTD Modeling"

In this paper, we introduce a finite-difference time-domain simulator that accurately models the interaction of microwaves with realistic soils, specifically from spaceborne interferometric synthetic aperture radar (InSAR). The modeled soils are characterized by surface roughness, correlation length, bulk moisture content, vertical moisture gradient, and small air-filled-void content. Simulation results include both backscatter and interferometric phase, and we are particularly interested in assessing the potential of the latter as a proxy for soil moisture. We find that differences in homogeneous bulk moisture result in only small phase differences (< 5?). In contrast, combinations of vertical moisture gradients and small air-filled voids, which may typically exist in more realistic soils, can produce phase changes > 30? for HH and > 50? for VV when the soil moisture is varied from 3% to 30% in the uppermost 2 cm of the soil. Phase changes of this magnitude are easily detectable by spaceborne InSAR techniques. While a strong phase response to a change in mean bulk moisture is common to vertical moisture gradient and small air-filled-void cases, their corresponding backscatter responses are very different. A vertical moisture gradient makes the backscatter response dramatically flatter compared with the case of uniform moisture; in contrast, the introduction of air-filled voids barely alters the backscatter. Thus, it may be possible to infer near-surface soil-structure parameters such as vertical gradients or fractions of voids and inhomogeneities from combined SAR phase and backscatter data. Future SAR sensors could be optimized for this purpose. Prior theoretical work based on the assumption of vertically uniform soil-moisture distributions may need to be adjusted, and the lack of a theory that accommodates more complex soil structures may explain why backscatter inversions have yet to result in a viable operational system. [J92]

"Micro-Doppler Effect Analysis and Feature Extraction in ISAR Imaging With Stepped-Frequency Chirp Signals"

The micro-Doppler (m-D) effect induced by the rotating parts or vibrations of the target provides a new approach for target recognition. To obtain high range resolution for the extraction of the fine m-D signatures of an inverse synthetic aperture radar target, the stepped-frequency chirp signal (SFCS) is used to synthesize the ultrabroad bandwidth and reduce the requirement of sample rates. In this paper, the m-D effect in SFCS is analyzed. The analytical expressions of the m-D signatures, which are extracted by an improved Hough transform method associated with time-frequency analysis, are deduced on the range-slow-time plane. The implementation of the algorithm is presented, particularly in those extreme cases of rotating (vibrating) frequencies and radii. The simulations validate the theoretical formulation and robustness of the proposed m-D extraction method. [J93]

"Capon- and APES-Based SAR Processing: Performance and Practical Considerations"

This paper discusses the use of Capon's minimum-variance method (MVM) and Amplitude and Phase

EStimation (APES) spectral-estimation algorithms to synthetic aperture radar range-azimuth focusing. The rationale of the algorithms is discussed. An implementation of a Capon or APES processing chain is explained, and processing parameters such as chip-image size, resampling factor, and diagonal loading are discussed. For multichannel cases, a joint-processing approach is presented. A set of Monte Carlo simulations are described and used to benchmark Capon- and APES-based processing against conventional matched-filter-based approaches. Both methods improve the resolution and reduce sidelobes. APES yields generally better estimates of amplitude and phase than Capon but with worse resolution. Results with RADARSAT-2 quad-polarization data over Barcelona are used to qualitatively study the real-life performance of these algorithms. [J94]

"Development of the TanDEM-X Calibration Concept: Analysis of Systematic Errors"

The TanDEM-X mission, result of the partnership between the German Aerospace Center (DLR) and Astrium GmbH, opens a new era in spaceborne radar remote sensing. The first bistatic satellite synthetic aperture radar mission is formed by flying TanDEM-X and TerraSAR-X in a closely controlled helix formation. The primary mission goal is the derivation of a high-precision global digital elevation model (DEM) according to High-Resolution Terrain Information (HRTI) level 3 accuracy. The finite precision of the baseline knowledge and uncompensated radar instrument drifts introduce errors that may compromise the height accuracy requirements. By means of a DEM calibration, which uses absolute height references, and the information provided by adjacent interferogram overlaps, these height errors can be minimized. This paper summarizes the exhaustive studies of the nature of the residual-error sources that have been carried out during the development of the DEM calibration concept. Models for these errors are set up and simulations of the resulting DEM height error for different scenarios provide the basis for the development of a successful DEM calibration strategy for the TanDEM-X mission. [J95]

"A Polarimetric Target Detector Using the Huynen Fork"

The contribution of synthetic aperture radar polarimetry in target detection is described and found to add valuable information. A new target detection methodology that makes novel use of the polarization fork of the target is described. The detector is based on a correlation procedure in the target space, and other target representations (e.g., Huynen parameters or ?? angle) can be employed. The mathematical formulation is general and can be applied to any kind of single target; however, in this paper, the detection is optimized for the odd and even bounces (the first two elements of the Pauli scattering vector) and for the oriented dipoles. Validation against real data shows significant agreement with the expected results based on the theoretical description. [J96]

"Coseismic Horizontal Offsets and Fault-Trace Mapping Using Phase Correlation of IRS Satellite Images: The 1999 Izmit (Turkey) Earthquake"

On August 17, 1999, a strong earthquake (Mw ?? 7.4) occurred along the western sector of the North Anatolian Fault system in Turkey. The epicenter was located near the city of Izmit, 50 km east of Istanbul. Previous works determined the coseismic surface displacements by satellite synthetic aperture radar (SAR) interferometry (InSAR) and satellite optical-image correlation. In 1999, the highest spatial resolution orbiting camera was the panchromatic sensor (PAN), a 5.8-m pixel sensor (SPOT 2 was a 10-m pixel sensor) onboard the Indian Remote Sensing (IRS) satellite. We propose to apply a new phase-correlation method to PAN images to study the coseismic rupture due to the Izmit earthquake. The phase-correlation method does not need phase unwrapping and was proved to be robust under a wide variety of circumstances. Image correlometry deals with the quantification of the subpixel offsets over the whole image, allowing displacement measurement with an accuracy that is proportional to the pixel size. We measured the near-field deformations exploiting two geometrically corrected IRS images with similar look angles. A quality check of the derived offset map was performed by comparison with GPS benchmarks and SPOT offsets. The results show that IRS PAN images can be correlated to derive coseismic slip offsets due to a large earthquake (and to map its fault trace). [J97]

"Tropical Cyclone Intensity Estimated From Wide-Swath SAR Images"

Due to the relatively small amount of in situdata available for the open oceans, remote sensing techniques take an important role in the retrieval of geophysical information, particularly during extreme events. The work presented here aims at the improvement of prediction of cyclone intensity using synthetic aperture radar (SAR) images. A new method to measure the hurricane intensity using SAR images, in combination with a parametric Holland-type model of wind speed, is presented. The algorithm is based on a least square minimization of the difference between the parametric model results and the SAR measurement. The radius of the maximum wind speed, required as input for the minimization procedure, is estimated from the SAR image using wavelet analysis. Information on wind direction is extracted from the SAR image through analysis of image features

caused by boundary layer rolls. The root-mean-square error of the suggested method has been validated to be equal to 3.9 m/s. The study is based on a data set of wide-swath SAR images of about 400 km ?? 400 km coverage, acquired by the European Envisat satellite, over tropical cyclones. As a case study, hurricane Katrina is investigated in detail. A total of five tropical cyclone images will be used to validate the results of the new algorithm. [J98]

"Earthquake Damage Assessment of Buildings Using VHR Optical and SAR Imagery"

Rapid damage assessment after natural disasters (e.g., earthquakes) and violent conflicts (e.g., war-related destruction) is crucial for initiating effective emergency response actions. Remote-sensing satellites equipped with very high spatial resolution (VHR) multispectral and synthetic aperture radar (SAR) imaging sensors can provide vital information due to their ability to map the affected areas with high geometric precision and in an uncensored manner. In this paper, we present a novel method that detects buildings destroyed in an earthquake using pre-event VHR optical and post-event detected VHR SAR imagery. The method operates at the level of individual buildings and assumes that they have a rectangular footprint and are isolated. First, the 3-D parameters of a building are estimated from the pre-event optical imagery. Second, the building information and the acquisition parameters of the VHR SAR scene are used to predict the expected signature of the building in the post-event SAR scene assuming that it is not affected by the event. Third, the similarity between the predicted image and the actual SAR image is analyzed. If the similarity is high, the building is likely to be still intact, whereas a low similarity indicates that the building is destroyed. A similarity threshold is used to classify the buildings. We demonstrate the feasibility and the effectiveness of the method for a subset of the town of Yingxiu, China, which was heavily damaged in the Sichuan earthquake of May 12, 2008. For the experiment, we use QuickBird and WorldView-1 optical imagery, and TerraSAR-X and COSMO-SkyMed SAR data. [J99]

"Interferometric Microrelief Sensing With TerraSAR-X-First Results"

The meter-scale ground resolution of TerraSAR-X spotlight images promises for the first time the 3-D detection of landforms and landform changes on the microrelief scale from a satellite-based remote sensing system. Using repeat-pass pairs of high-resolution spotlight images, this paper analyzes the spatial variation of coherence on the micro- and mesorelief scale and demonstrates the high potential as well as some limitations of this approach for digital elevation model generation, geomorphological mapping, and geomorphic-change detection in contrasting landscapes of the coastal desert of southern Peru. [J100]

"Coherency Matrix Estimation of Heterogeneous Clutter in High-Resolution Polarimetric SAR Images"

This paper presents an application of the recent advances in the field of spherically invariant random vector (SIRV) modeling for coherency matrix estimation in heterogeneous clutter. The complete description of the polarimetric synthetic aperture radar (POLSAR) data set is achieved by estimating the span and the normalized coherency independently. The normalized coherency describes the polarimetric diversity, while the span indicates the total received power. The main advantages of the proposed fixed-point (FP) estimator are that it does not require any a prioriinformation about the probability density function of the texture (or span) and that it can directly be applied on adaptive neighborhoods. Interesting results are obtained when coupling this FP estimator with an adaptive spatial support based on the scalar span information. Based on the SIRV model, a new maximum-likelihood distance measure is introduced for unsupervised POLSAR classification. The proposed method is tested with both simulated POLSAR data and airborne POLSAR images provided by the Radar Ae?? roporte?? Multi-Spectral d'Etude des Signatures system. Results of entropy/alpha/anisotropy decomposition, followed by unsupervised classification, allow discussing the use of the normalized coherency and the span as two separate descriptors of POLSAR data sets. [J101]

"Target Motion Ambiguities in Single-Aperture Synthetic Aperture Radar"

A simple approach to the detection and estimation of target motion based on phase measurements from a single-aperture synthetic-aperture radar (SAR) is presented. In this analysis the SAR is treated as a pure range-measuring device. Each stationary object in a scene produces a unique range-time history in the radar. Thus, ideal SAR processing is reduced to finding the response to the set of matched filters associated with stationary targets. For this purely geometrical model, it is shown that there exists a class of moving targets that are absolutely indistinguishable from a stationary target. These are targets that move in such a way that the range to the SAR is always identical to the range from the SAR to some stationary target. Moreover it turns out that most moving targets are also indistinguishable from some other moving targets. The idealized SAR is only sensitive to a single velocity component of the target, and thus most solutions are degenerate. Theoretical limits of the detection of motion are established that are dependent on SAR parameters and observation time. Fast-moving

(e.g. spaceborne) SARs can detect along-track motions with less ambiguity than a slow-moving SAR. It is shown that most moving targets do produce apparent motion in sequences of multilook SAR imagery. These apparent motions can be used to estimate the measurable component of target velocity. [J102]

"Polarimetric Characterization and Temporal Stability Analysis of Urban Target Scattering"

This paper studies the polarimetric-dispersion properties of urban targets and their evolution along time in terms of the geometrical configuration. The relations between target geometry and the scattering behavior have been defined through the analysis of large stacks of simulated images. Scattering maps and synthetic aperture radar (SAR) images have been synthesized with the numerical tool GRaphical Electromagnetic COmputing SAR for different qualitative models of two real buildings. Ground-based SAR (GB-SAR) data acquired in a subsidence measurement campaign has been used to assess the simulator's realism. These data have permitted the identification of the critical simulation parameters and their range of recommended values for realistic simulations. In the context of very high resolution images, the results derived from this study may be crucial for making progress in urban-image postprocessing. As the different resolution cells comprise few scattering centers showing a quasi-deterministic scattering behavior, nonprobabilistic models based on target's geometry seem more suited for scattering modeling. In these models, the geometry-scattering (GS) links precisely inferred from simulated images can be very important. In addition to change detection and land classification, GS models may help in improving the interpretation of subsidence results with differential interferometry. Certainly, new processing algorithms can be developed exploiting the available scattering data with more physical sense. In addition, they can take more advantage of the fine resolution and polarimetric capabilities of the new sensors, like TerraSAR-X or RADARSAT-2. [J103]

"The TerraSAR-X Mission and System Design"

This paper describes the TerraSAR-X mission concept within the context of a public-private partnership (PPP) agreement between the German Aerospace Center (DLR) and the industry. It briefly describes the PPP concept as well as the overall project organization. This paper then gives an overview of the satellite design and the corresponding ground segment, as well as the main mission parameters. After a short introduction to the scientific and commercial exploitation scheme, this paper finally focuses on the mission accomplishments achieved so far during the ongoing mission. [J104]

"Noise-Related Radiometric Correction in the TerraSAR-X Multimode SAR Processor"

Synthetic aperture radar (SAR) image intensity is disturbed by additive system noise. During SAR focusing, pattern corrections that are adapted to the characteristics of the wanted signal, but not to the characteristics of the noise, influence the spatial distribution of the noise power. Particularly in the case of ScanSAR, a distinct residual noise pattern in low backscatter areas results. This necessitates a noise-adapted radiometric correction of the focused image for almost all applications except interferometry. In this paper, we thoroughly investigate this topic. Based on signal theoretical and stochastic considerations, we develop a radiometric correction scheme. Simulations and the application of the algorithm to TerraSAR-X datatakes support the theoretical results. [J105]

"Mutual-Information-Based Registration of TerraSAR-X and Ikonos Imagery in Urban Areas"

The launch of high-resolution remote sensing satellites like TerraSAR-X, WorldView, and Ikonos has benefited the combined application of synthetic aperture radar (SAR) and optical imageries tremendously. Specifically, in case of natural calamities or disasters, decision makers can now easily use an old archived optical with a newly acquired (postdisaster) SAR image. Although the latest satellites provide the end user already georeferenced and orthorectified data products, still, registration differences exist between different data sets. These differences need to be taken care of through quick automated registration techniques before using the images in different applications. Specifically, mutual information (MI) has been utilized for the intricate SAR-optical registration problem. The computation of this metric involves estimating the joint histogram directly from image intensity values, which might have been generated from different sensor geometries and/or modalities (e.g., SAR and optical). Satellites carrying high-resolution remote sensing sensors like TerraSAR-X and Ikonos generate enormous data volume along with fine Earth observation details that might lead to failure of MI to detect correct registration parameters. In this paper, a solely histogram-based method to achieve automatic registration within TerraSAR-X and Ikonos images acquired specifically over urban areas is analyzed. Taking future sensors into a perspective, techniques like compression and segmentation for handling the enormous data volume and incompatible radiometry generated due to different SAR-optical image acquisition characteristics have been rightfully analyzed. The findings indicate that the proposed method is successful in estimating large global shifts followed by a fine refinement of registration parameters for high-resolution images acquired over dense urban

areas. [J106]

"SAR Calibration Aided by Permanent Scatterers"

We propose a calibration method suitable for a set of repeated synthetic aperture radar (SAR) acquisitions that uses both absolute calibrated devices (such as corner reflectors) and stable targets identified in the scene [the permanent scatterers (PSs)]. Precisely, the role of the PS is to extend the initial calibration sequence by monitoring the radiometric stability of the system throughout the whole mission life span. At a first step, this paper approaches the problem of PS-based normalization by an iterative maximum-likelihood method that exploits the stack of complex interferometric SAR images. Two solutions are given based on different assumptions on the PS phases. As a second step, the merging of these estimates with the available calibration information is discussed. Results achieved by experimental acquisitions are shown in two different SAR systems: 1) a C-band spaceborne SAR and 2) a Ku-band ground-based SAR. [J107]

"4-D SAR Imaging: The Case Study of Rome"

Four-dimensional synthetic aperture radar (SAR) imaging, also known as differential SAR tomography, is a new research topic in the framework of coherent multitemporal/multibaseline SAR processing that extends the interferometry concept. Four-dimensional SAR imaging-based processing could improve the capability of ground-scatterer monitoring with respect to classical differential interferometric SAR processing. The first results on the applicability of such an advanced tomographic SAR processing to real spaceborne data were recently discussed in the literature. In this letter, we present the results of an experiment with a data set that demonstrates the potentialities of this new technique for monitoring complex targets, such as infrastructures. [J108]

"Building Height Retrieval From VHR SAR Imagery Based on an Iterative Simulation and Matching Technique"

Experimental airborne synthetic aperture radar (SAR) systems achieve spatial resolutions of approximately 10 cm, whereas the new spaceborne very high spatial resolution (VHR) SAR sensors onboard the TerraSAR-X and COSMO-SkyMed satellites achieve spatial resolutions down to 1 m. In VHR SAR data, features from individual urban structures (i.e., buildings) can be identified by their characteristic settings in urban settlement patterns. In this paper, we present a novel concept for the height estimation of generic man-made structures from single detected SAR data. The proposed approach is based on the definition of a hypothesis on the height of the building and on the simulation of a SAR image for testing that hypothesis. A matching procedure is applied between the estimated and the actual SAR image in order to test the height hypothesis. The process is iterated for different height assumptions until the matching function is optimized, and thus, the building height is estimated. The efficiency of the proposed method is demonstrated on a set of 40 flat- and gable-roof buildings using two submeter VHR airborne and two 1-m resolution TerraSAR-X SAR scenes all acquired from the same residential area in Dorsten, Germany. The results show that, in the absence of string disturbing effects, the method is able to estimate the height of flat- and gable-roof buildings in the submeter data to the order of a meter, while the accuracy for the meter resolution spaceborne data is lower but still sufficient to estimate the number of floors of a building. [J109]

"Radar-Coding and Geocoding Lookup Tables for the Fusion of GIS and SAR Data in Mountain Areas"

Synthetic aperture radar (SAR) image orthorectification induces an important alteration of information due to the side-looking geometry of SAR acquisition. In high-relief areas, the difficulty is increased by the foldover effect: The images acquired with low incidence angles cannot be registered by a bijective transformation like polynomial transformations, as usually proposed by conventional software. In this letter, a simple and efficient method, fitted to geocoded data and SAR images, is introduced to propose a generic coregistration tool that takes SAR geometry into account without requiring the exact sensor model, specific parameters, and precise navigation data. This method is based on a simulated SAR image and on the computation of lookup tables (LUTs) that represent the coordinate transform from one geometry to the other. Results are presented on a high-relief area in the Alps, where satellite and airborne SAR images are used for glacier evolution monitoring. A comparison to other sensor-independent approaches has been performed, showing that the proposed approach performs better in mountain areas. The resulting LUTs allow merging SAR data with the georeferenced data, either in ground geometry by orthorectifying the SAR information or in radar geometry by the inverse transformation, namely, radar-coding data from a geographic information system, to improve the analysis of SAR images and the result interpretation. [J110]

"One-Dimensional Mirrored Interferometric Aperture Synthesis"

Aperture synthesis technique can provide high spatial resolution without requiring very large and massive real aperture. However, for a large aperture synthesis system, which will involve hundreds of antennas and thousands of correlators, system and its calibration are very complicated. In this letter, mirrored interferometric aperture synthesis (MIAS) is proposed, which can achieve the same spatial resolution as a large traditional aperture synthesis system but needs fewer antennas. First, the imaging principle of MIAS is presented. A new concept, named Cosine Visibility, is proposed to replace the visibility function used in traditional aperture synthesis. The relationship between the brightness temperature and the cosine visibility is a Cosine Transform. Inverse Cosine Transform can be applied to reconstruct the image of brightness temperature. Then, an example for MIAS is given, and a method is proposed to handle the problems of baselines missing and the rank defect associated with the underdetermined linear equations which relate the cross correlation between signals collected by pairs of antennas with the cosine visibility. Moreover, MIAS with a small array can provide higher and higher spatial resolution by combining more and more linear equations with the help of adjusting the distance from the array to the reflector. The simulation results demonstrate the validity of MIAS and the improvement of spatial resolution. The study in this letter provides a means to reduce the complexity of system and calibration of large traditional aperture synthesis systems. [J111]

"PolInSAR Statistical Analysis and Coherence Optimization Using Fractional Lower Order Statistics"

In this letter, the polarimetric synthetic aperture radar (SAR) interferometry (PolInSAR) statistical model is studied using the alpha-stable distribution. Based on this model, a vector coherence formulation using fractional lower order statistics is proposed. This vector coherence is the generalization of the vector coherence in the paper of Cloude and Papathanassiou when the PolInSAR data are non-Gaussian and conform to the symmetrical form of the alpha-stable distribution. The standard coherence optimization method in the aforementioned paper is modified based on this generalized vector coherence. Results were demonstrated using a small L-band PolInSAR data set and suggest that this proposed coherence optimization method reduces artifacts in the optimized phases in certain areas. [J112]

"Closed-Form Evaluation of the Second-Order Statistical Distribution of the Interferometric Phases in Dual-Baseline SAR Systems"

Multichannel inteferometric synthetic aperture radar (InSAR) systems allow to improve the accuracy of the estimation of the height profiles of the observed scenes. Multichannel images can be acquired by using different sensors operating at different frequencies (multifrequency InSAR) or acquiring multiple images with slightly different view angles (multibaseline InSAR). The enhanced accuracy height estimation is obtained exploiting the multichannel interferometric phases and an a prioriinaccurate ground profile and requires the knowledge of the joint probability distribution of the multichannel interferometric phases, whose evaluation in a closed form is very complicated and is not found in literature. In this paper, we evaluate the analytical form of the second-order probability density function (pdf) of dual-baseline InSAR phase interferograms, obtained from three mutually correlated interferometric images. The evaluation exploits the Gaussian model for the complex SAR images, takes into account the mutual correlation of all the images, and does not use any approximation. The closed form of the second-order joint pdf can be usefully adopted in statistical digital elevation model (DEM) estimation methods using dual-baseline SAR systems, which commonly use an approximate expression of the joint pdf of measured interferometric phases, given by the product of the marginal pdfs of each phase interferogram, obtained in the assumption of independent interferograms. The effect of this approximation is evaluated by computing the Cramer-Rao lower bounds and the mean square estimation errors obtained using the exact and the approximate model. Presented results represent the basis for the generalization to the case of more than two interferograms. [J113]

"GPU-Based Shooting and Bouncing Ray Method for Fast RCS Prediction"

The shooting and bouncing ray (SBR) method is highly effective in the radar cross section (RCS) prediction. For electrically large and complex targets, computing scattered fields is still time-consuming in many applications like range profile and ISAR simulation. In this paper, we propose a GPU-based SBR that is fully implemented on the graphics processing unit (GPU). Based on the stackless kd-tree traversal algorithm, the ray tube tracing can rapidly evaluate the exit position in a single pass on the GPU. We also present a technique for fast electromagnetic computing that allows the geometric optics (GO) and Physical optics (PO) integral to be carried out on the GPU efficiently during the ray tube tracing. Numerical experiments demonstrate that the GPU-based SBR can significantly improve the computational efficiency of the RCS prediction, about 30 times faster, while providing the same accuracy as the CPU-based SBR. [J114]

"TerraSAR-X Instrument Operations Rooted in the System Engineering and Calibration Project"

This paper presents the TerraSAR-X instrument operations embedded into the Instrument Operations and Calibration Segment. Special focus is on the data-take (DT) command generation. The command generation for standard DTs is discussed, and the nonnominal DT commanding is described for several examples which demonstrate the flexibility of both the TerraSAR-X instrument and the instrument operations system on-ground. [J115]

"Dual-Polarization C-Band Radar Observations of Sea Ice in the Amundsen Gulf"

Polarimetric observations of sea ice from synthetic aperture radar can, in principle, assist in sea-ice classification and ice-water discrimination. In this paper, we use dual-polarization ground-based scatterometer observations of sea ice to assess the potential value of spaceborne dual-polarization observations of sea ice for operational ice analysis, focusing on C-band and, in particular, the contribution of the HV backscatter coefficient and HH/VV polarization ratios. Results show that signature variability resulting from frost flowers, ice deformation, and snow cover can overwhelm systematic differences between younger ice types, up to first-year thin. As a result of this and noise floor limitations of spaceborne sensors, the HV backscatter coefficient makes visual ice type and open water discrimination easier only below about 30?? incidence angle. The HH/VV ratio is less impacted by the noise floor of spaceborne sensors but retains similar ambiguities for sea-ice classification. [J116]

"Model-Based Estimation of Forest Canopy Height in Red and Austrian Pine Stands Using Shuttle Radar Topography Mission and Ancillary Data: A Proof-of-Concept Study"

In this paper, accurate tree stand height retrieval is demonstrated using C-band Shuttle Radar Topography Mission (SRTM) height and ancillary data. The tree height retrieval algorithm is based on modeling uniform tree stands with a single layer of randomly oriented vegetation particles. For such scattering media, the scattering phase center height, as measured by SRTM, is a function of tree height, incidence angle, and the extinction coefficient of the medium. The extinction coefficient for uniform tree stands is calculated as a function of tree height and density using allometric equations and a fractal tree model. The accuracy of the proposed algorithm is demonstrated using SRTM and TOPSAR data for 15 red pine and Austrian pine stands (TOPSAR is an airborne interferometric synthetic aperture radar). The algorithm yields root-mean-square (rms) errors of 2.5-3.6 m, which is a substantial improvement over the 6.8-8.3-m rms errors from the raw SRTM minus National Elevation Dataset Heights. [J117]

"SAR and Multispectral Image Fusion Using Generalized IHS Transform Based on a Trous Wavelet and EMD Decompositions"

In the intensity hue saturation (IHS) based image fusion, the enhancement of the spatial information often leads to the distortion of the information in the spectral domain. In this paper, a spectral preserve fusion method is developed by introducing aГ‚Bï trous wavelet transform (AWT) and empirical mode decomposition (EMD) into one generalized IHS transform, which extends panchromatic sharpening of low-resolution multispectral images (LRMIs) through detail injection to the fusion of LRMIs and synthetic aperture radar imagery (SARI). The original LRMIs are first transformed into one low-resolution intensity component (LRIC) and the details from the SARI are abstracted using AWT. The LRIC and the approximation image of the SARI are fused through an intrinsic mode functions based model. Subsequently, high RIC produced through an inverse AWT is then substituted for the old one. High RMIs are obtained through an inverse IHS transform. Experiments reveal that this approach performs better than the AWT and IHS-AWT-based methods in preserving the spectral information of the LRMIs. The performance of the image fusion is examined both visually and quantitatively. [J118]

"IceSynth II: Synthesis of SAR Sea-Ice Imagery Using Region-Based Posterior Sampling"

A novel method for synthesizing synthetic aperture radar (SAR) sea-ice imagery named IceSynth II is presented. A Markov random field model is assumed, and a conditional sampling approach is used to learn local conditional posterior probability distributions on a regional basis. Synthetic SAR sea-ice images and the associated ground-truth segmentations are generated using a region-based posterior sampling approach. Experimental results using single-polarization RADARSAT-1 and dual-polarization RADARSAT-2 SAR sea-ice imagery provided by the Canadian Ice Service show that IceSynth II is capable of producing SAR sea-ice imagery that is more realistic than existing approaches. The synthesized images are well suited for performing systematic and reliable objective evaluation of SAR sea-ice image segmentation methods. [J119]

"Compressed Synthetic Aperture Radar"

In this paper, we introduce a new synthetic aperture radar (SAR) imaging modality which can provide a high-

resolution map of the spatial distribution of targets and terrain using a significantly reduced number of needed transmitted and/or received electromagnetic waveforms. This new imaging scheme, requires no new hardware components and allows the aperture to be compressed. It also presents many new applications and advantages which include strong resistance to countermesasures and interception, imaging much wider swaths and reduced on-board storage requirements. [J120]

"Focus FMCW SAR Data Using the Wavenumber Domain Algorithm"

The combination of frequency-modulation continuous-wave (FMCW) technology and synthetic aperture radar (SAR) promises a lightweight, cost-effective, and high-quality imaging sensor for remote sensing. However, the long signal duration time leads to the failure of the conventional start/stop approximation of the pulsed SAR. In this paper, a signal model is proposed to address the effects of the continuous motion during the transmit time on the echoed signal. Based on the model, an analytical point target reference spectrum is derived. From the spectrum, it will be seen that the continuous motion introduces an additional range-azimuth coupling term and a range walk term compared with the conventional pulsed SAR. The range walk term is well known, whereas the foregoing range-azimuth coupling term is formulated for the first time in the FMCW SAR community. For the squint and spotlight modes, these range walk and range-azimuth coupling terms might significantly degrade the image quality. In this paper, based on the proposed analytical signal model, we further discuss the application of the wavenumber domain algorithm for the FMCW SAR data. In addition, different approximations of the Stolt mapping are made to highlight the effect of the range-dependent higher-order range-azimuth coupling terms on the 2-D impulse responses. Finally, X-band simulated experiments and Ka-band real FMCW SAR data are used to validate the signal model and the processing method. [J121]

"Advanced Land Observing Satellite (ALOS) and Monitoring Global Environmental Change"

The Advanced Land Observing Satellite (ALOS) was developed for detailed observation of the Earth's surface and frequent monitoring of global environmental changes, using high-resolution optical (visible and near infrared push-broom) and active microwave sensors (L-band synthetic aperture radar). ALOS has four mission objectives: cartography, regional observations, disaster observations, and resource exploration. It has been operational since its launch in January 24, 2006, and is acquiring a large amount of land-surface data supported by the Ka-band intersatellite communication system that downlinks to ground receiving stations. A global systematic acquisition strategy is implemented for all three sensors to enable consistent data collection over all land areas on a repetitive basis. Through its three sensors, acquisition strategy, and communication infrastructure, the ALOS mission is aimed to contribute to monitoring water, carbon, and global climate change. In this paper, we describe ALOS and its contribution to global environmental monitoring. [J122]

"TerraSAR-X SAR Processing and Products"

The TerraSAR-X mission was launched in June 2007. After successful completion of the commissioning phase, the mission entered its operational phase in January 2008. Since that time, TerraSAR-X provides the scientific remote sensing community and commercial customers with high-quality spaceborne synthetic aperture radar (SAR) data products. The intention of this paper is to present the SAR data processing concept and the comprehensive portfolio of products reflecting the instrument's diverse imaging capabilities together with options of processing and achieved product quality as well as the essentials of SAR processing. Furthermore, it shall also provide details on how to fully exploit the precision of the TerraSAR-X products. [J123]

"Efficient Spotlight SAR MIMO Linear Collection Configurations"

We describe how a family of synthetic aperture radar (SAR) platforms flying linearly and transmitting mutually orthogonal waveforms at a common pulse repetition frequency (PRF) constitute a multiple-input multiple output (MIMO) radar system that reduces time spent collecting a SAR image and quantify the efficiency of such sensor configurations. We give efficient collection configurations for up to 15 platforms as well as asymptotically optimally efficient sequences of configurations. [J124]

"Experimental research of unsupervised Cameron/maximum-likelihood classification method for fully polarimetric synthetic aperture radar data"

In this study, experimental research on classification is applied to fully polarimetric data in X-band from China. Considering the amplitude and phase error between H and V channels in the system, the authors firstly correct the error in original data. The authors also deduce the formula of Cameron's classification method for the real data in our study. Then Cameron's method is used to initially classify the site image. Finally, the initial classification map defines training sets for the maximum-likelihood (ML) classifier. The advantages of this method are the automated classification and interpretation of each class based on the scattering mechanism.

The experiment demonstrates the feasibility of the proposed approach, which dramatically improves the X-band data classification result compared with the Cameron method and H/Г‚Вї/MLmethod. [J125]

"Automatic Extraction of Traffic Flows Using TerraSAR-X Along-Track Interferometry"

Spaceborne synthetic aperture radar (SAR) offers great potential for the measurement of ground traffic flows. A SAR with multiple receiving apertures aligned in flight direction repeatedly images the same ground area with a short time lag. This allows for an effective detection of moving ground objects, whose range variation translates into an interferometric phase signal between the receiving channels. The high-resolution German SAR satellite TerraSAR-X offers several ways to create multiple along-track apertures. We exploit this to demonstrate satellite-based traffic-flow measurements using along-track interferometry (ATI) and Displaced Phase Center Array techniques. In this paper, we address the usage of different TerraSAR-X ATI modes for data acquisition and describe an automatic near-real-time processing chain for the extraction of traffic information. The performance of this TerraSAR-X traffic processor is significantly driven by incorporating a prioriknowledge of road networks. We present examples of automatic traffic detection as well as empirical evaluations thereof using different kind of reference data. [J126]

"Introduction to the Issue on MIMO Radar and Its Applications"

The 17 papers in this special issue cover various aspects of the latest MIMO radar research and development. [J127]

"Segmentation of SAR Intensity Imagery With a Voronoi Tessellation, Bayesian Inference, and Reversible Jump MCMC Algorithm"

This paper presents a region-based approach to segmentation of the satellite synthetic aperture radar (SAR) intensity imagery. The approach is based on a Voronoi tessellation, the Bayesian inference, and the reversible jump Markov chain Monte Carlo (RJMCMC) algorithm. By Voronoi tessellation, the approach partitions a SAR image into a set of polygons corresponding to the components of the segmented homogenous regions. Each polygon is assigned a label to indicate a homogeneous region. The labels for all the polygons form a label field, which is characterized by an improved Potts model. The intensities of pixels in each polygon are assumed to satisfy identical and independent gamma distributions in terms of their label. Following the Bayesian paradigm, the posterior distribution that characterizes the SAR image segmentation can be obtained up to the integration constant. Then, a RJMCMC scheme is designed to simulate the posterior distribution and estimate its parameters. Finally, an optimal segmentation is obtained by the maximum a posteriori algorithm. The results obtained on both real Radarsat-1/2 and simulated SAR intensity images show that our approach works well and is very promising. [J128]

"On a Novel Approach Using MLCC and CFAR for the Improvement of Ship Detection by Synthetic Aperture Radar"

Multilook cross correlation (MLCC) is a useful technique in extracting the images of ships embedded in heavy sea clutter by synthetic aperture radar (SAR). In the ship detection experiment in 2006 by Phased Array L-band Synthetic Aperture Radar (PALSAR) on board the Advanced Land Observing Satellite, we applied MLCC to PALSAR data in order to extract small fishing boats. The result was that some boats were detected by thresholding MLCC coherence images under favorable conditions. However, it was also found that the threshold method was not suitable to automatically determine the threshold levels corresponding to the desired false alarm rate (FAR) values. In order to overcome this problem and to improve the accuracy of ship detection by MLCC, we propose a new and simple technique of MLCC-constant FAR (CFAR) or gamma-CFAR. In this method, CFAR is applied to interlook coherence images produced by MLCC. We tested this method using simulation and PALSAR data and then found out substantial improvement in signal-to-noise ratio and FAR in comparison with the coherence image alone. In this letter, we summarize the MLCC-CFAR algorithm and the experimental results. [J129]

"Imaging of Moving Targets With Multi-Static SAR Using an Overcomplete Dictionary"

This paper presents a method for imaging of moving targets using multi-static radar by treating the problem as one of joint spatial reflectivity signal inversion with respect to an overcomplete dictionary of target velocities. Existing approaches to dealing with moving targets in SAR solve the nonlinear problem of target scattering and motion estimation typically through decoupled matched filtering. In contrast, by using an overcomplete dictionary approach we effectively linearize the forward model and solve the moving target problem as a larger, unified regularized inversion problem subject to sparsity constraints. This unified framework allows estimation of scatter

motion and reflectivity to be done in an optimal and global way. We show examples of the potential of the new method for sensing configurations with transmitters and receivers randomly dispersed in a multi-static geometry within a narrow forward cone around the scene of interest. [J130]

"Sparse, Active Aperture Imaging"

We describe an approach to radar imaging of an isolated, rotating target using coherent, sparse, or highly thinned arrays of transmit/receive elements. The array elements are assumed to be randomly positioned and accurately surveyed after placement. Further, the isolated target is assumed to occupy a limited angular sector such that there is no source of backscatter beyond the sector occupied by the target. Estimates of the resolution and image quality are provided when the array elements are widely separated and operate with coherent, multiple-input multiple-output (MIMO) signaling and inverse synthetic aperture radar (ISAR) processing at each MIMO element pair. The sparse array operation can provide superior resolution when compared to the ISAR processing and accurate estimation of scattering properties with a modest number of sparse array elements. The performance of a model-based estimator to physical optics like scattering with MIMO signaling is described. Several important issues relating to feasibility remain to be investigated. These include establishing coherence and timing among the widely separated array elements, adaptive beamforming and processing requirements and coherence of the scattering phenomena with the widely separated MIMO elements. [J131]

"SAR image edge detection using curvelet transform and Duda operator"

Edge detection plays a critical role in image reconstruction of remote imaging systems. To gain better quality detection, a novel method is proposed that combines the curvelet transform and Duda operator in a special fashion for processing synthetic aperture radar (SAR) images. To extract the coarse regions in the image, the curvelet transform is first applied to the image and then, after some processing, the Duda operator locates the edges precisely inside the regions. The superiority of the proposed method is demonstrated for Pi-SAR image data. [J132]

"Scaling the 3-D Image of Spinning Space Debris via Bistatic Inverse Synthetic Aperture Radar"

In 3-D inverse synthetic aperture radar (ISAR) imaging of spinning space debris, the image obtained via the available algorithm is modified by a scaling factor. Determined by the angle between the spinning vector and the radar line of sight, this factor cannot be estimated by a monostatic radar in a short imaging interval. This letter derives the bistatic ISAR (Bi-ISAR) geometry and signal model for 3-D imaging of space debris. Then, a 3-D image scaling algorithm is introduced based on the connections between the mono- and bistatic echoes of the same scatterer. Numeric simulations have proved the validity of the proposed algorithm. [J133]

"Extending Loffeld's bistatic formula for the general bistatic SAR configuration"

This study derives an accurate bistatic point target reference spectrum based on a zeroth-order polynomial model. The spectrum contains only two hyperbolic square root terms that are very analogous in form to the analytical monostatic spectrum. The new formulation can be considered as an improvement of the Loffeld's bistatic formula (LBF) and allows it to handle a wider range of bistatic configurations. The original LBF works well only in the case where the contributions of transmitter and receiver to the total Doppler modulation are approximately equal. An earlier paper on the extended LBF (EBLF) uses time bandwidth product (TBP) to weight the azimuth phase modulation from each platform. However, this extension is valid only in the low squint bistatic geometry. Both LBF and ELBF are expanded up to the quadratic term to derive an approximate bistatic spectrum; however, they do not show a good focusing performance in the more complex bistatic geometry, for example, the high squint case. This is due to the inaccurate individual time-Doppler correspondences. In this study, a norm in Euclidean space is defined to derive the optimal individual time-Doppler correspondences. Using the accurate individual time-Doppler correspondences, a zeroth-order polynomial model can be used to readily derive a more accurate bistatic spectrum. Two simulation experiments in the high squint geometry are used to verify the accuracy of this new formulation. The first experiment uses a parallel-track spaceborne/spaceborne configuration, and the second experiment involves an orthogonal-track airborne/airborne case. [J134]

"Model-based sea mine classification with synthetic aperture sonar"

The quality and effectiveness of sensor information provided by mine-hunting autonomous underwater vehicles (AUVs) equipped with high-resolution sonars has improved drastically in recent years. In parallel, data rates have significantly increased resulting in information overload. Automatic target recognition (ATR) is regarded as a solution for this problem. This study describes a specific ATR technique based on model matching for application to high-resolution data. A sonar model for generation of high-resolution synthetic aperture sonar

(SAS) images is described and applied both as database generator and classification. The performance of the model matching, which is attained by correlation and stochastically, is evaluated using a large data set covering the variety expected in mine-hunting operations. The model-based features generated in this way are able to reach an acceptable classification performance. The article is concluded with one real data example, which is easily classified when training with the simulated database. Further work is next aimed to confirm performance on real data. [J135]

"Foreword to the Special Issue on TerraSAR-X: Mission, Calibration, and First Results"

The 34 papers in this special issue provide an overview of the TerraSAR-X mission, commissioning phase, calibration, data processing, and applications. [J136]

"The TerraSAR-X Satellite"

TerraSAR-X is a versatile synthetic aperture radar (SAR) satellite with active phased array antenna technology and represents the backbone of the German national radar Earth observation mission. With its large variety of different SAR imaging modes and its high operational flexibility, TerraSAR-X ideally serves the scientific community and users from the industrial sector and governmental institutions. The innovative satellite system design combines the rich experience from past German and European SAR space missions like X-SAR, SRTM, ERS 1 and 2, and Envisat combined with state-of-the-art Earth observation bus technology as used, e.g., on the CHAMP and GRACE satellites. [J137]

"Change Detection in Satellite Images Using a Genetic Algorithm Approach"

In this letter, we propose a novel method for unsupervised change detection in multitemporal satellite images by minimizing a cost function using a genetic algorithm (GA). The difference image computed from the multitemporal satellite images is partitioned into two distinct regions, namely, ??changed?? and ??unchanged,?? according to the binary change detection mask realization from the GA. For each region, the mean square error (MSE) between its difference image values and the average of its difference image values is calculated. The weighted sum of the MSE of the changed and unchanged regions is used as a cost value for the corresponding change detection mask realization. The GA is employed to find the final change detection mask with the minimum cost by evolving the initial realization of the binary change detection mask through generations. The proposed method is able to produce the change detection result on the difference image without a prioriassumptions. Change detection results are shown on multitemporal Advanced Synthetic Aperture Radar images acquired by the ESA/Envisat satellite and on multitemporal optical images acquired by the Landsat multispectral scanner. The comparisons with the state-of-the-art change detection methods are provided. [J138]

"SAR image heterogeneity and speckle filtering"

The ratio of the arithmetic to the geometric mean, a general index to test synthetic aperture radar (SAR) image homogeneity, is applied to the speckle reducing algorithm. A novel filter, based on improved speckle reducing anisotropic diffusion, is designed to denoise the SAR image. Experiments validate the effectiveness of the proposed method. [J139]

"Delineation of Urban Footprints From TerraSAR-X Data by Analyzing Speckle Characteristics and Intensity Information"

With a spatial resolution of up to 1 m, the German radar satellite TerraSAR-X (TSX) has significantly increased the usability of spaceborne synthetic aperture radar (SAR) imagery in the context of urban applications. This paper presents an approach toward the semiautomated detection of built-up areas (BAs) based on single-polarized TSX images. The proposed methodology includes a specific preprocessing of the SAR data and an automated image analysis procedure. The preprocessing focuses on the analysis of local speckle characteristics in order to provide a texture layer that highlights BAs. In the context of an object-oriented image analysis, this texture layer is used along with the original intensity information to automatically extract settlements. The technique is tested on the basis of 12 TSX scenes covering representative urban agglomerations distributed throughout the world. Overall, accuracies between 76% and 96% for the derived city footprints demonstrate the high potential of both the TSX imagery and the proposed analysis approach in detecting BAs. In order to demonstrate the robustness and transferability of the image analysis concept, we finally transferred the classification strategy from the object-oriented domain to a more general and simplified pixel-based approach. [J140]

"Experimental Verification of SAR-GMTI Improvement Through Antenna Switching"

Recently, theoretical investigations have shown that switching between parts of the transmit and/or receive aperture in a pulse-to-pulse cycle may improve the ground moving target indication (GMTI) performance of a two-channel radar system. This paper intends to verify these findings experimentally for the switching concept for the first time. Accordingly, six different GMTI modes were implemented in the system PAMIR (phased-array multifunctional imaging radar) of the Fraunhofer Institute for High Frequency Physics and Radar Techniques (Fraunhofer FHR) including three switching modes. An experiment was conducted using six cooperative vehicles following a predefined scenario to compare the GMTI performance and, in particular, the positioning accuracy of the different GMTI modes. The results of this experiment as well as the underlying signal processing are presented in this paper. The analysis is based on a multilook constant false-alarm rate detection scheme. Due to the heterogenous nature of the considered scene, the well-known test statistic for homogeneous terrain had to be extended accordingly, and a novel test statistics is proposed. [J141]

"Influence of Atmospheric Path Delay on the Absolute Geolocation Accuracy of TerraSAR-X High-Resolution Products"

Two coupled investigations of TerraSAR-X (TSX) high-resolution data are described in this paper: geometric validation, and estimation of the tropospheric path delay using measurements of corner reflectors (CRs) placed at different altitudes but nearly identical ranges. The CRs were placed within Alpine and valley sites in Switzerland, where terrain diversity provides ideal territory for geometric validation studies. Geometric validation was conducted using slant-range complex products from the spotlight and stripmap (SM) modes in ascending and descending configurations. Based on the delivered product annotations, the CR image positions were predicted, and these predictions were compared to their measuredimage positions. To isolate path delays caused by the atmosphere, six TSX SM scenes (~ 35 x 50 km) were examined containing four identical CRs with the same ranges and an altitude difference of ~ 3000 m. The CR arrangement made it possible to verify the annotated TSX atmospheric path delay by comparing the predicted slant range with the slant range obtained by measuring the reflector image coordinates. Range differences between the high- and low-altitude reflectors helped to quantify small variations in the path delay. Both SM and spotlight TSX products were verified to meet the specified accuracy requirements, even for scenes with extreme terrain variations, in spite of the simplicity of the atmospheric model currently integrated into the processor. Small potential improvements of the geolocation accuracy through the implementation of more comprehensive atmospheric modeling were demonstrated. [J142]

"Application of TerraSAR-X Data for Emergent Oil-Spill Monitoring"

Synthetic aperture radar (SAR) signals can propagate through hazardous weather and atmospheric conditions with heavy cloud cover, volcanic dust, snow, or rain. The all-weather capabilities of SARs have attracted significant interest in remote sensing communities, since serious environmental disasters such as oil spills have been highly ??elusive?? to optical sensors, making visible spectrum data vulnerable to rapidly changing atmospheric conditions. In this paper, we discuss the technical functionalities of TerraSAR-X from the emergency response perspective, describing its technical abilities in terms of a damping ratio, radiometric accuracy, and noise level with reference to the actual Hebei Spirit oil-spill incident that occurred on the west coast of the Korean peninsula in December 2007. The damping ratios estimated from the TerraSAR-X data as a function of Bragg wavenumber for various wind speeds indicate that TerraSAR-X data can be effectively used to identify oil-spill areas with acceptable accuracy. We also received ERS-2, ENVISAT, RADARSAT-1, and ALOS PALSAR data for this oil-spill event, not simultaneously but with varying time delays. The processing results for the multitemporal data sets obtained from the X- and C-band SAR systems are useful since they can be used to determine the near-real-time migration of spilt oil. The results of the current study indicate that there are distinct advantages of using X-band TerraSAR-X data for oil-spill detection compared to the data obtained at other available frequencies. [J143]

"Single and Multipolarimetric SAR Tomography of Forested Areas: A Parametric Approach"

In this paper, a technique is described for the tomographic characterization of forested areas through multiple synthetic aperture radar (SAR) observations, based on either single or multipolarimetric acquisitions. This technique is based on the idea of characterizing the Fourier spectrum of the multibaseline data as being constituted by two effective scattering centers displaced along the vertical direction, plus the associated decorrelation terms. As a result, SAR tomography will be formulated as the problem of detecting the number of scattering centers within the resolution cell, estimating the parameters that describe their spatial structure, and evaluating the associated backscattered powers. Parameter estimation is carried out through the covariance matching estimation technique, which provides an asymptotically optimal solution. The results of an experiment performed on a real P-band multibaseline fully polarimetric data set relative to the forested site of Remningstorp, Sweden, are reported. [J144]

"Evidence of Rainfall Signatures on X-Band Synthetic Aperture Radar Imagery Over Land"

Five spaceborne X-band synthetic aperture radars (X-SARs) are nowadays operating, and several more will be launched in the coming years. These X-SAR sensors, able to image the Earth's surface at metric resolution, may provide a unique opportunity to measure rainfall over land with spatial resolution of about a few hundred meters due to the moving-target degradation effects. This work is devoted to experimentally demonstrate this X-SAR capability, which can also be exploited to correct synthetic aperture radar (SAR) imagery for rainfall attenuation effects. Several case studies, selected from TerraSAR-X (TSX) overpasses over Europe and the southern U.S. in 2008, are qualitatively analyzed in terms of rainfall signatures. Visual validation of these rainfall SAR signatures is carried out by using available data from ground-based weather radars. A detailed data analysis for the case study of Hurricane ??Gustav?? on September 2, 2008, is carried out to assess a quantitative correlation among X-SAR response and near-surface precipitation rain rate. Two simplified empirical inversion algorithms, based on statistical regression and probability matching, are developed to retrieve rain rate from TSX cross-track ground-range measurements. The TSX-retrieved rain fields are compared to those estimated from the Next Generation Weather Radar (NEXRAD) in Mobile (Alabama, U.S.), showing a root-mean-square error less than 15 mm/h and a correlation of about 0.7. [J145]

"Motion Parameter Estimation in the SAR System With Low PRF Sampling"

A novel approach to motion parameter estimation with low pulse repetition frequency (PRF) sampling based on compressed sensing (CS) theory is introduced. As is known to us, when PRF is less than the Doppler spectrum bandwidth, moving targets suffer both Doppler centroid frequency ambiguity and Doppler spectrum ambiguity. Under this condition, the traditional parameter estimation method in the Doppler domain is out of action. The key of this letter converts motion parameter estimation in the synthetic aperture radar system with low PRF sampling into solving an optimization equation based on CS theory. Because moving targets in the scene can be regarded as sparse signals after clutter cancellation, an optimization algorithm based on CS theory is proposed to reconstruct sparse signals and meanwhile estimate the along-track velocities and azimuth positions of moving targets. Considering the fact that range cell migration of moving targets is not subject to PRF limitations, Radon transform is adopted to obtain unambiguous across-track velocities and range positions. Results on simulation and real data are provided to show the effectiveness of this method. [J146]

"The Geometric-Distortion Correction Algorithm for Circular-Scanning SAR Imaging"

The image formation scheme for circular-scanning synthetic aperture radar includes generating a set of focused subimages and the followed mosaiking processing. However, due to the particular acquisition geometry and irregular motion of the radar platform, the inevitable geometric distortions in the subimages are necessary to be corrected. In this letter, a 2-D geometric-distortion correction algorithm based on projection transformation between the scatterers and the images is presented, in condition of focusing the subimages using a linear range-Doppler algorithm. The point target simulation and real circular-scanning data implementation results are provided to demonstrate the validity of the proposed method. [J147]

"TerraSAR-X Antenna Calibration and Monitoring Based on a Precise Antenna Model"

The high flexibility and tight accuracy requirements of modern spaceborne synthetic aperture radar (SAR) systems require innovative technologies to calibrate and process SAR images. To perform accurate pattern correction during SAR processing, an antenna model can be used to derive the multitude of different antenna beams generated by active antenna steering. The application of such an antenna model could be successfully demonstrated for the TerraSAR-X mission, launched in 2007. The methodology and the results of the in-orbit verification with an achieved accuracy of better than ??0.2 dB are reviewed in this paper in detail, showing its outstanding accuracy. Additionally, the results of the antenna pattern long-term monitoring are described, pointing out the high stability of the system. [J148]

"Assessment of the Stereo-Radargrammetric Mapping Potential of TerraSAR-X Multibeam Spotlight Data"

TerraSAR-X can acquire image data in various resolutions down to a range of about 1 m. Moreover, the sensor can operate at various imaging beams and thus acquire image data at different off-nadir viewing angles. These circumstances led to a stimulation of the traditional stereo-mapping approach, as TerraSAR-X image pairs became available in high resolution and in various geometric dispositions. With respect to 3-D surface mapping, TerraSAR-X stereo data processing, therefore, is a serious alternative to synthetic aperture radar interferometry, which can be addressed as the evolving mapping technique of the last decade. Within the TerraSAR-X science program of the German Aerospace Center (DLR), high-resolution multibeam data sets in Spotlight mode were

acquired for several Austrian test sites. In general, three images were obtained from either ascending or descending orbits. In order to exploit the 3-D mapping accuracy of TerraSAR-X, stereo-radargrammetric mapping techniques were applied to the data sets, thereby utilizing stereo pairs as well as multi-image data sets in various dispositions. This paper focuses on one of the selected test sites and refers to the issues of 2-D and 3-D mapping-accuracy assessment as well as to surface model and vegetation-height-model generation. Validation of these products was widely restricted to visual analysis due to the lack of adequate high-quality reference products. [J149]

"Two-Dimensional Imaging via a Narrowband MIMO Radar System With Two Perpendicular Linear Arrays"

This paper presents a system model and method for the 2-D imaging application via a narrowband multiple-input multiple-output (MIMO) radar system with two perpendicular linear arrays. Furthermore, the imaging formulation for our method is developed through a Fourier integral processing, and the parameters of antenna array including the cross-range resolution, required size, and sampling interval are also examined. Different from the spatial sequential procedure sampling the scattered echoes during multiple snapshot illuminations in inverse synthetic aperture radar (ISAR) imaging, the proposed method utilizes a spatial parallel procedure to sample the scattered echoes during a single snapshot illumination. Consequently, the complex motion compensation in ISAR imaging can be avoided. Moreover, in our array configuration, multiple narrowband spectrum-shared waveforms coded with orthogonal polyphase sequences are employed. The mainlobes of the compressed echoes from the different filter band could be located in the same range bin, and thus, the range alignment in classical ISAR imaging is not necessary. Numerical simulations based on synthetic data are provided for testing our proposed method. [J150]

"Multistatic Synthetic Aperture Radar Image Formation"

In this paper, we consider a multistatic synthetic aperture radar (SAR) imaging scenario where a swarm of airborne antennas, some of which are transmitting, receiving or both, are traversing arbitrary flight trajectories and transmitting arbitrary waveforms without any form of multiplexing. The received signal at each receiving antenna may be interfered by the scattered signal due to multiple transmitters and additive thermal noise at the receiver. In this scenario, standard bistatic SAR image reconstruction algorithms result in artifacts in reconstructed images due to these interferences. In this paper, we use microlocal analysis in a statistical setting to develop a filtered-backprojection (FBP) type analytic image formation method that suppresses artifacts due to interference while preserving the location and orientation of edges of the scene in the reconstructed image. Our FBP-type algorithm exploits the second-order statistics of the target and noise to suppress the artifacts due to interference in a mean-square sense. We present numerical simulations to demonstrate the performance of our multistatic SAR image formation algorithm with the FBP-type bistatic SAR image reconstruction algorithm. While we mainly focus on radar applications, our image formation method is also applicable to other problems arising in fields such as acoustic, geophysical and medical imaging. [J151]

"High-Resolution Imaging Using a Wideband MIMO Radar System With Two Distributed Arrays"

Imaging a fast maneuvering target has been an active research area in past decades. Usually, an array antenna with multiple elements is implemented to avoid the motion compensations involved in the inverse synthetic aperture radar (ISAR) imaging. Nevertheless, there is a price dilemma due to the high level of hardware complexity compared to complex algorithm implemented in the ISAR imaging system with only one antenna. In this paper, a wideband multiple-input multiple-output (MIMO) radar system with two distributed arrays is proposed to reduce the hardware complexity of the system. Furthermore, the system model, the equivalent array production method and the imaging procedure are presented. As compared with the classical real aperture radar (RAR) imaging system, there is a very important contribution in our method that the lower hardware complexity can be involved in the imaging system since many additive virtual array elements can be obtained. Numerical simulations are provided for testing our system and imaging method. [J152]

"Problem of signal synchronisation in space-surface bistatic synthetic aperture radar based on global navigation satellite emissions-experimental results"

This study presents the synchronisation problem in `space-surface bistatic synthetic aperture radar (SS-BSAR)` system. Global Navigation Satellite Systems (GNSS) are considered as transmitters of opportunity. It highlights various important issues of synchronisation, specifically related to SS-BSAR utilising GLONASS as the transmitter. Experimental testing of the synchronisation algorithm is described and verified using the GLONASS satellite. Also, experimental images obtained from GLONASS are presented and briefly analysed. [J153]

"Three-Dimensional Imaging via Wideband MIMO Radar System"

The 3-D inverse synthetic aperture radar imaging fast maneuvering targets is an active research area in the past decades. Planar antenna arrays are used to avoid the motion compensation algorithms but at the cost of increasing the hardware complexity. In this letter, to reduce the hardware complexity of the imaging system, a wideband multiple-input multiple-output system with two perpendicular linear arrays is suggested. In contrast to the existing 3-D imaging methods with planar antenna arrays, with the proposed method, the lower hardware complexity is achieved by many additive virtual array elements. Simulations based on synthetic data are provided for testing the proposed method. [J154]

"Signatures of ERS-Envisat Interferometric SAR Coherence and Phase of Short Vegetation: An Analysis in the Case of Maize Fields"

Interferometric observations between the European Remote Sensing, ERS-2, synthetic aperture radar (SAR) and the Envisat Advanced SAR (ASAR) are unique since they are characterized by a short repeat-pass interval (28 min) and a perpendicular baseline of approximately 2 km. In vegetated areas, this configuration should preserve from strong temporal decorrelation and enhance the sensitivity of coherence and SAR interferometric (InSAR) phase to volumes with small heights. This assumption could be tested with the data acquired during the dedicated ERS-Envisat Tandem mission on October 15, 2007, over the Seeland region, Switzerland. Five maize fields and one sunflower field presented lower coherence and offsets of the interferometric phase, i.e. height, with respect to neighboring bare fields. To gain understanding on the interferometric signatures, the interferometric water cloud model was used to simulate coherence and InSAR height for the maize fields. Both the coherence and the InSAR height present clear dependence upon vegetation height and exhibit strong consistency. Simulations showed that the modeled coherence and InSAR height are most sensitive to the two-way attenuation and the temporal coherence of the vegetation. The best correspondence between the observed and modeled InSAR parameters was obtained with two-way attenuation values between 2 and 4 dB/m (corresponding to an extinction between 1 and 2 dB/m) and high temporal coherence of the vegetation (above 0.6), with this being due to the very stable conditions of the weather during the 28-min interval between image acquisitions. [J155]

"Automatic algorithm for inverse synthetic aperture radar images recognition and classification"

The authors propose an algorithm for automatic aircraft categories that is models classification from inverse synthetic aperture radar (ISAR) images that use pulse reflection shape and Doppler shifts of parts of aircraft that are in any maneuver that introduces rotation to the target. The authors artificially generated five different categories of ISAR aircraft using computer simulations and tested these simulated ISAR aircraft images of the airplanes defined by size and shape that are flying in a prescribed holding pattern. The authors investigate in what parts of the holding pattern the ISAR reflections provide information that makes it possible to identify to which of the five categories an aircraft in the holding pattern belongs. The obtained results show that it is possible in most parts of the holding pattern to successfully classify the various aircraft targets. [J156]

"Focusing Bistatic SAR Data in Airborne/Stationary Configuration"

This paper presents a frequency-domain-based focusing algorithm for the bistatic synthetic aperture radar (BiSAR) data in airborne/stationary configuration. In this bistatic configuration, only the moving platform contributes to the azimuth modulation, whereas the stationary platform introduces a range offset (RO) to the range migration trajectories of targets at the same range. The offset is determined by the azimuth position of different targets with respect to the stationary platform. Since the RO is position dependent, monostatic SAR imaging algorithms are not able to focus the bistatic data collected in this configuration. In this paper, an analytical bistatic point-target reference spectrum is derived, and then, a frequency-domain-based algorithm is developed to focus the bistatic data. It uses an interpolation-free wavenumber-domain algorithm as a basis and performs a range-variant interpolation to correct the position-dependent RO in the image domain after coarse focusing. The proposed algorithm is validated by the simulated data and the real BiSAR data acquired by the Forschungsgesellschaft fu??r Angewandte Naturwissenschaften's airborne SAR system, PAMIR, in December 2007. In this BiSAR experiment, an X-band transmitter was stationary operated on a hill with PAMIR as the receiver mounted on a Transall C-160. [J157]

"Unifying Experiment Design and Convex Regularization Techniques for Enhanced Imaging With Uncertain Remote Sensing Data-Part II: Adaptive Implementation and Performance Issues"

The unified descriptive experiment design regularization (DEDR) method from a companion paper provides a rigorous theoretical formalism for robust estimation of the power spatial spectrum pattern of the wavefield

scattered from an extended scene observed in the uncertain remote sensing (RS) environment. For the considered here imaging synthetic aperture radar (SAR) application, the proposed DEDR approach is aimed at performing, in a single optimized processing, SAR focusing, speckle reduction, and RS scene image enhancement and accounts for the possible presence of uncertain trajectory deviations. Being nonlinear and solution dependent, the optimal DEDR estimator requires rather complex signal processing operations ruled by the fixed-point iterative implementation process. To simplify further the processing, in this paper, we propose to incorporate the descriptive regularization via constructing the projections onto convex sets that enable us to factorize and parallelize the reconstructive image processing over the range and azimuth coordinates, design a family of such regularized easy-to-implement iterative algorithms, and provide the relevant computational recipes for their application to fractional imaging SAR. We also comment on the adaptive adjustment of the DEDR operational parameters directly from the actual speckle-corrupted scene images and demonstrate the effectiveness of the proposed adaptive DEDR techniques. [J158]

"A New Slant-Range Velocity Ambiguity Resolving Approach of Fast Moving Targets for SAR System"

This paper describes an ambiguity resolving approach for slant-range velocity estimation which utilizes the wideband characteristic of the transmitted signal (multiple wavelengths). Based on the wavelength dual-wavelength radar data. Then, two effective approaches are introduced to focus the moving target no matter the Doppler ambiguity exists or not. The slant-range velocity is estimated by the number of azimuth cell displacements between the two focused images. Both imaging methods have different properties and advantages. A performance analysis is made, and deleterious factors in practice are analyzed in detail. The effectiveness of the unambiguous slant-range velocity estimation approach is demonstrated with the use of simulated and real data. [J159]

"Processing of Sliding Spotlight and TOPS SAR Data Using Baseband Azimuth Scaling"

This paper presents an efficient phase preserving processor for the focusing of data acquired in sliding spotlight and Terrain Observation by Progressive Scans (TOPS) imaging modes. They share in common a linear variation of the Doppler centroid along the azimuth dimension, which is due to a steering of the antenna (either mechanically or electronically) throughout the data take. Existing approaches for the azimuth processing can become inefficient due to the additional processing to overcome the folding in the focused domain. In this paper, a new azimuth scaling approach is presented to perform the azimuth processing, whose kernel is exactly the same for sliding spotlight and TOPS modes. The possibility to use the proposed approach to process data acquired in the ScanSAR mode, as well as a discussion concerning staring spotlight, is also included. Simulations with point targets and real data acquired by TerraSAR-X in sliding spotlight and TOPS modes are used to validate the developed algorithm. [J160]

"Analysis of Gable-Roofed Building Signature in Multiaspect InSAR Data"

The spatial resolution of state-of-the-art synthetic aperture radar sensors enables the structure analysis of urban areas. The appearance of buildings in magnitude images in settlements is dominated by the effects of the inherent oblique scene illumination. In urban residential districts, salient pairs of parallel lines of bright magnitude are often caused by direct reflection and double-bounce signal at gable-roofed buildings. In this letter, the magnitude and interferometric phase signature of gable-roofed buildings are discussed to extract reliable building features for reconstruction. The analysis contains signature changes by varying illumination and building geometry. The presented approach is aiming at the reconstruction of gable-roofed buildings by a knowledge-based analysis considering the discussed effects. The reconstruction results are assessed by using a high-resolution LIDAR surface model as ground truth. [J161]

"Equivalence Analysis of Accuracy of Geolocation Models for Spaceborne InSAR"

There are two main geolocation models for spaceborne synthetic aperture radar (SAR) interferometry (InSAR): range Doppler (RD) and direct geocoding (DG) models. The RD model gets the target position by combining and solving the Doppler equation, slant-range equation, and the modified Earth model equation. The DG location model gets the target position through its 3-D coordinates by the Doppler equation and two slant-range equations. Usually, the geolocation accuracy analyses of these two models are discussed separately. It is confused which one is more precise and we should use during InSAR system designing. This paper deduced and compared the geolocation accuracies of these two models in the same frame-matrix. According to the matrix theory, the explicit expressions of the geolocation uncertainty of RD and DG models were deduced through the use of parameters in matrix form. After defining a new slant-range plane coordinate system, the precision of RD geolocation model and that of geocoding location model were compared quantificationally. It was presented that

the geolocation uncertainty formulas between RD and DG models were the same. Then, the conclusion that these two models would lead to the same precision in geolocation measurement was obtained. At last, computer simulation results were employed to confirm the mathematical analysis. [J162]

"Unifying Experiment Design and Convex Regularization Techniques for Enhanced Imaging With Uncertain Remote Sensing Data-Part I: Theory"

This paper considers the problem of high-resolution remote sensing (RS) of the environment formalized in the terms of a nonlinear ill-posed inverse problem of estimation of the power spatial spectrum pattern (SSP) of the wavefield scattered from an extended remotely sensed scene via processing the discrete measurements of a finite number of independent realizations of the observed degraded data signals [single realization of the trajectory signal in the case of synthetic aperture radar (SAR)]. We address a new descriptive experiment design regularization (DEDR) approach to treat the SSP reconstruction problem in the uncertain RS environment that unifies the paradigms of maximum likelihood nonparametric spectral estimation, descriptive experiment design, and worst case statistical performance optimization-based regularization. Pursuing such an approach, we establish a family of the DEDR-related SSP estimators that encompass a manifold of algorithms ranging from the traditional matched filter to the modified robust adaptive spatial filtering and minimum variance beamforming methods. The theoretical study is resumed with the development of a fixed-point iterative DEDR technique that incorporates the regularizing projections onto convex solution sets into the SSP reconstruction procedures to enforce the robustness and convergence. For the imaging SAR application, the proposed DEDR approach is aimed at performing, in a single optimized processing, adaptive SAR focusing, speckle reduction and RS scene image enhancement, and accounts for the possible presence of uncertain trajectory deviations. [J163]

"Coarse-to-Fine Approach for Urban Area Interpretation Using TerraSAR-X Data"

With the launch of the German TerraSAR-X system in June 2007, a new generation of high-resolution spaceborne synthetic aperture radar (SAR) data is available, which should facilitate the interpretation of urban environments. Our overall objective in this letter is to provide a semiautomatic tool for urban area interpretation using SAR data. We propose in this letter to fuse different automatic object extractors in order to provide more reliable pieces of interpretation. Our fusion is a coarse-to-fine approach. First, a segmentation of the image is performed to partition the scene into regions having similar properties. The second step consists in detecting bright and dark linear structures which are, in general, linked to the presence of buildings and roads (main classes in urban areas), respectively. The last step gives the final image interpretation using contextual knowledge. Evaluation of the proposed approach in mapping urban areas was carried out using real TerraSAR-X data over the city of Las Vegas in the U.S. [J164]

"On the Doppler Spreading Effect for the Range-Instantaneous-Doppler Technique in Inverse Synthetic Aperture Radar Imagery"

Inverse synthetic aperture radar (ISAR) is an all-weather radar technique which may generate high-resolution images of noncooperative targets. The standard range-Doppler algorithm (RDA) is usually employed for image generation. However, the images obtained with RDA are usually blurred because of the relative motion between radar and target. As a consequence, motion compensation techniques should be used to improve the imagery quality. The range-instantaneous-Doppler (RID) technique based on time-frequency transforms has been proposed for obtaining a sequence of focused ISAR images without the need of using motion compensation techniques. However, in this letter, it is clearly shown that the migration of the target scatterers in slant range indirectly induces Doppler spreading of the scatterers' point spread function in each of the ISAR images obtained by the RID technique. This Doppler spreading means blurring. It is important to highlight that the migration in slant range may be caused not only by the radial component of the translational motion but also by the rotational motion. The application of motion compensation techniques prior to the use of the RID technique allows us to mitigate the Doppler spreading, as shown here both for simulated and live data acquired by a high-resolution coherent radar. [J165]

"Predictive Iterated Kalman Filter for INS/GPS Integration and Its Application to SAR Motion Compensation"

This paper deals with the problem of state estimation for the integration of an inertial navigation system (INS) and Global Positioning System (GPS). For a nonlinear system that has the model error and white Gaussian noise, a predictive filter (PF) is used to estimate the model error, and based on this, a modified iterated extended Kalman filter (IEKF) is proposed and is called predictive iterated Kalman filter (PIKF). The basic idea of the PIKF is to compensate the state estimate by the estimated model error. An INS/GPS integration system is implemented using the PIKF and applied to synthetic aperture radar (SAR) motion compensation. Through flight

tests, it is shown that the PIKF has an obvious accuracy advantage over the IEKF and unscented Kalman filter (UKF) in velocity. [J166]

"Flood Detection in Urban Areas Using TerraSAR-X"

Flooding is a major hazard in both rural and urban areas worldwide, but it is in urban areas that the impacts are most severe. An investigation of the ability of high-resolution TerraSAR-X synthetic aperture radar (SAR) data to detect flooded regions in urban areas is described. The study uses a TerraSAR-X image of a one-in-150-year flood near Tewkesbury, U.K., in 2007, for which contemporaneous aerial photography exists for validation. The German Aerospace Center (DLR) SAR end-to-end simulator (SETES) was used in conjunction with airborne scanning laser altimetry (LiDAR) data to estimate regions of the image in which water would not be visible due to shadow or layover caused by buildings and taller vegetation. A semiautomatic algorithm for the detection of floodwater in urban areas is described, together with its validation using aerial photographs. Of the urban water pixels that are visible to TerraSAR-X, 76% were correctly detected, with an associated false positive rate of 25%. If all the urban water pixels were considered, including those in shadow and layover regions, these figures fell to 58% and 19%, respectively. The algorithm is aimed at producing urban flood extents with which to calibrate and validate urban flood inundation models, and these findings indicate that TerraSAR-X is capable of providing useful data for this purpose. [J167]

"Analysis of Local Variation of Soil Surface Parameters With TerraSAR-X Radar Data Over Bare Agricultural Fields"

The objective of this paper is to analyze the sensitivity of very high resolution TerraSAR-X radar data taken over bare soils to surface soil parameters and to study the spatial variability of these parameters at a fine scale (within a field plot). The relationship between the backscattering coefficient and the soil's parameters (moisture, surface roughness, texture, and local topography) was examined by means of four satellite images, as well as ground truth measurements, of each of the three agricultural plots, recorded during several field campaigns in the winter and spring of 2008. TerraSAR images demonstrate high potential for the identification of local variations of roughness and texture. An approach for the estimation of local moisture is proposed using an empirical method adapted to the scale of an individual field. The results show that, by using TerraSAR-X data to study bare agricultural fields, local variations in soil moisture can be retrieved with a root-mean-square error of 0.05 cm3??cm-3. [J168]

"TerraSAR-X System Performance Characterization and Verification"

This paper presents results from the synthetic aperture radar (SAR) system performance characterization, optimization, and verification as carried out during the TerraSAR-X commissioning phase. Starting from the acquisition geometry and instrument performance, fundamental acquisition parameters such as elevation beam definition, range timing, receiving gain, and block adaptive quantization setting are presented. The verification of the key performance parameters-ambiguities, impulse-response function, noise, and radiometric resolution-is discussed. ScanSAR and Spotlight particularities are described. [J169]

"Despeckling of TerraSAR-X Data Using Second-Generation Wavelets"

This letter presents the despeckling of synthetic aperture radar (SAR) images within the bandelet and contourlet domains. A model-based approach is presented for the despeckling of SAR images. The speckle-reduced estimate is found using the first-order Bayesian inference, and the best model's parameters are estimated using the second-order Bayesian inference. Synthetic and real images are used for evaluating the qualities of the despeckling methods. The experimental results showed that the combination of Bayesian inference and bandelet transform outperforms the contourlet-based despeckling algorithm using synthetic data and objective measurements. [J170]

"Gibbs Random Field Models for Model-Based Despeckling of SAR Images"

Synthetic aperture radar (SAR) images are affected by multiplicative noise called speckle. This noise makes automatic image classification and image interpretation difficult. Thus, many methods have been developed to remove speckle from SAR images while preserving the useful information of the scene such as texture and geometry. In this letter, a comparison between three different despeckling methods based on a Bayesian approach and Gibbs random fields is made. The used methods are Gauss-Markov random field (GMRF) and autobinomial modeling, which operate in the image domain, and the GMRF approach, which operates in the wavelet domain. Our methods are evaluated with synthetic and real SAR data (TerraSAR-X images). The experimental results show that, with these three methods, the speckle is well removed while structures are preserved; quantitative measures show that the autobinomial method provides the best smoothness and

sharpness criteria in real SAR data, while the wavelet-based method generates the smallest bias. [J171]

"TerraSAR-X Commissioning Phase Execution Summary"

This paper provides an overview of the TerraSAR-X commissioning phase (CP). The overall CP planning and preparation is presented. The strategy for data-take (DT) command generation is discussed, and statistical reports summarize the acquired CP DTs. An overview summary on the main results in the different characterization and verification areas is provided together with synthetic aperture radar image examples. [J172]

"TOPS Imaging With TerraSAR-X: Mode Design and Performance Analysis"

This paper reports about the performed investigations for the implementation of the wide-swath TOPS (Terrain Observation by Progressive Scan) imaging mode with TerraSAR-X (TSX). The TOPS mode overcomes the limitations imposed by the ScanSAR mode by steering the antenna along track during the acquisition of a burst. In this way, all targets are illuminated with the complete azimuth antenna pattern, and, thus, scalloping is circumvented, and an azimuth dependence of signal-to-noise ratio and distributed target ambiguity ratio (DTAR) is avoided. However, the use of electronically steered antennas leads to a quantization of the steering law and a nonideal pattern for squinted angles (grating lobes and main lobe reduction). The former provokes spurious peaks, while the latter introduces slight scalloping and DTAR deterioration. These effects are analyzed and quantified for TSX, and a TOPS system design approach is presented. Next, the requirements concerning interferometry are investigated. Finally, several results are shown with the TSX data, including a comparison between the TOPS and the ScanSAR modes and the reporting of the first TOPS interferometric results. [J173]

"Monitoring of Snow-Cover Properties During the Spring Melting Period in Forested Areas"

As spaceborne C-band synthetic aperture radar (SAR) observations are used for monitoring the snow cover during the spring melt period, temporal changes in backscatter from forest cover disturb the mapping of snow cover. This paper presents an analysis of snow backscattering properties in eight test areas situated around weather stations. Test areas represent open and forested landscapes in Northern Finland. Analyses are carried out using an extensive multitemporal ERS-2 C-band SAR data set from the snow melt period. We validate the following topics: 1) forest backscattering model for forest compensation; 2) Helsinki University of Technology (TKK) fractional snow-covered area (SCA) method with in situobservations; and 3) inversion of a combined forest/snow/ground backscattering model in an application to yield estimates of the relative changes of snow wetness during full snow cover conditions. The results show that the semiempirical TKK backscattering model describes the average C-band backscattering properties of all test regions well as a function of forest stem volume. Comparison of SCA estimation results with available ground-truth data also shows a good performance. The retrieved relative snow wetness values agree well with temperature observations. [J174]

"Three-Dimensional Coherent Radar Backscatter Model and Simulations of Scattering Phase Center of Forest Canopies"

A 3-D coherent radar backscatter model for forest canopies was developed and used to improve the understanding of synthetic aperture radar (SAR) interferometric data. The model was based on a realistic 3-D spatial structure of a forest stand, in which every scatterer has its deterministic location. A backscattering signal from a scatterer was mapped into a pixel according to its range or signal time delay. The range or the time delay also determines the phase of the scattered field. All scattering matrices within a pixel were coherently added to yield the total backscattering field of the pixel. The coherent radar backscatter model takes into account not only the scattering contribution from the scatterers in the forest canopy but also the direct backscattering of the ground surface. Forest stands with three different spatial structures were simulated using L-system and field measurements. The number and sizes of trees in these forest stands were identical, but the 2-D arrangements of the trees were different. The interferometric SAR (InSAR) signals of these scenes were simulated using the 3-D coherent SAR model, and the heights of scattering phase centers were estimated from the simulated InSAR data. The results reported in this paper show that the spatial structures of vegetation play an important role in the location of the scattering phase center. The height of scattering phase center depends on canopy height, attenuation of canopy, and the gaps within the canopy. This paper shows that the spatial structure needs to be considered when the InSAR data are used for the estimation of forest structural parameters. [J175]

"Evaluation of TerraSAR-X Observations for Wetland InSAR Application"

This paper assesses the potential of using spaceborne X-band synthetic aperture radar (SAR) data for monitoring water-level changes over wetlands. Our analysis is based on three sets of TerraSAR-X (TSX) observations acquired over South Florida's Everglades wetlands during an eight-month period in 2008. The first

set was acquired in single HH polarization stripmap mode over our northern study area, consisting of managed wetlands and urban environments. The second set was acquired in dual-polarization stripmap mode over the western half of the same area, consisting mostly of managed wetlands. The third set was also acquired with dual-polarization stripmap mode over our southern study area, consisting of natural flow freshand salt-water wetlands in the southern Everglades. The first data set was used for a proof-of-concept study to verify that X-band data can generate coherent interferograms in wetland areas. Interferometric processing of this data set shows a high level of coherence (> 0.35) over both wetland and urban regions, maintaining interferometric phase in all three interferograms spanning 11 days. Surprisingly, phase is maintained over some of the wetlands even for interferograms spanning 33 days. The other two data sets were used to evaluate interferometric coherence of all four polarization modes and to determine dominant scattering mechanism in each wetland environment. Our results show high coherence values (> 0.4) in all polarization modes, with highest values in HH, then VV, and lowest in HV or VH. Interferograms calculated from multipolarization data show very similar fringe patterns regardless of the polarization type, suggesting that the phase information in all polarization data reflects water-level changes in wetlands and that volume scattering may be less important than commonly believed. We also used the two multipolarization data sets to conduct the Pauli decomposition, finding a strong dependence of scattering mechanism on vegetation t--ype. The high interferometric coherence level of all polarization data suggests that a significant part of the X-band scattered signal interacts with lower sections of the vegetation (trunks and branches), because scattering from wind-affected canopies cannot support such a high coherence level. The high spatial resolution of TSX, combined with its 11-day repeat orbit, makes this X-band sensor surprisingly suitable for wetland interferometric SAR applications. [J176]

"A Novel Autofocusing Approach for Real-Time Through-Wall Imaging Under Unknown Wall Characteristics"

A novel real-time through-wall imaging (TWI) algorithm with autofocusing ability in the presence of wall ambiguities is proposed in this paper. The spectrum Green's function is employed to formulate the TWI algorithm, where the fast Fourier transform can be used to reconstruct the image in a very short computation time. The complex scattering process due to the presence of the wall is automatically included in the imaging formulation through the multilayer Green's function. The autofocusing is achieved by introducing a time factor in the TWI formulation to get a dynamic image at different focusing time. The image at the time instant when the defined entropy is minimized is stored as the output of the TWI result. Simulation results show that the proposed method can provide high-quality focused image in a short computation time regardless of the estimated value of the wall parameters. [J177]

"Segmentation and Classification of Polarimetric SAR Data Using Spectral Graph Partitioning"

A new approach for segmentation and classification of polarimetric synthetic aperture radar (POLSAR) data is proposed based on spectral graph partitioning. Since automated analysis techniques are often challenged due to the noisy properties of POLSAR data, human experts are employed to aid in the interpretation of such data in an operational setting. Humans can improve the performance of segmentation and classification of POLSAR data, because their vision system can apply cognitive skills that are not easy to incorporate into an automated system. The motivation for this paper is to incorporate some of these human perceptual skills into the computer algorithms. A framework that has recently emerged in computer vision for solving grouping problems with perceptually plausible results-spectral graph partitioning-is customized for POLSAR data. Segmentation is performed using the contour information in a region-based setting with the aid of spatial proximity. This is followed by a classification step performed through graph partitioning based on similarities of the mean coherence matrices obtained for each segment. Using the proposed approach, the results achieved are superior to the Wishart classifier. Automated parameter selection procedures are under development. This framework also suggests a way to accommodate different representations of polarimetric data and combine them with other information sources (e.g., optical imagery and digital elevation models). [J178]

"Ray-Tracing Simulation Techniques for Understanding High-Resolution SAR Images"

In this paper, a simulation concept is presented for creating synthetic aperture radar (SAR) reflectivity maps based on ray tracing. Three-dimensional models of man-made objects are illuminated by a virtual SAR sensor whose signal is approximated by rays sent through the model space. To this end, open-source software tools are adapted and extended to derive output data in SAR geometry followed by creating the reflectivity map. Rays can be followed for multiple reflections within the object scene. Signals having different multiple reflection levels are stored in separate image layers. For evaluating the potentials and limits of the simulation approach, simulated reflectivity maps and distribution maps are compared with real TerraSAR-X images for various complex man-made objects like a skyscraper in Tokyo, the Wynn Hotel in Las Vegas, and the Eiffel Tower in Paris. The results show that the simulation can provide very valuable information to interpret complex SAR images or to

predict the reflectivity of planned SAR image acquisitions. [J179]

"SAR Image Despeckling Using Edge Detection and Feature Clustering in Bandelet Domain"

To effectively preserve the edges of a synthetic aperture radar (SAR) image when despeckling, an algorithm with edge detection and fuzzy clustering in the translation-invariant second-generation bandelet transform (TIBT) domain is proposed in this letter. A Canny operator is first utilized to detect and remove edges from the SAR image. Then, TIBT and fuzzy C-mean clustering are employed to decompose and despeckle the edge-removed image, respectively. Finally, the removed edges are added to the reconstructed image. The algorithm suggests each coefficient in high-frequency subbands as the clustering feature, proposes a calculation method of the best clustering number, and defines the signal and noise in the clustering results. Experimental results show that the visual quality and evaluation indexes outperform the other methods with no edge preservation. The proposed algorithm effectively realizes both despeckling and edge preservation and reaches the state-of-the-art performance. [J180]

"Derivation and Discussion of the SAR Migration Algorithm Within Inverse Scattering Problem: Theoretical Analysis"

The analysis of synthetic aperture radar (SAR) migration developed by Gilmore has been refined within the context of the inverse scattering problem, particularly the distorted-wave Born approximation (DWBA). The SAR migration algorithm can be deduced from the DWBA-based inversion formulation when the following assumptions are satisfied: 1) homogeneous and nonfrequency-dependent background medium; 2) the exploding source model; and 3) the well-resolved targets described by an orthogonal relation derived in this paper. In addition, the other contributions of this paper are as follows: 1) The removal of the ??2term has been clarified by the derived orthogonal relation; 2) a scale factor that balances the near-far field has been derived; and 3) a novel SAR migration algorithm for the imaging of targets embedded in a layered medium has been proposed. [J181]

"ML-Based Fringe-Frequency Estimation for InSAR"

This letter focuses on estimating the local fringe frequency of the interferometric phase, under the hypothesis of superficial scattering. Starting from the formulation of the maximum-likelihood estimator, a new simplified estimator is derived. Due to computational efficiency and robustness versus model errors, the resulting estimator is suited for large data processing in the presence of model uncertainty. Furthermore, such an estimator can be straightforwardly extended to the multi-baseline case, resulting in the possibility to estimate the terrain slope with great accuracy. An application to real data is presented, based on a multi-baseline ENVISAT data set. [J182]

"Huber-Markov Model for Complex SAR Image Restoration"

This letter presents the despeckling of single-look complex (SLC) synthetic aperture radar (SAR) images using nonquadratic regularization. The objective function consists of an image model, a gradient, and a prior model. The Huber-Markov random field (HMRF) models the prior. A numerical solution is achieved through extensions of half-quadratic regularization methods using complex-valued SAR data. The proposed method using the HMRF prior together with nonquadratic regularization shows the superior results on SLC synthetic and actual SAR images. [J183]

"A Two-Dimensional Spectrum for General Bistatic SAR Processing"

This letter derives a 2-D point target spectrum for general bistatic synthetic aperture radar (SAR). For the bistatic configuration, the contributions of the transmitter and the receiver to the overall instantaneous Doppler are unequal due to the different slant range histories. In this letter, an instantaneous Doppler contribution ratio is proposed to represent the difference between the instantaneous Doppler contributions of the transmitter and the receiver, which varies with instantaneous Doppler and range frequency. Then, the 2-D spectrum is obtained by using the stationary phase principle and Taylor series expansion for general bistatic SAR. The accuracy of the spectrum is verified with a point target simulation of different general bistatic configurations. [J184]

"InSAR Coherence-Decomposition Analysis"

The phase coherence in synthetic aperture radar interferometry is often used in classification algorithms to detect possible temporal changes of the imaged terrain. However, in mountain areas, the interferometric coherence is also sensitive to the slight variations of the acquisition geometry. In this letter, we propose a very simple but effective method to separate the temporal decorrelation from the geometrical one. Assuming the imaged terrain can be modeled as a distributed target, the geometrical coherence can be estimated by exploiting a topographic model and the sensor acquisition parameters. The discrepancy between the geometrical coherence and the

observed one can then be ascribed to temporal changes. Moreover, in presence of pointlike targets, the hypothesis of distributed terrain is no longer valid, and higher values of the observed coherence with respect to the synthetic geometrical one can be used to detect such targets. The proposed approach allows then in mountain areas the following conditions: (1) a simple and very fast rough estimation of the temporal coherence, and (2) the identification of pointlike targets using just two images. The method has been applied and tested in the Badong (China) site using European Remote Sensing satellite tandem data. [J185]

"ISAR Imaging of Maneuvering Targets Based on the Range Centroid Doppler Technique"

A new inverse synthetic aperture radar (ISAR) imaging approach is presented for application in situations where the maneuverability of noncooperative target is not too severe and the Doppler variation of subechoes from scatterers can be approximated as a first-order polynomial. The proposed algorithm is referred to as the range centroid Doppler (RCD) ISAR imaging technique and is based on the stretch Keystone-Wigner transform (SKWT). The SKWT introduces a stretch weight factor containing a range of chirp rate into the autocorrelation function of each cross-range profile and uses a 1-D interpolation of the phase history which we call stretch keystone formatting. The processing simultaneously eliminates the effects of linear frequency migration for all signal components regardless of their unknown chirp rate in time-frequency plane, but not for the noise or for the cross terms. By utilizing this novel technique, clear ISAR imaging can be achieved for maneuvering targets without an exhaustive search procedure for the motion parameters. Performance comparison is carried out to evaluate the improvement of the RCD technique versus other methods such as the conventional range Doppler (RD) technique, the range instantaneous Doppler (RID) technique, and adaptive joint time-frequency (AJTF) technique. Examples provided demonstrate the effectiveness of the RCD technique with both simulated and experimental ISAR data. [J186]

"Road Network Extraction in VHR SAR Images of Urban and Suburban Areas by Means of Class-Aided Feature-Level Fusion"

In this paper, we propose to combine two road extractors from very high resolution synthetic aperture radar scenes: one more successful in rural areas and one explicitly designed for urban areas. In order to get the best combination of both, a rapid mapping filter for discriminating rural and urban scenes is utilized. Finally, the results are fused on a feature level and connected by means of a network optimization. The approach is tested and evaluated on TerraSAR-X data containing complex urban areas and urban-rural fringe scenes. [J187]

"Hypothesis Testing in Speckled Data With Stochastic Distances"

Images obtained with coherent illumination, as is the case of sonar, ultrasound-B, laser, and synthetic aperture radar, are affected by speckle noise which reduces the ability to extract information from the data. Specialized techniques are required to deal with such imagery, which has been modeled by the G0distribution and, under which, regions with different degrees of roughness and mean brightness can be characterized by two parameters; a third parameter, which is the number of looks, is related to the overall signal-to-noise ratio. Assessing distances between samples is an important step in image analysis; they provide grounds of the separability and, therefore, of the performance of classification procedures. This paper derives and compares eight stochastic distances and assesses the performance of hypothesis tests that employ them and maximum likelihood estimation. We conclude that tests based on the triangular distance have the closest empirical size to the theoretical one, while those based on the arithmetic-geometric distances have the best power. Since the power of tests based on the triangular distance is close to optimum, we conclude that the safest choice is using this distance for hypothesis testing, even when compared with classical distances as Kullback-Leibler and Bhattacharyya. [J188]

"Applying the Freeman-Durden Decomposition Concept to Polarimetric SAR Interferometry"

In this paper, the Freeman-Durden polarimetric decomposition concept is adapted to polarimetric SAR interferometry (PolInSAR) data. The covariance matrix obtained from PolInSAR observations is decomposed into the three scattering mechanisms matrices proposed by Freeman and Durden for polarimetric SAR (PolSAR) data. The objective is to describe each interferometric cross correlation as the sum of the contributions corresponding to direct, double-bounce, and random volume scattering processes. This procedure enables the retrieval not only of the magnitude associated with each mechanism but also of their location along the vertical dimension of the scene. One of the most important features of this algorithm is the potential to isolate more accurately the direct and volume contributions which usually cannot be correctly separated by means of PolSAR measurements. In addition, it is also possible to distinguish between direct scattering responses originated either at ground or produced by upper layers of vegetation. The proposed algorithm has been tested with simulated data from PolSARProSim software, laboratory data from maize and rice samples, and airborne data from a test

site with different scenarios. [J189]

"TerraSAR-X Data for Burn Severity Evaluation in Mediterranean Forests on Sloped Terrain"

TerraSAR-X (TSX) dual-polarized synthetic aperture radar (SAR) data from a test site in Spain have been investigated to determine the relationship between forest burn severity and SAR backscatter. The role of the local incidence angle on the backscatter coefficient has been also studied. Burn severity was estimated by means of composition burn index plots and the remotely sensed differenced normalized burn ratio index. To infer the potential of the TSX data for burn severity assessment, the determination coefficients obtained from linear regression analysis have been used. At horizontal transmit horizontal receive (HH) polarization, backscatter increased for slopes oriented toward the sensor and areas affected by high burn severity, whereas, at horizontal transmit vertical receive (HV) polarization, higher backscatter occurred for slopes oriented away from the sensor in areas of low burn severity. The dependence of the backscatter coefficient on topography for areas affected by forest fire has been confirmed. The HH backscatter presented a clear descending trend with the increase in local incidence angle, whereas the HV backscatter presented an ascending trend. The determination coefficients showed that, at HH polarization, better estimates of burn severity are obtained at low local incidence angles, whereas, for HV polarization, the best estimates are obtained at high local incidence angles. The dual-polarized X-band SAR data showed potential for burn severity estimation in the Mediterranean environment if local incidence angle is accounted for. [J190]

"Adaptive CLEAN With Target Refocusing for Through-Wall Image Improvement"

Signal processing techniques to improve building interior images are introduced. Specifically, an adaptive CLEAN algorithm is introduced in conjunction with target refocusing techniques to de-emphasize undesired signal effects from external walls, and thus more accurately image the lesser contrast objects. Instead of using the point spread function as in the conventional CLEAN algorithm, adaptive CLEAN incorporates a delay spread model found more appropriate for subtracting sidelobes that could obscure interior objects. Refocusing also allows for correcting target distortion and displacement due to through-wall propagation. It is shown that by combining adaptive CLEAN with target refocusing techniques, we are able to reconstruct interior targets (with minimal exterior wall distortion). The introduced processing techniques are demonstrated via simulations generated with a well validated high frequency ray tracing code, and with measured data. [J191]

"Assessing Ionospheric Influence on L-Band SAR Data: Implications on Coseismic Displacement Measurements of the 2008 Sichuan Earthquake"

Ionospheric contributions to the phase of L-band synthetic aperture radar (SAR) signals put severe limitations on ground displacement measurements retrieved by either differential SAR interferometry or radar amplitude-image offsets. Such contributions result in an ionospheric phase screen on the differential interferogram and in directional fluctuations in the relative position of azimuth pixels on offsets maps. In this letter, we propose a procedure for estimating and removing ionospheric contributions to surface displacement measurements derived from L-band SAR data. We test the procedure on SAR data from the May 28, 2008 Sichuan Earthquake. The applied corrections allow both a clearer interpretation of the surface rupture and a more accurate measurement of the surface displacement, which has important implications in earthquake modeling based on L-band SAR data. [J192]

"An Estimation Method for InSAR Interferometric Phase Based on MMSE Criterion"

In this paper, we propose a method based on minimum mean squared error (mmse) criterion to estimate synthetic aperture radar interferometry (InSAR) interferometric phase. In this method, the cross-correlation coefficient vector with large coregistration error is given first, and then, the cost function under the mmse criterion is used to estimate the InSAR interferometric phase. The method can auto-coregister the SAR images and reduce the interferometric phase noise simultaneously. Theoretical analysis and computer simulation results show that the method can provide an accurate estimate of the terrain interferometric phase (interferogram) even when the coregistration error reaches 1 pixel. [J193]

"The May 12, 2008, (Mw 7.9) Sichuan Earthquake (China): Multiframe ALOS-PALSAR DInSAR Analysis of Coseismic Deformation"

A destructive (Mw 7.9) earthquake affected the Sichuan province (China) on May 12, 2008. The seismic event ruptured approximately 270 km of the Yingxiu-Beichuan fault and about 70 km of the Guanxian-Anxian fault. Surface effects were suffered over a wide epicentral area (about 300 km E-W and 250 km N-S). We apply the differential synthetic aperture radar interferometry (DInSAR) technique to detect and measure the surface

displacement field, using a set of ALOS-PALSAR L-band SAR images. We combine an unprecedented high number of data (25 frames from six adjacent tracks) to encompass the entire area which has coseismically displaced. The resulting mosaic of differential interferograms covers an overall area of about 340 km E-W and 240 km N-S. We investigate the source of the Sichuan earthquake by modeling the DInSAR data. The geometry and position of the fault parameters are inferred by a nonlinear inversion, followed by a linear inversion to retrieve the relative slip distribution. Our results show two different source mechanisms for the 145-long Yingxiu-Beichuan fault and for the 105-long Beichuan-Qingchuan fault. Both faults are characterized by slip concentrations of up to 8 m. [J194]

"Mapping of Different Sea Ice Regimes Using Images From Sentinel-1 and ALOS Synthetic Aperture Radar"

Airborne C- and L-band synthetic aperture radar (SAR) images were acquired for three test sites over different sea ice regimes around Svalbard in March 2007, complemented by optical imagery, environmental data, and ice observations. One objective was to use the high-resolution low-noise radar data for investigations on the technical performance of European Space Agency's Sentinel-1 mission for sea ice mapping, the other to assess the potential gain of additional use of L-band SAR data currently available from Advanced Land Observing Satellite (ALOS). The airborne SAR images were employed to simulate data products resembling the interferometric wide-swath mode (IWSM) of Sentinel-1 and ALOS PALSAR fine resolution mode (FRM) in order to quantify the information loss due to the higher noise level and coarser spatial resolution. At the IWSM noise level, zones of deformation, level ice, and new ice can be well separated at like-polarization. At cross-polarization, the noise level is too high for a robust automated classification including thin ice, but deformed and level ice can be discriminated. PALSAR FRM is on average better suited to distinguish deformed and level ice over all ice regimes. It was worse for separating new from thicker level ice at two test sites. For the third test site with very few patches of new ice, the PALSAR FRM showed larger intensity contrasts between new and level ice than Sentinel-1 IWSM. The spatial resolution provided by the IWSM and FRM is sufficient to identify most ice features and types without ambiguities. Typical characteristics of the imaged ice regimes are described. [J195]

"Nonuniform Ground Motion Monitoring With TerraSAR-X Persistent Scatterer Interferometry"

In the past, the application of Persistent Scatterer Interferometry (PSI) was primarily possible in the case of slow (less than a few centimeters per year) uniform movements. In this paper, we show how PSI permits the monitoring of relatively fast (including rates up to > 50 cm/year) and nonuniform movements using TerraSAR-X repeat observations over deep-level mining. To enable this, parts of the PSI methodology were adapted to the special characteristics of the example studied. Apart from a description of the methodology used and the result achieved, error considerations and a validation of the result with in situ measurements are included. [J196]

"Ultrawideband Chirp Scaling Algorithm"

A new version of chirp scaling (CS), the so-called ultrawideband (UWB) CS (UCS), is proposed in this letter. UCS aims at UWB synthetic aperture radar (SAR) systems utilizing large fractional bandwidth and wide antenna beamwidth associated with a wide integration angle. Furthermore, it is also valid for SAR systems with special characteristics such as ground-moving-target-indication SAR systems with a very high pulse repetition frequency. [J197]

"Coherent MapDrift Technique"

A new parametric autofocus technique with a high accuracy of flight-parameter estimation dedicated to strip-mode synthetic aperture radar (SAR) systems is presented. Most of the known autofocus techniques require high-reflectivity targets (man-made targets) to obtain a properly focused SAR image. The technique proposed in this paper allows flight parameters to be estimated effectively, even for a low-contrast scene (e.g., forests, fields, small paths, etc.). The autofocus technique is based on well-known MapDrift (MD) principles. The presented technique is a coherent one, which allows flight parameters to be estimated more precisely than in the other well-known parametric technique referred to as classical MD. The presented technique allows flight parameters to be estimated with accuracy that is independent of the initial velocity error. It can be used for real-time processing for both Earth imaging and moving-target indication. [J198]

"Topographic Mapping of the German Tidal Flats Analyzing SAR Images With the Waterline Method"

The waterline method is used to derive the topography of the tidal flats along the German coast by evaluation of synthetic aperture radar (SAR) images. A series of about 70 European Remote Sensing Satellites SAR images of

the German Bight taken at different water levels within four years is analyzed to detect the borderline between tidal flats and adjacent water areas using a wavelet-based edge-detection algorithm. After geocoding, the waterlines are combined with the corresponding water levels to represent the topography on an irregularly spaced grid. The water levels are taken from a numerical tide model and corrected with the measured gauge data. Interpolation of these data into a regular grid yields a topographic map of the intertidal zone. While the general practicability of this method has been demonstrated in previous studies for smaller test areas, this paper is the first attempt to generate maps of a large area on a yearly basis. [J199]

"Covariance Estimation for dInSAR Surface Deformation Measurements in the Presence of Anisotropic Atmospheric Noise"

We study anisotropic spatial autocorrelation in differential synthetic aperture radar interferometric (dInSAR) measurements and its impact on geophysical parameter estimations. The dInSAR phase acquired by the satellite sensor is a superposition of different contributions, and when studying geophysical processes, we are usually only interested in the surface deformation part of the signal. Therefore, to obtain high-quality results, we would like to characterize and/or remove other phase components. A stochastic model has been found to be appropriate to describe atmospheric phase delay in dInSAR images. However, these phase delays are usually modeled as being isotropic, which is a simplification, because InSAR images often show directional atmospheric anomalies. Here, we analyze anisotropic structures and show validation results using both real and simulated data. We calculate experimental semivariograms of the dInSAR phase in several European Remote Sensing satellite-1/2 tandem interferograms. Based on the theory of random functions (RFs), we then fit anisotropic variogram models in the spatial domain, employing Mate??rn- and Bessel-family correlation functions in nested models to represent complex dInSAR covariance structures. The presented covariance function types, in the statistical framework of stationary RFs, are consistent with tropospheric delay models. We find that by using anisotropic data covariance information to weight dInSAR measurements, we can significantly improve both the precision and accuracy of geophysical parameter estimations. Furthermore, the improvement is dependent on how similar the deformation pattern is to the dominant structure of the anisotropic atmospheric signals. [J200]

"Investigation of Ocean Surface Wave Refraction Using TerraSAR-X Data"

As a scientific and technological continuation of the X-band Synthetic Aperture Radar (X-SAR) and Shuttle Radar Topography Mission (SRTM) missions, the new X-SAR, namely, TerraSAR-X (TSX), was launched on June 15, 2007. Since then, it has provided numerous high-quality data over land and ocean operationally. In this paper, surface wave refraction and diffraction are investigated using TSX imagery acquired over the coast of Terceira island situated in the North Atlantic. Peak wavelength and wave direction are determined by SAR 2-D image spectra. They are compared to measurements of X-band marine radar and results of the WAve prediction Model (WAM). Significant wave height in the near-shore shallow water region is estimated from TSX Spotlight mode data following the wave refraction laws and using the developed XWAVE empirical algorithm. Image spectra of the TSX subscenes in the full-coverage region are given to investigate significant changes of wave direction and length. By analyzing another TSX image acquired in StripMap mode, a shadow zone in the lee side of Terceira island is identified. It is influenced jointly by wave refraction and diffraction. Furthermore, a cross-sea pattern revealed in the image spectra is investigated. The cross sea is generated by the diffracted wave rays from the northern and southern coasts of the island. Less wave directional spreading for the cross-sea situation is observed as well when compared to the image spectra at the origin of diffraction. [J201]

"Multipolarization Microwave Scattering Model for Sahelian Grassland"

A coherent scattering formulation is developed for radar remote sensing of Sahelian grassland. This African vegetation is mainly composed of annual grass and shrubs. In the proposed procedure, first, a temporalmodel for generation of grass and shrub structures, which includes important realistic botanical information, is implemented. Because we develop a coherent scattering model, preserving the relative position of plant elements in a statistical manner as accurately as possible is very important. Shrubs are reproduced using cylindrical elements which represent trunks, branches, and thin green stems that function as leaves for these shrubs. Their crown shape is highly irregular, but for the most part can be encompassed in an ellipsoidal or cylindrical volume; on the other hand, the grass is represented as a set of cylindrical stalks and blade leaves. The scattered power from each grass element is added because multiple scattering among adjacent elements can be neglected at microwave frequencies. We calculate the soil scattering using the Integral Equation Method and neglect the soil volume scattering which may become significant for dry soil condition at high incidence angles. Backscatter statistics are acquired via a Monte Carlo simulation over a large number of realizations. The accuracy of the model is verified using measured data acquired by the C-band environmental satellite advanced synthetic aperture radar instrument at different incident angles. [J202]

"Fast Alternatives to for Polarimetric SAR"

The polarimetric entropy (H) and the alpha angle (α) are two important parameters for analyzing polarimetric synthetic aperture radar data. However, for some special cases, the unstableness of the alpha angle is found; in addition, time consumption for extracting both the parameters will become quite tedious for very large images by pixelwise eigendecomposition. To overcome these shortcomings, a fast algorithm to calculate the polarimetric entropy and two new parameters are proposed in this paper. The first parameter has similar properties to the alpha angle but is stable; the second also behaves similar to the polarimetric entropy. More importantly, both new parameters can be derived very quickly. Like the unsupervised Hα classification, the image can also be classified based on the two new parameters. The NASA/JPL AIRSAR L-band data of San Francisco are applied in the experiment. [J203]

"TerraSAR-X Mission Planning System: Automated Command Generation for Spacecraft Operations"

On June 15, 2007, TerraSAR-X was successfully launched from Baikonur, Kazakhstan. On board TerraSAR-X, a high-resolution X-band synthetic aperture radar (SAR) instrument is being operated as the primary payload. The user community requesting SAR products is composed of commercial and scientific partners as documented in a public-private-partnership agreement. The operations of the TerraSAR-X bus as well as payload operations are performed by the Mission Operations Segment (MOS). The Mission Planning System (MPS), which is a part of the MOS, has been designed to handle complex payload and standard bus operations in an automated manner. The purpose of this paper is to describe the concepts and the TerraSAR-X realization of the MPS. [J204]

"Sonar Measurements in Ship Wakes Simultaneous With TerraSAR-X Overpasses"

A pilot experiment was conducted in the period from April to June 2008 in the Straits of Florida near Port Everglades, Florida, in order to study the dynamics of far wakes of ships. In this experiment, a small boat with downward-looking sonar made ??snakelike?? sections through wakes of ships of opportunity during the TerraSAR-Xoverpasses. The ship and its parameters (length, speed, course, etc.) were identified utilizing an automated identification system. The sonar responded to the clouds of microbubbles generated in the ship wake by the propulsion system and ship-hull turbulence. The ship wakes were traced in the sonar signal typically from 10 to 30 min after the ship's passage. A preliminary analysis of the measurements suggests that the visibility of the centerline ship wake in synthetic aperture radar (SAR) images is correlated with the presence of microbubbles in the wake. This supports the hypothesis that natural surfactants scavenged and brought to the surface by rising bubbles play an important role in the wake visibility in SAR. The influence of the wind-wave field on the ship wake, as well as the effect of screening of the wind-wave field by the ship's hull, adds another level of complexity to wake patterns observed in SAR images. [J205]

"Automatic Correction of Range Migration in SAR Imaging"

A new technique is developed for the automatic correction of range migration in synthetic aperture radar imaging. In the range-Doppler domain, samples at a Doppler frequency constitute a Doppler slice. It is noted that, when there is no range migration, the Doppler slices have similar envelopes, i.e., the envelope of one Doppler slice roughly equals the envelope of another Doppler slice multiplied by a constant. Thus, range migration can be corrected by shifting the Doppler slices such that their envelopes are similar. The technique applies even when the radar moves irregularly or the target is moving. [J206]

"Fore and Aft Channel Reconstruction in the TerraSAR-X Dual Receive Antenna Mode"

The TerraSAR-X satellite is a high-resolution synthetic aperture radar (SAR) system launched in June 2007 which provides the option to split the antenna in along-track direction and sample two physical channels separately. Modern SARs are equipped with active phased array antennas and multiple channels. In order to keep costs low, TerraSAR-X uses the redundant receiver unit for the second channel such that fore and aft channel signals are combined by a hybrid coupler to form sum and difference channel data. The dual receive antenna (DRA) mode can either be used to acquire along-track interferometric data or to acquire signals with different polarizations at the same time (Quad-Pol). Fore and aft channel reconstruction is necessary if ground moving target indication (GMTI) algorithms such as the displaced phase center antenna technique or along-track interferometry shall be applied, and in order to separate the horizontally and vertically polarized received signal components. The proposed approach uses internal calibration pulses from different calibration beams in order to estimate and compensate the hardware impact. The theoretical framework together with the results from the experimental data evaluation for the fore and aft channel reconstruction of the TerraSAR-X DRA mode are presented. The impact of the receive hardware transformation matrix estimation accuracy on errors in the

reconstructed fore and aft channel image data is studied, and first examples on the GMTI capability of the TerraSAR-X DRA mode are given. [J207]

"PolSAR Data Segmentation by Combining Tensor Space Cluster Analysis and Markovian Framework"

We present a new segmentation method for the fully polarimetric synthetic aperture radar (PolSAR) data by coupling the cluster analysis in the tensor space and the Markov random field (MRF) framework. The PolSAR data are usually obtained as a set of 3 ?? 3 Hermitian positive definite polarimetric covariance matrices, which do not form a Euclidean space. If we regard each matrix as a tensor, the PolSAR data space can be represented as a Riemannian manifold. First, the mean shift algorithm is extended to the manifold to cluster such tensors. Then, under the MRF framework, the data energy term is defined by the memberships of all tensors in all the clusters, and the smoothness energy term is defined according to the cluster overlap rates. These parameters regarding the cluster analysis are computed under the Riemannian framework. The total energy is minimized using a graph-cut-based optimization to achieve the segmentation results. The effectiveness of the proposed method is verified using real fully PolSAR data and synthetic images. [J208]

"Minimum Entropy via Subspace for ISAR Autofocus"

In this letter, a novel approach to autofocus for inverse synthetic aperture radar (ISAR) imaging called minimum entropy via subspace autofocus is presented. This scheme uses the weighted signal subspace to express the phase errors left in the echoes after range-bin alignment and estimates the optimal weights sequentially via an optimization algorithm based on an entropy minimization principle, and its robustness and convergence can be ensured by the optimization method. Both the theoretical analysis and processing results of the real ISAR data have confirmed the feasibility of this new scheme. [J209]

"Bistatic TerraSAR-X/F-SAR Spaceborne-Airborne SAR Experiment: Description, Data Processing, and Results"

We report about the first X-band spaceborne-airborne bistatic synthetic aperture radar (SAR) experiment, conducted early November 2007, using the German satellite TerraSAR-X as transmitter and the German Aerospace Center's (DLR) new airborne radar system F-SAR as receiver. The importance of the experiment resides in both its pioneering character and its potential to serve as a test bed for the validation of nonstationary bistatic acquisitions, novel calibration and synchronization algorithms, and advanced imaging techniques. Due to the independent operation of the transmitter and receiver, an accurate synchronization procedure was needed during processing to make high-resolution imaging feasible. Precise phase-preserving bistatic focusing can only be achieved if time and phase synchronization exist. The synchronization approach, based on the evaluation of the range histories of several reference targets, was verified through a separate analysis of the range and Doppler contributions. After successful synchronization, nonstationary focusing was performed using a bistatic backprojection algorithm. During the campaign, stand-alone TerraSAR-X monostatic as well as interoperated TerraSAR-X/F-SAR bistatic data sets were recorded. As expected, the bistatic image shows a space-variant behavior in spatial resolution and in signal-to-noise ratio. Due to the selected configuration, the bistatic image outperforms its monostatic counterpart in almost the complete imaged scene. A detailed comparison between monostatic and bistatic images is given, illustrating the complementarity of both measurements in terms of backscatter and Doppler information. The results are of fundamental importance for the development of future nonsynchronized bistatic SAR systems. [J210]

"First Analysis of TerraSAR-X Along-Track InSAR-Derived Current Fields"

We present the first analysis of surface current fields derived from TerraSAR-X along-track interferometric synthetic aperture radar (along-track InSAR, ATI) data. The images were acquired over the mouth of the Elbe river (Germany) during six satellite overpasses in spring and summer 2008, using the experimental "aperture switching" mode of TerraSAR-X. In this mode, the phased-array synthetic aperture radar (SAR) antenna is split into two halves for receiving, but in contrast to the "dual receive antenna" mode, which uses two independent receivers in parallel, a single receiver is multiplexed to process signals from the two antenna halves in an alternating manner at a doubled pulse repetition frequency. The effective ATI baseline is on the order of 0.8 m. The SAR/ATI raw data processing is described in another paper in this issue. This paper focuses on the conversion of the basic interferograms into line-of-sight surface current fields, which includes an elimination of ship signatures, identification, and correction (as far as possible) of imaging artifacts, additional filtering and smoothing, and a subtraction of contributions of wave motions to detected velocities according to a theoretical model. We evaluate the quality of the results by comparison with current fields from a numerical flow model and with available in situdata. The ATI performance of TerraSAR-X is found to be basically consistent with theoretical

expectations. After applying the same data processing algorithms to all six images, mean differences between TerraSAR-X-derived currents and reference currents in our main test area range from -0.11 to + 0.08 m/s in five of the six cases with one outlier at +0.42 m/s. The spatial current variations within the TerraSAR-X-derived current fields are consistent with the model in three cases, but unrealistically strong variations across the images are found in the other three cases. We attribute this to shortcomings of our preliminary raw data processi--ng algorithms, which can probably be fixed after some more detailed analysis and testing. The results obtained so far encourage us to believe that our internal performance goal of a typical current measuring accuracy of 0.1 m/s at an effective spatial resolution better than 1 km can be met. [J211]

"Assessment of TerraSAR-X Products with a New Feature Extraction Application: Monitoring of Cylindrical Tanks"

There is no doubt that retrieving observed scene features is one of the most interesting and challenging activities in all fields of remote sensing: The successful extraction of scene parameters may not only mean the success of the adopted procedure but also the success of a prediction model, an image product, a sensor project, or even an entire mission. This paper is partly concerned with this. The mission, the sensor, and the products at issue are the TerraSAR-X; the feature retrieval approach is the deterministic model-based approach already tested on E-SAR images and now in phase of improvement and testing on high-resolution TerraSAR-X images. Together with assessing the performances of TerraSAR-X products, this paper deals with a new application which, until now, has not received enough attention even if being worth of it: monitoring of big tanks in suburban or urban areas. Detailed discussion concerning the most suitable product for this kind of application is accompanied by retrieval results carried out on recently acquired TerraSAR-X images. [J212]

"Efficient Wavenumber Domain Focusing for Ground-Based SAR"

We present an efficient focusing algorithm for synthetic aperture radar (SAR) data acquired in short bursts by a geometry with a large range spread, i.e., the case of ground-based (GB) SAR. The usual approach for focusing GB SAR data is the polar formatting algorithm, whose computational complexity, however, is quite relevant due to the nonseparability of the kernel. In this letter, we introduce a different format for the focused data, namely, the range-angular domain. Such format keeps the benefit of the polar format that samples data close to the resolution, but allows for the design of a separable kernel in the wavenumber domain. The proposed kernel exploits a modified Stolt interpolation and an efficient space-varying resampling. Results of processing on both simulated and real data are presented. [J213]

"APC Trajectory Design for "One-Active" Linear-Array Three-Dimensional Imaging SAR"

This paper discusses the antenna phase center trajectory (APCT) design for the "one-active" linear-array 3D imaging SAR (LASAR). First, we discuss the principle of the one-active LASAR and demonstrate its feasibility by experiment. To describe the 3D spatial resolution of the one-active LASAR, the relationship between the 3D ambiguity function (AF) of the one-active LASAR and the system parameters is discussed in detail. Based on the analysis, we divide the APCT design into three topics: the direction of the linear array, the length of the linear array, and the switching mode of the active element [named as antenna phase center function (APCF)]. On the first topic, we conclude that, when the range, along-track, and cross-track directions are orthogonal to each other, the ambiguity region of the one-active LASAR attains minimum, and the 3D spatial resolution can be separated into the range, along-track, and cross-track resolutions. On the second topic, we find that the cross-track resolution is determined by the length of the linear array and the frequency of the carrier. To ensure that the length of the linear array is acceptable, the carrier should be W-band wave or millimeter wave. On the third topic, the effect of APCF is researched, and we find that both the periodic APCF and the pseudorandom APCF can produce 3D resolution, except for the periodic rectangle APCF. For the pseudorandom APCF and the periodic APCF with short period, the cross-range 2D AF is or can be approximated as the product of two 1D AFs in the along- and cross-track directions. Finally, the distribution of the pseudorandom APCF is optimized by the Lagrange multiplier method under the minimum variance criterion, and we find that, when the pseudorandom APCF obeys the parabolic distribution, the cross-range 2D AF is optimal. [J214]

"Multichannel InSAR Building Edge Detection"

In this paper, the problem of building edge detection in synthetic aperture radar images is addressed. A new stochastic approach based on local Gaussian Markov random field (LGMRF) is proposed. The algorithm finds the edges of buildings starting from the estimation of the hyperparameters of the LGMRF model. The hyperparameters are seen as an indicator of the spatial correlation between adjacent pixels. The procedure is applied on interferometric data, using single-channel and multichannel configurations. The algorithm has been tested on simulated and real data, providing good results in both cases. [J215]

"Estimation of Forest Structure, Ground, and Canopy Layer Characteristics From Multibaseline Polarimetric Interferometric SAR Data"

This paper concerns forest parameter retrieval from polarimetric interferometric synthetic aperture radar (PolInSAR) data considering two layers, one for the ground under the vegetation and one for the volumetric canopy. A model is designed to combine a physical model-based polarimetric decomposition with the random-volume-over-ground (RVoG) PolInSAR parameter inversion approach. The combination of a polarimetric scattering media model with a PolInSAR RVoG vertical structure model provides the possibility to separate the ground and the volume coherency matrices based on polarimetric signatures and interferometric coherence diversity. The proposed polarimetric decomposition characterizes volumetric media by the degree of polarization orientation randomness and by the particle scattering anisotropy. Using the full model enhances the estimation of the vertical forest structure parameters by enabling us to estimate the ground-to-volume ratio, the temporal decorrelation, and the differential extinction. For forest vegetation observed at L-band, this model accounts for the ground topography, forest and canopy layer heights, wave attenuation in the canopy, tree morphology in the form of the angular distribution and the effective shapes of the branches, and the contributions from the ground level consisting of surface scattering and double-bounce ground-trunk interactions, as well as volumetric understory scattering. The parameter estimation performance is evaluated on real airborne L-band SAR data of the Traunstein test site, acquired by the German Aerospace Center (DLR)'s E-SAR sensor in 2003, in both single- and multibaseline configurations. The retrieved forest height is compared with the ground-truth measurements, revealing, for the given test site, an average root-mean-square error (rmse) of about 5 m in the repeat-pass configuration. This implies an improvement in rmse by over 2 m in comparison to the pure coherence-based RVoG PolInSAR parameter inversion. [J216]

"Segmentation of ISAR Images of Targets Moving in Formation"

This paper proposes a new method to separate inverse synthetic aperture radar (ISAR) images using the range-Doppler algorithm when multiple targets fly closely spaced in a formation. This method is composed of three steps. The first step is an initial range-Doppler imaging of the whole set of targets to obtain a ??bulk?? image. In this step, range profiles are aligned using a new cost function, which is the sum of the amplitudes of the pixels lying along a polynomial that models the trajectory of the bulk image. To reduce the probability of incorrectly aligning high-amplitude pixels from different targets, pixel amplitudes are converted to binary form: A number ?? of pixels with the greatest amplitudes are identified in the bulk range profile, and their amplitudes are converted to one; the amplitudes of the remaining pixels are converted to zero. This process gives each of the ?? pixels the same weight on the cost function. Then, phase adjustment is used to coarsely separate targets in a 2-D image. The second step is the separation of the bulk image into component images using a window of the target size. The third step is a second range-Doppler imaging, in which each ISAR image is enhanced using range alignment and phase adjustment. Simulations using three targets composed of point scattering centers prove that the proposed method can effectively segment three targets flying in a formation. [J217]

"The TerraSAR-X Ground Segment"

TerraSAR-X, the first national German remote-sensing satellite, was launched on June 15, 2007. It carries an X-band high-resolution synthetic aperture radar (SAR) instrument featuring imaging modes like StripMap, ScanSAR, and, particularly, SpotLight in a variety of different polarization modes. Primary mission goal is the provision of both science and commercial users with a variety of products from advanced SAR modes. The TerraSAR-X Ground Segment, which is provided by the German Aerospace Center (DLR), constitutes the central element for controlling and operating the TerraSAR-X satellite, for calibrating its SAR instrument, and for archiving the SAR data, as well as generating and distributing the basic data products. This paper depicts the ground-segment layout and describes its major elements. The ordering and product-generation workflow is presented. It introduces the applied prelaunch integration, testing, verification, and validation approach, a major key to the completion not only of the SAR technical-verification program but also the operational qualification of the ground segment itself within the commissioning phase. [J218]

"A Bistatic SAR Raw Data Simulator Based on Inverse Algorithm"

A synthetic aperture radar (SAR) raw data simulator is an important tool for testing the system parameters and the imaging algorithms. In this paper, a scene raw data simulator based on an inverse ω-kalgorithm for bistatic SAR of a translational invariant case is proposed. The differences between simulations of monostatic and bistatic SAR are also described. The algorithm proposed has high precision and can be used in long-baseline configuration and for single-pass interferometry. Implementation details are described, and plenty of simulation results are provided to validate the algorithm. [J219]

"Forest Modeling For Height Inversion Using Single-Baseline InSAR/Pol-InSAR Data"

The Random Volume over Ground (RVoG) model has been extensively applied to polarimetric synthetic aperture radar interferometry (Pol-InSAR) data for forest height inversion. The model assumes forest as a homogeneous volume of randomly oriented particles characterized by a constant extinction but does not take into account the forest vertical heterogeneity, to which interferometric coherence is sensitive. In order to integrate vertical heterogeneity in forest models, two complementary models, which take into consideration the forest natural structure, are investigated through analysis of volume interferometric coherence. The first model assumes a vertically varying extinction in the volume layer, and the second model considers predominant contributions localized in a finite height interval, modeled as a Gaussian-distributed backscatter. The two forest models are compared with constant extinction RVoG in the coherence and interferometric phase aspects. Finally, the contribution of these new models for forest height inversion using the Pol-InSAR technique is discussed in the context of a two-layer ground + canopy medium. [J220]

"TerraSAR-X Instrument Calibration Results and Extension for TanDEM-X"

Spaceborne remote sensing with synthetic aperture radar (SAR) has become an essential source of high-resolution and continuous Earth observation. Modern satellites like the German TerraSAR-X system provide state-of-the-art radar images with respect to operating flexibility and imaging quality. The outstanding performance of TerraSAR-X image products is achieved by an innovative calibration approach that minimizes systematic antenna and instrument characteristics. The active phased array X-band antenna is fed by 384 transmit/receive modules for electronic beam steering and shaping in the azimuth and elevation direction. The flexible radar instrument hosts an internal calibration system which guarantees the high radiometric stability of all SAR products. New techniques for antenna performance control have been successfully implemented, setting a high standard for next-generation SAR missions. This paper summarizes all essential calibration results of TerraSAR-X that cover internal instrument behavior. Furthermore, we give an outlook on the required bistatic calibration techniques for the future TanDEM-X mission that faces additional performance challenges when calibrating two TerraSAR-X satellites flying in close formation. [J221]

"A Contribution of Polarimetry to Satellite Differential SAR Interferometry: Increasing the Number of Pixel Candidates"

This letter presents a general method for increasing the number of pixel candidates, those selected for processing in advanced differential SAR interferometry, by means of the exploitation of the polarimetric information provided by new satellite sensors. The algorithm is formulated for two different criteria of selection: the average coherence over the stack of interferograms and the amplitude dispersion index of the stack of images. Experimental results obtained with dual-pol images of TerraSAR-X over an urban area have demonstrated the expected improvement. The number of pixel candidates for an arbitrary threshold is 60% higher than that for single-pol data when using the average coherence and three times higher when using the dispersion index. The approach has also been compared to a selection based on a set of conventional channels (the copolar linear channels and the first two Pauli ones), showing a slight improvement for coherence selection and an important one for amplitude dispersion selection. [J222]

"Scattering Model for a Pine Tree Employing VIE With a Broadband MLFMA and Comparison to ICA"

In this paper, we present accurate calculations of electromagnetic wave scattering from a high-detail pine tree model, which includes also the needles. We have deployed a volume integral equation (VIE) model, which takes into account high-order reflections between all scatterers, even between single needles. The pine tree is modeled as a realistic collection of dielectric cylinders. With the help of our calculations, we assess the importance of multiple scattering inside the pine canopy and the contribution of the needles to the scattering. We compare our calculations with a much simpler model output to determine the validity conditions for simplified approaches. As the simpler model, we use an infinite cylinder approximation (ICA) model which uses a truncated cylinder approximation and takes into account only the first-order reflections from single cylinders. Both models are bistatic, fully coherent, and fully polarimetric models suitable in calculating the scattering from a large and general collection of dielectric cylinders. Our results show that, for the C-band calculations, the VIE model output differs significantly from the simple ICA model output, indicating the importance of the higher order scattering between the needles and branches. However, for the L-band, the accurate VIE model gives similar results as the ICA model, indicating that, in this case, the higher order scattering between the needles can be neglected. [J223]

"ISAR Imaging of Maneuvering Target Based on the L-Class of Fourth-Order Complex-Lag PWVD"

In inverse synthetic aperture radar (ISAR) imaging of a maneuvering target, the received signal in a range bin can be characterized as a multicomponent polynomial phase signal (PPS) after motion compensation. The traditional discrete Fourier transform algorithm is not appropriate in analyzing the PPS. In this paper, the L-class of a fourth-order complex-lag polynomial Wigner-Ville distribution (PWVD) is presented to generate a high-resolution time-frequency distribution (TFD) for the multicomponent PPS. For a signal with polynomial phase up to order four (this is accurate enough in ISAR imaging), the cross-terms between different components can be reduced by the convolution in the frequency domain of the L-class of the fourth-order complex-lag PWVD. The new TFD is used in the ISAR imaging of the maneuvering target, and high-quality instantaneous ISAR images are obtained. Results of simulated and real data demonstrate the effectiveness of the method above. [J224]

"Cold Regions Hydrology High-Resolution Observatory for Snow and Cold Land Processes"

Snow is a critical component of the global water cycle and climate system, and a major source of water supply in many parts of the world. There is a lack of spatially distributed information on the accumulation of snow on land surfaces, glaciers, lake ice, and sea ice. Satellite missions for systematic and global snow observations will be essential to improve the representation of the cryosphere in climate models and to advance the knowledge and prediction of the water cycle variability and changes that depend on snow and ice resources. This paper describes the scientific drivers and technical approach of the proposed Cold Regions Hydrology High-Resolution Observatory (CoReH2O) satellite mission for snow and cold land processes. The sensor is a synthetic aperture radar operating at 17.2 and 9.6 GHz, VV and VH polarizations. The dual-frequency and dual-polarization design enables the decomposition of the scattering signal for retrieving snow mass and other physical properties of snow and ice. [J225]

"Cooperative Multimonostatic SAR: A New SAR Configuration for Improved Resolution"

This letter presents a new synthetic aperture radar (SAR) configuration that has been named cooperative multimonostatic SAR (CMM SAR). CMM SAR consists of a battery of monostatic SARs whose flight paths and frequency bands are coordinated in such a way that the final system produces high-resolution images. The point spread function (PSF) of CMM SAR has been used to quantify the gain in resolution as compared to a monostatic SAR system operating under the same k-space area. Three different configurations of CMM SAR have been proposed. Evaluations of these CMM SARs are done, and the results show substantial improvement in performance compared to the conventional monostatic SAR. One of these three CMM SARs is especially the most successful in terms of both gain in performance and simplicity in implementation. [J226]

"Very High Resolution Spaceborne SAR Tomography in Urban Environment"

Synthetic aperture radar tomography (TomoSAR) extends the synthetic aperture principle into the elevation direction for 3-D imaging. It uses stacks of several acquisitions from slightly different viewing angles (the elevation aperture) to reconstruct the reflectivity function along the elevation direction by means of spectral analysis for every azimuth-range pixel. The new class of meter-resolution spaceborne SAR systems (TerraSAR-X and COSMO-Skymed) offers a tremendous improvement in tomographic reconstruction of urban areas and man-made infrastructure. The high resolution fits well to the inherent scale of buildings (floor height, distance of windows, etc.). This paper demonstrates the tomographic potential of these SARs and the achievable quality on the basis of TerraSAR-X spotlight data of urban environment. A new Wiener-type regularization to the singular-value decomposition method-equivalent to a maximum a posteriori estimator-for TomoSAR is introduced and is extended to the differential case (4-D, i.e., space-time). Different model selection schemes for the estimation of the number of scatterers in a resolution cell are compared and proven to be applicable in practice. Two parametric estimation algorithms of the scatterers' elevation and their velocities are evaluated. First 3-D and 4-D reconstructions of an entire building complex (including its radar reflectivity) with very high level of detail from spaceborne SAR data by pixelwise TomoSAR are presented. [J227]

"Geodetically Accurate InSAR Data Processor"

We present a new interferometric synthetic aperture radar (InSAR) processing approach that capitalizes on the precise orbit tracking that is available with modern radar satellites. Our method uses an accurate orbit information along with motion-compensation techniques to propagate the radar echoes to positions along a noninertial virtual orbit frame in which the location and focusing equations are particularly simple, so that images are focused without requiring autofocus techniques and are computed efficiently. Motion compensation requires two additional focus correction phase terms that are implemented in the frequency domain. If the images from an interferometric pair or stack are all computed along the same reference orbit, flat-Earth topographic correction is not needed, and image coregistration is simplified, obviating many difficulties that are often encountered in

InSAR processing. We process several data sets collected by the ALOS PALSAR instrument and find that the geodetic accuracy of the radar images is 10-20 m, with up to 20 m of additional image distortion needed to align 100 km Ч 100 km scenes with reference digital elevation models. We validated the accuracy by using both known radar corner reflector locations and by the registration of the interferograms with digital maps. The topography-corrected interferograms are free from all geometric phase terms, and they clearly show the geophysical observables of crustal deformation, atmospheric phase, and ionospheric phase. [J228]

"A Novel Strategy for Radar Imaging Based on Compressive Sensing"

Radar data have already proven to be compressible with no significant losses for most of the applications in which it is used. In the framework of information theory, the compressibility of a signal implies that it can be decomposed onto a reduced set of basic elements. Since the same quantity of information is carried by the original signal and its decomposition, it can be deduced that a certain degree of redundancy exists in the explicit representation. According to the theory of compressive sensing (CS), due to this redundancy, it is possible to infer an accurate representation of an unknown compressible signal through a highly incomplete set of measurements. Based on this assumption, this paper proposes a novel method for the focusing of raw data in the framework of radar imaging. The technique presented is introduced as an alternative option to the traditional matched filtering, and it suggests that the new modes of acquisition of data are more efficient in orbital configurations. In this paper, this method is first tested on 1-D simulated signals, and results are discussed. An experiment with synthetic aperture radar (SAR) raw data is also described. Its purpose is to show the potential of CS applied to SAR systems. In particular, we show that an image can be reconstructed, without the loss of resolution, after dropping a large percentage of the received pulses, which would allow the implementation of wide-swath modes without reducing the azimuth resolution. [J229]

"Impact of Radarsat-2 SAR Ultrafine-Mode Parameters on Stereo-Radargrammetric DEMs"

The new high-resolution mode of Radarsat-2 was evaluated for digital elevation model (DEM) generation using stereo-radargrammetry with Toutin's 3-D physical model as part of the Canadian Space Agency's programs. In addition, the impact of radar parameters on stereo-extracted DEMs was evaluated. Three stereo pairs using different radar parameters (resolutions; HH and VV polarizations; slant and ground range; image spacing) from ultrafine-mode Radarsat-2 data acquired over a test site north of Quebec City, Canada, were formed to generate DEMs, which were thus compared to 15-cm-accurate lidar elevation data. Results showed a good accuracy for the three stereo-extracted DEMs: less than 0.8 m for the horizontal positioning and around 3 m (1) for the elevation on bare soils, with small 3-D biases (2-3 m). The HH stereo pair in slant-range format slightly but consistently achieved the best results. [J230]

"Micro-Doppler analysis of a rotating target in synthetic aperture radar"

Rotating targets cause phase modulation of the azimuthal phase history of a synthetic aperture radar (SAR) system. The phase modulation may be seen as a time-dependent micro-Doppler (m-D) frequency. This study presents two approaches for extracting m-D features from SAR images. In order to extract m-D features from SAR images, the time domain radar return is decomposed in two separate ways. One is based on wavelet decomposition in which the returned signal is decomposed into a set of components that are represented at different wavelet scales. The components are then reconstructed by applying the inverse wavelet transform. This wavelet approach has been used in previous m-D analysis work for an inverse SAR (ISAR) system, and it is presented here in the extraction of m-D features for a SAR system. The second approach is based on adaptive chirplet decomposition combined with time-frequency analysis. This new approach is introduced as an alternative to the wavelet approach of decomposing the SAR radar return. The results from the wavelet and adaptive chirplet decomposition proxcedures are compared, and the chirplet-based approach establishes itself as a viable alternative. The chirplet-based method of m-D extraction has been successfully applied to SAR data scene collected by the US Navy APY-6 radar. [J231]

"Terahertz Imaging Systems With Aperture Synthesis Techniques"

This paper presents the research and development of two terahertz imaging systems based on photonic and electronic principles, respectively. As part of this study, a survey of ongoing research in the field of terahertz imaging is provided focusing on security applications. Existing terahertz imaging systems are reviewed in terms of the employed architecture and data processing strategies. Active multichannel measurement method is found to be promising for real-time applications among the various terahertz imaging techniques and is chosen as a basis for the imaging instruments presented in this paper. An active system operation allows for a wide dynamic range, which is important for image quality. The described instruments employ a multichannel high-sensitivity heterodyne architecture and aperture filling techniques, with close to real-time image acquisition time. In the

case of the photonic imaging system, mechanical scanning is completely obsolete. We show 2-D images of simulated 3-D image data for both systems. The reconstruction algorithms are suitable for 3-D real-time operation, only limited by mechanical scanning. [J232]

"Sensitivity of X-, C-, and L-Band SAR Backscatter to Burn Severity in Mediterranean Pine Forests"

Synthetic aperture radar (SAR) data at X-, C-, and L-bands have been investigated to determine the relationship between backscatter and forest burn severity over three sites in Spain. The dependence of SAR backscatter on local incidence angle and environmental conditions has been analyzed. At HH and VV polarizations, the backscatter increased with burn severity for X- and C-bands, whereas it decreased for L-band. Cross-polarized (HV) backscatter decreased with burn severity for all frequencies. Determination coefficients were used to quantify the relationship between radar backscatter and burn severity for given intervals of local incidence angle. For X- and C-band copolarized data, higher determination coefficients were observed for slopes oriented toward the sensors, whereas for cross-polarized data, the determination coefficients were higher for slopes oriented away from the sensor. At L-band, the association strength of cross-polarized data to burn severity was high for all local incidence angles. C- and L-band cross-polarized backscatter showed better potential for burn severity estimation in the Mediterranean environment when the local incidence angle is accounted for. The small dynamic range observed for X-band data could hinder its use in forests affected by fires. [J233]

"Image Autocoregistration and Interferogram Estimation Using Extended COMET-EXIP Method"

In this paper, an extended COvariance Matching Estimation Techniques-Extend Invariance Principle (COMET-EXIP) method is proposed to estimate interferometric synthetic aperture radar or interferometric synthetic aperture sonar (InSAS) interferometric phase in the presence of large coregistration errors, even up to one pixel. First, the extended COMET-EXIP method is presented for the application of joint-pixel-model-based interferogram estimation, through choosing a novel "unstructured model" in terms of the parameters to be estimated and decoupling the interesting parameters from the uninteresting "nuisance parameters." Then, a fast algorithm of COMET-EXIP is proposed for the interferometric phase estimation. Finally, the ambiguity problem of the COMET-EXIP method is solved without introducing performance degradation. The simulated data and real data from the trial InSAS and X-SAR are used to verify the validity of the method. The results show that the method is robust for a wide range of signal-to-noise ratio and has a good performance on both fringe preserving and noise suppressing. In addition, the same computational speed level of the proposed method as that of the pivoting mean filtering is very attractive. [J234]

"Adaptive Target Detection With Application to Through-the-Wall Radar Imaging"

An adaptive detection scheme is proposed for radar imaging. The proposed detector is a postprocessing scheme derived for one-, two-, and three-dimensional data, and applied to through-the-wall imaging using synthetic aperture radar. The target image statistics depend on the target three-dimensional orientation and position. The statistics can also vary with the standoff distance of the imaging system because of the change in the corresponding scene image resolution. We propose an iterative target detection scheme for the cases in which no or partial a priori knowledge of the target image statistics is available. Properties of the proposed scheme, such as conditions of convergence and optimal configurations are introduced. The detector performance is examined under synthetic and real data. The latter is obtained using a synthetic aperture through-the-wall radar indoor imaging scanner implementing wideband delay and sum beamforming. [J235]

"Requirement on Antenna Cross-Polarization Isolation for the Operational Use of C-Band SAR Constellations in Maritime Surveillance"

The issue of antenna cross-polarization isolation has been previously discussed for the design of fully polarimetric synthetic aperture radars (SARs). Dual-polarized antennas with cross-polarization isolation that is better than -30 dB are desirable for more convenient polarimetric data calibration since measurements of antenna crosstalk (magnitude and phase) variations with incidence angle are not required. For an antenna with significant polarization crosstalk, it is still possible to retrieve pure polarization measurements of HH, HV, VH, and VV provided that the four corresponding received voltages are measured. However, it is not possible to recover from cross-polarization contamination for single- or dual-polarization measurements. Therefore, it is important to set up a minimum requirement on dual-polarized antenna isolation so that single- and dual-polarization applications are not unduly affected. In this letter, the minimum requirement on cross-polarization antenna isolation is investigated for operational use of C-band SARs in maritime surveillance applications. Calibrated polarimetric RADARSAT-2 data are used to simulate single- and dual-polarization data with cross-polarization contamination for a dual-polarized antenna with cross-polarization isolation ranging from -20 to -35 dB. It is

shown that the cross-polarization HV (or VH) channel can be significantly affected, particularly at steep incidence angles. As a result, key applications that require the use of pure HV, such as ship detection and wind-speed measurements, are significantly affected. A requirement for a minimum of -30-dB antenna isolation is established. Antennas with cross-polarization isolation better than -35 dB are desirable for reliable exploitation of HV data at steep incidence angles. [J236]

"SAR Processors Based on Signal or Interference Subspace Detector"

In this paper, we present a new synthetic aperture radar (SAR) processor relying on subspace detectors. The scattering pattern of the constituent element of the man-made target (MMT) to detect is used to improve the detection capabilities. In the particular case of foliage penetration (FOPEN), we propose to reduce the probability of false alarms by considering the scattering pattern of almost vertical trunks (modeled here as dielectric cylinders). New subspace detectors are derived to look for either an interference or a target element in a noisy environment. A new processor based on these subspace detectors is successively applied to simulated data. In addition, results obtained with real data reveal a significant improvement in the detection capabilities both in comparison with a classical SAR processor and with the subspace signal detector SAR (SSDSAR) processor (without interference model). [J237]

"Polarimetric Scattering Similarity Between a Random Scatterer and a Canonical Scatterer"

In this letter, we propose a novel parameter to measure the scattering similarity between a random scatterer and a canonical scatterer. Compared with the similarity parameter proposed by Yang, the novel parameter not only has some advantages, such as its independence of the spans of a coherence matrix, but also can be applied directly in the case of a random scatterer made up of multiscattering centers. As an example, the novel parameter is adopted to extract some scattering characteristics of a target. With the full polarimetric L-band airborne synthetic aperture radar data, we illustrate the veracity of the novel parameter in measuring scattering similarity and its application in terrain classification. [J238]

"Adaptive two-step calibration for high resolution and wide-swath SAR imaging"

In this study, the authors focus on the channel calibration for digital beam forming (DBF) synthetic aperture radar (SAR) imagery. Incorporated with DBF processing, multi-channel SAR is promising in high-resolution and wide-swath (HRWS) imaging. It coherently combines recorded multi-channel signals to overcome the spectrum ambiguity. However, the mismatch between channels and baseline errors phase should be compensated before the processing. In this study, the authors propose a novel calibration for DBF SAR imagery by making use of the orthognality between signal subspace and noise subspace. Based on that the imbalance is uncoupled in range and azimuth, the calibration has two steps: range calibration and azimuth calibration. The mismatch in range is estimated by an interpolation in time domain which is applicable in the presence of the Doppler ambiguity. The azimuth calibration is incorporated with the post-Doppler beam forming processing, which estimates the element error caused by baseline errors and channel imbalance. Real data are used to demonstrate the performance of Doppler ambiguity suppression after our calibration. The results confirm the validity of the approach. [J239]

"Rotational motion estimation for ISAR via triangle pose difference on two range-Doppler images"

Rotational motion estimation is essential for inverse synthetic aperture radar (ISAR) imaging and understanding. For an object rotating with a constant acceleration, a closed-form solution is proposed to jointly estimate the initial rotating velocity (IRV) and the rotating acceleration (RA) by exploiting the pose difference of a triangle on two range-Doppler (RD) images. Then, the RA can be compensated with interpolation processing and an equivalent uniformly rotating object may be obtained. After that, the estimated IRV can be used to re-scale the RD image into the homogeneous range-cross range domain, or to provide more satisfactory imaging result via elaborated algorithms such as polar format algorithm or convolution back-projection algorithm. Finally, experimental results with both simulated and real airplane data are provided to demonstrate the effectiveness of the proposed method. [J240]

"Simultaneous Observations and Analysis of Severe Storms Using Polarimetric X-Band SAR and Ground-Based Weather Radar"

Recent advances in synthetic aperture radar (SAR) technology have revived meteorological applications with this type of radar. SARs are designed for surface imaging, but now that several X-band multipolarization SAR satellites are in orbit, the attenuation and backscatter caused by precipitation can be better studied. The results presented here demonstrate some of the possibilities by analyzing observations from dual-polarization (HH, VV) TerraSAR-X (TSX) acquisitions over central Florida surrounding severe storms in August 2008. Simultaneous to the SAR acquisitions, WSR-88D ground weather radars in Melbourne and Tampa Bay, FL, collected reflectivity

and radial velocity data; the observed strong precipitation cells from convective storms are colocated with severe attenuation in the corresponding SAR images. The observations from SAR measurements are explained quantitatively by converting ground radar reflectivity into spaceborne radar attenuation via a theoretical model. In addition, polarization analysis comparing the SAR image to two additional TSX acquisitions 11 days apart and without rain provides an indication of storm-induced propagation effects on X-band SAR. Specifically, the copolar ratio Z_dr and the copolar correlation differences exhibit behavior that is better explained by the precipitation impact versus surface changes. Multiple regions with varying ground cover, including urban, and storm characteristics are analyzed to highlight the complexity of meteorological research using SAR while revealing a potential use of the technology to investigate the storm structure. [J241]

"Generalisation of inverse synthetic aperture radar autofocusing methods based on the minimisation of the Renyi entropy"

In order to obtain focused inverse synthetic aperture radar (ISAR) images, an accurate translational motion compensation is required. The phase adjustment step corresponds to fine compensation and must be properly designed. The authors introduce the Renyi entropy for autofocusing ISAR images. The Renyi entropy of order α is a generalisation of the standard Shannon entropy. When α tends to be the unity, the Renyi entropy tends to be the Shannon entropy. Here, we demonstrate that minimising the Renyi entropy for α = 2 is equivalent to maximising the contrast for ISAR autofocusing. Furthermore, it is also shown that maximising the peak value is equivalent to minimising the Renyi entropy for α tending to infinity. On the other hand, the authors propose to minimise the Renyi entropy with α = 0.5 to reconstruct an accurate ISAR image. Simulated data have been used to verify that, in terms of mean squared error, the proposed method with α =0.5 outperforms other autofocusing algorithms such as the method based on contrast maximisation or the one based on the minimisation of the standard Shannon entropy. The method has also been applied to real data. [J242]

"Interferometric focusing for the imaging of humans"

Different recent approaches have demonstrated the feasibility of applying millimetre-waves (MMW) for the imaging of objects at a person's body. The utilisation of MMW allows for the detection of both metallic and non-metallic objects. In order to reduce costs a low number of transmit-receive modules should be used. Furthermore, the person should also be illuminated from different angles in order to avoid shadowing effects as good as possible. A way to fulfil these two conditions is to place one sensor above and another one below the person and either rotate the person standing on a turntable (inverse synthetic aperture radar, ISAR) or move the sensors on a circular path around the person (synthetic aperture radar, SAR). The goal of the reconstruction is to obtain information about the shape of possible threats and their positions in all three dimensions. During processing as a first step, the reconstruction is done along range and azimuth, which span the principal surface given by the suggested sensor configuration. Afterwards, the third spatial dimension can be determined by combined evaluation of the resolution capabilities of the curved synthetic aperture and the interferometric phase of two coherent receiving channels of one sensor. [J243]

"Compact polarimetric SAR interferometry"

The authors discuss the role and performance of compact polarimetry in SAR interferometry. The considered SAR architecture transmits either a linearly polarised wave oriented at 45Г‚В° or a circularly polarised one, and receives at horizontal and vertical polarisation. Two polarimetric acquisitions are combined in an interferometric image, characterised by a polarimetric and interferometric (POLINSAR) covariance matrix. The expression of the covariance matrix for compact polarimetry is derived and the relationship between compact and full polarimetric covariance matrices is discussed. On the basis of symmetry properties of geophysical media, the authors propose a reconstruction algorithm of the full polarimetric information from a compact polarimetric dataset. The algorithm allows the assessment of compact POLINSAR and the comparison between the two compact configurations. The authors consider forested areas and compare the interferometric degree of coherence measured at different polarisations by compact polarimetry and full polarimetry. The study shows that the degree of coherence from a compact polarimetric architecture carries enough information for POLINSAR applications, such as forest parameters retrieval, if the symmetry properties are satisfied. Airborne data acquired by the DLR E-SAR sensor over the Traunstein forest are used to illustrate the results. [J244]

"Interferometric SAR Extended Coherence Calculation Based on Fractional Lower Order Statistics"

A polarimetric synthetic aperture radar (SAR) coherence calculation method based on fractional lower order statistics (FLOS) was proposed in Bian's paper. In this letter, we apply this approach to the coherence calculation for interferometric SAR (InSAR) and provide a detailed analysis. An L-band InSAR data set is used to provide comparative results between the coherence derived in the traditional manner and that based on FLOS.

In the areas around strong scatterers, the coherence is found to be biased due to the deviation of the statistical model from Gaussian when using the traditional coherence calculation. However, the coherence based on FLOS largely reduces this bias. From the experimental results using the InSAR data, we found that this method reduces the artifacts in the traditional coherence calculation method. The removal of bias due to sample estimation is also discussed. [J245]

"Interferometric methods for three-dimensional target reconstruction with multipass circular SAR"

The authors consider three-dimensional (3-D) target construction from SAR data collected on multiple complete circular apertures at different elevation angles. The 3-D resolution of circular SAR systems is constrained by two factors: the sparse sampling in elevation and the limited azimuthal persistence of the reflectors in the scene. Three-dimensional target reconstruction with multipass circular SAR data is further complicated by non-uniform elevation spacing in real flight paths and non-constant elevation angle throughout the circular passes. The authors first study parametric spectral estimation methods that extend standard IFSAR method of height estimation to apertures at more than two elevation angles. Next, they show that linear interpolation of the phase history data leads to unsatisfactory performance in 3-D reconstruction from non-uniformly sampled elevation passes. The authors then present a new sparsity regularised interpolation algorithm to preprocess non-uniform elevation samples to create a virtual uniformly spaced array. The authors illustrate the performance of the proposed method using data from EM simulations and data collected from a wideband X-band airborne sensor. [J246]

"Editorial Special Section on Synthetic Aperture Radar from EuSAR 2008, Friedrichshafen, Germany"

It is a pleasure to introduce this Special Section of IET Radar, Sonar & Navigation, dedicated to the 2008 European Conference on Synthetic Aperture Radar. EuSAR is the international conference devoted to the technology and techniques of Synthetic Aperture Radar (SAR). The conference is organised biennially and was first established in 1996. Since its inception, worldwide interest in EuSAR has steadily increased. While the first EuSAR featured two parallel sessions, the forthcoming conference (EuSAR 2010 in Aachen, Germany) will be partitioned into five parallel sessions. [J247]

"Scatterers characterisation in radar imaging using joint time-frequency analysis and polarimetric coherent decompositions"

Classical radar imaging generally considers targets as set of isotropic independent sources with a constant response in the measured frequency band. Nevertheless, new radar capabilities, in terms of signal bandwidth and angular excursion, may challenge this bright point model. Studies based on multidimensional time-frequency (TF) analysis, describing the angular and frequency behaviour of a scene-s reflectivity, showed that some scatterers may have anisotropic and dispersive responses. Polarisation diversity is an interesting additional source of information in radar imaging, and provides indicators closely linked to some geometric and electromagnetic properties of the observed objects. In this study, a fully polarimetric TF analysis is proposed for radar imaging (SAR, ISAR) that characterises the anisotropic and dispersive behaviour of the polarimetric response of deterministic targets. This method is based on the hyper-image concept, which describes the response of scatterers as a function of the observation angle, the emitted frequency and polarimetric canonical behaviours. Polarimetric hyper-images point out that non-stationary behaviours can be related to physical properties of the target (geometrical shape, relative orientation) and allow a better understanding of the scattering mechanisms. This polarimetric hyper-image representation is then used to detect non-stationary scatterers and to classify their behaviour. [J248]

"Signal-to-clutter ratio enhancement in bistatic very high frequency (VHF)-band SAR images of truck vehicles in forested and urban terrain"

Multiple scattering is often a dominating scattering mechanism in VHF-band SAR, in particular in scenes including forested and urban terrain. Most important in this context is multiple scattering generated by double- or triple-bounce scattering from structures with orthogonal corners which often dominate for monostatic SAR geometries. Examples include double-bounce scattering from vertical tree stems or building walls on horizontal ground. In such situations, bistatic SAR may offer a significant advantage compared to monostatic SAR by choosing a suitable bistatic imaging geometry. We give experimental results which show increased signal-to-clutter ratio in bistatic VHF-based SAR (28-73 MHz). Results show that the signal-to-clutter ratio of a vehicle truck in a background of forest and urban clutter increases by up to 10 dB when the broadside bistatic elevation angle increases from 4 to 20Г‚В°. The results indicate that significant improvement in detection performance can be expected for vehicle-sized objects in forest and urban terrain by using bistatic geometries in VHF-band SAR.

[J249]

"Bistatic SAR experiment with the Ingara imaging radar"

Synthetic aperture radar (SAR) operation in a bistatic configuration not only offers various advantages over its now well-established monostatic counterpart but also poses various challenges. As part of a research programme into the potential benefits and challenges of bistatic SAR, the Ingarafully polarimetric X-band airborne imaging radar system, developed and operated by the Australian Defence Science and Technology Organisation, was upgraded to conduct experimental SAR data collections in a bistatic geometry. Initial trials of the new bistatic SAR system were conducted between December 2007 and April 2008: these involved operation of the existing airborne radar in a fine-resolution (600 MHz bandwidth) circular spotlight-SAR mode, in conjunction with a newly developed fully polarimetric stationary ground-based bistatic receiver. These experimental trials produced a set of fully polarimetric simultaneously collected monostatic and bistatic SAR data, collected over a wide range of bistatic angles. Results from a preliminary analysis of the data have been encouraging: focussed fine-resolution imagery has been obtained, indicating the successful maintenance of synchronisation and phase stability between the independent airborne and ground-based systems. Furthermore, interferometric coherence has been demonstrated between single-pass simultaneously collected monostatic and bistatic images from the airborne and ground-based receivers, and between repeat-pass bistatic images from the ground-based receiver collected some 100 min apart. This study gives an overview of the Ingarabistatic SAR system, discusses the experiments and data processing and presents initial experimental results. [J250]

"Tomographic SAR Inversion by -Norm Regularization-The Compressive Sensing Approach"

Synthetic aperture radar (SAR) tomography (TomoSAR) extends the synthetic aperture principle into the elevation direction for 3-D imaging. The resolution in the elevation direction depends on the size of the elevation aperture, i.e., on the spread of orbit tracks. Since the orbits of modern meter-resolution spaceborne SAR systems, like TerraSAR-X, are tightly controlled, the tomographic elevation resolution is at least an order of magnitude lower than in range and azimuth. Hence, super-resolution reconstruction algorithms are desired. The high anisotropy of the 3-D tomographic resolution element renders the signals sparse in the elevation direction; only a few pointlike reflections are expected per azimuth-range cell. This property suggests using compressive sensing (CS) methods for tomographic reconstruction. This paper presents the theory of 4-D (differential, i.e., space-time) CS TomoSAR and compares it with parametric (nonlinear least squares) and nonparametric (singular value decomposition) reconstruction methods. Super-resolution properties and point localization accuracies are demonstrated using simulations and real data. A CS reconstruction of a building complex from TerraSAR-X spotlight data is presented. [J251]

"Estimating Surface Water Speeds With a Single-Phase Center SAR Versus an Along-Track Interferometric SAR"

Synthetic aperture radar (SAR) single-aperture systems are designed to image fixed scenes. Dual-antenna along-track interferometric (ATI) SAR systems are designed to detect moving targets and estimate their motion parameters. Although SAR systems are not designed to characterize moving targets, for localized targets, such as vehicles or ships, this problem has been addressed in the literature with some success. Distributed moving targets are hard to characterize, even for ATI systems. Estimating surface water speeds is an ideal example of this since the water returns are generated from weak returns randomly distributed in both time and space. The question asked here is can one measure surface water speeds with a single-phase center SAR system? The answer presented is a qualified yes, with the aid of an upper bound on the water speed, but not with the same accuracy as an ATI system. This upper bound and the collection geometry provide design criteria for the filtering of the phase information. Time-frequency (TF) methods provide another speed estimate as well as a rough profile of the speed across the water channel. A robust nonparametric TF method was developed and applied to estimate the speed. Comparisons between the ATI estimate and single-phase estimates are made using data from an X-band ATI-SAR system. [J252]

"Along-track interferometric sar imaging based on distributed compressed sensing"

For synthetic aperture radar (SAR), imaging based on compressed sensing (CS) can reconstruct the target scene with a reduced number of collected samples. But for a multi-channel along-track interferometric (ATI) SAR, the number of samples required could also be huge even though the CS processing is adopted. In this reported work, distributed compressed sensing (DCS) is introduced into ATI SAR. The ATI SAR based on DCS can achieve good performance and requires even fewer samples than that based on CS. [J253]

"A Novel Procedure for High Resolution Radar Signature Prediction of Near Field Targets"

A novel procedure for high resolution radar scattering signature prediction of near field targets is proposed and applied to radar-target end-game electromagnetic (EM) modeling as well as hard-ware-in-the-loop (HIL) simulation. By introducing the concept of distinct wave propagation vector (DWPV), this paper develops formulations of near field version of physical optics (PO), Michaeli's equivalent edge currents (EEC) and iterative physical optics (IPO) to predict the high frequency wideband EM scattering from targets with perfect electric conducting (PEC) surfaces in the near field region. In order to characterize the variation of the near field scattering from a complex target with respect to time variant radar-target interaction by using solely one succinct radar image, an approach for two-dimensional (2-D) high resolution inverse synthetic aperture radar (ISAR) image sequence generation and synthesis is developed. Numerical results demonstrate the applicability of the proposed procedure to generate high resolution radar scattering signatures of near field targets with high fidelity. [J254]

"An End-to-End Error Model for Classification Methods Based on Temporal Change or Polarization Ratio of SAR Intensities"

This paper aims at defining the expression of the probability of error of classification methods using a synthetic aperture radar (SAR) intensity ratio as a classification feature. The two SAR intensities involved in this ratio can be measurements from different dates, polarizations, or, also possibly, frequency bands. Previous works provided a baseline expression of the probability of error addressing the two-class problem with equal a prioriclass probabilities and no calibration error. This study brings up a novel expression of the error, providing the possibility to assess the effect of class probabilities and calibration errors. An extended expression is described for the n-class problem. The effect of calibration errors such as channel gain imbalance, radiometric stability, and crosstalk is assessed in the general case. The results indicate that, for the applications under study, channel gain imbalance is usually not a decisive parameter, but radiometric stability is more critical in methods based on the temporal change. Crosstalk has a negligible effect in the case of copolarizations. The impacts of other system parameters, such as ambiguity ratio, time-lapse between repeat-pass orbits, spatial resolution, and number of looks, are illustrated through a set of assumptions on the backscattering values of the considered classes. The model is validated by comparing some of its outputs to experimental results calculated from the application of rice fields mapping methods on real data. This error model constitutes a tool for the design of future SAR missions and for the development of robust classification methods using existing SAR instruments. [J255]

"Synthetic aperture ultrasound imaging of XLPE insulation of underground power cables"

Radar meets ultrasound; this article covers a new approach to testing underground power cable insulation in a nondestructive fashion. The possibilities and future potential of the combined use of two different imaging technologies are discussed. [J256]

"Resolution Enhancement for Inversed Synthetic Aperture Radar Imaging Under Low SNR via Improved Compressive Sensing"

The theory of compressed sampling (CS) indicates that exact recovery of an unknown sparse signal can be achieved from very limited samples. For inversed synthetic aperture radar (ISAR), the image of a target is usually constructed by strong scattering centers whose number is much smaller than that of pixels of an image plane. This sparsity of the ISAR signal intrinsically paves a way to apply CS to the reconstruction of high-resolution ISAR imagery. CS-based high-resolution ISAR imaging with limited pulses is developed, and it performs well in the case of high signal-to-noise ratios. However, strong noise and clutter are usually inevitable in radar imaging, which challenges current high-resolution imaging approaches based on parametric modeling, including the CS-based approach. In this paper, we present an improved version of CS-based high-resolution imaging to overcome strong noise and clutter by combining coherent projectors and weighting with the CS optimization for ISAR image generation. Real data are used to test the robustness of the improved CS imaging compared with other current techniques. Experimental results show that the approach is capable of precise estimation of scattering centers and effective suppression of noise. [J257]

"Improved Estimators of Faraday Rotation in Spaceborne Polarimetric SAR Data"

Spaceborne polarimetric synthetic aperture radar systems operating at lower frequencies, such as P-band, are significantly affected by Faraday rotation (FR). A new set of FR estimators is derived from the off-diagonal terms in the measured covariance matrix of a distributed target. These estimators have a phase ambiguity of period, instead of /2 as for the published estimators, and this ambiguity can be completely resolved for arbitrarily large values of FR using total electron content maps derived from Global Navigation Satellite System measurements. Simulations show that one of the new estimators has particularly high resistance to system noise and channel

amplitude imbalance but greater sensitivity to channel phase imbalance than the published estimators. Hence, the expected values of residual system distortion after calibration may affect the choice of estimator. [J258]

"Radiometric, Geometric, and Image Quality Assessment of ALOS AVNIR-2 and PRISM Sensors"

The Advanced Land Observing Satellite (ALOS) was launched on January 24, 2006, by a Japan Aerospace Exploration Agency (JAXA) H-IIA launcher. It carries three remote-sensing sensors: 1) the Advanced Visible and Near-Infrared Radiometer type 2 (AVNIR-2); 2) the Panchromatic Remote-Sensing Instrument for Stereo Mapping (PRISM); and 3) the Phased-Array type L-band Synthetic Aperture Radar (PALSAR). Within the framework of ALOS Data European Node, as part of the European Space Agency (ESA), the European Space Research Institute worked alongside JAXA to provide contributions to the ALOS commissioning phase plan. This paper summarizes the strategy that was adopted by ESA to define and implement a data verification plan for missions operated by external agencies; these missions are classified by the ESA as third-party missions. The ESA was supported in the design and execution of this plan by GAEL Consultant. The verification of ALOS optical data from PRISM and AVNIR-2 sensors was initiated 4 months after satellite launch, and a team of principal investigators assembled to provide technical expertise. This paper includes a description of the verification plan and summarizes the methodologies that were used for radiometric, geometric, and image quality assessment. The successful completion of the commissioning phase has led to the sensors being declared fit for operations. The consolidated measurements indicate that the radiometric calibration of the AVNIR-2 sensor is stable and agrees with the Landsat-7 Enhanced Thematic Mapper Plus and the Envisat MEdium-Resolution Imaging Spectrometer calibration. The geometrical accuracy of PRISM and AVNIR-2 products improved significantly and remains under control. The PRISM modulation transfer function is monitored for improved characterization. [J259]

"Automatic Target Recognition using Multipolar Bistatic Synthetic Aperture Radar Images"

Radar is a coherent sensor, which makes it suitable for the retrieval of the polarization information of the scattering process. Different algorithms have been proposed in the last few decades regarding how to analyze multipolar radar information. The extra information retrieved from the multipolar data has been shown to give more information regarding the physical features of the scatterer than the single polarization data. A few papers in the open literature have reported initial results regarding the use of monostatic multipolar data in radar-based automatic target recognition (ATR). However, a detailed report regarding the advantages of using multipolar data for ATR has not yet come in the open literature. Nor has there been any report on the use of multipolar data for bistatic radar-based ATR exercises. The work presented here deals with the task of using multipolar data for bistatic ATR A group of algorithms have been proposed and analyzed for the task of multipolar bistatic synthetic aperture radar (SAR) ATR Most of these algorithms are the contributions of the present work. For validating the algorithms, a simulated multipolar bistatic dataset has been used. It is also shown that using multipolar data not only improves the absolute performance of an ATR algorithm, it also makes it statistically more robust. Finally, the paper discusses a new algorithm to use multipolar data to avoid the decreased performance of an ATR algorithm that may arise from an uncalibrated bistatic multipolar radar system. [J260]

"Random Walk Approach for Wave Propagation through Atmospheric Layers for DInSAR Applications"

The accuracy and reliability of the measured differential path in satellite synthetic aperture radar (SAR) interferometry are strongly affected by the uncertainty in the estimation of the atmospheric contribution. Changes in the physical parameters of the medium, due to turbulence layers or gas concentrations, induce slight variations in the curvature of the propagation path that finally generate an overall disturbance term that is usually comparable, or even larger, than the displacement to be observed. A stochastic model for the three dimensional path field is derived by considering a plane wave propagating in a random layered medium. In the vertical direction a piecewise-linear walk, made by straight ray subpaths, is assumed, wherein the length of each path (thickness of the layer) and the number of paths are modelled as random variables. Along the horizontal plane mutual interactions among cells are defined through an interaction equation that closely resembles typical competitions in biological evolution models. The resulting parametric model is fitted with observations from the residual atmosphere, as measured after topographic removal in SAR images, and results are shown. [J261]

"Multi-Channel SAR-GMTI Method Robust to Coregistration Error of SAR Images"

High accuracy in complex images coregistration is essential in ground moving target indication (GMTI) processing of synthetic aperture radar (SAR) data, normally termed SAR-GMTI. The clutter suppression performance is proportional to the coregistration accuracy. In this correspondence, we propose a new SAR-GMTI approach, which is robust to the SAR images coregistration error. The observed clutter-plus-noise vector is built

using the neighboring pixels as the first step, thus the corresponding covariance matrix, termed as joint covariance matrix, can be estimated. The joint noise subspace is obtained by eigen-decomposing of the joint covariance matrix. The clutter is suppressed successfully by a projecting operation, i.e., a projection of the joint observed vector into the resulting joint noise subspace. The information of neighboring pixels is substantially exploited in the clutter suppression, resulting in the robustness, even at the presence of large coregistration error. Both the simulated and real multi-channel airborne data are used to validate the proposed approach. [J262]

"Estimation of Precession Parameters and Generation of ISAR Images of Ballistic Missile Targets"

The micro-motion properties of the rotational symmetry ballistic targets (BTs) are analyzed in the work presented here. A method for the estimation of precession frequency and the precession angle is proposed based on the polarization properties of the rotational symmetry ballistic targets (BTs). Compared with the traditional precession frequency estimation method, the estimated spectra of the harmonic frequencies are considerably smaller. In addition, an inverse synthetic aperture radar (ISAR) imaging technique based upon the micro-motion of BTs is proposed. The theoretical conclusions are confirmed by the application of the experimental data. [J263]

"Polarimetric SAR image fusion using nonnegative matrix factorisation and improved-RGB model"

Since different polarimetrie channels have different dynamical ranges, nonnegative matrix factorisation (NMF) is explored for fusing polarimetric SAR (PolSAR) data in a single colour image. The data of the three polarimetric channels (HH, HV and VV) with total power (TP) data is fully utilised to implement the NMF, and the choice of normalised factors for different polarimetric channels based on the same probability is applied, which produces an improved-RGB model. Combining the improved-RGB model with NMF, this approach brings in fusion images with higher spatial resolution and the power component preserved. [J264]

"nth-order multi-bit ΣΔ ADC using SAR quantiser"

An nth-order multi-bit delta-sigma (ΣΔ) analogue-to-digital converter (ADC) using a successive approximation register (SAR) quantiser is proposed. By exploiting the residue voltage of a multi-bit SAR ADC, the proposed ADC performs as an nth-order noise shaping converter with only one opamp and removes the need for a feedback multi-bit DAC. In addition, the proposed architecture is very reconfigurable and can be implemented as a bandpass ADC. [J265]

"Ground Array Calibration using Lunar InSAR Imagery"

A new technique of phase calibrating the uplink of a ground array consisting of large reflector antennas is studied. The Moon is selected as a calibration target since it falls within the array far-field and avoids the positioning error problem encountered by low-Earth orbit (LEO) calibration targets. As a distributed radar target, the Moon cannot be directly used like point targets. A planetary synthetic aperture radar (SAR) imaging technique is employed to divide the antenna footprint on the lunar surface into many small pixels. Each array element can form its own SAR image of each pixel and the phase differences (interferograms) among these images can be used to perform phase calibration. Orthogonal pseudonoise (PN) codes are used at different array elements to distinguish their signals at a common receiver. A practical design of the calibration system parameters is illustrated. In order to evaluate the performance of this calibration technique, a high-fidelity 3-D lunar surface profile and scattering model is developed. Simulation results are presented to show the effects of multi-pixel averaging, surface undulation, baseline separation, and image misregistration on the proposed calibration performance. [J266]

"Eco-Hydrological Characterization of Inland Wetlands in Africa Using L-Band SAR"

Maps describing the eco-hydrology of inland wetland systems in Africa are needed to identify and implement appropriate adaptive management plans related to land use and land cover. Many African countries lack regional baseline information on the temporal extent, distribution and characteristics of wetlands. This information is provided here in the form of maps which characterize two wetland sites of international importance in Malawi and Mozambique. Multi-temporal L-band Synthetic Aperture Radar (SAR) datasets are combined with Landsat Thematic Mapper and ASTER images, digital elevation models, and vegetation species data to provide information on wetland ecology and hydrology. These data were used as input to a hybrid, Decision Tree classifier and a Principal Components Analysis classification approach to produce maps depicting the spatial distribution of vegetation species and characterizing the wetland dynamics. The maps exhibit classification accuracies of 89% and 84% for the two sites respectively. The L-band SAR datasets have proved to be an essential information source in the production of these maps due to (i) frequent cloud cover/smoke which reduces the temporal coverage of optical data, and (ii) a systematic observation strategy and frequent image

acquisition which enables characterization of the flood dynamics at a high temporal resolution. [J267]

"Scaled Radon-Wigner Transform Imaging and Scaling of Maneuvering Target"

The use of scaled Radon-Wigner transform (RWT) imaging and simultaneous cross-range scaling is proposed for a maneuvering target using a signal model of a rotating target with uniform acceleration. Three steps are needed to realize such a process. First, the rotational parameters are calculated via the weighted linear least squares method after obtaining frequency modulation parameters of signals in multirange cells. Second, rotational parameters are used to compensate for the slow-time signals. Third, inverse synthetic aperture radar imaging of scaled RWT is implemented with cross-range scaling. Parameter substitution changes every component signal from a slanting line to a horizontal line in the time-frequency plane, and the horizontal line integral can be expressed as a cross-range profile. Compared with conventional RWT imaging methods, this algorithm improves calculation speed greatly and provides more stable imaging performance. This method was tested successfully with simulated and experimental radar data. [J268]

"Estimation of wall parameters by exploiting correlation of echoes in time domain"

Compensation of the effects of wall on through-the-wall synthetic aperture radar (SAR) imaging is a main concern. Wall parameters are essential for the compensation, which are normally not known a priori. After analysis of echo configuration characteristics in time domain, a new procedure for estimating wall parameters is proposed, which is based on the idea of exploiting the correlation between the measured returns reflected from the wall and the corresponding estimates calculated from a SAR return model of the wall together with electromagnetic theory. The new approach deals with echo data without imaging or localisation processing, and has a less resolution requirement. [J269]

"Using ALOS/PALSAR and RADARSAT-2 to Map Land Cover and Seasonal Inundation in the Brazilian Pantanal"

The Brazilian Pantanal is a large continuous tropical wetland with large biodiversity and many threatened habitats. The interplay between the distribution of vegetation, the hydrology, the climate and the geomorphology nourishes and sustains the large diversity of flora and fauna in this wetland, but it is poorly understood at the scale of the entire Pantanal. This study uses multi-temporal L-band ALOS/PALSAR and C-band RADARSAT-2 data to map ecosystems and create spatial-temporal maps of flood dynamics in the Brazilian Pantanal. First, an understanding of the backscattering characteristics of floodable and non-floodable habitats was developed. Second, a Level 1 object-based image analysis (OBIA) classification defining Forest, Savanna, Grasslands/Agriculture, Aquatic Vegetation and Open Water cover types was achieved with accuracy results of 81%. A Level 2 classification separating Flooded from Non-Flooded regions for five temporal periods over one year was also accomplished, showing the interannual variability among sub-regions in the Pantanal. Cross-sensor, multi-temporal SAR data was found to be useful in mapping both land cover and flood patterns in wetland areas. The generated maps will be a valuable asset for defining habitats required to conserve the Pantanal biodiversity and to mitigate the impacts of human development in the region. [J270]

"An Evaluation of the ALOS PALSAR L-Band Backscatter-Above Ground Biomass Relationship Queensland, Australia: Impacts of Surface Moisture Condition and Vegetation Structure"

Focusing on woody vegetation in Queensland, Australia, the study aimed to establish whether the relationship between Advanced Land Observing Satellite (ALOS) Phased Array L-band SAR (PALSAR) HH and HV backscattering coefficients and above ground biomass (AGB) was consistent within and between structural formations (forests, woodlands and open woodlands, including scrub). Across these formations, 2781 plot-based measurements (from 1139 sites) of tree diameters by species were collated, from which AGB was estimated using generic allometric equations. For Queensland, PALSAR fine beam dual (FBD) 50 m strip data for 2007 were provided through the Japanese Space Exploration Agency's (JAXA) Kyoto and Carbon (K&C) Initiative, with up to 3 acquisitions available for each Reference System for Planning (RSP) paths. When individual strips acquired over Queensland were combined, `banding' was evident within the resulting mosaics, with this attributed to enhanced L-band backscatter following rainfall events in some areas. Reference to Advanced Microwave Scanning Radiometer-EOS (AMSR-E) data indicated that strips with enhanced L-band backscatter corresponded to areas with increased effective vegetation water content (kg m-2) and, to a lesser extent, soil moisture (g cm-3). Regardless of moisture conditions, L-band HV topographically normalized backscattering intensities backscatter (σfo) increased asymptotically with AGB, with the saturation level being greatest for forests and least for open woodlands. However, under conditions of relative maximum surface moisture, L-band HV and HH σfowas enhanced by as much as 2.5 and 4.0 dB respectively, particularly for forests of lower AGB, with this resulting in an overall reduction in dynamic range. The saturation level also reduced at L-band HH for

forests and woodlands but remained similar for open woodlands. Differences in the rate of increase in bo--th L-band HH and HV σfowith AGB were observed between forests and the woodland categories (for both relatively wet and dry conditions) with these attributed, in part, to differences in the size class distribution and stem density between non-remnant (secondary) forests and remnant woodlands of lower AGB. The study concludes that PALSAR data acquired when surface moisture and rainfall are minimal allow better estimation of the AGB of woody vegetation and that retrieval algorithms ideally need to consider differences in surface moisture conditions and vegetation structure. [J271]

"Multichannel SAR With Reflector Antenna for High-Resolution Wide-Swath Imaging"

To overcome the inherent limitation between high azimuth resolution and wide swath in the conventional one-channel synthetic aperture radar (SAR) system, a large receiving planner antenna, which is split into multiple subapertures in both azimuth and elevation, is usually adopted. However, such a system has high system implementation complexity and requires azimuth signal reconstruction under nonuniform sampling condition. To reduce the complexity of the SAR system and processing algorithm, a reflector antenna is adopted in the spaceborne multichannel SAR system presented in this letter for high-resolution wide-swath (HRWS) imaging. According to the special characteristics of reflector antenna, a modified single-phase-center (SPC) technique is presented. The system configuration and imaging scheme are described in detail. A typical spaceborne SAR example with a reflector antenna for HRWS imaging is designed, and its performances are analyzed. Simulation results denote that the presented SAR system shows satisfactory performances with lower data rate, system load, and implementation complexity. [J272]

"PALSAR Wide-Area Mapping of Borneo: Methodology and Map Validation"

This paper describes the operational radar mapping processing chain developed and steps taken to produce a provisional wide-area PALSAR forest and land cover map covering Borneo for the year 2007, compliant with emerging international standards (CEOS guidelines, FAO LCCS). A Bayesian approach based on (unsupervised) mixture modeling followed by Markov Random Field (MRF) classification has been selected for its suitability and flexibility to deal with a situation where ground truth is sparse and sometimes ambiguous. The methodology is based on the classification of Fine Beam Single (FBS) and Fine Beam Dual (FBD) polarization (path) image pairs. To cover Borneo the equivalent of 554 standard images is required. Qualitative and quantitative validation results and findings are reported. The final overall accuracy assessment result shows the demonstration map product is in 85.5% full agreement with the independent reference dataset and in 7.8% 'partial agreement'. The accuracy achieved is widely considered adequate, a very promising result for a sub-continental high resolution map based on just single-year radar data. Approaches for further improvement of the accuracy of less accurately classified thematic classes such as grassland, cropland and shrubland are suggested. This work has been undertaken in part within the framework of the ALOS Kyoto & Carbon Initiative. [J273]

"Ortho-Rectification and Slope Correction of SAR Data Using DEM and Its Accuracy Evaluation"

This paper proposes an accurate ortho-rectification and slope correction method for Synthetic Aperture Radar (SAR) images using a digital elevation model (DEM). Since SAR observation is performed in the squint condition, the image is distorted both geometrically and radiometrically (e.g., through foreshortening, range and azimuth shift, layover, radiometric modulation associated with slope, and shadowing). Furthermore, the pixel height cannot be retrieved directly even when orbital data are accurate. The proposed method calculates the geometric and radiometric distortion components from a comparative process between the DEM-based Simulated SAR Image (DSSI) and the SAR slant range image. When applied to Advanced Land Observing Satellite (ALOS) Phased Array Type L-band SAR (PALSAR) data, the geometric accuracy of the ortho-rectified SAR image at the off-nadir angle of 34.3° was high, with a Root Mean Square Error (RMSE) of 11.9 m when evaluated against Ground Control Points (GCPs) deployed globally. The slope correction effectively reduced the radiometric variation caused by the terrain height variation. The proposed method can be applied to a range of SAR data to support a diversity of applications. [J274]

"The Kyoto & Carbon Initiative-A Brief Summary"

The Kyoto & Carbon (K&C) Initiative is an international collaboration led by the Japan Aerospace Exploration Agency (JAXA) that revolves primarily around the Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band SAR (PALSAR). The Initiative builds on the experience gained from the Global Rain Forest Mapping (GRFM) and Global Boreal Forest Mapping (GBFM) projects [1], [2], in which SAR data from the Japanese Earth Resources Satellite (JERS-1) were used to generate consistent image mosaics over the entire tropical and boreal zones of Earth. While the GRFM and GBFM projects were undertaken already in the mid 1990s, they demonstrated the utility of L-band SAR data for mapping and monitoring forest and wetland areas and the

importance of providing spatially and temporally consistent satellite acquisitions for regional-scale monitoring and surveillance. [J275]

"Generating Large-Scale High-Quality SAR Mosaic Datasets: Application to PALSAR Data for Global Monitoring"

This paper proposes a mosaicking algorithm to produce large-scale radiometrically and geometrically calibrated Synthetic Aperture Radar (SAR) datasets as a base for environmental monitoring of terrestrial biospheric and cryospheric changes. Features of the proposed method are thematic inclusion of a) long-strip processing of the SAR data, b) ortho-rectification and slope correction using a digital elevation model, c) suppression of differences in intensity between neighboring strips, and d) preparation of metadata (e.g., dates from launch, local incidence angle, radar shadow, layover, and valid/invalid data) to support dataset interpretation. The performance of the proposed method is evaluated using Advanced Land Observing Satellite (ALOS) Phased Array type L-band SAR (PALSAR) mosaics for Southeast Asia, Australia, and Africa. [J276]

"Facet Model of Moving Targets for ISAR Imaging and Radar Back-Scattering Simulation"

A facet model of targets is proposed to simulate inverse synthetic aperture radar (ISAR) images and radar back-scattering of moving targets with rigid and nonrigid motions. Targets are composed of solid objects which are modeled by triangular facets. It is shown that a facet can be treated as an equivalent point-scatterer whose radar cross section (RCS) and position depend on the shape of the triangle, the frequency, and the angle of incidence. A shadowing algorithm is also developed to detect the facets which actually have influence on the signal received by the radar. Besides, a facet division algorithm is implemented to improve the result of the shadowing algorithm and to have at least one facet per resolution cell. Finally, we apply our simulator to obtain the ISAR images of a ship and a helicopter and to calculate the micro-Doppler signature of a human. [J277]

"Estimation Method for InSAR Interferometric Phase Based on Generalized Correlation Steering Vector"

We propose a new method, based on the generalized correlation steering vector, to estimate synthetic aperture radar interferometry (InSAR) interferometric phase. In this method the generalized correlation steering vector with a large coregistration error is determined according to the joint data vector. The generalized correlation steering vector is then used to estimate the InSAR interferometric phase. The method can simultaneously auto-coregister the synthetic aperture radar (SAR) images and reduce the interferometric phase noise. Theoretical analysis and computer simulation results show that the method can provide an accurate estimate of the terrain interferometric phase (interferogram), even if the coregistration error reaches one pixel. [J278]

"ISAR imaging of multiple targets using particle imaging of multiple targets using particle swarm optimisation-adaptive joint time frequency approach"

When multiple radar targets are close to each other, the returned signals from these targets are overlapped in time. Therefore by applying conventional motion compensation algorithms designed for single target, the multiple targets cannot be resolved, and individual one cannot be clearly imaged. The authors conclude that whether the radar transmits linear frequency modulated (LFM) or stepped-frequency waveform, the chirp rate in the Doppler frequency shift induced by the translation motion is only concerned with the acceleration of the target. For different targets, the chirp rates are different from each other. Based on the different chirp rates, the signals from each target can be separated. Then a new algorithm based on the adaptive joint time frequency (AJTF) technique is proposed to separate the signals from different target in each cross-range cell. The use of the particle swarm optimisation (PSO) for multiple targets separation is a unique application of this evolutionary search. By the CLEAN technique, the number of targets need not be appointed. The simulation results confirm the efficiency of the proposed algorithm for multiple moving targets imaging. [J279]

"Focusing inverse synthetic aperture radar images with higher-order motion error using the adaptive joint-time-frequency algorithm optimised with the genetic algorithm and the particle swarm optimisation algorithm-comparison and results"

Algorithms based on the genetic algorithm (GA) and the particle swarm optimisation (PSO) algorithm were designed for focusing inverse synthetic aperture radar (ISAR) images that suffered from degradation because of Doppler smearing. These algorithms optimised the adaptive joint-time-frequency (AJTF) algorithm by replacing the exhaustive search as the primary search tool used to determine focusing parameters. The use of the PSO for ISAR image focusing is a unique application of this evolutionary search. Performance of the GA and the PSO were compared with the PSO producing the optimal results of being able to focus a 211pulse ISAR image with

second-order motion error in 9 s or 24 of the cost function calculations required for an exhaustive search. The PSO algorithm was then applied to a 211pulse ISAR image with fourth-order motion error. The PSO algorithm was able to focus this image in 20 s with 33 of the cost function calculations required by the exhaustive search. This study also introduces a new method of determining basis function suitability using the fast Fourier transform. [J280]

"Ultrawideband Synthetic Aperture Radar Unexploded Ordnance Detection"

Airborne ultrawideband (UWB) synthetic aperture radar (SAR) can perform wide-area detection of unexploded ordnance (UXO) to locate former bombing ranges efficiently. Two main issues in UWB SAR UXO detection, feature extraction, and discriminator design are considered. A space-wavenumber distribution and moment invariants-based method is proposed to extract the multi-aspect feature of UXO with both amplitude and spatial distribution information. Based on the extracted feature, a support vector machine (SVM) with hypersphere classification boundary, referred to as HS-SVM, is used as the UXO discriminator, which can be trained with a small training set of only UXO samples. Furthermore, the problem of HS-SVM kernel choice is studied, and the hidden Markov model (HMM) kernel is proved to be better than the Gaussian kernel. The efficiency of the proposed feature extraction method and the HMM kernel HS-SVM is validated using real data collected by a UWB SAR system. [J281]

"Synthetic Aperture Radar for Earth Observation from a Lunar Base: Performance and Potential Applications"

Starting from the reborn international interest in lunar exploration and the widely documented need for hyper-accurate measurements of Earth crustal dynamics, at a high revisit frequency and on a global scale, the idea of a Moon-based interferometric synthetic aperture radar (SAR) is presented. After introducing models to describe synthetic antenna formation and discussing key issues of a Moon-based radar for Earth remote sensing, a preliminary system design and performance analysis are conducted. Quantitative results are presented in terms of achievable resolutions and needed radar parameters. Although the Moon-based observatory requires technical solutions and a budget that likely make its realization distant, a comparison with currently planned spaceborne interferometric systems shows that it offers height measurement accuracies at a level and with a frequency not achievable otherwise. [J282]

"Frequency-Domain Bistatic SAR Processing for Spaceborne/Airborne Configuration"

This paper focuses on the bistatic synthetic aperture radar (BiSAR) signal processing in the spaceborne/airborne configuration. Due to the extreme differences in platform velocities and slant ranges, the airborne system operates in the inverse sliding spotlight mode, while the spaceborne system works in the sliding spotlight mode to achieve a tradeoff between the azimuth scene size and azimuth resolution. Such a mode is generally called double sliding spotlight mode. In this configuration, the echoed signal has two characteristics. Firstly, both transmitter and receiver have very short synthetic aperture times. Secondly, the airborne platform operates with wide squint difference, while the spaceborne platform works in the small squint case. According to these two features, we use different Taylor expansions to address the slant range histories of transmitter and receiver. Based on the presented model, a two-dimensional space-variant bistatic point target reference spectrum (BPTRS) is derived. Furthermore, we linearize the BPTRS to derive the transfer function of the baseband scene. From the transfer function, the signal features of the spaceborne/airborne configuration become very clear. Using the transfer function, the two-dimensional inverse scaled Fourier transform (ISFT) is used to focus the bistatic signal in the spaceborne/airborne configuration. [J283]

"SAR Imaging with Noise Radar"

Two ground-based coherent imaging systems designed on the basis of noise radar technology (NRT) using continuous waveform with a linear synthetic aperture and pulse coherent noise waveform with a circular synthetic aperture are presented. A short description of noise waveform synthetic aperture radar (SAR) theory and data processing algorithms are given. Experimental results obtained show that the quality of the imagery is comparable to that of frequency-modulation continuous-wave (FMCW) or stepped frequency radar systems. Experimental validation of the technique at different locations provides confidence in the ability of noise waveform SAR to achieve high-resolution imaging at low cost. The exploitation of the interferometric phase combining pairs of images spaced in time is shown to allow the detection of displacements in the scene with a submillimeter accuracy. [J284]

"Two-dimensional hermite S-method for high-resolution inverse synthetic aperture radar imaging applications"

The two-dimensional multiwindow S-method for radar imaging applications is proposed. It represents a combined technique that uses the standard S-method and the multiple windows approach based on the two-dimensional Hermite functions. The proposed method provides significant improvement of radar image concentration in comparison with the standard S-method. Also, it does not require an additional post-processing algorithm. The efficiency of the proposed method is demonstrated through various examples. [J285]

"An Efficient Slope-Deterministic Facet Model for SAR Imagery Simulation of Marine Scene"

An efficient slope-deterministic facet model for the computation of the radar scattering cross section from electrically large sea surface is presented. As a facet-based theory, it is a more comprehensive model which can adequately reflect the specular and diffuse configurations, as well as the mono- and bistatic features. Significant computational efficiency and good agreement with experimental data are observed, which make the proposed facet model well suitable for fast simulation on ocean synthetic aperture radar (SAR) imagery. Base on the facet model, a hybrid scheme is developed to analyze the high frequency composite scattering from the model of a ship at sea, in which the method of equivalent currents (MEC) and a hybrid frame which combines the four path model with the quasi-image method are employed to investigate the scattering characteristics of large ship-like target and its interactions with sea surface respectively. Finally, applications to SAR imagery simulation of marine scene are discussed with the help of the proposed sea and ship-sea scattering mechanism in detail. [J286]

"Sentinel-1 radar mission: Status and performance"

The ESA Sentinels constitute the first series of operational satellites responding to the Earth Observation needs of the EU-ESA Global Monitoring for Environment and Security (GMES) programme. The GMES space component relies on existing and planned space assets as well as on new complementary developments by ESA. This describes the Sentinel-1 mission, as imaging synthetic aperture radar (SAR) satellite constellation at C-band. It provides an overview of mission requirements, its applications and the technical concepts for the system. [J287]

"Wavefront curvature correction in one stationary bistatic SAR image focused via PFA"

The wavefront curvature error in one stationary bistatic synthetic aperture radar (SAR) image focused via the polar format algorithm (PFA) is analysed and a space-variant filtering method for wavefront curvature correction is proposed. The correction method presented, extends the focused scene size when using the bistatic PFA effectively. Point target simulation validates the filtering method. [J288]

"Backscattering and Statistical Information Fusion for Urban Area Mapping Using TerraSAR-X Data"

With the launch of the German TerraSAR-X system, a new generation of high-resolution spaceborne SAR data is available. This opens new perspectives and challenges for the automatic interpretation of urban environments. In fact, a rich information content, previously hidden or not clearly distinguishable in low resolution images such as urban structures (small buildings, vehicles, etc), is now disclosed. However, only proper approaches are able to retrieve automatically this new detailed information. This paper provides solutions for the semi-automatic interpretation and mapping of urban areas using the high resolution provided by TerraSAR-X data. Our solutions take into the increase, with the high resolution, of the visibility of some man-made structures whose scattering response has improved with the high frequency X-band SAR sensor carried by the TerraSAR-X system. They are mainly based on two steps. Firstly, we extract and describe two kinds of information: backscattering and statistical. Secondly, we propose to use information fusion techniques where intelligence has been introduced and enhanced in the way the different information is processed or treated, so that accurate mapping of urban areas could be reached. This mapping is performed through semantic categorization and retrieval of the different scene contents. Promising improvements and real progress toward automatic urban area mapping have been achieved using TerraSAR-X data. [J289]

"Inverse synthetic aperture radar image focusing using fast adaptive joint time-frequency and three-dimensional motion detection on experimental radar data"

This study presents two algorithms for enhancing the capabilities of the adaptive joint time-frequency (AJTF) approach and the three-dimensional (3D) motion detection method, respectively, on inverse synthetic aperture radar (ISAR) imaging. The first method is a modified AJTF motion compensation algorithm that is able to employ more than two prominent point scatterers for translation and rotation motion compensation, respectively. The second algorithm enhances a current 3D motion detection method. This algorithm improves the computation time for identifying 3D motion in ISAR images and selects the imaging time intervals with the least 3D motion. With

these enhanced detection algorithms, the authors have the ability to distinguish the time intervals when the target undergoes smooth two-dimensional (2D) motion from those containing more chaotic 3D motion. As a result, the authors can reliably detect those time intervals where 2D target motions are predominant to form well-focused ISAR images that are used in automatic target recognition applications. [J290]

"Cubic-phase function evaluation for multicomponent signals with application to SAR imaging"

A cubic-phase function evaluation technique for multicomponent frequency-modulated signals with non-overlapped components in the time-frequency (TF) plane is proposed. The proposed technique is based on the short-time Fourier transform. Cross-terms are removed or reduced in the same manner as in the case of the TF representation called the S-method. The proposed technique is applied for visualisation of signals in time-chirp-rate plane and parameter estimation of analytical and radar signals. In addition, a procedure for focusing SAR images by using estimated parameters is proposed in order to verify obtained results. [J291]

"Mapping Subsurface Geology in Sahara Using L-Band SAR: First Results From the ALOS/PALSAR Imaging Radar"

Within the framework of Kyoto & Carbon Initiative of the Japanese Space Agency (JAXA), we used JERS-1 and ALOS/PALSAR radar images to build regional and continental scale mosaics of Sahara. The unique capability of L-band SAR to map subsurface structures in arid areas revealed previously unknown geological features: craters, faults, paleo-rivers. The latter are of particular interest for water resource detection in arid regions. [J292]

"Estimating surface water flow speeds using time-frequency methods"

Synthetic aperture radar (SAR) image formation implicitly assumes that the backscattered returns arise from stationary isotropic targets. When objects move during the SAR integration time, signal anomalies appear that distort, displace and smear moving targets in the image. Although these anomalies degrade the image, they provide the information that allows analysis of the underlying target motion. Joint time-frequency analysis (JTFA) exploits these signal anomalies to estimate the motion of typical point targets. However, the weak, transient returns from water surface scatterers complicate standard JTFA estimates of water surface speeds. A time-frequency representation is applied based on the Capon-s spectral estimation technique that allows joint analysis of multiple azimuth lines, thereby increasing the signal-to-clutter ratio of weak scatterers. The authors compare the time-frequency estimate, employing single-phase-centre SAR data, to along-track interferometric SAR estimates of the same flow and show that both the methods produce comparable results. The authors derive the JTFA equations and estimate water surface speed for data collected at a specific imaging geometry. This study highlights the feasibility of using a single-phase-centre SAR system to determine the motion of slow moving distributed targets representative of water flow. [J293]

"Coherence improving algorithm for airborne multichannel SAR-GMTI"

The study develops an algorithm to improve coherence for the multichannel airborne along-track synthetic aperture radar (SAR), which can be used for ground moving target indication (GMTI) by comparing two SAR images obtained from different channels. The turbulent aircraft motion, beam pattern difference and frequency response difference that may degrade the coherence are discussed in detail. The aircraft motion error is firstly estimated and corrected based on the range compressed data. After focusing on the beam pattern differences and the receive channel imbalance are compensated using the two two-dimensional (2-D) adaptive filters, the first in the range-Doppler domain and the second in the range-frequency azimuth-time domain. It is shown that using the coherence improving algorithm the coherence of SAR complex image pairs can be improved greatly. The effectiveness of the algorithm is demonstrated with real data acquired by a Chinese X-band multichannel airborne SAR-GMTI system. [J294]

"An Impulse Response Function for Evaluation of UWB SAR Imaging"

Based on analysis of a point target imaged by different synthetic aperture radar (SAR) systems, the commonly used impulse response function in SAR Imaging (IRF-SAR)-a two-dimensional (2-D) sincfunction-is shown to be inappropriate for ultrawideband-ultrawidebeam (UWB) SAR systems utilizing a large fractional signal bandwidth and a wide antenna beamwidth. As a consequence, the applications of the 2-D sincfunction such as image quality measurements and spatial resolution estimations are limited to narrowband-narrowbeam (NB) SAR systems exploiting a small fractional signal bandwidth and a narrow antenna beamwidth. In this paper, a more general IRF-SAR, which aims at UWB SAR systems, is derived with an assumption of flat two-dimensional (2-D) Fourier transform (FT) of a SAR image and called IRF-USAR. However, the derived IRF-USAR is also valid for NB SAR systems. [J295]

"Decorrelation of L-Band and C-Band Interferometry Over Vegetated Areas in California"

Temporal decorrelation is one of the main limitations for recovering interseismic deformation along the San Andreas Fault system using interferometric synthetic aperture radar. To assess the improved correlation properties of L-band with respect to C-band, we analyzed L-band Advanced Land Observation Satellite (ALOS) interferograms with a range of temporal and spatial baselines over three vegetated areas in California and compared them with corresponding C-band European Remote Sensing Satellite (ERS) interferograms. Over the highly vegetated Northern California forests in the Coast Range area, ALOS remains remarkably well correlated over a 2-year period, whereas an ERS interferogram with a similar temporal and spatial baseline lost correlation. In Central California near Parkfield, we found a similar pattern in decorrelation behavior, which enabled the recovery of a fault creep and a local uplifting signal at L-band that was not apparent at C-band. In the Imperial Valley in Southern California, both ALOS and ERS have low correlation over farmlands. ALOS has lower correlation over some sandy surfaces than ERS, probably due to low signal-to-noise ratio. In general, L-band interferograms with similar seasonal acquisitions have higher correlation than those with dissimilar season. For both L- and C-band, correlation over vegetated areas decreases with time for intervals less than 1 year and then remains relatively constant at longer time intervals. The decorrelation time for L-band is more than 2 years in the forest in California whereas that for C-band is less than 6 months. Overall, these results suggest that L-band interferograms will reveal near-fault interseismic deformation once sufficient data become available. [J296]

"Antenna Directing Synchronization for Bistatic Synthetic Aperture Radar Systems"

Bistatic synthetic aperture radar (BiSAR) operates with a separate transmitter and receiver that are mounted on separate platforms. This spatial separation provides several operational advantages like reduced vulnerability for military applications and increased radar cross section. However, efficient spatial synchronization (antenna direction synchronization), time synchronization, and phase synchronization must be ensured for BiSAR systems. A literary search reveals that BiSAR synchronization, especially spatial synchronization, is still a technical challenge, and little work has been reported. As such, the impact of antenna directing synchronization errors including range dimension and azimuth dimension are analyzed with statistical models. Simulation results show that efficient spatial synchronization compensation is required for BiSAR high-resolution imaging. Hence, an antenna directing synchronization approach with multi-antenna on receive is proposed. [J297]

"Potentials and Limitations of Moon-Borne SAR Imaging"

Moon exploitation is among the next space mission priorities. Earth observation (EO), which is traditionally implemented on artificial lower Earth orbit satellites, can be, in principle, extended to the platform constituted by the natural Earth satellite. With this regard, we investigate the features related to the EO by a possible Moon-borne synthetic aperture radar system in terms of imaging characteristics and potential applications, as well as of expected limitations. [J298]

"On the Role of Phase Stability in SAR Multibaseline Applications"

This paper is meant to present a statistical analysis of the role of propagation disturbances (PDs), such as those due to atmospheric disturbances or to residual platform motion, in multibaseline synthetic aperture radar (SAR) interferometry (InSAR) and tomography (T-SAR) applications. The analysis will consider both pointlike and distributed targets in such a way as to cover all the cases that are relevant in the applications. In order to provide a tool for the evaluation of the impact of PDs on the analysis of an arbitrary scenario, a definition of signal-to-noise ratio (SNR) will be introduced that accounts for both the presence of PDs and the characteristics of the imaged scene. In the case of pointlike targets, it will be shown that such definition of SNR allows reusing well known results following after the Neyman-Pearson theory, thus providing a straightforward tool to asses phase-stability requirements for the detection and localization of multiple pointlike targets. In the case of distributed targets, instead, it will be provided a detailed analysis of the random fluctuations of the reconstructed scene as a function of the extent of the PDs, of the vertical structure of the imaged scene, and of the number of looks that are employed. Results from Monte Carlo simulations will be presented that fully support the theoretical developments within this paper. The most relevant conclusion of this paper is that the impact of PDs is more severe in the case where the imaged scene is characterized by a complex vertical structure or when multiple pointlike targets are present. As a consequence, it follows that the T-SAR analyses require either a higher phase stability or a more accurate phase calibration with respect to InSAR analyses. Finally, an example of phase-stability analysis and phase calibration of a real data set will be shown, based on a P-band data set relative to the forest site of Remningstorp, Sweden. [J299]

"UAV flight plan optimzed for sensor requirements"

To achieve surveillance missions at a safe distance, the UAV surveillance radar shall provide Synthetic Aperture Radar (SAR) images and also SIGINT and EO/IR payloads. This presents the flight plans generated for these UAV by new generation technologies (genetic algorithms) respecting the constraints of uses of the sensors (angles, distances of recording), the UAV performances (load factor in bend, height of cruise, speed of maximal stamina) as well as the environment of the theatre of operation (relief, meteorology, and restricted zones). [J300]

"Two Novel Bayesian Multiscale Approaches for Speckle Suppression in SAR Images"

Speckle suppression is a prerequisite for many synthetic aperture radar (SAR) image-processing tasks. Previously, we introduced a Bayesian-based speckle-suppression method that employed the 2-D generalized autoregressive conditional heteroscedasticity (2D-GARCH) model for wavelet coefficients of log-transformed SAR images. Based on this method, we propose two new Bayesian speckle-suppression approaches in this paper. In the first approach, we introduce a new heteroscedastic model, i.e., the 2D-GARCH Mixture (2D-GARCH-M) model, as an extension of the 2D-GARCH model. This new model can capture the characteristics of wavelet coefficients. Also, the 2D-GARCH-M model introduces additional flexibility in the model formulation in comparison with the 2D-GARCH model, which results in better characterization of SAR image subbands and improved restoration in noisy environments. Then, we design a Bayesian estimator for estimating the clean-image wavelet coefficients based on 2D-GARCH-M modeling. In the second approach, the logarithm of an image is analyzed by means of the curvelet transform instead of wavelet transform. Then, we study the statistical properties of curvelet coefficients, and we demonstrate that the 2D-GARCH model can capture the characteristics of curvelet coefficients, such as heavy tailed marginal distribution, and the dependences among them. Consequently, under the 2D-GARCH model, we design a Bayesian estimator for estimating the clean-image curvelet coefficients. Finally, we compare these methods with other denoising methods applied on artificially speckled and actual SAR images, and we verify the performance improvement in utilizing the new strategies. [J301]

"Single-Range Image Fusion for Spinning Space Debris Radar Imaging"

In this letter, a novel single-range image fusion method for radar imaging of spinning space debris with dimensions smaller than the radar range resolution is proposed. On the assumption that the target consists of isolated isotropic scattering centers, a 2-D image can be obtained using single-range unit cross-range echo data, which have a theoretical resolution of a quarter of a wavelength. The proposed approach is computationally efficient particularly for smaller sized targets, as the total rotational angle is divided into four small sections, allowing for easier processing of each region. Moreover, the proposed method can be used to directly obtain an image in Cartesian coordinates, unlike current algorithms where images are obtained in a polar format, requiring reformatting to the Cartesian grid. The validity of the proposed approach is confirmed using numerical simulations. [J302]

"Numerical Simulation of the Wind-Stress Effect on SAR Imagery of Far Wakes of Ships"

Centerline wakes of ships in synthetic aperture radar (SAR) images were modeled in 2-D with the computational fluid dynamics (CFD) software Fluent and a radar-imaging algorithm. We initialized the model with a pair of vortices generated by a ship hull and applied wind stress perpendicular to the ship wake. Results of the CFD simulation using a nonhydrostatic model have demonstrated ship-wake asymmetry with respect to the wind-stress direction relative to the ship course. Due to the wind stress, flow convergence increased on the upwind side of the centerline wake and reduced on the downwind side of the wake. The radar-imaging algorithm processed with the surface velocity field produced by the CFD model revealed ship-wake asymmetry relative to the wind direction. These results are qualitatively consistent with SAR images from the TerraSAR-X satellite and representative statistics of photographic images of the ship wake collected from a volunteer observing ship. [J303]

"A Novel Hierarchical Method of Ship Detection from Spaceborne Optical Image Based on Shape and Texture Features"

Ship detection from remote sensing imagery is very important, with a wide array of applications in areas such as fishery management, vessel traffic services, and naval warfare. This paper focuses on the issue of ship detection from spaceborne optical images (SDSOI). Although advantages of synthetic-aperture radar (SAR) result in that most of current ship detection approaches are based on SAR images, disadvantages of SAR still exist, such as the limited number of SAR sensors, the relatively long revisit cycle, and the relatively lower resolution. With the increasing number of and the resulting improvement in continuous coverage of the optical sensors, SDSOI can partly overcome the shortcomings of SAR-based approaches and should be investigated to help satisfy the requirements of real-time ship monitoring. In SDSOI, several factors such as clouds, ocean waves, and small

islands affect the performance of ship detection. This paper proposes a novel hierarchical complete and operational SDSOI approach based on shape and texture features, which is considered a sequential coarse-to-fine elimination process of false alarms. First, simple shape analysis is adopted to eliminate evident false candidates generated by image segmentation with global and local information and to extract ship candidates with missing alarms as low as possible. Second, a novel semisupervised hierarchical classification approach based on various features is presented to distinguish between ships and nonships to remove most false alarms. Besides a complete and operational SDSOI approach, the other contributions of our approach include the following three aspects: 1) it classifies ship candidates by using their class probability distributions rather than the direct extracted features; 2) the relevant classes are automatically built by the samples' appearances and their feature attribute in a semisupervised mode; and 3) besides commonly used shape and texture features, a new texture operator, i.e., loca--l multiple patterns, is introduced to enhance the representation ability of the feature set in feature extraction. Experimental results of SDSOI on a large image set captured by optical sensors from multiple satellites show that our approach is effective in distinguishing between ships and nonships, and obtains a satisfactory ship detection performance. [J304]

"Passive and Active L-Band Microwave Observations and Modeling of Ocean Surface Winds"

L-band microwave backscatter and brightness temperature of sea surfaces acquired using the Passive/Active L-band Sensor during the High Ocean Wind campaign are reported in terms of their dependence on ocean surface wind speed and direction. We find that the L-band VV, HH, and HV radar backscatter data increase by 6-7 dB from 5 to 25 m/s wind speed at a 45° incidence angle. The data suggest the validity of Phased Array type L-band Synthetic Aperture Radar (PALSAR) HH model function between 5 and 15 m/s wind speeds, but show that the extrapolation of PALSAR model at above 20 m/s wind speeds overpredicts A0and a1coefficients. There is wind direction dependence in the radar backscatter with about 4 dB differences between upwind and crosswind observations at 24 m/s wind speed for VV and HH. The passive brightness temperatures show about a 5-K change for TVand a 7-K change for THfor a wind speed increasing from 5 to 25 m/s. Circle flight data suggest a wind direction response of about 1-2 K in TVand THat 14 and 24 m/s wind speeds. The L-band microwave data show excellent linear correlation with the surface wind speed with a correlation better than 0.95. The results support the use of L-band radar data for estimating the wind-driven excess brightness temperature of sea surfaces. The data also support the applications of L-band microwave signals for high-resolution (kilometer scale) observation of ocean surface winds under high wind conditions (10-28 m/s). [J305]

"RADARSAT-2 and Coastal Applications: Surface Wind, Waterline, and Intertidal Flat Roughness"

RADARSAT-2 is a follow-up to RADARSAT-1 and is an all weather Earth observation satellite with fully polarimetric imaging capability. The synthetic aperture radars (SARs) onboard both RADARSATs are C-band imaging radars and they are well suited for Earth's ecosystem monitoring and maritime surveillance, because of the near polar orbit and their unique all weather imaging capability, independent of solar illumination. In this paper, RADARSAT-2 is first introduced and several applications of various modes of SAR data to coastal zone problems are discussed, including the coastal surface wind, waterline mapping, and polarimetric SAR data inversion for topographic and geological parameters of tidal flats. Coastal zones, the important interface between the land and the ocean, where a large proportion of the world's population inhabits, continuously change and evolve. The dynamic interaction of coastal winds, coupled with the coastal waves and currents, continuously erode rocks and land mass, and move and deposit various sediments on a continuous basis, along with the tides. Estimation of wind speeds and directions in coastal areas are empirically formulated and can further be improved with the available fully polarimetric data from RADARSAT-2. The water line mapping critically depends on the SAR frequency, or the wavelength of the SAR data used, and RADARSAT-2 SAR data using C-band should map waterlines more accurately than the longer wavelength L- or P-band SAR systems. The roughness parameters and partial information on the tidal flat compositions can be obtained from fully polarimetric SAR data. Some results obtained from NASA AIRSAR(2000) L-band data and RADARSAT-2(2008) C-band data do not fully agree with field measurements and further investigation is in progress. The inversion of polarimetric SAR data is a very complex problem and critically depends on the SAR signal frequency and model functions. RADARSAT-2 is an imaging radar, which is very flexible and powerfu--l tool for potential coastal zone applications. Key RADARSAT-2 features and potential coastal zone application capabilities are also briefly reviewed. [J306]

"Height Retrieval of Isolated Buildings From Single High-Resolution SAR Images"

Detection of man-made structures in urban areas, in terms of both geometric and electromagnetic features, from a single, possibly high resolution (HR), synthetic aperture radar (SAR) image is a highly interesting open challenge. Within this framework, a possible approach for the extraction of some relevant parameters, describing the shape and materials of a generic building, is proposed here. The approach is based on sound

electromagnetic models for the radar returns of each element of the urban scene. A fully analytical representation of electromagnetic returns from the scene constituents to an active microwave sensor is employed. Some possible applications of feature extractions from real SAR images, based on the aforementioned approach, have already been presented in the literature as first examples of potentiality of a model-based approach, but here, the overall theory is analyzed and discussed in depth, to move to general considerations about its soundness and applicability, and the efficiency of further applications may be derived. For the sake of conciseness, although the proposed approach is general and can be applied for the retrieval of different scene parameters (in principle, anyone contributing to the radar return), we focus here on the extraction of the building height, and we assume that the other parameters are either a prioriknown (e.g., electromagnetic properties of the materials) or have been previously retrieved from the same SAR image (e.g., building length and width). An analysis of the sensitiveness of the height retrieval to both model inaccuracies and errors on the knowledge of the other parameters is performed. Some simulation examples accompany and validate the solution scheme that we propose. [J307]

"An ISAR Imaging Method Based on MIMO Technique"

With the inverse synthetic aperture radar (ISAR) imaging model, targets should move smoothly during the coherent processing interval (CPI). Since the CPI is quite long, fluctuations of a target's velocity and gesture will deteriorate image quality. This paper presents a multiple-input-multiple-output (MIMO)-ISAR imaging method by combining MIMO techniques and ISAR imaging theory. By using a special M-transmitter N-receiver linear array, a group of Morthogonal phase-code modulation signals with identical bandwidth and center frequency is transmitted. With a matched filter set, every target response corresponding to the orthogonal signals can be isolated at each receiving channel, and range compression is completed simultaneously. Based on phase center approximation theory, the minimum entropy criterion is used to rearrange the echo data after the target's velocity has been estimated, and then, the azimuth imaging will finally finish. The analysis of imaging and simulation results show that the minimum CPI of the MIMO-ISAR imaging method is 1/MNof the conventional ISAR imaging method under the same azimuth-resolution condition. It means that most flying targets can satisfy the condition that targets should move smoothly during CPI; therefore, the applicability and the quality of ISAR imaging will be improved. [J308]

"Multistatic and MIMO Distributed ISAR for Enhanced Cross-Range Resolution of Rotating Targets"

In this paper, we present a new technique to exploit the data acquired simultaneously by multiple radar sensors carried by multiple air platforms to increase the cross-range resolution of inverse synthetic aperture radar (ISAR) images of rotating targets. This distributed ISAR technique is devised for two different cases: 1) multiple-input-multiple-output (MIMO) case with each platform carrying an active radar that transmits and receives RF waveforms and 2) multistatic case with a single platform carrying an active radar (transmitting and receiving) and the remaining platforms equipped with passive sensors (namely, receiving only). The processing chain proposed for the distributed ISAR is shown, together with the results obtained against simulated ISAR data for both the MIMO and the multistatic cases. The performance analysis shows that the proposed technique is able to provide an increase of the cross-range resolution up to the number of platforms in the multistatic case and even higher in the MIMO case, if the platforms are properly located. This is of great benefit in applications where the target rotation angle is insufficient to guarantee the desired resolution. A typical case is the imaging of ship targets with rotation induced by the sea swell structure under low sea state conditions. To make the results appealing for practical application, the performance degradation is also analyzed arising from errors in the knowledge of both the target rotation motion and the acquisition geometry. Experimental data collected by a ground-based radar operating together with a rotating platform are processed by following the presented distributed ISAR technique to validate the proposed approach. [J309]

"Topographic Correction for ALOS PALSAR Interferometry"

L-band synthetic aperture radar (SAR) interferometry is very successful for mapping ground deformation in densely vegetated regions. However, due to its larger wavelength, the capacity to detect slow deformation over a short period of time is limited. Stacking and small baseline subset (SBAS) techniques are routinely used to produce time series of deformation and average deformation rates by reducing the contribution of topographic and atmospheric noise. For large sets of images that are presently available from C-band European Remote Sensing Satellites (ERS-1/2) and Environmental Satellite (ENVISAT), the standard stacking and SBAS algorithms are accurate. However, the same algorithms are often inaccurate when used for processing of interferograms from L-band Advanced Land Observing Satellite Phased Array type L-band SAR (ALOS PALSAR). This happens because only a limited number of interferograms is acquired and also because of large spatial baselines often correlated with the time of acquisition. In this paper two techniques are suggested that can be used for removing

the residual topographic component from stacking and SBAS results, thereby increasing their accuracy. [J310]

"Bistatic SAR Experiments With PAMIR and TerraSAR-X-Setup, Processing, and Image Results"

The spatial separation of the transmitter and the receiver in bistatic synthetic aperture radar (SAR) enables a variety of data acquisition geometries to achieve benefits like the increased information content of bistatic SAR data. In the case of hybrid bistatic SAR constellations where the transmitter is spaceborne and the receiver is onboard an aircraft, one has to deal with a huge discrepancy between platform velocities. This paper presents bistatic spaceborne/airborne SAR experiments, where the radar satellite TerraSAR-X is used as a transmitter and the airborne SAR sensor Phased Array Multifunctional Imaging Radar (PAMIR) of the Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR) is used as a receiver. Both sensors are equipped with phased-array antennas, which offer the possibility of beam steering and could be used for the first time for the "double sliding spotlight mode." In this mode, the space- and airborne sensors operate with different sliding factors (ratio between footprint and platform velocity). The performance of two different experiments is analyzed, and the novel double sliding spotlight mode is presented. This paper describes the experimental setups, the synchronization system, and the data acquisition. The image results were processed by a modified backprojection algorithm and a frequency-domain algorithm. The analysis of the final bistatic images comprises the spatial resolution and the scattering behavior of selected objects. Parts of the bistatic SAR images are compared with the corresponding monostatic images of PAMIR and TerraSAR-X. It will be shown that hybrid bistatic SAR is a worthwhile and helpful addition to current monostatic SAR. [J311]

"Imaging of Fractal Profiles"

In this paper, a model for radar images of fractal (topologically 1-D) profiles is introduced. A twofold approach is followed: on one hand, we analytically solve the problem whenever small-slope profiles are in order; on the other hand, we present a partly analytical and partly numerical setup to cope with the general-slope case. By means of the analytical approach, we evaluate in closed form both the structure function and the power density spectrum of the radar signal. An appropriately smoothed (physical) fractional Brownian model (fBm) process is employed; its introduction is justified by the finite sensor resolution. A fractal scattering model is employed. It is shown that for a fractal profile modeled as an fBm stochastic process, the backscattered signal turns out to be strictly related to the associated fractional Gaussian noise process if a small-slope regime for the observed profile can be assumed. In the analytical-numerical framework, a profile with prescribed fractal parameters is first synthesized; then, fractal scattering methods (applicable to wider slope regimes with respect to the previous case) are employed to compute the signal backscattered toward the sensor. Finally, the power density spectrum of the acquired radar image is estimated. The obtained spectra are favorably compared with the theoretical results, and a parametric study is performed to assess the overall method behavior. [J312]

"A New Method of Deriving Spectrum for Bistatic SAR Processing"

The formulation of a point target spectrum is a key step in deriving synthetic aperture radar focusing algorithms, which exploits the processing efficiency of the frequency domain. However, the existence of a double-square root in the bistatic range equation makes it difficult to find an exact analytical solution for the 2-D spectrum. In this letter, according to the idea of function optimal approach, we derive a new 2-D point target spectrum on the basis of Legendre polynomial expansion, which is more exact than the existing spectra during the synthetic aperture time. [J313]

"MATLAB for Signal Processing on Multiprocessors and Multicores"

MATLAB is a popular choice for algorithm development in signal and image processing. While traditionally done using sequential MATLAB running on desktop systems, in recent years there has been a surge of interest in running MATLAB in parallel to take advantage of multiprocessor and multicore systems. In this article, we discuss three variations of multiprocessor parallel MATLAB, two of which are available as commercial, supported products. We also consider running MATLAB with key computations speeded up using multithreaded computations on multicore general-purpose graphical processing units (GPGPUs). Two signal processing kernels (fast Fourier transform (FFT) and convolution) and two full applications [synthetic aperture radar (SAR) imaging and superconducting quantum interference devices (SQIF)] are used to illustrate the use of parallel MATLAB. [J314]

"Synthetic Aperture Radar Processing with GPGPU"

This article focuses on methodologies with recurrent use to code examples that try to couple with the flow of the main steps of the SAR processing. The possibility to be comprehensive was prevented by the wide scenario of variations of the focusing algorithm as well as the spread of applications. The reader should look at this work as

a sample of possibilities offered by this new technology and a collection of suggestions and considerations that may guide to new applications and horizons. [J315]

"An Efficient and Flexible Statistical Model Based on Generalized Gamma Distribution for Amplitude SAR Images"

In the context of synthetic aperture radar (SAR) image processing and applications, the precise modeling of statistical knowledge is a crucial problem. In this paper, an efficient and flexible statistical model, called generalized Gamma Rayleigh (G??R) distribution, for amplitude SAR images is proposed by assuming a two-sided generalized Gamma distribution for the real and imaginary parts of the complex SAR backscattered signal. It is shown that the Rayleigh and recently proposed generalized Gaussian Rayleigh distributions can be regarded as special cases of G??R distribution. Considering that the probability density function estimation problem is formulated as a parameter estimation one for the parametric statistical analysis of SAR images, a two-stage estimator based on second-kind cumulants is derived for the parameters of G??R distribution. Furthermore, experimental results on several actual SAR images are given to demonstrate the validity and flexibility of the proposed model. [J316]

"Three-Component Model-Based Decomposition for Polarimetric SAR Data"

An improved three-component decomposition for polarimetric synthetic aperture radar (SAR) data is proposed in this paper. The reasons for the emergence of negative powers in the Freeman decomposition have been analyzed, and three corresponding improvements are included in the proposed method. First, the deorientation process is applied to the coherency matrix before it is decomposed into three scattering components. Then, the coherency matrix with the maximal polarimetric entropy, i.e., the unit matrix, is used as the new volume-scattering model instead of the original one adopted in the Freeman decomposition. A power constraint is also added to the proposed three-component decomposition. The E-SAR polarimetric data acquired over the Oberpfaffenhofen area in Germany are applied in the experiment. The results show that the pixels with negative powers are totally eliminated by the proposed decomposition, demonstrating the effectiveness of the new model. [J317]

"Remapping the world in 3D"

During the past few years, we have witnessed the explosive growth in demand for three-dimensional geospatial data and the popularization of related applications has reached levels never before imaged. Arguably, the major catalysts behind the increasing interest in geospatial information by the general public have been Internet search engines like Google, which places integrated maps into its results, and satellite imagery-based mapping software such as Google Earth and Microsoft Virtual Earth, which offer users a three-dimensional experience. [J318]

"Definition of ICESat Selection Criteria for Their Use as Height References for TanDEM-X"

The TanDEM-X satellite synthetic aperture radar (SAR) mission, which is the result of the partnership between the German Aerospace Center (DLR) and Astrium GmbH, has the goal to deliver a high-precision global digital elevation model (DEM). The X-band SAR interferometry-derived DEMs contain absolute and relative height errors that have to be minimized with the help of height references in order to achieve the specified accuracies. ICESat laser altimetry data are suited for this task, due to their accuracy and global distribution. In order to gain experience in the comparison between a radar-derived DEM and ICESat GLA14 elevation data, an X-band DEM was acquired over a test region with the experimental airborne radar system of DLR in Oberpfaffenhofen. Additionally, a laser DEM of the area was used to verify the height accuracy claimed by previously published ICESat studies over different terrain types and after applying different selection threshold criteria. The analyses described in this paper are the basis for the definition of a suitable global ICESat selection strategy and include the computation of the density of selected ICESat samples over the Earth. These aspects are crucial for a successful TanDEM-X DEM generation. [J319]

"Multichannel Azimuth Processing in ScanSAR and TOPS Mode Operation"

Due to a system-inherent limitation, conventional synthetic aperture radar (SAR) is incapable of imaging a wide swath with high geometric resolution. This restriction can be overcome by systems with multiple receive channels in combination with an additional digital signal processing network. So far, the application of such digital beamforming algorithms for high-resolution wide-swath SAR imaging has been restricted to multichannel systems in stripmap operation. However, in stripmap mode, the overall azimuth antenna length restricts the achievable swath width, thus preventing very wide swaths as requested by future SAR missions. Consequently, new concepts for ultrawide-swath imaging are needed. A promising candidate is a SAR system with multiple azimuth channels being operated in burst mode. This paper analyzes innovative ScanSAR and Terrain Observation by

Progressive Scans (TOPS) system concepts with regard to multichannel azimuth processing. For this, the theoretical analyses, performance figures, and SAR signal processing, which had previously been derived for multichannel stripmap mode, are extended to systems operating in burst modes. The investigations reveal that multichannel ScanSAR systems enable the imaging of ultrawide swaths with high azimuth resolution and compact antenna lengths. These considerations are embedded in a multichannel ScanSAR system design example to demonstrate its capability to image an ultrawide swath of 400 km with a high geometric resolution of 5 m. In a next step, this system is adapted to TOPS mode operation, including an innovative "staircase" multichannel processing approach optimized for TOPS. [J320]

"Single-Pass Bistatic SAR Interferometry Using Fixed-Receiver Configurations: Theory and Experimental Validation"

In this paper, bistatic interferometry using fixed-receiver configurations is addressed both theoretically and experimentally. The analytical expressions for interferometric phase and height sensitivity are derived, and a full interferometric processing chain for digital elevation model (DEM) generation is presented. The derived expressions are general, and they can be applied to two possible acquisition geometries: backscatteringand forward scattering. The theoretical developments are complemented with experimental results done with the bistatic receiver Synthetic Aperture radar Bistatic Receiver for INterferometric Applications. The obtained DEMs are compared with a DEM from the Shuttle Radar Topography Mission and a digital terrain model from the Institut Cartografic de Catalunya. The comparison allows one to validate the results and demonstrate to which particular features of the scene that the bistatic radar is sensitive. [J321]

"Validation of the ASAR Global Monitoring Mode Soil Moisture Product Using the NAFE'05 Data Set"

The Advanced Synthetic Aperture Radar (ASAR) Global Monitoring (GM) mode offers an opportunity for global soil moisture (SM) monitoring at much finer spatial resolution than that provided by the currently operational Advanced Microwave Scanning Radiometer for the Earth Observing System and future planned missions such as Soil Moisture and Ocean Salinity and Soil Moisture Active Passive. Considering the difficulties in modeling the complex soil-vegetation scattering mechanisms and the great need of ancillary data for microwave backscatter SM inversion, algorithms based on temporal change are currently the best method to examine SM variability. This paper evaluates the spatial sensitivity of the ASAR GM surface SM product derived using the temporal change detection methodology developed by the Vienna University of Technology. This evaluation is made for an area in southeastern Australia using data from the National Airborne Field Experiment 2005. The spatial evaluation is made using three different types of SM data (station, field, and airborne) across several different scales (1-25 km). Results confirmed the expected better agreement when using point (Rstation= 0.75) data as compared to spatial (RPLMR, 1 km= 0.4) data. While the aircraft-ASAR GM correlation values at 1-km resolution were low, they significantly improved when averaged to 5 km (RPLMR, 5 km= 0.67) or coarser. Consequently, this assessment shows the ASAR GM potential for monitoring SM when averaged to a spatial resolution of at least 5 km. [J322]

"Ship Detection Using TerraSAR-X Images in the Campos Basin (Brazil)"

The very large extent of the Brazilian coast (~8000 km) and the growing maritime vessel traffic demand that research be made on ancillary methods to monitor and control ship's traffic in national waters. An important tool for this purpose is the use of orbital synthetic aperture radar (SAR) imagery, particularly due to its ability to work day and night and to suffer almost no interference of cloud coverage. In this letter, we investigate some ship detection concepts, as applied to TerraSAR-X (TSX) ScanSAR images (16-m resolution), in VV and HH polarization. Ocean clutter statistical parameters are estimated, and the Kolmogorov-Smirnov test is used to verify the goodness of fit for the K-distribution to TSX images. A constant false alarm rate (CFAR) target detection algorithm is developed, and its performance is verified. Incidence angle, CFAR's window size, and probability of false alarm influence are further analyzed. [J323]

"Multiplicative Noise Removal Using Variable Splitting and Constrained Optimization"

Multiplicative noise (also known as speckle noise) models are central to the study of coherent imaging systems, such as synthetic aperture radar and sonar, and ultrasound and laser imaging. These models introduce two additional layers of difficulties with respect to the standard Gaussian additive noise scenario: (1) the noise is multiplied by (rather than added to) the original image; (2) the noise is not Gaussian, with Rayleigh and Gamma being commonly used densities. These two features of multiplicative noise models preclude the direct application of most state-of-the-art algorithms, which are designed for solving unconstrained optimization problems where the objective has two terms: a quadratic data term (log-likelihood), reflecting the additive and Gaussian nature of

the noise, plus a convex (possibly nonsmooth) regularizer (e.g., a total variation or wavelet-based regularizer/prior). In this paper, we address these difficulties by: (1) converting the multiplicative model into an additive one by taking logarithms, as proposed by some other authors; (2) using variable splitting to obtain an equivalent constrained problem; and (3) dealing with this optimization problem using the augmented Lagrangian framework. A set of experiments shows that the proposed method, which we name MIDAL (multiplicative image denoising by augmented Lagrangian), yields state-of-the-art results both in terms of speed and denoising performance. [J324]

"A Channel Awareness Vehicle Detector"

State-of-the-art traffic-flow-detection technology includes the use of a looped vehicle detector, an infrared detector, an image detector, and a microwave detector. However, there are limitations that are associated with each detector. In this paper, we propose a channel awareness vehicle detector that can overcome these limitations. It employs only one pair of transmitter-receiver antennas to simultaneously perform the multilane and multivehicle identifications. By using the characteristics of channel variations, the proposed vehicle detector can determine the vehicle location, speed, and type. Our measurement results demonstrate its capabilities. [J325]

"Sparsity and Compressed Sensing in Radar Imaging"

Remote sensing with radar is typically an ill-posed linear inverse problem: a scene is to be inferred from limited measurements of scattered electric fields. Parsimonious models provide a compressed representation of the unknown scene and offer a means for regularizing the inversion task. The emerging field of compressed sensing combines nonlinear reconstruction algorithms and pseudorandom linear measurements to provide reconstruction guarantees for sparse solutions to linear inverse problems. This paper surveys the use of sparse reconstruction algorithms and randomized measurement strategies in radar processing. Although the two themes have a long history in radar literature, the accessible framework provided by compressed sensing illuminates the impact of joining these themes. Potential future directions are conjectured both for extension of theory motivated by practice and for modification of practice based on theoretical insights. [J326]

"Interferometric Synthetic Aperture Radar (SAR) Missions Employing Formation Flying"

This paper presents an overview of single-pass interferometric Synthetic Aperture Radar (SAR) missions employing two or more satellites flying in a close formation. The simultaneous reception of the scattered radar echoes from different viewing directions by multiple spatially distributed antennas enables the acquisition of unique Earth observation products for environmental and climate monitoring. After a short introduction to the basic principles and applications of SAR interferometry, designs for the twin satellite missions TanDEM-X and Tandem-L are presented. The primary objective of TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement) is the generation of a global Digital Elevation Model (DEM) with unprecedented accuracy as the basis for a wide range of scientific research as well as for commercial DEM production. This goal is achieved by enhancing the TerraSAR-X mission with a second TerraSAR-X like satellite that will be launched in spring 2010. Both satellites act then as a large single-pass SAR interferometer with the opportunity for flexible baseline selection. Building upon the experience gathered with the TanDEM-X mission design, the fully polarimetric L-band twin satellite formation Tandem-L is proposed. Important objectives of this highly capable interferometric SAR mission are the global acquisition of three-dimensional forest structure and biomass inventories, large-scale measurements of millimetric displacements due to tectonic shifts, and systematic observations of glacier movements. The sophisticated mission concept and the high data-acquisition capacity of Tandem-L will moreover provide a unique data source to systematically observe, analyze, and quantify the dynamics of a wide range of additional processes in the bio-, litho-, hydro-, and cryosphere. By this, Tandem-L will be an essential step to advance our understanding of the Earth system and its intricate dynamics. Enabling technologies and techniques are described in detail. An ou--tlook on future interferometric and tomographic concepts and developments, including multistatic SAR systems with multiple receivers, is provided. [J327]

"Radar Imaging From Geosynchronous Orbit: Temporal Decorrelation Aspects"

Synthetic aperture radar imaging from geosynchronous orbit has significant potential advantages over conventional low-Earth orbit radars, but it also has challenges to overcome. The baseline mission we consider is an L-band geosynchronous passive (bistatic) radar achieving a spatial resolution of about 100 m with an integration time of 8 h. The atmosphere changes its structure on timescales of minutes to hours, and this has to be compensated if useful images are to be provided. The analysis shows that ionospheric delay is the major source of temporal decorrelation; other effects, such as tropospheric delay and Earth tides, have to be dealt with but appear to be easier to handle. [J328]

"Sparse Array 3-D ISAR Imaging Based on Maximum Likelihood Estimation and CLEAN Technique"

Large 2-D sparse array provides high angular resolution microwave images but artifacts are also induced by the high sidelobes of the beam pattern, thus, limiting its dynamic range. CLEAN technique has been used in the literature to extract strong scatterers for use in subsequent signal cancellation (artifacts removal). However, the performance of DFT parameters estimation based CLEAN algorithm for the estimation of the signal amplitudes is known to be poor, and this affects the signal cancellation. In this paper, DFT is used only to provide the initial estimates, and the maximum likelihood parameters estimation method with steepest descent implementation is then used to improve the precision of the calculated scatterers positions and amplitudes. Time domain information is also used to reduce the sidelobe levels. As a result, clear, artifact-free images could be obtained. The effects of multiple reflections and rotation speed estimation error are also discussed. The proposed method has been verified using numerical simulations and it has been shown to be effective. [J329]

"Enhancement of Coupled Multichannel Images Using Sparsity Constraints"

We consider the problem of joint enhancement of multichannel images with pixel based constraints on the multichannel data. Previous work by Cetin and Karl introduced nonquadratic regularization methods for SAR image enhancement using sparsity enforcing penalty terms. We formulate an optimization problem that jointly enhances complex-valued multichannel images while preserving the cross-channel information, which we include as constraints tying the multichannel images together. We pose this problem as a joint optimization problem with constraints. We first reformulate it as an equivalent (unconstrained) dual problem and develop a numerically-efficient method for solving it. We develop the Dual Descent method, which has low complexity, for solving the joint optimization problem. The algorithm is applied to both an interferometric synthetic aperture radar (IFSAR) problem, in which the relative phase between two complex-valued images indicate height, and to a synthetic multimodal medical image example. [J330]

"The Surface Water and Ocean Topography Mission: Observing Terrestrial Surface Water and Oceanic Submesoscale Eddies"

The elevation of the ocean surface has been measured for over two decades from spaceborne altimeters. However, existing altimeter measurements are not adequate to characterize the dynamic variations of most inland water bodies, nor of ocean eddies at scales of less than about 100 km, notwithstanding that such eddies play a key role in ocean circulation and climate change. For terrestrial hydrology, in situ and spaceborne measurements of water surface elevation form the basis for estimates of water storage change in lakes, reservoirs, and wetlands, and of river discharge. However, storage in most inland water bodies, e.g., millions of Arctic lakes, is not readily measured using existing technologies. A solution to the needs of both surface water hydrology and physical oceanography communities is the measurement of water elevations along rivers, lakes, streams, and wetlands and over the ocean surface using swath altimetry. The proposed surface water and ocean topography (SWOT) mission will make such measurements. The core technology for SWOT is the Ka-band radar interferometer (KaRIN), which would achieve spatial resolution on the order of tens of meters and centimetric vertical precision when averaged over targets of interest. Average revisit times will depend upon latitude, with two to four revisits at low to mid latitudes and up to ten revisits at high latitudes per ~20-day orbit repeat period. [J331]

"Clear-Cut Detection in Swedish Boreal Forest Using Multi-Temporal ALOS PALSAR Backscatter Data"

An extensive dataset of images acquired by the Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) is investigated for clear-cut detection in the county of Vajsterbotten, Sweden. Strong forest/non-forest contrast and temporal consistency were found for the Fine Beam Dual HV-polarized backscatter in summer/fall. In consequence of a clear-cut between image acquisitions, the HV-backscatter dropped in most cases between 2 and 3 dB. Thus, a simple thresholding algorithm that exploits the temporal consistency of time series of HV-backscatter measurements has been developed for clear-cut detection. The detection algorithm was applied at pixel level to ALOS PALSAR strip images with a pixel size of 50 m. The performance of the detection algorithm was tested with three different threshold values (2.0, 2.5 and 3.0 dB). The classification accuracy increased from 57.4% to 78.2% for decreasing value of the threshold. Conversely, the classification error increased from 3.0% to 9.7%. For about 90% of the clear-felled polygons used for accuracy assessment the proportion of pixels correctly detected as clear-felled was above 50% when using a threshold value of 2.0 dB. For the threshold values of 2.5 and 3.0 dB the corresponding figures were 80% and 65%, respectively. The total area classified as clear-felled during the time frame of the ALOS PALSAR data differed by 5% compared to an estimate of notified fellings for the same period of time when using a

detection threshold of 2.5 dB. The performance of the simple detection algorithm is reasonable when aiming at detecting clear-cuts, whereas there are shortcomings in terms of delineation. [J332]

"Detection of Moving Targets by Focusing in UWB SAR-Theory and Experimental Results"

Moving-target detection in ultrawideband (UWB) synthetic aperture radar (SAR) is associated with long integration time and must accommodate azimuth focusing for reliable detection. This paper presents the theory on detection of moving targets by focusing and experimental results on single-channel SAR data aimed at evaluating the detection performance. The results with respect to both simulated and real data show that the ability to detect moving targets increases significantly when applying the proposed detection technique. The improvement in signal-to-clutter noise ratio, which is a basic requisite for evaluating the performance, reaches approximately 20 dB, using only single-channel SAR data. This gain will be preserved for the case of multichannel SAR data. The reference system for this study is the airborne UWB low-frequency SAR Coherent All RAdio BAnd Sensing II. [J333]

"A New CFAR Ship Detection Algorithm Based on 2-D Joint Log-Normal Distribution in SAR Images"

The characteristic difference between targets and clutter is analyzed. Considering the ship target's gray intensity distribution and its shape difference compared to the clutter, in this letter, a new algorithm is presented based on correlation. The algorithm utilizes the strong gray intensity correlation in the ship target; also, the joint gray intensity distribution using 2-D joint log-normal distribution of a pixel with neighboring pixels in the clutter is modeled, which can be used for correlation-based joint constant false alarm rate detection. Using this algorithm, the false alarms caused by speckle and local background nonhomogeneity can be greatly reduced. The detection performance is much better. [J334]

"Mapping of Sand Layer Thickness in Deserts Using SAR Interferometry"

This paper presents an interferometric synthetic aperture radar (InSAR) system to map the bedrock topography underneath the sand in deserts and arid areas. This is anticipated to greatly increase the efficiency of oil field and ground water exploration as well as environmental and archaeological studies. The proposed system consists of two InSAR subsystems, one operating at Ka-band to map the sand topography and the other operates in the VHF band to map the subsurface topography. The different issues associated with InSAR processing for subsurface mapping are discussed. It is shown that conventional InSAR processing produces unacceptable error in height estimation since it does not account for the refraction and the different propagation velocity in the sand. Thus, a new inversion algorithm is developed which can be used to accurately estimate the bedrock topography for arbitrary sand and bedrock geometries. A sensitivity analysis is then presented to show the effect of the different systematic and random errors. The inversion algorithm is verified experimentally for flat sand case using a scaled model that was implemented in the lab. [J335]

"A Through-Dielectric Radar Imaging System"

Through-lossy-slab radar imaging will be shown at stand-off ranges using a low-power, ultrawideband (UWB), frequency modulated continuous wave (FMCW) radar system. FMCW is desirable for through-slab applications because of the signal gain resulting from pulse compression of long transmit pulses (1.926-4.069 GHz chirp in 10 ms). The difficulty in utilizing FMCW radar for this application is that the air-slab boundary dominates the scattered return from the target scene and limits the upper bound of the receiver dynamic range, reducing sensitivity for targets behind the slab. A method of range-gating out the air-slab boundary by significant band-limiting of the IF stages facilitates imaging of low radar cross section (RCS) targets behind the slab. This sensor is combined with a 1D linear rail and utilized as a rail synthetic aperture radar (SAR) imaging system. A 2D model of a slab and cylinder shows that image blurring due to the slab is negligible when the SAR is located at a stand-off range of 6 m or greater, and thus, the two-way attenuation due to wave propagation through the slab is the greatest challenge at stand-off ranges when the air-slab boundary is range-gated out of the scattered return. Measurements agree with the model, and also show that this radar is capable of imaging target scenes of cylinders and rods 15.24 cm in height and 0.95 cm in diameter behind a 10 cm thick lossy dielectric slab. Further, this system is capable of imaging free-space target scenes with transmit power as low as 5 pW, providing capability for RCS measurement. [J336]

"Dual-Tree Complex Wavelet Transform Based SAR Despeckling Using Interscale Dependence"

In this paper, a dual-tree complex wavelet transform (DTCWT) based despeckling algorithm is proposed for synthetic aperture radar (SAR) images, considering the significant dependences of the wavelet coefficients across different scales. The DTCWT has the advantage of improved directional selectivity, approximate shift

invariance, and perfect reconstruction over the discrete wavelet transform. The wavelet coefficients in each subband are modeled with a bivariate Cauchy probability density function (PDF) which takes into account the statistical dependence among the wavelet coefficients. Mellin transform of two dependent random variables is utilized to estimate the dispersion parameter of the bivariate Cauchy PDF from the noisy observations. This method is faster and effective when compared to that of the earlier techniques on numerical integration. Within this framework, we propose a new method for despeckling SAR images employing a maximum a posteriori estimator. Experimental results show that the proposed method based on bivariate Cauchy prior achieves better performance in terms of equivalent number of looks, peak signal-to-noise ratio, and Pratt's figure of merit. [J337]

"Physical Meaning of Perturbative Solutions for Scattering From and Through Multilayered Structures With Rough Interfaces"

Theoretical formulas without a clear comprehension of their intrinsic meaning are of difficult use in the context of practical applications. In this paper, we investigate on the physical meaning of existing first-order solutions for the field scattered by layered structures with rough interfaces, which were derived by Imperatore in the framework of perturbation theory. To capture the intrinsic significance of the closed-form scattering solutions, suitable expansions are rigorously performed by leveraging on local scattering descriptors. The obtained series expansions, which can be seen as ray series, can be then accurately analyzed showing that each term has a direct physical explanation. The analysis is carried out for both from- and through-layered-structure scattering configurations. As a result, analytical perturbative solutions turn out to be completely interpretable by simple physical concepts, so that the global scattering response can be interpreted as the superposition of single-scattering interaction mechanisms taking place locally, which are filteredby the layered structure. The meaning of the first-order approximation is also discussed in the layered structure context. Finally, we give a complete explanation for the scattering enhancement phenomenon contemplated in the first-order limit. [J338]

"Angular Backscatter Variation in L-Band ALOS ScanSAR Images of Tropical Forest Areas"

Scanning synthetic aperture radar (ScanSAR) systems provide continuous information over large areas, but for effective use of such products in tropical forest, the decrease of radar backscatter with large variation of incidence angles requires attention. This letter analyzes the dependence of radar backscatter on incidence angle for L-band ScanSAR images of tropical forest. We investigated and modeled the angular backscatter effect per land-cover class in three ScanSAR images of the Colombian Orinoco. We found that there is an evident effect of incidence angle on radar backscatter, depending on land-cover class, moisture content, and physical structure of the reflecting targets. To normalize the angular backscatter variation, we proposed two methods. The first one applies a cosine correction estimated through linear regression. The second one models the radar backscatter of flooded forest considering second-order signal interactions. The model explains the observed backscatter of flooded forest areas in the rainy season (R2that is larger than 0.77). [J339]

"Polarimetric SAR Data in Land Cover Mapping in Boreal Zone"

This paper compares ALOS PALSAR fully polarimetric and dual-polarized data in the application area of land cover mapping. To assure versatile comparison of the data, different classification methods and different features of data are used. Two of the classification methods used are based on supervised classification and two on unsupervised classification. Polarimetric data are used in three ways: (1) as fully polarimetric data; (2) features calculated from fully polarimetric data; and (3) intensity data of selected channels. Combinations of six (water, field, sparse forest, dense forest, peat land, and urban areas), five, four, and three classes were used for classification. Fully polarimetric data gave better results (87.5%-84.7% with three classes; open land areas, forest, and water) than intensity data only (83.6%-78.6%), but the differences in the overall accuracies between the methods were not more than 7.6%. Kappa coefficients of agreement are moderate for all the classifications. Supervised classification can be expected to perform better than unsupervised classification, given that the training areas can be selected accurately. Dual polarization data were found to be an attractive alternative in cases where fully polarimetric data are not available or it is of low resolution. With intensities of selected polarimetric features, it was possible to obtain a high classification accuracy as with fully polarimetric data. This also opens possibilities for nonspecialist users to benefit from polarimetric information in classification. [J340]

"Measurement of Ionospheric TEC in Spaceborne SAR Data"

The propagation of spaceborne radar signals operating at L-band frequency or below can be seriously affected by the ionosphere. At high states of solar activity, Faraday rotation (FR) and signal path delays disturb radar polarimetry and reduce resolution in range and azimuth. While these effects are negligible at X-band, FR and the frequency-dependent path delays can become seriously problematic starting at L-band. For quality assurance and calibration purposes, existing L-band or potential spaceborne P-band missions require the estimation of the

ionospheric state before or during the data take. This paper introduces two approaches for measuring the ionospheric total electron content (TEC) from single-polarized spaceborne SAR data. The two methods are demonstrated using simulations. Both methods leverage knowledge of the frequency-dependent path delay through the ionosphere: The first estimates TEC from the phase error of the filter mismatch, while the second gauges path-delay differences between up and down chirps. FR, mean (direct current) offsets, and noise contributions are also considered in the simulations. Finally, possibilities for further methodological improvements are discussed. [J341]

"An Analytical Method of Updating the Range Derivatives and a Simple Image Registration Method for the MSR-Based Range Doppler Algorithm"

Based on the method of series reversion, Neo developed a quite accurate range Doppler algorithm (RDA). In performing this RDA, the range derivatives need to be updated along the range. In this letter, first, we will give an analytical method to update the range derivatives for this RDA. The proposed method mainly exploits two points the first is the introduction of a reference vector on the ground plane of the bistatic geometry, and the second is the use of the principle of series reversion. Second, based on this new method of updating the range derivatives, we present a simple image registration method for mapping the focused image onto the ground plane, which needs a 1-D interpolation only in the range direction. Third, a motion compensation method is also proposed. [J342]

"Velocity Estimation and Range Shift Compensation for High Range Resolution Profiling in Stepped-Frequency Radar"

In this letter, a novel radial velocity estimation and range shift compensation algorithm is proposed for high-range resolution profiling of moving targets in stepped-frequency (SF) radar. Compared to traditional methods, this algorithm is based on a more precise signal model, and can therefore achieve much higher estimation accuracy. Furthermore, the range shift problem caused by target motion can be resolved without alterations to the radar waveform. The performance of this algorithm is demonstrated using simulated and experimental results. [J343]

"A New Strategy to Estimate Local Fringe Frequencies for InSAR Phase Noise Reduction"

A new approach is presented to estimate the fringe frequencies in interferometric synthetic aperture radar (InSAR) phase image. A first-order model is usually used for fringe frequency estimation, but in steep regions or low-correlation regions, it often fails. In this letter, a prefiltered interferogram, obtained by the slope-compensated or conventional mean filter, is divided into small patches and unwrapped separately. Subsequently, we differentiate the local-phase-unwrapping results to obtain the fringe frequencies. Furthermore, the invalid fringe frequencies are eliminated by a statistical threshold. Finally, the interferogram is filtered by compensating the estimated fringe frequencies in the averaging window of the mean filter. The proposed method can obtain continuous fringe frequency estimation, and it is not constrained by the first-order model. The effectiveness of the proposed approach is verified by the simulated and real InSAR data. [J344]

"A Simple Moment Method of Forest Biomass Estimation From Non-Gaussian Texture Information by High-Resolution Polarimetric SAR"

A simple method is described to estimate forest biomass by high-resolution polarimetric synthetic aperture radar (SAR). The method is based on the regression analysis between the measured biomass from the ground survey and the second intensity moment of the non-Gaussian texture in the cross-polarized L-band SAR images. The SAR data used in the analysis were acquired by the airborne polarimetric interferometric SAR over the coniferous forest in Hokkaido, Japan. The regression analysis was first carried out, and a model function was derived to relate the intensity moment and the measured biomass in 19 forest stands. Using this model function, the biomass values were estimated and compared with those of 21 different stands with known biomass. The average accuracy of the moment model was found to be 85%, which is similar to that of the previous K -distribution model. The advantage of this method over the distribution-based model is that there is no need to search a specific distribution function which fits best to the image texture. [J345]

"Flexible Dynamic Block Adaptive Quantization for Sentinel-1 SAR Missions"

The letter introduces a novel quantizer suited for medium to high-resolution synthetic aperture radar (SAR) systems, like the forthcoming SENTINEL-1 SAR. The Flexible Dynamic Block Adaptive Quantization (FDBAQ) extends the concept of the Block Adaptive Quantization (BAQ), used in spaceborne SAR since the Magellan mission, by adaptively tuning the quantizer rate according to the local signal-to-noise-ratio (SNR). A design is

presented aiming to optimize the average bit-rate, while constraining the minimum SNR. FDBAQ optimized performance is then evaluated using backscatter maps derived from ENVIronment SATellite (ENVISAT) data. [J346]

"RFI Suppression in Ultrawideband SAR Using an Adaptive Line Enhancer"

In this letter, we propose an approach to suppress radio-frequency interference (RFI) in ultrawideband (UWB) low-frequency synthetic aperture radar (SAR). According to the proposal, RFI is suppressed by using an adaptive line enhancer controlled by the normalized least mean square algorithm. The approach is tested successfully on real UWB low-frequency SAR data. In order to keep the computational burden down, possible ways to integrate the RFI suppression approach into SAR imaging algorithms are also suggested. [J347]

"Noniterative Super-Resolution Technique Combining SVA With Modified Geometric Mean Filter"

We propose a super-resolution algorithm that combines spatially variant apodization (SVA) with a modified geometric mean filter to improve the resolution of synthetic aperture radar (SAR) images and reduce sidelobes simultaneously. This method does not require iterative calculation. The efficacy of the proposed algorithm is verified by simulation with point targets and in experiments with a real SAR image. The proposed method improved resolution by 40% compared to SVA and phase-extension inverse filtering. [J348]

"An Array Error Estimation Method for Constellation SAR Systems"

In practice, unavoidable array errors, consisting of phase and position errors, significantly degrade the performance of constellation synthetic aperture radar (SAR) systems. Therefore, methods are required to estimate these errors. In constellation SAR systems, the clutter spectrum components within a Doppler bin can be used as calibration sources with known directions. In this letter, it is observed that the steering vectors of the spectrum components in one Doppler bin are conjugate with those of the spectrum components in its contrary Doppler bin on condition that each SAR operates in side-looking mode and its nominal left coordinate is zero, which is easy to realize. We obtain a new phase error estimation method based on this observation. An array error estimation method, which estimates phase and position errors simultaneously, is proposed via combining the new phase error estimation method with the least squares method for estimating position errors. The advantages of the proposed method include its capability to directly estimate phase and position errors without joint iteration between the estimations of phase and position errors; thus, it performs well, while the conventional method behaves unstably because it may converge to a local optimal solution, when position errors are large. Furthermore, mathematical analysis indicates that the proposed method has less computational load. In addition, computer simulations show that it performs better than the conventional method. The only cost is that it employs twice as many Doppler bins as the conventional method does, which is endurable because there are numerous Doppler bins. [J349]

"Signal level Simulator for netted text radar waveforms evaluation"

When evaluating the performances of radar waveforms, it is crucial to understand how the signal is affected by multiple interactions with the environment and the system hardware. Analysis of complex radar systems, such as multistatic and netted designs (see Figure 1) is often intractable without the application of a dedicated radar simulation system. Recent research into radar simulation has focused primarily on synthetic aperture radar (SAR) systems [1] and is not entirely applicable to traditional radar systems concerned with the location and tracking of remote targets. A complete simulator has been designed for the accurate simulation of raw returns in complex, multistatic, and netted radars, and is applicable to pulsed and continuous wave (CW) systems, and both active and passive radar systems. The Flexible Simulator for Multistatic Radars (FERS) can be used to simulate radar systems with arbitrary waveforms and arbitrary numbers of receivers, transmitters, and scatterers. Herein, algorithms for the simulation of raw radar return signals are presented, based on interpolation and modification of the transmitted signal and modeling of the radar hardware and environment. The algorithms are expected to be especially valuable for the simulation of emerging radar technologies, such as Passive Coherent Location (PCL) [2], netted radar and phased array radar. Preliminary results, presented herein, suggest that these algorithms can simulate physical systems with excellent accuracy. [J350]

"Simulating X-Band Interferometric Height in a Spruce Forest From Airborne Laser Scanning"

The aim of this study is to use airborne laser scanning (ALS) data to simulate synthetic aperture radar interferometry (InSAR) elevation data [digital elevation model (DEM)] from the spatial distribution of scatterers. A Shuttle Radar Topography Mission X-band DEM data set and an ALS data set from a spruce-dominated forest area are used. A 3-D grid of voxels is made from the spatial distribution of ALS first echoes. The slant angle penetration rate of the SAR microwaves (PSAR) is simulated to be a function of the vertical ALS penetration rate

(PALS), i.e., PSAR= PALS4. The InSAR DEM and heights above the ground are fairly well reproduced by the simulator. A total least squares regression model between the simulated and measured InSAR DEMs has an R2value of 0.99 and a slope of 1: 1. By subtracting the ALS-based terrain heights (digital terrain model), we obtained InSAR heights, which were reproduced with an R2value of 0.78, a slope of 0.96, and a root-mean-square error of 2.3 m. With the simulator, it was demonstrated how a disturbance event would affect the InSAR height. Unfortunately, the relationship was curvilinear and concave, which means that the method is not very sensitive to weak disturbances. This might be partly overcome by using a more vertical incidence angle of the SAR microwaves. The simulator might be used for validation or ground truthing of the InSAR data, as well as gaining understanding of how vegetation changes affect the InSAR data. [J351]

"Far-Field Limit of PFA for SAR Moving Target Imaging"

A new formulation of the polar format algorithm (PFA) for spotlight synthetic aperture radar (SAR) imaging is presented, which is useful when investigating its response to the moving target. Our work starts with examining the commonly adopted implementation of the PFA, i.e., the separable 1-D range and azimuth resampling procedures for their roles in range cell migration (RCM) correction, respectively. It is shown that the former performs RCM predeformation, while the latter is, substantially, the combination of RCM linearization and the keystone transform (KT), i.e., a well-known technique for SAR imaging of moving targets. The new formulation approach is applied to analyze the moving target. The far-field limit of the PFA for moving target focusing is derived, which can be used to predict the target's impulse response (IPR) function. The work presented might be helpful when considering a SAR system with the capability of ground moving target indication and imaging (GMTI&Im). [J352]

"Canonical Scattering Feature Models for 3D and Bistatic SAR"

This paper develops three-dimensional (3D), bistatic parametric models that describe canonical radar scattering responses of several geometric objects. These models find use in inverse scattering-based processing of high-frequency radar returns. Canonical feature models are useful for extracting geometry from synthetic-aperture radar (SAR) scattering measurements and as feature primitives for automatic target recognition (ATR) and scene visualization. Previous work has considered monostatic feature models for two-dimensional (2D) radar processing; we extend this work to consider bistatic and 3D radar apertures. In the work presented here, we generalize geometric theory of diffraction (GTD) solutions for several scattering mechanisms in a plane. Products of these planar mechanisms in azimuth and elevation are used to produce 3D bistatic scattering models for six canonical shapes: a rectangular plate, dihedral, trihedral, cylinder, top-hat, and sphere. The derived models are characterized by a small number of parameters, and are shown to agree with results obtained from high-frequency, asymptotic scattering simulations. [J353]

"Radar Micro-Doppler Signature Analysis with HHT"

Radar micro-Doppler signature analysis of vibrating targets with the joint time-frequency methods can provide useful information for target detection, classification, and recognition. We employ a well-known method for nonlinear and nonstationary signals, Hilbert-Huang transform (HHT) as a new approach in micro-Doppler analysis. Simulation and experimental results show that it can achieve better performance than the traditional Cohen's class time-frequency methods. [J354]

"A Lossless Compression Algorithm for SAR Amplitude Imagery Based on Modified Quadtree Coding of Bit Plane"

A lossless compression algorithm for synthetic aperture radar (SAR) amplitude images based on modified quadtree bit-plane coding is proposed. First, a SAR amplitude image is divided into independent bit planes, and then, the probability of bit "0" is computed and compared with the predefined threshold in order to select the optimal block size for each bit plane. Finally, a modified quadtree coding method is adopted to encode each block data. Additionally, the computing method of predefined threshold is also addressed in this letter. The experimental results show that the proposed method outperforms previous methods for all SAR images of the test sets; an average 0.895-bpp decrease in bit rate was observed when compared with JPEG-LS. [J355]

"Phase Unwrapping by Markov Chain Monte Carlo Energy Minimization"

Phase unwrapping (PU) is a process to obtain the absolute value of a phase field from the wrapped one. Ideally, without phase noise, singularity, and aliasing problems, the phase information can be unwrapped easily. However, the phase data are always contaminated by noise and discontinuities, making the PU process more complicated. Hence, a suitable PU algorithm is required to address the problems appropriately. Markov Chain Monte Carlo (MCMC) Energy Minimization is usually used to partially remove phase noise. In this letter, the

MCMC energy minimization that yields the unwrapped phase is shown. Furthermore, the capability of the proposed method to unwrap simulated and actual InSAR phase images is also demonstrated (Fujiyama Mount). [J356]

"Discrete Almost-Symmetric Wave Packets and Multiscale Geometrical Representation of (Seismic) Waves"

We discuss a multiscale geometrical representation of (seismic) waves through a decomposition into wave packets. Wave packets can be thought of as certain localized "fat" plane waves. Here, we construct discrete almost-symmetric 3-D wave packets by using the unequally spaced fast Fourier transform. The resulting discrete transform is unitary, implying that the reconstruction operator is simply the adjoint of the decomposition operator. Another relevant aspect of the discretization scheme is the appearance of parameters that control the tiling of the phase space that corresponds with the dyadic parabolic decomposition, preserving the relative parabolic scaling while adapting to the physical problem at hand. We consider applications in exploration and global seismology, in particular for higher dimensional data regularization, seismic map migration, denoising, directional regularity analysis, and feature extraction. [J357]

"Estimation of the Backscatter Vertical Profile of a Pine Forest Using Single Baseline P-Band (Pol-)InSAR Data"

The vertical backscatter profile of a pine forest constituted by stands of different height is inverted from a single baseline P-band Pol-InSAR data in order to identify scatterers in the canopy. The proposed approach uses the Gaussian vertical backscatter profile model, which associates an interferometric coherence expression to a vertical scatterers' distribution characterized by relative standard deviation and elevation. The methodology, which uses in situmeasurements of forest height and unbiased ground level estimation, is applied to HV and VV channels, providing accuracy given sufficiently low ground-to-canopy power ratios. Inverted backscatter profiles show maximum power converging toward the basis of the tree crown on highest forests, where the largest branches are located, indicating the high sensitivity of P-band measurements to the forest structure and to the vertical biomass distribution. Over lower stands with larger tree densities, the power peak is located in the upper part of the canopy, which can be explained by a stronger attenuation in the canopy. [J358]

"A Low Complexity Blind Estimator of Narrowband Polynomial Phase Signals"

Consider the problem of estimating the parameters of multiple polynomial phase signals observed by a sensor array. In practice, it is difficult to maintain a precisely calibrated array. The array manifold is then assumed to be unknown, and the estimation is referred to as blind estimation. To date, only an approximated maximum likelihood estimator (AMLE) was suggested for blindly estimating the polynomial coefficients of each signal. However, this estimator requires a multidimensional search over the entire coefficient space. Instead, we propose an estimation approach which is based on two steps. First, the signals are separated using a blind source separation technique, which exploits the constant modulus property of the signals. Then, the coefficients of each polynomial are estimated using a least squares method applied to the unwrapped phase of the estimated signal. This estimator does not involve any search in the coefficient spaces. The computational complexity of the proposed estimator increases linearly with respect to the polynomial order, whereas that of the AMLE increases exponentially. Simulation results show that the proposed estimator achieves the Cramer-Rao lower bound at moderate or high signal to noise ratio. [J359]

"A Model-Spectrum-Based Flattening Algorithm for Airborne Single-Pass SAR Interferometry"

An effective method is proposed to remove the flat-Earth phase (i.e., flattening) in airborne single-pass interferometric synthetic aperture radar (InSAR) imaging. Two conventional flattening methods, namely, the orbit-equation algorithm and the fringe-frequency algorithm, are used for comparison. The orbit-equation algorithm is theoretically accurate, but the orbit ephemeris that it requires is maybe inaccurate or even unknown. The fringe-frequency algorithm is effective in spaceborne InSAR flattening, but in airborne cases, a phase trend will remain in the residual interferogram with this method. To overcome these limitations, this letter presents a novel flattening algorithm by combining the two conventional methods for airborne single-pass InSAR flattening. By exploiting a reasonable model of the flat-Earth phase and the spectrum information of the practical interferogram, the proposed algorithm is able to flatten the interferogram accurately without knowledge of the airplane trajectory (except for the airplane height). Finally, some experimental results demonstrate the effectiveness of the proposed flattening algorithm. [J360]

"Recent Retreat of Wilkins Ice Shelf Reveals New Insights in Ice Shelf Breakup Mechanisms"

The disintegration of various ice shelves on the Antarctic Peninsula has demonstrated their vulnerability and impacts on tributary glaciers. A satellite image of Wilkins Ice Shelf (WIS) from July of 2007 reveals the formation of a large new double fracture, accompanied by numerous small fractures. We show that bending stresses induced by buoyancy forces were responsible for fracture formation. On February 28-29, 2008, an area of about 425 km2broke up at a narrow connection of the WIS to one of its confining islands. In contrast to Larsen B Ice Shelf, melt ponds that drain into crevasses played no role in this breakup process. A further breakup of 160 km2in the same area occurred on May 30-31, 2008 and documented that breakup can occur during austral winter. Radar images reveal a frozen surface, which demonstrates that in this breakup, surface melt water did not play a role. We conclude that ice shelves with strong thickness contrasts carry potential for disintegration. The fact that the WIS experienced two breakup events under two widely contrasting surface conditions (one during the melt season and one during winter) reveals that there may be several reasons for the disintegration of ice shelves that operate under differing circumstances. [J361]

"Using a Ground-Based SAR Interferometer and a Terrestrial Laser Scanner to Monitor a Snow-Covered Slope: Results From an Experimental Data Collection in Tyrol (Austria)"

In this paper, we report on an experimental activity aimed at investigating the potential of two terrestrial remote-sensing techniques, namely, ground-based SAR (GB SAR) interferometry and terrestrial laser scanning, in order to retrieve snow-depth (SD) measurements in mountainous regions. Terrestrial laser scanning is a more consolidated technique based on the measurement of the optical (near infrared) reflectivity, and it is affected by the surface of the snow layer: a temporal data sequence allows us to estimate the absolute SD variation. Recent use of SAR interferometry to evaluate snow-mass characteristics is based on relating the measured interferometric phase shift to a change in the snow mass. Interferometric GB SAR measurements and terrestrial laser scanner scans were collected together with pointwise conventional measurements of physical snow parameters during the winters of 2005/2006 and 2006/2007. The experiment was carried out in the Wattener Lizum, a high Alpine area at about 2000-m elevation north of the main ridge of the Austrian Alps in Tyrol. Notwithstanding the difficulty of providing both lengthy data record in dry snow conditions and detailed knowledge of the observed snow characteristics, the obtained results confirmed the presence of a clearly measurable interferometric phase variation in relation to the growing height of the snow layer. A comparison of the SD maps obtained through the two techniques shows differences partly due to the different nature of the two observations. [J362]

"Foreword to the Special Issue on Retrieval of Bio- and Geophysical Parameters From SAR Data for Land Applications"

This IEEE Transactions on Geoscience and Remote Sensing (TGRS) special issue is dedicated to the advances in synthetic aperture radar (SAR) techniques and applications presented at the 5th International Symposium on Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications (BioGeoSAR), which was organized by Consiglio Nazionale delle Ricerche, with active support from the European Space Agency, and held in Bari, Italy, on September 25-28, 2007. The purpose of the symposium has been to provide a forum for researchers to review current trends in the field of retrieval of quantitative information from SAR data and to present and discuss new ideas and new research directions. The BioGeoSAR symposia are usually held every three years in Europe with worldwide participation. [J363]

"Automatic Model-Based Estimation of Boreal Forest Stem Volume From Repeat Pass C-band InSAR Coherence"

C-band repeat pass interferometric synthetic aperture radar coherence can provide high-accuracy estimates of boreal forest stem volume in spite of environmental dependence. Typically, the retrieval methods require a data set of insitumeasurements for training the model linking coherence to stem volume. The drawback is the need for such data and the incapacity to take into account spatial variations of environmental conditions. Here, we demonstrate a model training method that does not require reference data. For the investigated case, the relative root mean square error of stem volume is 18% or as good as obtained using the traditional training method with insitudata. [J364]

"Sparse Two-Dimensional Phase Unwrapping Using Regular-Grid Methods"

Phase unwrapping is usually defined as the reconstruction of a function sampled on a spatial grid given its value modulo 2pi. Phase unwrapping is a key step in image reconstruction in many imaging techniques including interferometric synthetic aperture radar (InSAR). In recent years, many new methods have been developed to exploit the presence of coherent or persistent scattering points for extracting deformation signatures in regions where the conventional InSAR fails. These techniques often yield measurements that are only poorly sampled

spatially, yet these sparse data must still be unwrapped if we are to be able to extract useful geophysical information. The conventional well-sampled 2-D phase unwrapping problem based on phase residues is fairly well understood, and many novel techniques involving geometry and network flow concepts have been implemented successfully to date. For sparse data, residues may be computed over the Delaunay triangulation of the data points, but published algorithms meet with limited success when the sparse data are unwrapped. The advantages of modern unwrapping methods applicable to well-sampled data are often lost when sparse data are analyzed. In this letter, we show that a nearest neighbor interpolation scheme allows powerful and existing 2-D solvers to be applied to sparse data. We present results using both simulated and real data sets to illustrate our method. [J365]

"A Particle Filter Approach for InSAR Phase Filtering and Unwrapping"

This paper presents a new phase-unwrapping (PU) algorithm for SAR interferometry that makes use of a particle filter (PF) to perform simultaneously noise filtering and PU. The formulation of this technique provides independence from noise statistics and is not constrained by the nonlinearity of the problem. In addition, an enhanced variant of this method combining a PF with artificial-intelligence search strategies and an omnidirectional local phase estimator, based on the mode of the power spectral density, is also presented. Results obtained with synthetic and real data show a significant improvement with respect to other conventional unwrapping algorithms in some situations. [J366]

"Water Level Estimation and Reduction of Hydraulic Model Calibration Uncertainties Using Satellite SAR Images of Floods"

Exploitation of river inundation satellite images, particularly for operational applications, is mostly restricted to flood extent mapping. However, there lies significant potential for improvement in a 3-D characterization of floods (i.e., flood depth maps) and an integration of the remote-sensing-derived (RSD) characteristics in hydraulic models. This paper aims at developing synthetic aperture radar (SAR) image analysis methods that go beyond flood extent mapping to assess the potential of these images in the spatiotemporal characterization of flood events. To meet this aim, two research issues were addressed. The first issue relates to water level estimation. The proposed method, which is an adaptation to SAR images of the method developed for water level estimation using flood aerial photographs, is composed of three steps: (1) extraction of flood extent limits that are relevant for water level estimation; (2) water level estimation by merging relevant limits with a Digital Elevation Model; and (3) constraining of the water level estimates using hydraulic coherence concepts. Applied to an ENVISAT image of an Alzette River flood (2003, Grand Duchy of Luxembourg), this provides plusmn54-cm average vertical uncertainty water levels that were validated using a sample of ground surveyed high water marks. The second issue aims at better constraining hydraulic models using these RSD water levels. To meet this aim, a "traditional" calibration using recorded hydrographs is completed via comparison between simulated and RSD water levels. This integration of the RSD characteristics proves to better constrain the model (i.e., the number of parameter sets providing acceptable results with respect to observations has been reduced). Furthermore, simulations of a flood event of a different return period (2007) using the model calibrated for the 2003 flood event shows the reliability of the latter for flood forecasting. [J367]

"Omega-k Algorithm for Airborne Forward-Looking Bistatic Spotlight SAR Imaging"

For flexibility and cost reduction, the forward-looking bistatic spotlight synthetic aperture radar (FL-BSSAR) which uses the side-looking transmitter and the forward-looking receiver has been studied recently. For the FL-BSSAR imaging, we introduce a modified omega-k algorithm. Specifically, using rotation and shifting of the receiver path and resampling of the transmitter path, we convert the FL-BSSAR into the side-looking BSSAR. Then, we modify the matched filter and Stolt interpolation using the principle of the stationary phase to obtain the SAR image. Simulation results show that the modified omega-k algorithm enhances the image quality. [J368]

"Tropical-Forest-Parameter Estimation by Means of Pol-InSAR: The INDREX-II Campaign"

This paper addresses the potential and limitations of polarimetric synthetic aperture radar (SAR) interferometry (Pol-InSAR) inversion techniques for quantitative forest-parameter estimation in tropical forests by making use of the unique data set acquired in the frame of the second Indonesian Airborne Radar Experiment (INDREX-II) campaign-including Pol-InSAR, light detection and ranging (LIDAR), and ground measurements-over typical Southeast Asia forest formations. The performance of Pol-InSAR inversion is not only assessed primarily at L- and P-band but also at higher frequencies, namely, X-band. critical performance parameters such as the ldquovisibility of the groundrdquo at L- and P-band as well as temporal decorrelation in short-time repeat-pass interferometry are discussed and quantitatively assessed. Inversion performance is validated against LIDAR and ground measurements over different test sites. [J369]

"Two-Dimensional Spectrum Matched Filter Banks for High-Speed Spinning-Target Three-Dimensional ISAR Imaging"

In this letter, a 3-D inversed synthetic aperture radar imaging algorithm for targets in high-speed spinning is proposed based on 2-D spectrum matched filter (MF) banks. Each spectrum MF bank yields a focused slice for its corresponding scatterers. By extracting the spatial parameters from all slices, the 3-D image of the target can be constructed. Numeric simulation confirms the validity of the algorithm. [J370]

"Cassini RADAR Sequence Planning and Instrument Performance"

The Cassini RADAR is a multimode instrument used to map the surface of Titan, the atmosphere of Saturn, the Saturn ring system, and to explore the properties of the icy satellites. Four different active mode bandwidths and a passive radiometer mode provide a wide range of flexibility in taking measurements. The scatterometer mode is used for real aperture imaging of Titan, high-altitude (around 20 000 km) synthetic aperture imaging of Titan and Iapetus, and long range (up to 700 000 km) detection of disk integrated albedos for satellites in the Saturn system. Two SAR modes are used for high- and medium-resolution (300-1000 m) imaging of Titan's surface during close flybys. A high-bandwidth altimeter mode is used for topographic profiling in selected areas with a range resolution of about 35 m. The passive radiometer mode is used to map emission from Titan, from Saturn's atmosphere, from the rings, and from the icy satellites. Repeated scans with differing polarizations using both active and passive data provide data that can usefully constrain models of surface composition and structure. The radar and radiometer receivers show very good stability, and calibration observations have provided an absolute calibration good to about 1.3 dB. Relative uncertainties within a pass and between passes can be even smaller. Data are currently being processed and delivered to the planetary data system at quarterly intervals one year after being acquired. [J371]

"Bistatic point target reference spectrum in the presence of trajectory deviations"

The point target reference spectrum (BPTRS) of bistatic SAR in the presence of trajectory deviations based on Loffeld's bistatic formula (LBF) is developed. The presented BPTRS is suitable for the general air-borne bistatic configuration. For the air-borne bistatic SAR, both the transmitter and the receiver will contribute to the trajectory deviation. The compensation of trajectory deviations becomes more complex because of the separate locations of the transmitter and receiver. The authors focus on the effects of trajectory deviations on the point target spectrum of bistatic SAR. The proposed BPTRS is verified by simulation experiments performed in the azimuth-invariant configuration. [J372]

"ISAR Imaging of a Ship Target Using Product High-Order Matched-Phase Transform"

Inverse synthetic aperture radar (ISAR) imaging of a ship target is very important compared with the plane target, and the imaging condition of the ship target is more complicated than that of the plane target due to the complexity of the ship's movement. In this letter, the received signal of a ship target is modeled as a multicomponent cubic phase signal, and the product high-order matched-phase transform is proposed to estimate the parameters of each component. Then, the instantaneous ISAR images can be obtained. Results of real data demonstrate the effectiveness of the new method proposed. [J373]

"Target Detection in SAR Images Based on a Level Set Approach"

This paper introduces a new framework for point target detection in synthetic aperture radar (SAR) images. We focus on the task of locating reflective small regions using a level-set-based algorithm. Unlike most of the approaches in image segmentation, we address an algorithm that incorporates speckle statistics instead of empirical parameters and also discards speckle filtering. The curve evolves according to speckle statistics, initially propagating with a maximum upward velocity in homogeneous areas. Our approach is validated by a series of tests on synthetic and real SAR images and compared with three other segmentation algorithms, demonstrating that it configures a novel and efficient method for target-detection purpose. [J374]

"Near-Space Wide-Swath Radar Imaging With Multiaperture Antenna"

Near-space, defined as the altitude region between 20 and 100 km, offers many capabilities that are not accessible for low Earth-orbit (LEO) satellites or airplanes because it is above storm and not constrained by orbital mechanics and high fuel consumption. Hence, a high flying speed can be obtained for the maneuvering vehicles operating in near-space. This offers a promising solution to simultaneous high-resolution and wide-swath synthetic aperture radar (SAR) imaging. As such, one near-space wide-swath SAR imaging technique is presented in this letter. The system configuration, signal model, and imaging scheme are described. An example

near-space SAR system is designed, and its imaging performance is analyzed. Simulation results show that near-space maneuvering vehicle SAR indeed seems to be a promising solution to wide-swath SAR imaging. [J375]

"The Canberra high altitude mission platform"

This presents the capabilities of two English Electric Aviation Canberra aircraft owned by High Altitude Mapping Missions, Inc. These aircraft are available for high altitude commercial, government, and scientific missions. The basic specifications of the Canberra are provided and compared to other high-performance jet aircraft falling into the same category. This describes the high altitude flight characteristics and mission capabilities of the Canberras. The aircraft are configured to conduct up to eight-hour flight operations with up to six hours at 50,000 feet altitude. Shorter missions can be conducted at higher altitudes. Potential missions include: IFSAR, magnetic field mapping, gravity field mapping, imaging (SAR, IR, & hyper-spectral), LIDAR, communications relay, dropsonde deployment, hybrid rocket launching, severe storm monitoring, and disaster monitoring. Canberra high altitude operations have minimal weather impact on missions, are free from flight constraints imposed by air traffic control, can do large area coverage, and long mission times. [J376]

"Automatic Detection of Terrain Surface Changes After Wenchuan Earthquake, May 2008, From ALOS SAR Images Using 2EM-MRF Method"

A method of two-threshold expectation maximum and Markov random field is presented to automatic detection of terrain surface changes after the Wenchuan earthquake, on May 12, 2008, using multitemporal ALOS PALSAR images. As an example in the Beichuan area, three kinds of terrain surface changes, i.e., scattering enhanced, reduced, and no-changed, are automatically detected and classified. By using the tool of Google Earth, the surface change situation after the earthquake can be shown in multiazimuth views as an animated cartoon. The detection and classification are also compared with optical photographs. [J377]

"Potential of Estimating Soil Moisture Under Vegetation Cover by Means of PolSAR"

In this paper, the potential of using polarimetric SAR (PolSAR) acquisitions for the estimation of volumetric soil moisture under agricultural vegetation is investigated. Soil-moisture estimation by means of SAR is a topic that is intensively investigated but yet not solved satisfactorily. The key problem is the presence of vegetation cover which biases soil-moisture estimates. In this paper, we discuss the problem of soil-moisture estimation in the presence of agricultural vegetation by means of L-band PolSAR images. SAR polarimetry allows the decomposition of the scattering signature into canonical scattering components and their quantification. We discuss simple canonical models for surface, dihedral, and vegetation scattering and use them to model and interpret scattering processes. The performance and modifications of the individual scattering components are discussed. The obtained surface and dihedral components are then used to retrieve surface soil moisture. The investigations cover, for the first time, the whole vegetation-growing period for three crop types using SAR data and ground measurements acquired in the frame of the AgriSAR campaign. [J378]

"A Matched-Filter-Bank-Based 3-D Imaging Algorithm for Rapidly Spinning Targets"

For rapidly spinning targets, such as the rotating ground radar antenna, helicopter blades, spinning space debris, etc., the scatterers on the target may rotate for several periods in the observation time. Since the range and Doppler information of these scatterers are no longer constant, the conventional range-Doppler-based imaging algorithms are invalid. Meanwhile, 3-D imaging is necessary to obtain additional information for the spinning target. However, the available interferometric inverse synthetic radar (ISAR) and snapshot 3-D imaging algorithms do not work well since they require low target spinning speed. In this paper, a matched-filter-bank-based 3-D imaging algorithm for rapidly spinning targets is proposed, based on target motion features. This algorithm utilizes the rapidly rotating turntable model of the ISAR target instead of the slow rotating one. First, 2-D image slices of the target are obtained from the output of the matched filter bank by changing matching parameters. Then, a series of 2-D image slices are combined to form the 3-D target image. Since this algorithm applies to the monostatic radar system, it is easy to implement in practical applications. Both the theoretical derivation and the simulation results have proved the validity of the proposed algorithm. [J379]

"Motion-Compensation Improvement for Widebeam, Multiple-Receiver SAS Systems"

The effect that uncompensated motion errors have on synthetic aperture sonar (SAS) imagery can be severe. Time-domain beamforming SAS reconstruction is able to compensate arbitrary track errors, but the more efficient frequency-domain reconstruction algorithms, such as the range-Doppler, chirp-scaling, and wave number (akarange migration or Stolt-mapping) algorithms do not allow for simple compensation, especially for widebeam sonars. Data processed via these block algorithms is usually compensated before azimuth compression in a

computationally inexpensive preprocessing step. Unfortunately, this compensation assumes a narrowbeam geometry, causing blurring in high-resolution images collected with widebeam sonars. In this paper, we demonstrate a new technique for compensation of large, but known, motion errors in data collected with widebeam geometry sonars. The technique relies on obtaining angle-of-arrival information from the multiple-receiver array configuration typical in high-resolution SAS systems. The new method of compensating for motion errors was found to significantly outperform the previous techniques in a simulation of point-reflector imagery. [J380]

"Focusing of Airborne Synthetic Aperture Radar Data From Highly Nonlinear Flight Tracks"

Standard focusing of data from synthetic aperture radar (SAR) assumes a straight recording track of the sensor platform. Small nonlinearities of airborne platform tracks are corrected for during a motion-compensation step while maintaining the assumption of a linear flight path. This paper describes the processing of SAR data acquired from nonlinear tracks, typical of sensors mounted on small aircraft or drones flying at low altitude. Such aircraft do not fly along straight tracks, but the trajectory depends on topography, influences of weather and wind, or the shape of areas of interest such as rivers or traffic routes. Two potential approaches for processing SAR data from such highly nonlinear flight tracks are proposed, namely, a patchwise frequency-domain processing and mosaicking technique and a time-domain back-projection-based technique. Both are evaluated with the help of experimental data featuring tracks with altitude changes, a double bend, a 90deg curve, and a linear flight track. In order to assess the quality of the focused data, close-ups of amplitude images are compared, impulse response functions of a point target are analyzed, and the coherence is evaluated. The experimental data were acquired by the German Aerospace Center's E-SAR L-band system. [J381]

"High-Resolution Three-Dimensional Imaging of Spinning Space Debris"

Since space debris could post a significant threat to orbiting objects around the Earth, their reorganization, measurement, and catalogue are of great importance. This paper establishes a 3-D inverse synthetic aperture radar (ISAR) imaging geometry and signal model for space debris. Then, a 3-D imaging algorithm is proposed to realize coherent imaging in the range-slow-time domain. This algorithm is based on the complex-valued back-projection transform according to the spinning nature of space debris. The simulation results for both point scattering and continuous targets have proved the validity of the proposed algorithm. [J382]

"Narrow-Band Interference Suppression for SAR Based on Complex Empirical Mode Decomposition"

Narrow-band interference (NBI) is a common interference source in synthetic aperture radar (SAR) imaging. Its existence will degrade the imaging quality greatly. Based on detailed analysis on the characteristics of NBI, this letter proposes a new NBI suppression algorithm using the complex empirical mode decomposition (CEMD) method. In this algorithm, echoes that include NBI are recognized in the time domain first. Then, these echoes are decomposed into a number of intrinsic mode functions (IMFs) via the CEMD. After that, IMFs that correspond to NBI are subtracted from the echoes by thresholding. Finally, well-focused SAR imagery can be obtained from the separated target echoes using traditional SAR imaging algorithms. The effective data loss in this algorithm is smaller than other NBI suppression approaches. In addition, this algorithm is robust to time-varying NBI. Imaging results of measured data have proved the validity of this algorithm. [J383]

"SAR Images of Rooms and Buildings Based on FDTD Computer Models"

This paper presents synthetic aperture radar (SAR) images of rooms and buildings based on numerical simulations, with application to sensing through the wall (STTW) scenarios. We use the finite-difference time-domain modeling technique to compute the radar return from configurations of increasing complexity, where humans and furniture objects are placed in a room. We apply SAR image formation techniques and analyze the images obtained for various wall materials, aspect angles, and radar parameters. We investigate the multipath propagation issues relevant to STTW imaging radar and discuss the radar parameter tradeoff based on image quality. We also look at images obtained in cross-polarization, demonstrating how this radar operational mode can achieve significant clutter rejection. The phenomenological results obtained in this paper can be used as guidance by radar engineers in order to optimize the performance of STTW SAR imaging systems. [J384]

"High-Frequency EM Characterization of Through-Wall Building Imaging"

A high-frequency asymptotic technique based on the Uniform Geometric Theory of Diffraction (UTD) is employed for building interior imaging. The analysis is implemented using a ray-tracing technique to account for multiple scattering interactions in a building, along with a set of heuristic diffraction coefficients for dielectric wedges and

corners. Imaging of the synthetic aperture radar data is carried out by the conventional fast Fourier transform method to transform to the downrange domain, and combined with a coherent near-zone imaging function for cross-range. Comparisons with experimental data for a scaled-down building model are given to demonstrate the suitability and efficacy of our analysis for through-wall building imaging. The UTD ray mechanisms account for the dominant scattering features observed in the image. [J385]

"A Time-Series Approach to Estimate Soil Moisture Using Polarimetric Radar Data"

Electromagnetic scattering from a rough surface is a function of both surface roughness and dielectric constant of the scattering surface. Therefore, in order to estimate soil moisture of a bare surface accurately from radar measurements, the effects of surface roughness must be compensated for properly. Several algorithms have been developed to estimate soil moisture from a polarimetric radar image, all with limited ranges of applicability. No theoretical algorithm has been reported to retrieve volumetric soil moisture of a vegetated surface. In this paper, we examine a different approach to estimate soil moisture that exploits the fact that the backscattering cross section from a natural object changes over short timescales mainly due to variations in soil moisture. We develop a model function that expresses copolarized backscattering cross sections (sigmahhand sigmavv) in terms of volumetric soil moisture using L-band experimental data for both bare and vegetated surfaces. In order to estimate soil moisture, two unknowns in the model function must be determined. We propose a viable approach to determine these two unknowns using combined radiometer and radar data. This time-series approach also provides a framework to utilize aprioriknowledge on soil moisture to improve the retrieval accuracy of volumetric soil moisture. We demonstrate that this time-series algorithm is a simple and robust way to estimate soil moisture for both bare and vegetated surfaces. [J386]

"Unsupervised Synthetic Aperture Radar Image Segmentation Using Fisher Distributions"

A new and fast unsupervised technique for segmentation of high-resolution synthetic aperture radar (SAR) images into homogeneous regions is proposed. This technique is based on Fisher probability density functions (pdfs) of the intensity fluctuations and on an image model that consists of a patchwork of homogeneous regions with polygonal boundaries. The segmentation is obtained by minimizing the stochastic complexity of the image. Different strategies for the pdf parameter estimation are analyzed, and a fast and robust technique is proposed. Finally, the relevance of the proposed approach is demonstrated on high-resolution SAR images. [J387]

"Detection of Single Scatterers in Multidimensional SAR Imaging"

Multidimensional synthetic aperture radar (SAR) imaging is a technique based on coherent SAR data combination for space (full 3-D) and space deformation-velocity (4-D) analysis. It is an extension of the concepts of SAR interferometry and differential interferometry SAR and offers new options for the analysis and monitoring of ground scenes. In this paper, we consider the problem of detecting single scatterers for localization and monitoring issues. To this end, we resort to a constant false alarm rate (CFAR) detection scheme which can be synthesized according to three different design criteria: generalized likelihood ratio test, Rao test, and Wald test. At the analysis stage, the performance of the aforementioned detector is compared to that of a previously proposed CFAR scheme, based on the multi-interferogram complex coherence and widely used in persistent scatterer interferometry. The analysis is conducted both on simulated and on real SAR data, acquired by ERS-1/2 satellites. Finally, Cramer-Rao lower bounds for the estimation of the scatterer elevation and velocity are provided. [J388]

"Ultrawideband (UWB) Radar Imaging of Building Interior: Measurements and Predictions"

In this paper, we explore using the ultrawideband radar technology for sensing through-the-wall imaging. We conducted a field experiment with our in-house designed impulse-based radar, in which a stripmap synthetic aperture radar (SAR) geometry was employed in mapping an abandoned army barrack building with a large footprint area. The images obtained from two sides of the building were combined in order to obtain the full building layout, including the interior structure. Computer simulations performed with Xpatch, a physical optics-based ray tracing code, are used to explain some phenomena observed in the measured SAR images. [J389]

"Fundamentals of Radar Signal Processing (Richards, M.A.; 2005) [JBook review]"

This book introduces the fundamental concepts of radar by building upon digital signal processing concepts. It provides a thorough covering of all of the basic radar topics, in addition to more advanced topics, such as CFAR detection, synthetic aperture radar (SAR), and space-time adaptive processing (STAP). The book is clear, concise, and informative, and represents a valuable resource for both the classroom and the professional world. [J390]

"On the Combination of Multisensor Data Using Meta-Gaussian Distributions"

With the ever-increasing number and diversity of Earth observation satellites, it steadily becomes more important to be able to analyze compound data sets consisting of different types of images acquired by different sensors. In this paper, we examine different ways of obtaining joint distributions of such images, and we propose a method that enables incorporation of correlations between images while keeping a good fit to the marginal distributions. The approach basically consists of two steps. First, the marginal densities are specified. Based on this specification, each marginal variable is transformed to a normal distributed variable. The joint distribution of the transformed variables is assumed to be multivariate normal. Transforming back to the original scale gives a joint distribution with dependence, where the initial marginal distributions are preserved. The parameters of the new joint distribution can be estimated. The focus is on marginal distributions that are Gamma, K, or Gaussian, although any distribution could be considered. The joint distributions produced by the transformation method can be used in supervised classification of radar and optical images. Results obtained for a set of four-look synthetic aperture radar (SAR) images, as well as a combination of SAR and optical images, are presented. [J391]

"Focusing Spaceborne/Airborne Hybrid Bistatic SAR Data Using Wavenumber-Domain Algorithm"

This paper focuses on the bistatic synthetic aperture radar (SAR) data processing in a spaceborne/airborne hybrid bistatic configuration. Due to the extreme differences in platform velocities and slant ranges, the airborne system operates in the inverse sliding-spotlight mode, while the spaceborne system works in the sliding-spotlight mode to achieve a tradeoff between azimuth scene size and azimuth resolution. In this extreme bistatic configuration, our original bistatic formula shows a limitation of accurately describing the bistatic point-target reference spectrum, owing to the assumption of equal contributions of transmitter and receiver to the total Doppler spectrum. We extend our previous formula using the weighting operation where the weighting factor is the ratio of the azimuth time-bandwidth product (TBP) of the platform to the total azimuth TBP. In this paper, the bistatic-deformation and azimuth-dependent range-cell-migration terms were removed with phase multiplications performed blockwise in range-azimuth subsections. The remaining quasi-monostatic term shows the characteristic of the conventional monostatic SAR besides an additional azimuth-scaling term. For the monostatic characteristic, any precision monostatic SAR processing algorithms can handle. In this paper, we prefer the wavenumber-domain algorithm (also known as Omega-K), since it can accurately correct the range dependence of the range-azimuth coupling, as well as the azimuth-frequency dependence. For the azimuth-scaling term, an inverse scaled Fourier transformation is performed to correct it. Finally, a hybrid spaceborne/airborne simulation experiment is conducted to validate the proposed processing procedure. [J392]

"On the performance analysis of composite multipath/shadowing channels using the G-distribution"

Composite multipath fading/shadowing environments are frequently encountered in different realistic scenarios. These channels are generally modeled as a mixture of Nakagami-m multipath fading and log-normal shadowing. The resulting composite probability density function (pdf) is not available in closed form, thereby making the performance evaluation of communication links in these channels cumbersome. In this paper, we propose to model composite channels by the G-distribution. This pdf arises when the log-normal shadowing is substituted by the inverse-Gaussian one. This substitution will prove to be very accurate for several shadowing conditions. In this paper we conduct a performance evaluation of single-user communication systems operating in a composite channel. Our study starts by deriving an analytical expression for the outage probability. Then, we derive the moment generating function of the G-distribution, hence facilitating the calculation of average bit error probabilities. We also derive analytical expressions for the channel capacity for three adaptive transmission techniques, namely, i) optimal rate adaptation with constant power, ii) optimal power and rate adaptation, and iii) channel inversion with fixed rate. [J393]

"Study of Hypersaline Deposits and Analysis of Their Signature in Airborne and Spaceborne SAR Data: Example of Death Valley, California"

Field measurements of dielectric properties of hypersaline deposits were realized over an arid site located in Death Valley, CA. The dielectric constant of salt and water mixtures is usually high but can show large variations, depending on the considered salt. We confirmed values observed on the field with laboratory measurements and used these results to model both the amplitude and phase behaviors of the synthetic aperture radar (SAR) signal at C- and L-bands. Our analytical simulations allow reproducing specific copolar signatures observed in both Airborne SAR (AIRSAR) and Spaceborne Imaging Radar (SIR-C) data, corresponding to the saltpan of the Cottonball Basin. More precisely, the main objective of the present paper is to understand the influence of soil salinity as a function of soil moisture on the dielectric constant of soils and then on the backscattering coefficients recorded by airborne and spaceborne SAR systems. We also propose the copolarized backscattering ratio and phase difference as indicators of moistened and salt-affected soils. More

precisely, we show that these copolar indicators should allow monitoring of the seasonal variations of the dielectric properties of saline deposits at both C- and L-bands. Because of the frequency dependence of the ionic conductivity, we also show that L-band SAR systems should be efficient tools for detecting both soil moisture and salinity, while C-band SAR systems are more suitable for the monitoring of soil moisture only. Through the study of terrestrial evaporitic environments by means of spaceborne SAR systems, our results could also be of great interest for defining future planetary missions, particularly for the exploration of Mars. [J394]

"The Two-Scale BPM Scattering Model for Sea Biogenic Slicks Contrast"

Sea oil slick observation by means of synthetic aperture radar is still a scientific and operational challenge. In this paper, the sea surface scattering with and without biogenic slicks is analyzed by using the two-scale Boundary Perturbation Method scattering model. The surface slick is supposed to modify both the full-range sea surface spectrum and the slope probability density function by means of the Marangoni damping and by a reduced friction velocity. In this paper, the full-range Universite Catholique de Louvain sea surface spectrum is considered. A new contrast model, which overcomes the drawbacks of the contrast model based on the untilted Small Perturbation Method scattering model, is presented and illustrated in some L- and C-band biogenic slick cases. [J395]

"Characterizing L-Band Scattering of Paddy Rice in Southeast China With Radiative Transfer Model and Multitemporal ALOS/PALSAR Imagery"

Rice is a major food supply in southeast China. With increased population and urbanization, reliable rice mapping is critical in this region. Because of frequent cloud cover and precipitation during the rice-growing season, it is difficult to conduct large-area rice monitoring with optical remote sensing techniques. L-band synthetic aperture radar (SAR), with its all-weather day and night imaging and canopy penetration capabilities, provides a unique alternative. In this study, a first-order radiative transfer model was developed to simulate L-band scattering properties of paddy rice. Three Advanced Land Observing Satellite (ALOS)/Phased-Array-Type L-band Synthetic Aperture Radar (PALSAR) images in dual-polarization mode (HH and HV) acquired in early tillering (June 28, 2007), tillering (August 13, 2007), and heading (September 28, 2007) stages were processed to test the temporal variation of rice backscatter. It was found that plant height and leaf mass amount were the two major structural parameters that contributed to rice backscatter in PALSAR images. The variation of the simulated HH backscatter matched with PALSAR observations in sample fields, although the simulated backscatter coefficients were around 3 dB lower than image-extracted values. Leaf volume scattering and leaf-ground double bounce were found as the two major scattering components in L-band HH polarization and increased with leaf layer height and density. This paper demonstrated that L-band HH backscatter was more sensitive to rice's structural variation than the VV backscatter and may therefore be more useful in rice mapping and modeling studies. [J396]

"MCA: A Multichannel Approach to SAR Autofocus"

We present a new noniterative approach to synthetic aperture radar (SAR) autofocus, termed the multichannel autofocus (MCA) algorithm. The key in the approach is to exploit the multichannel redundancy of the defocusing operation to create a linear subspace, where the unknown perfectly focused image resides, expressed in terms of a known basis formed from the given defocused image. A unique solution for the perfectly focused image is then directly determined through a linear algebraic formulation by invoking an additional image support condition. The MCA approach is found to be computationally efficient and robust and does not require prior assumptions about the SAR scene used in existing methods. In addition, the vector-space formulation of MCA allows sharpness metric optimization to be easily incorporated within the restoration framework as a regularization term. We present experimental results characterizing the performance of MCA in comparison with conventional autofocus methods and discuss the practical implementation of the technique. [J397]

"Spaceborne Spotlight SAR Interferometry With TerraSAR-X"

Recently, synthetic aperture radar (SAR) data with 1-m resolution acquired by satellites in spotlight mode became available to the public. In this paper, we elucidate the differences between interferometric processing of strip map and of spotlight SAR data, and we outline adequate algorithms for key processing steps such as azimuth Doppler filtering. We further present first TerraSAR-X spotlight interferograms, together with an evaluation of the paraeters that are critical for interferometry. Our results indicate a very good geometric accuracy, stability, and phase fidelity of the TerraSAR-X sensor and its products. From the interferograms, we are able to determine the heights of larger buildings and millimeter-scale structural deformation in several examples. The high detail level of imaged buildings and the good temporal phase coherence of urban areas in X-band make spotlight interferometry an exciting processing technique that enables new applications such as

surveying individual buildings. [J398]

"Polarimetric Dual-Baseline InSAR Building Height Estimation at L-Band"

This letter generalizes a multibaseline interferometric synthetic aperture radar (InSAR) signal model to the polarimetric scenario. Based on this formulation, two high-performance spectral analysis techniques are adapted to process multibaseline Pol-InSAR observations. These new methods enhance the height estimation of scatterers by calculating optimal polarization combinations and allow the determination of their physical characteristics. Applying the proposed algorithms to urban environments, the building layover problem is analyzed by means of polarimetric dual-baseline InSAR measurements: the ground and building height are estimated. The techniques are validated using dual-baseline Pol-InSAR data acquired by DLR's Experimental SAR (E-SAR) system over Dresden city. [J399]

"An Efficient Method for Performance Monitoring of Active Phased Array Antennas"

Modern synthetic aperture radars (SARs) are equipped with active phased array antennas to electronically generate various antenna beams. The TerraSAR-X satellite is a high resolution SAR system launched in June 2007. Its active phased array X-band antenna hosts 384 transmit/receive modules (TRMs) for controlling the electronic beam steering in azimuth and elevation direction. The precise modeling of the antenna performance is only possible if the actual characteristics of each individual TRM are monitored. TerraSAR-X has been equipped with an innovative characterization mode based on a coding technique, which is the so-called pseudonoise gating method. The individual and simultaneous characterization of all TRMs is realized under most realistic conditions with power supply loads like in nominal radar operation. For the first time, this novel technique has been applied on a spaceborne SAR system. [J400]

"Model-Based Compensation of Topographic Effects for Improved Stem-Volume Retrieval From CARABAS-II VHF-Band SAR Images"

A limiting factor that has been identified for stem-volume retrieval in coniferous forests using VHF synthetic aperture radar is that the backscatter varies depending on ground topography. On sloping ground, the backscatter from a forest is reduced, since the dominant ground-trunk double-bounce scattering mechanism is changed. This leads to underestimation of stem volume, and the variations caused by topography can obscure real variations in stem volume. By using multiple images acquired with different flight headings and combining the image information with ground-topography data in a model-based inversion method, we are able to compensate for the ground-topography influence on the backscatter. The inversion method is based on image segmentation and the optimal estimation method. Using four or more images from the CARABAS-II system and a coarse digital elevation model with 50-m horizontal grid, the stem volume can be retrieved with an average root-mean-square error (rmse) of less than 60 m3ha-1for stem volumes in range of 80-700 m3ha-1(in terms of above-ground biomass, this is equivalent to an rmse of less than 40 ton ldr ha-1over the range of 50-400 ton ldr ha-1). The retrieval accuracy is similar to that previously obtained for similar forests standing on flat and horizontal ground. [J401]

"A Fast and Accurate Far-Field Pseudopolar Format Radar Imaging Algorithm"

A novel imaging algorithm to be used under the condition of having an image scene in the far field of a linear radar aperture is presented. This is an application scenario that is drastically different from those of spaceborne and airborne synthetic aperture radar (SAR) systems, which has not been properly addressed to date. The technique is particularly tailored for a stepped-frequency continuous wave (CW) or frequency-modulated CW radar. The radar aperture must be linear and can be formed either with a physical or synthetic array. With the suggested method, the radar reflectivity of the image scene is obtained through an interpolation-free series expansion, where only 2-D fast Fourier transforms of the frequency-domain backscatter data are required. The resulting image is sampled on a ldquopolarlikerdquo or pseudopolar grid, which is introduced to simplify the formulation. The main advantages of this method are its extremely low computational cost and the high accuracy of the resulting imagery. The technique is extensively validated both with numerical simulations and two ground-based SAR data sets. Last but not least, numerical simulations show that this technique can be used with an ultrawideband radar of 1 GHz of bandwidth. [J402]

"Exploitation of Ship Scattering in Polarimetric SAR for an Improved Classification Under High Clutter Conditions"

This paper evaluates the potentialities of polarimetric ship scattering for basing classification methods that provide reasonable performance within cluttered scenes. Both simulated and airborne polarimetric synthetic

aperture radar (SAR) images have been used to validate the conclusions of a previous phenomenological study. Numerical simulations have been carried out with GRECOSAR, a polarimetric interferometric SAR simulation tool that is able to process highly complex targets with a fast and accurate radar-cross-section prediction module. A representative set of scenarios has been defined, which includes various realistic ship models, sea states, and imaging geometries. In all of them, a two-scale sea surface model precisely accounting for sea-ship interaction and sea clutter has been added. The analysis of different images has shown that, with an adequate spatial resolution, ships may be characterized by a particular spatial arrangement and polarization state distribution of dominant scattering centers. This feature has allowed one to propose a new classification algorithm, which shows a promising behavior after various preliminary tests. In this paper, the performance of this technique is further evaluated with realistic clutter. The results show that robust classification is possible even in highly cluttered scenes if quad-pol imagery is available. On the contrary, in low clutter conditions, the usage of less restrictive solutions, like circular dual-pol schemes, is feasible and may still get an acceptable performance. [J403]

"Windowed Fourier Transform for Noise Reduction of SAR Interferograms"

In this letter, since these methods are able to process signals locally, two spatial frequency analyses including windowed Fourier transform and wavelet transform are used to reduce synthetic aperture radar interferometric phase noise. [J404]

"Estimation of Surface Roughness Parameter in Intertidal Mudflat Using Airborne Polarimetric SAR Data"

The coastal zones of the Korean peninsula are well known for their large tide ranges and vast expanse of intertidal flats. In this paper, methods of extracting the roughness of the scattering surface of intertidal mudflats from polarimetric synthetic aperture radar (SAR) data have been investigated. The L-band NASA/Jet Propulsion Laboratories airborne SAR data, which were acquired in the intertidal zone during PACRIM-II Korea campaign, were used to estimate the roughness of intertidal mudflats. Surface roughness can be utilized as a useful parameter to monitor the fishery activities in intertidal flats as well as the changes in textural characteristics of surface sediments. In order to retrieve roughness parameters, such as the rms height and the correlation length, of intertidal mudflats, three types of roughness inversion algorithms, based on the Integral Equation Method (IEM), semiempirical, and extended-Bragg models, have been investigated and developed. The inversion algorithms based on the IEM and semiempirical models can be applied to the dual-polarized SAR, while the extended-Bragg model-based inversion approach is also applicable to the fully polarimetric SAR observations. Results indicate the fully polarimetric approach is more pertinent to monitor geophysical parameters from space than the dual polarimetric approach, even if it is possible to reduce the number of unknown surface variables in the specific case of inversion problems. [J405]

"Through-the-Wall SAR Attributed Scattering Center Feature Estimation"

We consider characterization of building interior structure from two-pass interferometric circular synthetic aperture radar data. We model returns from complex building structures as the sum of the responses from scattering primitives-plates, dihedrals, and trihedrals-observed through transfer functions that characterize both the transmission through and reflection from dielectric surfaces. Maximum-likelihood estimates for the location of primitive features and wall propagation/reflection parameters are obtained through a two-stage detection-and-estimation algorithm. We employ a sparse reconstruction algorithm to detect primitive signatures in the presence of wall effects and refine our estimates using a nonlinear minimization of local cost functions. We show that using simplified wall and primitive models, we can extract geometrically relevant features which can be combined to reveal 3-D floorplan estimates of buildings. Examples illustrate the effectiveness of the feature extraction approach. [J406]

"New SAR Processor Based on Matched Subspace Detectors"

This paper deals with a new synthetic aperture radar (SAR) processor based on a subspace detector designed for man-made target (MMT) detection. As MMTs are more accurately described by a set of canonical elements than with isotropic points, we develop a new algorithm which aims at using new models, instead of the isotropic point model commonly used in SAR processors. A subspace detector matched to canonical elements is included in the SAR processing. The implementation and the optimization of subspace detector SAR (SDSAR) algorithm is described. Simple examples of MMT detection in simulations and real data with a target hidden in a forest show the power of our approach. The SDSAR algorithm is shown to be the first robust and tractable algorithm relying on realistic scattering assumptions about the target. [J407]

"Comparison of SAR-Based Snow-Covered Area Estimation Methods for the Boreal Forest Zone"

Spaceborne synthetic aperture radar data have been utilized for regional-scale snow-covered area (SCA) monitoring for several years. Different methods have been developed and demonstrated for different geographical regions. A method utilizing a single reference image for SCA estimation has been shown to function well on mountainous and nonforested regions. For the boreal forest zone, a method using two reference images and a forest compensation procedure has been previously utilized. The single-reference-image method is evaluated here for the boreal forest zone, and its performance is compared with the Helsinki University of Technology (TKK) SCA method that is specifically developed for boreal forest regions. The SCA evaluations are carried out using Radarsat-1 data for the snow-melt seasons of 2004-2007. The SCA estimation accuracies for the radar-based methods are determined using optical satellite-based SCA data as reference. The results show that SCA estimation using a single reference image is usable for the boreal forest zone, although the accuracy is significantly weaker than that of the TKK-developed boreal forest-specific SCA method. The best accuracy obtained shows a root-mean-square error (rmse) of 0.176 for the single-reference-image method and an rmse of 0.123 for the TKK SCA method. [J408]

"Through-the-Wall Imaging Using Differential SAR"

An algorithm for imaging of targets behind walls is proposed to reduce the wall reflection and enhance the signal-to-clutter ratio. The image formation is based on differential synthetic-aperture-radar image formation employing a continuous-wave radar system. In this approach, instead of using individual backscattered signals, the image is formed by employing the difference signals obtained by subtracting two successive signals along the track. This way, specular reflections are totally eliminated without the need for the knowledge of the wall parameters. This also affects the point target response which is corrected by an integration process. By using backscattered fields from small trihedral corner reflectors behind a poured concrete wall, measured over a frequency band of 1-2.5 GHz, the proposed method is demonstrated. [J409]

"Phenomenological Vessel Scattering Study Based on Simulated Inverse SAR Imagery"

This paper presents a study on the origin of the dominating scattering mechanisms observed in polarimetric synthetic aperture radar (SAR) images of ships. The study has been made by using numerical simulations, which have been carried out with a radar cross section (RCS) prediction tool (GRaphical Electromagnetic COmputing) and a SAR simulator. Extensive series of simulations has been run for realistic 3-D geometrical models of ships with various sizes. Different radar parameters, aspect angles, and sea surface states have been considered in the scenario. Data analysis with coherent target decompositions has indicated characteristic polarimetric signatures for particular ships within a specific range of viewing angles. This happens at highly oblique incidences where the responses appear to be less sensitive to changes in the operating frequency and bearing angles. Under such conditions, ship scattering can be schematized by the distribution of a set of guide scatterers with high RCS. Their positions and polarimetric characteristics are quantitatively summarized in a new feature vector, which has been proposed to be the basis for classification algorithms. Key ideas about this vector are presented at the end of this paper, jointly with some examples related to three different ships. Recent publications have shown that they can be successfully cast within a new unsupervised vessel classification scheme. [J410]

"Polarization Symmetric Scatterer Metric Space"

The coherent polarization scattering matrix decomposition presented in Cameron et al. brought attention to the importance of Symmetric Scatterer Space, the space of scattering matrices corresponding to symmetric scatterers. Each symmetric scatterer scattering matrix can be associated with a complex number z, the scatterer-type parameter, where |z| les 1. A distance measure, d(z1, z2), was defined on Symmetric Scatterer Space providing a means of comparing scattering matrices. It will be demonstrated that Symmetric Scatterer Space is a metric space with metric d(z1, z2). A new mapping of the Unit Disc representation of Symmetric Scatterer Space to a sphere is also presented along with a metric on the sphere, ds(thetas1, phi1; thetas2, phi2), that is equivalent to the metric d(z1, z2) on the Unit Disc. [J411]

"Analysis by Wavelet Frames of Spatial Statistics in SAR Data for Characterizing Structural Properties of Forests"

Spatial statistics (texture) in SAR backscatter data of forested areas bears information on structural and geometric properties that could be useful in mapping forest extent, species type, and stages of regeneration or degradation. Based on a previously published theoretical approach in deriving texture measures from SAR data using wavelet frames, experiments are reported that aim to characterize, from a purely observational point of

view, wavelet texture measures' sensitivity with respect to target structural properties and SAR configurations. Suitable analytical tools are introduced to represent dependences in the combined space-scale-polarization domain through signatures that condense information in graphical form. Moreover, class separability, afforded by wavelet texture measures in a supervised classification setting and based on the Fischer linear discriminant analysis, is considered. This paper focuses on two structurally different forest types (tropical rain forest in the Central Africa Congo Floodplain and mixed-species wooded savanna in Queensland, Australia) and uses data from orbital radars, particularly from the Japanese Advanced Land Observing Satellite Phased Arrayed L-band Synthetic Aperture Radar. The analysis indicated that textural information from spatial statistics can provide, in some cases, better class separability in forest mapping with respect to one-point statistics, although spatial resolution in texture products is reduced. However, dependences of texture measures on the polarization state are detected, particularly in forests where a greater diversity of scattering mechanisms occurs. [J412]

"Estimation of the Surface Velocity Field of the Aletsch Glacier Using Multibaseline Airborne SAR Interferometry"

This paper presents a methodology to process airborne interferometric synthetic aperture radar (SAR) data to measure surface velocity fields (SVFs) of temperate glaciers, and applies it to data acquired over the Aletsch glacier. The first part of this paper deals with the main limitation in airborne interferometric SAR to retrieve reliable interferometric products, namely, the existence of the so-called residual motion errors-inaccuracies on the order of a few centimeters in the navigation system. An extended multisquint approach is proposed for their estimation in the case of nonstationary scenes. The second part of this paper expounds an efficient methodology to derive SVFs with airborne systems, where the line-of-sight displacement is estimated using differential interferometry and the along-track component by estimating the azimuth coregistration offsets. The necessary steps to finally obtain the 3-D SVF are also presented, as well as the possibility of combining different acquisition geometries. Airborne interferometric SAR data acquired by the Experimental SAR system of the German aerospace center over the Aletsch glacier, located in the Swiss Alps, are used to evaluate the performance of the proposed approach. The motion of the corner reflectors deployed in the scene is retrieved with an accuracy between 1 and 5 cm/day using L-band data. [J413]

"Analysis of Phase Error Effects on Stripmap SAS"

It is often of interest to consider how uncompensated platform motion can degrade the ideal point scatterer response (PSR) of a synthetic aperture sonar (SAS). This information can be used to shape the design of the sonar itself as well as that of the platform carrying it. Also, knowledge of how certain types of motion affect a SAS image can reduce the time spent in troubleshooting motion estimation and compensation schemes. In the field of spotlight-mode synthetic aperture radar (SAR), the effects of phase errors across the synthetic aperture are well documented (for example, Chapter 5 of Carrara, 1995). The counterpart problem for the stripmap mode is less well developed in the literature. This paper explores the effects of uncompensated phase errors on stripmap imagery and shows that, under certain conditions, they are similar to those for spotlight mode processing. [J414]

"Time-Reversal Detection Using Antenna Arrays"

The paper studies detection of a target buried in a rich scattering medium by time reversal. We use a multi-static configuration with receive and transmit arrays of antennas. In time reversal, the backscattered field is recorded, time reversed, and retransmitted (mathematically or physically) into the same scattering medium. We derive two array detectors: the time-reversal channel matched filter when the target channel response is known; and the time-reversal generalized-likelihood ratio test (TR-GLRT) when the target channel response is unknown. The noise added in the initial probing step to the time-reversal signal makes the analysis of the TR-GLRT detector non trivial. The paper derives closed form expressions for the signal-to-noise ratio gain provided by this detector over the corresponding conventional clutter subtraction energy detector in the two extreme conditions of weak and strong (electronic additive) noise and shows that time reversal provides, under weak noise, the optimal waveform shape to probe the environment. We analyze the impact of the array configuration on the detection performance. Finally, experiments with electromagnetic data collected in a multipath scattering laboratory environment confirm our analytical results. Under the realistic conditions tested, time reversal provides detection gains over conventional detection that range from 2 to 4.7 dB. [J415]

"Brightness-Temperature Retrieval Methods in Synthetic Aperture Radiometers"

Brightness-temperature retrieval techniques for synthetic aperture radiometers are reviewed. Three different approaches to combine measured visibility and antenna temperatures, along with instrument characterization data, into a general equation to invert are presented. Discretization and windowing techniques are briefly

discussed, and formulas for reciprocal grids using rectangular and hexagonal samplings are given. Two known techniques are used to invert the equation, namely, inverse Fourier transform and G-matrix pseudoinverse. The proposed preprocessing approaches combined with these two inversion methods are implemented with real data measured by an airborne Y-shaped interferometric radiometer over land and water, and are compared. The images indicate that best results are obtained when inverting an incremental visibility obtained after substracting a term that includes the individual antenna temperatures, the physical temperatures of the receivers, and a flat-target response directly measured from cold-sky looks. [J416]

"Measurement of Ionospheric Faraday Rotation in Simulated and Real Spaceborne SAR Data"

The influence of the atmosphere on a frequency-modulated electromagnetic wave traversing the ionosphere is becoming increasingly important for recent and upcoming low-frequency and wide-bandwidth spaceborne synthetic aperture radar (SAR) systems. The ionized ionosphere induces Faraday rotation (FR) at these frequencies that affects radar polarimetry and causes signal path delays resulting in a reduced range resolution. The work at hand introduces a simulation model of SAR signals passing through the atmosphere, including both frequency-dependent FR and path delays. Based on simulation results from this model [proven with real Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar (PALSAR) data], estimation of FR in quad-polarized SAR data using the given approach is shown for raw, range-compressed, and focused radar images. Path delays and signal chirp bandwidth effects are considered. Investigations discuss the suitability of raw and compressed data versus combination of total electron content maps with the Earth's magnetic field for FR estimation and deduced from a large number of analyzed PALSAR data sets. [J417]

"Enhanced SAR-Based Snow-Covered Area Estimation Method for Boreal Forest Zone"

In this paper, an enhanced method for fractional snow-covered area (SCA) estimation for the boreal forest zone is presented. The new approach, based on utilizing weather station data alongside with spaceborne synthetic aperture radar (SAR) imagery, leads to a significantly improved estimation accuracy. While the Helsinki University of Technology (TKK) SAR-based SCA estimation method serves as a basic tool in the SCA estimation, the ground-based weather station observations are employed to still strengthen its performance at the nearly melt-off or totally melt-off conditions. The method is still improved by a new reference image selection process, leading to more accurate results and an easier adaptivity to new areas. The SCA estimation accuracy of the new enhanced method is compared with optical satellite-based SCA data. Evaluation of the method is carried out using Radarsat wide-swath data for the snow-melt seasons of 2004-2006. The results show a significant increase in accuracy when the enhanced SCA method is applied. Correlation between the radar-based and optical comparison data increases from 0.914 to 0.947 and root-mean-square error improves from 0.151 to 0.123 with the new method. Traditionally, the TKK method has provided SCA estimates for Finnish third-order subdrainage basins. In this paper, the method is adapted to produce SCA estimates also in 5 times 5 km spatial resolution. The analyses for the 5 times 5 km method indicate poorer estimation accuracy than the nominal drainage-basin-based method. [J418]

"Chirp-Scaling Algorithm for Bistatic SAR Data in the Constant-Offset Configuration"

This paper discusses the processing method for bistatic SAR data in the constant-offset configuration. The constant-offset configuration is also known as the azimuth stationary or invariant configuration where transmitter and receiver follow each other, moving on identical velocity vector. In this paper, the proposed processing method for bistatic SAR data is based on Loffeld's bistatic formula that consists of two terms, i.e., the quasi-monostatic (QM) term and bistatic-deformation (BD) term. Our basic idea is to linearize the aforementioned two terms and then incorporate the BD term into the QM term to obtain an analogous monostatic spectrum. Based on the new spectrum, any efficient 2-D frequency or range-Doppler domain processor can easily be employed to process the bistatic data, where the Doppler phase parameters of the processor need to be adjusted. In this paper, we concentrate on the application of chirp-scaling-algorithm (CSA) processor. In addition, a bistatic-motion error model is developed where the position deviations of the two platforms are simplified as the bistatic slant-range displacement in the zero Doppler plane. Using this model, the monostatic motion-compensation technique is applied and integrated into CSA to compensate the trajectory deviations of transmitter and receiver. Finally, real and simulated data are used to validate the proposed processing method. [J419]

"Unambiguous Reconstruction and High-Resolution Imaging for Multiple-Channel SAR and Airborne Experiment Results"

Azimuth ambiguity occurs in synthetic aperture radar (SAR) systems due to the well-known constraint of minimum antenna area, particularly at high resolutions and wide swaths. A space time domain method can be utilized to remove this ambiguity if the multiple-channel data are available. In this letter, a modified approach is

presented to determine the filter weight vectors. This approach was successfully applied to the real data, which were collected by an experimental airborne multiple-channel SAR system. The channel imbalance and the error in antenna phase center position are analyzed in detail. [J420]

"Radix- Resolution-Fusion for LASAR via Orthogonal Complement Decomposition"

This letter concerns the resolution-fusion method for linear array 3-D imaging SAR (LASAR). Limited by the length of the linear array, the cross-track resolution of LASAR is often lower than that in the along-track direction. To overcome this disadvantage, we assume that there are two LASAR systems whose trajectories are orthogonal to each other. Thus, we obtain a row low-resolution image and a column low-resolution image of the same scene. Using the orthogonal complement decomposition technique, we fuse the two images into one quasi-high-resolution image. Moreover, we find that the fusion distortion is unavoidable and contains the high-frequency component in both row and column directions. The information loss ratio is (N- 1)2/N2(Ndenotes the ratio of low resolution to high resolution). For a smooth image, the energy loss ratio is near to zero. With the increase of the noise energy, the energy loss ratio increases correspondingly. When the noise submerges the image completely, the energy loss ratio converges to the information loss ratio. [J421]

"An Adaptive and Fast CFAR Algorithm Based on Automatic Censoring for Target Detection in High-Resolution SAR Images"

An adaptive and fast constant false alarm rate (CFAR) algorithm based on automatic censoring (AC) is proposed for target detection in high-resolution synthetic aperture radar (SAR) images. First, an adaptive global threshold is selected to obtain an index matrix which labels whether each pixel of the image is a potential target pixel or not. Second, by using the index matrix, the clutter environment can be determined adaptively to prescreen the clutter pixels in the sliding window used for detecting. The G0distribution, which can model multilook SAR images within an extensive range of degree of homogeneity, is adopted as the statistical model of clutter in this paper. With the introduction of AC, the proposed algorithm gains good CFAR detection performance for homogeneous regions, clutter edge, and multitarget situations. Meanwhile, the corresponding fast algorithm greatly reduces the computational load. Finally, target clustering is implemented to obtain more accurate target regions. According to the theoretical performance analysis and the experiment results of typical real SAR images, the proposed algorithm is shown to be of good performance and strong practicability. [J422]

"Suitability and Limitations of ENVISAT ASAR for Monitoring Small Reservoirs in a Semiarid Area"

In semiarid regions, thousands of small reservoirs provide the rural population with water, but their storage volumes and hydrological impact are largely unknown. This paper analyzes the suitability of weather-independent radar satellite images for monitoring small reservoir surfaces. The surface areas of three reservoirs were extracted from 21 of 22 ENVISAT Advanced Synthetic Aperture Radar scenes, acquired bimonthly from June 2005 to August 2006. The reservoir surface areas were determined with a quasi-manual classification approach, as stringent classification rules often failed due to the spatial and temporal variability of the backscatter from the water. The land-water contrast is critical for the detection of water bodies. Additionally, wind has a significant impact on the classification results and affects the water surface and the backscattered radar signal (Bragg scattering) above a wind speed threshold of 2.6 mmiddots-1. The analysis of 15 months of wind speed data shows that, on 96% of the days, wind speeds were below the Bragg scattering criterion at the time of night time acquisitions, as opposed to 50% during the morning acquisition time. Night time acquisitions are strongly advisable over day time acquisitions due to lower wind interference. Over the year, radar images are most affected by wind during the onset of the rainy season (May and June). We conclude that radar and optical systems are complimentary. Radar is suitable during the rainy season but is affected by wind and lack of vegetation context during the dry season. [J423]

"Implementation of SDR Digital Beamformer for Microsatellite SAR"

The hardware reconfiguration feature of a software-defined radio (SDR) architecture can support multiple modes of a digital beamformer (DBF) striving for compactness and efficient processing power, which are important issues for microsatellite synthetic aperture radar (SAR) systems. In this letter, based on the SDR architecture, a DBF system, consisting of multiple beam, direction-of-arrival (DOA) estimation, and null-steering operation modes, is realized using a field-programmable gate array (FPGA) processor. Since the hardware reconfiguration has to be processed with minimal delay, the FPGA hardware must be of modularized design. Different modes can share the common module during mode switching. Experimental results verify the performance of DOA, null steering, and mode switching. The processing time of each DBF mode is less than the cross-range pulse repetition interval of the microsatellite SAR system. [J424]

"Shape and Motion Reconstruction from 3D-to-1D Orthographically Projected Data via Object-Image Relations"

This paper describes an invariant-based shape- and motion reconstruction algorithm for 3D-to-1D orthographically projected range data taken from unknown viewpoints. The algorithm exploits the object-image relation that arises in echo-based range data and represents a simplification and unification of previous work in the literature. Unlike one proposed approach, this method does not require uniqueness constraints, which makes its algorithmic form independent of the translation removal process (centroid removal, range alignment, etc.). The new algorithm, which simultaneously incorporates every projection and does not use an initialization in the optimization process, requires fewer calculations and is more straightforward than the previous approach. Additionally, the new algorithm is shown to be the natural extension of the approach developed by Tomasi and Kanade for 3D-to-2D orthographically projected data and is applied to a realistic inverse synthetic aperture radar imaging scenario, as well as experiments with varying amounts of aperture diversity and noise. [J425]

"Effects of Birefringence Within Ice Sheets on Obliquely Propagating Radio Waves"

In this paper, effects of birefringence on radio waves obliquely propagating though polar ice sheets are examined to facilitate interpretations of bistatic and side-looking radar data. A formalism applicable for arbitrary radar configurations is developed to predict the returned power from within and beneath the ice sheets that have arbitrary alignments of ice crystals (ice fabrics). We applied this formalism to a range of ice fabrics found in ice cores and assessed the effects of birefringence in terms of ray-path configurations, ice fabrics, and radar frequency. Predicted frequency dependence of the bed return power replicates prominent features observed at Greenland NGRIP ice-core site. Results show that birefringence in ice of 1 km or more thickness with strong (weak) fabric can reduce the power returned from the bed 2 dB or more at frequencies higher than 200 MHz (20 MHz) as compared to isotropic ice. This suggests that quantitative interpretation of the power returned from the bed requires careful assessment of birefringence almost everywhere over the ice sheets. Application of this formalism also suggests a radar-frequency range usable for attenuation measurements, possible effects of fabric on synthetic aperture radar processing, and a feasibility of remote sensing of ice fabric. [J426]

"Four-Dimensional SAR Imaging for Height Estimation and Monitoring of Single and Double Scatterers"

The superposition of contributions from different stable targets within the same pixel is a phenomenon that may impair the imaging and monitoring of ground scatterers via the multipass synthetic aperture radar (SAR) interferometry technique. Three-dimensional SAR imaging, also known as SAR tomography, uses multiple views to profile the scattering power at different heights. This technique has been shown to be capable of separating interfering target responses on real data. Differential SAR tomography has been recently proposed as a technique that extends the potentialities of SAR tomography to the target deformation monitoring. It performs a 4-D space-velocity imaging that enables not only separating interfering targets in elevation but also distinguishing their single slow deformation velocities. This work addresses for the first time the application of 4-D SAR imaging to real data to determine the height and mean deformation velocity of single scatterers and double-scattering mechanisms interfering at high resolution in the same pixel. It also discusses the postprocessing steps required to identify the presence of stable single and double scatterers after elevation-velocity focusing. Moreover, it proposes a technique for the extraction of time series from interfering targets to measure possible nonlinear temporal deformations. [J427]

"LMMSE 3-D SAR Focusing"

Three-dimensional synthetic aperture radar (SAR) imaging, a technique also known as SAR tomography, uses multiple views to extend the capability of SAR systems to 3-D imaging by achieving a profiling of the scattering power at different heights. Multiple views are obtained with the current satellite technology via successive passes of a single antenna SAR sensor over the same scene, but next-generation sensor formations are foreseen to acquire multistatic data. Conventional processing, such as the beamforming, or singular values decomposition inversion is based on geometrical derivations and, hence, assumes the accurate phase calibration and the absence of target decorrelation. This paper analyzes the effects of phase miscalibration due to residual uncompensated atmospheric contribution and temporal decorrelation and proposes a 3-D imaging technique based on a linear minimum mean square error approach. The resulting algorithm extends the possibilities of the conventional processing by carrying out an integration of data that accounts for the aprioridata correlation properties. Hence, it allows handling of the presence of additional stochastic contributions such as: temporal coherence losses and atmospheric phase miscalibration. Moreover, with reference to future bistatic and multistatic systems, it permits an improved coherent integration of data acquired by simultaneous antenna in repeated passes. [J428]

"Exploiting SAR and VHR Optical Images to Quantify Damage Caused by the 2003 Bam Earthquake"

Using satellite sensors to detect urban damage and other surface changes due to earthquakes is gaining increasing interest. Optical images at different resolutions and radar images represent useful tools for this application, particularly when more frequent revisit times will be available with the implementation of new missions and future possible constellations of satellites. Very high resolution (VHR) images (on the order of 1 m or less) may provide information at the scale of a single building, whereas images at resolutions on the order of tens of meters may give indications of damage levels at a district scale. Both types of information may be extremely important if provided with sufficient timeliness to rescue teams. The earthquake that hit the city of Bam, Iran, has been taken as a test case, where QuickBird VHR optical images and advanced synthetic aperture radar data were available both before and after the event. Methods to process these data in order to detect damage and to extract features used to estimate damage levels are investigated in this paper, pointing out the significant potential of these satellite data and their possible synergy. [J429]

"DEM Generation Combining SAR Polarimetry and Shape-From-Shading Techniques"

Estimation of the polarization orientation angle shifts induced by terrain azimuth slope variations is a recently developed application in radar polarimetry. In general, without any prior knowledge on the terrain, two polarimetric SAR (POLSAR) flight passes are required to derive terrain slopes in perpendicular directions for digital elevation model (DEM) generation. Moreover, we note that SAR intensity is a strong indicator of the range component of the terrain slopes. In this letter, we developed a method for DEM generation requiring only one POLSAR flight pass, by combining orientation angle estimation and a shape-from-shading technique. In particular, when limited POLSAR data are available, this POLSAR technique provides an alternative way for DEM generation. National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA/JPL) AIRSAR L-band POLSAR data over Camp Roberts, California, is used to demonstrate the results of the method proposed in this letter, and a DEM derived from simultaneously measured C-band interferometric SAR from NASA/JPL topographic SAR instrument is selected as the comparative ground truth to validate the effectiveness of this single POLSAR method. Analyses and discussions are also included in this letter. [J430]

"Optimum Data Vector Approach to Multibaseline SAR Interferometry Phase Unwrapping"

Phase unwrapping is a key problem not only in all quantitative applications of synthetic aperture radar (SAR) interferometry but also in other fields. In this letter, a new phase unwrapping approach is investigated. Our study is based on the model of the optimum data vector. In order to autocoregister the SAR images, the proposed method takes advantage of the multibaseline optimal weighted joint data vector by extracting all the coherence information available in the neighboring pixels. Moreover, the method employs the projection of the joint signal subspace onto the corresponding noise subspace to estimate the unwrapped interferometric phases (or the terrain heights). The proposed method can accurately determine the dimensions of the noise subspace and provide the robust unwrapped interferometric phases even in the presence of the large image coregistration errors. Moreover, the multibaseline processing idea is a combination of data optimization, image coregistration, interferogram filtering, and phase unwrapping. [J431]

"Hierarchical Feature-Based Classification Approach for Fast and User-Interactive SAR Image Interpretation"

The framework of this paper is focused on semiautomatic fast recognition of areas of interest for fast and user-interactive synthetic aperture radar (SAR) image interpretation for which only a unique intensity SAR image is available. The goal is to label regions into classes significant to a given application in an image, as rapidly as possible. A semiautomated ldquoroughrdquo classification is proposed. It defines the information extraction as a two-level procedure. The technique is based on a first partition image into homogeneous regions using the approach proposed by Galland Then, discrimination characteristics are determined in each homogeneous region. This allows one to automatically obtain a first segmentation of the image into semantic regions of interest. Finally, this segmentation can be easily modified by a user in a limited computational time. At this level, they are considered as ldquoobjects,rdquo to identify which typical class of ground it can be attached to. Among a large set of tested measures, we have selected the most pertinent ones for the considered SAR images. In fact, we will see that to obtain an accurate measures estimation, measures need to be estimated inside a neighborhood as homogeneously as possible. This can be achieved with a reasonable confidence in the proposed approach due to the homogeneity properties of the segmentation technique applied. In this paper, we focus on linear structures, urban structures, agricultural parcels, and forest areas extraction in SAR images. [J432]

"Omega-k Algorithm for Airborne Spatial Invariant Bistatic Spotlight SAR Imaging"

Bistatic spotlight synthetic aperture radar (SAR) which uses a separated transmitter and receiver has been studied intensively due to its flexibility. To reconstruct the image for the bistatic SAR in the parallel track configuration, where the transmitter and the receiver have equal velocity, we modify the omega-k algorithm. Specifically, using the extended Taylor approximation (ETA), we convert the parallel track configuration into the single track configuration. Then, using the principle of the stationary phase, we propose an analytical method to increase the image quality of bistatic SAR systems. [J433]

"Performance of Stereoradargrammetric Methods Applied to Spaceborne Monostatic-Bistatic Synthetic Aperture Radar"

This paper aims to investigate the performance of stereoradargrammetric methods applied to spaceborne monostatic-bistatic synthetic aperture radar (SAR) data for digital elevation model (DEM) generation. Stereoradargrammetric techniques for robust DEM generation were successfully experienced on monostatic repeat-pass SIR-A, SIR-B, SIR-C/X-SAR, ERS1/2, JERS-1, and Radarsat data. However, novel configurations achievable by modern spacecraft flying in formation will allow for the attainment of very large baselines between the antennas in a single-pass bistatic geometry so that the height determination accuracy can benefit from both stereo effect and simultaneous acquisition. Five models for relief reconstruction by monostatic-bistatic SAR stereoradargrammetry are presented, and an error budget is assessed for each of them. Results of the sensitivity analysis exhibit metric accuracy, and therefore, the technique could be applied for height reconstruction as a methodology complementary to SAR interferometry. [J434]

"Improved Sigma Filter for Speckle Filtering of SAR Imagery"

The Lee sigma filter was developed in 1983 based on the simple concept of two-sigma probability, and it was reasonably effective in speckle filtering. However, deficiencies were discovered in producing biased estimation and in blurring and depressing strong reflected targets. The advancement of synthetic aperture radar (SAR) technology with high-resolution data of large dimensions demands better and efficient speckle filtering algorithms. In this paper, we extend and improve the Lee sigma filter by eliminating these deficiencies. The bias problem is solved by redefining the sigma range based on the speckle probability density functions. To mitigate the problems of blurring and depressing strong reflective scatterers, a target signature preservation technique is developed. In addition, we incorporate the minimum-mean-square-error estimator for adaptive speckle reduction. Simulated SAR data are used to quantitatively evaluate the characteristics of this improved sigma filter and to validate its effectiveness. The proposed algorithm is applied to spaceborne and airborne SAR data to demonstrate its overall speckle filtering characteristics as compared with other algorithms. This improved sigma filter remains simple in concept and is computationally efficient but without the deficiencies of the original Lee sigma filter. [J435]

"DEM Reconstruction Accuracy in Multichannel SAR Interferometry"

Interferometric synthetic aperture radar (InSAR) systems allow the estimation of the height profile of the Earth surface. When the height profile of the observed scene is characterized by high slopes or exhibits strong height discontinuities, the height reconstruction obtained from a single interferogram is ambiguous, since the solution of the estimation problem is not unique. To solve this ambiguity and restore the solution uniqueness, multiple interferograms, obtained with different baselines and/or with different frequencies, have to be used (multichannel InSAR). The height profile can then be estimated from multiple interferograms using maximum likelihood (ML) estimation techniques or by means of maximum aposteriori(MAP) estimation techniques, which take into account the relation between adjacent pixels. In this paper, the height estimation accuracy achievable with a given multibaseline interferometric configuration and using the aforementioned estimation techniques in terms of Cramer-Rao lower bound for the ML and of error lower bound for the MAP, is analyzed and discussed. It is shown that the MAP technique outperforms the ML one and that its attainable accuracy is not sensitive to the baselines choice, while mainly depends on the ground slopes. [J436]

"Singular Unit Restoration in Interferograms Based on Complex-Valued Markov Random Field Model for Phase Unwrapping"

In generating a digital elevation map from an interferogram obtained by interferometric synthetic aperture radar, the filtering process is as important as the phase unwrapping process. Before unwrapping, we usually have to restore the data image by reducing so-called singular points (SPs) by filtering process without destroying or smearing delicate fringes. Previously, an effective SP restoration method was proposed based on the complex-valued Markov random field (CMRF) model. However, there is still room for improvement in the definition of SPs and in the formulation of CMRF parameter estimation. In this letter, we propose a novel scheme by introducing a

new concept, namely, the ldquosingular unit.rdquo We also estimate CMRF parameters locally as a weighted sum by taking the distance and SP numbers in sample sites into account. By using this restoration method, we demonstrate a high-performance removal of SPs. We also find that delicate landscape features, which are often lost in conventional filtering, are preserved appropriately. We confirm the quality in higher signal-to-noise ratios obtained against actual height data. [J437]

"A Novel Approach to Range Doppler SAR Processing Based on Legendre Orthogonal Polynomials"

The range Doppler algorithm (RDA) is based on Taylor series expansion for the transfer function (TF) phase component, resulting in increasing phase error as the range frequency or the squint angle increases. We introduce Legendre orthogonal polynomials into synthetic aperture radar data processing steps to replace Taylor series expansion used in approximating the TF phase. A novel range Doppler imaging approach based on Legendre expansion is addressed with an extended RDA as example, and the analytical expressions of the new phase multiplication factors are then derived. The simulation results show that the proposed method provides better focusing performance than the conventional RDA in the same squint case and is more suitable for the large squint mode while there is negligible increment of computation load. [J438]

"Comparison of Compact Polarimetric Synthetic Aperture Radar Modes"

Compact polarimetry is a technique that allows construction of pseudo quad-pol information from dual-polarization synthetic aperture radar (SAR) systems. Compact polarimetry showed promise of being able to reduce the complexity, cost, mass, and data rate of a SAR system while attempting to maintain many capabilities of a fully polarimetric system. In this paper, we study different transmit/receive configurations to determine which polarimetric configurations allow for superior reconstruction of the fully polarimetric data. We discuss modifications of the original reconstruction algorithm proposed by Souyris, which show potential to better reconstruct fully polarimetric data. [J439]

"New ISAR imaging algorithm based on modified Wigner-Ville distribution"

Inverse synthetic aperture radar (ISAR) imaging of air, space or ship targets with complex motion has attracted the attention of many researchers in the past decade. Complex motion of targets induce cross-range scatterer-variant quadratic phase terms, which will degrade the cross-range resolution and affect focusing quality. A new algorithm is proposed for the ISAR imaging of complex moving targets. First, conventional range alignment, phase compensation and range compression are performed over the raw phase history data such that each range bin can be modelled as the sum of several linear frequency modulation or chirp signals. Secondly, a modified-Wigner-Ville distribution (referred to as M-WVD) approach is proposed, which is based on a scale transform in the time-frequency distribution plane and can effectively suppress the troublesome cross-term interference associated with WVD via coherent integration. Finally, the azimuth ISAR image can be obtained via a simple maximisation projection from the two-dimensional accumulated plot to the azimuth dimension. Compared with existing WVD-based ISAR imaging algorithms, the proposed method has the following features: better cross-term interference reduction achieved at no resolution loss, computationally more efficient with no expensive two-dimensional parameter search, and higher signal processing gain because of coherent integration during the whole imaging time. Both numerical and experimental results are provided to demonstrate the performance of the proposed method. [J440]

"Wheat Crop Mapping by Using ASAR AP Data"

The purpose of this paper is to assess the use of C-band HH/VV backscatter ratio for mapping winter wheat. This paper analyzes two temporal series of images acquired in 2006 and 2007 by the Advanced Synthetic Aperture Radar (ASAR) system in alternating polarization (AP) mode, over an agricultural site located in southern Italy. Results on test data show that classification accuracies between 75% and 80% can be achieved by using a single ASAR image, acquired during the peak of the wheat-growing season. To achieve accuracies close to 90%, a spatial averaging at field scale is necessary. [J441]

"Snowpack Characterization in Mountainous Regions Using C-Band SAR Data and a Meteorological Model"

This paper presents a method to characterize snow cover in mountainous regions using dual-polarization C-band synthetic aperture radar (SAR) data. It is demonstrated that an accurate modeling of the liquid water distribution inside the snowpack, using a multilayer meteorological snow model, is required to characterize snow with precision. A multilayer-snow electromagnetic (EM) backscattering model is developed based on the vector

radiative transfer, the strong fluctuation theory, and physical parameters supplied by the meteorological model. However, the limited resolution of the meteorological snow model is insufficient for predicting a refined EM backscattering at a massif scale. An adequate spatial reorganization of these snow profiles, based on a comparison between simulated and measured dual-polarization SAR data, leads to a better estimation of some snowpack parameters. In particular, the monitoring of snow liquid water content is presented improving the capacity of wet snow mapping as compared to a classical SAR-based method. This methodology shows good capacities both for qualitative and quantitative snow assessments, opening the way for a new operational method. [J442]

"Application of Target Decomposition Theorems Over Snow-Covered Forested Areas"

This paper compares two well-known polarimetric decomposition theorems, Cloude-Pottier and Freeman-Durden, applied to L- and C-band Airborne Polarimetric Synthetic Aperture Radar (AIRSAR-POLSAR) data acquired during the Cold-Land Processes Field Experiments. Three field campaigns were carried out in February 2002, March 2002, and March 2003 over a snow-covered open terrain, a sparse coniferous forest, and a dense coniferous forest. The analysis evaluates the ability of the two target decomposition methods for the identification and understanding of the main scattering mechanisms. [J443]

"Estimation of the Minimum Number of Tracks for SAR Tomography"

Synthetic aperture radar tomography (SARTom) is the natural extension of SAR interferometry to solve for multiple phase centers within a resolution cell and obtain the 3-D representation of a scene. This paper deals with the determination of the minimum number of tracks required to perform SARTom. Through the prolate spheroidal wave functions, the number of equivalent targets of a volumetric source is derived, and from it, the minimum number of observations required to apply subspace superresolution methods is computed. The minimum tomographic aperture length is also investigated. The results are validated on real data acquired in L-band by the experimental SAR system of the German Aerospace Center. [J444]

"Glacier Velocity Monitoring by Maximum Likelihood Texture Tracking"

The performance of a tracking algorithm considering remotely sensed data strongly depends on a correct statistical description of the data, i.e., its noise model. The objective of this paper is to introduce a new intensity tracking algorithm for synthetic aperture radar (SAR) data, considering its multiplicative speckle/noise model. The proposed tracking algorithm is discussed regarding the measurement of glacier velocities. Glacier monitoring exhibits complex spatial and temporal dynamics including snowfall, melting, and ice flows at a variety of spatial and temporal scales. Due to these complex characteristics, most traditional methods based on SAR suffer from speckle decorrelation that results in a low signal-to-noise ratio. The proposed tracking technique improves the accuracy of the classical intensity tracking technique by making use of the temporal speckle structure. Even though a new intensity-based matching algorithm is proposed, particularly for incoherent data sets, the analysis of the proposed technique was also performed for correlated data sets. As it is demonstrated, the velocity monitoring can be continuously performed by using the maximum likelihood (ML) texture tracking without any assumption concerning the correlation of the data set. The ML texture tracking approach was tested on ENVISAT-ASAR data acquired during summer 2004 over the Inyltshik glacier in Kyrgyzstan, representing one of the largest alpine glacier systems of the world. It will be demonstrated that the proposed technique is capable of robustly and precisely detecting the surface velocity field and velocity changes in time. [J445]

"An Analysis of Texture Measures in PCA-Based Unsupervised Classification of SAR Images"

In single-band single-polarized SAR images, intensity and texture are the information source available for unsupervised land cover classification. Every textural feature measure identifies texture patterns by different approaches. For efficient land cover classification, textural measures have to be chosen suitably. Therefore, in this letter, the role of various intensity and textural measures is analyzed for their discriminative ability for unsupervised SAR image classification into various land cover types like water, urban, and vegetation areas. To make the algorithm adaptable, these textural features are fused using principal component analysis (PCA), and principal components are used for classification purposes. To highlight the effectiveness of PCA, the difference between PCA- and non-PCA-based classifications is also analyzed. Analysis of the role of texture measures for unsupervised classification of real-world SAR data with application of PCA is presented in this letter. The analysis of how every individual feature measure contributes for classification process is presented, and then, textural measures for a feature set are chosen according to their role in improving classification accuracy. By analysis, it is observed that the feature set comprising mean, variance, wavelet components, semivariogram, lacunarity, and weighted rank fill ratio provides good classification accuracy of up to 90.4% than by using individual textural measures, and this increased accuracy justifies the complexity involved in the process. [J446]

"3-D Radargrammetric Modeling of RADARSAT-2 Ultrafine Mode: Preliminary Results of the Geometric Calibration"

The geometry and the accuracy of the 3-D cartographic localization of RADARSAT-2 images are being evaluated as part of the Canadian Space Agency's Science and Operational Applications Research program. In a first step, the Toutin's 3-D physical model, previously developed for RADARSAT-1, was adapted to RADARSAT-2 sensor and applied to two ultrafine mode images (U2 and U25) acquired over an area in Beauport, Quebec. Both the 3-D modeling computed with only 12 ground control points and its geometric localization were evaluated with different check data: 1) independent check points; 2) the two quasi-epipolar images; 3) the two orthoimages; and 4) 1-m accurate orthophotos. All four results and validations are in agreement and confirm that the 3-D geometric localization and restitution accuracy are 1 m in planimetry and 2 m in elevation. The checked data error being included in these evaluations and the relative error computed from the quasi-epipolar comparison provided a high level of confidence that the precision of Toutin's 3-D radargrammetric model is better than 0.25 m. [J447]

"DEM Reconstruction in Layover Areas From SAR and Auxiliary Input Data"

In this letter, a methodology to overcome the layover problem and obtain the 3-D reconstruction of urban areas will be discussed. Interferometric synthetic aperture radar (SAR) (InSAR) systems allow the estimation of height profiles of the Earth surface, but in the case of urban scenarios, estimation becomes a hard task due to the presence of SAR geometrical distortions, with layover above all. First, the layover signal in InSAR images is investigated; then, a procedure to specifically manage layover areas is presented. The proposed method consists of introducing an auxiliary data exploitation, optical data or SAR shadowing, in the maximum a posteriori statistical estimation technique to improve the digital elevation model reconstruction, particularly on phase discontinuities. We test the method on simulated data, showing its effectiveness. [J448]

"Using Altimetry Waveform Data and Ancillary Information From SRTM, Landsat, and MODIS to Retrieve River Characteristics"

In this paper, spaceborne radar altimeters are shown to have the potential for monitoring the height of large rivers with accuracies of approximately 1 m. However, the need for a better height accuracy and the observations of smaller continental basins have led to studies on how to improve and extend the use of nadir-altimeter data. Conventional retracking techniques over land are limited to the examination of altimeter waveforms on a case-by-case basis. Due to the arbitrary geometry which may be present at altimeter river crossings, this approach may be limited to large rivers, which approximate ocean crossings. To overcome this limitation, we introduce a waveform-fitting method which uses the entire set of waveforms associated with a water crossing, rather than individual waveforms. By using ancillary data, such as digital elevation model (obtained from Shuttle Radar Topography Mission and Gtopo30) and classification maps (obtained from Landsat and MODIS), it is possible to recast the retracking problems as a maximum-likelihood-estimation problem. Theoretical power returns based on the a priori knowledge of the observed scenes are generated, resulting in a parametric library of waveform histories, which is then used to constrain the estimation. For demonstration, we concentrate on the river Meuse in northern western Europe and on the river Lena in Russia. The Meuse has important social impact, since it has flooded in the past and better real-time predictions of its changing stage may improve flood-forecasting skill. Furthermore, it presents a challenge to conventional nadir-altimeter waveform retracking. We will present both theoretical performance results and demonstrate the feasibility based on real altimeter data. [J449]

"Using ENVISAT ASAR Global Mode Data for Surface Soil Moisture Retrieval Over Oklahoma, USA"

The Advanced Synthetic Aperture Radar (ASAR) onboard of the satellite ENVISAT can be operated in global monitoring (GM) mode. ASAR GM mode has delivered the first global multiyear C-band backscatter data set in HH polarization at a spatial resolution of 1 km. This paper investigates if ASAR GM can be used for retrieving soil moisture using a change detection approach over large regions. A method previously developed for the European Remote Sensing (ERS) scatterometer is adapted for use with ASAR GM and tested over Oklahoma, USA. The ASAR-GM-derived relative soil moisture index is compared to 50-km ERS soil moisture data and pointlike insitumeasurements from the Oklahoma MESONET. Even though the scale gap from ASAR GM to the insitumeasurements is less pronounced than in the case of the ERS scatterometer, the correlation for ASAR against the insitumeasurements is, in general, somewhat weaker than for the ERS scatterometer. The analysis suggests that this is mainly due to the much higher noise level of ASAR GM compared to the ERS scatterometer. Therefore, some spatial averaging to 3-10 km is recommended to reduce the noise of the ASAR GM soil moisture images. Nevertheless, the study demonstrates that ASAR GM allows resolving spatial details in

the soil moisture patterns not observable in the ERS scatterometer measurements while still retaining the basic capability of the ERS scatterometer to capture temporal trends over large areas. [J450]

"Observation of Sea-Ice Thickness Using ENVISAT Data From LЬtzow-Holm Bay, East Antarctica"

To investigate the suitability of synthetic aperture radar (SAR) polarization data to estimate the sea-ice thickness in early summer in Lutzow-Holm Bay, Antarctica, we compared insituice thicknesses with the corresponding backscattering co-efficient for each polarization and the VV-to-HH backscattering ratio. The VV-to-HH backscattering ratio was derived from data acquired by ENVISAT Advanced SAR (ASAR). This ratio is related to the near-surface dielectric constant of the sea ice, which is, in turn, related to the developing process of ice and, thus, its thickness via changes in the near-surface sea-ice salinity. The sea ice encountered in the study area is close first-year pack ice and fast ice. For these old and relatively rough sea-ice types, the VV-to-HH backscattering ratio can be expected to depend on salinity-driven changes in the near-surface dielectric constant rather than changes of the surface roughness. We applied the empirical relationships between the ice thickness and the VV-to-HH backscattering ratio with the linear and logarithm fits to ASAR data. The linear fit gave the reliable result, with an rms error being 0.08 m and a correlation coefficient being 0.91, when compared to insitufast-ice thickness. [J451]

"Monitoring of the Rice Cropping System in the Mekong Delta Using ENVISAT/ASAR Dual Polarization Data"

The rice cropping system in Asia is undergoing major changes to cope with increasing demography and changing climate, making rice monitoring a critical issue. Past studies have demonstrated the use of C-band synthetic aperture radar (SAR) data to map rice areas. The methods were based on the temporal change of intensity backscattering coefficient of vertically or horizontally co-polarized data (VV or HH). In this paper, we assess the use of the HH/VV polarization ratio derived from Advanced SAR (ASAR) data from ENVISAT data for the production of rice paddy maps. The approach is based on past knowledge on the polarization behavior of rice canopy, i.e., VV backscattering is much lower than HH during a large part of the rice season, due to the attenuation of the wave by the vertical structure of the plants. The methodology is developed for the Mekong Delta, Vietnam, where a complex cropping pattern is found (one to three crops of rice per year). The approach includes a statistical analysis of the HH/VV distributions of rice and non-rice classes at different dates. The analysis results confirm that HH/VV can be used as classifier and point out the need for relevant speckle filtering prior to classification. A classification method is developed and applied to single- and multidate data sets. The methods are tested at one district of the province of An Giang and extended to the whole province. Comparisons of the mapping results to geographic-information-system land-use data and official agricultural statistics show very good agreement. The method will be further applied to the entire Mekong Delta. [J452]

"Waveform-Diversity-Based Millimeter-Wave UAV SAR Remote Sensing"

To integrate a synthetic aperture radar (SAR) into an operational unmanned airborne vehicle (UAV), it should be as small as possible to meet stringent limitations of size, weight, and power consumption. It appears that the novel combination of millimeter-wave frequency-modulated continuous-wave (FMCW) technology and SAR techniques can provide an optimal solution. However, some efficient techniques should be applied to resolve range/Doppler ambiguities in FMCW UAV SAR systems. As such, a technique of waveform-diversity-based millimeter-wave UAV SAR imaging is presented in this paper. Along with the described system concept and signal model, the performance of the diversified waveforms evaluated by their cross correlations is detailed. As the conventional stop-and-go approximation is not valid for FMCW SAR, a modified wavenumber-domain algorithm with a consideration of continuous antenna motion during transmission and reception is derived. This imaging algorithm is validated with computer simulations. Furthermore, one parallel direct-digital-synthesizer-driven phase-locked-loop synthesizer with adaptive nonlinearity compensation, which has been validated by the experimental results, is proposed to obtain a millimeter-wave FMCW signal with fine frequency linearity. [J453]

"Pencil Back-Projection Method for SAR Imaging"

We present a high-resolution method for spotlight mode SAR imaging that utilizes parametric modeling of projected target reflectivity density function and tomographic reconstruction. The method requires no polar-to-cartesian interpolation in spectral domain. Utilization of forward-backward total least squares bandpass matrix pencil method allows super resolution to be achieved in range for a single imaging angle. Hence, the quality of the image reconstructed by convolution back-projection is also improved. It is shown that the method is very resistant to noise and can generate images down to very low SNR values. Direct formulation in terms of physical quantities such as electric field and current density is another contribution of this paper. [J454]

"Speckle Suppression in SAR Images Using the 2-D GARCH Model"

A novel Bayesian-based speckle suppression method for Synthetic Aperture Radar (SAR) images is presented that preserves the structural features and textural information of the scene. First, the logarithmic transform of the original image is analyzed into the multiscale wavelet domain. We show that the wavelet coefficients of SAR images have significantly non-Gaussian statistics that are best described by the 2-D GARCH model. By using the 2-D GARCH model on the wavelet coefficients, we are capable of taking into account important characteristics of wavelet coefficients, such as heavy tailed marginal distribution and the dependencies between the coefficients. Furthermore, we use a maximum a posteriori (MAP) estimator for estimating the clean image wavelet coefficients. Finally, we compare our proposed method with various speckle suppression methods applied on synthetic and actual SAR images and we verify the performance improvement in utilizing the new strategy. [J455]

"Experimental results on ISAR imaging with stepped-frequency waveforms"

A simple and successful processing for the bandwidth synthetic of stepped-frequency waveforms (SFWs) is presented. The high range resolution is obtained by combining the sub-pulses of SFWs in the frequency domain. The overlapping bandwidth of the two adjacent sub-pulses is used to estimate phase errors. Also the usual motion compensation approach is avoided if the band coherent processing is used. Experimental results of the ship target are shown. [J456]

"Detecting and Downscaling Wet Areas on Boreal Landscapes"

This letter presents an approach to classify wet areas from European Remote Sensing 2 (ERS-2) synthetic aperture radar (SAR)-, Landsat Thematic Mapper (TM)-, and Light Detection and Ranging (LiDAR)-derived terrain data and downscale the result from the coarse resolution of satellite images to finer resolutions needed for land managers. Using discrete wavelet transform (DWT) and support vector machines (SVM), the algorithm finds multiple relationships between the radar, optical, and terrain data and wet areas at different spatial scales. Decomposing and reconstructing processes are performed using a 2-D DWT (2D-DWT) and inverse 2D-DWT respectively. The underlying relationships between radar, optical, and terrain data and wet areas are learned by training an SVM at the coarse resolution of the wet-area map. The SVM is then applied on the predictors at a finer resolution to produce wet-area detailing images, which are needed to reconstruct a finer resolution wet-area map. The algorithm is applied to a boreal landscape in northern Alberta, Canada, characterized by many wet-area features including ephemeral and permanent streams and wetlands. [J457]

"Measurements of Faraday Rotation Using Polarimetric PALSAR Images"

For spaceborne synthetic aperture radar (SAR) systems operating at L-band frequencies or lower, the ionosphere may have a significant impact on the SAR images. The largest effect at L-band is caused by Faraday rotation (FR). Several studies have modeled the effect of FR and/or devised models to measure and correct FR. With the launch of the fully polarimetric L-band system Phased Array-type L-band SAR (PALSAR), it has become possible to test both models and measurement techniques on real SAR data. In this letter, the quality of calibrated polarimetric PALSAR data is assessed, and FR is measured. It is found that residual crosstalk and channel imbalance are small in the PALSAR data. Two methods are used to measure FR, the first using in-scene distributed targets and the second using large trihedrals. The two methods show very good agreement. The measurements are compared with values of the total electron content using a linear model. It is found that the model and measurements are in good agreement, with a root-mean-square error of 0.3degor 15% of the mean FR angle. [J458]

"Using Multilook Averaging for Coherently Modeled Scattering From a Pine Tree at L-Band"

In this letter, we study scattering from a scots pine tree by using a realistic cylinder model of the tree and the coherent electric field scattering model. We study the directional variability of bistatic and monostatic scattering at L-band and show that, due to large variations in results, some averaging technique should be used to describe and interpret the model output efficiently. We propose that the needed averaging can be done by multilooking and that multilook data could be easily generated by rotating the tree model randomly around its vertical axis. We show that the resulting scattering data obey generally the multidimensional Gaussian distribution or the more general K-distribution, in a way similar to synthetic aperture radar (SAR) image pixels, and can therefore be represented by a single averaged covariance matrix. The trunk-ground reflection to the backscattering direction adds to the model output non-Gaussian behavior, which can be treated as texture. Covariance matrix formalism allows us to use descriptors which are commonly used to analyze SAR images, like target entropy and alpha angle. The method helps interpretation and comparison between the model output and

SAR image. [J459]

"Polarimetric Differential SAR Interferometry: First Results With Ground-Based Measurements"

The Remote Sensing Laboratory of the Universitat Politecnica de Catalunya carried out a one-year measuring campaign in the village of Sallent, northeastern Spain, using a polarimetric ground-based synthetic aperture radar (SAR) sensor. The objective was to study the subsidence phenomenon induced by the salt mining activity conducted in this area up to the middle of the last century. Zero-Baseline polarimetric SAR (PolSAR) data were gathered at X-band in nine different days, from June 2006 to March 2007. In this letter, the problem of extracting subsidence information from fully PolSAR acquisitions for the retrieval of high-quality deformation maps is addressed. After compensating for the atmospheric artifacts caused by troposphere changes, the linear component of the deformation process is estimated separately for each polarization channel with the Coherent Pixels Technique (CPT). Afterward, a novel polarimetric approach mixing the differential-phase information of each polarization channel is proposed. The results obtained in the two cases are quantitatively compared, and the advantages provided by the polarimetric acquisitions are finally stressed. [J460]

"Data Flow and Workflow Organization-The Data Management for the TerraSAR-X Payload Ground Segment"

The payload ground segment (PGS) for the recently launched German radar satellite, TerraSAR-X, performs the operational data management of the acquired satellite data. This comprises well-known functions such as reception, systematic and on-demand processing, archiving and cataloguing, ordering, and dissemination of digital Earth-observation products. In addition, it comprises new functions like large-scale multimode acquisition ordering by users, integration with a commercial service segment, and new interfaces and workflows within the complete ground segment. The TerraSAR-X PGS is based on the Data Information and Management System (DIMS), the multimission data-handling infrastructure of the German Remote Sensing Data Center (DFD) at the German Aerospace Center. The development and integration of the new functions and complex workflows for TerraSAR-X were achieved and successfully tested on time. After the support of commissioning phase for five months, the system is now operational. As an intended side effect, the PGS for TerraSAR-X is, in several aspects, a pattern being reused for upcoming future missions, thus substantially reducing overall developmental costs. This paper investigates features of the TerraSAR-X PGS that enable the reuse in a multimission environment. It summarizes the achieved enhancements and extensions of DIMS to support the TerraSAR-X mission. Special emphasis is placed on the implementation of the request workflow initiated by user orders and the corresponding data flow within the distributed DFD multimission facility. [J461]

"Spaceborne Bistatic SAR Processing Using the EETF4 Algorithm"

In this letter, the fourth-order extended exact transfer function (EETF4) is adapted for spaceborne bistatic synthetic aperture radar (SAR) processing. The problems with high squint and large bistatic Doppler centroid variations are analyzed, and it is shown that if both transmitter and receiver are highly squinted in the same direction, then it may be demanding to achieve perfect quality of the point targets. It is shown that if both transmitter and receiver have high squint in opposite directions with small Doppler centroid variations, then the SAR image can be processed very precisely. [J462]

"Space-Surface Bistatic SAR Image Formation Algorithms"

This paper presents algorithms designed for a subclass of bistatic synthetic aperture radar (BSAR) called space-surface BSAR (SS-BSAR). Two SS-BSAR configurations are considered. The first one assumes a stationary, spaceborne transmitter and a moving airborne receiver. The second case is the generalized SS-BSAR configuration, where the transmitter is nonstationary. The transmitter and receiver have essentially different flight paths and velocities. For each configuration under investigation, the characteristics of the corresponding SS-BSAR received signal are examined first. Then, each proposed algorithm is derived analytically, and verified via simulation. [J463]

"TerraSAR-X Precise Trajectory Estimation and Quality Assessment"

Since the launch of TerraSAR-X on June 15, 2007, the required precise orbit products have been provided by the German Space Operations Center to support operational spaceborne synthetic aperture radar (SAR) and interferometric SAR image processing. The TerraSAR-X precise trajectory is reconstructed solely based on the Global Positioning System (GPS) measurements from a geodetic-grade dual-frequency Integrated Geodetic and Occultation Receiver (IGOR) onboard the spacecraft. The GPS-based precise orbit determination (POD) strategy used in the estimation of the precise TerraSAR-X orbit and its performance will be fully described in this paper. Five-month statistics from the internal and external orbit assessment indicate a root-mean-squared 3-D orbit

accuracy of better than 10 and 20 cm for the precise science orbit and precise rapid orbit (PRO) products, respectively. The POD performance of the backup single-frequency MosaicGNSS receiver to support operational PRO product generation in case of IGOR tracking failure or interruptions is described as well. [J464]

"Robust ISAR Range Alignment via Minimizing the Entropy of the Average Range Profile"

In this letter, a novel global approach to range alignment for inverse synthetic aperture radar (ISAR) image formation is presented. The algorithm is based on the minimization of the entropy of the average range profile (ARP), and the processing chain is capable of exploiting the efficiency of the fast Fourier transform. With respect to the existing global methods, the new one requires no exhaustive search operation and eliminates the necessity of the parametric model for the relative offset among the range profiles. The derivation of the algorithm indicates that the presented methodology is essentially an iterative solution to a set of simultaneous equations, and its robustness is also ensured by the iterative structure. Some alternative criteria, such as the maximum contrast of the ARP, can be introduced into the algorithm with a minor change in the entropy-based method. The convergence and robustness of the presented algorithm have been validated by experimental ISAR data. [J465]

"New applications of transponder in focusing distributed synthetic aperture radar data"

High-precision phase synchronisation or compensation techniques must be provided for distributed synthetic aperture radar (DiSAR), which operates with separate transmitters and receivers. The use of a novel transponder that was proposed for calibrating high-resolution imaging radars to compensate oscillator frequency instability is investigated here. This transponder modulates the radar pulses in a manner that the retransmitted signal shows two additional Doppler frequencies, which enables their separation from the scene echoes. In this way, DiSAR frequency synchronisation errors can be compensated. Thereafter, the DiSAR raw data is focused by using a derived image formation algorithm. The originality of this text lies in the phase compensation technique via transponder for DiSAR systems, as well as an image formation algorithm with integrated synchronisation compensation. [J466]

"Improved, Approximate, Time-Domain ML Estimators of Chirp Signal Parameters and Their Performance Analysis"

We derive an improved, approximate, maximum likelihood (ML) estimator for the parameters of a single-component chirp signal in the time domain, which has much lower computational complexity than that of the traditional estimators in the frequency domain. We term it the zero-order amplitude weighted phase-based estimator (AWPE). It is a weighted linear combination of the phases of the received signal samples, where the weights are determined by the amplitudes of the received signals. It achieves better performance than the only existing time-domain estimator in the literature that only exploits the phase information. A phase unwrapping (PU) algorithm is needed to recover the phase information correctly from the received signal samples. Several PU algorithms are compared and analyzed. A new, robust PU algorithm based on the first-order phase differences of the consecutive received signal samples is proposed. This new unwrapping algorithm has smaller PU failure probability than that based directly on the phases of the received signal samples. The need for PU can even be removed by using the second-order phase differences of the consecutive received signal samples. Two additional structures for the ML-based AWPE using the phase differences are derived starting from using the zero-order AWPE obtained. The first is based on the first-order phase differences and the second on the second-order phase differences. When the PU algorithm works perfectly, i.e., no phase unwrapping failure occurs, the estimators based on phase differences do not perform as well as the original one based on absolute phase information due to the increased noise variance. This is also applicable when the chirp parameters take on very small values. However, when no knowledge of the ranges of the chirp parameters is available, and the possible PU failures are taken into account, the estimators based on the phase differences could perform better. Performance analysis of the estimators is given based on--an improved phase noise model. It is easy to verify that the estimates obtained are unbiased. The cramer-rao lower bound (CRLB) on the mean-square error (MSE) is derived. The MSE performance of the estimators approaches the CRLB at high signal-to-noise ratios. The variance performance of the estimators based on phase differences is analyzed, whose validity is demonstrated by simulation results. [J467]

"Optimization of Soil Hydraulic Model Parameters Using Synthetic Aperture Radar Data: An Integrated Multidisciplinary Approach"

It is widely recognized that synthetic aperture radar (SAR) data are a very valuable source of information for the modeling of the interactions between the land surface and the atmosphere. During the last couple of decades, most of the research on the use of SAR data in hydrologic applications has been focused on the retrieval of land and biogeophysical parameters (e.g., soil moisture contents). One relatively unexplored issue consists of the

optimization of soil hydraulic model parameters, such as, for example, hydraulic conductivity values, through remote sensing. This is due to the fact that no direct relationships between the remote-sensing observations, more specifically radar backscatter values, and the parameter values can be derived. However, land surface models can provide these relationships. The objective of this paper is to retrieve a number of soil physical model parameters through a combination of remote sensing and land surface modeling. Spatially distributed and multitemporal SAR-based soil moisture maps are the basis of the study. The surface soil moisture values are used in a parameter estimation procedure based on the extended Kalman filter equations. In fact, the land surface model is, thus, used to determine the relationship between the soil physical parameters and the remote-sensing data. An analysis is then performed, relating the retrieved soil parameters to the soil texture data available over the study area. The results of the study show that there is a potential to retrieve soil physical model parameters through a combination of land surface modeling and remote sensing. [J468]

"Algebraic Synthesis of Forest Scenarios From Multibaseline PolInSAR Data"

In this paper, a new methodology is proposed for the analysis of forested areas basing on multipolarimetric multibaseline synthetic aperture radar (SAR) surveys. Such a methodology is based on three hypotheses: 1) statistical uncorrelation of the different scattering mechanisms (SMs), such as ground, volume, and ground-trunk scattering; 2) independence of volumetric and temporal coherence losses of each SM on the choice of the polarimetric channel; and 3) invariance (up to a scale factor) of the average polarimetric signature of each SM with respect to the choice of the track. Under these hypotheses, the data covariance matrix can be expressed as a Sum of Kronecker Products, after which it follows that K SMs are uniquely identified by K (K-1) real numbers. This result provides the basis to perform SM separation by employing not only model-based approaches, generally retained in literature but also model-free and hybrid approaches, while yielding the best Least Square solution given the hypothesis of K SMs. It will be shown that this approach to SM separation is consistent with the inversion procedures usually exploited in single-baseline polarimetric SAR interferometry. Experimental validation of this methodology is provided on the basis of the P-band data set relative to the forest site of Remningstorp, Sweden, acquired by German Aerospace Center's E-SAR airborne system in the framework of the European Space Agency campaign BioSAR. [J469]

"The Contribution of ALOS PALSAR Multipolarization and Polarimetric Data to Crop Classification"

Mapping and monitoring changes in the distribution of cropland provide information that aids sustainable approaches to agriculture and supports early warning of threats to global and regional food security. This paper tested the capability of Phased Array type L-band Synthetic Aperture Radar (SAR) (PALSAR) multipolarization and polarimetric data for crop classification. L-band results were compared with those achieved with a C-band SAR data set (ASAR and RADARSAT-1), an integrated C- and L-band data set, and a multitemporal optical data set. Using all L-band linear polarizations, corn, soybeans, cereals, and hay-pasture were classified to an overall accuracy of 70%. A more temporally rich C-band data set provided an accuracy of 80%. Larger biomass crops were well classified using the PALSAR data. C-band data were needed to accurately classify low biomass crops. With a multifrequency data set, an overall accuracy of 88.7% was reached, and many individual crops were classified to accuracies better than 90%. These results were competitive with the overall accuracy achieved using three Landsat images (88.0%). L-band parameters derived from three decomposition approaches (Cloude-Pottier, Freeman-Durden, and Krogager) produced superior crop classification accuracies relative to those achieved using the linear polarizations. Using the Krogager decomposition parameters from all three PALSAR acquisitions, an overall accuracy of 77.2% was achieved. The results reported in this paper emphasize the value of polarimetric, as well as multifrequency SAR, data for crop classification. With such a diverse capability, a SAR-only approach to crop classification becomes increasingly viable. [J470]

"Feature Enhancement of Stripmap-Mode SAR Images Based on an Optimization Scheme"

Based on a nonquadratic-optimization method originally proposed for spotlight-mode SAR image reconstruction, a modification for stripmap-mode SAR images is presented in this letter. This is done by mathematically reformulating the projection kernel and numerically putting it into a form that is suitable for optimization. The performance was evaluated by measures of the target contrast and 3-dB beamwidth using Radarsat-1 data. Results were analyzed and compared with those using minimum-variance and multiple-signal-classification methods. Results demonstrate that the target's features are effectively enhanced and that the dominant scattering centers are well separated using the proposed method. In addition, the image fuzziness is greatly reduced, and the image fidelity is well preserved. The effectiveness of the modification is thus validated. [J471]

"Estimating Spatiotemporal Ground Deformation With Improved Persistent-Scatterer Radar Interferometry"

Synthetic aperture radar interferometry has been applied widely in recent years to ground deformation monitoring although difficulties are often encountered when applying the technology, among which the spatial and temporal decorrelation and atmospheric artifacts are the most prominent. The persistent-scatterer interferometric synthetic aperture radar (PS-InSAR) technique has overcome some of the difficulties by focusing only on the temporally coherent radar targets in a time series of synthetic aperture radar (SAR) images. This paper presents an improved PS-InSAR technique by introducing PS-neighborhood networking and empirical mode decomposition (EMD) approaches in the PS-InSAR solution. Linear deformation rates and topographic errors are estimated based on a least squares method, while the nonlinear deformation and atmospheric signals are computed by singular value decomposition and the EMD method. An area in Phoenix, AZ, is used as a test site to determine its historical subsidence with 39 C-band SAR images acquired by European Remote Sensing 1 and 2 satellites from 1992 to 2000. [J472]

"Azimuth Phase Center Adaptation on Transmit for High-Resolution Wide-Swath SAR Imaging"

Synthetic aperture radar (SAR) systems with multiple receive channels allow for high-resolution wide-swath imaging thus overcoming a fundamental limitation of conventional single-aperture SAR. By using multiple apertures in azimuth, additional samples are received for each transmitted pulse. This allows for a reduced pulse repetition frequency (PRF) thereby enabling a wider swath. However, a nonoptimum PRF is associated with a nonuniform sample spacing in azimuth and needs to be compensated by a multichannel reconstruction algorithm. For strong deviations from the optimum PRF, the inverse character of such an algorithm might result in a degraded performance. This can be overcome by an innovative advanced transmit antenna architecture which allows for a pulse-to-pulse shift of the phase center. Such an antenna enables the adaptive adjustment of the system's phase center positions to the respective PRF, thereby ensuring constant performance over a clearly extended PRF range. In particular, in combination with conventional multichannel processing strategies, this technique represents the next step toward a fully active multiple-input multiple-output (MIMO) SAR and has a great potential for future systems. [J473]

"DEM Error Retrieval by Analyzing Time Series of Differential Interferograms"

Two-pass differential synthetic aperture radar interferometry processing have been successfully used by the scientific community to derive velocity fields. Nevertheless, a precise digital elevation model (DEM) is necessary to remove the topographic component from the interferograms. This letter presents a novel method to detect and retrieve DEM errors by analyzing time series of differential interferograms. The principle of the method is based on the comparison of fringe patterns with the perpendicular baseline. First, a mathematical description of the algorithm is exposed. Then, the algorithm is applied on a series of four one-day European Remote Sensing 1 and 2 satellite (ERS-1/2) interferograms. [J474]

"Fast implementation of optimal target radial velocity estimation for multi-channel SAR-GMTI"

Optimal target radial velocity estimation for SAR-GMTI using polynomial rooting is developed. The developed method first obtains all extreme values of the likelihood function by polynomial rooting, and then searches the maximum among these extreme values to obtain the global optimal solution. It has much lower computational complexity compared to the velocity search method when the search step is small. Simulation results are given to demonstrate the effectiveness of the method. [J475]

"Calibration of Polarimetric PALSAR Imagery Affected by Faraday Rotation Using Polarization Orientation"

For spaceborne polarimetric synthetic aperture radar (SAR), it is important to ensure the removal of both polarimetric system distortion and the effect of Faraday rotation. This paper proposes a new calibration method to derive the system distortion using polarization orientation (PO) induced in built-up areas and applies to Phased-Array-Type L-Band SAR (PALSAR) calibration. Faraday rotation is corrected by the circular-polarization-based method from the distortion matrix (DM)-calibrated data. The derived DMs do not coincide with those by the Japan Aerospace Exploration Agency (JAXA), but our calibration results compare well to JAXA's results in PO angles and calibrator's responses. The two results satisfy polarimetric calibration requirements, and the cross-polarized isolation improves by more than 5 dB after Faraday rotation correction following DM calibration-even in the case of small Faraday rotation (-2deg to -0.5deg). The proposed method is robust to noise and is useful when using an area of mixed polarimetric response for calibration. This method is also applicable to a large crosstalk system and the case of large Faraday rotation. [J476]

"Maritime border control multisensor system"

This focuses on the classification task performed into a multi-sensor system for the coastal surveillance. The

system is composed of two platforms of sensors: a land-based platform equipped with a land based radar, an Automatic Identification System (AIS) and an infrared camera (IR); an airborne platform carrying an airborne radar that can operate in a spotlight Synthetic Aperture Radar (SAR) mode, a video camera, and a second IR camera. The tasks performed by the system are the detection, tracking, identification, and classification of multiple targets, the evaluation of their threat level, and the selection of an intervention on them. The classification algorithm implemented inside the system exploits an analytical approach based on the confusion matrix (CM) of the imaging sensors that belong to the system. Some measures of effectiveness (MoE) of the system are evaluated, considering both cases where an ideal error-free classification process and a non-ideal classification process are performed. [J477]

"Emulating Dynamic Target in Compact Radar Ranges. Part I: Theory"

Analytical expressions are developed that describe the artifacts encountered when translating, rotating, and vibrating point sources are imaged by compact radar ranges (CRRs) emulating airborne synthetic-aperture radar (SAR). The approach starts with coherent-aperture imaging basics and develops a general solution for imaging using the Born approximation. We show that moving-target artifacts on CRRs are similar to the artifacts encountered with SAR moving targets, suggesting that CRRs may be suitable for such emulations. [J478]

"Automatic Target Recognition by Means of Polarimetric ISAR Images and Neural Networks"

Inverse synthetic aperture radar (ISAR) images are often used for classifying and recognizing targets. Moreover, the use of fully polarimetric ISAR (Pol-ISAR) images enhances classification capabilities. In this paper, the authors propose a novel automatic target recognition (ATR) technique based on the use of fully Pol-ISAR images and neural networks (NNs). In order to reduce the amount of data processed by the classifier, the brightest scattering centers are first extracted by means of the Pol-CLEAN technique, and then, their scattering matrices are decomposed using Cameron's decomposition. A classifier based on the use of multilayer perceptron NN that makes use of the features extracted from the Pol-ISAR images is then implemented. A proof-of-concept test is performed on real data acquired during a controlled experiment in an anechoic chamber. [J479]

"The Application of the Principle of Chirp Scaling in Processing Stepped Chirps in Spotlight SAR"

A new approach to process stepped chirps in spotlight synthetic aperture radar is presented in this letter, which is based on exploiting the principle of chirp scaling (PCS). In particular, PCS is integrated into the polar format algorithm (PFA), obtaining a more efficient solution compared with the existing polar interpolation technique. The main contribution of this letter is the implementation of azimuth scaling, in which the bandwidth synthesis is embedded. The algorithm is developed dedicatedly for dealing with stepped chirps. The signal processing flow is investigated in detail, in which no interpolations but only fast Fourier transform and complex multiplications are involved. Point-target simulation has validated the new approach and indicated that it is more efficient than the classic interpolation-based one. The achieved computational gain measured in execution time is around 25%-30%. [J480]

"Support Vector Machine for Multifrequency SAR Polarimetric Data Classification"

The objective of this paper is twofold: first, to assess the potential of radar data for tropical vegetation cartography and, second, to evaluate the contribution of different polarimetric indicators that can be derived from a fully polarimetric data set. Because of its ability to take numerous and heterogeneous parameters into account, such as the various polarimetric indicators under consideration, a support vector machine (SVM) algorithm is used in the classification step. The contribution of the different polarimetric indicators is estimated through a greedy forward and backward method. Results have been assessed with AIRSAR polarimetric data polarimetric data acquired over a dense tropical environment. The results are compared to those obtained with the standard Wishart approach, for single frequency and multifrequency bands. It is shown that, when radar data do not satisfy the Wishart distribution, the SVM algorithm performs much better than the Wishart approach, when applied to an optimized set of polarimetric indicators. [J481]

"Linear and adaptive spaceborne threedimensional SAR tomography: a comparison on real data"

Three-dimensional (3-D) synthetic aperture radar (SAR) imaging is a recent technique, based on coherent SAR data combination, and aims to obtain a full 3-D analysis in space. It is a multibaseline extension of the SAR interferometry concept and offers new options for the analysis and monitoring of ground scenes by means of the capability of separating the scattering phenomena along the height dimension. In this work, the authors summarise and extend the results obtained by processing real ERS satellite urban data characterised by a long time span of acquisition and non-uniformly spaced satellite passes, comparing the performance in height focusing obtained with a singular value decomposition (SVD)-based method and adaptive beamforming. [J482]

"PALSAR Radiometric and Geometric Calibration"

This paper summarizes the results obtained from geometric and radiometric calibrations of the Phased-Array L-Band Synthetic Aperture Radar (PALSAR) on the Advanced Land Observing Satellite, which has been in space for three years. All of the imaging modes of the PALSAR, i.e., single, dual, and full polarimetric strip modes and scanning synthetic aperture radar (SCANSAR), were calibrated and validated using a total of 572 calibration points collected worldwide and distributed targets selected primarily from the Amazon forest. Through raw-data characterization, antenna-pattern estimation using the distributed target data, and polarimetric calibration using the Faraday rotation-free area in the Amazon, we performed the PALSAR radiometric and geometric calibrations and confirmed that the geometric accuracy of the strip mode is 9.7-m root mean square (rms), the geometric accuracy of SCANSAR is 70 m, and the radiometric accuracy is 0.76 dB from a corner-reflector analysis and 0.22 dB from the Amazon data analysis (standard deviation). Polarimetric calibration was successful, resulting in a VV/HH amplitude balance of 1.013 (0.0561 dB) with a standard deviation of 0.062 and a phase balance of 0.612deg with a standard deviation of 2.66deg . [J483]

"Multiscale Change Detection in Multitemporal Satellite Images"

In this letter, we propose a novel technique for unsupervised change detection in multitemporal satellite images. The difference image which is computed from multitemporal images acquired on the same geographical area at two different time instances is decomposed using S-levels undecimated discrete wavelet transform (UDWT). For each pixel in the difference image, a multiscale feature vector is extracted using the subbands of the UDWT decomposition and the difference image itself. The final change detection map is achieved by clustering the multiscale feature vectors using k-means algorithm into two disjoint classes: changed and unchanged. Experimental results confirm the efficacy of the proposed approach on both optical and synthetic aperture radar images. [J484]

"Comparison of the ASI Ice Concentration Algorithm With Landsat-7 ETM+ and SAR Imagery"

Continuous monitoring of sea ice and its changes is mainly done by passive microwave sensors on satellites. One frequently used technique of retrieving sea-ice concentrations is the Arctic Radiation and Turbulence Interaction STudy Sea Ice (ASI) algorithm, which uses the near-90-GHz channels, here those of the Advanced Microwave Scanning Radiometer-Earth Observing System to calculate sea-ice concentrations. The ASI ice concentrations are compared with ice concentrations derived from the following: 1) the multispectral imager Enhanced Thematic Mapper Plus operating on Landsat and 2) from Envisat and Radarsat SAR images. In this paper, we focus on marginal ice zones, as the ice concentrations in those regions are in general observed with higher errors. First-year ice (bias: -1%-0% and rms error: 1%-4%) and young ice (bias: -4%-0% and rms error: 3%-9%) are fairly well recognized with little underestimation of ASI ice concentrations with respect to Landsat ice concentrations. New ice is identified with less accuracy by the ASI algorithm (bias: -16%-9% and rms error: 18.3%-26.2%). Averaged over all ice types, the bias ranges between -8.4% and 4.5%, and the rms error ranges between 2.0% and 17.4%. Discrepancies mainly occur in polynya areas (underestimation by ASI) and along the ice edge (overestimation by ASI). The results of the ASI-SAR comparison yield contrasting results. ASI underestimates the ice concentrations near the ice edge but overestimates them in some interior areas (bias: -2.9%-2.5% and rms error: 16.9%-20.1%). The discrepancies between both comparisons may be due to the different interaction mechanisms of the different sensor types, particularly with the newly formed ice. [J485]

"Synthetic Aperture Sonar: A Review of Current Status"

This is a review paper that surveys past work in, and the recent status of, active synthetic aperture sonar (SAS). It covers the early historical development of SAS with its provenance in synthetic aperture radar (SAR) and flows through into what work has been published in the open literature up to early 2007. The list of references is sufficiently complete to include most past and recent SAS publications in the open refereed literature. [J486]

"Position Correction Using Echoes From a Navigation Fix for Synthetic Aperture Sonar Imaging"

In synthetic aperture sonar (SAS), the platform position must be known sufficiently accurately for signals to be added coherently along the synthetic aperture. Often, the onboard navigation system is insufficiently accurate by itself, so corrections are needed. A well-known method is the displaced phase center antenna (DPCA) procedure for correcting platform position using seabed echoes. DPCA methods have the advantage of insensitivity to changing interference patterns, moving specular reflection, and changing occlusion, with aspect. However, when seabed echoes are unusable, either because they are too weak, or because they are corrupted by multipath, the seabed DCPA method may fail. Therefore, we present an alternative DPCA method using sonar echoes from a suitable navigation fix, based on an object detected after standard beamforming. In our proposed system, look

angle is obtained by tracking the centroid of the rectified image of the fix object. When the standard DPCA correction equations are modified for a fixed reflector, it turns out that they provide incremental range and look-angle errors, precisely the values required when the target itself is used as the navigation fix. Moreover, the values obtained are then self-compensating for errors in estimating seabed depth or forward motion of the platform. The navigation fix is selected by bracketing in range, and beamforming overlapping subsets of the receiver array. In this paper, we present experimental results at transmitter frequencies of 25 and 100 kHz where our method enabled well-focused SAS images to be generated with little recourse to other navigation information. Hence, SAS can be carried out, even when a sophisticated inertial navigation system (INS) is not available. [J487]

"Efficient SAR Raw Data Generation for Anisotropic Urban Scenes Based on Inverse Processing"

This letter describes efficient synthetic aperture radar raw data generation in the wavenumber domain using inverse processing. An exact form based on an inverse Omega-k algorithm and an approximate form based on an inverse Chirp Scaling algorithm are described, and examples are presented for a point scatterer. A methodology to incorporate the anisotropic behavior of an urban scene in a reflectivity map is also presented and demonstrated by means of a subaperture analysis. [J488]

"Iterative Weighted Maximum Likelihood Denoising With Probabilistic Patch-Based Weights"

Image denoising is an important problem in image processing since noise may interfere with visual or automatic interpretation. This paper presents a new approach for image denoising in the case of a known uncorrelated noise model. The proposed filter is an extension of the nonlocal means (NL means) algorithm introduced by Buades, which performs a weighted average of the values of similar pixels. Pixel similarity is defined in NL means as the Euclidean distance between patches (rectangular windows centered on each two pixels). In this paper, a more general and statistically grounded similarity criterion is proposed which depends on the noise distribution model. The denoising process is expressed as a weighted maximum likelihood estimation problem where the weights are derived in a data-driven way. These weights can be iteratively refined based on both the similarity between noisy patches and the similarity of patches extracted from the previous estimate. We show that this iterative process noticeably improves the denoising performance, especially in the case of low signal-to-noise ratio images such as synthetic aperture radar (SAR) images. Numerical experiments illustrate that the technique can be successfully applied to the classical case of additive Gaussian noise but also to cases such as multiplicative speckle noise. The proposed denoising technique seems to improve on the state of the art performance in that latter case. [J489]

"Joint Regularization of Phase and Amplitude of InSAR Data: Application to 3-D Reconstruction"

Interferometric synthetic aperture radar (SAR) images suffer from a strong noise, and their regularization is often a prerequisite for successful use of their information. Independently of the unwrapping problem, interferometric phase denoising is a difficult task due to shadows and discontinuities. In this paper, we propose to jointly filter phase and amplitude data in a Markovian framework. The regularization term is expressed by the minimization of the total variation and may combine different information (phase, amplitude, optical data). First, a fast and approximate optimization algorithm for vectorial data is briefly presented. Then, two applications are described. The first one is a direct application of this algorithm for 3-D reconstruction in urban areas with very high resolution images. The second one is an adaptation of this framework to the fusion of SAR and optical data. Results on aerial SAR images are presented. [J490]

"Comparative Study on the Performance of Multiparameter SAR Data for Operational Urban Areas Extraction Using Textural Features"

The advent of a new generation of synthetic aperture radar (SAR) satellites, such as Advanced SAR/Environmental Satellite (C-band), Phased Array Type L-band Synthetic Aperture Radar/Advanced Land Observing Satellite (L-band), and TerraSAR-X (X-band), offers advanced potentials for the detection of urban tissue. In this letter, we analyze and compare the performance of multiple types of SAR images in terms of band frequency, polarization, incidence angle, and spatial resolution for the purpose of operational urban areas delineation. As a reference for comparison, we use a proven method for extracting textural features based on a Gaussian Markov Random Field (GMRF) model. The results of urban areas delineation are quantitatively analyzed allowing performing intrasensor and intersensors comparisons. Sensitivity of the GMRF model with respect to texture window size and to spatial resolutions of SAR images is also investigated. Intrasensor comparison shows that polarization and incidence angle play a significant role in the potential of the GMRF model for the extraction of urban areas from SAR images. Intersensors comparison evidences the better performances of X-band images, acquired at 1-m spatial resolution, when resampled to resolutions of 5 and 10

m. [J491]

"Multi-feature based automatic recognition of ship targets in ISAR"

This paper deals with the problem of non-cooperative target recognition. Specifically, the aim is the automatic recognition of ship targets from inverse synthetic aperture radar (ISAR) images. For this purpose a new two-step multi-feature based technique is proposed; this technique uses a number of features extracted from the ship radar image and matches these features with those extracted from the images obtained by properly projecting the target models of the classification library. Both cases of a priori known or unknown ship aspect angles are considered: the knowledge of the ship aspect (as available from tracking data) allows the selection of the candidate models on the basis of the matching between the ship and the model length, thus resulting in a performance improvement. Moreover, both single- and multi-frame-based processing techniques are proposed in order to assess the performance improvement achievable when an increasing number of ISAR images are involved in the decision; the fusion strategy adopted for the exploitation of the information from the multiple images is also described. The performance of the overall proposed technique is deeply investigated against simulated data. Results of its application to a set of live ISAR images of a ship target are also provided showing the effectiveness of the proposed approach. [J492]

"An Optimized Algorithm for InSAR Phase Unwrapping Based on Particle Filtering, Matrix Pencil, and Region-Growing Techniques"

This letter presents a new phase unwrapping algorithm for synthetic aperture radar interferometry which combines a particle filter, a matrix-pencil (MP) local slope estimator, and an optimized region-growing technique. The advantages of the new method rely on the following contributions: The MP estimator provides better resolution to the local slope estimation, the particle filter enables simultaneous unwrapping and filtering without a prioristatistics constraints, and the implemented region-growing technique adds diversity of unwrapping paths and ensures an optimum solution. Results introduced in this letter illustrate the main aspects of the new approach. [J493]

"Signatures of ALOS PALSAR L-Band Backscatter in Swedish Forest"

The Phased Array type L-band Synthetic Aperture Radar onboard the Advanced Land Observing Satellite has, since its launch, been acquiring an extensive data set of images over two forest test sites in Sweden. The sites of Remningstorp (Lat. 58deg30' N, Long. 13deg40' E) in the south and Krycklan (Lat. 64deg14' N, Long. 19deg50' E) in the north of Sweden are characterized by hemiboreal and boreal forests, respectively. In this paper, we have investigated the signatures of standwise backscatter measurements from forests with different growth stages in relation to polarization, environmental conditions, image viewing geometry, and spatial resolution. The HV backscatter presented stronger sensitivity to the forest growth stage than the HH and VV backscatter. Under unfrozen conditions, the dynamic range of fine-beam data acquired at 34.3deg was 8-9 dB for the HV polarization and 6-7 dB for the HH polarization. At 21.5deg, in the polarimetric mode, the dynamic range was 6, 7, and 9 dB at VV, HH, and HV polarizations, respectively. Regardless of the specific polarization, the backscatter was temporally consistent under unfrozen conditions, with a small increase of backscatter in regrowing young forest for wet conditions. Under thawing and frozen conditions, repeated measurements were available only for the HH backscatter at 34.3deg. For thawing conditions, the backscatter level was similar to the unfrozen conditions even though the signatures differed depending on temperature dynamics, snow-cover properties, and precipitation. Under frozen conditions, the signatures varied depending on temperature. For images acquired when the temperature was well below the freezing point, the backscatter was low, and the dynamic range was small (2-4 dB); nonetheless, the measurements were consistent. Images acquired when temperature was close to the freezing point presented a behavior similar to unfrozen conditions. The sensitivity of the backscatter to the image viewing geometry for d--ifferent growth stages was studied for data acquired under dry unfrozen conditions. The backscatter difference increased for increasing look angle because of the increase in volume scattering and the decrease of ground-surface backscatter. The largest difference was observed at 41.5deg with 2.5-4-dB difference for the HH and 4-5-dB difference for the HV case. Loss of spatial resolution (20-50 m) did not have any effect on the backscatter signatures in Krycklan, whereas in Remningstorp, the smallest stands were affected. [J494]

"Generalized Frequency-Domain SAR Processing"

The range-Doppler algorithm and the chirp-scaling algorithm (CSA) process synthetic aperture radar (SAR) data with approximations to ideal SAR processing. These approximations are invalid for data from systems with wide beamwidths, large bandwidths, and/or low center frequencies. While simple and efficient, these frequency-domain methods are thus limited by the SAR parameters. This paper explores these limits and proposes a

generalized chirp-scaling approach for extending the utility of frequency-domain processing. We demonstrate how different order approximations of the SAR signal in the 2-D frequency domain affect image focusing for varying SAR parameters. From these results, a guideline is set forth, which suggests the required order of approximation terms for proper focusing. A proposed generalized frequency-domain processing approach is derived. This method is an efficient arbitrary-order CSA that processes the data using the appropriate number of approximation terms. The new method is demonstrated using simulated data. [J495]

"Employing a Method on SAR and Optical Images for Forest Biomass Estimation"

In this paper, we develop a novel method for forest biomass estimation. The intensity values of Advanced Land Observation Satellite-Advanced Visible and Near Infrared Radiometer type 2 and PRISM images and the texture features of the Japanese Earth Resources Satellite 1 image are used in a multilayer perceptron neural network (MLPNN) that relates them to the forest variable measurements on the ground. A proposed speckle noise model is also applied for modeling and reducing the speckle noise in the synthetic aperture radar (SAR) image. Reducing the speckle would improve the discrimination among different land use types and would make the textual classifiers more efficient in SAR images. Ideally, filters will reduce the speckle without loss of information. In the process of the forest biomass estimation, the filters should preserve the backscattering coefficient values and edges between different areas. We investigate both quantitative and qualitative criteria in speckle reduction and texture preservation to evaluate the performance of the proposed filter in the forest biomass estimation. We will also show that the biomass estimation accuracy is significantly improved in an MLPNN when the radar and the optical data are used in combination compared to estimating the biomass by using a single datum only. The root-mean-square error (rmse) value is decreased when the proposed method is used (rmse= 2.175 ton) compared with that of the classic method (rmse= 5.34 ton). [J496]

"The Impact of Multipath on High-Resolution SAS Image Statistics"

As with traditional sonar, synthetic aperture sonar (SAS) is susceptible to multipath contamination, reducing the quality and also modifying the statistics of the image. Such multipath contaminants may either be environmentally induced, as is often the case when attempting to image ranges greater than the water depth resulting in returns from the boundaries, or may be induced by the system's supporting structure itself. A clear understanding of such statistical impact is necessary to advance synthetic aperture formation algorithms and for predicting system performance. Broadband acoustic data suitable for SAS processing collected with a rail-mounted mobile-tower as part of the U.S. Office of Naval Research (ONR)-funded Sediment Acoustics eXperiment 2004 (SAX04) are analyzed in this paper. Analysis focused on both system structure and environmentally induced multipath using the K-distribution shape parameter as a metric. High-resolution sonar imagery often exhibited significantly non-Rayleigh, heavy-tailed envelope statistics, characterized by a low equivalent K-distribution shape parameter. Analysis showed a clear and significant increase in the estimated shape parameter in the presence of multipath, representing a trend toward a Rayleigh-distributed envelope. A model for reverberation is presented to provide bounds of the statistical impact using observable image intensity level increases in synthetic-aperture-formed images caused by multipath contamination. This model further shows potential for statistical impact when multipath arrivals are of similar level as the direct path even when not observable in the image (e.g., within 10 dB). [J497]

"HRR Automatic Target Recognition from Superresolution Scattering Center Features"

The work presented here introduces a procedure for the automatic recognition of ground-based targets from high range resolution (HRR) profile sequences that may be obtained from a synthetic aperture radar (SAR) platform. The procedure incorporates an adaptive target mask and uses a superresolution algorithm to identify the cross-range positions of target scattering centers. These are used to generate a pseudoimage of the target whose low-order discrete cosine transform coefficients form the recognizer feature vector. Within the recognizer, the states of a hidden Markov model (HMM) are used to represent the target orientation and a Gaussian mixture model is used for the feature vector distribution. In a closed-set identification experiment, the misclassification rate for ten MSTAR targets was 2.8%. Also presented are results from open-set experiments and investigates the effect on recognizer performance of variations in feature vector dimension, azimuth aperture, and target variants. [J498]

"Improved autofocusing of stepped-frequency ISAR images using new form of particle swarm optimisation"

An autofocusing method is proposed to compensate for the inter-pulse phase errors in stepped-frequency ISAR imaging. A genetic algorithm, particle swarm optimisation (PSO), and a combination of PSOs (CPSO) model were applied and compared with the existing subarray averaging and entropy minimisation method. In

simulations using measured data, CPSO gave the most accurate and stable results. [J499]

"A New Method for Correcting ScanSAR Scalloping Using Forests and Inter-SCAN Banding Employing Dynamic Filtering"

The Scanning Synthetic Aperture Radar (ScanSAR) is very useful for Earth observation because of its wider imaging swath and shorter revisit time. However, ScanSAR is sometimes affected by the following three artifacts: (1) scalloping, which often appears as repeating weak azimuth stripes at both edges of the focused burst image; (2) azimuth ambiguity (i.e., a form of ghosting that appears over the adjacent uniform area when the pulse repetition frequency is below the Doppler bandwidth); and (3) radiometric discontinuity (i.e., banding) between two adjacent scans. This paper proposes three methods to correct these artifacts, which are, specifically, the proposal for scalloping correction using Amazon Rainforest data, band limitation, and the correction for the inter SCAN banding using the dynamic gain correction algorithm. Several corrected sample data sets of the Phased-Array L-band SAR onboard the Advanced Land-Observing Satellite are presented to demonstrate the validity of the proposed methods. [J500]

"The PALSAR Polarimetric Mode for Sea Oil Slick Observation"

A study on sea oil slick observation by means of L-band polarimetric synthetic aperture radar (SAR) data is accomplished. It is based on different sea surface scattering mechanism expected with and without surface slicks. Polarimetric measurements are processed by means of a simple and very effective filtering technique which is electromagnetically based on the Mueller scattering matrix. Moreover, some polarimetric features, evaluated on both slick-free and slick-covered sea surfaces, are analyzed for confirming the filter output. Experiments are accomplished on the polarimetric SAR data acquired by the Phased Array-type L-band Synthetic Aperture Radar (PALSAR) sensor, mounted on board of the Advanced Land Observing Satellite (ALOS), and are relevant to oil slick, due to a tank accident, and look-alikes. Results demonstrate for the first time that L-band polarimetric SAR measurements are useful for oil slick observation purposes and witness the capability of the ALOS PALSAR data for such application. [J501]

"Verification of Polarimetric Calibration Method Including Faraday Rotation Compensation Using PALSAR Data"

The spaceborne Phased Array L-band Synthetic Aperture Radar (PALSAR) needs polarimetric calibration in order for PALSAR data to be utilized for various applications such as geophysical analysis. In case of a PALSAR system using L-band, the Faraday rotation (FR) effect, which rotates the polarization plane of radio waves, becomes a problem when full-polarimetric observation data are used, such as target classification using polarization synthesis. Therefore, we need to estimate and remove both antenna distortion matrices and the FR effect. In this paper, we propose a polarimetric calibration method taking both channel imbalance and crosstalk of receiving and transmitting antennas and FR effect into consideration using two reference reflectors, namely, polarization preserving reflector and polarization rotating one. Then, we apply our calibration method to PALSAR data and derive antenna distortion matrices and FR angle simultaneously. Our calibration results show that the estimated antenna distortion matrices are almost equal to the calibration results from the Japan Aerospace Exploration Agency and that the estimated FR angle has a reasonable value. [J502]

"Report on First International Summer School on Radar/SAR"

In the picturesque Rhine Valley close to Bonn, more than 30 young students and scientists from all corners of the world congregated from July 24 to 31, 2009, to participate in the 1st International Summer School on Radar/SAR. The summer school was the initiative of Prof. Dr. Joachim Ender, director of one of Europe's foremost radar research establishments: the Fraunhofer Institute for High Frequency Physics and Radar (formerly, FGAN-FHR). Fraunhofer-FHR, in cooperation with renowned experts from across Europe and Canada, combined their creativity and scientific prowess to put together a program that would appeal to young scientists (particularly PhD candidates) across the globe. [J503]

"The German satellite mission TerraSAR-X"

TerraSAR-X is Germany's first national remote sensing satellite being implemented in a public-private partnership between the German Aerospace Centre (DLR) and EATS Astrium GmbH. TerraSAR-X was launched on June 15, 2007 and will supply high-quality radar data for purposes of scientific observation of the Earth for a period of at least five years. At the same time, it is designed to satisfy the steadily growing demand of the private sector for remote sensing data in the commercial market. [J504]

"Arctic sea ice mapping with satellite radars"

The drastic reduction of Arctic sea ice in recent years demands ice monitoring over various spatial and temporal scales. Sea ice backscatter signatures from field measurements and from model analyses are obtained at L-band and C-band frequencies. Based on these signatures, capabilities for Arctic sea ice mapping are determined for current and future satellite active microwave sensors including synthetic aperture radars (SAR) and scatterometers. This study includes L-band and C-band radars such as the ERS (European Remote Sensing), Envisat (Environmental Satellite), RADARSAT-1 and 2, ALOS (Advanced Land Observing Satellite), and DESDnyl (Deformation, Ecosystem Structure, and Dynamics of Ice). SARs with resolutions from 10 to 100 m, and the SMAP (Soil Moisture Active-Passive) scatterometer with resolutions from 1 to 10 km. [J505]

"Polarimetric PALSAR Calibration"

Polarimetric Phased-Array-type L-band Synthetic Aperture Radar (PALSAR) system parameters are assessed using data sets collected over several calibration sites. The data collected over the Amazonian rain forest help validate the hypothesis that Faraday rotation is zero near the equator. The analysis of the Amazonian forest data and the response of the corner reflectors deployed there during the PALSAR acquisitions lead to the conclusion that the antenna is highly isolated (better than -35 dB). These results are confirmed using the data collected over calibration sites located in Sweden and Canada. The 5-m-height corner reflector deployed at the Remningstorp (Sweden) calibration site by Chalmers University of Technology provides accurate measurement of antenna parameters and detection of a (2deg -3deg) Faraday rotation during day-time acquisitions, whereas no Faraday rotation was noted during night-time acquisitions. Small Faraday rotation angles (2deg-3deg) have been measured using acquisitions over the DLR Oberpfaffenhofen and the Ottawa calibration sites. The presence of small but still significant Faraday rotation (2deg-3deg) induces a corner reflector return at the cross-polarization HV and VH that should not be interpreted as the actual antenna crosstalk. These results show that the PALSAR antenna is highly isolated (better than -35 dB), and diagonal antenna distortion matrices (with zero crosstalk terms) can be used for accurate calibration of PALSAR polarimetric data. [J506]

"Foreword to the Special Issue on Calibration and Validation of ALOS Sensors (PALSAR, AVNIR-2, and PRISM) and Their Use for Bio- and Geophysical Parameter Retrievals"

The 17 papers in this special issue focus on the calibration and validation of ALOS sensors and their use for bio- and geophysical parameter retrievals. [J507]

"Wideband multipath rejection for shallow water synthetic aperture sonar imaging"

Synthetic aperture sonar (SAS) is an emerging technology for seafloor imaging, which has an appealing property of range- and frequency-independent spatial processing resolution. However, for a low-frequency SAS system operated in shallow water environments, there are often strong sea surface and bottom reflected multipath components that interfere with the desired echo signals. Based upon a small vertically displaced hydrophone array, several spatial processing algorithms have been proposed for multipath reduction. Most of these algorithms, however, are only applicable to narrowband signals, whereas wideband signals are usually used in low-to-medium-frequency SAS systems in order to achieve a high range resolution. This paper presents a steered robust Capon beamforming (SRCB) approach, and applies the approach, together with the data-independent delay-and-sum beamforming and the conventional wideband robust Capon beamforming, to wideband multipath rejection for shallow water SAS imaging. Numerical simulations of the proposed SAS processing have verified the performance improvements on output image quality over conventional processing in terms of both ghost target strength reduction and contrast enhancement. [J508]

"Theory and simulation of ionospheric effects on synthetic aperture radar"

Space-based synthetic aperture radar (SAR) necessarily involves imaging through the ionosphere. At low frequencies (VHF, UHF and L-band) the ionosphere will degrade the SAR image. Previous work has shown that the amount of image degradation strongly depends on the integrated strength of ionospheric turbulence, CkL. The focusing, sidelobes and integrated sidelobe ratio all depend on CkLin a manner that can be directly predicted by a simple analytic theory, which is reviewed and extended to cover any synthetic aperture length. Simulations of the ionosphere, using a thin phase screen parabolic equation approach, are performed under different ionospheric conditions for a number of possible SAR systems and the results compared with the analytic theory. It is concluded that, provided that the scattering is weak, the theory represents a good predictor of SAR performance, even at UHF. The known statistics of CkLcan therefore be used to predict the performance of any trans-ionospheric SAR without performing a simulation. [J509]

"GPS-Based Time & Phase Synchronization Processing for Distributed SAR"

Distributed synthetic aperture radar (DiSAR), including bi- and multistatic SAR, operates with distinct transmitting and receiving antennas that are mounted on separate platforms. Spatial separation has several operational advantages, such as reduced vulnerability in military applications and increased radar cross section (RCS); which may increase the capability, reliability, and flexibility of future aerospace remote sensing missions. However, in this configuration, there is no cancellation of reference oscillator phase noise as in monostatic cases. There are additional technical problems associated with temporal synchronization of the transmit and receive systems. Therefore, highly accurate time and phase synchronization must be provided. Little work on these challenges has been reported. This paper presents a Global Positioning System (GPS)-based technique for achieving successful time and phase synchronization for DiSAR. This technique offers high-frequency stability. More importantly, residual time synchronization errors may be compensated for with a high-precision range alignment method, and residual phase synchronization errors may be compensated for with a subaperture autofocus algorithm. [J510]

"A Velocity Estimation Algorithm of Moving Targets using Single Antenna SAR"

A new algorithm is proposed for velocity estimation of moving targets in single antenna synthetic aperture radar (SAR). Based on the fact that different velocity vectors cause different geometrical figures of the two-dimensional (2-D) signature in the range-Doppler (RD) domain, this algorithm estimates the azimuth and range velocities by a 2-D search such that the range cell migration correction (RCMC) and the second range compression (SRC) are correctly performed. It is shown that, using the proposed algorithm, the Doppler ambiguity problem can be avoided and satisfactory accurate velocity estimation can be obtained in high signal-to-clutter ratio (SCR) scenarios. [J511]

"A Generalized Approach to Multiresolution Complex SAR Signal Processing"

Multiresolution synthetic aperture radar (SAR) image formation has been proven to be beneficial in a variety of applications such as improved imaging and target detection as well as speckle reduction. SAR signal processing traditionally carried out in the Fourier domain has inherent limitations in the context of image formation at hierarchical scales. We present a generalized approach to the formation of multiresolution SAR images using biorthogonal shift-invariant discrete wavelet transform (SIDWT) in both range and azimuth directions. Particularly in azimuth, the inherent subband decomposition property of wavelet packet transform is introduced to produce multiscale complex matched filtering without involving any approximations. This generalized approach also includes the formulation of multilook processing within the discrete wavelet transform (DWT) paradigm. The efficiency of the algorithm in parallel form of execution to generate hierarchical scale SAR images is shown. Analytical results and sample imagery of diffuse backscatter are presented to validate the method. [J512]

"Dynamic Targets in CRRs Part II: Experiments and SAR Correspondence"

Expressions describing the correspondence between moving-target artifacts for synthetic-aperture radar (SAR) and compact radar range (CRR) emulations are developed. Experimental results are then presented to verify the accuracy of these equations and to characterize the capacity of CRRs to emulate translating, vibrating, and rotating targets. We show that phase-compensation techniques can be applied to CRR data, providing a suitable test bed for SAR phase-compensation techniques. [J513]

"Parametric Methods for Strip-Map SAR Doppler Ambiguity Resolution"

Physical modeling of the Doppler centroid (DC) can be used to predict synthetic aperture radar (SAR) Doppler ambiguity when antenna attitude is controlled or measured precisely enough. It is shown that the same model proves useful even in the cases of higher attitude uncertainty, if it is combined with suitable adaptive techniques. In this paper, Doppler ambiguity resolution is formulated as a hypothesis testing problem over a domain of integer values that are directly related to the attitude uncertainty. A test statistic is derived from the entire SAR scene using data adaptive processing. A broad class of such adaptive algorithms is analyzed in a unified way, starting from the range-azimuth coupling in the frequency domain and multilook techniques. The analysis includes two well-known and two new multilook methods for Doppler ambiguity resolution. A suitable test statistic is proposed for each of these methods and its dependency on the scene spatial correlation is discussed. Experimental results confirm the robustness of the combined scheme. [J514]

"High Range Resolution Profiles as Motion-Invariant Features for Moving Ground Targets Identification in SAR-Based Automatic Target Recognition"

A quantitative model analysis is presented to justify the extraction of high range resolution (HRR) profiles from

synthetic aperture radar (SAR) images as motion-invariant features for identifying moving ground targets. A comparative study is conducted to assess the effectiveness in the identification process between using HRR profiles and SAR images as target signatures. The results indicate that HRR profiles are just as viable as SAR image for identification. Furthermore, a score-level multi-look fusion identification method has been investigated. It is found that a correct accurate identification rate of greater than 99 percent, a low false alarm rate, and a high level of identification confidence can be achieved, providing very robust performance. [J515]

"A Model for Generating Synthetic VHF SAR Forest Clutter Images"

We propose a model for generating low-frequency synthetic aperture radar (SAR) clutter that relates model parameters to physical characteristics of the scene. The model includes both distributed scattering and large-amplitude discrete clutter responses. The model also incorporates the SAR imaging process, which introduces correlation among image pixels. The model may be used to generate synthetic clutter for a range of environmental operating conditions for use in target detection performance evaluation of the radar and automatic target detection/recognition algorithms. We derive a statistical representation of the proposed clutter model's pixel amplitudes and compare with measured data from the CARABAS-II SAR. Simulated clutter images capture the structure and amplitude responses seen in the measured data. A statistical analysis shows an order of magnitude improvement in model fit error compared with standard maximum-likelihood (ML) density fitting methods. [J516]

"Azimuth-invariant bistatic multichannel synthetic aperture radar for moving target detection and location"

Ground moving target indication (GMTI) is one of the most important applications of the bistatic synthetic aperture radar (SAR) system as well as the monostatic system. An algorithm for moving target detection and location is presented with an azimuth-invariant bistatic multichannel SAR, which consists of one transmitter (channel) and multireceivers (multichannel). The algorithm is based on the discussion of the particularities of the bistatic SAR configuration including coherence improvement and clutter characteristics. Then, the corresponding compensating methods including two-dimensional range-azimuth prefiltering and bistatic differential range correction are proposed to solve these particularities. It is shown that using the compensating methods, the stationary clutter can be suppressed and the moving parameters of ground targets can be estimated accurately. Finally, simulation results demonstrate the effectiveness of the proposed algorithm. [J517]

"Multibaseline InSAR height estimation through joint covariance matrix fitting"

A new joint processing method based on joint covariance matrix fitting is presented for the multibaseline synthetic aperture radar interferometry. This method can make full use of the interferometric information embedded in the joint covariance matrix to estimate the terrain height without eigendecomposition and eigenspace division, and is insensitive to the rank variation of the joint signal subspace. By fitting the sample joint covariance matrix tapered with the coherence matrix, this method can work robustly with a finite sample support, which also makes it possible to recover the detail of terrain profile with a small neighbouring sample support. The results of numerical simulations demonstrate the validation of the proposed method. [J518]

"Pitch estimation for non-cooperative maritime targets in ISAR scenarios"

Maritime targets are usually involved in complex motions that complicate the generation of focused inverse synthetic aperture radar (ISAR) images and their scaling in cross-range. By assuming some hypotheses that translate to some restrictions in the maritime surveillance scenario, a signal model for the phase history is derived. This function is calculated here using phase gradient autofocus and can be related to the pitch motion of the ship, which may consequently be estimated. The amplitude and the period of this pitch estimate allow us to select imaging times at which the ISAR images are descriptive for classification purposes. The cross-range scaling of these images is also achieved. Simulated data are used to validate the technique and to evaluate its performance when deviations from the nominal scenario are present. Results obtained with live data acquired by a high-resolution radar confirm the effectiveness of the approach. [J519]

"Orthogonal Block Coded ECCM Schemes Against Repeat Radar Jammers"

This paper develops radar signaling schemes to combat the impact of repeat jammers on radar systems. Robustness against jammers is achieved by employing the concept of pulse diversity where the radar, at each pulse repetition interval, emits either a modified version of the previous waveform or a new waveform following a specific orthogonal structure. Two pulse coding techniques are presented; both enable the radar to separate the signals being reflected off the true targets and the false reflectors being emulated by a jammer. Simulations are used to show the validity of the introduced concepts. [J520]

"Quantitative SNR Analysis for ISAR Imaging using LPFT"

This paper presents the quantitative analysis of signal-to-noise ratio (SNR) for the local polynomial Fourier transform (LPFT) used for application of inverse synthetic aperture radar (ISAR) imaging. The relationship between the LPFT and Wigner-Ville distribution (WVD) is derived and theoretical analysis on the SNR achieved by using the LPFT is given. Comparisons on the SNR performances achieved by using the LPFT, the short-time Fourier transform (STFT) and the Fourier transform (FT) are presented to illustrate the merits of using the LPFT. Measures are also taken to minimize the required computational complexity by reducing the overlap length between adjacent segments of input data. Simulation results of processing radar data show the performance improvements achieved by using the LPFT. [J521]

"ISAR imaging of manoeuvring targets with the range instantaneous chirp rate technique"

The conventional range instantaneous Doppler (RID) algorithm is a well accepted inverse synthetic aperture radar (ISAR) imaging method for manoeuvring targets. In the RID imaging, the cross-range resolution depends on the instantaneous Doppler of scatterers at the imaging instant. For a high manoeuvring target, the instantaneous Doppler of scatterers may be small at some imaging instants and the satisfactory RID images may not be obtained. On the other hand, a large instantaneous chirp rate is often present for the same scatterer at the same instant for RID imaging. In order to obtain some additional information of a manoeuvring target, a novel ISAR imaging approach, referred to as the range instantaneous chirp (RIC), is proposed based on instantaneous chirp rate of scatterer to provide cross-range resolution. Using the proposed imaging algorithm, with the same received data of RID, a RIC image is generated at the same instant with a different `view`. Therefore the RIC image may provide some additional information that is not shown in the RID image. With both the RIC and RID images, a better target recognition and identification can be achieved for high-manoeuvring targets. The proposed RIC algorithm is verified by raw radar data. [J522]

"A New Numerical Method for Calculating Extrema of Received Power for Polarimetric SAR"

A numerical method called cross-step iteration is proposed to calculate the maximal/minimal received power for polarized imagery based on a target's Kennaugh matrix. This method is much more efficient than the systematic method, which searches for the extrema of received power by varying the polarization ellipse angles of receiving and transmitting polarizations. It is also more advantageous than the Schuler method, which has been adopted by the PolSARPro package, because the cross-step iteration method requires less computation time and can derive both the maximal and minimal received powers, whereas the Schuler method is designed to work out only the maximal received power. The analytical model of received-power optimization indicates that the first eigenvalue of the Kennaugh matrix is the supremum of the maximal received power. The difference between these two parameters reflects the depolarization effect of the target's backscattering, which might be useful for target discrimination. [J523]

"A Feasibility Assessment for Low-Cost InSAR Formation-Flying Microsatellites"

Multistatic interferometric synthetic aperture radar (InSAR) is a promising potential payload for a small satellite constellation. CanX-4 and CanX-5 are a pair of formation-flying nanosatellites launching in 2009; once formation flight has been demonstrated, a future multistatic InSAR constellation of low-cost microsatellites can exploit subcentimeter intersatellite baseline knowledge, with digital elevation map height errors on the order of 1 m in the flat-terrain case. This paper evaluates the feasibility of such a mission, using case studies of commonly proposed configurations: the Interferometric Cartwheel, the Cross-Track Pendulum, and the Cartwheel-Pendulum (Car-Pe) configuration. In each case, several SAR transmitters are considered: L-, C-, and X-band transmitters with parameters mirroring existing ldquolargerdquo satellite SAR missions, and a theoretical X-band microsatellite transmitter. The available interferometric baselines, ground coverage, and image resolutions are evaluated in each scenario. The X-band ldquomicrordquo transmitter is feasible, but the low transmit power severely limits the ground coverage. The X-band ldquolargerdquo transmitter provides the largest ground coverage and the highest resolution along with the X-band ldquomicrordquo option. The resolutions are wavelength dependent and remain relatively constant among the configurations. The operating areas of the pendulum demonstrate the largest degree of overlap, while the longer along-track baselines of the cartwheel result in a smaller overlap. Both two-receiver (pendulum and cartwheel) configurations demonstrate baseline characteristics that may be optimal for different applications, while the three-receiver Car-Pe demonstrates the advantages of both the pendulum and cartwheel. [J524]

"Integration of InSAR Time-Series Analysis and Water-Vapor Correction for Mapping Postseismic Motion After the 2003 Bam (Iran) Earthquake"

Atmospheric water-vapor effects represent a major limitation of interferometric synthetic aperture radar (InSAR) techniques, including InSAR time-series (TS) approaches (e.g., persistent or permanent scatterers and small-baseline subset). For the first time, this paper demonstrates the use of InSAR TS with precipitable water-vapor (InSAR TS + PWV) correction model for deformation mapping. We use MEdium Resolution Imaging Spectrometer (MERIS) near-infrafred (NIR) water-vapor data for InSAR atmospheric correction when they are available. For the dates when the NIR data are blocked by clouds, an atmospheric phase screen (APS) model has been developed to estimate atmospheric effects using partially water-vapor-corrected interferograms. Cross validation reveals that the estimated APS agreed with MERIS-derived line-of-sight path delays with a small standard deviation (0.3-0.5 cm) and a high correlation coefficient (0.84-0.98). This paper shows that a better TS of postseismic motion after the 2003 Bam (Iran) earthquake is achievable after reduction of water-vapor effects using the InSAR TS + PWV technique with coincident MERIS NIR water-vapor data. [J525]

"Estimating Spatiotemporal Ground Deformation With Improved Permanent-Scatterer Radar Interferometry"

Synthetic aperture radar interferometry has been applied widely in recent years to ground deformation monitoring although difficulties are often encountered when applying the technology, among which the spatial and temporal decorrelation and atmospheric artifacts are the most prominent. The permanent-scatterer interferometric synthetic aperture radar (PS-InSAR) technique has overcome some of the difficulties by focusing only on the temporally coherent radar targets in a time series of synthetic aperture radar (SAR) images. This paper presents an improved PS-InSAR technique by introducing PS-neighborhood networking and empirical mode decomposition (EMD) approaches in the PS-InSAR solution. Linear deformation rates and topographic errors are estimated based on a least squares method, while the nonlinear deformation and atmospheric signals are computed by singular value decomposition and the EMD method. An area in Phoenix, AZ, is used as a test site to determine its historical subsidence with 39 C-band SAR images acquired by European Remote Sensing 1 and 2 satellites from 1992 to 2000. [J526]

"Separation Between Water and Land in SAR Images Using Region-Based Level Sets"

This letter presents a method for the separation between land and water in synthetic aperture radar (SAR) amplitude images. The proposed technique uses region-based level sets and adopts a mixture of lognormal densities as the probabilistic model for the pixel intensities in both water and land classes. The expectation-maximization algorithm is used to estimate the probability density functions for each class. Experimental results with real SAR images of riverbeds, flood extent areas, and shorelines demonstrate the good performance of the proposed algorithm compared with state-of-the-art approaches. [J527]

"A Spatially Adjusted Elevation Model in Dronning Maud Land, Antarctica, Based on Differential SAR Interferometry"

In this paper, a new digital elevation model (DEM) is derived for the ice sheet in western Dronning Maud Land, Antarctica. It is based on differential interferometric synthetic aperture radar (SAR) from the European Remote Sensing 1/2 (ERS-1/2) satellites, in combination with ICESat's Geoscience Laser Altimeter System (GLAS). A DEM mosaic is compiled out of 116 scenes from the ERS-1 ice phase in 1994 and the ERS-1/2 tandem mission between 1996 and 1997 with the GLAS data acquired in 2003 that served as ground control. Using three different SAR processors, uncertainties in phase stability and baseline model, resulting in height errors of up to 20 m, are exemplified. Atmospheric influences at the same order of magnitude are demonstrated, and corresponding scenes are excluded. For validation of the DEM mosaic, covering an area of about 130 000 km2on a 50-m grid, independent ICESat heights (2004-2007), ground-based kinematic GPS (2005), and airborne laser scanner data (ALS, 2007) are used. Excluding small areas with low phase coherence, the DEM differs in mean and standard deviation by 0.5 + /-10.1, 1.1 + /-6.4, and 3.1 +/-4.0 m from ICESat, GPS, and ALS, respectively. The excluded data points may deviate by more than 50 m. In order to suppress the spatially variable noise below a 5-m threshold, 18% of the DEM area is selectively averaged to a final product at varying horizontal spatial resolution. Apart from mountainous areas, the new DEM outperforms other currently available DEMs and may serve as a benchmark for future elevation models such as from the TanDEM-X mission to spatially monitor ice sheet elevation. [J528]

"The Utility of Spaceborne Radar to Render Flood Inundation Maps Based on Multialgorithm Ensembles"

On December 12, 2006, both the European Remote Sensing Satellite 2 and Environmental Satellite recorded a high-magnitude flood event on the River Dee in Wales (U.K.) only 28 min apart. This unique opportunity enables the creation of a very rare but extremely useful observed data set for flood inundation studies. For flood

management purposes, hydrodynamic models are often run after an event but with field data gauged during the event to approximate both flood area and depth. As an adequate aprioridefinition of model parameters is difficult, they tend to be run with multiple parameter sets to generate a likelihood of inundation map. However, as field observations of events are often very scarce, these output maps cannot be validated with field-observed probabilities. This paper illustrates how this unique set of spaceborne radar images can be used in combination with five widely used image processing techniques to generate an event-specific inundation map that expresses a degree of belief that a given pixel is possibly flooded. It is expected that the value of this multialgorithm ensemble-based map opens up new ways to evaluate the performance of hydrodynamic models, as it contains information which has, to the authors' knowledge, not previously been available. [J529]

"Autobinomial Model for SAR Image Despeckling and Information Extraction"

This paper presents a model-based despeckling (MBD) of synthetic aperture radar (SAR) images using Bayesian analysis. The SAR image is despeckled using first-order Bayesian inference. The novelty in this paper is an autobinomial model (ABM), which models a priorprobability density function (pdf); meanwhile, the likelihoodpdf is modeled as a gamma distribution. Analytically, a solution for a maximum aposterioriestimate using an autobinomial prior cannot be computed; therefore, an approximation is introduced using differential. The best ABM for approximating the texture parameters in SAR images is found by using second-order Bayesian inference. The edges in the SAR images are detected using region borders, which have statistically different properties. Coefficient of variation is used to distinguish between homogeneous and heterogeneous areas. The experimental results show that the proposed method preserves the textural features and removes noise significantly in the homogeneous and heterogeneous regions. The proposed despeckling method is good regarding objective measures for synthetic images and better despeckles the real SAR images, when compared with the state-of-the-art MBD methods. [J530]

"Fast and Adaptive Method for SAR Superresolution Imaging Based on Point Scattering Model and Optimal Basis Selection"

A novel fast and adaptive method for synthetic aperture radar (SAR) superresolution imaging is developed. Based on the point scattering model in the phase history domain, a dictionary is constructed so that the superresolution imaging process can be converted to a problem of sparse parameter estimation. The approximate orthogonality of this dictionary is exploited by theoretical derivation and experimental verification. Based on the orthogonality of the dictionary, we propose a fast algorithm for basis selection. Meanwhile, a threshold for obtaining the number and positions of the scattering centers is determined automatically from the inner product curves of the bases and observed data. Furthermore, the sensitivity of the threshold on estimation performance is analyzed. To reduce the burden of mass calculation and memory, a simplified superresolution imaging process is designed according to the characteristics of the imaging parameters. The experimental results of the simulated images and an MSTAR image illustrate the validity of this method and its robustness in the case of the high noise level. Compared with the traditional regularization method with the sparsity constraint, our proposed method suffers less computation complexity and has better adaptability. [J531]

"Coherence-Improving Algorithm for Image Pairs of Bistatic SARs With Nonparallel Trajectories"

Ground moving target indication (GMTI) is one of the most important applications in a general bistatic synthetic aperture radar (SAR) system, where the transmitter and receiver move along nonparallel trajectories with different velocities. In order to improve the capability of clutter cancellation in bistatic SAR/GMTI processing, the coherence between two echoes collected by two receivers is investigated, and the full-coherence conditions are derived. A new coherence-improving algorithm for general bistatic SAR complex image pairs is proposed, which can be realized in the following steps: 2-D range azimuth prefiltering processing, relative geometric deformation correction, and image registration. An approximate implementation of 2-D prefiltering and the corresponding prefilter parameter analysis are also given. Last, two numerical experiment results are given to demonstrate the effectiveness of the proposed algorithm. [J532]

"A Closed-Form Expression Relating Classification Accuracy to SAR System Calibration Uncertainty"

The choice of synthetic aperture radar (SAR) system design parameters such as radiometric calibration uncertainty and noise-equivalent sigma zero has a significant impact on applications exploiting SAR image data. However, methods for quantitatively translating the impact of system and mission parameter choices into the application context are lacking. This letter addresses this subject and derives a closed-form algebraic expression for translating radiometric biases due to calibration uncertainties-an important SAR engineering specification-into estimates of classification uncertainties for the restricted case of two homogeneous classes characterized by

different backscatter intensity levels. The expression is exploited within this letter to estimate the potential impact of radiometric uncertainty on SAR-derived thematic maps. The results indicate that classification results based on the joint use of data from future SAR constellations in particular may be significantly degraded due to calibration uncertainties. [J533]

"Large-Area Soil Moisture Estimation Using Multi-Incidence-Angle RADARSAT-1 SAR Data"

The sensitivity of synthetic aperture radar (SAR) backscatter to soil moisture has been adequately established. However, monitoring of soil moisture over large agricultural areas is still difficult because SAR backscatter is also sensitive to other target properties like surface roughness, crop cover, and soil texture (soil type), along with its strong sensitivity to soil moisture. Hence, to develop a methodology for large-area soil moisture estimation using SAR, it is necessary to incorporate the effects of surface roughness, crop cover, and soil texture in the soil moisture retrieval model. In this paper, a methodology for soil moisture estimation over a large area is developed using a pair of low- and high-incidence-angle RADARSAT-1 SAR data over parts of Agra, Mathura, and Bharatpur districts, India, during March 1999. The methodology requires acquisition of synthetic aperture radar data at low and high incidence angles, such that the soil moisture changes are negligible between the two acquisitions. In order to demonstrate the applicability of the developed methodology, the same was validated over a different area (parts of Saharanpur and Haridwar districts, India) during March 2005. Both test sites provided the variety of agricultural heterogeneity required for development and validation of the methodology for large-area soil moisture estimation. The proposed methodology offers an approach to incorporate the effects of surface roughness, crop cover, and soil texture in the soil moisture retrieval model from the space platform, without making any assumptions on the distributions of these parameters or without knowing the actual values of these parameters on ground. [J534]

"A Characterization of Shannon Entropy and Bhattacharyya Measure of Contrast in Polarimetric and Interferometric SAR Image"

We analyze the application of Shannon entropy and Bhattacharyya distance for the characterization of polarimetric interferometric synthetic aperture radar (PolInSAR) images. We discuss the relevance of the decomposition of the Shannon entropy of a homogeneous region into the sum of three physically meaningful terms that depend respectively on intensity, polarimetry, and interferometry. We also discuss an analogous decomposition property for the Bhattacharyya distance, which is an efficient measure of the contrast between two regions. We illustrate the application of this approach for analyzing different contributions in the information content of PolInSAR images. [J535]

"Wavelet-Based SAR Image Despeckling and Information Extraction, Using Particle Filter"

This paper proposes a new-wavelet-based synthetic aperture radar (SAR) image despeckling algorithm using the sequential Monte Carlo method. A model-based Bayesian approach is proposed. This paper presents two methods for SAR image despeckling. The first method, called WGGPF, models a prior with Generalized Gaussian (GG) probability density function (pdf) and the second method, called WGMPF, models prior with a Generalized Gaussian Markov random field (GGMRF). The likelihood pdf is modeled using a Gaussian pdf. The GGMRF model is used because it enables texture parameter estimation. The prior is modeled using GG pdf, when texture parameters are not needed. A particle filter is used for drawing particles from the prior for different shape parameters of GG pdf. When the GGMRF prior is used, the particles are drawn from prior in order to estimate noise-free wavelet coefficients and for those coefficients the texture parameter is changed in order to obtain the best textural parameters. The texture parameters are changed for a predefined set of shape parameters of GGMRF. The particles with the highest weights represents the final noise-free estimate with corresponding textural parameters. The despeckling algorithms are compared with the state-of-the-art methods using synthetic and real SAR data. The experimental results show that the proposed despeckling algorithms efficiently remove noise and proposed methods are comparable with the state-of-the-art methods regarding objective measurements. The proposed WGMPF preserves textures of the real, high-resolution SAR images well. [J536]

"Unsupervised Change Detection From Multichannel SAR Data by Markovian Data Fusion"

In applications related to environmental monitoring and disaster management, multichannel synthetic aperture radar (SAR) data present a great potential, owing both to their insensitivity to atmospheric and Sun-illumination conditions and to the improved discrimination capability they may provide as compared with single-channel SAR. However, exploiting this potential requires accurate and automatic techniques to generate change maps from (multichannel) SAR images acquired over the same geographic region in different polarizations or at different frequencies at different times. In this paper, a contextual unsupervised change-detection technique (based on a

data-fusion approach) is proposed for two-date multichannel SAR images. Each SAR channel is modeled as a distinct information source, and a Markovian approach to data fusion is adopted. A Markov random field model is introduced that combines together the information conveyed by each SAR channel and the spatial contextual information concerning the correlation among neighboring pixels and formulated by using ldquoenergy functions.rdquo In order to address the task of the estimation of the model parameters, the expectation-maximization algorithm is combined with the recently proposed ldquomethod of log-cumulants.rdquo The proposed technique was experimentally validated with semisimulated multipolarization and multifrequency data and with real SIR-C/XSAR images. [J537]

"On-Ground Characterization of the SMOS Payload"

The on-ground characterization of the synthetic aperture radiometer onboard the Soil Moisture and Ocean Salinity mission is described. Characterization includes basic functionality, internal calibration, thermal cycling, response to point and flat sources, self-radio-frequency interference, and others. The description of the different tests performed as well as the detailed results are provided. The results show that the instrument is very stable and has all gains and offsets consistent with the ones obtained at subsystem level. On the other hand, the phase of the visibility has a larger variation with temperature than expected, a small signal leakage from the local oscillators is present, and a small interference from the X-band transmitter during short periods of time has been detected. The implementation of internal-calibration procedures, along with the accurate thermal characterization performed, have been used to produce highly accurate brightness-temperature values well within specifications. [J538]

"Antenna Mask Design for SAR Performance Optimization"

In this letter, an effective technique for synthetic aperture radar (SAR) antenna mask design is presented for optimizing the system performance of an active phased array SAR. The SAR antenna radiation pattern has an important effect on the system performance. Therefore, the authors derived the quantitative equations for the SAR antenna mainlobe and sidelobe mask design on the basis of the system performance measures such as the range-to-ambiguity ratio (RAR), the noise-equivalent sigma zero (NESZ), and the radiometric accuracy. The antenna mask template should be designed to minimize the ambiguous signals reflected from the antenna sidelobes and maximize the system sensitivity, i.e., the NESZ, determined by the antenna mainlobe. The simple iterative method such as random-mutation hill climbing was utilized to successfully assign the sidelobe level at each ambiguous area using the derived equations. Finally, the antenna patterns were synthesized with reference to the optimized antenna mask templates using the particle swarm optimization, and the swath width, RAR, and NESZ performances were evaluated in order to confirm the effectiveness of the proposed technique. [J539]

"Alternatives to Target Entropy and Alpha Angle in SAR Polarimetry"

The purpose of this paper is to discuss two polarimetric parameters which are widely used in synthetic aperture radar (SAR) polarimetry, namely, target entropy and alpha angle. We propose alternative parameters based on our analysis on how they are connected to covariance matrix similarity invariants and how they can be physically interpreted in optical polarimetry. The proposed alternatives can be computed by a fairly simple algorithm and even by the use of software without complex mathematics abilities. As an example, a NASA/Jet Propulsion Laboratory Airborne SAR L-band image of the San Francisco Bay is used to compare the proposed parameter schemes with the original entropy and alpha. A coherent rationale for these alternative parameters is formulated in order to provide insight to polarimetric parameter interpretation. [J540]

"Space-Based Motion Estimators-Evaluation With the First RADARSAT-2 MODEX Data"

Synthetic aperture radar (SAR)-based motion estimation algorithms, which have been developed and validated for airborne SAR data, are now being extended to the RADARSAT-2 Moving Object Detection Experiment (MODEX). Several modifications of the classical along-track interferometry (ATI) approach are considered. Some of the first MODEX results are presented, demonstrating the estimation of target position and velocity from a commercial satellite using ATI methods. [J541]

"An L-Band Ocean Geophysical Model Function Derived From PALSAR"

This paper examines L-band normalized radar cross section (NRCS) dependence on ocean surface wind. More than 90 000 match-ups, each consisting of the L-band HH NRCS, incidence angles, wind speeds, and wind directions, were collected from the Phased-Array L-Band Synthetic Aperture Radar (PALSAR) and scatterometer wind vectors. Based on the match-ups, the L-band HH NRCS dependence on incidence angle and wind vector is modeled for 0-20-m/s wind speeds and 17deg-43deg incidence angles. The derived relation indicates that the wind sensitivity of the L-band NRCS is less than that of the C-band at moderate winds and large incidence

angles, whereas comparable at stronger winds ((>10 m/s) and small incidence angles. The upwind-crosswind difference is amplified in the 10-15-m/s range followed by an almost zero amplitude from 4 to 8 m/s, which represents a clear phase shift with the C-band VV and Ku-band HH models. Wind speeds are then estimated from the match-ups, based on the derived model function. A comparison with the reference scatterometer winds reveals a 0.05-m/s bias and a 1.85-m/s root mean square error, where crosswind data give rise to large errors due to low wind sensitivity at wind speeds of around 10 m/s, particularly at large incidence angles. The L-band NRCS behavior in strong winds (>20 m/s), at which the C-band is saturated, was not determined in the current model due to the limited number of the match-ups. [J542]

"Monitoring Sugarcane Growth Using ENVISAT ASAR Data"

The objective of this paper is to investigate potential of satellite C-band synthetic aperture radar (SAR) radar in monitoring sugarcane growth in southern China. This paper proposes a method to map sugarcane growing area and retrieve sugarcane leaf area index (LAI) in different growth stages using ENVISAT Advanced SAR (ASAR) alternating polarization HH/HV data. The temporal response of ASAR alternating polarization HH/HV data to sugarcane fields and sugarcane LAI was first analyzed in the study area. The analysis shows that sugarcane fields have increasing temporal radar response trend with sugarcane growth and ratio of ASAR HV to HH data has a better correlation with the increase of sugarcane LAI. A theoretical radiative transfer model was adopted to interpret the trend. Based on the temporal variation of the radar response of sugarcane fields, a method for mapping sugarcane planting area was developed using ASAR HH and HV polarization data at two acquisition dates with a certain classification accuracy. The empirical models were also established to estimate LAI of sugarcane using the HV/HH polarization ratio. The results suggest that C-band ASAR data appear promising in the development of an operational system for monitoring sugarcane growth in southern China. [J543]

"Simulation of ASIRAS Altimeter Echoes for Snow-Covered First-Year Sea Ice"

We have developed a simulator for the European Space Agency's Airborne SAR/Interferometric Radar Altimeter System (ASIRAS) altimeter echoes from snow-covered first-year sea ice. The simulated echoes are used to investigate how measurements are affected by the snow and ice characteristics. Our simulations show that when the snow cover is dry, the echo from the upper ice surface typically dominates. The simulated echoes prove to be very sensitive to the presence of liquid water in snow and the small-scale roughness of the ice surface. The accurate estimation of the ice freeboard is likely possible only under dry snow conditions and when the snow load is known. The ASIRAS simulator concept can also be used for the CryoSat altimeter. [J544]

"An Improvement of the Performance of Multiple-Aperture SAR Interferometry (MAI)"

Multiple-aperture synthetic aperture radar (SAR) interferometry (MAI) enables the measurement of along-track surface deformations by means of split-beam SAR processing. This paper examines the effects of flat-Earth and topographic phases on the MAI phase and derives formulas to correct them. Detailed MAI processing steps are introduced and discussed with particular consideration given to coherence improvement, as well as to computational efficiency. Forward- and backward-looking MAI pairs have different perpendicular baselines, which play a key role in phase distortion; consequently, an orbital deviation of only a few centimeters could result in a significant flat-Earth phase. A second-order polynomial model was used to estimate the perpendicular baseline difference. European Remote Sensing 2 satellite SAR data sets of the Hector Mine earthquake event in 1999 were used for performance evaluation. The proposed processing with the flat-Earth and topographic phase corrections achieved precision of along-track deformation ranging from 10.2 to 13.1 cm. Two coseismic pairs were compared and the standard deviation of the difference between the two independent measurements was 7.0 cm, with a mean difference of -0.24 cm. Thus, the measurement accuracy of MAI was improved using flat-Earth correction and coherence enhancement. [J545]

"Bistatic SAR Data Focusing Using an Omega-K Algorithm Based on Method of Series Reversion"

This paper deals with an omega-K algorithm for focusing bistatic synthetic aperture radar (SAR) data. The key of the proposed algorithm is the derivation of a frequency mapping function by using Neo's method of series reversion. The registration of the focused image onto the ground plane is discussed in detail, which is based on a conclusion that the targets whose instantaneous Doppler frequencies at zero azimuth time are the same as that of the reference target at zero azimuth time will all be focused at the reference target's azimuth position in the focused image. The range invariance region size, which the proposed algorithm can process, is also determined in this paper. The proposed algorithm can handle extreme bistatic configurations with wide apertures and large squint angles. The effectiveness of the proposed algorithm is confirmed by simulation results. Although developed for the azimuth-invariant case, the proposed algorithm can be readily extended to the azimuth-variant case, as long as we divide the SAR data into blocks in the azimuth direction so that each block of SAR data can

be assumed quasi-stationary in the azimuth direction. [J546]

"Motion Compensation for UAV SAR Based on Raw Radar Data"

Unmanned aerial vehicle (UAV) synthetic aperture radar (SAR) is very important for battlefield awareness. For SAR systems mounted on a UAV, the motion errors can be considerably high due to atmospheric turbulence and aircraft properties, such as its small size, which makes motion compensation (MOCO) in UAV SAR more urgent than other SAR systems. In this paper, based on 3-D motion error analysis, a novel 3-D MOCO method is proposed. The main idea is to extract necessary motion parameters, i.e., forward velocity and displacement in line-of-sight direction, from radar raw data, based on an instantaneous Doppler rate estimate. Experimental results show that the proposed method is suitable for low- or medium-altitude UAV SAR systems equipped with a low-accuracy inertial navigation system. [J547]

"Data Compression for Multilook Polarimetric SAR Data"

This letter attempts to address the problem on the emergence of negative eigenvalues in the coherency matrix after the compressing of multilook polarimetric synthetic aperture radar (SAR) data. A new nine-parameter expression for the eigenvalue decomposition of the coherency matrix is introduced, and a new compression algorithm is proposed for multilook polarimetric data with this expression. By comparing it with the NASA/Jet Propulsion Laboratory's Airborne SAR compression algorithm, the authors analyze the new algorithm's compression accuracy, signal-to-noise ratio, and the ability to preserve the data's polarimetric property. For polarimetric SAR data, it is important to preserve the polarimetric property of a target. The proposed algorithm has this ability which is illustrated by the comparison of the polarimetric signatures. Finally, the effectiveness of the proposed methods is demonstrated by using the experimental SAR data. [J548]

"Sea Surface Manifestation of Along-Tidal-Channel Underwater Ridges Imaged by SAR"

A group of submerged ocean bottom sand ridges in the Bohai Sea, China, are shown in RADARSAT-1 and ENVISAT synthetic aperture radar (SAR) images. The sand ridges appear as fingerlike quasi-linear features in the SAR images. Examining the detailed local bathymetry chart, we find that these features coincide with the satellite images. The heights of the sand ridges are less than 10 m, and the water depth is between 10 and 30 m. The spacing of the sand ridges is about 10 km, and the length of the sand ridges is about 20 km. The same sand ridges are also visible on a Moderate Resolution Imaging Spectroradiometer (MODIS) true-color image. The semidiurnal and diurnal tidal currents in this area are almost parallel to the major axis of these sand ridges. These observations cannot be explained using the existing 1-D SAR imaging model, which is not applicable to sand ridges parallel to the tidal current. In this paper, we consider the shallow-water current bathymetry in a 2-D space. An analytical ocean model was applied to demonstrate the temporal variations of the current divergence and convergence that are induced by the along-sand-ridge-direction current and ridge interaction. A radar simulation model is used to simulate the variation of normalized radar cross section (NRCS) induced by the ocean surface current. The simulated NRCS variation is similar to that extracted from the calibrated SAR image. Simulation results also show that the NRCS variation becomes negligible when the ocean current is set to about half of the maximum tidal current. [J549]

"A New Coherency Formalism for Change Detection and Phenomenology in SAR Imagery: A Field Approach"

Optimal utilization of complex synthetic aperture radar imagery for coherent change detection (CCD) is achieved by maximizing the amount of information extracted from the coherent correlation of images. Conventional techniques cannot fully exploit the coherent information due to limited application of few products or indicators, e.g., correlation factor and phase maps. Also, considering the lack of a systematic formulation of change observables and their nature, unsupervised change detection or classification is not feasible. To address this, an analytic framework is established by taking advantage of the analogy to partially polarized electromagnetic fields to introduce vectors and observables that can establish a complete change space. Decomposition of the coherent correlation or change characteristics into this basis set can provide a better understanding of the associated change phenomenology. [J550]

"Airborne along-track interferometry for GMTI"

Synthetic Aperture Radar (SAR) Along-Track Interferometry (ATI) has been used extensively to measure ocean surface currents. Given its ability to measure small velocities (~10 cm/s) of relatively radar-dark water surfaces, there is great potential that this technique can be adapted for ground moving target indication (GMTI) applications, particularly as a method for detecting very slow targets with small radar cross-sections. Herein, we describe preliminary results from an ATI GMTI experiment. The SAR data described were collected by the dual-

frequency NASA/JPL airborne radar in its standard dual-baseline ATI mode. The radar system imaged a variety of control targets including a pick-up truck, sport utility vehicles, passenger cars, a bicycle, and pedestrians over multiple flight passes. The control targets had horizontal velocities of less than 5 m/s. The cross-sections of the targets were not purposely enhanced, although the targets' reflectivities may have been affected by the existence of the GPS equipment used to record the targets' positions. Single-look and multiple-look interferograms processed to the full azimuth resolution were analyzed. In the data processed to date, all of the targets were observed by visual inspection in at least one of the four combinations of dual-frequency, dual-baseline interferometric data. This extremely promising result demonstrates the potential of ATI for GMTI applications. [J551]

"Assessment of Atmospheric Propagation Effects in SAR Images"

TerraSAR-X, the first civil German synthetic aperture radar (SAR) satellite, was successfully launched on June 15, 2007. After 4.5 days, the first processed image was obtained. The overall quality of the image was outstanding; however, suspicious features could be identified which showed precipitation-related signatures. These rain-cell signatures are thoroughly investigated, and the physical background of the related propagation effects is provided. In addition, rain-cell signatures from former missions like SIR-C/X and the Shuttle Radar Topography Mission are provided for comparison. During the commissioning phase of TerraSAR-X, a total of 12 000 scenes were investigated for potential propagation effects, and about 100 scenes revealed atmospheric effects to a visible extent. Some of the particularly interesting events were selected and are discussed in greater detail. An interesting case of data acquisition over New York will be presented, which shows typical rain-cell signatures, and the SAR image will be compared with weather-radar data acquired nearly simultaneously (within the same minute). By comparing the images, it can be clearly seen that reflectivities in the weather-radar image of 50 dBZ may cause visible artifacts in SAR images. Furthermore, in this paper, we discuss the influence of the atmosphere (troposphere) on the external calibration of TerraSAR-X. By acquiring simultaneous weather-radar data over the test site and the SAR acquisition, it was possible to flag affected SAR images and to exclude them from the procedure to derive the absolute calibration constant. Thus, it was possible to decrease the 1 sigma uncertainty of the absolute calibration factor by 0.15 dB. [J552]

"Ship Detection Using Polarization Cross-Entropy"

In this letter, polarization cross-entropy is introduced based on the eigendecomposition of the polarimetric coherence matrix. Then, the new parameter is employed for ship detection. From experimental results, it is derived that the distribution of the polarization cross-entropy in ocean regions can be well approximated by a generalized exponential distribution. Then, a constant-false-alarm-rate ship-detection method is proposed based on the distribution of the polarization cross-entropy. Using experimental results, the authors demonstrate the effectiveness of the new method in ship detection. [J553]

"Polarimetric SAR Internal Calibration Scheme Based on T/R Module Orthogonal Phase Coding"

Two important aspects of internal calibration of polarimetric synthetic aperture radar (SAR) are discussed, i.e., individual transmit/receive module (TRM) calibration and system gain calibration. The system has a general structure utilizing a phased array antenna composed of dual-channel TRMs. TRM gain and phase calibration is carried out using orthogonal phase coding (OPC). The signal of the individual TRM is phase-encoded according to a set of orthogonal codes to be separated from the composite calibration signal. OPC uses 1 bit of a digital phase-shifter for encoding, without the need for additional encoding hardware. Performance of the method is examined. Calibration results are developed both theoretically and through simulation in case of TRM amplifier or phase-shifter failure. Zero-padding is used to eliminate calibration error of the first TRM. A crosstalk model is proposed to investigate the effect of imperfect isolation between the two polarization channels of each TRM, and a way to reduce this error is also given. At last, system path gain variation is measured utilizing the internal calibration loop. The OPC method has an accuracy of 0.2 dB for gain and better than 2deg for phase, with 10-dB signal-to-noise ratio and perfect isolation between the two polarization channels. The error due to imperfect isolation is usually small and can be ignored. The simple way to detect TRM malfunction is verified through simulation, and it is also in accordance with TerraSAR-X in-orbit calibration outcomes. The proposed OPC method is shown to be an effective way of internally calibrating TRMs of a phased array antenna. [J554]

"Digital Beamforming on Receive: Techniques and Optimization Strategies for High-Resolution Wide-Swath SAR Imaging"

Synthetic Aperture Radar (SAR) is a well-proven imaging technique for remote sensing of the Earth. However, conventional SAR systems are not capable of fulfilling the increasing demands for improved spatial resolution and wider swath coverage. To overcome these inherent limitations, several innovative techniques have been

suggested which employ multiple receive-apertures to gather additional information along the synthetic aperture. These digital beamforming (DBF) on receive techniques are reviewed with particular emphasis on the multi-aperture signal processing in azimuth and a multi-aperture reconstruction algorithm is presented that allows for the unambiguous recovery of the Doppler spectrum. The impact of Doppler aliasing is investigated and an analytic expression for the residual azimuth ambiguities is derived. Further, the influence of the processing on the signal-to-noise ratio (SNR) is analyzed, resulting in a pulse repetition frequency (PRF) dependent factor describing the SNR scaling of the multi-aperture beamforming network. The focus is then turned to a complete high-resolution wide-swath SAR system design example which demonstrates the intricate connection between multi-aperture azimuth processing and the system architecture. In this regard, alternative processing approaches are compared with the multi-aperture reconstruction algorithm. In a next step, optimization strategies are discussed as pattern tapering, prebeamshaping-on-receive, and modified processing algorithms. In this context, the analytic expressions for both the residual ambiguities and the SNR scaling factor are generalized to cascaded beamforming networks. The suggested techniques can moreover be extended in many ways. Examples discussed are a combination with ScanSAR burst mode operation and the transfer to multistatic sparse array configurations. [J555]

"Configuration, Orbit Design of InSAR Formation Based on Mean Elements"

A mission requirements-based configuration method of interferometric synthetic-aperture radar (InSAR) formation to design dual-satellite formation by mean orbital elements is derived. The configuration and initial orbital elements of two coordinated running satellites InSAR formation are designed when system parameters, such as the resolution of slant distance, latitude domain of ground coverage area, and the side-looking angle of the synthetic-aperture radar (SAR) beam center, are given. [J556]

"Optimal Determination of Antenna Height and Power in a Mass per Swath Width Sense for a Given Incidence Angle"

An optimal antenna height and power determination is proposed for the cost-effective implementation of the spaceborne stripmap synthetic aperture radar (SAR) satellite. For a given azimuth resolution, the antenna height and the average transmitted RF power of the SAR antenna are determined so that the mass per swath width of a SAR satellite can be minimized with the constraints on the signal-to-noise ratio (SNR) and ambiguities, given the SAR geometry (an altitude and an incidence angle) and radar wavelength. The illustrative design example shows that the mass per swath width of a SAR satellite, obtained from the proposed optimization, for the required SNR (SNRreq= 10 dB) and the specified incidence angle (eta = 45 deg), is about 72% of that resulted from utilizing the minimum antenna height. [J557]

"Hybrid GPU-Based Single- and Double-Bounce SAR Simulation"

In this paper, a new hybrid graphics-processing-unit (GPU)-based real-time synthetic aperture radar (SAR) simulation system is presented. Previous real-time SAR simulators only supported single-bounce simulation in real time. The new hybrid system uses the rasterization approach for real-time single-bounce simulation and a new image-based GPU ray-tracing approach for monostatic SAR double-bounce simulation. This approach provides fast simulation results even while simulating complex and extended scenes. The simulation results are compared to a high-resolution airborne SAR image, and the limitations of the approach are discussed. [J558]

"Operational Large-Area Forest Monitoring in Siberia Using ALOS PALSAR Summer Intensities and Winter Coherence"

Focusing on Siberia, the feasibility of using Advanced Land Observing Satellite Phased Arrayed L-band Synthetic Aperture Radar (PALSAR) summer-intensity and winter-coherence images for large-area forest monitoring was investigated. Fine beam dual horizontal/horizontal and horizontal/vertical (polarization) intensity strip images were acquired during the summer of 2007. The processing consisted of radiometric calibration, orthorectification, and topographic normalization. The coherence was estimated from interferometric pairs with 46-day repeat-pass intervals. The pairs were acquired during the winters of 2006/2007 and 2007/2008. During both winters, suitable weather conditions that allow for low temporal decorrelation had been reported. By using PALSAR intensities and winter-coherence data, areas of forest and nonforest were separated. By combining both data types, a minimal overlap of the class signatures was observed, even though the analysis was conducted at the pixel level and no speckle filter was applied. The study concludes that the operational delineation of forest cover using PALSAR data is feasible. By applying a segmentation-based classification, an accuracy of 93% was obtained. [J559]

"Relationship Between PALSAR Backscatter and Surface-Roughness Parameters From Iron

Laterites in CarajЂs, Amazon Region"

The objective of this investigation was to evaluate the influence of micro- and macrotopography on PALSAR fine-beam dual backscattering in the characterization of iron laterites in Carajas Province, Amazon Region. The moderate linear correlation between sigma0and surface roughness indicated that, only for L-HH polarization, sigma0was modulated by the morphology of the geological surfaces. [J560]

"Modeling and Simulation of SAR Image Texture"

The characteristics of synthetic aperture radar (SAR) image texture may be related to the properties of underlying elemental scene scatterers through established models based on the properties of a backscattering coefficient (in this paper, we use and unnormalized coefficient s) of these scatterers. In this paper, we generate raw SAR data by simulating the statistical characteristics of elemental scene scatterers such as the order of the gamma distribution, the form and length of their spatial correlation, and their spatial density. This simulation is carried out using a SAR signal simulation system called cSAR. We describe a particular set of methods to simulate image texture used in cSAR, and provide a detailed analysis of simulated sand of the speckle and texture characteristics of simulated images. We found that the distribution of swas strongly affected by the order, density, and correlation length of the underlying scatterers. We found that the simulated SAR images were consistently K-distributed as expected. The estimated image order was a strong function of the scattering properties and that the estimated image order is a relatively weak descriptor of image texture when used on its own. The correspondence between the observed image autocorrelation function (ACF) and the theoretical models of Oliver is excellent, and we could estimate the scatterer correlation length by fitting the Oliver model to the observed ACF. We combined the estimated image order and correlation length and found potential for using these two image texture descriptors in classification and segmentation algorithms. [J561]

"SAR image despeckling via bilateral filtering"

Bilateral filtering (BF) can realise both smoothing images and preserving edges, whereas its filtering results are always influenced since its two parameters are difficult to configure to the optimum. In this reported work, the application of BF is extended to synthetic aperture radar (SAR) image despeckling, and the despeckling evaluation indexes, including the equivalent number of looks and the edge save index, are used to estimate the parameters. After BF with estimated parameters imposed on a normalised SAR image, further processing can achieve both despeckling and edge preservation simultaneously. Experimental results show that the visual quality and evaluation indexes of the proposed algorithm outperform the classical Lee filtering. [J562]

"An Accurate Strategy for 3-D Ground-Based SAR Imaging"

In this letter, an analytical description of the 2-D and 3-D imaging of ground-based synthetic aperture radar data is given. The ability of the 3-D imaging to separate targets along the elevation direction will also be shown, thus allowing their complete localization in space. The validation of the proposed method is done by exploiting simulated data. [J563]

"Forest Biophysical Parameter Estimation Using L- and P-Band Polarimetric SAR Data"

L- and P-band airborne polarimetric synthetic aperture radar (SAR) data acquired by the RAMSES system over different height maritime pine (Pinus Pinaster Ait.) stands of the Nezer forest (Landes, France) have been evaluated for forest biophysical parameter estimation. A pseudolinear correlation has been brought to evidence at P-band between polarimetric anisotropy and mean tree height, which is also linked to other biophysical parameters in the Nezer forest, meaning that SAR polarimetry constitutes a promising tool for forest parameter retrieval at low frequency. The spatial conditions have been evaluated through the quantification of the impact of signal-to-noise ratio diminution and resolution degradation on the forest height inversion. It has been shown that the inversion accuracy remains acceptable for N Esigma0, representing the noise level of the SAR image, which is lower than -15 dB, and for spatial resolution increasing up to 15 m. [J564]

"Cross-Range Scaling for ISAR Based on Image Rotation Correlation"

For better understanding of the imaging result provided by inverse synthetic aperture radar (ISAR), it is more desirable to present it from the conventional range-Doppler domain to the homogeneous range-cross-range domain. To accomplish the process of cross-range scaling, the rotating velocity (RV) of the target should be estimated first. For a uniformly planar rotating object, a novel method based on a concept of rotation correlation is proposed to obtain the RV in this letter, and neither prominent scattering centers nor phase coefficient extraction is required. Furthermore, a three-step fast-Fourier-transform-based convolution interpolation scheme is proposed to realize the above correlation, which makes the proposed method more efficient for

implementation. Finally, experimental results with both simulated and real ISAR data are provided to demonstrate the effectiveness of the proposed method for different targets. [J565]

"Achieving Higher Resolution ISAR Imaging With Limited Pulses via Compressed Sampling"

Recent theory of compressed sampling (CS) suggests that exact recovery of an unknown sparse signal with overwhelming probability can be achieved from very limited number of samples. In this letter, we adapt this idea and present a framework of high-resolution inverse synthetic aperture radar imaging with limited measured data. During the framework, we mathematically convert the imaging into a problem of signal reconstruction with orthogonal basis; hence, a conceptive upper bound of the cross-range resolution is presented based on the CS theory. Real data results show that the CS imaging approach outperforms the conventional range-Doppler one in resolution. [J566]

"Phase of Target Scattering for Wetland Characterization Using Polarimetric C-Band SAR"

Wetlands continue to be under threat, and there is a major need for mapping and monitoring wetlands for better management and protection of these sensitive areas. Only a few studies have been published on wetland characterization using polarimetric synthetic aperture radars (SARs). The most successful results have been obtained using the phase difference between HH and VV polarizations, phiHH- phiVV, which has shown promise for separating flooded wetland classes. Recently, we have introduced a new decomposition, the Touzi decomposition, which describes target scattering type in terms of a complex entity, the symmetric scattering type. Huynen's target helicity is used to assess the symmetric nature of target scattering. In this paper, the new complex-scattering-type parameters, the magnitude alphasand phase Phialphas, are investigated for wetland characterization. The use of the dominant-scattering-type phase Phialphasmakes it possible to discriminate shrub bogs from poor (sedge or shrub) fens. These two classes cannot be separated using phiHH- phiVV, or the radiometric scattering information provided by alphas, the Cloude alpha, the entropy H, and the multipolarization HH-HV-VV channels. phialphas, which cannot detect deep (45 cm below the peat surface) water flow in a bog, is more sensitive to the shallower (10-20-cm) fen beneath water, and this makes possible the separation of poor fens from shrub bogs. Phialphasalso permits the discrimination of conifer-dominated treed bog from upland deciduous forest under leafy conditions. Target helicity information is exploited to introduce a new parameter, the target asymmetry. The latter is shown very promising for detection of forest changes between leafy and no-leaf conditions. The analysis of low-entropy marsh scattering showed that both the scattering-type magnitude and phas--e alphasand Phialphas, respectively, as well as the maximum polarization intensity of the dominant scattering m, are needed for a better understanding of marsh complex scattering mechanisms. The unique information provided by the new roll-invariant decomposition parameters are demonstrated using repeat-pass Convair-580 polarimetric C-band SAR data collected in June and October 1995 over the RAMSAR Mer Bleue wetland site near Ottawa (Canada). [J567]

"Selecting Suitable Coherent Processing Time Window Lengths for Ground-Based ISAR Imaging of Cooperative Sea Vessels"

Inverse synthetic aperture radar (ISAR) imaging of sea vessels is a challenging task because their 3-D rotational motion over the coherent processing interval (CPI) often leads to blurred images. The selection of the duration of the CPI, also known as the coherent processing time window length (CPTWL), is critical because it should be short enough to limit the blurring caused by the 3-D rotational motion and long enough to ensure that the desired cross-range resolution is obtained. This paper proposes an algorithm, referred to as the motion-aided CPTWL selector (MACS) algorithm, which selects suitable CPTWLs for ISAR imaging of cooperative sea vessels. The suggested CPTWLs may be used to obtain motion-compensated ISAR images that have the desired medium cross-range resolution and limited blurring due to 3-D rotational motion. The proposed algorithm is applied to measured motion data of three different classes of sea vessels: a yacht, a fishing trawler, and a survey vessel. Results show that longer CPTWLs are needed for larger vessels in order to obtain ISAR images with the desired cross-range resolution. The effectiveness of the CPTWLs, suggested by the MACS algorithm, is shown using measured radar data. The suggested CPTWLs may also be used to select an effective initial CPTWL for Martorella/Berizzi's optimum imaging selection algorithm when it is applied to measured radar data of small vessels. Lastly, the proposed technique offers significant computational savings for radar cross section measurement applications where a few high-quality ISAR images are desired from long radar recordings. [J568]

"Sparse Two-Dimensional Phase Unwrapping Using Regular Grid Methods"

Phase unwrapping is usually defined as the reconstruction of a function sampled on a spatial grid given its value modulo 2pi. Phase unwrapping is a key step in image reconstruction in many imaging techniques including interferometric synthetic aperture radar (InSAR). In recent years, many new methods have been developed to

exploit the presence of coherent or persistent scattering points for extracting deformation signatures in regions where conventional InSAR fails. These techniques often yield measurements that are only poorly sampled spatially, yet these sparse data must still be unwrapped if we are to be able to extract useful geophysical information. The conventional well-sampled 2-D phase unwrapping problem based on phase residues is fairly well understood and many novel techniques involving geometry and network flow concepts have been implemented successfully to date. For sparse data, residues may be computed over the Delaunay triangulation of the data points, but published algorithms meet with limited success when the sparse data are unwrapped. The advantages of modern unwrapping methods applicable to well-sampled data are often lost when sparse data are analyzed. In this letter, we show that a nearest neighbor interpolation scheme allows powerful and existing 2-D solvers to be applied to sparse data. We present results using both simulated and real data sets to illustrate our method. [J569]

"SAR Image Regularization With Fast Approximate Discrete Minimization"

Synthetic aperture radar (SAR) images, like other coherent imaging modalities, suffer from speckle noise. The presence of this noise makes the automatic interpretation of images a challenging task and noise reduction is often a prerequisite for successful use of classical image processing algorithms. Numerous approaches have been proposed to filter speckle noise. Markov random field (MRF) modelization provides a convenient way to express both data fidelity constraints and desirable properties of the filtered image. In this context, total variation minimization has been extensively used to constrain the oscillations in the regularized image while preserving its edges. Speckle noise follows heavy-tailed distributions, and the MRF formulation leads to a minimization problem involving nonconvex log-likelihood terms. Such a minimization can be performed efficiently by computing minimum cuts on weighted graphs. Due to memory constraints, exact minimization, although theoretically possible, is not achievable on large images required by remote sensing applications. The computational burden of the state-of-the-art algorithm for approximate minimization (namely the alpha -expansion) is too heavy specially when considering joint regularization of several images. We show that a satisfying solution can be reached, in few iterations, by performing a graph-cut-based combinatorial exploration of large trial moves. This algorithm is applied to joint regularization of the amplitude and interferometric phase in urban area SAR images. [J570]

"An Extended Nonlinear Chirp-Scaling Algorithm for Focusing Large-Baseline Azimuth-Invariant Bistatic SAR Data"

For an azimuth-invariant bistatic synthetic aperture radar (BiSAR), not only is the secondary range compression dependent on range, but also the range-cell migration in the range-Doppler domain is nonlinearly dependent on range. To get a better focusing performance, the two range-dependent factors must be taken into account in an imaging algorithm. In this letter, a nonlinear chirp-scaling algorithm is extended for focusing the BiSAR data under a large baseline and a wide range swath. This algorithm leads to more effective processing with computational efficiency, and no interpolation is required. [J571]

"RKHS Bayes Discriminant: A Subspace Constrained Nonlinear Feature Projection for Signal Detection"

Given the knowledge of class probability densities, aprioriprobabilities, and relative risk levels, Bayes classifier provides the optimal minimum-risk decision rule. Specifically, focusing on the two-class (detection) scenario, under certain symmetry assumptions, matched filters provide optimal results for the detection problem. Noticing that the Bayes classifier is in fact a nonlinear projection of the feature vector to a single-dimensional statistic, in this paper, we develop a smooth nonlinear projection filter constrained to the estimated span of class conditional distributions as does the Bayes classifier. The nonlinear projection filter is designed in a reproducing kernel Hilbert space leading to an analytical solution both for the filter and the optimal threshold. The proposed approach is tested on typical detection problems, such as neural spike detection or automatic target detection in synthetic aperture radar (SAR) imagery. Results are compared with linear and kernel discriminant analysis, as well as classification algorithms such as support vector machine, AdaBoost and LogitBoost. [J572]

"Estimation of the Equivalent Number of Looks in Polarimetric Synthetic Aperture Radar Imagery"

This paper addresses estimation of the equivalent number of looks (ENL), an important parameter in statistical modeling of multilook synthetic aperture radar (SAR) images. Two new ENL estimators are discovered by looking at certain moments of the multilook polarimetric covariance matrix, which is commonly used to represent multilook polarimetric SAR (PolSAR) data, and assuming that the covariance matrix is complex Wishart distributed. First, a second-order trace moment provides a polarimetric extension of the ENL definition and also a matrix-variate version of the conventional ENL estimator. The second estimator is obtained from the log-

determinant matrix moment and is also shown to be the maximum likelihood estimator under the Wishart model. It proves to have much lower variance than any other known ENL estimator, whether applied to single-polarization or PolSAR data. Moreover, this estimator is less affected by texture and thus provides more accurate results than other estimators should the assumption of Gaussian statistics for the complex scattering coefficients be violated. These are the first known estimators to use the full covariance matrix as input, rather than individual intensity channels, and therefore to utilize all the statistical information available. We finally demonstrate how an ENL estimate can be computed automatically from the empirical density of small sample estimates calculated over a whole scene. We show that this method is more robust than procedures where the estimate is calculated in a manually selected region of interest. [J573]

"Layover Solution in SAR Imaging: A Statistical Approach"

In this letter, a statistical-based approach to recover layover solution in synthetic aperture radar (SAR) images is proposed. The aim of this letter is to develop a methodology in order to separate different scattering contributions collapsed in a single SAR image pixel. After a brief discussion about layover, the proposed model is presented, followed by a discussion about achievable performances using Cramer-Rao lower bounds. In the final part of this letter, the performances of a maximum likelihood estimator are evaluated in a simulated data scenario, showing the effectiveness of the method. [J574]

"Effects of Non-Uniform Motion in Through-the-Wall SAR Imaging"

Synthetic aperture radar (SAR) provides high resolution images that are well suited for through-the-wall target detection and recognition. As targets behind-the-wall undergo non-uniform motions, such as vibration, rotation and acceleration, their patterns can be recognized. To understand these signatures in through-the-wall SAR, we model and analyze the non-uniform motion-induced Doppler effect as well as the focused target SAR image. In particular, the wall effects on the focused SAR image and the micro-Doppler are formulated and analyzed. These analyses facilitate improving the target recognition performance by quantitatively estimating the parameters of the micro-Doppler signatures as well as the SAR imaging. We further analyze the detection performance of the non-uniform motion-induced target based on the generalized likelihood ratio test (GLRT) technique. The relationship between motion parameters and the detection performance allows us to evaluate the performance bound and the minimum detectable parameters. [J575]

"Raw signal processing of stripmap bistatic synthetic aperture radar"

Under the translational invariant (TI) configuration of stripmap imaging bistatic synthetic aperture radar (BISAR), the frequency domain expression of signal model is developed. Two forms, with an approximation of extracting the range dependence and an accurate iterative solution, as well as their respective focusing methods, that is the approximated solution method and the iterative solution method are presented here. The range-Doppler method is extended to the TI configuration of BISAR. Imaging simulation of the point targets and comparison with the bistatic backprojection method shows the feasibility of these methods as well as their merits and demerits. [J576]

"Multichannel Phase Unwrapping With Graph Cuts"

Markovian approaches have proven to be effective for solving the multichannel phase-unwrapping (PU) problem, particularly when dealing with noisy data and big discontinuities. This letter presents a Markovian approach to solve the PU problem based on a new apriorimodel, the total variation, and graph-cut-based optimization algorithms. The proposed method turns out to be fast, simple, and robust. Moreover, compared with other approaches, the proposed algorithm is able to unwrap and restore the solution at the same time, without any additional filtering. A set of experimental results on both simulated and real data illustrates the effectiveness of our approach. [J577]

"Traffic Surveillance System Based on a High-Resolution Radar"

Traffic surveillance is an important civilian application of radars. The current high-resolution radars give new opportunities so that the traffic application may be redefined. In this paper, a traffic scenario with a high-resolution radar is presented. A range-bin alignment method, the Global Range Alignment, which comes from the focusing techniques in inverse synthetic aperture radar, is applied to obtain further capabilities than the usual velocity measurement: distinction between vehicle types via length estimation and adequate management in situations with simultaneous targets. Preliminary results from a real scenario using a high-resolution linear frequency-modulated continuous-wave millimeter-wave radar are shown. [J578]

"Autofocusing of moving objects in SAR data based on adaptive notch filtering"

This paper proposes a new autofocusing method for synthetic aperture radar (SAR) imaging of complex moving structures such as ships on the ocean. This method is well suited for linear uniform motion as well as for nonuniform motion that may be caused by ocean waves. The key step is a modified adaptive notch filter (ANF) that can retrieve phase modulation due to motion. Simulation examples and real SAR results are presented. [J579]

"Novel approach for ISAR image cross-range scaling"

Inverse synthetic aperture radar (ISAR) imaging systems produce electromagnetic images of targets in the range-Doppler domain. In order to rescale the image in a homogeneous range-cross range domain (meters by meters), the modulus of the target effective rotation vector must be known. Although in some cases it can be retrieved by means of ancillary data, in most cases the modulus of the target effective rotation vector must be estimated. A blind technique is proposed for estimating the modulus of the target effective rotation vector that exploits information carried by the chirp rate of scattering centres. A technique based on image segmentation, local polynomial Fourier transform (LPFT), and image contrast (IC) maximisation is used in order to extract the scattering centres and estimate their chirp rate. Simulated and real data analyses are provided to confirm the effectiveness of the proposed algorithm. [J580]

"Three-Dimensional ISAR Imaging Using a Two-Dimensional Sparse Antenna Array"

Conventional antenna array 3-D inverse synthetic aperture radar (ISAR) imaging method does imaging by first carrying out ISAR imaging for all the different antennas and then using array direction of arrival (DOA) estimation on every scatterer to get the position of that scatterer. The aperture formed by the target's motion is used to separate the scatterers, and the antenna array aperture is used for position measurement. In this letter, a 3-D imaging method based on a combination of sparse array beamforming and ISAR imaging is proposed, where 3-D images are formed by space-time match filtering. The estimation of the target's rotation parameters is also given. Simulation results have shown the effectiveness of the proposed methods. [J581]

"Phase-Offset Estimation in Multichannel SAR Interferometry"

Multichannel interferometric synthetic aperture radar (InSAR) systems allow the estimation of the height profile of the Earth's surface, exploiting the availability of multiple radar acquisitions, obtained via different baselines/frequencies. Statistical approaches, in particular maximum aposterioritechnique and Markov random-field image models, can be exploited for such estimation problem, which proved to be effective. However, despite the particular solution method used, the problem with multichannel interferometry is that interferograms can be affected from the presence of undetermined phase offsets, which makes it difficult to get correct height estimation in any case. In this letter, we present a procedure to estimate these phase offsets using statistical estimation; we test the procedure on both simulated and real data. For the latter, we show how an optimal estimation of the phase offsets can be used to improve the resolution of an available Shuttle Radar Topography Mission digital elevation model. The obtained results prove the effectiveness of the method and assess the overall quality of the height estimation procedure. [J582]

"Atomic decomposition for radar applications"

In this paper, we explore the promising capabilities of atomic decomposition (AD) for radar-related applications from a practical point of view. Some enhancements and new approaches are proposed herein, and their implementations are fully detailed. We apply the AD algorithms in two different environments, for signal detection where high sensitivity is the main requirement, and for inverse synthetic aperture radar (ISAR) imaging where focused images, target feature extraction, and computational burden are the fundamental concerns. [J583]

"The Pyramids of Gizeh Seen by TerraSAR-X-A Prime Example for Unexpected Scattering Mechanisms in SAR"

Multiple scattering may render synthetic aperture radar (SAR) image interpretation difficult, particularly when it comes to imaging of man-made structures. In medium-resolution SAR images, contributions from different scattering mechanisms can only be distinguished for large objects and under favorable conditions, like bridges over calm water. Since the launches of TerraSAR-X and COSMO-SkyMed, high-resolution SAR imagery is readily available from every spot on the Earth, and multiple scattering image features will be increasingly found in many of these data. Some of the first TerraSAR-X images show the pyramids of Gizeh in a seemingly unexpected geometry. Instead of being geometrically distorted, the near-range faces of the pyramids look like ground projected. This letter explains this image puzzle by a mixture of two scattering effects. The theory is

confirmed by an interferometric evaluation. The discussed image artifact can be seen as representative for many other multiple-scattering SAR imaging scenarios in high-resolution images. This letter also demonstrates once again that the interpretation of complex scattering configurations benefits from interferometric information. [J584]

"Modified difference change detector for small targets in SAR imagery"

One of the most straightforward techniques for detecting changes in an image involves forming the difference between a test image and a reference image. Unfortunately, such a technique can give rise to a large number of false alarms due to the statistical variability of the underlying pixel values, as has been well established within the radar community over the years. One method for dealing with this large number of false alarms involves forming the ratio, rather than the difference, of two synthetic aperture radar (SAR) images. We introduce a modified version of the standard differencing technique to overcome problems associated with pixel value variability. The new (modified) differencing approach utilizes assumptions about the statistics of the image background and the object being sought (target) to reduce the number of false alarms due to highly variable background (clutter) regions, and it includes the standard ratio test as a special case. In fact, we find that the modified difference approach can also be viewed as a modified version of the ratio test with a threshold that varies as a function of the background clutter radar cross section (RCS). We also present an abridged, albeit suboptimal, version of this approach that eliminates assumptions regarding the target's probability distribution, and we analyze both of the approaches. We then compare these results with those obtained with a standard ratio test, and illustrate how the modified difference test reduces to the ratio test under certain operating conditions. The abridged version of the modified approach is applied to high resolution synthetic aperture radar imagery and compared with results obtained with the classical differencing technique, and following this, the modified difference technique is compared with the standard ratio test. Results suggest that under appropriate conditions the abridged, modified technique can successfully detect changes without the need for any image segmentation. [J585]

"SBAS-DInSAR Analysis of Very Extended Areas: First Results on a 60 000- Test Site"

We present the results of the first experiment to survey the temporal evolution of the deformation affecting very large areas using the small baseline subset (SBAS) differential synthetic aperture radar interferometry (DInSAR) algorithm. In particular, we have analyzed a set of 264 descending European Remote Sensing (ERS) SAR data frames from 1992 to 2000; these data are relevant to an area in central Nevada (U.S.) that extends for about 600times100 km. The starting point of our study has been the generation of an appropriate set of small baseline multilook interferograms computed from long SAR image strips, which were obtained by jointly focusing six contiguous raw data frames. Following their generation, the selected interferograms, which are computed on a spatial grid of 160times160 m, have been inverted via the SBAS technique to retrieve, for each coherent pixel, the displacement time series and the corresponding mean deformation velocity. The presented results are, to our knowledge, the first ones with such an extended multitemporal SAR data set, and they demonstrate the effectiveness of the approach to analyze the deformation of the investigated zone. [J586]

"A New Look at the Bistatic-to-Monostatic Conversion for Tandem SAR Image Formation"

The bistatic synthetic aperture radar (SAR) data, which are converted into equivalent monostatic data by proper preprocessing, can be processed by standard monostatic focusing algorithms. The dip moveout (DMO) approach, which is derived from seismic data processing, converts the bistatic data into equivalent monostatic data by a short time-domain Rocca's smile operator. A 2D exact point-target (PT) reference spectrum is derived in this letter for the tandem bistatic configuration. The geometry-based bistatic formulation is shown to be actually equivalent to Rocca's smile operator, although they are derived from the pure SAR and geophysics points of view, respectively. Moreover, the new PT spectrum can be extended to deal with azimuth-invariant bistatic SAR data. Interpretations on the equivalent monostatic range wavenumber are presented in this letter, which help understand the conversion from the radar signal processing viewpoint. [J587]

"Ground Moving Target Indication Using an InSAR System With a Hybrid Baseline"

In this letter, a two-channel airborne experimental interferometric synthetic aperture radar (InSAR) designed for terrain height estimation is exploited to acquire the ability of ground moving target indication (GMTI). Due to the hybrid baseline of this system, the interferometric phase changes with the target motion as well as the terrain height. The fluctuation of the interferometric phase worsens the performance of the clutter suppression and the radial velocity estimation. In order to resolve this problem, a GMTI method with three steps is proposed. After two steps are used to eliminate the local flat-Earth phase and the cross-track interferometric phase of the scene, respectively, an adaptive filtering method is used to suppress the stationary clutter with the benefit of calibrating the sensor responses. A conventional constant false alarm rate detector is then used to indicate the

moving targets. The validity of the proposed method is demonstrated with real data collected using an experimental airborne InSAR system. [J588]

"Analysis of Ground-Based SAR Data With Diverse Temporal Baselines"

In this paper, the algorithms developed for satellite synthetic aperture radar (SAR) interferometry were adapted to the ground-based SAR (GB-SAR) configuration and used for detecting the displacements of an alpine landslide which have occurred over many years. Indeed GB-SAR interferometry is based on the same principles as satellite SAR techniques but benefits from the GB-SAR's versatility and capability of gathering many images per day. In monitoring applications of landslides moving only few centimeters per year, as the case here reported, the GB-SAR sensor is installed at repeated intervals several months apart over the observation period. Although the revisiting time is very similar to the satellite one, for each survey, lasting two or three days, more than ten images are available. They are analyzed separately and in combination with images from other surveys for coherent pixel selection. Interferograms are formed by cross-combining images from different surveys. Finally, the evolution of the deformation across the surveys is retrieved in a least square sense without any assumptions on its regularity. The used GB-SAR technique is described in detail in this paper, and the results obtained with regard to a landslide in the Italian Alps that has been monitored over a period of about three years are discussed. [J589]

"Refocusing Through Building Walls Using Synthetic Aperture Radar"

Through-wall imaging/sensing using a synthetic aperture array technique is studied by employing ultrawideband antennas and for wide incidence angles. The propagation through building walls, such as brick and poured concrete in response to point sources near the walls, is simulated by using high-frequency methods. Reciprocity is used to find the responses of point targets behind walls, which are then used to simulate the synthetic aperture radar (SAR) imaging through the walls. The effect of building walls on the target-image distortions is investigated by simulations and measurements. It is shown that by using the idea of match filtering, the effect of the wall can be compensated for, and the point target response can be reconstructed, provided that the wall parameters are known. An optimization method based on minimization of squared error in the SAR image domain within an area confined within the expected point-spread function is used to estimate the wall parameters and sharpen the image simultaneously. A controlled experiment within the laboratory environment is performed to verify the methods presented. It is shown that for an ultrawideband system operating over a frequency band of 1-3 GHz, highly distorted images of two point targets in close proximity of each other behind a wall can be resolved after refocusing. A dual-frequency synthetic method is also presented that can improve the cross-range resolution of the refocused image. [J590]

"Classifying Multilevel Imagery From SAR and Optical Sensors by Decision Fusion"

A strategy for the joint classification of multiple segmentation levels from multisensor imagery is introduced by using synthetic aperture radar and optical data. At first, the two data sets are separately segmented, creating independent aggregation levels at different scales. Each individual level from the two sensors is then preclassified by a support vector machine (SVM). The original outputs of each SVM, i.e., images showing the distances of the pixels to the hyperplane fitted by the SVM, are used in a decision fusion to determine the final classes. The fusion strategy is based on the application of an additional classifier, which is applied on the preclassification results. Both a second SVM and random forests (RF) were tested for the decision fusion. The results are compared with SVM and RF applied to the full data set without preclassification. Both the integration of multilevel information and the use of multisensor imagery increase the overall accuracy. It is shown that the classification of multilevel-multisource data sets with SVM and RF is feasible and does not require a definition of ideal aggregation levels. The proposed decision fusion approach that applies RF to the preclassification outperforms all other approaches. [J591]

"Conditional Copulas for Change Detection in Heterogeneous Remote Sensing Images"

A new preprocessing technique is presented in this paper to automatically highlight changes in multitemporal strongly heterogeneous remotely sensed images. The proposed technique is devoted to the case where the two acquisitions, before and after a given event, are significantly different, due, for instance, to different sensors, acquisition modalities, or climatic conditions. In a previous study, it was proven that the local statistics of the images acquired at the two dates could be used to extract a relevant change indicator. Nevertheless, this measure is valid when the two observations have been derived from similar acquisitions. When the acquisition modalities differ, local statistics tend to be too different from one image to the other one to be relevant in highlighting the ground evolution without mixing with the changes at ground. The technique proposed in this paper to overcome this limitation is based on the assumption that some dependence indeed exists between the

two images in unchanged areas. This dependence is modeled by quantile regression applied according to the copula theory and used to perform an estimation of the local statistics that would have been observed if the acquisition conditions of the first image had been similar to the ones of the second image. The method yields an estimate of the local statistics of the first image through the point of view of the second one. Then, usual Kullback-Leibler-based comparisons of those statistics are applied to define a change measure, which may be analyzed (e.g., by thresholding) in order to detect changes. Experimental results are shown to validate the proposed method by using a pair of Synthetic Aperture Radar (SAR) images onboard European Remote Sensing (ERS) Satellite images and a pair of optical-SAR images (from the High Resolution Visible (HRV) sensor onboard Satellite Pour l'Observation de la Terre (SPOT) satellite and from ERS-SAR) acquired before and after a flood. [J592]

"Neuroinspired Architecture for Robust Classifier Fusion of Multisensor Imagery"

Two new algorithms for robust and fault-tolerant classifier combination are presented. The attractor dynamics (AD) algorithm models some properties of sensory integration in the central nervous system and is based on the application of the dynamical systems for classifier fusion. The classifier masking (CM) algorithm is a nonneural version of the AD algorithm based on finding intersecting classifier intervals. Both of the proposed algorithms employ the idea of consensus among individual classifiers. The individual classifiers have been trained using resampled feature sets. They fuse the information from advanced synthetic aperture radar, medium resolution imaging spectrometer, and advanced along track scanning radiometer envisat satellite sensors for the improved sea ice classification. The results of our experiments show that training and combing the individual classifier outputs in a multiple classifier system significantly improve the robustness and the fault tolerance of the classification system as compared to the single classifier combining all sources of information. The robustness of the single classifier has been largely reduced in cases of single sensor failures (87.9 % in normal conditions versus 64.8% and 66.1% for two artificially corrupted data sets), whereas the CM algorithm is more tolerant to the sensor and preprocessing errors (86.4% in normal conditions versus 78.9% and 73.6% for two artificially corrupted data sets). The performance of the CM algorithm is superior to those of the simple multiple classifier combination strategies based on classifier averaging and majority voting (78.9% versus 70.9% and 69.5%, respectively) because the AD and CM algorithms are able to discard the corrupted classifier outputs based on classifier agreement and, in fact, represent hybrid approaches combining the properties of classifier averaging and classifier selection methods. [J593]

"Application of Subarray Averaging and Entropy Minimization Algorithm to Stepped-Frequency ISAR Autofocus"

Subarray averaging and entropy minimization (SAEM) algorithm is applied to stepped-frequency ISAR autofocus to compensate for the phase error along the down-range due to high target speed and low pulse repetition frequency (PRF) of radar systems. In stepped-frequency radar systems, the phase error due to target motion in each burst make range profiles blur. Thus, the stepped-frequency ISAR often adopts a high PRF radar system in order to suppress the effect of target motion in each burst. However, it inevitably leads to loss of many advantages by adopting low PRF radars in stepped-frequency ISAR imaging. In order to take advantage of a low PRF radar in stepped-frequency ISAR imaging, this paper makes use of a method called SAEM (subarray averaging and entropy minimization) that uses a subarray averaging concept in conjunction with the entropy cost function in order to find the target's motion parameters. Well-focused ISAR images also can be provided from the combination of the SAEM and a traditional autofocus algorithm, even when low PRF stepped-frequency waveform is used. The effectiveness of this method is illustrated and analyzed with simulated targets comprised of point scatters and measured Boeing-737 data. [J594]

"Overview of the TECSAR Satellite Hardware and Mosaic Mode"

TECSAR satellite is part of a spaceborne synthetic-aperture-radar (SAR) satellite technology demonstration program. The purpose of this program is to develop and evaluate the technologies required to achieve high-resolution images combined with large-area coverage. These requirements can be fulfilled by designing a satellite with multimode operation. The TECSAR satellite is developed by the MBT Space Division, Israel Aerospace Industries, acting as a prime contractor, which develops the satellite bus, and by ELTA Systems Ltd., which develops the SAR payload. This paper reviews the TECSAR radar system design, which enables to perform a variety of operational modes. It also describes the unique hardware components: deployable parabolic mesh antenna, multitube transmitter, and data-link transmission unit. The unique mosaic mode is presented. It is shown that this mode is the spot version of the scan mode. [J595]

"On the Design and Evaluation of Multiobjective Single-Channel SAR Image Segmentation

Algorithms"

Multiobjective segmentation algorithms are based on an objective function, consisting of two or more terms, that is minimized by using an optimization algorithm. The objective terms represent differing segmentation objectives, the most popular of which are statistical likelihood of pixel values and smoothness of segment boundaries. Many assumptions are built into the objective function, and we present a case study based on the algorithm of Stewart to demonstrate the importance of analyzing algorithm characteristics to test the validity of hidden assumptions. We develop a set of simulated test images and a novel segmentation performance metric for use with simulated data. An innovative aspect of the Stewart algorithm (SA) is the probability of false alarm (PFA) model used to weight the objective terms. This is intended to dynamically balance the terms as the algorithm progresses. The PFA model is only valid for false edges, and we have shown that the number of selected true edges increases as segmentation evolves, making the theoretical weight model increasingly invalid. In addition, we found problems with several other algorithm assumptions. We tested algorithm performance against a fixed-weight version. We found that the performance of the SA was worse than a fixed-weight version. Thus, while the two-term objective function algorithm does deliver reasonable performance for multilook data, the fixed-weight version gives better performance. While these results hold only for simulated data, we believe that the experimental results indicate the need for a more powerful approach to multiobjective synthetic aperture radar segmentation. [J596]

"Results from trials of a planar, incoherent, synthetic aperture sonar for underwater imaging"

Synthetic aperture sonar (SAS) techniques can yield high-resolution images with a small physical array. Their application in the underwater environment is usually confined to the deployment and synthesis of linear apertures. Incoherent SAS processing is a suboptimal approach compared with coherent SAS processing as the absence of phase information results in an inferior along-track resolution and a higher sidelobe level. The absence of phase information implies that incoherent processing is not constrained by phase-aliasing. Incoherent SAS can accommodate non-uniform inter-ping spacing and is tolerant to trajectory estimation errors of the order of the range-compressed pulse length. This presents new opportunities for a robust surveying system. Apertures of nonlinear shapes can be synthesised depending on the nature and requirement of the specific application and environment. Surveys can be conducted with minimal hardware deployment, such as by a diver. On the basis of this concept, tank trial results of a 3-dimensional incoherent SAS technique utilising the synthesis of 2D apertures are presented. Broadband pulses are employed to achieve optimal survey resolution. The feasibility of this technique is demonstrated for both monostatic and single-transmit, multiple-receive configurations. Practical results are shown for arbitrary-surface apertures sampled at non-uniformly separated positions. [J597]

"Estimating building dimensions from synthetic aperture radar image sequences"

The problem of automatically extracting building dimensions from synthetic aperture radar (SAR) image sequences of urban scenes is considered. An algorithm based on the delineation of shadows using active contours constrained by a simple wire-frame building model has been developed and demonstrated using SAR imagery of a village on Salisbury plain. The core of the algorithm is a novel technique for target delineation involving multiple active contours evolving simultaneously. In particular, a technique referred to as multiple hypothesis delineation, in which contours can be in several states simultaneously, is developed and shown to lead to considerable improvement in convergence time and delineation accuracy when used to delineate multiple targets in close proximity. The technique is applied to the automatic estimation of building dimensions by delineation of shadows in a sequence of SAR images of an urban scene. The estimation of building dimensions is automatic; user interaction is limited identifying a building of interest and a region of background clutter close to the building. Results are presented for six different buildings, in each case two SAR images were used in the estimation process separated in illumination angle by either 28deg or 90deg. The estimates of building dimensions are compared with the actual building dimensions obtained from architectural drawings. The algorithm was found to perform robustly and provide reasonably accurate estimates of the building dimensions, typically within ~10% of the true values. [J598]

"POLSAR Image Analysis of Wetlands Using a Modified Four-Component Scattering Power Decomposition"

It is important to monitor environmental changes of the Earth's cover by remotely sensed data. This paper analyzes seasonal changes of a wetland by a modified polarimetric four-component scattering power decomposition method. The data sets analyzed here are L- and X-band fully polarimetric synthetic aperture radar (POLSAR) data, which have been acquired by the NICT/JAXA airborne polarimetric and interferometric synthetic aperture radar system in 2004. Since there existed a deficiency in the currently adopted decomposition schemes in that negative powers appear in a few pixels in the image analysis, we modified the approach taking into account physical conditions. It is shown by the modified scheme that the seasonal changes and features of

the vegetation near Sakata Lagoon in Niigata, Japan, are observed clearly, demonstrating the utility of POLSAR image analysis for wetland assessments in general. [J599]

"Some Aspects of Improving the Frequency Scaling Algorithm for Dechirped SAR Data Processing"

The frequency scaling algorithm (FSA) was proposed to process the synthetic aperture radar (SAR) data acquired via the dechirp-on-receive approach. Some aspects of improving the FSA are investigated in this paper, based on which an extended FSA (EFSA) is presented. The general purpose of the EFSA is to reduce the effect of range spectrum shift of the intermediate processing results, which occurs during the scaling operation in the FSA, so as to achieve a more effective utilization of the processed bandwidth. The EFSA is implemented through time shifting the scaling and the inverse scaling functions used in the FSA and also the adjustment of the scaling factor. The derivation of the EFSA is detailed in this paper. Point target simulation in squinted imaging geometry indicates that the presented algorithm is more suitable for large-squint applications. [J600]

"An Error Prediction Framework for Interferometric SAR Data"

Three of the major error sources in interferometric synthetic aperture radar measurements of terrain elevation and displacement are baseline errors, atmospheric path length errors, and phase unwrapping errors. In many processing schemes, these errors are calibrated out by using ground control points (GCPs) (or an external digital elevation model). In this paper, a simple framework for the prediction of error standard deviation is outlined and investigated. Inputs are GCP position, aprioriGCP accuracy, baseline calibration method along with a closed-form model for the covariance of atmospheric path length disturbances, and a model for phase unwrapping errors. The procedure can be implemented as a stand-alone add-on to standard interferometric processors. It is validated by using a set of single-frame interferograms acquired over Rome, Italy, and a double difference data set over Flevoland, The Netherlands. [J601]

"Noise Reduction in Interferograms Using the Wavelet Packet Transform and Wiener Filtering"

A novel noise reduction scheme for synthetic aperture radar (SAR) interferograms based on the wavelet packet transform (WPT) and the Wiener filter is introduced in this letter. First, by employing the WPT in the spatial frequency domain, the real and imaginary parts of the complex noisy interferogram are decomposed, respectively, and the wavelet coefficients are obtained. Then, for these coefficients, Wiener filtering is adopted to remove noise. This scheme can filter noise adaptively according to the local noise level, without requiring any a priori information. By using a simulated noisy interferogram and two ENVISAT advanced synthetic aperture radar C-band interferograms, the performance of this scheme, in terms of noise reduction and fringes preservation, is reported and compared with other filter algorithms. The experimental results demonstrate the effectiveness of the proposed scheme. [J602]

"Improvement of Image Segmentation Accuracy Based on Multiscale Optimization Procedure"

This letter proposes an optimization approach that enhances the quality of image segmentation using the software Definiens Developer. The procedure aims at the minimization of over- and undersegmentations in order to attain more accurate segmentation results. The optimization iteratively combines a sequence of multiscale segmentation, feature-based classification, and classification-based object refinement. The developed method has been applied to various remotely sensed data and is compared to the results achieved with the established segmentation procedures provided by the Definiens Developer software. The quantitative assessment of segmentation accuracy based on reference objects is derived from an aerial image, and a high-resolution synthetic aperture radar scene shows an improvement of 20%-40% in object accuracy by applying the proposed procedure. [J603]

"Squint Spotlight SAR Raw Signal Simulation in the Frequency Domain Using Optical Principles"

Synthetic aperture radar (SAR) distributed target scene raw signal simulation is an important tool for the study and test of SAR systems and processing algorithms, mission planning, and inversion algorithm design. In this paper, the squint spotlight SAR scene model is evaluated to achieve spotlight SAR raw signals in the 2-D frequency domain and the precision of the model is analyzed. It is known that the range migration phenomenon in the time domain is explained as the coupling between the range and azimuth in the 2-D frequency domain. To realize the coupling relation in the 2-D frequency, interpolation may be needed. However, interpolation is a time-consuming manipulation. For efficiency, some signal processing methods are employed to couple the range and azimuth frequencies. Those tricks are derived from some optical principles, which give us some novel thoughts. Therefore, the efficiency of the simulator is highly improved, which facilitates its application to the verification and test of the real-time processor. [J604]

"An Omega-K Algorithm With Phase Error Compensation for Bistatic SAR of a Translational Invariant Case"

This paper first shows the 3D property of bistatic synthetic aperture radar (BiSAR) geometry, which clarifies that the algorithms for bistatic SAR should be deduced in 3D space. It then models the bistatic echo according to the 3D geometry and obtains the signal spectrum in the wavenumber domain. Based on the spectrum, the formula for the wavenumber-domain interpolation of the omega-K algorithm is deduced, and the residual phase is obtained. Then, the impacts of the residual phase, including position displacement, range, and azimuth defocusing, and a constant phase for each pixel, are explicated. Finally, the simulating results exhibited at the end of this paper validate the correctness of the analysis and the feasibility of the algorithm. [J605]

"SAR for disaster management"

In the last couple of years, an indigenous airborne synthetic aperture radar for disaster management (DMSAR) has been under development at SAC / ISRO, as a capacity building measure for evolving an effective disaster management support (DMS) system in India. Synthetic aperture radar (SAR) has an unique role to play in the mapping and monitoring of large areas affected by natural disasters, especially floods, owing to its unique capability to see through clouds as well as all-weather imaging capability. DMSAR is presently mounted on-board Beechcraft B-200 aircraft and will he subsequently carried on a jet class aircraft and utilized for estimating the extent of damage over large areas (~50-75 Km) and also assess the effectiveness of the relief measures undertaken during disasters like floods. Considering the unique application requirements of disaster management, one of the major essential and critical requirements is the generation and availability of DMSAR images in real- or near-real-time with very fast turn-around times. DMSAR image generation involves complex signal processing of the acquired raw data, involving data decompression, two-dimensional SAR processing, motion sensing and compensation tasks, and image mosaicing on display as well as storage of processed SAR images on suitable recording media. [J606]

"A Bistatic Point Target Reference Spectrum for General Bistatic SAR Processing"

A bistatic point target reference spectrum (BPTRS) based on Loffeld's bistatic formula (LBF) is derived in this letter. For LBF, the same contributions of the transmitter and receiver to the total azimuth modulation are assumed. This assumption results in the failure of LBF in the extreme configuration (i.e., spaceborne/airborne configuration). For general bistatic configurations, the azimuth modulations are unequal for the transmitter and receiver due to the different slant ranges and velocities. Therefore, the azimuth time-bandwidth products (TBPs) from the transmitter and receiver are different; in some cases (e.g., spaceborne/airborne case), one of them might be very small, which might even result in a serious error of the principle of stationary phase. This letter uses TBP to weight the azimuth phase modulation contributions of the transmitter and receiver to the common azimuth spectrum to approximately obtain the point of stationary phase of the total azimuth phase history. Simulations show that the proposed BPTRS can work well for spaceborne/airborne configurations. [J607]

"A Two-Dimensional Spectrum Model for General Bistatic SAR"

This paper derives a 2-D spectrum model for general bistatic synthetic aperture radar (SAR). By introducing some new parameters such as equivalent monostatic parameters, bistatic factor, and weighted-equivalent range, the 2-D spectrum of general bistatic SAR can be expressed in the form of monostatic SAR even when the transmitter and receiver move along unparallel trajectories with different velocities. The result formulates bistatic SAR into an equivalent monostatic SAR model and would be useful for developing efficient bistatic SAR algorithms in frequency-domain or hybrid-domain processing. Simulation results are given to validate the performance of the model. For special bistatic SAR configurations, the model can be simplified. Compared to other similar models, the proposed model is clearer and much more concise. [J608]

"Sea Ice Deformation State From Synthetic Aperture Radar Imagery-Part II: Effects of Spatial Resolution and Noise Level"

C- and L-band airborne synthetic aperture radar (SAR) imagery acquired at like- and cross-polarizations over sea ice under winter conditions is examined with the objective to study the discrimination between level ice and ice deformation features. High-resolution low-noise data were analyzed in the first paper. In this second paper, the main topics are the effects of spatial resolution and signal-to-noise ratio. Airborne high-resolution SAR scenes are used to generate a sequence of images with increasingly coarser spatial resolution from 5 to 25 m, keeping the number of looks constant. The signal-to-noise ratio is varied between typical noise levels for airborne imagery and satellite data. Areal fraction of deformed ice and average deformation distance are determined for each image product. At L-band, the retrieved values of the areal fraction get larger as the image

resolution is degraded. The areal fraction at C-band remains constant. The retrieved average distance between deformation features increases both at C- and L-bands as the image resolution gets coarser. The influence of noise becomes noticeable if its level is equal or larger than the average intensity backscattered from the level ice. The retrieval of deformation parameters using simulated images that resemble ERS-2 SAR, Envisat ASAR, and ALOS PALSAR data products is discussed. Basic differences between real and simulated ERS-2 SAR images are analyzed. [J609]

"A Low-Power High-Sensitivity X-Band Rail SAR Imaging System [JMeasurement's Corner]"

Wideband radar imaging with range gating and high sensitivity can be achieved with the use of low-cost commercially available narrowband IF filters. Such filters reduce the effective receiver noise bandwidth of the radar system. This allows for high sensitivity, comparable to that of single-sideband radio receivers, while at the same time acquiring de-chirped wide-band received waveforms. A carefully developed radar architecture, based on the use of these IF filters, is shown in this paper. This radar architecture is then implemented in an X-band linear rail synthetic-aperture-radar (SAR) imaging system. The X- band rail SAR is a linear FM-chirped radar, which chirps from approximately 7.5 GHz to 12.5 GHz. The radar front end is mounted onto an eight-foot-long linear rail. The transmitted power is adjustable to 10dBm or less. It will be shown that objects as small as groups of pushpins in free space can be imaged using transmitted power as low as 10 nW. These results are compared to previous direct-conversion X-band FMCW rail SAR work. A high-sensitivity X-band rail SAR such as this could be useful for measuring low-radar-cross-section (RCS) targets. This radar could be used in high clutter environments that require a range gate. This low-power X-band rail SAR could be useful for operation in restricted transmission areas, where maximum radiated power is severely limited. Other applications include any that require low transmitter power, such as automotive radar. [J610]

"Our Other Contributions"

{no data available} [J611]

"Errors analysis of transponder-based radiometric calibration for high-resolution imaging radars"

Calibration is often required for precision measurement instruments like synthetic aperture radar (SAR) such that an image pixel intensity is directly expressed in terms of the surface backscatter coefficient. An active reflector named as transponder is an effective SAR calibration device which yields a larger radar cross-section than a corner reflector. Likewise, encoding the retransmitted signal can decouple the transponder from the background scatterers, hence, it can be used to calibrate SAR for radiometry, polarimetry and interferometry. However, as this transponder acts as an amplitude modulator, any signal errors in the transponder will result in degraded performance of radiation calibration. Literature search reveals that little work has been reported. As such, various kinds of signal errors and their effects on radiometric calibration are investigated. The system configuration and corresponding signal processing algorithms are detailed. Starting with an investigation of different errors, closed analytic expressions for calibration performance are derived. Furthermore, the most essential element of this transponder, one X-band wideband voltage-controlled attenuator, is developed. Experimental results show that, because of its low cost and wideband modulation technique, this transponder has extensive applications, not just for radiometric calibration. [J612]

"Along-track interferometry for ground moving target indication"

Synthetic aperture radar (SAR) along-track interferometry (ATI) has been used extensively to measure ocean surface currents. Given its ability to measure small velocities (~10 cm/s) of relatively radar-dark water surfaces, there is great potential that this technique can be adapted for ground moving target indication (GMTI) applications, particularly as a method for detecting very slow targets with small radar cross-sections. Herein, we describe preliminary results from an ATI GMTI experiment. The SAR data described were collected by the dual-frequency NASA/JPL airborne radar in its standard dual-baseline ATI mode. The radar system imaged a variety of control targets including a pickup truck, sport utility vehicles, passenger cars, a bicycle, and pedestrians over multiple flight passes. The control targets had horizontal velocities of less than 5 m/s. The cross-sections of the targets were not purposely enhanced, although the targets' reflectivities may have been affected by the existence of the GPS equipment used to record the targets' positions. Single-look and multiple-look interferograms processed to the full azimuth resolution were analyzed. In the data processed to date, all of the targets were observed by visual inspection in at least one of the four combinations of dual-frequency, dual-baseline interferometric data. This extremely promising result demonstrates the potential of ATI for GMTI applications. [J613]

"Potential Effects of the Ionosphere on Space-Based SAR Imaging"

There has been a considerable interest in the use of lower frequency (VHF/UHF) space-based synthetic aperture radar (SAR) for realizing the foliage and ground penetration. The phase perturbation, signal distortion and imaging resolution degradation by the ionosphere will be particularly severe, however the model is not yet well established and still needs to be further studied. In this paper, on the basis of possible improvements for the model proposed by Ishimaru and others, potential ionospheric effects on SAR imaging are evaluated. First, for analyzing azimuthal resolution, we apply the fourth moment recently obtained in general case of strong fluctuation regimes, which is expected to give results for wider conditions. The Gaussian approximation was used in the previous model; however it is only valid in the fully saturated regimes. Second, for analyzing image shift and distortion, besides group delay, the higher-order dispersion is considered. Third, for discussing range resolution degraded due to pulse broadening, besides the dispersion, the multiple scattering of ionospheric turbulence is studied. Fourth, the Faraday rotation effect is analyzed. Numerical simulations are shown using ionospheric turbulence spectrum and TEC inferred from the International Reference Ionosphere (IRI) and satellite beacon observations. [J614]

"Short Courses"

{no data available} [J615]

"Validation of the Submetric Accuracy of Vertical Positioning of PSs in C-Band"

The permanent scatterers (PSs) technique is an operational tool in the context of spaceborne synthetic aperture radar interferometry for monitoring the displacement of radar targets with millimetric accuracy. Recently, the target localization capability of the PS technique has been subject of study, and the possibility of generating digital elevation models (DEMs) and digital terrain models (DTMs) by means of the height of a sparse set of points has been evaluated. In this letter, for the first time, the PS height estimate has been validated by exploiting about 250,000 spot heights at street level derived from photogrammetric techniques in the urban area around Milan, Italy. The very high correlation between the two independent measurements confirms the theoretical submetric accuracy of vertical positioning. A multitrack PS DTM has then been generated and compared to the spot heights together with the corresponding Shuttle Radar Topography Mission (SRTM) DEM, showing the very high improvement given by the PS technique to the freely available topographic data. The results have been obtained by processing about 300 European Space Agency (ESA) European Remote Sensing (ERS) satellite and Envisat images acquired from two descending tracks and an ascending one over Milan. [J616]

"A Robust State Space Model for the Characterization of Extended Returns in Radar Target Signatures"

Analysis of radar scattering from targets with curved boundaries, such as objects comprising cylindrical and conical shapes, is important to many aerospace applications. The radar return is composed of a well-characterized physical optics response in the illuminated region where the transmitter and receiver are not shadowed by the object, and a combination of modal responses (e.g., creeping waves and edge-diffracted fields) in the shadow region. The modal responses have longer down-range than scattering centers located on the object, and therefore, produce extended (or off-body) returns in ISAR images, which are not well-understood. However, these returns are strongly dependent on local features of the object, and thus contain valuable information with regard to the target's geometrical and physical composition. Multiple reflections from illuminated facets, as well as multiply diffracted waves, can also add coherently in the direction of the receiver and produce such returns. This paper applies a robust, coherent-processing system identification technique, originally developed for radar sensor fusion, to estimate amplitude and phase of the scatterers that characterize extended returns in the target signature. Examples are presented that highlight the extraction of creeping waves using measured data on a cone-sphere. [J617]

"High-Resolution Through-the-Wall Radar Imaging Using Beamspace MUSIC"

The MUSIC algorithm is a high-resolution direction finding technique which has been successfully applied to enhance radar imaging in inverse synthetic aperture radar (ISAR). Although this signal subspace-based method has proven effective when dealing with point targets and high signal-to-noise ratio (SNR), it may fail to work when directly applied to extended targets or target returns of low SNR. The Beamspace MUSIC (BS-MUSIC), in which the MUSIC algorithm is applied to multiple beams, is capable of locating spatially extended targets in low SNR environments. In this paper, we consider BS-MUSIC as an image formation method for indoor radar imaging problems and sensing through-the-wall applications. We compare BS-MUSIC performance to conventional beamforming and element-space MUSIC. Imaging results, using both synthesized and real data, demonstrate the advantages of the proposed algorithm in depicting targets behind walls. [J618]

"Focusing Azimuth-Invariant Bistatic SAR Data With Chirp Scaling"

This letter presents a bistatic chirp scaling algorithm to processing the azimuth-invariant bistatic synthetic aperture radar data. Two methods are used to derive the different parts of the range-Doppler expression of the point target. Compared with the method relying on the two-order expansion of the bistatic range model, the new algorithm can give the close-form azimuth modulation. Through the introduction of the fractional Fourier transform into the range processing, the resolutions are enhanced further. [J619]

"Effect of Salinity on the Dielectric Properties of Geological Materials: Implication for Soil Moisture Detection by Means of Radar Remote Sensing"

We consider the exploitation of dielectric properties of saline deposits for the detection and mapping of moisture in arid regions on both Earth and Mars. We present simulated and experimental study in order to assess the effect of salinity on the complex permittivity of geological materials and, therefore, on the radar backscattering coefficient in the [1-7 GHz] frequency range. Laboratory measurements are performed on sand/sodium chloride aqueous mixtures using a vectorial network analyzer coupled to an open-ended coaxial dielectric probe. We aim at calibrating and validating semiempirical dielectric mixing models. In particular, we evaluated the dependence of the real and imaginary parts of complex permittivity on the microwave frequency, water content, and salinity. Our results confirm that if the real part is mainly affected by the moisture content, the imaginary part is more sensitive to salinity. In addition to the classic formulas of mixing models, the ionic-conductivity losses, which are due to mobile ions in the saline solution, are taken into account in order to better assess the effect of salinity on the dielectric properties of mixtures. Dielectric mixing models are then used as input parameters for the simulation of the radar backscattering coefficients by means of an analytical model: the integral equation model. Simulation results show that salinity should have a significant impact on the radar backscattering recorded in synthetic aperture radar data in terms of the magnitude of the backscattering coefficient. Moreover, our results suggest that VV polarization provides a greater sensitivity to salinity than HH polarization. [J620]

"Potential for Surface Parameter Estimation Using Compact Polarimetric SAR"

The retrieval of soil surface parameters using a dual-polarization synthetic aperture radar operating in a compact polarimetric mode is examined. It is shown that by employing a two-component model of surface polarimetric coherency, soil surface parameter retrieval is possible directly from measurements without the need for any additional assumptions. Model surface parameters inverted by using the full polarimetric coherency matrix may be recovered equally well from a compact polarimetric coherency matrix. [J621]

"Development and Implementation of Ultra-Wideband See-Through-Wall Imaging System Based on Sampling Oscilloscope"

A low-cost experimental UWB synthetic aperture radar has been developed for high-resolution see-through-drywall imaging application. The developed SAR-based system is comprised of an UWB Vivaldi array, off-the-shelf components, and RF instruments. System integration including hardware and software aspects is in detailed discussion. The running system focuses on 8-12 GHz operation, but the very flexible system architecture allows it to be easily scaled to cover the lower frequency band, such as 2-4 GHz which is more suitable for the see-through-concrete wall application. [J622]

"Limitations in the Hydrologic Applications of C-Band SRTM DEMs in Low-Relief Settings"

The shuttle radar topography mission (SRTM) data represent a major breakthrough in terms of providing accurate and consistent elevation data on a worldwide basis. These data are being used in many scientific applications, hydrology in particular. This letter examines the feasibility of using SRTM data for hydrologic characterizations, particularly in a region of low relief exemplified by the Otter Tail basin in Minnesota. The Version 2 SRTM data product provides a useful starting place for estimating the stage for larger lakes. Indications for Minnesota are that these estimates are accurate to several meters but are biased toward underestimation. Over land, the inherent noise in the data makes watershed boundary and stream network extraction problematic. We found large errors in estimated basin shape and area, and in the geometry of extracted stream networks, as compared to more traditional U.S. Geological Survey data products. [J623]

"Fisher Distribution for Texture Modeling of Polarimetric SAR Data"

The multilook polarimetric synthetic aperture radar (PolSAR) covariance matrix is generally modeled by a complex Wishart distribution. For textured areas, the product model is used, and the texture component is modeled by a Gamma distribution. In many cases, the assumption of Gamma-distributed texture is not

appropriate. The Fisher distribution does not have this limitation and can represent a large set of texture distributions. As an example, we examine its advantage for an urban area. From a Fisher-distributed texture component, we derive the distribution of the complex covariance matrix for multilook PolSAR data. The obtained distribution is expressed in terms of the KummerU confluent hypergeometric function of the second kind. Those distributions are related to the Mellin transform and second-kind statistics (Log-statistics). The new KummerU-based distribution should provide in many cases a better representation of textured areas than the classic Kdistribution. Finally, we show that the new model can discriminate regions with different texture distribution in a segmentation experiment with synthetic textured PolSAR images. [J624]

"Interactive Dynamic Range Reduction for SAR Images"

The visualization of synthetic aperture radar (SAR) data involves the mapping from high dynamic range amplitude values to gray values of a lower dynamic range display device. This dynamic range reduction process controls the amount of information in the displayed result and is therefore an important part of each SAR visualization system. Interactive systems provide the user with immediate feedback on the changes of the reduction method and its parameters. In this letter, we examine different dynamic range reduction techniques known from the tone mapping of optical images. The techniques are analyzed, regarding their applicability to SAR data, and incorporated into our interactive visualization framework based on programmable graphics hardware. [J625]

"Least Squares-Based Filter for Remote SensingImage Noise Reduction"

The Vondrak filter is a unique technique for smoothing data. The filter aims to achieve a balance between the fidelity and the smoothness of the filtered results. It can therefore preserve the original attributes of the observational data while, at the same time, smooth out the noise. We reformulate the 1-D Vondrak filter that has been widely used in data processing in fields such as astronomy and geophysics and then extend it into two dimensions. The method of conjugate gradients is used to solve the least squares optimization problem. The proposed 2-D filter is a powerful tool for enhancing the quality of various geoscience and remote sensing data such as satellite images. Various tests with simulated and real synthetic aperture radar interferograms show that the new filter is very effective in removing the noise. [J626]

"Spectral Clustering Ensemble Applied to SAR Image Segmentation"

Spectral clustering (SC) has been used with success in the field of computer vision for data clustering. In this paper, a new algorithm named SC ensemble (SCE) is proposed for the segmentation of synthetic aperture radar (SAR) images. The gray-level cooccurrence matrix-based statistic features and the energy features from the undecimated wavelet decomposition extracted for each pixel being the input, our algorithm performs segmentation by combining multiple SC results as opposed to using outcomes of a single clustering process in the existing literature. The random subspace, random scaling parameter, and Nystrom approximation for component SC are applied to construct the SCE. This technique provides necessary diversity as well as high quality of component learners for an efficient ensemble. It also overcomes the shortcomings faced by the SC, such as the selection of scaling parameter, and the instability resulted from the Nystrom approximation method in image segmentation. Experimental results show that the proposed method is effective for SAR image segmentation and insensitive to the scaling parameter. [J627]

"Wideband synthetic aperture beamforming for through-the-wall imaging [JLecture Notes]"

Through-the-wall radar imaging (TWRI) and sensing is emerging as an important area of research and development. A TWRI system provides enhanced situational awareness in operational environments for a variety of civilian and military applications. In particular, a TWRI system facilitates realtime information gathering and intelligent decision-making about the contents of the indoor scene. Compared to other radar applications, TWRI faces unique challenges due to signal propagation through walls. The composition and thickness of the wall, its dielectric constant, and the angle of incidence affect the strength and characteristics of the propagating signal. The change in propagation speed and wave refraction must be taken into account for effective and accurate imaging. In this article, we present a synthetic aperture beamforming approach that uses ray perturbation theory to account for the effects of transmission through a single uniform wall. [J628]

"Three-Dimensional ISAR Imaging Based on Antenna Array"

In this paper, a 3D inverse synthetic aperture radar (ISAR) imaging method based on an antenna array configuration is proposed. The performance of conventional interferometric ISAR imaging system using three antennas is poor, as the positions of scatterers, which have the same range-Doppler value and projected onto the ISAR plane as a synthesis scatterer, cannot be correctly estimated. However, by using two antenna arrays

perpendicular to each other, the system's ability to separate these scatterers can be improved. The criterion for the selection of a range unit that contains an isolated scatterer in the 2-D array domain for doing motion compensation is discussed. If there is no range unit which contains only an isolated scatterer, then radial and cross-range motion compensation has to be carried out by motion parameter estimation. Two cross-range motion parameters measurement algorithms, one based on array processing of the range profile and another based on correlation of ISAR images of different antennas, are proposed. The coordinates registration problem for the scatterers of a synthesis scatterer is also discussed. Simulation results have shown the effectiveness of the proposed methods. [J629]

"IRGS: Image Segmentation Using Edge Penalties and Region Growing"

This paper proposes an image segmentation method named iterative region growing using semantics (IRGS), which is characterized by two aspects. First, it uses graduated increased edge penalty (GIEP) functions within the traditional Markov random field (MRF) context model in formulating the objective functions. Second, IRGS uses a region growing technique in searching for the solutions to these objective functions. The proposed IRGS is an improvement over traditional MRF based approaches in that the edge strength information is utilized and a more stable estimation of model parameters is achieved. Moreover, the IRGS method provides the possibility of building a hierarchical representation of the image content, and allows various region features and even domain knowledge to be incorporated in the segmentation process. The algorithm has been successfully tested on several artificial images and synthetic aperture radar (SAR) images. [J630]

"Rice Mapping and Monitoring Using ENVISAT ASAR Data"

Radar remote sensing technology has become an important method for stable and long-time rice monitoring for its capability to operate in all weather conditions. In this letter, ENVISAT advanced synthetic aperture radar (ASAR) alternative-polarization VV/HH data were used for rice monitoring in the Xinghua rice experiment site in the middle of Jiangsu Province. First, a threshold classification method was developed for mapping rice growth area according to the different characteristic of backscatter coefficients between paddy rice and other land surface objects. Then, relational models were built for retrieving rice growth parameters from ASAR images based on correlation analysis between backscatter coefficients and field measurements. Meanwhile, an optical multispectral image was used as ancillary data for rice parameters retrieval. As expected, the retrieved rice growth parameters were consistent with those of field measurements. [J631]

"Processing of Azimuth-Invariant Bistatic SAR Data Using the Range Doppler Algorithm"

This paper discusses bistatic synthetic aperture radar processing (complex image formation) using the Range Doppler Algorithm. The key step is to use an analytical form of the signal spectrum derived by the method of series reversion. The spectrum is used for secondary range compression (SRC), range cell migration correction, and azimuth compression. The algorithm is able to focus the azimuth-invariant bistatic configuration where the transmitter and receiver platforms are moving in parallel tracks with identical velocities. Moreover, the algorithm is able to handle reasonably high squints and wide apertures because SRC can be performed in the 2-D frequency domain. [J632]

"High-Resolution Three-Dimensional Radar Imaging for Rapidly Spinning Targets"

A 3-D inverse synthetic aperture radar imaging method for rapidly spinning targets, i.e., a generalized Radon transform (GRT)-CLEAN algorithm, is proposed in this paper. The signal model is first changed into an equivalent high-speed turntable model after the compensation of the translational motion. Second, based on the relationship between the range profile variation of the spinning targets and the scatterers' positions, the GRT is utilized to estimate the scatterers' positions. Finally, combining the GRT with the modified CLEAN approach, the parameters of each scatterer and, thus, the 3-D image of the targets can be obtained. In addition to the development of the GRT-CLEAN algorithm, the estimation and compensation of the linear translational motion error in the imaging process is also considered in this paper. Good images yielded confirm the effectiveness of the GRT-CLEAN algorithm in the simulations. [J633]

"Using C-Band Synthetic Aperture Radar Data to Monitor Forested Wetland Hydrology in Maryland's Coastal Plain, USA"

Hydrology (i.e., inundation and soil moisture) is the most important abiotic factor controlling wetland function and extent, and scientists predict that wetland hydrology can be significantly altered over relatively short timescales due to climate change and anthropogenic impact. Whereas broadscale hydrology is difficult to monitor in forested wetlands with ground-based and optical remote sensing methods, C-band synthetic aperture radar (SAR) systems have the potential to improve the capability to monitor forested wetland hydrology. In this study, we

examined the use of Environmental Satellite Advanced SAR (C-HH and C-VV) data for monitoring levels of inundation and soil moisture throughout the year in a typical Mid-Atlantic floodplain and some of the main limitations inherent to C-band data (i.e., polarization and plant phenology) in this environment. The relationships between the backscatter coefficient and inundation, soil moisture, tree basal area, tree height, and forest canopy closure were examined. Significant differences in C-HH were found between forested areas of varying hydrology (0%-60% area inundated) throughout the year and in C-VV during the leaf-off season. As expected, C-HH SAR backscatter was better correlated with inundation and soil moisture than was C-VV SAR backscatter, and the correlations between both polarizations of backscatter and hydrology were stronger during the leaf-off season (C-HH leaf-off, leaf-on ; C-VV leaf-off, leaf-on ; all significant at level). Based on our findings, we concluded that the C-HH data are useful for monitoring hydrology beneath forest canopies throughout the year, whereas the C-VV data can be used during the leaf-off season. Our findings support previous studies that concluded that C-band imagery can be used to monitor forested wetland hydrology in large floodplains that are fully inundated. However, this study used detailed in situ measurements and demonstrated that C-band SAR data can also be used to monitor-forested wetland hydrology in smaller partially inundated floodplains, which are more common in the Mid-Atlantic. [J634]

"Signal-to-noise ratio analysis to estimate ocean wave heights from X-band marine radar image time series"

This work analyses the structure of the different contributions to the image spectrum derived by the three-dimensional Fourier decomposition of sea clutter time series measured by ordinary X-band marine radars. The goal of this investigation is to derive a method to estimate the significant wave height of the ocean wave fields imaged by the radar. The proposed method is an extension of a technique developed for the analysis of ocean wave fields by using synthetic aperture radar systems. The basic idea behind this method is that the significant wave height is linearly dependent on the square root of the signal-to-noise ratio, where the signal is assumed as the radar analysis estimation of the wave spectral energy and the noise is computed as the energy due to the sea surface roughness, which is closely related to the speckle of the radar image. The proposed method to estimate wave heights is validated using data sets of sea clutter images measured by a marine radar and significant wave heights derived from measurements taken by a buoy used as reference sensor. [J635]

"Change Detection in Multisensor SAR Images Using Bivariate Gamma Distributions"

This paper studies a family of distributions constructed from multivariate gamma distributions to model the statistical properties of multisensor synthetic aperture radar (SAR) images. These distributions referred to as multisensor multivariate gamma distributions (MuMGDs) are potentially interesting for detecting changes in SAR images acquired by different sensors having different numbers of looks. The first part of this paper compares different estimators for the parameters of MuMGDs. These estimators are based on the maximum likelihood principle, the method of inference function for margins, and the method of moments. The second part of the paper studies change detection algorithms based on the estimated correlation coefficient of MuMGDs. Simulation results conducted on synthetic and real data illustrate the performance of these change detectors. [J636]

"High-Resolution SAR Interferometry: Estimation of Local Frequencies in the Context of Alpine Glaciers"

Synthetic aperture radar (SAR) interferometric data offer the opportunity to measure temperate glacier surface topography and displacement. The increase of the resolution provided by the most recent SAR systems has some critical implications. For instance, a reliable estimate of the phase gradient can only be achieved by using interferogram local frequencies. In this paper, an original two-step method for estimating local frequencies is proposed. The 2-D phase signal is considered to have two deterministic components corresponding to low-resolution (LR) fringes and high-resolution (HR) patterns due to the local microrelief, respectively. The first step of the proposed algorithm consists in the LR phase flattening. In the second step, the local HR frequencies are estimated from the phase 2-D autocorrelation function computed on adaptive neighborhoods. This neighborhood is the set of connected pixels belonging to the same HR spatial feature and respecting the ldquolocal stationarityrdquo hypothesis. Results with both simulated TerraSAR-X interferograms and real airborne E-SAR images are presented to illustrate the potential of the proposed method. [J637]

"X-Band Airborne Differential Interferometry: Results of the OrbiSAR Campaign Over the Perugia Area"

Differential synthetic aperture radar interferometry (DInSAR) is a remote sensing technique that allows monitoring ground deformation with accuracy of the order of fractions of the radiated wavelength, by means of proper combination and processing of repeat-pass data. In contrast to the satellite case, application of such a

technique to airborne data is not, today, a well-established task. Several airborne campaigns, involving mainly C/L-band data, have been planned in the last years to exploit the potentialities of these more flexible platforms for deformation monitoring. In this paper, we show the results of an airborne DInSAR X-band experiment carried out over the Perugia area (center of Italy) by using the OrbiSAR system. We discuss the processing chain applied to the acquired data, which allows achieving a satisfactory compromise between accuracy and efficiency. Eleven repeated passes were carried out in two days; two corner reflectors were located on the ground in a hilly region. One corner reflector was vertically moved between the two days to evaluate the system detection capability. Moreover, we carry out an analysis of all possible differential interferograms for a region 2 4 km wide. [J638]

"Time and phase synchronisation via direct-path signal for bistatic synthetic aperture radar systems"

Bistatic synthetic aperture radar (BiSAR) operates with distinct transmitter and receiver that are mounted on separate platforms. Such a spatial separation results in problems and special requirements that are either not encountered or encountered in less serious form for monostatic SAR. Directly associated with these requirements one has to solve the problems of highly accurate time and phase synchronisations. The impact of oscillator frequency instability on BiSAR is analysed, and a time and phase synchronisation technique via direct-path signal is proposed. With the proposed technique, the direct-path signal of transmitter is received with one appropriative antenna and divided into two channels, one is passed through an envelope detector and used to synchronise the sampling clock, and the other is down-converted and used to compensate the phase synchronisation errors. Finally, the residual time synchronisation error is compensated with range alignment, and the residual phase synchronisation error is compensated with global positioning system/inertial navigation system/inertial measurement units (GPS/INS/IMU) information; then the focusing of BiSAR image can be achieved. Based on this technique, a prototype linearly frequency modulated BiSAR synchronisation system is constructed.The effectiveness of this proposed technique is verified with simulation data. [J639]

"Uniform rotational motion compensation for inverse synthetic aperture radar with non-cooperative targets"

In the current scenario of high-range resolution radars, the rotational motion of the target usually generates migration through resolution cells (MTRC) in the inverse synthetic aperture radar (ISAR) images. A technique to correct the MTRC in the case of uniform rotation rate is proposed. An estimation of the rotation vector of the non-cooperative targets is not required. The approach compensates the rotational motion in two steps: the slant-range rotation compensation (SRRC) and the cross-range rotation compensation (CRRC). CRRC is based on an extension of phase difference (PD) and on a robust method to delete outliers. The technique is verified both with simulated and live data from a millimetre-wave linear frequency-modulated continuous wave radar. A comparison with a minimum entropy-based technique is also made. [J640]

"Phase Unwrapping for SAR Interferometry-A Data Fusion Approach by Kalman Filtering"

This paper considers the problem of unwrapping the phase image obtained from a noisy interferometric synthetic aperture radar (InSAR) image. The implicit nonlinearity of the problem is reflected, as well as the drawbacks of this nonlinearity on the performance of phase unwrapping approaches. Some general concepts concerning basic estimation techniques are shortly reviewed. On this background, a Kalman filter-based data fusion approach to unwrap and simultaneously filter the phases of InSAR images is developed. The data fusion concept exploits phase information extracted from the complex interferogram rather than from the phase image and fuses that information with phase slope information extracted from the power spectral density of the interferogram. [J641]

"Classifiers and Confidence Estimation for Oil Spill Detection in ENVISAT ASAR Images"

An improved classification approach is proposed for automatic oil spill detection in synthetic aperture radar images. The performance of statistical classifiers and support vector machines is compared. Regularized statistical classifiers prove to perform the best on this problem. To allow the user to tune the system with respect to the tradeoff between the number of true positive alarms and the number of false positives, an automatic confidence estimator has been developed. Combining the regularized classifier with confidence estimation leads to acceptable performance. [J642]

"Multibaseline Polarimetric SAR Interferometry Coherence Optimization"

This letter analyzes different approaches for polarimetric optimization of multibaseline (MB) interferometric coherences. Two general methods are developed to simultaneously optimize coherences for more than two data

sets. The first method provides every data set with a distinct dominant scattering mechanism (SM). The second optimization method is constrained to use equal SMs at all data sets. As the experimental results indicate, MB coherence optimization does improve the accuracy in the estimation of dominant SMs and the associated interferometric phases. Both methods are evaluated on real data acquired by the German Aerospace Agency (DLR)'s enhanced synthetic aperture radar sensor (ESAR) at L-band. [J643]

"Atmospheric Artifact Compensation in Ground-Based DInSAR Applications"

In this letter, a coherence-based technique for atmospheric artifact removal in ground-based (GB) zero-baseline synthetic aperture radar (SAR) acquisitions is proposed. For this purpose, polarimetric measurements acquired using the GB-SAR sensor developed at the Universitat Politecnica de Catalunya are employed. The heterogeneous environment of Collserola Park in the outskirts of Barcelona, Spain, was selected as the test area. Data sets were acquired at X-band during one week in June 2005. The effects of the atmosphere variations between successive zero-baseline SAR polarimetric acquisitions are treated here in detail. The need to compensate for the resulting phase-difference errors when retrieving interferometric information is put forward. A compensation technique is then proposed and evaluated using the control points placed inside the observed scene. [J644]

"Basic Slant Range-Doppler Modeling of Moving Scatterers for SAR Applications"

A fundamental spectral domain model for moving point and distribution of scatterers is presented. The approach is accurate as the spherical phase front is rigorously treated throughout the Doppler analysis. Due to the analytic nature of the model in the range-Doppler plain, large squint-angle operations (e.g., SpotSAR) can be characterized. Furthermore, motion characteristics can be extracted in the subaperture level to better reflect the general motion (e.g., nonuniform). The range-Doppler model can serve as a tool for polarimetric and multichannel analysis. [J645]

"Bistatic Spotlight SAR Processing Using the Frequency-Scaling Algorithm"

This letter derives the bistatic point target spectrum for the translational invariant case. Based on the derived spectrum and the linear approximation of the bistatic range cell migration factor, a bistatic frequency-scaling algorithm (FSA) is proposed for spotlight synthetic aperture radar data processing. This algorithm leads to a very precise and efficient processing since it performs the focusing in the frequency domain and no interpolation is required in the whole processing chain. In addition, it is shown that the case considered in the monostatic FSA is a specialization of the more general one considered in this letter. Finally, simulation results are provided to illustrate the validity of the presented approach. [J646]

"Efficient SAR Raw Data Generation Including Low Squint Angles and Platform Instabilities"

The performance of high-resolution synthetic aperture radar (SAR) systems under degrading conditions such as uncontrolled platform motion can only be analyzed and evaluated by modeling the whole imaging system through simulation. A major scientific problem, however, is the generation of spotlight mode SAR raw data because of the need for high numerical and modeling accuracy, and restricted computer time and space. Taking into account a squinted geometry and platform instabilities, the common generation of raw data in the time domain becomes time inefficient. This letter proposes a raw data generator with which the spotlight mode raw data set of an extended scene can be simulated and which combines the precision obtainable when working in the time domain with the efficiency of work in the frequency domain. The generated raw data are processed and analyzed to quantify the quality of the proposed simulation tool. [J647]

"Vegetation Mapping for Landmine Detection Using Long-Wave Hyperspectral Imagery"

We develop a vegetation mapping method using long-wave hyperspectral imagery and apply it to landmine detection. The novel aspect of the method is that it makes use of emissivity skewness. The main purpose of vegetation detection for mine detection is to minimize false alarms. Vegetation, such as round bushes, may be mistaken as mines by mine detection algorithms, particularly in synthetic aperture radar (SAR) imagery. We employ an unsupervised vegetation detection algorithm that exploits statistics of emissivity spectra of vegetation in the long-wave infrared spectrum for identification. This information is incorporated into a Choquet integral-based fusion structure, which fuses detector outputs from hyperspectral imagery and SAR imagery. Vegetation mapping is shown to improve mine detection results over a variety of images and fusion models. [J648]

"Bistatic Synthetic Aperture Radar Imaging for Arbitrary Flight Trajectories"

In this paper, we present an analytic, filtered backprojection (FBP) type inversion method for bistatic synthetic

aperture radar (BISAR). We consider a BISAR system where a scene of interest is illuminated by electromagnetic waves that are transmitted, at known times, from positions along an arbitrary, but known, flight trajectory and the scattered waves are measured from positions along a different flight trajectory which is also arbitrary, but known. We assume a single-scattering model for the radar data, and we assume that the ground topography is known but not necessarily flat. We use microlocal analysis to develop the FBP-type reconstruction method. We analyze the computational complexity of the numerical implementation of the method and present numerical simulations to demonstrate its performance. [J649]

"Multidimensional Waveform Encoding: A New Digital Beamforming Technique for Synthetic Aperture Radar Remote Sensing"

This paper introduces the innovative concept of multidimensional waveform encoding for spaceborne synthetic aperture radar (SAR). The combination of this technique with digital beamforming on receive enables a new generation of SAR systems with improved performance and flexible imaging capabilities. Examples are high-resolution wide-swath radar imaging with compact antennas, enhanced sensitivity for applications like alongtrack interferometry and moving object indication, and the implementation of hybrid SAR imaging modes that are well suited to satisfy hitherto incompatible user requirements. Implementation-specific issues are discussed and performance examples demonstrate the potential of the new technique for different remote sensing applications. [J650]

"Pine Forest Height Inversion Using Single-Pass X-Band PolInSAR Data"

A sparse pine forest is investigated at X-band on a single-pass polarimetric synthetic aperture radar interferometry (PolInSAR) data set using HH and HV channels. These first preliminary results show that the associated phase centers present a significant vertical separation (about 6 m) allowed by penetration through gaps in the canopy. Forest parameter inversion using the random volume over ground (RVoG) model is evaluated and adapted at this frequency. The forest height can be retrieved accurately by supposing a high mean extinction coefficient (around 1.6 (dB/m). The penetration depth is estimated to be around 4 m, based on the forest height ground measurements. Finally, a time-frequency analysis using a sublook decomposition is performed to increase the vertical separation of the polarimetric phase centers. As a consequence, RVoG-inversion performance is improved, and a penetration depth that is in better accordance with a previous work (of the order of 2 m) is found. This paper has shown that the height inversion of a pine forest was possible using PolInSAR X-band data and that the performance was more dependent on the forest density than at lower frequencies. [J651]

"Model-Associated Forest Parameter Retrieval Using VHF SAR Data at the Individual Tree Level"

A simple statistical extension at the individual tree level for an earlier-developed very high frequency forest backscatter model is proposed. This extended model treats trunk volumes as random quantities. A concept of random forest reflection coefficient is also introduced to characterize radar returns from individual trees. Based on the extended model, a set of algorithms for estimating the mean trunk (stem) volume from synthetic aperture radar data at the individual tree level is developed assuming that the areal tree density is known. The algorithms are specified for different scenarios related to a prioriinformation on parameters of statistical distributions for the trunk volume and fluctuations of the forest reflection coefficient. An approximate lower bound on the standard deviation in the unbiased estimation of the mean trunk (stem) volume is proposed. This bound can be readily obtained by means of computer simulation for any specified statistical distribution for the trunk volume and fluctuations of the forest reflection coefficient. Performance analysis for the proposed algorithms is numerically performed by means of Monte Carlo simulation for a variety of scenarios. This analysis has shown that the algorithms provide nearly unbiased and efficient estimates, and the proposed lower bound is a very accurate approximation. The results of the study have demonstrated that the approach and methods developed in this paper suggest promising solutions in accurate forest parameter retrieval. [J652]

"Improving Coherence of Complex Image Pairs Obtained by Along-Track Bistatic SARs Using Range-Azimuth Prefiltering"

An along-track interferometric synthetic aperture radar (SAR) can be used for ground moving target indication (GMTI) by comparing two SAR images obtained at different observation times. Different geometries of the two observations bring the decorrelation noise, which will degrade the detection performance. For bistatic SARs, the decorrelation theory is quite different from that for monostatic ones. This paper deals with the coherence between two complex SAR images formed by two along-track bistatic SARs with different baseline lengths. Using the single scattering model, the coherence between the two echoes collected by the two receivers is investigated, and the full-coherence conditions are derived. Then, a new method based on range-azimuth

prefiltering is proposed to improve the coherence of complex image pairs. As the precise prefiltering is complicated, its three approximate implementations are given. The effects of prefiltering on SAR images are also analyzed. Finally, simulation results validate the effectiveness of the proposed method. [J653]

"Matching-Pursuit-Based Analysis of Moving Objects in Polarimetric SAR Images"

This letter deals with the analysis of moving and nonstationary objects in already focused synthetic aperture radar (SAR) images. A method based on the matching pursuit (MP) algorithm is proposed to decompose the SAR signal into a set of atoms. A model of a moving object response with frequency- and angle-dependent reflectivity is introduced to design the MP atoms. Each selected atom is associated to a scatterer of the scene and is parameterized by relevant physical descriptors, leading to a multidimensional model of the object. The efficiency of this technique is demonstrated in terms of SAR response refocusing and physical parameter map derivation, using a polarimetric SAR image of a moving object lying in a natural background. [J654]

"Autofocus for ISAR Imaging Using Higher Order Statistics"

Autofocus is imperative for inverse synthetic aperture radar (ISAR) imaging. In this letter, a new approach for ISAR autofocus is developed by using fourth-order statistics properties of the radarpsilas return signal. After the ISAR signal model is established, the approach is described. The results of processing real data confirm the effectiveness of the proposed approach and show its capability for suppressing noise. The developed approach has a numerical stability and a smaller computational load compared with the maximum image contrast and the minimum image entropy methods. [J655]

"Accuracy of the -Distribution Regression Model for Forest Biomass Estimation by High-Resolution Polarimetric SAR: Comparison of Model Estimation and Field Data"

In our previous regression model for estimating forest biomass, it was shown that non-Gaussian amplitude fluctuations in high-resolution polarimetric synthetic aperture radar (SAR) data of coniferous forests can accurately be described by the -distribution and that the order parameter of the -distribution can be useful in estimating the tree biomass of coniferous forests from L-band cross-polarization amplitude images in a wider range than the conventional method using the radar cross section alone. The result was based on the analysis of the ldquoground-truthrdquo biomass data of 19 forest stands and airborne polarimetric interferometric SAR L-band data over the Tomakomai forests in Hokkaido, Japan. From this relation, an empirical regression model was developed to estimate forest biomass from SAR data. In this paper, we report the results on further analyses of this regression model. The validity of the -distribution is first reconfirmed using the Akaike information criterion, followed by the description on the accuracy of the model. To examine model accuracy, we carried out further field measurements on 22 forest stands in 2005, and the ground survey was made in 2006 to find out the causes of several anomalous data. Based on a comparison of the model-based biomass and the ground-truth data, the accuracy of the model was found to be approximately 86%. The regression model was then updated for practical application in estimating the biomass of the Hokkaido forests by including the ground-truth data of all 41 forest stands. [J656]

"Simultaneous Least Squares Adjustment of Multiframe Velocities Derived From Interferometric and Speckle-Tracking Methods"

This letter extends the simultaneous least squares adjustment method to the calibration and merging of velocity measurements, which are obtained by applying interferometric and speckle-tracking methods to multiple frames of repeat-pass interferometric synthetic aperture radar (InSAR) data. The underlying observation equations have been derived for velocity control points and tie points. By exploiting a set of tie points, individual frames within a strip or a block can be correlated with each other, and the parameters of calibration models for all individual frames can be simultaneously determined. With Radarsat InSAR data over the Recovery Glacier, Antarctica, we demonstrate that our simultaneous least squares adjustment method has effectively removed velocity discontinuities between adjacent frames and greatly reduced the velocity-control-point requirement. [J657]

"Processing of Envisat Alternating Polarization Data for Vessel Detection"

The alternating polarization (AP)-mode data from Envisat/Advanced Synthetic Aperture Radar (ASAR) can simultaneously generate two well-georegistered images in different polarizations, including VV/HH, HH/HV, and VV/VH combinations. This additional polarimetric information between channels is helpful for enhancing the accuracy of vessel detection. In this letter, different processing methods of AP single-look complex (APS) and precision (APP) data for vessel detection are investigated. For APS data, we propose a dual-polarization whitening fusion filter to combine dual-channel data and present its superiority to other traditional detectors. For

APP data, based on the distinct polarimetric properties of each polarization, we utilize different fusion methods for different polarization combinations, including a wavelets-based method for VV/HH and a simple product fusion method for the other two pairs including the cross-polarization channel (HV or VH). Finally, in the experiments, we use real Envisat AP data sets to verify the method, and the results of our proposed processing strategy indicate that it cannot only suppress the speckle and the sea clutter but also improve the vessel detection performance. [J658]

"Estimation of the Temporal Evolution of the Deformation Using Airborne Differential SAR Interferometry"

This paper presents airborne differential synthetic aperture radar (SAR) interferometry results using a stack of 14 images, which were acquired by the Experimental SAR system of the German Aerospace Center (DLR) during a time span of 2.5 h. An advanced differential technique is used to retrieve the error in the digital elevation model and the temporal evolution of the deformation for every coherent pixel in the image. The two main limitations in airborne SAR processing are analyzed, namely, the existence of residual motion errors (RMEs) (inaccuracies in the navigation system on the order of 1-5 cm) and the accommodation of the topography and the aperture dependence on motion errors during the processing. The coupling between them is also addressed, showing that the estimation of the differential RME, i.e., baseline error, can be biased when using techniques based on the coregistration between interferometric looks. The SAR focusing chain to process the data is also presented together with the modifications in the differential interferometry processor to deal with the remaining baseline error. The detected motion of a corner reflector and the measured deformation in several agricultural fields allows one to validate the proposed techniques. [J659]

"Analytic Search Method for Interferometric SAR Image Registration"

We propose an analytic search method for interferometric synthetic aperture radar (InSAR) image registration. An analytic cost function is established, and the subpixel offsets associated with the maximum of the cost function are continuously searched by direction-alternate optimization methods along vertical and horizontal directions. We establish a novel dual-quartic analytic cost function for extraction of subpixel offsets from a corresponding pixel pair established by pixel-level registration. A robust optimization method that is called biiteration algorithm for searching the maximum point of the dual-quartic cost function is developed to solve the subpixel offsets. Since the dual-quartic cost function is quartic if one of two parameters is fixed, one of two substeps including in each iterative step of the efficient biiterative method is to find the solution by the secant method. The performances of the proposed method are shown by using simulated and real data and compared with those of representative existing registration method. [J660]

"Urban Mapping Using Coarse SAR and Optical Data: Outcome of the 2007 GRSS Data Fusion Contest"

The 2007 data fusion contest that was organized by the IEEE Geoscience and Remote Sensing Data Fusion Technical Committee was dealing with the extraction of a land use/land cover maps in and around an urban area, exploiting multitemporal and multisource coarse-resolution data sets. In particular, synthetic aperture radar and optical data from satellite sensors were considered. Excellent indicators for mapping accuracy were obtained by the top teams. The best algorithm is based on a neural classification enhanced by preprocessing and postprocessing steps. [J661]

"Estimation of Radial Velocity of Moving Targets by Along-Track Interferometric SAR Systems"

Along-track interferometric synthetic aperture radar (AT-InSAR) can be used to estimate the radial velocity of ground moving targets, starting from interferometric phase measures. The estimation obtained from a single-phase interferogram suffers from ambiguities. To solve these problems, multichannel AT-InSAR systems are required. In this letter, we analyze the radial velocity maximum-likelihood estimation accuracy with respect to AT-InSAR system parameters, such as velocity values and different clutter and thermal noise levels. We consider two different models for the target response: a deterministic model and a zero-mean Gaussian model. The presented results show that AT-InSAR systems exhibit better estimation accuracies for low-velocity values (slow targets). [J662]

"Data-Level Fusion of Multilook Inverse Synthetic Aperture Radar Images"

Although techniques for resolution enhancement in single-aspect radar imaging have made rapid progress in recent years, it does not necessarily imply that such enhanced images will improve target identification or recognition. However, when multiple looks of the same target from different aspects are obtained, the available

knowledge increases, allowing more useful target information to be extracted. Physics-based image fusion techniques can be developed by processing the raw data collected from multiple inverse synthetic aperture radar sensors, even if these individual images are at different resolutions. We derive an appropriate data fusion rule to generate a composite image containing enhanced target shape characteristics for improved target recognition. The rule maps multiple data sets collected by multiple radars with different system parameters on to the same spatial-frequency space. The composite image can be reconstructed using the inverse 2-D Fourier transform over the separated multiple integration areas. An algorithm called the Matrix Fourier Transform is proposed to realize such a complicated integral. This algorithm can be regarded as an exact interpolation such that there is no information loss caused by data fusion. The rotation centers need to be carefully selected to properly register the multiple images before performing the fusion. A comparison of the image attribute rating curve between the fused image and the spatially averaged images quantifies the improvement in the detected target features. The technique shows considerable improvement over a simple spatial averaging algorithm and thereby enhances target recognition. [J663]

"Motion error correction of range migration algorithm for aircraft spotlight SAR imaging"

Since a motion error is the main phase error source in the aircraft synthetic aperture radar, several reconstruction algorithms with motion error correction have been developed. An efficient motion compensation via the known motion error information is proposed. Specifically, the proposed method is based on the subarea technique with shifting and the subaperture technique via the mean values of the motion errors. Then, using the extended Taylor approximation and the principle of the stationary phase, the motion errors are corrected through compensation at the mixing stage and the Stolt interpolation stage. [J664]

"The Hybrid CramЙr-Rao Bound on Broadside DOA Estimation of Extended Sources in Presence of Array Errors"

In this correspondence we derive explicit expressions for the hybrid Cramer-Rao lower bound (HCRB) on the estimation accuracy of signal direction of arrival (DOA) from data collected by randomly perturbed arrays. The presence of a wavefront spatial decorrelation, which is modeled as a multiplicative correlated noise, has also been taken into account in the data model, since it is typical in those applications involving extended sources. In particular, we consider perturbations in sensor positions. Existing approaches to DOA HCRB calculation do not consider the presence of multiplicative noise and are referred to the assumption of small perturbations only, still not being worked out explicitly. Here, we assume that the impinging wavefronts are coming from broadside or more generally from a narrow DOA sector, allowing the explicit derivation of the HCRB for any variance of the sensor positioning errors in the line-of-sight direction. This scenario corresponds to the typical operative condition of remote sensing systems such as synthetic aperture radar (SAR) multibaseline interferometers, for which a few HCRB sample curves are reported. [J665]

"Response to “Corrections to ‘Calibration of Linearly Polarized Polarimetric SAR Data Subject to Faraday Rotation’” [Jorig. paper Aug 04 1617-1624]"

Provides a response to the corrections submitted (vol. 46, no. 4, p. 1278, Apr 08) to the original article. [J666]

"A New Adaptive Multiresolution Noise-Filtering Approach for SAR Interferometric Phase Images"

This letter presents a novel adaptive multiresolution technique to estimate the local fringe frequency in synthetic aperture radar (SAR) interferometric phase images. According to the coherent summation principle, the size and the shape of the interferogram spatial resolution for local frequency estimation are adapted pixel by pixel to track the topographic changes and optimize the space-frequency resolution. We show that, comparing conventional filters with the processing window of a fixed size (such as 7 times 7) and shape (such as a square), the proposed approach avoids the loss of phase fringes and provides a more accurate representation of the scene topography. In this letter, we present a method to eliminate invalid frequency estimation. A fast frequency estimation approach modified from the method proposed by Trouve et al. is also shown. Finally, both simulated data and actual SAR data are utilized to illustrate the effectiveness of the proposed method. [J667]

"Using SAR Images to Detect Ships From Sea Clutter"

An innovative constant false alarm rate (CFAR) algorithm was studied for ship detection using synthetic aperture radar (SAR) images of the sea. Two advances were achieved. An alpha-stable distribution rather than a traditional Weibull or -distribution was used to model the distribution of sea clutter. The distribution of sea clutter in a SAR image was typically heterogeneous, caused mainly by variable wind and current conditions. Image segmentation was carried out to improve the homogeneity of the distribution in each subimage or region. In

comparison with ship detection using the CFAR algorithms based on the Weibull or K -distribution, our algorithm detected the most number of ships with the smallest number of false alarms. [J668]

"Brightness Temperature Map Reconstruction from Dual-Polarimetric Visibilities in Synthetic Aperture Imaging Radiometry"

Synthetic aperture imaging radiometers are powerful sensors for high-resolution observations of the Earth at low microwave frequencies. Within this context, the European Space Agency is currently developing the soil moisture and ocean salinity (SMOS) mission devoted to the monitoring of SMOS at global scale from L-band spaceborne radiometric observations obtained with a 2-D interferometer. This paper is concerned with the reconstruction of radiometric brightness temperature maps from interferometric measurements. More exactly, it extends the concept of ldquoband-limited resolving matrixrdquo to the case of the processing of dual-polarimetric data. [J669]

"Genetic SVM Approach to Semisupervised Multitemporal Classification"

The updating of classification maps, as new image acquisitions are obtained, raises the problem of ground-truth information (training samples) updating. In this context, semisupervised multitemporal classification represents an interesting though still not well consolidated approach to tackle this issue. In this letter, we propose a novel methodological solution based on this approach. Its underlying idea is to update the ground-truth information through an automatic estimation process, which exploits archived ground-truth information as well as basic indications from the user about allowed/forbidden class transitions from an acquisition date to another. This updating problem is formulated by means of the support vector machine classification approach and a constrained multiobjective optimization genetic algorithm. Experimental results on a multitemporal data set consisting of two multisensor (Landsat-5 Thematic Mapper and European Remote Sensing satellite synthetic aperture radar) images are reported and discussed. [J670]

"Signal Processing Issues for the Exploitation of Pulse-to-Pulse Encoding SAR Transponders"

Synthetic aperture radar signal processing issues related to the exploitation of a pulse-to-pulse encoding transponder using pseudorandom codes discussed analytically. Namely the focusing algorithm, the code synchronization procedure and the properties of the code induced gain against non-encoding point scatterers and distributed ones. A time-domain processing algorithm and a code synchronization procedure are proposed and validated on simulated data and on a European Remote Sensing Satellite-2 data set containing prototypes of such a device. The interaction of the transponder signal with terrain backscattering is analyzed by deriving parameters that are useful for performance assessment. These are related to the relevant parameters in radiometric calibration, interferometric applications, and tagging. [J671]

"Using a Grid-Based Filter to Solve InSAR Phase Unwrapping"

This letter presents a phase-unwrapping (PU) algorithm for synthetic aperture radar interferometry based on a grid-based filter. The proposed PU algorithm, which is based on state-space techniques, simultaneously performs noise filtering and PU. The formulation of this technique provides independence from noise statistics and is not constrained by the nonlinearity of the problem. Results obtained with synthetic data show a significant improvement with respect to other conventional PU algorithms in some situations. [J672]

"Corrections to “Calibration of Linearly Polarized Polarimetric SAR Data Subject to Faraday Rotation” [JAug 04 1617-1624]"

In the above titled paper (ibid., vol. 42, no. 8, pp. 1617-1624, Aug 04), Equation (15) has an error. Corrections are presented here. [J673]

"Three-Dimensional Stereo Reconstruction of Buildings Using Polarimetric SAR Images Acquired in Opposite Directions"

Polarimetric synthetic aperture radar (SAR) images describe objects via polarization synthesis and present much richer information than monopolarized SAR images. Furthermore, multidirectional flights of polarimetric SAR can see 3-D stereo objects in different angles. The height and the location of the 3-D objects can be retrieved from the polarimetric SAR images in multidirectional flights. This letter presents a tractable approach for the reconstruction of 3-D stereo buildings from two airborne PI-SAR images taken from opposite directions (at X-band with a spatial resolution of 1.5 m). [J674]

"Radar Polarization Orientation Shifts in Built-Up Areas"

Polarization orientation angle shifts can be seen not only in rugged terrain areas but also in urban areas. The latter is explained by backscatter from a wall of a building or house, which is equivalent to a tilted ground-surface patch. From the scattering model of built-up areas, the polarization orientation angle shift in the built-up areas is given as, where is the wall or street orientation angle, and is the radar incidence angle. Japan Aerospace Exploration Agency Pi-SAR L-band polarimetric data of Gifu, Japan, show a good agreement with the theory. The phase difference between VH and HH polarizations is used to demonstrate the contribution of double-bounce scattering ground-wall and wall-ground over a wide range of wall orientation angles. [J675]

"Receiver Operating Characteristic Curve Confidence Intervals and Regions"

Many researchers have presented results showing the empirical performance of target detection algorithms using hyperspectral or synthetic aperture radar imagery. In nearly all cases, these probabilities of detection and false alarm are presented as precise values as opposed to their true nature as estimates of random values. In this letter, we provide analytical tools and examples of computing confidence intervals and regions around these estimates commonly presented as points on receiver operating characteristic (ROC) curves. It is suggested that these tools be adopted by researchers when presenting their results to provide their audience with a quantitative metric for proper interpretation of empirically estimated ROC curves. [J676]

"A Method to Extend the Estimation Range of the Existing Time-Domain Doppler Centroid Estimators"

In this letter, we use the summation-by-parts formula as a simple tool to extend the estimation range of a certain class of the already existing correlation-based Doppler centroid estimators. The resulting estimators are as robust as the original ones but cover a much larger estimation range of about 50% of the pulse-repetition frequency. Two examples with simulations are provided to demonstrate the benefits of the proposal. [J677]

"A Stationary Wavelet-Domain Wiener Filter for Correlated Speckle"

In this paper, we develop a Wiener-type speckle filter that operates in the stationary wavelet domain. We denote it as the stationarywavelet-domainWiener(SWW) speckle filter. We assume that both the speckle-free image and the speckle contribution have spatial correlations and utilize well-established models for the power density spectrum of the radar cross section to estimate the autospectra that define the filter. It turns out that the filter is independent of the wavelet-domain scale level, i.e., the filter is the same at all scale levels. The SWW filter works on nonoverlapping blocks in the wavelet domain, which are obtained by a quadtree algorithm. Due to the dyadic support of the wavelet coefficients, a natural smoothing is carried out on the boundaries between neighboring blocks, and no visual boundary effects can be observed. The SWW filter is unbiased and shows good performance in despeckling synthetic aperture radar (SAR) images. It smooths homogeneous areas while preserving textured areas and point scatterers. In contrast to most other speckle filters, the SWW filter requires the SAR data to be given in single-look complex form. [J678]

"A Tunable Closed-Form Model for the Structure Function of Tropospheric Delay"

Several interferometric synthetic aperture radar applications could benefit from the availability of a closed-form model for the second-order statistics of atmospheric delay. Due to the variability of the latter, it would also be desirable for the model to be tunable to some acquisition-specific information, describing the atmospheric state. In this letter, a closed-form expression for the zenith delay structure function of tropospheric propagation delay is derived from a two-regime power spectral density function reported in the literature. The power at a specific spatial frequency is used as a free model parameter, which may be tuned to available measurements or, in the absence of these, to atmospheric statistics. The latter approach is used to compare the derived model with previously published results. [J679]

"Doppler Keystone Transform: An Approach Suitable for Parallel Implementation of SAR Moving Target Imaging"

In this letter, a synthetic aperture radar (SAR) data reformatting approach named Doppler keystone transform (DKT) is proposed to correct the range migration of a moving target. By using the DKT, the SAR imaging program, i.e., the 2-D matched filtering, can be transformed into separate 1-D operations along range or azimuth direction, and therefore, the DKT is suitable for the parallel implementation of SAR imaging of the moving target. Our simulations show that by combining the DKT and the Doppler phase compensation methods, the moving target can be well imaged in high signal-clutter-ratio case. [J680]

"Conditioning Water Stages From Satellite Imagery on Uncertain Data Points"

Observed spatially distributed water stages with uncertainty are of considerable importance for flood modeling and management purposes but are difficult to collect in the field during a flood event. Synthetic aperture radar (SAR) remote sensing offers an inviting alternative to provide this kind of data. A straightforward technique to derive water stages from a single SAR flood image is to extract heights from a digital elevation model at the flood boundaries. Schumann et al. have presented a regression modeling approach as an improvement to this simple technique. However, regression modeling associated with their model may restrict output to mapping purposes rather than extend it to integration with other data or models. This letter introduces an inviting alternative that conducts statistical analysis on river cross-sectional data points, thereby allowing uncertainty assessment of remote-sensing-derived water stages without any regression modeling constraint. This renders remote-sensing data fit for, e.g., flood inundation model evaluation with uncertainty in observations and data assimilation studies, where (linear) ldquotransformation,rdquo i.e., modeling, to observed data should be minimal. [J681]

"Using Multibaseline InSAR to Recover Layovered Terrain Considering Wideband Array Problem"

This letter deals with the problems of retrieving height and synthetic aperture radar (SAR) reflectivity of layovered terrain using multibaseline SAR interferometry (InSAR). In particular, we focus on the wideband array problem caused by practically large InSAR arrays and high-resolution SAR images, i.e., the problem of signal envelope misalignment, which is neglected in the work by Gini We propose two methods to eliminate or mitigate the effect of envelope misalignment, one called the aligning method and the other called the joint range cell processing method. In the aligning method, we align each signal envelope for each searched height of the layovered components (i.e., ground resolution cells with different altitudes) during searching procedure. The joint range cell processing method jointly processes the neighboring cells in range to estimate the parameters of layovered components so that the effect of the envelope misalignment can be mitigated. Theoretical analysis and computer simulation results show that both methods have the ability to provide accurate estimation of the heights and radar reflectivities of multiple layovered resolution cells in the presence of large envelope misalignments. [J682]

"Ground Moving Target Indication With Tandem Satellite Constellations"

Ground moving target indication (GMTI) from space by existing dual-channel radar systems such as TerraSAR-X and RADARSAT-2 has been shown to perform only insufficiently with respect to the relocation error of targets to their true ground position. Only two parallel receiver channels are too little to suppress the severe ground clutter and to estimate the target's parameters. Although this deficiency may partly be alleviated through antenna aperture switching, the resulting positioning accuracy is still not adequate for effective traffic monitoring purposes. Satisfactory results are only achievable with extended apertures, primarily with satellite constellations. This letter presents a statistical analysis of the performance of different concepts for cooperating back-to-back flying satellite systems. Particularly in anticipation of TanDEM-X, which will form the first operational GMTI-capable coherent synthetic aperture radar constellation after its launch in 2009. [J683]

"3-D SAR Tomography: The Multibaseline Sector Interpolation Approach"

Multibaseline (MB) synthetic aperture radar (SAR) tomography is a promising mode of SAR interferometry, allowing full 3-D imaging of volumetric and layover scatterers in place of a single elevation estimation capability for each SAR cell However, Fourier-based MB SAR tomography is generally affected by unsatisfactory imaging quality due to a typically low number of baselines with irregular distribution. In this paper, we improve the basic elevation focusing technique by reconstructing a set of uniform baselines data exploiting in the interpolation step the ancillary information about the extension of a height sector which contains all the scatterers. This aprioriinformation can be derived from the knowledge of the kind of the observed scenario (e.g., forest or urban). To demonstrate the concept, an imaging enhancement analysis is carried out by simulation. [J684]

"On the Mueller Scattering Matrix for SAR Sea Oil Slick Observation"

In this letter, a fully polarimetric electromagnetic model for sea surface Mueller matrix is exploited to characterize the scattering from oil and biogenic slicks, under low-to-moderate wind conditions. The model predicts a completely different scattering mechanism for oil-covered and oil-free sea surface, while biogenic slicks are indistinguishable from sea surface in terms of polarimetric scattering. Following this theoretical rationale, a simple and very effective filtering technique is proposed for synthetic aperture radar (SAR) sea oil slick observation. Experiments, accomplished over C-band multilook complex SIR-C/X-SAR data, show the effectiveness of the proposed model and the capabilities of the filter to both observe oil slicks and distinguish them from biogenic look-alikes. [J685]

"Quaternion-Based Transformation for Extraction of Image-Generating Doppler for ISAR"

Inverse synthetic aperture radar (ISAR) is an imaging technique that is dependent on an object's rotational motion over a coherent processing interval. Maritime vessels and aircraft possess 3-D rotational motion, whereas it is only their ISAR contributing motion that is useful to the ISAR imaging process; the contributing motion consists of the Doppler generating axis and the effective angle of rotation. This letter presents a quaternion-based transformation that converts measured attitude and position data into an object's Doppler generating axis and effective angular rotation rate. This transformation is significant since it isolates the component of the motion that directly influences the ISAR image. It provides an alternative approach that can be used to understand the causes of blurring of most ISAR images of sea vessels as well to identify good imaging intervals for applications such as cooperative ISAR for radar cross section measurement purposes. [J686]

"Estimation of Ship Radial Speed by Adaptive Processing of RADARSAT-1 Fine Mode Data"

This letter describes a new method for estimating the radial component of a ship's velocity using single-channel synthetic aperture radar data acquired by RADARSAT-1. Unlike previous methods, this approach is applicable in the absence of any visible wakes. Experimental results confirm the robustness of the proposed algorithm. [J687]

"Comparison of Processing Algorithms for a Delay/Doppler Altimeter"

The use of a radar altimeter is to measure the height of the reflecting surface when the instrument passes overhead. A delay/Doppler altimeter (DDA) reduces the along-track resolution cell using correlation of pulses within burst, as in a synthetic aperture radar, with the net effect of synthesizing an array with a narrower lobe. The processing of DDA data therefore implies the correction of the phase delay of pulses, which is said to be Dopplerbeamsharpeningsince it can be reduced to a DFT in the along-track direction. The noise term on Doppler echoes is decreased by incoherent summing of contributions of different bursts. Summation of these contributions requires that pointing of each beam is directed toward a given output grid of samples on ground, and this can be a nontrivial task, depending on the topography profile. In this letter, a comparison between different beam sharpening algorithms is presented: Two of them are similar in their basic idea even if with different implementations; the third one can be considered as reference since no approximations are needed in principle, but is computationally inefficient. What results is that the first couple can be considered basically equivalent in terms of precision and computational efficiency, with little differences at the change of the environmental conditions. Results based on simulated data of simple and complex scenarios are presented as support of the reasoning. [J688]

"Level Set Method for SAR Image Coregistration"

In this letter, a novel approach for the coregistration of synthetic aperture radar (SAR) images is proposed based on the level set method. The features of regions are detected by segmenting the images, and the images are coregistered by matching the detected features. The energy functional of level sets is formulated with respect to detecting and matching features. The coregistration is achieved by minimizing the energy functional. Compared with the conventional tie-patch method, the results on a series of simulated experiments and real SAR data demonstrate the feasibility of the proposed approach. [J689]

"Region-Based Classification of Polarimetric SAR Images Using Wishart MRF"

The scattering measurements of individual pixels in polarimetric SAR images are affected by speckle; hence, the performance of classification approaches, taking individual pixels as elements, would be damaged. By introducing the spatial relation between adjacent pixels, a novel classification method, taking regions as elements, is proposed using a Markov random field (MRF). In this method, an image is oversegmented into a large amount of rectangular regions first. Then, to use fully the statistical aprioriknowledge of the data and the spatial relation of neighboring pixels, a Wishart MRF model, combining the Wishart distribution with the MRF, is proposed, and an iterative conditional mode algorithm is adopted to adjust oversegmentation results so that the shapes of all regions match the ground truth better. Finally, a Wishart-based maximum likelihood, based on regions, is used to obtain a classification map. Real polarimetric images are used in experiments. Compared with the other three frequently used methods, higher accuracy is observed, and classification maps are in better agreement with the initial ground maps, using the proposed method. [J690]

"Multiple-Component Scattering Model for Polarimetric SAR Image Decomposition"

A multiple-component scattering model (MCSM) is proposed to decompose polarimetric synthetic aperture radar (PolSAR) images. The MCSM extends a three-component scattering model, which describes single-bounce, double-bounce, volume, helix, and wire scattering as elementary scattering mechanisms in the analysis of PolSAR images. It can be found that double-bounce, helix, and wire scattering are predominant in urban areas. These elementary scattering mechanisms correspond to the asymmetric reflection condition that the copolar and

cross-polar correlations are not close to zero. The MCSM is demonstrated with a German Aerospace Center (DLR) Experimental Synthetic Aperture Radar (ESAR) L-band full-polarized image of the Oberpfaffenhofen Test Site Area (DE), Germany, which was obtained on September 30, 2000. The result of this decomposition confirmed that the proposed model is effective for analysis of buildings in urban areas. [J691]

"Image-Quality Focusing of Rotating SAR Targets"

Synthetic aperture radar (SAR) is a popular tool for long-range imaging of stationary ground objects. Moving targets in the imaged scene will have a mismatch to the matched filter in the image formation process, thus degrading target image quality. In this letter, the impact of uncompensated target rotation in SAR imagery is studied. An efficient algorithm for image-quality-based target rotation correction is proposed. [J692]

"An Approach for Solving Rank-Deficient Systems That Enable Atmospheric Path Delay and Water Vapor Content Estimation"

This paper develops mathematical techniques and makes use of interferometric synthetic aperture radar (InSAR) for improving the quality of digital elevation models derived from SAR images and providing accurate estimations of atmospheric path and absolute phase delays and water vapor content estimation. The problem of solving parameters such as atmospheric path delay, height, and unwrapping errors is to be described in a mathematical form that uses QR factorization techniques for solving rank-deficient systems. A new approach for the solution of rank-deficient systems with few independent equations is proposed. In the new approach, the bounds are considered known and provided by the eigenvalues. New eigenvalues are added inside the bounds. During the implementation, attention is given not to exceed the bounds of the reorganized matrix. This approach is the first time that is used for phase parameterization in terms of height, tropospheric delay, and phase unwrapping errors. Expanding the approach was also studied for absolute phase delay and water vapor content estimation. The investigation and the implementation of the approach make use of ENVISAT images. The validation of results was implemented through GPS and meteorological measurements. [J693]

"Land Use and Land Cover Mapping in the Brazilian Amazon Using Polarimetric Airborne P-Band SAR Data"

In September 2000, an airborne synthetic aperture radar (SAR) mission acquired unprecedented full polarimetric P-band data over the Tapajos National Forest (Para State), which is an area in the Brazilian Amazon which has been continuously monitored in the last three decades. Eight land use/cover classes were identified, namely, primary forest, regeneration older than 25 years, regeneration between 12 and 25 years, regeneration between 6 and 12 years, regeneration younger than six years, crops/pasture, bare soil, and floodplain (FP). The objective of this paper is to analyze the potential of full polarimetric P-band data in distinguishing different land use/cover classes with a minimum established Kappa value of 75%, using the latest development on SAR statistical characterization. The iterated conditional mode (ICM) contextual classifier was applied to amplitude, intensity images, biomass index, and some polarimetric parameters (entropy, alpha angle, and anisotropy) extracted from the polarimetric P-band data. As the accuracy obtained for eight classes was not acceptable, another two sets, with five and four classes, were formed by the combination of the previous ones. They were defined by confusion matrix analysis and by the graphical analysis of average backscatter values, entropy, [alpha] angle, and anisotropy images and by the H/alpha plans of the land use samples. The classification accuracy with four classes (three levels of biomass plus FP) was then considered acceptable with a Kappa value of 76.81%, using the ICM classification with the adequate bivariate distribution for the HV and VV channels. [J694]

"Additional Corrections to “Unconstrained Inversion of Waveheight Spectra From SAR Image” [JFeb 02 261-270]"

Lyzenga's paper ("Unconstrained inversion of waveheight spectra from SAR images" IEEE Trans. Geosci. Remote Sens., vol. 40, no. 2, pp. 261-270, Feb. 2002) after being corrected (ibid., vol. 40, no. 3, p. 729, Mar. 2002) has still a few remaining errors. This paper presents the additional corrections. [J695]

"A Comparison of Algorithms for Retrieving Soil Moisture from ENVISAT/ASAR Images"

In this paper, we present an intercomparison of algorithms for retrieving soil moisture content (SMC) from ENVIronmental SATtellite (ENVISAT)/Advanced Synthetic Aperture Radar images. The algorithms taken into consideration were a feedforward artificial neural network (ANN) with two hidden layers, a statistical approach based on Bayes' theorem, and an iterative algorithm based on the nelder-mead direct-search method. The comparison was carried out by using both simulated and experimental data. Simulated data were obtained by means of the integral equation model (IEM). Experimental data were collected in an agricultural area in Northern

Italy during 2003-2005; they included backscattering coefficient at HH and HV polarizations and at an incidence angle of thetas = 23deg, as well as detailed ground truth measurements of SMC, surface roughness, and vegetation parameters. HH-polarized data were related to SMC, whereas the information of the cross-polarized channel was used to correct the backscatter for the effects of surface roughness. A comparison of the algorithms with experimental data showed that all the tested approaches produced SMC values that are very close to the measured ones. However, the predictions of the ANN were slightly more suitable than the other methods for generating maps in reasonable time. The production of moisture maps carried out at different dates using this algorithm pointed out the feasibility of separating up to six levels of spatial/temporal variations of SMC in the range of 10%-35%. [J696]

"Radar Bistatic Configurations for Soil Moisture Retrieval: A Simulation Study"

The possible contribution of bistatic radar measurements for bare soil moisture retrieval is investigated in this paper. A simulation study based on well-established electromagnetic models of rough surface scattering (both coherent and incoherent components) has been accomplished for this purpose. The retrieval accuracy has been evaluated by using both the Cramer-Rao lower bound and the error variance of a linear regression estimator, thus considering slightly different assumptions on retrieval conditions. Both methods have allowed us to identify the optimal system configurations in terms of observation directions, polarizations, and frequency. This identification has been carried out for single-polarization and multipolarization receivers and for the case in which bistatic measurements are complemented by monostatic ones, which are expected to be available through already-existing spaceborne synthetic aperture radars. The optimal systems have first been singled out by considering a Gaussian autocorrelation function (ACF) and a constant value of correlation length. Successively, the simulations for an exponential ACF and a variable correlation length have been analyzed, demonstrating that the results substantially remain the same. The comparison between the soil moisture estimation accuracy yielded by the optimal configurations and that provided by the standard monostatic radar has shown that a significant improvement in the quality of retrieval can be achieved by complementing bistatic and monostatic measurements. [J697]

"An Improved NLCS Algorithm With Capability Analysis for One-Stationary BiSAR"

This paper deals with the imaging problem of one-stationary bistatic SAR (BiSAR) with large bistatic angle. An improved nonlinear chirp scaling (NLCS) algorithm is proposed for this BiSAR. The main work here includes three aspects. First, a range chirp scaling function for correcting the differential range cell migration correction is derived. Then, the azimuth perturbation is generated by local fit method, which makes the NLCS algorithm suitable for the large bistatic angle case. Furthermore, the negative effects introduced by the perturbation (including phase error and locality error) are discussed, and some compensation methods are proposed to enhance the capability of the algorithm. The simulating results exhibited at the end of this paper validate the correctness of the analysis and the feasibility of the algorithm. [J698]

"Angular and Radiometric Resolution of Y-Shaped Nonuniform Synthetic Aperture Radiometers for Earth Observation"

MIRAS is the single payload of the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite mission, and it will be the first synthetic aperture radiometer for Earth observation from space. It consists of an array of 69 antennas uniformly spaced along three arms forming a Y-shaped antenna array. This work analyzes the angular resolution improvement, and the radiometric performance degradation when the spacing between antennas is geometrically increased. [J699]

"A Physical Full-Resolution SAR Ship Detection Filter"

Synthetic aperture radar (SAR) ship detection is an important application in the context of environment and security monitoring. It allows monitoring traffic, fisheries, and associating ships with oil discharge over wide areas with high spatial resolution almost independently from weather conditions and both day and night time. Since full-resolution SAR images are heavily affected by the presence of speckle, ship detection algorithms generally employ speckle reduced SAR images at the expense of a degradation of the spatial resolution. A new physical approach, which considers ships as dominant scatterers and, therefore, responsible for a strong and coherent backscattered signal, is here proposed. Based on this rationale, a new simple and very effective filtering technique, which is able to process full-resolution SAR images, has been conceived and implemented. Experiments, accomplished over C-band European Remote Sensing satellite (ERS) 1/2 single-look complex SAR images, show the effectiveness of the proposed approach. [J700]

"Averaging and Formulation Impact on GB-SAR Topographic Mapping"

A novel processor for the generation of a digital terrain model (DTM) using ground-based synthetic aperture radar (GB-SAR) imagery is presented. The performance of the processor has been assessed using the archive of C-band GB-SAR images available at the Joint Research Centre from the Sion Valley (CH) test site, from which a high-resolution ground-truth DTM is available. In order to reduce the standard deviation of the differences between the two DTMs, several techniques have been applied: interferogram averaging, phase referencing, and differential path calibration. In addition, different formulations have been reviewed, and its impact has been quantified in the DTM accuracy obtained. Results show that the standard deviation of the differences between the ground-truth DTM and that of the C-band GB-SAR can be reduced from the 5 m that was previously reported down to 3 m with the new processor. [J701]

"Theory and Application of Motion Compensation for LFM-CW SAR"

Small low-cost high-resolution synthetic aperture radar (SAR) systems are made possible by using a linear frequency-modulated continuous-wave (LFM-CW) signal. SAR processing assumes that the sensor is moving in a straight line at a constant speed, but in actuality, an unmanned aerial vehicle (UAV) or airplane will often significantly deviate from this ideal. This nonideal motion can seriously degrade the SAR image quality. In a continuous-wave system, this motion happens during the radar pulse, which means that existing motion compensation techniques that approximate the position as constant over a pulse are limited for LFM-CW SAR. Small aircraft and UAVs are particularly susceptible to atmospheric turbulence, making the need for motion compensation even greater for SARs operating on these platforms. In this paper, the LFM-CW SAR signal model is presented, and processing algorithms are discussed. The effects of nonideal motion on the SAR signal are derived, and new methods for motion correction are developed, which correct for motion during the pulse. These new motion correction algorithms are verified with simulated data and with actual data collected using the Brigham Young University muSAR system. [J702]

"Metamorphic HEMT MMICs and Modules for Use in a High-Bandwidth 210 GHz Radar"

In this paper, we present the development of advanced W-band and G-band millimeter-wave monolithic integrated circuits (MMICs) and modules for use in a high-resolution radar system operating at 210 GHz. A W-band frequency multiplier by six as well as a subharmonically pumped 210 GHz dual-gate field-effect transistor (FET) mixer and a 105 GHz power amplifier circuit have been successfully realized using our 0.1 mum InAlAs/InGaAs based depletion-type metamorphic high electron mobility transistor (mHEMT) technology in combination with grounded coplanar circuit topology (GCPW). Additionally, a 210 GHz low-noise amplifier MMIC was fabricated using our advanced 0.05 mum mHEMT technology. To package the circuits, a set of waveguide-to-microstrip transitions has been realized on 50 mum thick quartz substrates, covering the frequency range between 75 and 220 GHz. The presented millimeter-wave components were developed for use in a novel 210 GHz radar demonstrator COBRA-210, which delivers an instantaneous bandwidth of 8 GHz and an outstanding spatial resolution of 1.8 cm. [J703]

"Synthetic Aperture Hitchhiker Imaging"

We introduce a novel synthetic-aperture imaging method for radar systems that relies on sources of opportunity. We consider receivers that fly along arbitrary, but known, flight trajectories and develop a spatio-temporal correlation-based filtered-backprojection-type image reconstruction method. The method involves first correlating the measurements from two different receiver locations. This leads to a forward model where the radiance of the target scene is projected onto the intersection of certain hyperboloids with the surface topography. We next use microlocal techniques to develop a filtered-backprojection-type inversion method to recover the scene radiance. The method is applicable to both stationary and mobile, and cooperative and noncooperative sources of opportunity. Additionally, it is applicable to nonideal imaging scenarios such as those involving arbitrary flight trajectories, and has the desirable property of preserving the visible edges of the scene radiance. We present an analysis of the computational complexity of the image reconstruction method and demonstrate its performance in numerical simulations for single and multiple transmitters of opportunity. [J704]

"Some Reflections on Bistatic SAR of Forward-Looking Configuration"

Forward-looking imaging has many potential applications, but it is impossible with the usual monostatic synthetic aperture radar (SAR) principle. Through the bistatic SAR configuration, forward-looking imaging can be realized for one of the bistatic platforms. This letter designs a bistatic configuration with a stationary transmitter and a forward-looking airborne receiver. It then analyzes the 2-D resolution and finds out which geometric parameter affects the imaging ability mostly. Besides, it gives out the signal formulation in the frequency domain and shows its imaging characteristics. Then, an imaging method is chosen for this special configuration, and the simulation results are exhibited, which validate the correctness of the analysis and prove the 2-D imaging ability of forward-

looking bistatic SAR. [J705]

"Imaging of Micromotion Targets With Rotating Parts Based on Empirical-Mode Decomposition"

For micromotion targets with rotating parts, the inverse synthetic-aperture-radar image of the main body may be shadowed by the micro-Doppler. To solve this problem, this paper proposes an imaging algorithm based on the complex-valued empirical-mode decomposition. First, the radar echoes are decomposed into a series of complex-valued intrinsic-mode functions (IMFs). Then, the IMFs from the rotating parts and those from the main body are separated according to the characteristics of their zero-crossings. Finally, the well-focused imaging of the main body via traditional imaging algorithm and the accurate parameter estimation of the rotating part can be obtained. Both the imaging results for the simulated and measured data are given to verify the validity of the proposed algorithm. [J706]

"Squint LFMCW SAR Data Processing Using Doppler-Centroid-Dependent Frequency Scaling Algorithm"

A linear frequency-modulated continuous-wave (LFMCW) synthetic aperture radar (SAR) is a highly miniaturized SAR that is suitable for use on a small unmanned aerial vehicle. In squint stripmap mode, the LFMCW SAR image quality is degraded by the presence of nonlinearities in the transmitted signal, combined with the large bandwidth introduced by the frequency scaling in the nonlinear frequency scaling (NLFS) algorithm. This paper proposes an extension of the NLFS algorithm called the Doppler-centroid-dependent frequency scaling algorithm. The algorithm introduces a new Doppler-centroid-dependent scaling factor to decrease the introduced bandwidth, effectively removing the range frequency aliasing, without extra computational load. Nonlinearity correction is performed at the same time as range cell migration correction. The validity of the proposed algorithm is demonstrated with point target simulation results. [J707]

"Model-Based Polarimetric SAR Speckle Filter"

In this paper, a new framework to filter speckle noise in polarimetric synthetic aperture radar (PolSAR) data is presented. The proposed filter, named the model-based PolSAR (MBPolSAR) filter, is based on exploiting the multiplicative-additive speckle noise model for multidimensional SAR data. The entries of the sample covariance matrix are processed according to this multiplicative-additive speckle noise model as a function of the complex correlation coefficient. Hence, the covariance matrix elements are processed differently. This filtering scheme improves the reduction of speckle noise and ameliorates the estimation of the polarimetric information. The filtering performances of the MBPolSAR approach are first tested quantitatively by means of simulated PolSAR data. In a second stage, they are evaluated by means of experimental SAR data acquired by the Deutsches Zentrum fu umlr Luft-und Raumfahrt. [J708]

"Parametric Velocity Synthetic Aperture Radar: Multilook Processing and Its Applications"

Based on a parametric model and some optimum methods, it has been previously proved that parametric velocity synthetic aperture radar (VSAR) may improve the performances of moving target detection and parameter estimation simultaneously. In this paper, multilook processing is studied for parametric VSAR. At first, statistical signal models are established for azimuth multilook processing (AMLP) and range multilook processing (RMLP), respectively. By combining the multiple AMLP sublook pixel vectors, it is shown that the clutter parameter estimation accuracy can be further improved via the maximum-likelihood estimation methods. Meanwhile, based on the adaptive implementation for the optimum processing of VSAR, RMLP can be used to improve slowly moving target detection performance via the noncoherent integration of multiple range sublooks. Furthermore, it is shown that the Doppler frequencies of moving targets vary linearly with different range sublooks due to the different carrier frequencies of sublooks. Therefore, based on a proposed novel two-step multilook diversity (TS-MLD) estimator for RMLP, the "azimuth location ambiguity" of VSAR can be well resolved via least squares linear regression, without configuration change of the conventional VSAR. Also, the estimation accuracy of target's unambiguous Doppler frequency, as well as target's azimuth location, is derived for the proposed TS-MLD method. Finally, numerical experiments and scene simulations are provided to demonstrate the effectiveness of the proposed multilook-based methods. [J709]

"Phase Synchronization and Doppler Centroid Estimation in Fixed Receiver Bistatic SAR Systems"

This paper discusses temporal and phase synchronization in bistatic synthetic aperture radar (SAR) systems that use orbital sensors as coherent sources of opportunity and receivers at a fixed location. The discussion is particularized to SAR Bistatic Receiver for INterferometric Applications (SABRINA), a ground-based bistatic receiver that uses ENVISAT and ERS-2 as transmitters. Transmitter-receiver synchronization is hindered by the presence of independent reference oscillators at the transmit and receive end and by the lack of a common time

frame. Phase synchronization and pulse alignment are achieved using a dedicated channel that receives a clean signal directly from the satellite. How to align the acquired data with the satellite orbit and how to estimate the Doppler centroid (DC) are studied. It is shown that in the bistatic configuration considered, the receiver provides an implicit control point which limits the negative impact of a DC misestimation on the resulting images. An algorithm to achieve this temporal alignment using the apparent phase history of the received pulses is proposed. Finally, this algorithm is validated through Monte Carlo simulations and experimental data acquired by SABRINA. [J710]

"On the Exploitation of Target Statistics for SAR Interferometry Applications"

This paper focuses on multiimage synthetic aperture radar interferometry (InSAR) in the presence of distributed scatterers, paying particular attention to the role of target decorrelation in the estimation process. This phenomenon is accounted for by splitting the analysis into two steps. In the first step, we estimate the interferometric phases from the data, whereas in the second step, we use these phases to retrieve the physical parameters of interest, such as line-of-sight (LOS) displacement and residual topography. In both steps, we make the hypothesis that target statistics are at least approximately known. This approach is suited both to derive the performances of InSAR with different decorrelation models and for providing an actual estimate of LOS motion and topography. Results achieved from Monte Carlo simulations and a set of repeated pass ENVISAT images are shown. [J711]

"The wavenumber algorithm for full-matrix imaging using an ultrasonic array"

Ultrasonic imaging using full-matrix capture, e.g., via the total focusing method (TFM), has been shown to increase angular inspection coverage and improve sensitivity to small defects in nondestructive evaluation. In this paper, we develop a Fourier-domain approach to full-matrix imaging based on the wavenumber algorithm used in synthetic aperture radar and sonar. The extension to the wavenumber algorithm for full-matrix data is described and the performance of the new algorithm compared with the TFM, which we use as a representative benchmark for the time-domain algorithms. The wavenumber algorithm provides a mathematically rigorous solution to the inverse problem for the assumed forward wave propagation model, whereas the TFM employs heuristic delay-and-sum beamforming. Consequently, the wavenumber algorithm has an improved point-spread function and provides better imagery. However, the major advantage of the wavenumber algorithm is its superior computational performance. For large arrays and images, the wavenumber algorithm is several orders of magnitude faster than the TFM. On the other hand, the key advantage of the TFM is its flexibility. The wavenumber algorithm requires a regularly sampled linear array, while the TFM can handle arbitrary imaging geometries. The TFM and the wavenumber algorithm are compared using simulated and experimental data. [J712]

"Effect of standing stubble on radar backscatter from harvested rice fields"

The radar backscatter from standing rice stubble in a harvested rice field is computed numerically using the method of moments with the equivalence principle and impedance sheet theory. The radar backscatter from a bare surface is also computed based on an empirical model, and combined with the numerical results from the standing rice stubble. Based on the analyses of the radar backscatter for various conditions of standing stubble, it is found that the effect of the standing stubble in a typical harvested rice field is negligible when the water content of the stubble is less than about 40%. [J713]

"Simultaneous reduction of sidelobes and grating lobes by realising nonlinear synthetic wideband waveforms in SAR processing"

An alternative method of SAR signal processing which can be used to simultaneously reduce sidelobes and grating lobes of synthetic wideband waveforms (SWW) is proposed. The method applies the super spatially variant apodisation technique to each subpulse image of the SWW, and then cuts appropriate portions of the expanded spectra of the subpulses to effectively realise a nonlinear SWW with much better characteristics. [J714]

"Surface-Tracing-Based LASAR 3-D Imaging Method via Multiresolution Approximation"

This paper concerns the surface-tracing-based (STB) linear-array synthetic-aperture-radar (LASAR) 3-D imaging technique. The basic idea of this technique is to consider the 3-D SAR imaging problem as tracing a surface in the low height-resolution level. The STB 3-D imaging technique first initiates a low-resolution digital elevation map (DEM) using 3-D backprojection (BP) algorithm, predicts a higher resolution DEM from the known elevation using multivariate-interpolation technique, searches from the predicted elevation and obtains a higher resolution

DEM, then repeats the prediction and searching recursively and obtains the fine-resolution DEM finally. By converting the 3-D LASAR imaging problem to a 2-D surface-tracing problem, the STB 3-D imaging technique can reduce the computational complexity by one order. The computational cost of STB 3-D imaging technique is analyzed, and we find out that the computational cost of STB 3-D LASAR imaging technique is determined by the surface prediction error and the fluctuation of ground. In particular, for normal distribution, when one of the earlier two factors is small, the computational cost is proportional to the other factor approximately. Finally, a new STB 3-D BP algorithm that implements the surface-prediction operation via multiresolution-approximation (MRA) technique (named as MRA 3-D BP algorithm) is presented. By operating the interpolation in frequency domain, the computational cost of MRA algorithm for sparse LASAR is near to that of RD algorithm for full-element LASAR. [J715]

"Feature Extraction and Discriminator Design for Landmine Detection on Double-Hump Signature in Ultrawideband SAR"

An air- or vehicleborne ultrawideband synthetic aperture radar (UWB SAR) has ground penetrating capability, which provides a sufficient approach to detect landmines over wide areas from a safe standoff distance. In this paper, a support vector machine (SVM) with hypersphere classification boundary, which is referred to as HyperSphere-SVM (HS-SVM), using a hidden Markov model (HMM) kernel on the feature vector extracted by a postfilter-based method is proposed for landmine detection. The postfilter-based method can extract the feature containing not only the amplitude but also the amplitude varying information of the double-hump signature of metallic and plastic landmines. Compared with simple kernels, e.g., the Gaussian kernel, the HMM kernel employs the state-transition information in the extracted feature into the discrimination procedure and, thus, can improve detection performance. The proposed postfilter-based feature extraction method and the HMM kernel HS-SVM are verified on the field data collected by a UWB SAR system in different scenarios. [J716]

"A GB-SAR Processor for Snow Avalanche Identification"

An algorithm for the automatic detection and classification of snow avalanches has been developed and assessed through the archive of synthetic aperture radar (SAR) images acquired during six winter campaigns with a ground-based linear SAR. The scheme, based on the following classic steps: 1) detection; 2) features extraction; and 3) object classification, is fully described in this paper, representing the first attempt to implement a semiautomatic near-real-time operational snow avalanche monitoring tool by SAR. Detection of possible avalanche events is performed by the combined application of thresholding and morphological filters to the differential coherence of consecutive images. Classification of events likely to be snow avalanches is based on statistics extracted from the whole image and features associated to the single regions. Tests have been conducted over more than 60 000 images. Results show a drastic reduction on the images to manually supervise (2.2%). With a 9% false-negative rate and 60% accuracy over the 2.2% of images to examine, the processor represents an interesting support tool for the daily operations of avalanche risk assessment in a commercial ski resort. [J717]

"Sea-Surface Polarization Ratio From Envisat ASAR AP Data"

The polarization ratio (VV/HH) of normalized radar cross section over ocean surface is processed from Envisat Advanced Synthetic Aperture Radar (ASAR) alternating polarization (AP) data and compared with existing electromagnetic (EM) scattering models. The processing of the AP data is based on Level0 (raw data) product that enables us to accurately compute the contribution from additive noise separately from each burst. This is important in estimating the correct polarization ratio, particularly at higher incidence angles where the relative contribution from noise becomes severe. A recently published EM scattering model, general curvature method (GCM), is extended here to incorporate scattering from breaking waves. The performance of this model with and without breaking waves is compared with AP data and with other models for the polarization ratio. The extended GCM model is furthermore used to assess the performance of wind speed retrieval in HH polarization. The inclusion of wave breaking in the GCM model reduces the polarization ratio standard deviation from 0.64 to 0.50 and the bias from -0.34 to 0.16, as compared to the measured ASAR AP polarization ratio. The best semiempirical model from literature gives 0.51 and 0.63 for the standard deviation and bias, respectively. The difference in performance is shown to be caused by the wind speed dependence not accounted for in the semiempirical model. Validation of the new polarization ratio model in combination with C-band Model Function (CMOD) for wind speed retrieval at HH polarization shows similar performance as at VV polarization. We conclude that the GCM polarization ratio model incorporating wave-breaking effects is found to reproduce well polarization ratio measurements (ASAR AP) versus wind vector and incidence angle. [J718]

"Study on Spaceborne/Airborne Hybrid Bistatic SAR Image Formation in Frequency Domain"

To better understand the fundamental of the spaceborne/airborne hybrid bistatic SAR (SA-BSAR) image formation, the range cell migration (RCM) of the SA-BSAR is studied in the range-Doppler domain, where the RCM in SA-BSAR can be explicitly expressed in close form. Through the analysis of RCM relationship with target's azimuth and range position, we can find that, because of the system platforms' velocity difference along the azimuth direction, the RCM in SA-BSAR is 2D space variant. Therefore, the fundamental of frequency-domain image formation in SA-BSAR is to process the 2D space-variant RCM correction (RCMC) for nonreferent targets besides the bulk RCMC operation in the frequency domain. Furthermore, appropriate solutions in the frequency domain to remove the RCM in SA-BSAR are proposed and verified with five-point-target simulation. [J719]

"Polar format agorithm using chirp scaling for spotlight SAR image formation"

A novel implementation of the polar format algorithm (PFA) using the principle of chirp scaling (PCS) for spotlight synthetic aperture radar (SAR) image formation is addressed. A PFA completely free of interpolation has been achieved in moderate squinted imaging geometry. The presented approach consists of the range and azimuth scaling of the polar samples, in which only fast Fourier transforms (FFTs) and complex vector multiplications are involved. Following different processing chains, the dechirped and the chirped SAR signals are treated separately in this paper. Relative to the classic polyphase filter that uses the long sinc kernel, the new solution is able to attain a comparable result, but is much quicker by exploiting inherent properties of the linear frequency modulated (LFM) signal. Point target simulation has validated the presented methodology. [J720]

"A Fast Robust Chinese Remainder Theorem Based Phase Unwrapping Algorithm"

A robust phase unwrapping based on the Chinese remainder theorem (CRT) has been proposed lately, and it has applications in synthetic aperture radar (SAR) imaging for moving targets. It also leads to a type of robust CRT. This algorithm requires a two-dimensional searching. In this letter, we propose a new and fast algorithm that only does one-dimensional searching and therefore reduces the complexity significantly. [J721]

"SAR Image Segmentation Based on Level Set With Stationary Global Minimum"

In this letter, we propose a new level-set-based energy functional for the purpose of synthetic aperture radar (SAR) image segmentation into Gamma homogeneous regions. The segmentation of SAR images is a difficult problem due to the presence of speckles, which can be modeled as strong multiplicative noise. Our proposed energy functional is designed to get a stationary global minimum. As a result, the level set function that evolves by the Euler-Lagrange equation of the energy functional has a unique stationary convergence state. Moreover, it is easy to set a termination criterion on the curve evolution via a level set by using our energy functional. The experimental results on both synthetic and real SAR images demonstrate the effectiveness of our method. [J722]

"The Polar Format Imaging Algorithm Based on Double Chirp-Z Transforms"

Spotlight mode offers finer azimuth resolution than that achievable in stripmap mode using the same physical antenna. The most popular spotlight synthetic aperture radar (SAR) reconstruction method is the classic polar format algorithm (PFA). However, PFA needs to perform range and azimuth interpolation operations during SAR imaging, which, in turn, affect the imaging precision and the computation efficiency. In this letter, we present a novel polar format algorithm, which may avoid interpolation operations by double chirp-Z transform. In this letter, we also analyze the nondefocus and the nondistortion constraints and discuss the along-track acceleration constraint for the PFA as well. [J723]

"A Novel Algorithm for Estimating the Rotation Angle in ISAR Imaging"

A novel algorithm for estimating the rotation angle in inverse synthetic aperture radar imaging by generally considering the received signals as cubic phase signals is presented. The rotation angle is determined by the coefficients of the cubic phase signals, and the results of real data demonstrate the validity of the algorithm. [J724]

"Accuracy and Resolution of ALOS Interferometry: Vector Deformation Maps of the Father's Day Intrusion at Kilauea"

We assess the spatial resolution and phase noise of interferograms made from L-band Advanced Land Observing Satellite (ALOS) synthetic-aperture-radar (SAR) data and compare these results with corresponding C-band measurements from European Space Agency Remote Sensing Satellite (ERS). Based on cross-spectral analysis of phase gradients, we find that the spatial resolution of ALOS interferograms is 1.3times better than ERS interferograms. The phase noise of ALOS (i.e., line-of-sight precision in the 100-5000-m wavelength band)

is 1.6times worse than ERS (3.3 mm versus 2.1 mm). In both cases, the largest source of error is tropospheric phase delay. Vector deformation maps associated with the June 17, 2007 (Father's day) intrusion along the east rift zone of the Kilauea Volcano were recovered using just four ALOS SAR images from two look directions. Comparisons with deformation vectors from 19 continuous GPS sites show rms line-of-site precision of 14 mm and rms azimuth precision (flight direction) of 71 mm. This azimuth precision is at least 4times better than the corresponding measurements made at C-band. Phase coherence is high even in heavily vegetated areas in agreement with previous results. This improved coherence combined with similar or better accuracy and resolution suggests that L-band ALOS will outperform C-band ERS in the recovery of slow crustal deformation. [J725]

"Forest Height Inversion Using High-Resolution P-Band Pol-InSAR Data"

In this paper, a high-resolution P-band Pol-InSAR data set acquired by the airborne RAMSES system over pine forest stands of different height is investigated. A significant penetration depth in all the polarimetric channels and a wide range of polarimetric phase center heights are observed, attesting of an interaction of the radar waves with different forest structural elements. The main objective of this paper concerns forest height inversion at P-band. First, forest-modeling assumptions are evaluated using aprioriinformation, such as ground-level and forest height measurements. The full extend of the forest height is shown to be responsible of the volume decorrelation, and a significant orientation effect is clearly identified over the highest stands. As a consequence, the Oriented Volume over Ground model (OVoG) is determined to be the most appropriated model for the forest height inversion. At P-band, the ground contribution is present in all the polarimetric channels due to the important penetration at this frequency. To overcome this difficulty, a time-frequency optimization method based on sublook decomposition is developed to separate the pure ground and canopy contributions, allowing forest height estimation with OVoG with an rms error on the order of 2 m. In the last section of this paper, a sensitivity analysis of the inversion with respect to two important system parameters, the signal-to-noise ratio and the resolution, is presented, leading to a discussion on the inversion robustness in spaceborne conditions, where these system parameters are the most deteriorated as compared to airborne configurations. [J726]

"Inversion of Spaceborne X-Band Synthetic Aperture Radar Measurements for Precipitation Remote Sensing Over Land"

Several spaceborne X-band synthetic aperture radar (X-SAR) systems were launched in 2007, and more will be launched in the current decade. These sensors may significantly augment the sensors that comprise the global precipitation mission (GPM) constellation. X-SAR rainfall measurements may be beneficial particularly over land where rainfall is difficult to measure by means of satellite microwave radiometers. Inversion techniques to quantitatively derive precipitation fields over land at high spatial resolution are developed and illustrated in this paper. These inversion algorithms are the model-oriented statistical (MOS) methodology and the Volterra integral equation (VIE) approach. Simplified rain-cloud models are used to train and test the inversion algorithms by evaluating the expected error budget. Two case studies, using data obtained from measurements of SIR-C/X-SAR in 1994 over Bangladesh and the Amazon, are introduced, and retrieved precipitation maps are discussed. Even though no validation of the precipitation estimates was possible, the obtained results are encouraging, showing physically consistent retrieved structures and patterns. [J727]

"Improved Space-Based Moving Target Indication via Alternate Transmission and Receiver Switching"

Ground moving target indication (GMTI) by space-based radar systems requires special antenna and data acquisition concepts to overcome the problem of discriminating target signals from clutter returns. Owing to the high satellite speed, the clutter contains a broad mixture of radial velocities within the antenna beam, leading to a large Doppler spread. Effective clutter suppression can solely be achieved by multiple aperture or phase center antennas. For space-based systems, however, the number of receiver channels connected to subapertures is very limited due to their weight, volume, and high data rates (current systems such as TerraSAR-X and RADARSAT-2 possess only two). This classical along-track interferometry architecture, in which the antenna is split into two halves, achieves only suboptimum GMTI performance. This paper presents and statistically analyzes an innovative approach to create additional independent phase centers to improve the GMTI performance considerably. The extra degrees of freedom are created by cyclical phase and amplitude switchings of the transmit/receive modules for transmitter and receiver between pulses, hence trading Doppler bandwidth for extra spatial diversity. In the first part of this paper, different strategies of spatial-temporal diversity are introduced and analyzed for realistic system parameters with respect to ambiguities and detection performance. The second part is concerned with the elaborate theoretical analysis of the relocation improvement for the spatial diversity approach. [J728]

"Characterizing Bidimensional Roughness of Agricultural Soil Surfaces for SAR Modeling"

In the description of agricultural soil roughness, the hypothesis of surface isotropy is currently admitted, and linear measurements are often used to characterize the soil roughness considered as a single-scale process. However, multiscale roughness is frequently observed, and tillage practices created oriented roughness. This paper presents a new technique to measure precisely the bidimensional soil roughness. Digital elevation model derived using photogrammetric technique reproduces the millimeter-scale height variations of three different soil surfaces (ploughed, smoothed, and row structured field) over about 8 m2. A single surface measurement is sufficient to accurately measure the soil roughness parameters. Geostatistic parameterization allows the measurement of the roughness anisotropy. For smooth surface, a two-scale roughness is observed. Anisotropy is observed in the larger scale roughness. The proposed method allows the computation of the bidimensional correlation function, which is required by the integral equation method model for the simulation of the SAR signal over anisotropic soil surfaces. [J729]

"Doppler Ambiguity Resolving in Compressed Azimuth Time and Range Frequency Domain"

For high-quality synthetic aperture radar (SAR) processing, Doppler centroid ambiguity resolving is an essential procedure. A novel method for the resolution of Doppler ambiguity is presented which exploits the fact that, in the compressed azimuth time and range frequency domain, all targets span the same range frequency bandwidth and exhibit the same slope which is just proportional to the Doppler ambiguity number. The slope is removed by interpolation so that a simplified Radon transform can be applied. The use of entropy to find the maximum concentration of the Radon-transformed image can improve the robustness of the method. The proposed method directly gives a reliable estimate of the Doppler ambiguity number and is not affected by the azimuth partially covered targets. Experimental results show that the proposed method works well in medium- to high-contrast scenes. [J730]

"Regional Mapping of the Offshore Wind Resource: Towards a Significant Contribution From Space-Borne Synthetic Aperture Radars"

This paper reviews and discusses the benefits of synthetic aperture radar (SAR) satellite imagery for regional mapping of the offshore wind resources, mostly in comparison to the more standard approach of numerical mesoscale and/or microscale models. Remote sensing measurements can be used as a complementary approach to numerical models, as well as a semi-autonomous approach to assess offshore and coastal wind resources using such methods as the newly developed strategic sampling. An important benefit of using SAR satellite data is to validate numerical model results, and possibly to provide surface wind data to pilot numerical models in coastal regions where observations are scarce. A relatively small sample of SAR scenes can already indicates the best wind sites for offshore wind farms that should be investigated for further analysis. Finally, future challenges facing remote sensing to support the wind energy fields, including new satellites and methodology improvements for the SAR technique, are reviewed. [J731]

"Spatial Indexes for the Extraction of Formal and Informal Human Settlements From High-Resolution SAR Images"

In this paper, a novel procedure for extracting human settlement extent in high-resolution SAR images, based on local autocorrelation and morphological processing, is presented. The algorithm is based on two steps. Hints for human settlements by information fusion based on local indexes of spatial autocorrelation are the outputs of the first step. A morphological chain builds on top of them the final settlements' borders. Examples from very different areas, i.e., the Darfur region in Sudan and the Lombardy region in Italy, stress the robustness of the procedure as well as its effectiveness. [J732]

"A range profiling technique for synthetic wideband radar"

A technique is proposed for reconstructing wide range profiles using stepped-frequency waveforms (SWFs). The technique is based on reconstructing range sub-profiles. With respect to previous methods, the proposed technique can be applied to any kind of SWFs. Moreover, for a given range resolution, long range profiles can be formed without increasing the number of transmitted frequencies. Theoretical results are also derived that provide a correct setting of waveform and processing parameter. Finally, as case studies, the proposed method is applied to three SFWs, namely short-pulse stepped-frequency, linear frequency modulated stepped frequency and phase-coded stepped-frequency waveforms. Simulations prove the effectiveness of the proposed range profile reconstruction. [J733]

"Quality enhancement of image generated with bistatic ground based noise waveform SAR"

A new method for quality enhancement in a noise synthetic aperture radar (SAR) image and the first results of its application to the SAR image generated with the use of a bistatic Ka-band ground-based noise waveform SAR (GB NW-SAR) are presented. A SAR image generated with a noise SAR suffers from the masking effect which is tied to residual random fluctuations in noise radar response from bright scatterers in the scene. This is similar to the masking effect present in the deterministic waveform SAR when the signal sidelobes of echoes from bright scatterers may mask the main response from a weaker target. The procedure presented is a variation of the CLEAN algorithm. Knowing precisely the emitted signal and finding positions of the strongest scatterers one may model the echo signal originated from a selected scatterer. Extraction of the modelled signal from the received one reduces the residual fluctuations and makes it possible to clean the image and increase its dynamic range. The final image is constructed from the cleaned signal and the previously removed strongest scatterers. A theoretical background is provided to the proposed procedure and its application to enhance the SAR image using simulated data as well as data generated by the Ka-band bistatic GB NW-SAR is demonstrated. The GB NW-SAR, recently developed and tested in LNDES IRE NASU, may operate in CW and pulse random signal regimes for short range applications. [J734]

"Mutual interference and low probability of interception capabilities of noise radar"

Recently, there has been considerable interest in noise radar over a wide spectrum of applications, such as through-wall surveillance, tracking, Doppler estimation, polarimetry, interferometry, ground penetrating or subsurface profiling, detection, synthetic aperture radar (SAR) imaging, inverse SAR imaging, foliage penetration imaging etc. Major advantages of using noise in the transmit signal are its inherent immunity from radio frequency and electromagnetic interference, improved spectrum efficiency, and hostile jamming as well as being very difficult to detect. The basic theory of digital signal processing in noise radar design is treated. The theory supports the use of noise waveforms for radar detection and imaging in such applications as covert military surveillance and reconnaissance. It is shown that by using wideband noise waveforms, one can achieve high resolution and reduced range estimation ambiguity. Mutual interference and low probability of interception capabilities of noise radar are also evaluated. The simulation results show the usefulness of the noise radar technology to improve on conventional radars. [J735]

"Compression of multi-polarimetric SAR intensity images based on 3D-matrix transform"

The algorithms for multi-polarimetric synthetic aperture radar (SAR) intensity image compression are investigated. First, the multi-polarimetric SAR intensity images (HH, HV and VV) are considered as a 3D-matrix unit, and then a 3D-matrix transform is adopted to remove the redundancies, which includes ID discrete cosine transform (DCT) in the polarimetric channels and 2D discrete wavelet transform (DWT) in each polarimetric SAR image plane. After the 3D-matrix transform, two methods are proposed to encode the 3D mixed coefficients. One is a bit allocation encoding based on differential entropy and the other is a 3D set partitioning in hierarchical trees (SPIHT) encoding which is an improvement of the conventional SPIHT. The two methods can remove not only the redundancies of the image inside but also the redundancies among the polarimetric channels, because they do not process every channel image separately. Both the theory and experimental results show that the proposed methods are efficient. [J736]

"Synergetic Use of Radar and Optical Satellite Images to Support Severe Storm Prediction for Offshore Wind Farming"

In this paper, we show how satellite images taken by space-borne radar sensors can be used to determine mesoscale high-resolution wind fields in synergy with cloud parameters from optical data and, thus, help in the task of maintenance and planning offshore wind farms. The aim of this paper is to use synthetic aperture radar (SAR) and medium resolution imaging spectrometer (MERIS) onboard the environmental satellite (ENVISAT) in synergy to analyze severe weather systems, in particular, to describe the spatial evolution of the atmospheric boundary layer processes involved in cold air outbreaks. We investigated the fine-scale structure of a severe weather case on November 1, 2006 over the North Sea using satellite data. The satellite data are compared with numerical model results of the German Weather Service ldquoLokal Modellrdquo (LM) and the high-resolution limited area model (HIRLAM). LM and HIRLAM show differences in mesoscale turbulent behavior and coastal shadowing. Maximum wind speeds of up to 25 m/s are measured by SAR and are confirmed by the models. Significant differences are observed in the location of the maxima. High-resolution ENVISAT ASAR measurements provide very detailed information on small-scale atmospheric features, which seem to not be captured well by the analyzed numerical models, in particular, in coastal areas. Meteosat second generation (MSG) is used to determine the movement of cloud patterns. Cloud patterns seen in the optical data and radar cross-section modulation give a consistent dynamical picture of the atmospheric processes. The relevance for offshore wind farming is discussed. [J737]

"Electromagnetic Coherent Tomography Array Imaging in Random Scattering Media"

Imaging through discrete random media is an important problem in several applications such as medicine, remote sensing, and security. Discrete random media create scattering which deteriorates the quality of the image and there have been several efforts to mitigate the problem. We propose an array processing method called coherence tomography array (CTA) whose algorithm is derived from that of optical coherence tomography. We use the Monte Carlo method to simulate the imaging scenarios in random scattering media. The results show that CTA can be used to alleviate the clutter effects from discrete random scatterers. [J738]

"Slant Plane CSAR Processing Using Householder Transform"

Fourier analysis-based focusing of synthetic aperture radar (SAR) data collected during circular flight path is a recent advancement in SAR signal processing. This paper uses the Householder transform to obtain a ground plane circular SAR (CSAR) signal phase history from the slant plane CSAR phase history by inverting the linear shift-varying system model, thereby circumventing the need for explicitly computing a pseudo-inverse. The Householder transform has recently been shown to have improved error bounds and stability as an underdetermined and ill-conditioned system solver, and the Householder transform is computationally efficient. [J739]

"Inverse synthetic aperture radar imaging of ship target with complex motion"

High-resolution inverse synthetic aperture radar (ISAR) imaging and recognition of ship target is very important for many applications. Although the principle of ISAR imaging of ship target on the sea is the same as that of flying target in the sky, the former usually has more complex motion (fluctuation with the oceanic waves) than the latter, which makes the motion compensation very difficult. However, the change in phase chirp rate caused by the complex motion of ships will deteriorate the azimuth focusing quality. In this paper, we first model the complex motion of ship target with cubic phase terms (parameterised on chirp rate and its change rate), then a new ISAR imaging method, referred to as TC-DechirpClean, is proposed, which estimates the chirp rate and the change rate of chirp rate of all scatters in the time-chirp distribution plane. Both numerical and experimental results are provided to demonstrate the performance of the proposed method. [J740]

"Theoretical limits on SAR imposed by the ionosphere"

The ultimate theoretical limitations on space-based synthetic aperture radar (SAR) image formation that are imposed by the ionosphere are examined. The effects on the SAR image are derived from first principles, and it is shown that the ionosphere will cause defocusing in both the range and along track directions. The performance of an autofocus procedure is then examined, and it is shown that the range defocusing can always be removed, but the range time delay can only be determined for high percentage bandwidths and high signal-to-noise plus clutter ratios. It is also shown that the performance limits of autofocus are not determined by the absolute total electron content, but are given by the amount of ionospheric turbulence, which limits the along track resolution. The relationship between the requirement for a focussed SAR image and the S4index and the integrated strength of turbulence CkLis derived. [J741]

"Monitoring Urban Land Cover in Rome, Italy, and Its Changes by Single-Polarization Multitemporal SAR Images"

This study contributes an assessment of the potential of single-polarization decametric synthetic aperture radar (SAR) images in classifying land cover within and around large urban areas and in monitoring their changes. The decision task is performed on a pixel basis and is carried out by supervised neural network algorithms fed by radar image features including backscattering intensity, coherence and textural parameters. Two configurations are considered: a short-term classification and change detection scheme intended for providing information in near-real time and a long-term scheme aimed at observing the urban changes at year time scales. We use a pair of interferometric images for the short-term case, while the long-term exercise utilizes two interferometric pairs and a fifth single acquisition. The images are acquired by the ERS SAR in late winter, spring and early summer over 836 square kilometers including Rome, Italy, and its surroundings. The accuracy of the short-term algorithm in discriminating seven types of surface is higher than 86%, while the accuracy of the long-term algorithm is beyond 88%. The many changes undergone by Rome from 1994 to 1999 have been identified by the postclassification comparison change detection procedure. The pixel-by-pixel analysis of the results has been carried out for a 160 square kilometers test area, obtaining a correct detection above 82% (less than 18% missed alarms and 0.3% false alarms). [J742]

"Ka-band bistatic ground-based noise waveform SAR for short-range applications"

The designing and testing of a new Ka-band ground-based noise waveform synthetic aperture radar (GB NW-SAR) are presented. Its design is based upon new synthetic aperture antennas and noise radar technology. The authors present preliminary results of its indoor trials. The GB NW-SAR designed may be reconfigured for operation in mono-, bi- and multistatic (or MIMO) modes in both CW and pulse regimes using single- and dual-frequency modes to enhance range resolution via expanding the frequency bandwidth of the signal. Potential resolution of the GB NW-SAR is 15 cm both in range and azimuth. Results of indoor trials are presented for both SAR imaging and differential interferometry measurements. Designed and tested Ka-band GB NW-SAR is applicable for precise remote monitoring of various manmade or natural objects, such as ceilings and roofs of big halls and hangars, dams, bridges, TV towers etc. [J743]

"Radarsat-1 and ERS InSAR Analysis Over Southeastern Coastal Louisiana: Implications for Mapping Water-Level Changes Beneath Swamp Forests"

Detailed analysis of C-band European Remote Sensing 1 and 2 (ERS-1/ERS-2) and Radarsat-1 interferometric synthetic aperture radar (InSAR) imagery was conducted to study water-level changes of coastal wetlands of southeastern Louisiana. Radar backscattering and InSAR coherence suggest that the dominant radar backscattering mechanism for swamp forest and saline marsh is double-bounce backscattering, implying that InSAR images can be used to estimate water-level changes with unprecedented spatial details. On the one hand, InSAR images suggest that water-level changes over the study site can be dynamic and spatially heterogeneous and cannot be represented by readings from sparsely distributed gauge stations. On the other hand, InSAR phase measurements are disconnected by structures and other barriers and require absolute water-level measurements from gauge stations or other sources to convert InSAR phase values to absolute water-level changes. [J744]

"Focusing Bistatic SAR Data Using the Nonlinear Chirp Scaling Algorithm"

Bistatic synthetic aperture radar data are more challenging to process than the common monostatic counterparts because the flight geometry is more complicated and the data are usually nonstationary. Whereas time-domain algorithms can handle general bistatic cases, they are very inefficient; therefore, frequency-domain methods are preferred. Several frequency-domain monostatic algorithms have been modified to handle a limited number of bistatic cases, but a general algorithm is sought, which can handle cases such as nonequal platform velocities, nonparallel flight tracks, and high squints. In this paper, we modify the nonlinear chirp scaling (NLCS) algorithm to handle a general case of bistatic data. The key is to use a linear range cell migration correction to reduce the range-azimuth coupling, an NLCS to precondition the data for azimuth compression, and a series expansion to obtain an accurate form of the signal spectrum. The azimuth nonstationarity is handled through the use of invariance regions. Simulations have shown that the modified NLCS algorithm can handle data with more complicated bistatic geometries than the previous algorithms. [J745]

"Information Theory-Based Approach for Contrast Analysis in Polarimetric and/or Interferometric SAR Images"

We propose a new approach for evaluating the contribution of the different channels of polarimetric and interferometric synthetic aperture radar (PolInSAR) images. For that purpose, we demonstrate that the Bhattacharyya distance between the probability density functions of neighboring regions in the image provides an efficient scalar contrast measure. We show that the analysis of this contrast measure allows one to precisely characterize the contribution of each channel for different system configurations, including intensity, polarimetric, and interferometric images. We illustrate this approach using a real synthetic aperture radar image to compare several polarimetric system architectures. Since PolInSAR imaging configurations can correspond to complex and expensive systems, the proposed method can be helpful in system imaging optimization. [J746]

"Sparse Representation in Structured Dictionaries With Application to Synthetic Aperture Radar"

Sparse signal representations and approximations from overcomplete dictionaries have become an invaluable tool recently. In this paper, we develop a new, heuristic, graph-structured, sparse signal representation algorithm for overcomplete dictionaries that can be decomposed into subdictionaries and whose dictionary elements can be arranged in a hierarchy. Around this algorithm, we construct a methodology for advanced image formation in wide-angle synthetic aperture radar (SAR), defining an approach for joint anisotropy characterization and image formation. Additionally, we develop a coordinate descent method for jointly optimizing a parameterized dictionary and recovering a sparse representation using that dictionary. The motivation is to characterize a phenomenon in wide-angle SAR that has not been given much attention before: migratory scattering centers, i.e., scatterers whose apparent spatial location depends on aspect angle. Finally, we address the topic of recovering solutions that are sparse in more than one objective domain by introducing a suitable sparsifying cost function. We encode

geometric objectives into SAR image formation through sparsity in two domains, including the normal parameter space of the Hough transform. [J747]

"Imaging Simulation of Bistatic Synthetic Aperture Radar and Its Polarimetric Analysis"

Employing the 3-D mapping and projection algorithm (MPA), an imaging simulation of bistatic synthetic aperture radar (BISAR) observation over a complex scenario is developed. Based on the explicit expression of the point target response of stripmap BISAR imaging, raw data are efficiently generated from the scattering map precalculated by MPA. Some examples of BISAR image simulation are studied. The polarimetric characteristics of a BISAR image are then discussed. It is found that some typical polarimetric parameters such as Cloude's alpha, beta and gamma and might become unable to describe the scattering mechanism under bistatic observation. A transform of unified bistatic polar bases for a BISAR image is proposed. The parameters alpha, beta and gamma and are modified to retain the property of orientation independence in the bistatic circumstance. Analysis of simulated images shows that the redefined alpha, beta and gamma and after the unified bistatic polar bases transform well describe different scattering mechanisms in BISAR imaging. It provides a primary tool for BISAR image interpretation and terrain classification. [J748]

"A Multistatic GNSS Synthetic Aperture Radar for Surface Characterization"

Bistatic global navigation satellite system (GNSS) radar has received increased attention in recent years within both the radar and GNSS communities. In this paper, the traditional bistatic GNSS radar and bistatic synthetic aperture radar (SAR) concepts are fused into a more generic multistatic GNSS SAR system for surface characterization. This is done by using the range and Doppler processing techniques on signals transmitted by multiple satellites to determine the angular dependence of the surface reflectivity. The method has also been tested experimentally, and the results are presented. [J749]

"Parametric Velocity Synthetic Aperture Radar:Signal Modeling and Optimal Methods"

Velocity synthetic aperture radar (VSAR) is equipped with a linear array to receive the echoes from a radar illuminating area via multiple channels, each of which can reconstruct a reflectivity image for the same stationary scene. Based on analysis of pixel vector sampled among multi-images, VSAR may effectively suppress the strong ground clutter and improve moving target detection and location. In this paper, different Doppler-distributed properties are derived for the moving target and clutter, respectively. Then, we propose a novel parametric statistical model for VSAR by dividing the pixel vector into three components, namely, target, clutter, and noise. Furthermore, a method of adaptive implementation of optimal processing (AIOP-VSAR) is presented for moving target detection. It is shown that the optimum detection performance may be obtained via AIOP-VSAR, particularly for the slowly moving target in an inhomogeneous clutter environment. Also, the Cramer-Rao bounds (CRBs) are derived for the estimation of unknown model parameters, as well as the azimuth locations of moving targets, and the maximum-likelihood methods are proposed to reach these CRBs. Based on the proposed target detection and parameter estimation methods, we present a complete parametric flowchart for VSAR. It is demonstrated that the proposed flowchart may effectively mitigate the "azimuth location ambiguity" of VSAR and has the super-resolution ability to resolve "velocity layover" for multiple targets. Finally, some detailed numerical experiments and scene simulations are provided to show the effectiveness of the proposed methods. [J750]

"A Physical-Optics Model for Double-Bounce Scattering From Tree Stems Standing on an Undulating Ground Surface"

In this paper, a model for prediction of radar backscatter from coniferous forests in the VHF and UHF band is proposed. The model includes the double-bounce scattering originating from vertical stems standing on an undulating ground surface and is based on a physical-optics approach. The model can be used to assess the importance of ground topography in synthetic aperture radar (SAR) imagery of forests, and it is applicable to SAR systems using horizontally transmit and receive polarization (HH). The model was validated against data from the airborne SAR systems CARABAS-II and LORA. Precision measurements of ground topography and forest characterization at a single tree level were used as model input to simulate SAR images. The simulated images were compared to radar data in the frequency bands 22-82 and 225- 470 MHz, and it was found that the model could predict much of the variation in backscatter observed in images (R2= 0.44 and 0.65 at best, for the lower and higher frequency band, respectively), which should be compared to R2= 0.1 if the same model, but assuming a flat ground, was used. The results thus indicate that ground topography must be considered when predicting the variations in backscatter in the SAR images studied. The model did, however, fail to predict the absolute values of the backscattered intensity. The reason for the discrepancy is believed to be the value chosen for stem dielectric constant and unmodeled effects due to wave attenuation, tilting stems, and small-

scale surface roughness. [J751]

"From Glacier Facies to SAR Backscatter Zones via GPR"

We present a comparison between data acquired with frequency-modulated ground-penetrating radar (GPR) and satellite synthetic aperture radar (SAR). Both radars are polarimetric and operate at a center frequency of 5.3 GHz. The field site is the polythermal glacier Kongsvegen, Svalbard. Along glacier GPR profiles cover the ablation area and the accumulation area, where the latter consists of superimposed ice (SI) and firn. The glacier facies are clearly identifiable on the GPR profiles, although we show that the copolarized response is better for distinguishing different ice zones, whereas the SI-firn boundary is most obvious in the cross-polarized response. A calibrated backscatter coefficient is calculated for the GPR data and compared with the SAR backscatter coefficient. The SAR zones are in very good agreement with the GPR-derived glacier facies. We show that, in the ablation area, the SAR response is dominated by backscatter from the previous summer surface. In the SI and firn areas, it is dominated by sources below the previous summer surface. [J752]

"Segmentation-Based MAP Despeckling of SAR Images in the Undecimated Wavelet Domain"

In this paper, a novel despeckling algorithm based on undecimated wavelet decomposition and maximum aposterioriestimation is proposed. Such a method represents an improvement with respect to the filter presented by the authors, and it is based on the same conjecture that the probability density functions (pdfs) of the wavelet coefficients follow a generalized Gaussian (GG) distribution. However, the approach introduced here presents two major novelties: 1) theoretically exact expressions for the estimation of the GG parameters are derived: such expressions do not require further assumptions other than the multiplicative model with uncorrelated speckle, and hold also in the case of a strongly correlated reflectivity; 2) a model for the classification of the wavelet coefficients according to their texture energy is introduced. This model allows us to classify the wavelet coefficients into classes having different degrees of heterogeneity, so that adhocestimation approaches can be devised for the different sets of coefficients. Three different implementations, characterized by different approaches for incorporating into the filtering procedure the information deriving from the segmentation of the wavelet coefficients, are proposed. Experimental results, carried out on both artificially speckled images and true synthetic aperture radar images, demonstrate that the proposed filtering approach outperforms the previous filters, irrespective of the features of the underlying reflectivity. [J753]

"A Comparison of Point Target Spectra Derived for Bistatic SAR Processing"

The existence of a double hyperbola in the bistatic range equation makes it difficult to find an exact analytical solution for the 2D point target spectrum. Several approximate solutions for the spectrum have been derived and used to focus bistatic synthetic aperture radar data. In this paper, we establish the relationship between three independently derived bistatic point target spectra. The first spectrum is Loffeld's bistatic formula, which consists of a quasi-monostatic and a bistatic phase term. The second spectrum makes use of Rocca's smile operator, which transforms bistatic data in a defined configuration to a monostatic equivalent. The third spectrum is derived using a power series-called the method of series reversion (MSR). The MSR spectrum is the most general among the three. This paper shows that this spectrum can be reduced to the same formulation as the former two when certain conditions are met. In addition, a new approximate spectrum is derived using a Taylor series expansion about the two stationary phase points of the transmitter and receiver. We also give an alternative geometrical proof of the relationship between Rocca's smile operator and Loffeld's bistatic deformation term. The accuracies of the point target spectra are demonstrated using simulations of an X-band bistatic airborne radar with a fixed baseline. [J754]

"Physical Models for Polarimetric SAR Analysis"

Polarimetric signatures can be used to support target identification in the context of synthetic aperture radar (SAR). In this paper, we derive analytic expressions for the polarimetric signatures in the SAR image domain, for a class of localized scatters that may be found in a composite target. Specifically, we consider a convex surface, curved and straight edges, and a dihedral. For each of these subscatterers, we use asymptotic techniques to construct analytic expressions for the polarimetric images as a function of the target's geometry and orientation relative to the SAR scan, then extract Huynen's polarimetric parameters, and finally discuss the subscatterer identification in the composite image domain. [J755]

"A Recursive Filter for Despeckling SAR Images"

This correspondence proposes a recursive algorithm for noise reduction in synthetic aperture radar imagery. Excellent despeckling in conjunction with feature preservation is achieved by incorporating a discontinuity-adaptive Markov random field prior within the unscented Kalman filter framework through importance sampling.

The performance of this method is demonstrated on both synthetic and real examples. [J756]

"Radar Imaging of Urban Areas by Means of Very High-Resolution SAR and Interferometric SAR"

In remote-sensing applications, the monitoring of urban areas by means of synthetic aperture radar (SAR) sensors has grown into a valuable and indispensable tool. Although SAR imaging with a spatial resolution down to 1 m is widespread, a resolution as fine as 10 cm and below is offered only by very few SAR sensors worldwide. In this paper, the potential of very high-resolution radar imaging of urban areas by means of SAR and interferometric imaging will be demonstrated and discussed. Results of urban SAR imaging down to subdecimeter resolution will be shown. Even though the immanent layover situation in urban areas is an obstacle to simple image understanding, a remedy can be found by using interferometric SAR imaging. Interferometric results based on very high-resolution SAR images acquired over urban areas, partially with a severe layover situation, will be presented. The corresponding data was acquired with the phased array multifunctional imaging radar (PAMIR), the X-band demonstrator of the Research Institute for High Frequency Physics and Radar Techniques (FHR), Forschungsgesellschaft fur Angewandte Naturwissenschaften (FGAN), Wachtberg, Germany. It can be stated that high-resolution interferometric SAR will be an important basis for upcoming radar-based urban analysis. [J757]

"Wide-Area Traffic Monitoring With the SAR/GMTI System PAMIR"

This paper presents a wide area traffic monitoring experiment under real conditions, using the scan-MTI mode of the airborne radar sensor PAMIR. This flexible GMTI (Ground Moving Target Indication) mode was designed in order to rapidly monitor wide areas for moving targets. The scan operation enables the detection of targets from different aspect angles with a high revisit rate. The parameters (e.g., radial velocity, signal-to-noise ratio, and positioning accuracy) of the detected vehicles are investigated and compared to the expected theoretical GMTI performance. It will be shown that the scan-MTI mode is particularly adapted to perform an efficient wide-area traffic monitoring. [J758]

"An Autofocus Approach for Residual Motion Errors With Application to Airborne Repeat-Pass SAR Interferometry"

Airborne repeat-pass SAR systems are very sensible to subwavelength deviations from the reference track. To enable repeat-pass interferometry, a high-precision navigation system is needed. Due to the limit of accuracy of such systems, deviations in the order of centimeters remain between the real track and the processed one, causing mainly undesirable phase undulations and misregistration in the interferograms, referred to as residual motion errors. Up to now, only interferometric approaches, as multisquint, are used to compensate for such residual errors. In this paper, we present for the first time the use of the autofocus technique for residual motion errors in the repeat-pass interferometric context. A very robust autofocus technique has to be used to cope with the demands of the repeat-pass applications. We propose a new robust autofocus algorithm based on the weighted least squares phase estimation and the phase curvature autofocus (PCA) extended to the range-dependent case. We call this new algorithm weighted PCA. Different from multisquint, the autofocus approach has the advantage of being able to estimate motion deviations independently, leading to better focused data and correct impulse-response positioning. As a consequence, better coherence and interferometric-phase accuracy are achieved. Repeat-pass interferometry based only on image processing gains in robustness and reliability, since its performance does not deteriorate with time decorrelation and no assumptions need to be made on the interferometric phase. Repeat-pass data of the E-SAR system of the German Aerospace Center (DLR) are used to demonstrate the performance of the proposed approach. [J759]

"Model-Based Interpretation of High-Resolution SAR Images of Buildings"

High-resolution (HR) synthetic aperture radar (SAR) images of urban areas reveal a large variety of details that, although potentially bringing a lot of information, are often very difficult to interpret. Until now, most of the research activity in this field has been devoted to the attempt to retrieve geometric information on buildings in terms of their positions and sizes, by using simplified geometrical models. However, this approach does not allow us to fully exploit the large amount of information present in HR SAR images. In order to improve information retrieval from such images, and, hence, their interpretation, in this paper, we propose to employ a more refined model that accounts for both geometrical (including fine details) and electromagnetic properties of the building. A meaningful case study is presented to show that the main features appearing on the SAR image of a building can be interpreted by using our geometric and electromagnetic model. In addition, a first example of retrieval of the complex dielectric constant of building materials from a SAR image is presented. [J760]

"Feature Extraction and Visualization of Bridges Over Water From High-Resolution InSAR Data

and One Orthophoto"

Modern airborne SAR sensor systems provide geometric resolution in the order well below half a meter. By SAR interferometry from pairs of such images, DEM of the same grid size can be obtained. In data of this kind, many features of urban objects become visible, which were beyond the scope of radar remote sensing only a few years ago. However, because of the side-looking SAR sensor principle, layover and occlusion issues inevitably arise in undulated terrain or urban areas. Therefore, SAR data are difficult to interpret even for senior human interpreters. Furthermore, the quality of the InSAR DEM may vary significantly depending on the local topography. In order to support interpretation, SAR data are often analyzed using additional complementary information provided by maps or other remote sensing imagery. In this paper, object feature extraction and visualization from high-resolution InSAR data and one orthophoto is discussed for the example of a scene containing several bridges over water. Bridges are key elements of man-made infrastructure. Monitoring of these important connecting parts of the traffic network is vital for applications such as disaster management or in the context of political crisis, for instance, to evacuate inhabitants and to deliver goods and equipment. Aims of the approach are to derive key features of the bridge's geometry from the complementary data sources, to determine the water level, smooth the noisy InSAR DEM data, especially at water surfaces, and, finally, to generate an improved 3-D visualization of the scene by overlapping the optical image on the InSAR DEM. [J761]

"A Contrast-Based Algorithm For Synthetic Range-Profile Motion Compensation"

In stepped-frequency radar, target motions produce range-profile distortions. Range shift, signal-to-noise ratio loss, and symmetric spreading are produced by target radial velocity, whereas target radial acceleration is mainly responsible for asymmetric smearing. Acceleration-distortion effects are usually negligible when a high Pulse Repetition Frequency (PRF) is used, although this is not the case for low-PRF radars. In this paper, a new motion-compensation technique based on contrast optimization is proposed. The innovative contributions of this paper are as follows: (1) A theoretical analysis of the distortions produced by target motions on the reconstruction of synthetic aperture radar is provided; (2) the proposed technique compensates both phase terms, which are due to target radial velocity and acceleration; therefore, synthetic range profiles can be focused by processing low-PRF radar returns; (3) a new cost function for the synthetic range profiles (namely, contrast) is defined and used for motion compensation; (4) the proposed technique can be applied to any kind of stepped-frequency waveforms; and (5) an estimation error analysis is performed, first theoretically and then by means of both simulations and real data. [J762]

"Principle and Methods on Bistatic SAR Signal Processing via Time Correlation"

In this paper, we discuss the mapping between the 3-D scene space and the bistatic synthetic aperture radar (SAR) image space and show that when the direction of the angular velocity of the bistatic SAR remains constant, the process of bistatic SAR imaging can be approximately modeled as a perspective operator from the 3-D scene space to the 2-D image space, and the perspective line is perpendicular to the plane determined by the composition direction of the T/R line of sight and the composition direction of the angular velocity of the T/R platform. Then, we show that the 2-D point spread function of the bistatic SAR is determined not only by the range and ldquoazimuthrdquo resolutions but also by the geometry of the bistatic SAR and the bases of the SAR image space, and the concept ldquoambiguity regionrdquo is introduced to describe the ambiguity problem in the 3-D scene space. Then, the range-Doppler algorithm is discussed, and a new translational-variant bistatic SAR imaging method is proposed, which uses the scaled inverse fast Fourier transform (IFFT) technique to eliminate the translational-variant feature of the SAR space resolution. The space truncation error of this new algorithm is discussed to analyze the depth of focus of the scaled IFFT bistatic SAR imaging algorithms, and we find that the upper bounce of the space truncation error is proportional to the square of the distance from the scatterer to the T/R platforms. Last, the effects of motion measurement errors are discussed in detail, and, through theoretical analysis and numerical experiments, we show that the absolute position measurement error, the baseline measurement error, the perpendicular (vertical) component of the absolute velocity measurement error (AVME), and the perpendicular component of the relative velocity measurement error (RVME) cause SAR image shifting in the image space mainly, and the parallel component of the AVME and the parallel component of the RVME cause the SAR image to s--everely defocus. [J763]

"Evaluation and Bias Removal of Multilook Effect on Entropy/Alpha/Anisotropy in Polarimetric SAR Decomposition"

Entropy, alpha, and anisotropy (H/alpha/A) of the polarimetric target decomposition have been an effective and popular tool for polarimetric synthetic aperture radar (SAR) image analysis and for a geophysical parameter estimation. However, multilook processing can severely affect the values of these parameters. In this paper, a Monte Carlo simulation is used to evaluate and remove the bias generated by the multilook effect on these parameters for various media composed of grassland, forest, and urban returns. Due to insufficient averaging,

entropy is underestimated, and anisotropy is overestimated. We also found that the bias in the alpha angle can be either underestimated or overestimated depending on scattering mechanisms. Based on simulation results, efficient bias removal procedures have been developed. In particular, the entropy bias can be precisely corrected, and the amount of correction is independent of the radar frequency and SAR systems. Data from L-band Advanced Land Observing Satellite/phased array type L-band SAR, German Aerospace Research Center (DLR)/enhanced SAR, Jet Propulsion Laboratory (JPL)/airborne SAR, and X-band polarimetric and interferometric SAR are used for demonstration in this paper. [J764]

"Prediction, Detection, and Correction of Faraday Rotation in Full-Polarimetric L-Band SAR Data"

With the synthetic aperture radar (SAR) sensor PALSAR onboard the Advanced Land Observing Satellite, a new full-polarimetric spaceborne L-band SAR instrument has been launched into orbit. At L-band, Faraday rotation (FR) can reach significant values, degrading the quality of the received SAR data. One-way rotations exceeding 25 degare likely to happen during the lifetime of PALSAR, which will significantly reduce the accuracy of geophysical parameter recovery if uncorrected. Therefore, the estimation and correction of FR effects is a prerequisite for data quality and continuity. In this paper, methods for estimating FR are presented and analyzed. The first unambiguous detection of FR in SAR data is presented. A set of real data examples indicates the quality and sensitivity of FR estimation from PALSAR data, allowing the measurement of FR with high precision in areas where such measurements were previously inaccessible. In examples, we present the detection of kilometer-scale ionospheric disturbances, a spatial scale that is not detectable by ground-based GPS measurements. An FR prediction method is presented and validated. Approaches to correct for the estimated FR effects are applied, and their effectiveness is tested on real data. [J765]

"Classification With a Non-Gaussian Model for PolSAR Data"

In this paper, we present a generalized Wishart classifier derived from a non-Gaussian model for polarimetric synthetic aperture radar (PolSAR) data. Our starting point is to demonstrate that the scale mixture of Gaussian (SMoG) distribution model is suitable for modeling PolSAR data. We show that the distribution of the sample covariance matrix for the SMoG model is given as a generalization of the Wishart distribution and present this expression in integral form. We then derive the closed-form solution for one particular SMoG distribution, which is known as the multivariate K-distribution. Based on this new distribution for the sample covariance matrix, termed as the K-Wishart distribution, we propose a Bayesian classification scheme, which can be used in both supervised and unsupervised modes. To demonstrate the effect of including non-Gaussianity, we present a detailed comparison with the standard Wishart classifier using airborne EMISAR data. [J766]

"The Compact Polarimetry Alternative for Spaceborne SAR at Low Frequency"

In spaceborne synthetic aperture radar (SAR), a single-polarization on-transmit offers twice the swath width compared to full polarization. This is linked to SAR system design issues, and, without getting into the technical details deserving by themselves a full paper, we can just mention the swath characteristics of ALOS PALSAR (the Advanced Land Observing Satellite, Phased Array L-Band Synthetic Aperture Radar), reducing from 70 km for the dual-pol mode to 30 km for the full polarization mode. The reduced coverage in the full polarization mode has a harmful impact on the revisit time, which is always a major drive for the Earth-observing community. The options chosen up to now for dual-pol system designs (or single-polarization on-transmit) rely on a linear polarization on-transmit [either horizontal (H) or vertical (V)], with two orthogonal polarizations on-receive. Souyris and Raney in earlier papers proposed more pertinent alternatives for the selection of the transmit polarization leading to a better characterization of the scattering mechanisms. In this paper, the analysis is pursued in more depth by including the effect of the ionosphere on the wave propagation and extending the applications to polarimetric interferometry SAR (PolInSAR). A compact mode is developed where the transmit polarization is circular, whereas the only constraint on the two receiving polarizations is independence. Indeed, the choice of the polarizations of the two receive channels does not matter, as any polarization on-receive can be synthesized from these two measurements. This is, however, not the case for the unique transmit polarization. At a low frequency, where the ionosphere has a significant effect, the circular transmit polarization is the only sensible option, as it provides an effective constant polarization as seen by the scattering surface. This is an essential condition for a meaningful multitemporal analysis. Both the polarimetric SAR applications and the PolInSAR appl--ications in the context of this compact polarimetry (CP) mode are explored. A pseudocovariance matrix can be reconstructed following Souyris' proposed approach for distributed targets and is shown to be very similar to the full polarimetric (FP) covariance matrix. The reconstruction of the cross-polarized Sigma0 is shown to be reliable and to have very low sensitivity to Faraday rotation. A PolInSAR vegetation height inversion for P-band is presented and applied to the CP data with a level of performance that is similar to the one derived from FP (a 1.2-m root-mean-square height error on the ONERA Airborne radar (RAMSES) data over the Landes Forest). A procedure is developed to correct for the ionospheric effects for the PolInSAR

acquisition in the FP or CP mode and is assessed on the data simulated from an airborne acquisition. The results demonstrate that the technique is efficient and robust. The calibration of CP data is identified as an important challenge to be solved, and some clues are provided to address the problem. [J767]

"Measurement and Characterization of Entropy and Degree of Polarization of Weather Radar Targets"

To date, few polarimetric weather radars have exhibited the capability to measure full scattering matrices. In contrast, in the synthetic aperture radar (SAR) community, considerable experience has been gained in dealing with complete scattering matrices and their statistical behavior. This paper aims to place weather radar parameters in a wider context in order to exploit more general concepts like target decomposition theorems and polarization basis transformations. Entropy, which is a fully polarimetric variable derived from the Cloude-Pottier decomposition, and the degree of polarization, which is derived from Wolf's coherence matrix, are the subject of this paper. The theoretical analysis carried out in the first part is checked against fully polarimetric data from POLDIRAD, which is the german aerospace center research weather radar. The entropy and the degree of polarization are compared with the copolar correlation coefficient in order to understand whether they can add value to radar meteorological investigations. Because the degree of polarization is available to conventional dual-polarization coherent systems, it is important to assess its potential for operational use. [J768]

"Remote Sensing Observation Used in Offshore Wind Energy"

Remote sensing observations used in offshore wind energy are described in three parts: ground-based techniques and applications, airborne techniques and applications, and satellite-based techniques and applications. Ground-based remote sensing of winds is relevant, in particular, for new large wind turbines where meteorological masts do not enable observations across the rotor-plane, i.e., at 100 to 200 m above ground level. Light detection and ranging (LiDAR) and sound detection and ranging (SoDAR) offer capabilities to observe winds at high heights. Airborne synthetic aperture radar (SAR) used for ocean wind mapping provides the basis for detailed offshore wind farm wake studies and is highly useful for development of new wind retrieval algorithms from C-, L-, and X-band data. Satellite observations from SAR and scatterometer are used in offshore wind resource estimation. SAR has the advantage of covering the coastal zone where most offshore wind farms are located. The number of samples from scatterometer is relatively high and the scatterometer-based estimate on wind resources appears to agree well with coastal offshore meteorological observations in the North Sea. Finally, passive microwave ocean winds have been used to index the potential offshore wind power production, and the results compare well with observed power production (mainly land-based) covering nearly two decades for the Danish area. [J769]

"Translational rotational motion compensation: a single algorithm for different radar maging applications"

A single algorithm for various radar imaging applications is presented. The idea behind the proposed approach is that any motion between radar and target can always be modelled as a composition of translational and rotational components. Novel techniques to estimate and compensate these two motion components are discussed and also validated by application to real radar data for different targets (ships, aircraft, ground). By the translational-rotational-motion-compensation algorithm, good results can be achieved, especially in cases characterised by evident variation of the rotation rate during the coherent processing time for imaging. This usually happens in aircraft, ship or ground mover inverse synthetic aperture radar (ISAR) imaging as well as in squinted or for.ward-looking SAR. In any case, the efficiency and the accuracy of the algorithm presented for translational motion compensation might be the initial step of alternative radar imaging processing. The simplicity of the proposed algorithms makes them suitable and convenient for real-time application even for compact and low-weight radar systems to be fitted on board unmanned aerial vehicles (UAV) or other airborne platforms. The proposed concept is the result of the authors' decennial experience devoted to achieve a single, simple, robust, reliable and efficient signal processing algorithm for several real-time radar imaging applications. [J770]

"Motion compensation in ISAR imaging using the registration-restoration-fusion approach"

The distortion in the inverse synthetic aperture radar (ISAR) image of a target is a result of small time-varying perturbed motion experienced by the target during the image integration period and is attributed to a phase modulation effect of the radar return from the target. Large distortion in ISAR images of a moving target has been investigated and demonstrated under controlled experiments and simulation. Results from the analysis suggest that severe distortion is attributed to the phase modulation effect where a time-varying Doppler frequency provides the smearing mechanism. For applications of target identification, the registration-restoration-fusion method has been developed to refocus the distorted ISAR images. This method has been applied to both

the experimental and simulated ISAR data. Results demonstrate that the registration-restoration-fusion motion compensation approach can improve the distorted ISAR image better than what can be achieved by conventional Fourier transform methods. This study also adds insight into the distortion mechanisms that affect the ISAR images of a target in motion. [J771]

"SAR imaging of moving targets using polynomial Fourier transform"

The polynomial Fourier transform (FT) is employed as a tool for the SAR imaging of moving targets. An efficient algorithm is proposed that can be used for radar images containing both moving and stationary targets. The proposed algorithm can be used in the form of the second-order polynomial FT, but it can also be extended to higher-order and order-adaptive polynomial FT forms. [J772]

"A Wavelet-Based Technique for Sea Wind Extraction from SAR Images"

We present the follow-up of our previously published work, where we described a wavelet-based method to characterize the sea surface backscatter structures in Synthetic Aperture Radar (SAR) images. The method relies on the ability of the 2-D continuous wavelet technique to detect the spatial structure of the Marine Atmospheric Boundary Layer (MABL) and to isolate wind-related cells and features. The analysis of the cells' geometry, molded by the radiometric characteristics of the sea surface, permits the identification of the wind direction inside the cells, due to the along-wind asymmetry of backscatter structures, and thus the computation of the wind speed through standard algorithms. Twenty-one SAR images (ERS-2 and Envisat ASAR Wide Swath) over the Mediterranean Sea have been analyzed, and the results are compared with satellite wind fields. The images cover a range of meteorological conditions from low to moderate winds. Comparison of the SAR-derived wind fields with those provided by satellite scatterometers indicates a good score of success (roughly 70%-80%). The developed methodology, once tested over an adequate number of images to derive statistically reliable results, could be routinely used to enrich SAR images with the wind field as well as to characterize the MABL in terms of size, distribution, and shape of the backscatter cells. [J773]

"Editorial: Signal processing techniques for ISAR and feature extraction"

Inverse synthetic aperture radar (ISAR) is a non-cooperative target recognition technique that has been investigated for target identification by the combat identification (ID) community for the past decade. Recently, ISAR imaging of moving targets has been an area of vigorous research. ISAR imaging is an effective way to acquire high resolution images of targets of interest at long range and as such is an irreplaceable tool in the task of non-cooperative target recognition. Its applications include detection, imaging, and classification of ships and aircraft with airborne, maritime, and land-based radar systems. Being radar-based, this imaging technique can be employed in all weather and day/night conditions. [J774]

"Recent developments in detection, imaging and classification for airborne maritime surveillance"

The role of maritime patrol missions is to monitor large oceanic areas. The authors focus on a complete signal-processing sequence from the primary detection of the targets to their classification or recognition from an airborne radar. Contrary to the classical approach in which detection, tracking, imaging and classification are considered separately, here the authors propose an integrated strategy based on a close cooperation among all of them. Recent developments in high range resolution target detection are presented and their integration in the complete system is discussed to limit false alarms. High-resolution ISAR imaging of ships is then tackled and associated with a feature extraction process and a support vector machine classifier. A set of real data is used to illustrate the imaging and classification results. [J775]

"Micro-Doppler analysis of wheels and pedestrians in ISAR imaging"

In radar imaging, it is well known that relative motion or deformations of parts of illuminated objects induce additional features in the Doppler frequency spectrum. These features are called micro-Doppler effect and appear as sidebands around the central Doppler frequency. They can provide valuable information about the structure of the moving parts and may be used for identification purposes. Previous papers have mostly focused on 1D micro-Doppler analysis. The authors propose to emphasise the analysis of such `non-stationary targets` using a 2D imaging space, using both the micro-Doppler and a high-range resolution analysis. As in 2D-ISAR imaging, range separation enables to better discriminate the various effects caused by the time-varying reflectors. The study is focused on two different common examples: rotating wheels and human motion. With the help of micro-Doppler signature, information on the geometrical features of wheels (position, orientation) and on the gait of pedestrians can be extracted. Examples will be shown with simulated and experimental data. [J776]

"Polarimetric ISAR autofocusing"

Interest in polarimetric inverse synthetic aperture radar (ISAR) systems has been growing because of their capability to provide extra information about the imaged target compared with single polarisation ISAR systems. Target classification and recognition can be improved by exploiting full polarisation ISAR images. Moreover, full polarisation can be exploited for improving image formation and in particular image autofocusing. Two novel image autofocusing techniques are defined by extending two well-known single polarisation autofocusing techniques, namely the image contrast-based autofocus and image entropy-based autofocus. A performance analysis is carried out by comparing the results obtained by using the extended and the original autofocusing techniques. [J777]

"Manoeuvring target motion parameter estimation for ISAR image fusion"

In inverse synthetic aperture radar (ISAR) imaging applications, generating an image of a manoeuvring target is a challenge due to the tradeoff between the fine image resolution requirements and the temporal variability of the Doppler response. The time frequency transform (TFT) is a common method to solve this problem. Prior TFT-based research assumes that the ISAR observes the target from a single fixed aspect. Because of its manoeuvring characteristics, the target motion features are sometimes not extractable from the observing aspect, but become much more distinct from other aspects. ISAR image fusion is thus able to provide significant advantages, since multiple looks of the same target from different aspects will increase the available knowledge. After constructing the common projection plane and building up the physical connection between radars and the manoeuvring target, the parameters that describe the target motion are estimated for very short time duration within which the Doppler response can be assumed to be a constant. Simulation results confirm the effectiveness of the estimation procedure and thus the fusion method. The authors conclude that the ISAR system must be carefully configured in order to realise the full benefits of their image fusion technique for manoeuvring targets. [J778]

"Real-time motion compensation, image formation and image enhancement of moving targets in ISAR and SAR using S-methodbased approach"

The commonly used technique for inverse synthetic aperture radar (ISAR)/synthetic aperture radar signal analysis is a two-dimensional Fourier transform (FT), which results in an image of the target's reflectivity mapped onto a range and cross-range plane. However, in cases where the line-of-sight projections of the target's point velocities change or there is uncompensated movement within the coherent integration time, the FT produces blurred images. For target recognition applications, mainly those in military surveillance and reconnaissance operations, a blurred ISAR image has to be refocused quickly so that it can be used for real-time target identification. Two standard techniques used for improvement of blurred ISAR images are motion compensation and the use of quadratic time-frequency representations. Both are computationally intensive. The authors present an effective quadratic time-frequency representation, the S-method. This approach performs better than the Fourier transform method by drastically improving images of fast manoeuvring targets and by increasing the SNR in both low and high noise environments. These advantages are a result of the S-method's ability to automatically compensate for quadratic and all even higher-order phase terms. Thus, targets with constant acceleration will undergo full motion compensation and their point scatterers will each be localised. It should be noted that the source of the quadratic term can come not only from acceleration, but also from non-uniform rotational motion and the cosine term in wide-angle imaging. The method is also computationally simple, requiring only slight modifications to the existing FT-based algorithm. The effectiveness of the S-method is demonstrated through application to simulated and experimental data sets. [J779]

"Slope-based frame selection and scaling technique for ship ISAR imaging"

The authors address the problem of optimum imaging time selection and angular motion estimation for ship ISAR or hybrid SAR/ISAR imaging. The aim is to select proper imaging times and to estimate ship angular motion in order to obtain high-quality top view or side view scaled images of the ship, suitable for processing by classification/identification procedures. For this purpose, a new technique is proposed, able to select the time instants better suited for top or side view image formation and to estimate the rotation motion for image scaling. The technique is based on a novel model of the phase/Doppler frequency of the generic ship scatterer and operates entirely in the range-Doppler image domain (as obtained via Fourier transform) by using the slopes of some extracted linear features, thus without requiring coherent processing. The performance of the complete ISAR technique is analysed in depth; the results of the application of the proposed technique to both simulated and live ISAR data prove the effectiveness of the proposed approach. [J780]

"Two-dimensional ISAR model and image reconstruction with stepped frequency-modulated signal"

A two-dimensional (2-D) inverse synthetic aperture radar (ISAR) return signal model that employs stepped frequency (SF) modulation is developed. The geometry of the examined ISAR scenario is described by analytical geometrical equations. The target to be imaged is represented by a rectangular grid of point scatterers, moving along a rectilinear trajectory at constant speed, without any rotational motion. Thus, the inverse synthetic aperture results from the translational motion of the target for a short period of time. The process of ISAR signal modelling through coherent summation of the SF-modulated signals reflected from different point scatterers of the target is thoroughly described. Moreover, an efficient ISAR image reconstruction approach, including cross-correlation-based range compression and fast-Fourier-transform-based azimuth compression, is presented through analytical mathematical expressions. Numerical simulations are carried out for various SF ISAR scenarios and high-resolution ISAR images are obtained by applying the proposed ISAR image reconstruction approach. Simulation results (ISAR images and corresponding entropy values) indicate the validity of the proposed 2-D SF ISAR return signal model and the efficiency of the proposed imaging algorithms. Finally, a numerical simulation result is illustrated, which shows the comparison of the performance of the proposed ISAR image reconstruction algorithms based on SF and linear frequency modulation waveforms. It is shown that the two waveforms attain almost the same ISAR image resolution. [J781]

"Spatially Adaptive Wavelet-Based Method Using the Cauchy Prior for Denoising the SAR Images"

The speckle noise complicates the human and automatic interpretation of synthetic aperture radar (SAR) images. Thus, the reduction of speckle is critical in various SAR image processing tasks. In this paper, we introduce a new spatially adaptive wavelet-based Bayesian method for despeckling the SAR images. The wavelet coefficients of the logarithmically transformed reflectance and speckle noise are modeled using the zero-location Cauchy and zero-mean Gaussian distributions, respectively. These prior distributions are then exploited to develop a Bayesian minimum mean absolute error estimator as well as a maximum a posteriori estimator. A new context-based technique with a reduced complexity is proposed for incorporating the spatial dependency of the wavelet coefficients with the Bayesian estimation processes. Experiments are carried out using typical noise-free images corrupted with simulated speckle noise as well as real SAR images, and the results show that the proposed method performs favorably in comparison to some of the existing methods in terms of the peak signal-to-noise ratio, speckle statistics and structural similarity index, and in its ability to suppress the speckle in the homogeneous regions [J782]

"Design of an S/X dual-band dual-polarised microstrip antenna array for SAR applications"

A novel design of dual-band dual-polarised microstrip antenna arrays for synthetic aperture radar applications with a frequency ratio of about 1:3 is presented. Stacked microstrip dipoles and square patches are used as the radiating elements at S- and X-bands, respectively. The microstrip dipoles are approximately coupled and the square patches are probe-fed. Experimental data show good agreement between simulated and measured results. The measured impedance bandwidth (VSWRles2) the prototype array reaches 8.9% and 17% for Sand X-bands, respectively, and the measured isolation between polarisations for both bands are better than -20 dB. The measured crosspolarisation level is les-26 dB for the S-band and les-31 dB for the X-band. The work verifies the practicability of the dual-band dual-polarised microstrip antenna array design, using the combination of microstrip dipoles and patches, and good bandwidth and isolation performance of the prototype array has been achieved [J783]

"Fiber-Optic Transceiver Module for High-Speed Intrasatellite Networks"

High-speed intrasatellite networks are needed to interconnect units such as synthetic aperture radars, high-resolution cameras, and fast image-compression processors that produce data beyond gigabits per second. We have developed a fiber-optic link, named SpaceFibre, which operates up to 3.125 Gb/s and is compatible with the existing SpaceWire network. The link provides symmetrical, bidirectional, full-duplex, and point-to-point communication. It employs 850-nm vertical-cavity surface emitting lasers, radiation-hardened laser-optimized 50/125 mum graded-index fibers, and GaAs p-i-n photo diodes. The transceiver electronics is realized using a multilayer-ceramic-substrate technology that enables the passive alignment of optical fibers to active devices. The SpaceFibre link demonstrator was tested to transfer data at 2.5 Gb/s over 100 m with a bit error rate of less than 1.3middot10-14. Fiber-pigtailed modules were stressed with temperature variations from -40degC to +85degC, vibrations up to 30 g, and mechanical shocks up to 3900 g. The test results of 20 modules show that the SpaceFibre link is a promising candidate for the upcoming high-speed intrasatellite networks [J784]

"Data Fusion for Reconstruction of a DTM, Under a Woodland Canopy, From Airborne L-band InSAR"

This paper investigates the utility of different parameters from polarimetric interferometric synthetic aperture radar

(InSAR) data for the identification of ground pixels in a woodland area to enable accurate digital terrain model (DTM) generation from the InSAR height of the selected ground hit pixels. The parameters assessed include radar backscatter, interferometric coherence, surface scattering proportion (based on Freeman-Durden decomposition), and standard deviation of the interferometric height. The method is applied to Monks Wood, a small seminatural deciduous woodland in Cambridgeshire, U.K., using airborne E-SAR data collected in June 2000. The 1428 variations of SAR-derived terrain models are validated with theodolite data and a light detection and ranging-derived DTM. The results show that increasing the amount of data used in the DTM creation does not necessarily increase the accuracy of the final DTM. The most accurate method, for the whole wood, was a fixed-window minimum-filtering algorithm, followed by a mean filter. However, for a spatial subset of the area using the upsi3backscattering coefficient to identify ground pixels outperforms the minimum filtering method. The findings suggest that backscatter information may often be undervalued in estimating terrain height under forest canopies [J785]

"A Takagi–Sugeno Fuzzy Rule-Based Model for Soil Moisture Retrieval From SAR Under Soil Roughness Uncertainty"

Radar remote sensing has shown its potential for retrieving soil moisture from bare soil surfaces. Since the backscattering process is also influenced by soil roughness, the characterization of this roughness is crucial for an accurate soil moisture retrieval. However, several field experiments have shown a large variability of the roughness parameters. Describing these parameters by means of possibility distributions allows to account for their uncertainty. Verhoest et al. introduced a retrieval procedure which calculates from these uncertain roughness parameters the possibility distribution of retrieved soil moisture, from which a soil moisture value and uncertainty upon the retrieval are estimated. The main disadvantage of their technique is the high computational demand, which hampers an operational application. In this paper, a fuzzy modeling approach, which is based on fuzzy rules of the Takagi-Sugeno type, is introduced that accurately simulates the soil moisture and the uncertainty upon its retrieved value as obtained by the possibilistic procedure [J786]

"Nonstationary Hidden Markov Models for Multiaspect Discriminative Feature Extraction From Radar Targets"

This paper presents a new scheme for radar target recognition, in which we fuse sequential radar echoes from multiple target-radar aspect angles. The nonstationary hidden Markov model (NSHMM) is employed to characterize the sequential information contained in multiaspect radar echoes. Features from echoes are extracted via the multirelax algorithm, and moments are used to reduce the extracted-feature dimensionality. The proposed NSHMM has many parameters and states to be estimated, so the Markov chain Monte Carlo sampling algorithm is adopted. Finally, this new scheme is demonstrated with experiments on inverse synthetic aperture radar data [J787]

"Adaptive boosting for SAR automatic target recognition"

The paper proposed a novel automatic target recognition (ATR) system for classification of three types of ground vehicles in the moving and stationary target acquisition and recognition (MSTAR) public release database. First MSTAR image chips are represented as fine and raw feature vectors, where raw features compensate for the target pose estimation error that corrupts fine image features. Then, the chips are classified by using the adaptive boosting (AdaBoost) algorithm with the radial basis function (RBF) network as the base learner. Since the RBF network is a binary classifier, the multiclass problem was decomposed into a set of binary ones through the error-correcting output codes (ECOC) method, specifying a dictionary of code words for the set of three possible classes. AdaBoost combines the classification results of the RBF network for each binary problem into a code word, which is then "decoded" as one of the code words (i.e., ground-vehicle classes) in the specified dictionary. Along with classification, within the AdaBoost framework, we also conduct efficient fusion of the fine and raw image-feature vectors. The results of large-scale experiments demonstrate that our ATR scheme outperforms the state-of-the-art systems reported in the literature [J788]

"Measurement of radar signatures of passenger cars: airborne SAR multi-frequency and polarimetric experiment"

The launch of SAR satellites with high-resolution and dual-receive antenna capabilities opens new possibilities for traffic-monitoring applications on a global scale. Thus, it will be possible to detect cars and measure their speed from the acquired along track interferometric data. The development of vehicle-detection algorithms requires the knowledge of the radar signatures of vehicles, especially under consideration of the geometry of the radar look direction and the vehicle orientation. The radar signatures of the non-moving cars are presented. They are estimated experimentally from airborne E-SAR multi-frequency and polarimetric data, which have been

collected during a flight campaign in 2003. Radar signatures are estimated for a considerable part of aspect angles ranging from 0deg to 180deg. The large synthetic aperture length of the E-SAR radar sensor allows the look processing of data and therefore allows an increase of the aspect angle resolution. The radar signature analysis for one type of passenger cars showed that the largest radar cross-section values and thus the greatest chance for high probability of detection are for cars standing in rear and front views of radar beam direction. This holds true for all frequencies and co-polarisations. Radar cross-section values for cross-polarisations and diagonal views are much lower and are therefore less suitable for car detection. The radar signature profile over a considerable range of aspect angles in fine resolution can be used further for the verification of simulation studies and for the performance prediction for traffic monitoring with a coming German TerraSAR-X satellite [J789]

"Radar Interferometric Measurements With a Planar Patch Antenna Array"

A planar patch antenna array has been made for radar interferometry. The antenna array consists of 32 rectangular patches on a ceramic loaded teflon substrate. The patches are individually coupled to the microwave electronics in two orthogonal circular polarizations. The radar interferometer is intended for topographic imaging in industrial environment, in this case, a blast furnace producing hot metal for the steel and metal industry. Ordinary imaging techniques with IR or visible radiation are not possible to use due to high temperatures, scattering from dust and particles. A model of blast furnace burden material surface was measured and detected. [J790]

"An Efficient Implementation of a Robust Phase-Unwrapping Algorithm"

A robust phase-unwrapping algorithm has been recently proposed and applied to accurately locate fast moving targets in multifrequency antenna array synthetic aperture radar imaging. This algorithm is based on two dimensional (2-D) searching and its complexity may be high. In this letter, we propose an efficient implementation of the robust phase-unwrapping algorithm. We show that the range of the 2-D searching, and therefore the complexity of the robust phase-unwrapping algorithm, can be significantly reduced [J791]

"Doppler aliasing reduction in SAR imagery using stepped-frequency waveforms"

A new technique for eliminating Doppler aliasing artifacts in synthetic aperture radar (SAR) imagery is presented. The technique uses continuous transmission of stepped-frequency (SF) waveforms to generate a simple, but effective, approximation of a two-dimensional |sinc|2 ambiguity function. This approach ensures aliasing artifacts are placed at nulls in a Doppler filter, effectively removing them from the imagery. Various methods of generating SF waveforms are introduced and their performance is quantified. Finally, simulated SAR imagery shows elimination of more than 99% of the aliased energy [J792]

"On the design of SAR apertures using the Cramer-Rao bound"

The Cramer-Rao inequality is applied to the likelihood function of the synthetic aperture radar (SAR) scatterer parameter vector to relate the choice of flight path to estimation performance. Estimation error bounds for the scatterer parameter vector (including height) are developed for multi-dimensional synthetic apertures, and quantify the performance enhancement over a limited sector of the image plane relative to standard-aperture single-pass SAR missions. An efficient means for the design and analysis of SAR waveforms and flight paths is proposed using simulated scattering models that are limited in size. Comparison of the error bounds to those for standard-aperture SAR show that estimates of scatterer range and cross-range positions are accurate for multi-dimensional aperture SAR, even with the additional estimator for height. Furthermore, multi-dimensional SAR is shown to address the layover problem [J793]

"Moving target location and imaging using dual-speed velocity SAR"

Velocity synthetic aperture radar (VSAR) is an effective tool for slowly moving target detection, location and imaging. However, it may mislocate fast moving targets because of the azimuth location ambiguity. The VSAR is generalised from flying with single speed to flying with dual-speed to resolve the azimuth location ambiguity. This new system is named dual-speed velocity SAR (DS-VSAR). Using DS-VSAR, the locations of both slowly and fast moving targets can be estimated accurately, and in the meantime the clutter can be suppressed. Some numerical examples are given to prove the effectiveness of DS-VSAR [J794]

"Quartic-Phase Algorithm for Highly Squinted SAR Data Processing"

In this letter, an algorithm based on a quartic-phase model is discussed for processing highly squinted synthetic aperture radar (SAR) data from a large range swath. In the algorithm, a precise quartic-phase model is adopted

to describe a range-dependent property of the SAR signal; a constant factor and a secondary scaling process are introduced to make the algorithm easy to be utilized compared with traditional nonlinear chirp scaling algorithms. The novel algorithm can process SAR data under a squint angle above 50deg and achieve a focus depth over 60 km [J795]

"A Segment-Based Speckle Filter Using Multisensoral Remote Sensing Imagery"

In the proposed approach, the well-known enhanced Lee filter is modified to allow the integration of feature outlines-previously extracted from segmented optical images. The filter is applied to several ENVISAT ASAR images that cover urban, agricultural, and forest areas during different plant phenological stages. The performance of this segment-based speckle filter is compared to those of other filters using ratio images, visual interpretation, and statistical indexes. The approach reduces the loss of radiometry and spatial information. It performs comparable to more complex methods and outperforms common techniques [J796]

"Reduced-Dimensional Processing for Ground Moving Target Detection in Distributed Space-Based Radar"

With multisatellite radar systems, several additional features are achieved: multistatic observation, interferometry, ground moving target indication (GMTI). In this letter, a new reduced-dimensional method based on joint pixels sum-difference (Sigma-Delta) data for clutter rejection and GMTI is proposed. The reduced-dimensional joint pixels Sigma-Delta data are obtained by the orthogonal projection of the joint pixels data of different synthetic aperture radar (SAR) images generated by a multisatellite radar system. In the sense of statistic expectation, the joint pixels Sigma-Delta data contain the common and different information among SAR images. Then, the objective of clutter cancellation and GMTI can be achieved by adaptive processing. Simulation results demonstrate the effectiveness and robustness of the proposed method even with clutter fluctuation and image coregistration errors [J797]

"Unsupervised Change Detection From Multichannel SAR Images"

Multichannel synthetic aperture radar (SAR) data present a good potential for environmental monitoring and disaster management, owing both to their insensitivity to atmospheric and sun-illumination conditions, and to the improved discrimination capability they may provide as compared to single-channel SAR. However, this requires accurate and possibly automatic techniques to generate change maps from multichannel SAR images acquired from the same geographic area at different times. In this letter, an automatic unsupervised contextual change-detection method is proposed for two-date multichannel SAR images, by integrating a SAR-specific extension of the Fisher transform with a variant of the expectation-maximization algorithm and with Markov random fields. The method is validated by experiments on SIR-C/XSAR data [J798]

"SABRINA: A SAR Bistatic Receiver for Interferometric Applications"

This letter discusses the implementation of SABRINA, Synthetic Aperture radar Bistatic Receiver for Interferometric Applications. The ground resolution of a fixed-receiver bistatic system is studied, showing that it is comparable to that of a monostatic system. Due to the short distance from target to receiver, large sensitivity is obtained. The noncooperative nature of the bistatic system forces a conservative data-acquisition strategy based on continuously sampling the scattered signal during a temporal window around the predicted satellite overpass time. Also, to be able to synchronize the system in time and in frequency, sampling of a direct signal obtained through an antenna pointed at the satellite is required. Besides the signal processing required to phase-lock the received signal, the bistatic synthetic aperture radar processing needs to take into account the azimuth-dependent phase history. First focused images obtained with the SABRINA-ENVISAT combination are discussed [J799]

"Feature-Independent Aperture Evaluator for the Curvilinear SAR"

Curvilinear synthetic aperture radar (SAR), as a more practicable 3-D SAR imaging system, utilizes parametric target feature estimates extracted from the received data to reconstruct the target image. The reconstructed image quality is then impacted by the estimation accuracy of the features. In this letter, through discussing the correlation between the system parameters and the estimation performance of the curvilinear SAR, a conclusion can be drawn on how the overall location accuracy of a target is determined by the correlation between the azimuth and elevation coordinates of the flight path, compactly characterizing the curvilinear aperture. Consequently, a new index, determined only with the aperture parameters, is proposed as an aperture evaluator, which is referred to as the feature-independent aperture evaluator (FAE). FAE can be used for guiding the operational aperture design [J800]

"Coregistration Based on Three Parts of Two Complex Images and Contoured Windows for Synthetic Aperture Radar Interferometry"

The coregistration of complex image pairs is a very important step in synthetic aperture radar interferometry (InSAR) data processing. This letter proposes a novel coregistration method that only needs three arbitrary parts of the two complex images instead of four parts in the existing coregistration methods. This method constitutes an integrated three-part method for InSAR data processing with our contoured-correlation-interferometry method for phase-image generation. Saving one part transmission makes a significant advantage when processing SAR images on satellites. Furthermore, we demonstrate that, by means of using fringe contoured windows instead of squared windows, the accuracy of the coregistration for both the three-part coregistration method and the existing methods can be improved considerably [J801]

"SAR Imaging Degradation by Ionospheric Irregularities Based on TFTPCF Analysis"

The effects of ionospheric irregularities on spaceborne synthetic aperture radar (SAR) signal propagation with double path and multilook angle are studied in a model in which a two-frequency and two-position coherence function (TFTPCF) has been adopted for analysis. The TFTPCF is derived from the phase-screen principle. The ambiguity function based on TFTPCF has been used to analyze the effects of ionospheric turbulence on range resolution and cross resolution. The results show that, in some cases, the effects from the irregularities on SAR imaging can be very serious [J802]

"Comparisons Between SAR Backscattering Coefficient and Results of a Thermodynamic Snow/Ice Model for the Baltic Sea Land-Fast Sea Ice"

We have compared the time series of C-band HH-polarization backscattering coefficients (sigmadeg) of the Baltic Sea land-fast level ice with results from a 1-D high-resolution thermodynamic snow/ice model (HIGHTSI). The sigmadeg time series were obtained from ENVISAT synthetic aperture radar (SAR) images. The study period was from the middle of the winter to the early melt season, February 3-April 7, 2004. Due to the large incidence angle range of the SAR images, the sigmadeg values were divided into three subseries. In general, the HIGHTSI results greatly helped to interpret the sigmadeg behavior with changing ice and weather conditions. The modeled snow-surface temperature, cases of snow melting, and evolution of snow and ice thickness were related to the changes in sigmadeg. Equally useful information could not be obtained solely on the basis of large-scale atmospheric models. Realistic forcing data for HIGHTSI were available in the form of coastal-weather observations and model results of the European Centre of Medium-Range Weather Forecasts (ECMWF). The latter make it possible to apply HIGHTSI in the interpretation of SAR data from all ice-covered seas. There were some cases where detailed ground truth, combined with theoretical sigmadeg modeling, would have been needed for interpretation of the sigmadeg trends. A very interesting observation was the large variation of level ice sigmadeg with changing weather conditions, which complicates automatic classification of the SAR images, and thus, the algorithms must be tuned for different ice conditions. The HIGHTSI model could act as an indicator of various ice conditions for algorithm development [J803]

"Analysis of the Effects of Faraday Rotation on Spaceborne Polarimetric SAR Observations at -Band"

Spaceborne microwave observation of subcanopy and subsurface requires the polarimetric synthetic aperture radar (SAR) technology at lower microwave frequencies, such as P-band. However, SAR observation at P-band is remarkably influenced by the Faraday rotation (FR) effect through the ionosphere. An example in this paper illustrates why the measured polarimetric data with FR at P-band cannot be directly applied to terrain surface classification. We further present that the parameters u, nu, H, alpha, A for terrain surface classification derived from the polarimetric data without FR, which are recovered from the data with FR, can be applied to the surface classification, there is a plusmnpi/2 ambiguity error unresolved. Based on gradual change of the FR degree along a geographical location, a method to eliminate the plusmnpi/2 ambiguity error is designed. Thus, the polarimetric scattering vector and Mueller matrix without FR and plusmnpi/2 ambiguity can be fully inverted from the measured polarimetric data with FR [J804]

"Submillimeter Accuracy of InSAR Time Series: Experimental Validation"

This paper presents the results of a blind experiment that is performed using two pairs of dihedral reflectors. The aim of the experiment was to demonstrate that interferometric synthetic aperture radar (InSAR) measurements can indeed allow a displacement time series estimation with submillimeter accuracy (both in horizontal and vertical directions), provided that the data are properly processed and the impact of in situas well as atmospheric effects is minimized. One pair of dihedral reflectors was moved a few millimeters between SAR acquisitions, in

the vertical and east-west (EW) directions, and the ground truth was compared with the InSAR data. The experiment was designed to allow a multiplatform and multigeometry analysis, i.e., each reflector was carefully pointed in order to be visible in both Envisat and Radarsat acquisitions. Moreover, two pairs of reflectors were used to allow the combination of data gathered along ascending and descending orbits. The standard deviation of the error is 0.75 mm in the vertical direction and 0.58 mm in the horizontal (EW) direction. GPS data were also collected during this experiment in order to cross-check the SAR results [J805]

"A New Statistical Similarity Measure for Change Detection in Multitemporal SAR Images and Its Extension to Multiscale Change Analysis"

In this paper, we present a new similarity measure for automatic change detection in multitemporal synthetic aperture radar images. This measure is based on the evolution of the local statistics of the image between two dates. The local statistics are estimated by using a cumulant-based series expansion, which approximates probability density functions in the neighborhood of each pixel in the image. The degree of evolution of the local statistics is measured using the Kullback-Leibler divergence. An analytical expression for this detector is given, allowing a simple computation which depends on the four first statistical moments of the pixels inside the analysis window only. The proposed change indicator is compared to the classical mean ratio detector and also to other model-based approaches. Tests on the simulated and real data show that our detector outperforms all the others. The fast computation of the proposed detector allows a multiscale approach in the change detection for operational use. The so-called multiscale change profile (MCP) is introduced to yield change information on a wide range of scales and to better characterize the appropriate scale. Two simple yet useful examples of applications show that the MCP allows the design of change indicators, which provide better results than a monoscale analysis [J806]

"Use of C-Band Ground Penetrating Radar to Determine Backscatter Sources Within Glaciers"

The question of penetration of synthetic aperture radar (SAR) signals at C-band frequency into polar glaciers is addressed by comparing ground penetrating radar (GPR) and SAR backscatter signatures. Profiles of the Kongsvegen glacier, Svalbard, were obtained with a C-band GPR. The received signal is converted to the equivalent radar cross section using the standard radar equation, thus mapping the effective scattering sources within the glacier at this frequency. The depth of the observed scattering sources is greatest in the superimposed ice where layers are clearly seen to a depth of approximately 14 m. The very high scattering properties of the upper firn layers preclude layers deeper than approximately 6 m from being imaged. Integrating the radar cross sections over the depth gives a single backscatter value that we compare with the backscatter coefficient (scattering cross section per unit area) of the processed SAR data for the same profile. The comparison indicates that for coincidentally acquired GPR and SAR data, the radar cross section measured by the GPR does represent the features that contribute to the SAR signal [J807]

"A Split-Based Approach to Unsupervised Change Detection in Large-Size Multitemporal Images: Application to Tsunami-Damage Assessment"

This paper presents a split-based approach (SBA) to automatic and unsupervised change detection in large-size multitemporal remote-sensing images. Unlike standard methods that are presented in the literature, the proposed approach can detect in a consistent and reliable way changes in images of large size also when the extension of the changed area is small (and, therefore, the prior probability of the class of changed pixels is very small). The method is based on the following: 1) a split of the large-size image into subimages; 2) an adaptive analysis of each subimage; and 3) an automatic split-based threshold-selection procedure. This general approach is used for defining a system for damage assessment in multitemporal synthetic aperture radar (SAR) images. The proposed system has been developed to properly identify different levels of damages that are induced by tsunamis along coastal areas. Experimental results that are obtained on multitemporal RADARSAT-1 SAR images of the Sumatra Island, Indonesia, confirm the effectiveness of both the proposed SBA and the presented system for tsunami-damage assessment [J808]

"Radar Signatures of Sahelian Surfaces in Mali Using ENVISAT-ASAR Data"

This paper presents an analysis of ENSIVAT advanced synthetic aperture radar data acquired over a Sahelian region located in Mali, West Africa. The considered period is 2004-2005 and includes two rainy seasons. Emphasis is put on two ScanSAR modes, namely, the global monitoring (GM) and the wide swath (WS) modes characterized by spatial resolutions of about 1 km and 150 m, respectively. Results show that the WS mode offers better performance in terms of radiometric resolution, radiometric stability, and speckle reduction than the GM mode. The latter is more appropriate for studies at large scale (> 10 times 10 km). In both modes, pronounced angular and temporal signatures are observed for most soil surfaces, and azimuthal effects are

observed on markedly orientated rocky surfaces. In contrast, polarization differences (VV/HH) are small during the dry season except on flat loamy soil surfaces. Finally, a relationship is observed between the normalized WS backscattering signal at HH polarization and the surface soil moisture of sandy soils. [J809]

"InSAR Elevation Bias Caused by Penetration Into Uniform Volumes"

Natural media like cold-land ice, vegetation, and dry sand are subject to a substantial penetration at microwave frequencies. For such media, the synthetic aperture radar (SAR) phase center is located below the surface, and consequently, the surface elevation determined with SAR interferometry (InSAR) is biased downward. For infinitely deep uniform volumes, the elevation bias is often equated with the penetration depth, but in this paper, it is shown that the two quantities generally differ. The interferometric bias is approximately equal to the two-way power-penetration depth if the latter is small compared to the ambiguity height, but for increasing penetration depth, the bias approaches one quarter of the ambiguity height. Consequently, no phase wrapping results even if the penetration depth exceeds the ambiguity height. The ratio of the InSAR elevation bias to the ambiguity height depends only on the ratio of the penetration depth to the ambiguity height, and the bias can be expressed in terms of the InSAR coherence magnitude, which makes it possible to correct the InSAR surface elevation for the bias. The volume depth can be considered infinite if it exceeds the penetration depth by a factor of two to five and if the surface scattering from the top and the bottom of the volume is negligible. [J810]

"UAVSAR: New NASA Airborne SAR System for Research"

NASA's Jet Propulsion Laboratory is currently building a reconfigurable, polarimetric L-band synthetic aperture radar (SAR), specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. Differential interferometry can provide key deformation measurements, important for studies of earthquakes, volcanoes, and other dynamically changing phenomena. Using precision real-time GPS and a sensor controlled flight management system, the system will be able to fly pre-defined paths with great precision. The expected performance of the flight control system will constrain the flight path to be within a 10 m diameter tube about the desired flight track. The radar will be designed to be operable on a Unpiloted Arial Vehicle (UAV) but will initially be demonstrated on a NASA Gulfstream III. The radar will be fully polarimetric, with a range bandwidth of 80 MHz (2 m range resolution), and will support a 16 km range swath. The antenna will be electronically steered along track to assure that the antenna beam can be directed independently, regardless of the wind direction and speed. Other features supported by the antenna include elevation monopulse and pulse-to-pulse re-steering capabilities that will enable some novel modes of operation. The system will nominally operate at 45,000 feet (13,800 m). The program began as an Instrument Incubator Project (IIP) funded by NASA Earth Science and Technology Office (ESTO). [J811]

"Online courses"

First Page of the Article [J812]

"R. Keith Raney Wins the 2007 IEEE Dennis J. Picard Medal for Radar Technologies and Applications"

R. Keith Raney is the recipient of the 2007 IEEE Dennis J. Picard Medal for Radar Technologies and Applications. A biography for Dr. Raney is provided. [J813]

"Coherence- and Amplitude-Based Analysis of Seismogenic Damage in Bam, Iran, Using ENVISAT ASAR Data"

The sensitivity of synthetic aperture radar (SAR) and interferometric SAR (InSAR) to surface properties, especially changes in height and roughness, combined with an all-weather capability, makes radar remote sensing a potential tool for mapping urban damage caused by earthquakes. With InSAR, surface displacement has been mapped successfully and in detail, but for urban-damage mapping, results have so far been less conclusive. ENVISAT Advanced SAR images of Bam, Iran, that were acquired before and after the 2003 earthquake were used. Between preseismic and coseismic image pairs, coherence decreased with increasing damage levels. However, contrary to previous studies, earthquake damage caused both increases and decreases in amplitude. Therefore, its absolute value, which correlated with damage level, was used. Individually, coherence difference led to better results than absolute amplitude change, although still with limited accuracy. The combination of both resulted in an overall accuracy of 52%. Since vegetation causes decorrelation, a predisaster Advanced Spaceborne Thermal Emission and Reflection Radiometer image was used to mask out vegetated areas, which improved the accuracy by 4%. The ground-truth map showed damage levels per district instead of per pixel. Therefore, the ratio of pixels classified as "damage" and "nondamage" was calculated for each damage

class of the map, and a clear relation was found. This shows that the aggregation level of the map partly explains the low-accuracy figures of the pixel-based evaluation. Although improvement was made, InSAR techniques for urban-damage mapping do not yet provide the accuracy levels needed for disaster mitigation. However, substantial improvements can be expected from instruments with higher spatial resolution, such as the recently launched Phased Array type L-band SAR and Terra SAR-X [J814]

"Reconstruction of DEMs From ERS-1/2 Tandem Data in Mountainous Area Facilitated by SRTM Data"

A new approach is presented in this paper to produce Digital Elevation Model (DEM) in mountainous areas with steep slope using ERS-1/2 tandem data. In order to reduce the impact of phase errors on the Interferometric Synthetic Aperture Radar (InSAR)-generated DEM, an external DEM such as that from Shuttle Radar Topography Mission (SRTM) is utilized in this approach. The proposed algorithm includes two steps: The first step is to model and remove phase trends with a linear regression analysis before converting phase to height; the second step is to filter unreliable height points before interpolating the DEM from the InSAR height map. The critical points are the following: 1) determining the one-to-one correspondence between the interferogram and the SRTM DEM before knowing the InSAR-derived elevation values and 2) estimating the elevation range of every pixel from SRTM DEM. To solve the first problem, an iteratively geocoding algorithm is performed. A DEM interpolation error model solves the second one. For InSAR data processing, the SRTM DEM is not only usable for modeling systematic phase errors but also for filtering gross height errors. The experiments in Zhangbei and the Three Gorges areas in China show that our approach has improved the accuracy of the resulting DEMs significantly without any ground control points. [J815]

"Automatic target recognition using multi-diversity radar"

The information content of radar target signatures is a key aspect for automatic target recognition. The role of high-range resolution is investigated as a function of the illuminating wavelength. The classification performance is evaluated using (i) full-scale 2D inverse synthetic aperture radar images obtained from a stepped-frequency chirp modulation radar system and (ii) the corresponding sub-spectra of the target reflectivity function forming lower resolution images at differing centre frequencies. The classification performance as given by different combinations of RF frequencies are also evaluated and compared with the coherent reconstruction from the full bandwidth. Finally, the classification results are also computed using multiple aspects to sense the target. In this way, classification performance as function of diversity space is examined. [J816]

"Bistatic SAR ATR"

With the present revival of interest in bistatic radar systems, research in that area has gained momentum. Given some of the strategic advantages for a bistatic configuration, and technological advances in the past few years, large-scale implementation of the bistatic systems is a scope for the near future. If the bistatic systems are to replace the monostatic systems (at least partially), then all the existing usages of a monostatic system should be manageable in a bistatic system. A detailed investigation of the possibilities of an automatic target recognition (ATR) facility in a bistatic radar system is presented. Because of the lack of data, experiments were carried out on simulated data. Still, the results are positive and make a positive case for the introduction of the bistatic configuration. First, it was found that, contrary to the popular expectation that the bistatic ATR performance might be substantially worse than the monostatic ATR performance, the bistatic ATR performed fairly well (though not better than the monostatic ATR). Second, the ATR performance does not deteriorate substantially with increasing bistatic angle. Last, the polarimetric data from bistatic scattering were found to have distinct information, contrary to expert opinions. Along with these results, suggestions were also made about how to stabilise the bistatic-ATR performance with changing bistatic angle. Finally, a new fast and robust ATR algorithm (developed in the present work) has been presented. [J817]

"Space-surface bistatic synthetic aperture radar with global navigation satellite system transmitter of opportunity-experimental results"

Progress in the study of space-surface synthetic aperture radar is presented. Global navigation satellite system is considered as the transmitter of opportunity. It highlights the various important issues to successfully obtain an image. The experimental testing of the imaging algorithm is presented and verified using a GLONASS satellite signal. [J818]

"Automatic Reconstruction of Building Objects From Multiaspect Meter-Resolution SAR Images"

Reconstruction of 3-D objects from multiaspect high- resolution synthetic aperture radar (SAR) images is of great

importance for SAR technology applications. In this paper, simple building objects are modeled as cuboids, and an approach for automatic reconstruction of 3-D building objects from multiaspect SAR images in meter resolution is developed. The edge detector of constant false alarm rate and a Hough transform technique for parallel line segment pairs are first employed to extract the parallelogram-like image of the building walls in SAR images. A set of probability density functions is presented to describe the object images and their multiaspect coherence. The maximum-likelihood estimation of an object is then derived from its multiaspect object images. A hybrid priority criterion is defined to evaluate the reliability of the reconstruction result. An automatic reconstruction algorithm is further developed to match object images of different aspects and, finally, to reconstruct the building objects. Besides, an iterative method is proposed for the coregistration of multiaspect building images. Four-aspect simulated images of a virtual scene and four-aspect Pi-SAR images over the campus of Tohoku University, Japan, are investigated. Reconstruction of building objects from their multiaspect images shows the fidelity of the whole process chain and the feasibility of 3-D objects automatic reconstruction from multiaspect SAR images. At last, a practical application that is based on spaceborne meter-resolution SAR is proposed. [J819]

"Design, optimization, and validation of a planar nine-element Quasi-Yagi antenna array for X-band applications [JAntenna designer's Notebook]"

A planar antenna array, based on nine identical quasi-Yagi elements, is presented in this paper. Contrary to conventional designs, the feeding network is composed of three-way power dividers, which are carefully designed in order to provide synchronized output signals over a wide frequency range. The use of spline-shaped microstrip lines suppresses coupling effects by parallel lines. Thus, signal distortions within the feeding network are minimized. Compared to conventional designs with eight elements, the additional antenna element will enhance the gain of the array, which is between 10.5 dBi and 13 dBi in the X band. The input return loss of the antenna array is below -15 dB over most parts of the relevant spectrum, with a total bandwidth of 45%. The planar antenna array is well suited as a radiating element in linear phased arrays for multifunction radars, including SAR and MTI. Additionally, the suitability of this antenna for phased-array applications is studied by an experimental setup consisting of five antenna plates. [J820]

"Short Courses"

{no data available} [J821]

"Estimation of Forest Fuel Load From Radar Remote Sensing"

Understanding fire behavior characteristics and planning for fire management require maps showing the distribution of wildfire fuel loads at medium to fine spatial resolution across large landscapes. Radar sensors from airborne or spaceborne platforms have the potential of providing quantitative information about the forest structure and biomass components that can be readily translated to meaningful fuel load estimates for fire management. In this paper, we used multifrequency polarimetric synthetic aperture radar (SAR) imagery acquired over a large area of the Yellowstone National Park by the Airborne SAR sensor to estimate the distribution of forest biomass and canopy fuel loads. Semiempirical algorithms were developed to estimate crown and stem biomass and three major fuel load parameters, namely: 1) canopy fuel weight; 2) canopy bulk density; and 3) foliage moisture content. These estimates, when compared directly to measurements made at plot and stand levels, provided more than 70% accuracy and, when partitioned into fuel load classes, provided more than 85% accuracy. Specifically, the radar-generated fuel parameters were in good agreement with the field-based fuel measurements, resulting in coefficients of determination of R2=85 for the canopy fuel weight, R2 =0.84 for canopy bulk density, and R2=0.78 for the foliage biomass [J822]

"High-Resolution 3-D Flood Information From Radar Imagery for Flood Hazard Management"

This paper presents a remote-sensing-based steady-state flood inundation model to improve preventive flood-management strategies and flood disaster management. The Regression and Elevation-based Flood Information eXtraction (REFIX) model is based on regression analysis and uses a remotely sensed flood extent and a high-resolution floodplain digital elevation model to compute flood depths for a given flood event. The root mean squared error of the REFIX, compared to ground-surveyed high water marks, is 18 cm for the January 2003 flood event on the River Alzette floodplain (G.D. of Luxembourg), on which the model is developed. Applying the same methodology on a reach of the River Mosel, France, shows that for some more complex river configurations (in this case, a meandering river reach that contains a number of hydraulic structures), piecewise regression is required to yield more accurate flood water-line estimations. A comparison with a simulation from the Hydrologic Engineering Centers River Analysis System hydraulic flood model, calibrated on the same events, shows that, for both events, the REFIX model approximates the water line reliably [J823]

"Comments on “Water Quality Retrievals From Combined Landsat TM Data and ERS-2 SAR Data in the Gulf of Finland”"

A paper by Zhang, using a feedforward artificial neural network (ANN) for water quality retrievals from combined Thematic Mapper data and synthetic aperture radar data in the Gulf of Finland, has been published in this journal. This correspondence attempts to discuss and comment on the paper by Zhang The amount of data used in the paper by Zhang is not enough to determine the number of fitting parameters in the networks. Therefore, the models are not mathematically sound or justified. The conclusion is that ANN modeling should be used with care and enough data [J824]

"A Multitemporal Method for Correction of Tropospheric Effects in Differential SAR Interferometry: Application to the Gulf of Corinth Earthquake"

Tropospheric inhomogeneities can form a major error source in differential synthetic aperture radar interferometry measurements, which are used in slow-deformation monitoring. Indeed, variations of atmospheric conditions between two radar acquisitions produce variations in the signal path of two images and, thus, additional fringes on differential interferograms. These effects have a strong influence on interferograms and must be compensated to obtain reliable deformation measurements. This paper presents a methodological approach to reduce at both global and local scales tropospheric contributions directly from differential interferograms. It first requires refined knowledge of the stable scatterers that can only be obtained from the analysis of a large population of multitemporal interferograms. The correction of global-scale atmospheric contribution exploits the correlation between phase and topography. The correction of local artifacts is based on the correlation between interferograms containing one common acquisition. This technique is validated on a database of 81 differential interferograms covering the Gulf of Corinth (Greece) and used to improve the measurements of ground deformation compared to global positioning system measurements [J825]

"A Novel Approach for Disaster Monitoring: Fractal Models and Tools"

In this paper, we present a complete framework to support the monitoring of natural and man-made disasters by means of synthetic aperture radar (SAR) images. The fractal geometry is the most appropriate mathematical instrument in describing the irregularity of a natural observed scene, by means of few effective and reliable parameters. Therefore, fractal concepts can be used to model and identify geometrical changes that occurred in areas hit by disasters. We present an overall framework employing fractal-based models, algorithms, and tools to support the identification of natural area changes due to natural or man-made disasters. Such a framework includes an algorithm used to extract fractal parameters from a 2-D signal, a fractal interpolation tool, and a SAR raw-signal simulator. The combined use of these tools provides an innovative instrument for disaster monitoring applications. In this paper, we implement the fractal framework to obtain a relation between the fractal parameters of a SAR image and those of the relative imaged area. In addition, a case study is discussed, showing the potentiality of our framework for flooding detection [J826]

"Rapid Damage Detection in the Bam Area Using Multitemporal SAR and Exploiting Ancillary Data"

In this paper, the problem of rapid earthquake damage detection in urban areas using multitemporal synthetic aperture radar data is addressed. It is shown that the combination of intensity and phase features enhances the damage pattern extracted from the data temporal stack using a spatially aware classifier. Moreover, the use of ancillary data, easily available for urban areas, further improves the accuracy by discarding uninteresting parts of the scene and forcing homogeneous classification within city blocks to avoid "class-blurring" effects consequential to the window-based computation of relevant measures. The procedure is validated based on results for the town of Bam, Iran, and compared with ground-based survey maps [J827]

"A Physically Consistent Speckle Model for Marine SLC SAR Images"

A new physically based speckle model for marine single-look complex (SLC) synthetic aperture radar (SAR) images is here presented and investigated. The model allows using full-resolution SAR images instead of multilook SAR images, in which, at the expense of a coarser spatial resolution, the speckle is mitigated. The model is based on the three-parameters generalized-K (GK) probability density function (pdf). GK pdf is a suitable physically-based speckle model for marine SAR images ensuring a continuous and physically consistent transition among different scattering scenarios. This speckle model embodies Rayleigh, K, and Rice scattering scenes which are typical of marine scenes. The use of the three parameters, related to the GK pdf ones, is able to highlight the presence of both low backscattering areas and areas in which a small dominant scatterer is present. This is operationally interesting in SAR oil spill detection procedures. [J828]

"Remote data sensing using SAR and harmonic reradiators"

In sensor networks distributed over large areas, communication by means of active transmitters on sensor nodes is inherently energy expensive and poses a significant bottleneck to achieve a long battery life. We propose modulated reradiation of radar illumination as a means to transmit information from a group of sensors to an airborne radar. This puts the communications energy burden on the radar transmitter rather than on the sensor nodes, thus increasing their battery lifetimes. To distinguish the sensor return from the clutter return, the modulation on the sensors is done by switching a nonlinear load on the sensor antenna and processing the harmonic reradiation. We present techniques to transmit information from the sensors, which use stripmap mode synthetic aperture radar (SAR) ideas to decode the information and to simultaneously obtain a geographic map of the sensor locations. [J829]

"Optimum relative speed discretisation for detection of moving objects in wide band SAR"

Here, ground moving target indication (GMTI) using synthetic aperture radar (SAR) is considered. SAR GMTI requires that relative speed between the target and the SAR platform is included in the detection algorithm. A separation between the true relative speed and the relative speed used in the SAR process will cause unfocused targets, and decrease detectability. Blind hypotheses of relative speeds are used in the detection phase of moving targets in SAR. The step size between the hypotheses (or discretisation step) in relative speed involves a trade off between the number of hypotheses to test and detectability. A large number of tests will increase detectability but will also increase computation load and vice versa. The relevance of relative speed increases as the azimuth integration time gets larger. Long integration time is associated with low signature moving target detection in strong clutter environments, or for SAR GMTI at low frequencies. The optimum discretisation of normalised relative speed for moving target detection has been determined. The optimum discretisation is derived from the moving target impulse response. Use of optimum discretisation reduces the computation burden in SAR GMTI and secures the detectability. [J830]

"UWB Array-Based Sensor for Near-Field Imaging"

In this paper, the development of an ultra-wideband (UWB) array-based time-domain radar sensor for near-field imaging is described. The radar sensor is designed to be used within a vehicle-mounted multisensor system for humanitarian demining. The main novelty of the radar lies in the system design with a single transmitter and multichannel receiver. Design of the UWB antenna array is also novel. The radar produces 3D images of subsurface by 1D mechanical scanning. The imaging capability of the radar is realized via electronic steering of the receive antenna footprint in a cross-scan direction and synthetic aperture processing in an along-scan direction. Imaging via footprint steering allows for a drastic increase in the scanning speed. [J831]

"Conceptual Case for Assimilating Interferometric Synthetic Aperture Radar Data Into the HAZUS-MH Earthquake Module"

The study of the Earth as a system is being adopted widely by geoscientists. Numerical models and simulations are providing the capability to rapidly test hypotheses and make forecasts of complex geophysical behavior. International efforts are seeking to integrate existing and emerging Earth observation systems into a global network, with enhanced data distribution, models, and decision support tools. Remote sensing is poised to fulfil the increasing need for a synoptic framework. However, the desire to improve the connection between scientific research and societal benefits has not been matched with resources and tools required to bridge the gap between research and applications. Natural hazards research and disaster management are a prime example. Here, we present a conceptual case for how interferometric synthetic aperture radar (InSAR) data could make a definitive contribution to understanding earthquake processes while simultaneously supporting policy- and decision-making. InSAR measurements derived from time series of radar observations from Earth orbit uniquely can provide geographically comprehensive maps of surface deformation. Observing system simulations are suggested to evaluate the potential contributions of a future system. Simulations would adopt an open seismic hazard analysis (SHA) framework, OpenSHA, recognizing the need for more physics-based modeling and computational infrastructure. SHA is employed by the HAZUS-MH earthquake module to estimate losses. InSAR measurements of strain accumulation would provide event magnitude recurrence bounds for probabilistic SHA, while coseismic InSAR measurements would add constraints on fault rupture models for deterministic approaches. Moreover, interferograms would be incorporated graphically as proxy seismic risk maps for planning and mitigation [J832]

"Joint estimation of Doppler centroid and rate for SAR with large range migration"

For synthetic aperture radar (SAR) with large range migration, the estimation accuracy of Doppler rate may be

poor without range migration correction (RMC), while inversely the correct RMC needs the accurate knowledge of Doppler parameters. By exploiting the statistical property of SAR range-Doppler domain signal, a novel Doppler parameter estimation method is proposed to solve the above dilemma. Free of a priori knowledge of platform motion including antenna beam pointing direction and flying velocity, the proposed method can realise pulse repetition frequency-ambiguity resolving, clutter-locking and auto-focusing both accurately and jointly. It is also robust to scene contrast. Experimental results based on real RADARSAT data are provided to demonstrate the effectiveness of the proposed method. [J833]

"Two-dimensional nonparametric spectral analysis in missing data case"

We consider two-dimensional (2-D) nonparametric complex spectral estimation (with its 1-D counterpart as a special case) of data matrices with missing samples occurring in arbitrary patterns. Previously, the missing amplitude and phase estimation-expectation maximization (MAPES-EM) algorithms were developed for the general 1-D missing-data problem and shown to have excellent spectral estimation performance. In this correspondence, we present 2-D extensions of MAPES-EM and develop another 2-D MAPES algorithm, referred to as MAPES-CM, which solves a maximum likelihood problem iteratively via cyclic maximization (CM). Compared with MAPES-EM, MAPES-CM has similar spectral estimation performance but is computationally much more efficient, which is especially important for long data sequences and 2-D applications such as synthetic aperture radar (SAR) imaging. [J834]

"Eigensubspace-Based Filtering With Application in Narrow-Band Interference Suppression for SAR"

Synthetic aperture radar (SAR) has found wide applications in many areas, e.g., battlefield awareness. However, SAR is vulnerable to various kinds of interference, among which narrow-band interference (NBI) is commonly used. In this letter, an eigensubspace-based filtering approach is proposed for NBI suppression in SAR without using passive-sniff data as the reference signal. Moreover, the proposed method can deal with smart or interrupted NBI. Both simulation and experimental results are provided to illustrate the performance of the proposed approach [J835]

"A Keystone Transform Without Interpolation for SAR Ground Moving-Target Imaging"

Synthetic aperture radar (SAR) image formation for a ground moving target necessitates the compensation of the unknown target trajectory. The keystone transform has been employed to remove the linear component of the range migration for the moving target, where interpolation is required. In this letter, a realization of the keystone transform avoiding interpolation is presented. The kernel of this transform, i.e., the range-frequency-dependent azimuth time rescaling, is implemented using only complex multiplications and fast Fourier transforms based on the scaling principle, which has been successfully applied in the equalization of the space-variant range cell migration in SAR processing. In addition, the moving target is coarsely focused according to the SAR geometry and the platform velocity while exploiting the scaling principle. This preliminary focusing is helpful in the isolation of the moving target from ground clutter, so as to facilitate a more refined processing with respect to each mover. SAR raw data combined with simulated echoes of moving targets are utilized to validate the presented approach [J836]

"Wind-Vector Estimation for RADARSAT-1 SAR Images: Validation of Wind-Direction Estimates Based Upon Geometry Diversity"

In this letter, a new wind-vector algorithm is presented that uses radar backscatter sigma0measurements at two adjacent subscenes of RADARSAT-1 synthetic aperture radar (SAR) images, with each subscene having slightly different geometry. Resultant wind vectors are validated using in situ buoy measurements and compared with wind vectors determined from a hybrid wind-retrieval model using wind directions determined by spectral analysis of wind-induced image streaks and observed by colocated QuikSCAT measurements. The hybrid wind-retrieval model consists of CMOD-IFR2 [applicable to C-band vertical-vertical (VV) polarization] and a C-band copolarization ratio according to Kirchhoff scattering. The new algorithm displays improved skill in wind-vector estimation for RADARSAT-1 SAR data when compared to conventional wind-retrieval methodology. In addition, unlike conventional methods, the present method is applicable to RADARSAT-1 images both with and without visible streaks. However, this method requires ancillary data such as buoy measurements to resolve the ambiguity in retrieved wind direction [J837]

"A Two-Dimensional Spectrum for Bistatic SAR Processing Using Series Reversion"

This letter derives the two-dimensional point target spectrum for an arbitrary bistatic synthetic aperture radar

configuration. The method described makes use of series reversion, the method of stationary phase, and Fourier transform pairs to derive the point target spectrum. The accuracy of the spectrum is controlled by keeping enough terms in the two series expansions, and is verified with a point target simulation [J838]

"A Technique for Jamming Bi- and Multistatic SAR Systems"

Bi- and multistatic synthetic aperture radars (SARs) can achieve reduced vulnerability in military systems, especially in directional responsive jamming, and avoid physical attack to radar platforms. In this letter, a technique for jamming bi- and multistatic SAR systems is proposed, which is implemented with a novel transponder. This technique is based on a delayed retransmission of the received radar signal toward the scene. Unlike conventional delayed jamming, here, the jammer's delay time is random in the whole range interval. Moreover, the jamming signal is not retransmitted to the receiver directly but to the areas with targets that need to be protected against being imaged by radar. By this, it is then possible to jam the radar echoes independent of the receiver location [J839]

"An Adaptive Contoured Window Filter for Interferometric Synthetic Aperture Radar"

An adaptive contoured window filter is proposed to filter off the noise from phase images of interferometric synthetic aperture radar (InSAR) in this letter. The contoured windows can best satisfy the requirement that constrains the phase signal constant inside windows on which low-pass filtering can remove the noise well while the fringe phases are well preserved. The contoured windows are determined by tracing along the local fringe orientation. An algorithm for determining window sizes adaptive to the fringe density is also proposed. The theoretical analysis and experiments prove that the proposed filter can greatly remove decorrelation noise while preserving the fringe phase well, even for those fringes with strong curvatures for InSAR processing [J840]

"Analysis of the Backscattering Coefficient of Salt-Affected Soils Using Modeling and RADARSAT-1 SAR Data"

Salt significantly changes the backscattering coefficient of wet soil. This is easily observed on RADARSAT-1 synthetic aperture radar (SAR) images acquired over a salty depression located in the Egyptian desert. The aim of this paper is to use backscattering models to understand the behavior of the backscattering coefficient over salt-affected soils and to evaluate the possibility of monitoring the salt content. Simulations conducted over salt-affected soils show a lower sensitivity of these models to soil moisture compared to nonaffected soils. Besides, there is no model suitable to represent the variation of the backscattering coefficient due to changes in soil salinity. These results are discussed with regard to the magnitude of the two components of the dielectric constant (epsiv' and epsiv''). Based on a series of relationships, we propose a parametric formulation that allows us to determine the salinity acting on RADARSAT-1 SAR images without any use of backscattering models [J841]

"Vibration and Rotation in Millimeter-Wave SAR"

Synthetic aperture radar (SAR) provides high-resolution images of static ground scenes, whereas processing of data containing ground object motion results in varying focusing effects. Special cases of such motion are vibration and rotation, which are closely related to each other. Their patterns may be distinctly recognizable in focused SAR intensity images as well as in a time-frequency analysis. Millimeter-wave (mmW) SAR is well suited to image vibration because its wavelength is close to typical vibration amplitudes. Through a thorough motion analysis in a standard SAR system model, we show the effects of rotation and vibration in mmW SAR theoretically and in simulated and real data [J842]

"Application of DInSAR-GPS Optimization for Derivation of Fine-Scale Surface Motion Maps of Southern California"

A method based on random field theory and Gibbs-Markov random fields equivalency within Bayesian statistical framework is used to derive 3-D surface motion maps from sparse global positioning system (GPS) measurements and differential interferometric synthetic aperture radar (DInSAR) interferogram in the southern California region. The minimization of the Gibbs energy function is performed analytically, which is possible in the case when neighboring pixels are considered independent. The problem is well posed and the solution is unique and stable and not biased by the continuity condition. The technique produces a 3-D field containing estimates of surface motion on the spatial scale of the DInSAR image, over a given time period, complete with error estimates. Significant improvement in the accuracy of the vertical component and moderate improvement in the accuracy of the horizontal components of velocity are achieved in comparison with the GPS data alone. The method can be expanded to account for other available data sets, such as additional interferograms, lidar, or

leveling data, in order to achieve even higher accuracy [J843]

"A Fusion Scheme for Joint Retrieval of Urban Height Map and Classification From High-Resolution Interferometric SAR Images"

The retrieval of 3-D surface models of the Earth is a major issue of remote sensing. Some nice results have already been obtained at medium resolution with optical and radar imaging sensors. For instance, missions such as the Shuttle Radar Topography Mission (SRTM) or the SPOT HRS have provided accurate digital terrain models. The computation of a digital surface model (DSM) over urban areas is the new challenging issue. Since the recent improvements in radar image resolution, synthetic aperture radar (SAR) interferometry, which had already proved its efficiency at low resolution, has provided an accurate tool for urban 3-D monitoring. However, the complexity of urban areas and high-resolution SAR images prevents the straightforward computation of an accurate DSM. In this paper, an original high-level processing chain is proposed to solve this problem, and some results on real data are discussed. The processing chain includes three main steps, namely: (1) information extraction; (2) fusion; and (3) correction. Our main contribution addresses the merging step, where we aim at retrieving both a classification and a DSM while imposing minimal constraint on the building shapes. The joint derivation of height and class enables the introduction of more contextual information. As a consequence, more flexibility toward scene architecture is possible. First, the initial images (interferogram, amplitude, and coherence images) are converted into higher-level information mapping with different approaches (filtering, object recognition, or global classification). Second, these new images are merged into a Markovian framework to jointly retrieve an improved classification and a height map. Third, DSM and classification are improved by computing layover and shadow from the estimated DSM. Comparison between shadow/layover and classification allows some corrections. This paper mainly addresses the second step, while the two others are briefly explained and referred to already publis- hed papers. The results obtained on real images are compared to ground truth and indicate a very good accuracy in spite of limited image resolution. The major limit of DSM computation remains the initial spatial and altimetric resolutions that need to be made more precise [J844]

"Adding Sensitivity to the MLBF Doppler Centroid Estimator"

The multilook beat frequency (MLBF) algorithm is the Doppler centroid estimator most commonly used in practice to solve the Doppler ambiguity. However, it still makes errors, notably in medium- or low-contrast scenes. In this paper, we present two ways in which the estimation sensitivity of the MLBF algorithm can be improved. First, we give a more thorough frequency-domain explanation of how the MLBF algorithm works and explain how cross beating and range migration cause estimation difficulties. The first improvement to the algorithm replaces the fast Fourier transform (FFT)-based beat frequency estimator with a more accurate one that uses phase increments. It avoids the FFT limitations of resolution and quantization, especially when the signal is discontinuous in one range cell due to range cell migration or burst mode operation (ScanSAR). A second improvement uses range cell migration correction to straighten the target trajectories before the beat frequency estimator is applied. This has the effect of narrowing the bandwidth of the beat signal and reducing the effect of cross beating. Finally, experiments with RADARSAT-1 data are used to illustrate the improved estimation accuracy of the modified algorithm [J845]

"On the Extension of Multidimensional Speckle Noise Model From Single-Look to Multilook SAR Imagery"

Speckle noise represents one of the major problems when synthetic aperture radar (SAR) data are considered. Despite the fact that speckle is caused by the scattering process itself, it must be considered as a noise source due to the complexity of the scattering process. The presence of speckle makes data interpretation difficult, but it also affects the quantitative retrieval of physical parameters. In the case of one-dimensional SAR systems, speckle is completely determined by a multiplicative noise component. Nevertheless, for multidimensional SAR systems, speckle results from the combination of multiplicative and additive noise components. This model has been first developed for single-look data. The objective of this paper is to extend the single-look data model to define a multilook multidimensional speckle noise model. The asymptotic analysis of this extension, for a large number of averaged samples, is also considered to assess the model properties. Details and validation of the multilook multidimensional speckle noise model are provided both theoretically and by means of experimental SAR data acquired by the experimental synthetic aperture radar system, operated by the German Aerospace Center [J846]

"SAR Polarimetry to Observe Oil Spills"

A study on sea oil spill observation by means of polarimetric synthetic aperture radar (SAR) data is accomplished. It is based on the use of a polarimetric constant false alarm rate filter to detect dark patches over

SAR images. Then, the target decomposition theorem is exploited to distinguish oil spills and look-alikes. Experiments are conducted on polarimetric SAR data acquired during the SIR-C/X-SAR mission on October 1994. The data were processed and calibrated at the Jet Propulsion Laboratory, National Aeronautics and Space Administration. Results show that the new polarimetric approach is able to assist classification [J847]

"Theoretical Evaluation of Several Possible Along-Track InSAR Modes of TerraSAR-X for Ocean Current Measurements"

The German satellite TerraSAR-X, scheduled for launch in late 2006, will permit high-resolution ocean current measurements by along-track interferometric SAR (along-track InSAR) in various experimental modes of operation, using different sections of its X-band SAR antenna array with a total length of 4.8 m as individual receive antennas. Depending on antenna and receive-chain settings, effective InSAR time lags of about 0.17 to 0.29 ms can be realized in combination with different noise levels, single-look resolutions, swath widths, and incidence angles. We give an overview of the characteristics of the possible InSAR modes and evaluate their suitability for current measurements on the basis of simulated data products. Our results indicate that the quality of interferometric stripmap data from TerraSAR-X will be clearly superior to the quality of the existing data acquired over the Dutch coast during the Shuttle Radar Topography Mission; accurate current retrievals can be expected at effective spatial resolutions on the order of 500 m. However, in modes using a multiplexed single receive chain, the effective swath width of stripmap data will be limited to only 15 km, while dual receive-chain operation offers a swath width of 30 km for stripmap data and promises a reasonable data quality even for ScanSAR data with a maximum swath width of 100 km. Finally, we consider fundamental relations between along-track baseline, instrument noise, and resulting InSAR phase noise to discuss the potential for current measuring performance improvements of TerraSAR-X follow-on satellites [J848]

"A Two-Dimensional Bandwidth Extrapolation Technique for Polarimetric Synthetic Aperture Radar Images"

The resolution of a synthetic aperture radar (SAR) image, in range and azimuth, is determined by the transmitted bandwidth and the synthetic aperture length, respectively. Various superresolution techniques for improving resolution have been proposed, and we have proposed an algorithm that we call polarimetric bandwidth extrapolation (PBWE). To apply PBWE to a radar image, one needs to first apply PBWE in the range direction and then in the azimuth direction, or vice versa . In this paper, PBWE is further extended to the 2-D case. This extended case (2D-PBWE) utilizes a 2-D polarimetric linear prediction model and expands the spatial frequency bandwidth in range and azimuth directions simultaneously. The performance of the 2D-PBWE is shown through a simulated radar image and a real polarimetric SAR image [J849]

"Target Scattering Decomposition in Terms of Roll-Invariant Target Parameters"

The Kennaugh-Huynen scattering matrix con-diagonalization is projected into the Pauli basis to derive a new scattering vector model for the representation of coherent target scattering. This model permits a polarization basis invariant representation of coherent target scattering in terms of five independent target parameters, the magnitude and phase of the symmetric scattering type introduced in this paper, and the maximum polarization parameters (orientation, helicity, and maximum return). The new scattering vector model served for the assessment of the Cloude-Pottier incoherent target decomposition. Whereas the Cloude-Pottier scattering type alpha and entropy H are roll invariant, beta and the so-called target-phase parameters do depend on the target orientation angle for asymmetric scattering. The scattering vector model is then used as the basis for the development of new coherent and incoherent target decompositions in terms of unique and roll-invariant target parameters. It is shown that both the phase and magnitude of the symmetric scattering type should be used for an unambiguous description of symmetric target scattering. Target helicity is required for the assessment of the symmetry-asymmetry nature of target scattering. The symmetric scattering type phase is shown to be very promising for wetland classification in particular, using polarimetric Convair-580 synthetic aperture radar data collected over the Ramsar Mer Bleue wetland site to the east of Ottawa, Ontario, Canada [J850]

"Enhancement of Low-Contrast Curvilinear Features in Imagery"

A new method is described for enhancing low-contrast curvilinear features in imagery that combines directional filtering with Fischler, Tenenbaum and Wolf's F*algorithm for computing minimum cost paths. The method exploits a phenomenon called "the stability of lines over angle." The idea is that when a directionally filtered image contains a line plus noise, minimum cost paths tend to be aligned in the direction of the line with random jumps between parallel paths. When the input image contains noise only, the direction of minimum cost paths resemble random walks with drift. As the direction of the filter changes, minimum cost paths that follow true features persist and are more stable over angle than those that follow noise. Adding them up in an accumulator

array over angle produces a larger number of votes along signal paths than along noise paths. This provides a means for enhancing trajectories of low-contrast features. Several examples illustrate the enhancement of forest trails in USGS aerial imagery, linear features on Mars, and roads in synthetic aperture radar imagery [J851]

"Optimal Sharpness Function for SAR Autofocus"

Phase-error correction through the optimization of an image-domain sharpness function provides one method for the auto-focus of synthetic aperture radar (SAR) imagery. Several ad-hoc sharpness functions have been proposed, implemented, and analyzed, but none of these has been motivated as the solution to a well-defined statistical estimation problem. In this letter, a SAR sharpness function is derived that induces the solution to maximum-likelihood and maximum-posterior estimation for idealized SAR data. Furthermore, a limiting form of the optimal sharpness function is shown to be the popular intensity-squared sharpness [J852]

"Estimating Snow Accumulation From InSAR Correlation Observations"

Snow accumulation in remote regions, such as Greenland and Antarctica, is a key factor for estimating the Earth's ice mass balance. In situdata are sparse; hence, they are useful to derive snow accumulation from remote sensing observations, such as microwave thermal emission and radar brightness. These data are usually interpreted using electromagnetic models in which volume scattering is the dominant mechanism. The main limitation of this approach is that microwave brightness is not well related to backscatter if the ice sheet is layered. Because larger grain size and thicker annual layers both increase radar image brightness, with the first corresponding to lower accumulation rate and the second to higher accumulation rate, models of radar brightness alone cannot accurately reflect accumulation. Consideration of correlation measurements can also resolve this ambiguity. We introduce an interferometric ice scattering model that relates the interferometric synthetic aperture radar correlation and radar brightness to both ice grain size and hoar layer spacing in the dry-snow zone of Greenland. We use this model and the European Remote Sensing satellite radar observations to derive several parameters related to snow accumulation rates in a small area in the dry-snow zone. These parameters show agreement with four in situcore accumulation rate measurements in this area, whereas models using only radar brightness data do not match the observed variation in accumulation rates [J853]

"A Sharpened Dynamic Range of a Generalized Chinese Remainder Theorem for Multiple Integers"

A generalized Chinese remainder theorem (CRT) for multiple integers from residue sets has been studied recently, where the remainders in a residue set are not ordered. In this correspondence, we first propose a majority method and then based on the proposed majority method we present a sharpened dynamic range of multiple integers that can be uniquely determined from their residue sets [J854]

"Spatial Interpolation of Elevation Data With Variable Density: A New Methodology to Derive Quality DEMs"

A new methodology for spatial interpolation of elevation data with variable density is proposed. The method is based on two-step interpolation and data processing to minimize interpolation artifacts caused by variable data density. In the first step, the parameterization of the spline interpolation method is focused on areas with sparse data that need smoother interpolation. Then, the resulting surface in these areas is randomly sampled to densify the original data set. In the second step, the parameterization of the interpolation method is focused on areas with a required high level of detail. The final resulting surface contains the properties of surfaces optimized for different data densities and levels of detail [J855]

"Effect of Look Angle on the Accuracy Performance of Fixed-Baseline Interferometric SAR"

The effect of look angle on the accuracy performance of fixed-baseline interferometric synthetic aperture radar is studied. It is shown that there exists an optimal look angle that minimizes the variance of the surface height estimate for a resolution cell, and it depends upon the system as well as surface parameters. Numerical analysis confirming the existence of the optimal look angle is presented [J856]

"Synergistic Fusion of Interferometric and Speckle-Tracking Methods for Deriving Surface Velocity From Interferometric SAR Data"

This letter presents a technique to adjust and unify disconnected interferogram fringe regions for the derivation of accurate surface-velocity measurements. The interferogram from repeat-pass interferometric synthetic aperture radar data is often partitioned by shear margins of ice streams and other low-coherence zones into many small disconnected fringe regions. Although these isolated fringe regions can be unwrapped separately, the unwrapped

phase for each region is referenced to a different seed point. Our technique exploits absolute range-offset measurements from the speckle-tracking method to bridge the isolated fringe regions in the interferogram. In this way, the unwrapped phases in these regions can be adjusted into consistent surface-displacement measurements with a common reference point. Using Radarsat interferometric data in Antarctica, we demonstrated that the synergetic fusion of the measurements from the interferometric and speckle-tracking methods can produce a highly accurate two-dimensional velocity field [J857]

"Grid Computing Yields Earthquake Forecast"

The physical forces that govern seismic events are so complex that scientists have struggled to assemble forecasts on the scale of decades. Now a new statistical technique has enabled John Rundle and his team at the University of California to narrow the forecast window to less than three years. The calculations require a day of supercomputing time, but he and his partners plan to automate research-quality forecasts and make them available online. You can only do this with grid computing. The idea of linking supercomputers into a computational grid to confront big problems isn't a new one, but Rundle and others in Earth science are doing something different. They're linking grids together-effectively, using grids of grids-thanks to a software movement that takes its name from the musical phenomenon known as the mashup [J858]

"Accurate Centerline Detection and Line Width Estimation of Thick Lines Using the Radon Transform"

Centerline detection and line width estimation are important for many computer vision applications, e.g., road network extraction from high resolution remotely sensed imagery. Radon transform-based linear feature detection has many advantages over other approaches: for example, its robustness in noisy images. However, it usually fails to detect the centerline of a thick line due to the peak selection problem. In this paper, several key issues that affect the centerline detection using the radon transform are investigated. A mean filter is proposed to locate the true peak in the radon image and a profile analysis technique is used to further refine the line parameters. The thetas-boundary problem of the radon transform is also discussed and the erroneous line parameters are corrected. Intensive experiments have shown that the proposed methodology is effective in finding the centerline and estimating the line width of thick lines [J859]

"Selection of Forest Stands for Stem Volume Retrieval From Stable ERS Tandem InSAR Observations"

Environmental factors influence the accuracy in stem volume retrieval using European Remote Sensing Satellite (ERS) tandem synthetic aperture radar (SAR) interferometry. Some forest stands are more sensitive than others to heterogeneity of environmental properties, forest properties, and noise. It is shown that the consistency of coherence observations between different image pairs or the consistency of the estimated stem volume can be used to sort forest stands according to increasing errors in stem volume estimates associated with varying forest properties. Fifteen ERS tandem pairs were used to determine the relative root mean square error (RMSE) of stem volume estimated from C-band SAR interferometry. The test site, Tuusula in Finland, contains 210 forest stands with stem volumes up to 539 m3/ha. RMSE varies between 17% and 63% depending on number and type of stands included in the retrieval accuracy analysis. The more homogeneous forest stands with larger area and higher stem volumes of spruce and pine are those with highest retrieval accuracy [J860]

"Interpreting ISAR Images by Means of Parseval's Theorem"

When interpreting inverse synthetic aperture radar images it is of great value to be able to assign RCS-values to different areas of the image. It is shown that this can be done by means of Parseval's theorem [J861]

"On the Reduction of the Reconstruction Bias in Synthetic Aperture Imaging Radiometry (Corrected) "

Synthetic aperture imaging radiometers (SAIRs) are powerful instruments for high-resolution observation of planetary surfaces at low microwave frequencies. This paper is concerned with the reconstruction of radiometric brightness temperature maps from SAIR interferometric measurements. Even in the absence of modeling errors and radiometric noise, a systematic error, or bias, has been observed in the reconstructed maps. The origin of this bias is analyzed and an efficient solution is proposed for reducing it. The core reconstruction procedure is not changed, and no additional measurements are needed. Throughout the scientific rationale, particular emphasis is laid on numerical simulations carried out for the Soil Moisture and Ocean Salinity space mission, a project led by the European Space Agency and devoted to the remote sensing of soil moisture and ocean salinity from a low-orbit platform [J862]

"Analysis of Random Step Frequency Radar and Comparison With Experiments"

Linear stepped frequency radar is used in wide-band radar applications, such as airborne synthetic aperture radar (SAR), turntable inverse SAR, and ground penetration radar. The frequency is stepped linearly with a constant frequency change, and range cells are formed by fast Fourier transform processing. The covered bandwidth defines the range resolution, and the length of the frequency step restricts the nonambiguous range interval. A random choice of the transmitted frequencies suppresses the range ambiguity, improves covert detection, and reduces the signal interference between adjacent sensors. As a result of the random modulation, however, a noise component is added to the range/Doppler sidelobes. In this paper, relationships of random step frequency radar are compared with frequency-modulated continuous wave noise radar and the statistical characteristics of the ambiguity function and the sidelobe noise floor are analyzed. Algorithms are investigated, which reduce the sidelobes and the noise-floor contribution from strong dominating reflectors in the scene. Theoretical predictions are compared with Monte Carlo simulations and experimental data [J863]

"Snow-Covered Area Estimation Using Satellite Radar Wide-Swath Images"

Satellite radar-based remote sensing of snow cover during the snow-melt season has been widely studied for different geographical regions, such as mountainous, open, and forested areas. However, a single method has not been found to function well on all regions. The investigations on boreal forest zone have allowed the Helsinki University of Technology (TKK) to develop a snow-covered area (SCA) method that is feasible using spatially limited European Remote Sensing-1/2 Satellite data. This paper investigates the use of wide-swath radar data for boreal forest SCA estimation for the first time. The TKK SCA method is adapted here for HH-polarization Radarsat data. The predominant aspect originated by the use of wide-swath synthetic aperture radar (SAR) data is the large variation in the radar incidence angle. The effect of incidence angle variation on SCA estimation is characterized in this paper. The foundation for operational implementation of the TKK SCA method is also established by an error propagation analysis presented in this paper. The error propagation analysis is compared with accuracy characteristics acquired between SAR and optical SCA evaluation. The performance of forest compensation, which is a key element of the TKK method, was analyzed for the wide-swath radar data. Furthermore, the correlation between the topography and the SCA estimation accuracy was examined in this paper. This paper lays the foundation for operational SCA estimation on boreal forest zone using wide-swath SAR data [J864]

"Range migration algorithm for airborne squint mode spotlight SAR imaging"

Since the reference signal based on the fixed reference range is used in the range migration algorithm (RMA), the RMA is not available to process an airborne squint-mode spotlight synthetic aperture radar (SAR) data. Thus, the modified reference signal to transform a squint-mode data to a broadside-mode data is introduced on the basis of the coordinate transformation and the extended Taylor approximation. Then, using the principle of the stationary phase, the presented formulation is analysed. Moreover, to compensate curvature errors, the proposed method is extended on the basis of the subarea technique. Finally, the effectiveness of the proposed method is demonstrated by some numerical simulations via a pulsed spotlight SAR simulator [J865]

"Phase Unwrapping and A Robust Chinese Remainder Theorem"

In the conventional Chinese remainder theorem (CRT), a small error in a remainder may cause a large error in the solution of an integer, i.e., CRT is not robust. In this letter, we first propose a robust phase unwrapping algorithm with applications in radar signal processing. Motivated from the phase unwrapping algorithm, we then derive a type of robust CRT [J866]

"Enhancing target shadows in SAR images"

A method called fixed focus shadow enhancement is proposed. The purpose is to sharpen target shadows in synthetic aperture radar images. The method applies a fixed focus range to a given target, resulting in a sharp target image and a sharp target shadow. Other parts of the radar image, including the background against which the shadow is seen, are smeared [J867]

"Combining Airborne Photographs and Spaceborne SAR Data to Monitor Temperate Glaciers: Potentials and Limits"

Monitoring temperate glacier activity has become more and more necessary for economical and security reasons and as an indicator of the local effects of global climate change. Remote sensing data provide useful information on such complex geophysical objects, but they require specific processing techniques to cope with the difficult

context of moving and changing features in high-relief areas. This paper presents the first results of a project involving four laboratories developing and combining specific methods to extract information from optical and synthetic aperture radar (SAR) data. Two different information sources are processed, namely: 1) airborne photography and 2) spaceborne C-band SAR interferometry. The difficulties and limitations of their processing in the context of Alpine glaciers are discussed and illustrated on two glaciers located in the Mont-Blanc area. The results obtained by aerial triangulation techniques provide digital terrain models with an accuracy that is better than 30 cm, which is compatible with the computation of volume balance and useful for precise georeferencing and slope measurement updating. The results obtained by SAR differential interferometry using European Remote Sensing Satellite images show that it is possible to measure temperate glacier surface velocity fields from October to April in one-day interferograms with approximately 20-m ground sampling. This allows to derive ice surface strain rate fields required to model the glacier flow. These different measurements are complementary to results obtained during the summer from satellite optical data and ground measurements that are available only in few accessible points [J868]

"Dependence of Waterline Mapping on Radar Frequency Used for SAR Images in Intertidal Areas"

Waterline detection in the intertidal areas was investigated through synthetic aperture radar (SAR) images and field measurements. Two valuable facts were found in this letter: 1) A discrepancy of waterlines between L- and P-band airborne SAR images was discovered and investigated through precise global positioning system measurements and the theory of the SAR imaging mechanism. In the intertidal areas having low slopes, the Bragg waves resonant with the radar signal can reside in different depths depending on the radar frequency, with the result that the boundary between water and land can be mapped differently in the respective SAR images. 2) Intertidal areas covered with a water film present low radar backscatter in SAR images, which can cause mislocation of waterlines [J869]

"A Novel Method for Removal of Emitter Noise in SAR Images"

Traditionally, interfering emitter signatures have been removed through notched filtering in the range (fast-time) dimension. This works well when a narrowband emitter interferes with a wideband radar pulse; however, when the emitter and radar signal bandwidths are comparable, then this approach fails since the noise is distributed throughout the pulse and the image as well. In cases where the interfering signal is localized in the cross range, joint time-frequency methods can often focus this interference signal, thereby transforming the image. In this transformed image, the interferer is the foreground, and the desired synthetic aperture radar image is blurred and now the background. The focused compressed interferer can be analyzed and censored from the transformed image. Back transformation restores the image with the interference removed. This technique has been fully automated and applied to an Electromagnetics Institute Synthetic Aperture Radar (EMISAR) image contaminated by a nonstationary emitter. The cleansed image is virtually free of the emitter interference [J870]

"A Novel Technique for Noise Reduction in InSAR Images"

This letter proposes a new technique for noise reduction applied to synthetic aperture radar interferometry. This technique involves a nonlinear filter that separates the interferogram into two components: one containing the smooth (low frequency) part and the other containing the detail (high frequency) part. The smooth part is obtained using a combination of a median filter and a smoothing filter. The detail component is obtained by subtracting the smooth component from the original signal. This detail component is filtered to remove noise and then added to the smooth component to generate the final output. Both simulated and real data are used to evaluate the performance of the proposed technique under different conditions. The experimental results show that the proposed technique outperforms most commonly used interferometric phase filters [J871]

"Experimental Demonstration of the Corbella Equation for Aperture Synthesis Microwave Radiometry"

The fundamental equation of aperture synthesis microwave radiometry has been recently revised into a new so-called Corbella equation to include antenna coupling effects and the interferometry formulation into a single equation. This equation has been experimentally demonstrated for the first time with a full prototype of the Microwave Imaging Radiometer with Aperture Synthesis. Several tests have been carried out to demonstrate the new visibility equation with different targets. The test results show better agreement with simulations based on the Corbella equation than the old fundamental equation. An initial analysis of the influence of the antenna pattern characterization errors shows the importance of these errors in the final results according to the new formulation [J872]

"Observations of Snow Water Equivalent Change on Landfast First-Year Sea Ice in Winter Using

Synthetic Aperture Radar Data"

In this paper, we examine the utility of synthetic aperture radar (SAR) backscatter data to detect a change in snow water equivalent (SWE) over landfast first-year sea ice during winter at relatively cold temperatures. We begin by reviewing the theoretical framework for linking microwave scattering from SAR to the thermodynamic and electrical properties of first-year sea ice. Previous research has demonstrated that for a given ice thickness and air-temperature change, a thick snow cover will result in a smaller change in the snow-ice interface temperature than will a thin snow cover. This small change in the interface temperature will result in a relatively small change in the brine volume at the interface and the resulting complex permittivity, thereby producing a relatively small change in scattering. A thin snow cover produces the opposite effect-a greater change in interface temperature, brine volume, permittivity, and scattering. This work is extended here to illustrate a variation of this effect over landfast first-year sea ice using in situ measurements of physical snow properties and RADARSAT-1 SAR imagery acquired during the winter of 1999 in the central Canadian Archipelago at cold (~-26degC) and moderately cold (~-14degC) snow-sea-ice interface temperatures. We utilize in situ data from five validation sites to demonstrate how the change in microwave scattering covaries and is inversely proportional with the change in the magnitude of SWE. These changes are shown to be detectable over both short (2 days) and longer (45 days) time durations [J873]

"Coherence Loci for a Homogeneous Volume Over a Double-Bounce Ground Return"

The formulation of the polarimetric interferometric coherences derived by simple homogeneous-volume-over-ground models is revisited for the case of ground returns dominated by the double-bounce terms. The differences between single-transmit (single-tx) and alternate-transmit modes of the interferometer are analyzed by inspecting the positions of the coherences on the complex plane. An additional volume-decorrelation term appears when the interferometer is operated in a single-tx mode, which adds complexity in the potential inversion of the model parameters. This effect is even more noticeable for the cross-polar channels in the oriented case, since the phase of the coherence with an infinite ground-to-volume ratio does not correspond to the topographic phase, as observed for the copolar channels [J874]

"Statistical Analysis of High-Resolution SAR Ground Clutter Data"

This paper deals with the problem of modeling high-resolution synthetic aperture radar clutter data from different vegetated areas. We analyzed moving and stationary target recognition (MSTAR) data sets focusing on histograms, moments, and covariance of clutter amplitude, texture, and speckle. The most celebrated statistical models are tested on real data of grass field or wood and trees to validate the goodness of fit of the compound Gaussian model in different scenarios. The results demonstrate that for grass fields, the compound Gaussian model provides a good data fitting. This is not the case for woods images where the speckle is not more Gaussian distributed. Covariance analysis and concluding remarks complete this paper [J875]

"A Joint Image Coregistration, Phase Noise Suppression, and Phase Unwrapping Method Based on Subspace Projection for Multibaseline InSAR Systems"

As is well known, image coregistration, interferometric phase noise suppression, and phase unwrapping are three key processing procedures of synthetic aperture radar interferometry (InSAR). The three procedures are cascaded in the conventional processing flow of InSAR. Unlike the conventional processing flow, in this paper we propose a joint processing idea to carry out image coregistration, interferometric phase noise filtering, and phase unwrapping simultaneously based on subspace projection for multibaseline InSAR systems. The joint processing method can perform the fine coregistration of all SAR images implicitly by extracting the correlation information in the neighboring pixel sets, suppress the phase noise by utilizing the orthogonality of the signal subspace and the corresponding noise subspace, and optimally estimate the unwrapped interferometric phases (or the terrain heights) by combining the pixel coherence and the baseline diversity of a multibaseline InSAR system. Simulated results are presented to verify the effectiveness of the joint processing method [J876]

"Bistatic Linear Antenna Array SAR for Moving Target Detection, Location, and Imaging With Two Passive Airborne Radars"

In this paper, we propose a bistatic linear array synthetic aperture radar (BLA-SAR) system for moving target detection, location, and imaging. In the BLA-SAR system, a geostationary satellite is used as a transmitter, and two airborne linear array radars are used as passive receivers, where the transmitted waveforms from the geostationary satellite may have two different carrier frequencies, two linear array antennas on two different airplanes may be equipped with different spacings, or two airplanes may fly with two different velocities. It is shown that, using the BLA-SAR, not only the stationary clutter can be suppressed but also locations of both slow and fast moving targets can be accurately estimated. Furthermore, an effective BLA-SAR algorithm of

moving target imaging is also proposed. Lastly, some numerical experiments are given to demonstrate the effectiveness of the BLA-SAR [J877]

"Phase Unwrapping via Graph Cuts"

Phase unwrapping is the inference of absolute phase from modulo-2pi phase. This paper introduces a new energy minimization framework for phase unwrapping. The considered objective functions are first-order Markov random fields. We provide an exact energy minimization algorithm, whenever the corresponding clique potentials are convex, namely for the phase unwrapping classical Lpnorm, with pges1. Its complexity is KT(n,3n), where K is the length of the absolute phase domain measured in 2pi units and T(n,m) is the complexity of a max-flow computation in a graph with n nodes and m edges. For nonconvex clique potentials, often used owing to their discontinuity preserving ability, we face an NP-hard problem for which we devise an approximate solution. Both algorithms solve integer optimization problems by computing a sequence of binary optimizations, each one solved by graph cut techniques. Accordingly, we name the two algorithms PUMA, for phase unwrapping max-flow/min-cut. A set of experimental results illustrates the effectiveness of the proposed approach and its competitiveness in comparison with state-of-the-art phase unwrapping algorithms [J878]

"Range Resampling in the Polar Format Algorithm for Spotlight SAR Image Formation Using the Chirp z -Transform"

Besides an inverse two-dimensional (2-D) Fourier transform, the polar format algorithm (PFA) for the spotlight synthetic aperture radar (SAR) image formation can be normally divided into two cascaded processing stages, which are called the range and azimuth resampling, respectively. This paper focuses on a new implementation of the first stage, i.e., the range resampling, using the chirp z-transform (CZT). The presented algorithm requires no interpolation. It works for the SAR system directly digitizing the echo signal, as well as that employing the dechirp-on-receive approach. The parameters of the CZT, including the frequency spacing and the start frequency, are derived to accommodate the PFA in both cases. Related filtering and compensation procedures are developed for the chirp z-transformed range signal with and without dechirp, respectively, in order to achieve a signal format entirely suitable for the azimuth resampling. Furthermore, incorporating the new algorithm with the existing CZT-based azimuth resampling and focusing algorithm, we can achieve a PFA totally free of interpolation. The presented approach has been validated by point target simulation, and the test is carried out with a very critical relative bandwidth of 30% [J879]

"On the Reduction of the Reconstruction Bias in Synthetic Aperture Imaging Radiometry"

Synthetic aperture imaging radiometers (SAIRs) are powerful instruments for high-resolution observation of planetary surfaces at low microwave frequencies. This paper is concerned with the reconstruction of radiometric brightness temperature maps from SAIR interferometric measurements. Even in the absence of modeling errors and radiometric noise, a systematic error, or bias, has been observed in the reconstructed maps. The origin of this bias is analyzed and an efficient solution is proposed for reducing it. The core reconstruction procedure is not changed, and no additional measurements are needed. Throughout the scientific rationale, particular emphasis is laid on numerical simulations carried out for the Soil Moisture and Ocean Salinity space mission, a project led by the European Space Agency and devoted to the remote sensing of soil moisture and ocean salinity from a low-orbit platform [J880]

"Capabilities of Dual-Frequency Millimeter Wave SAR With Monopulse Processing for Ground Moving Target Indication"

Ground moving target indication (GMTI) for synthetic aperture radar (SAR) provides information on nonstatic objects in radar imagery of a static ground scene. An efficient approach for GMTI is the use of multichannel SAR systems for a space- and time-variant analysis of moving targets. This allows the indication, correction of position displacement, and estimation of radial velocity components of moving targets in a SAR image. All three steps are possible due to a determinable Doppler frequency shift in the radar signal caused by radial target movement. This paper focuses on the millimeter wave (mmW) SAR system MEMPHIS with multichannel amplitude-comparison monopulse data acquisition and the ability to use carrier frequencies of 35 and 94 GHz simultaneously, making it a dual-frequency SAR. This paper includes mmW-specific SAR GMTI considerations, an adaptive algorithm to collect velocity and position information on moving targets with mmW monopulse radar, and a discussion on GMTI blind speed elimination and target velocity ambiguity resolving by dual-frequency SAR. To determine the capabilities of both, system and algorithm, three large-scale experiments with MEMPHIS in different environments are presented [J881]

"February 2007 Distinguished Lectures Program"

{no data available} [J882]

"Discriminating real objects in radar imaging by exploiting the squared modulus of the continuous wavelet transform"

New technique based on continuous wavelet transform (CWT) for classifying objects in synthetic aperture radar (SAR) imaging is presented. The CWT allows to analyse two-dimensional SAR images to highlight the frequency and angular behaviour of the scatterers. This technique allows to build a SAR hyperimage, that is, a four-dimensional data cube which represents for each spatial location (x, y) of the scatterer in the image, its frequency and angular energy behaviour. When analysing different targets, objects or areas in SAR images, it has been recently observed that some scatterers belonging to a same class of objects could have similar frequency and angular energy responses. The previous observations have motivated the determination to exploit these energy responses to discriminate these objects. This discrimination is performed by frequency and angular correlations between the response of a particular scatterer (measured) and those of all the scatterers in the SAR image. Some examples of discrimination from real SAR data are presented and show an interest of the method for target classification and recognition for SAR imaging [J883]

"Approach for single channel SAR ground moving target imaging and motion parameter estimation"

In recent years, ground moving target imaging in synthetic aperture radar (SAR) has attracted the attention of many researchers all over the world. A novel approach is proposed for the ground moving target imaging and motion parameter estimation using single channel SAR. First, a second-order generalised keystone formatting method is used to compensate for the range curvature. Secondly, the estimated slope of the target echo's envelope is used for the range walk compensation. Thirdly, Doppler parameters of moving targets obtained via spectral analysis are used for the imaging and positioning of ground moving targets. Finally, motion parameters of moving targets can be estimated on the basis of the relationship between Doppler and motion parameters. Both numerical and experimental results are provided to demonstrate the performance of the proposed approach [J884]

"Oil Spill Detection in Radarsat and Envisat SAR Images"

We present algorithms for automatic detection of oil spills in synthetic aperture radar (SAR) images. The algorithms consist of three main parts, namely: 1) detection of dark spots; 2) feature extraction from the dark spot candidates; and 3) classification of dark spots as oil spills or look-alikes. The algorithms have been trained on a large number of Radarsat and Envisat Advanced Synthetic Aperture Radar (ASAR) images. The performance of the algorithm is compared to manual and semiautomatic approaches in a benchmark study using 59 Radarsat and Envisat images. The algorithms can be considered to be a good alternative to manual inspection when large ocean areas are to be inspected [J885]

"Shift–Scale Complex Correlation for Wide-Angle Coherent Cross-Track SAR Stereo Processing"

Automated synthetic aperture radar (SAR) stereo correspondence becomes increasingly difficult when imaging high-relief terrain utilizing large stereo crossing-angle geometries because high-relief SAR image features can undergo significant spatial distortions, causing a failure of traditional correlation matching. This paper presents eight coherent spotlight-mode cross-track stereo pairs with stereo crossing angles averaging 93.7deg collected over a terrain with slopes greater than 20deg. These stereo pairs suffer from terrain-induced distortions, resulting in a decrease in complex correlation (coherence) when utilizing scanning-window correlation calculations. The search to maximize complex correlation is changed from a shift-only (disparity) search to a shift-and-scale search using the downhill simplex method. This approach is tested against complex imagery with simulated distortions and then employed on the eight wide-angle stereo collects. The resulting digital terrain maps (DTMs) are compared to ground truth. Using a shift-and-scale correlation approach to estimate disparity, the relative height errors decrease, and the number of reliable DTM posts increase [J886]

"CWLFM Radar for Ship Detection and Identification"

Continuous wave lineal frequency modulated (CWLFM) radar presents some interesting advantages for coast surveillance and control as well as low probability of interception (LPI). This paper presents real results obtained with a radar prototype and processed with ISAR techniques. Also, results of an automatic ship identification system applied to simulated ISAR images are exposed. Moreover, radar behavior with unfavorable meteorological conditions is discussed [J887]

"Modelling and enhancement of interrupted synthetic aperture radar imagery"

A synthetic aperture radar system can be made compatible with other interleaved modes if the impact of the interruptions in operation necessary to accommodate these can be ameliorated. The ways in which this might be done are discussed. Effects of regular and random interruptions are characterised by simulation and analysis. Two methods of image enhancement, based on interpolation and apodisation, are then discussed; the latter appears to hold more promise of practical usefulness. [J888]

"Texture-Preserving Despeckling of SAR Images Using Evidence Framework"

In this letter, a texture-preserving despeckling algorithm for synthetic aperture radar images using an evidence framework is proposed. The salient aspects of this approach are given as follows. (1) The maximum a posteriori estimate can be guaranteed to converge to the optima by selecting the Gaussian distribution and Gaussian Markov random field model as the likelihood function and prior model, respectively. (2) MacKay's evidence framework can automatically sustain the balance between speckle reduction and texture preservation. (3) We use the Jeffreys prior to perform the second-level inference of the evidence framework. Experimental results are given to demonstrate the validity of the proposed despeckling method. [J889]

"Motion Analysis in SAR Images of Unfocused Objects Using Time-Frequency Methods"

Synthetic aperture radar (SAR) image formation processing assumes that the scene is stationary, and to focus an object, one coherently sums a large number of independent returns. Any target motion introduces phases that distort and/or translate the target's image. Target motion produces a smear primarily in the azimuth direction of the SAR image. Time-frequency (TF) modeling is used to analyze and correct the residual phase distortions. An interactive focusing algorithm based on TF modeling demonstrates how to correct the phase and to rapidly focus the mover. This is demonstrated on two watercraft observed in a SAR image. Then, two time-frequency representations (TFRs) are applied to estimate the motion parameters of the movers or refocus them or both. The first is the short-time Fourier transform, from which a velocity profile is constructed based on the length of the smear. The second TFR is the time-frequency distribution series, which is a robust derivative of the Wigner-Ville distribution that works well in this SAR environment. The smear is a modulated chirp, from which a velocity profile is plotted and the phase corrections are integrated to focus the movers. The relationship between these two methods is discussed. Both methods show good agreement on the example. [J890]

"Geocoding of Synthetic Aperture Radar Images Using Digital Vector Maps"

In this letter, a possible approach to automate synthetic aperture radar (SAR) geocoding (or to automatically refine the existing one) is presented. The procedure is based on edge detection, where ground control lines obtained from digital vector maps are located in the SAR images. In geocoding, affine, projective, and rigorous SAR sensor transformation models can be used. According to the experiments, the procedure seems to be accurate and reliable as long as the initial values of the geocoding transformation model are accurate enough. The procedure copes well with displacements of about ten pixels on SAR images, but good results have been obtained in cases of even larger displacements. According to the well-defined checkpoints, the resulting geocoding accuracies for test images were around a few pixels. When the rigorous SAR sensor model was used, the accuracies were less than two pixels in most cases. [J891]

"Effects of Forest Biomass and Stand Consolidation on P-Band Backscatter"

In previous studies, P-band synthetic aperture radar (SAR) has shown potential for biomass retrieval in forests. However, while measurements show a general agreement that backscatter increases with increasing biomass, different studies show that the backscatter from stands of similar biomass can significantly vary depending on forest structure, hence making biomass retrieval more challenging. In this letter, we show that, while biomass may be the single most important parameter determining the backscatter from a forest, the number density of trees has also a major impact. This can be explained using simple arguments, leading us to propose the use of the biomass-consolidation index to describe P-band HV-polarized backscatter. This is supported by electromagnetic-modeling studies and by a few measurements from boreal forest made with the AIRSAR system over the BOREAS test site in Canada. [J892]

"Radar Signatures of a Passenger Car"

Upcoming new synthetic aperture radar (SAR) satellites such as TerraSAR-X and Radarsat-2 offer high spatial image resolution and dual receive antenna capabilities, which open new opportunities for worldwide traffic monitoring applications. If the radar cross section (RCS) of the vehicles is strong enough, they can be detected in the SAR data, and their speed can be measured. For system performance prediction and algorithm development, it is therefore indispensable to know the RCS of typical passenger cars. The geometry parameters that have to be considered are the radar look direction, incidence angle, and vehicle orientation. In this letter, the

radar signatures of nonmoving or parking cars are presented. They are measured experimentally from airborne experimental SAR (E-SAR) data, which have been collected during flight campaigns in 2005 and 2006 with multiple overflights at different aircraft headings. The radar signatures could be measured for the whole range of aspect angles from 0 to 180 and with high angular resolution due to the large synthetic aperture length of the E-SAR radar sensor. The analysis for one type of passenger car and particular incidence angles showed that the largest radar cross-sectional values and, thus, the greatest chance of detection of the vehicles appear when the car is seen from the front, back, and side. Radar cross-sectional values for slanted views are much lower and are therefore less suitable for car detection. The measurements have been performed in the -band (9.6 GHz) with VV-polarization, and at incidence angles of 41.5deg and 42.5deg. The derived radar signature profile can also be used for the verification of radar cross-sectional simulation studies. [J893]

"DEM by Ground-Based SAR Interferometry"

In this letter, a ground-based synthetic aperture radar (SAR) interferometer was used to generate digital elevation maps (DEMs) of the illuminated area. With respect to other ground-based data processing techniques, here, the effect of the propagation through the atmosphere is considered. An algorithm similar to multipass satellite SAR techniques was developed in accordance with the phase model used in the ground-based interferometry. Many images taken from different viewing angles were collected and combined to form different interferograms at a test site in Austria. Results from this technique have been compared with an existing geographic model of the test area. [J894]

"High-Resolution Spaceborne SAR Focusing by SVD-Stolt"

In spaceborne synthetic aperture radars (SARs), the orbit curvature may prevent the use of the processor, causing artifacts that depend on both the extent of the orbit arc and the slant range interval. A viable solution has been derived by extending the singular value decomposition-Stolt approach that was proposed for geophysical applications to microwave SAR. The resulting processor has the same simple scheme as the approach but a different (numerical) computation of both the reference and the Stolt interpolation. [J895]

"Modeling Interferogram Stacks"

Synthetic aperture radar interferometry is limited by temporal and geometrical decorrelation. Permanent scatterers (PSs) are helpful to overcome these problems, but their density in agricultural and out-of-town areas is not always sufficient. The forthcoming availability of satellite platforms with thinner orbital tubes and shorter revisit times will enhance the use of interferogram stacks, which are usable for distributed and progressively decorrelating targets, like those found in agricultural areas. To estimate the possibilities of the interferogram stack technique, a Markovian model for the temporal decorrelation is considered. ERS-1 data measured in C-band over Rome with a three-day repeat cycle are used to identify the parameters for this model, namely, the decorrelation time (estimated as 40 days) and the short-term coherence (estimated as 0.6). In the hypothesis of small deviations from a model of the motion, the optimal weights to be used to combine a sequence of interferograms taken at intervals that are shorter than the decorrelation time are calculated in the cases of progressive and sinusoidal ground motion. The dispersion of the optimal estimate of the motion is then determined. This model is extended to frequencies other than C-band. These evaluations are compared with the known results obtained for PSs. As an example, the case of a time interval between the takes of T = 12 days is considered. With N consecutive images, interferogram stack results are equivalent to PSs if the pixel count in the window used to smooth the interferograms grows with N2. [J896]

"Inferring Vegetation Water Content From C- and L-Band SAR Images"

This paper addresses the capability of synthetic aperture radar and optical images in combination with theoretical models to detect the vegetation water content (VWC) at field level. In this paper, a retrieval algorithm for the estimation of VWC from AirSAR acquired on vegetated fields during the SMEX'02 experiment is addressed. The aforementioned campaign has been chosen because, along with sensor observations, extensive ground truth measurements were acquired. The retrieval procedure, which is based on a Bayesian approach, has been initially developed for soil moisture extraction. It consists of two modules: one is pertinent to bare soils and the other one has been modified for vegetated fields. The last one uses the synergy with optical images to correct for the contribution of VWC. The VWC, a variable in the inversion procedure, as well as soil moisture can be estimated. The results indicate a good correlation with both ground measurements and VWC calculated from Landsat images through the use of normalized difference water index (NDWI). Furthermore, in the inversion procedure, the introduction of the dependence on roughness improves the estimates. This indicates that, even for dense vegetation, the contribution from bare soil greatly influences the radar signal. Three main levels of VWC are discriminated in the inversion procedure: values below 1 kg/m2, values between 1 and 3 kg/m2, and

values greater than 3 kg/m2. [J897]

"Classifying Multifrequency Fully Polarimetric Imagery With Multiple Sources of Statistical Evidence and Contextual Information"

This paper presents the use of a new distribution for fully polarimetric image classification. Several classification strategies are compared in order to assess the importance of a careful statistical modeling of the data and the complementary nature of the information provided by different frequencies. Spatial context, which is relevant in order to obtain good results with noisy data, is described by means of the multiclass Potts model, and an iterated conditional modes classification algorithm that employs pseudolikelihood is proposed. The data are described using multivariate Gaussian laws and fully multilook polarimetric distributions arising from the multiplicative model. L-band, C-band, and both bands are used to assess the influence of dimensionality on the classification. Contextual and pointwise maximum-likelihood classifications are compared using real data. Results show that both context and number of frequencies contribute for better classification products, and that, a careful statistical description of the data leads to improved results. [J898]

"On Localization Performance in Imaging Sensor Nets"

We propose a massively scalable ldquoimagingrdquo architecture for sensor networks, in which sensor nodes act as ldquopixelsrdquo that electronically reflect (and possibly modulate data on top of) a beacon transmitted by a collector node. The collector employs sophisticated radar and image processing techniques to localize the responding sensor nodes, and (if data modulation is present) multiuser data demodulation techniques to extract the data sent by multiple sensors. The sensors do not need to know their own locations, do not need to communicate with each other, and can be randomly deployed. In this initial exposition, we develop basic insight into the localization capabilities of this approach, ignoring sensor data modulation. This reduces to an idealized one-bit, on-off keyed, communication model in which the the sensors are either ldquoactiverdquo or ldquoinactive,rdquo with the active sensors responding to the collector's beacon without superimposing data modulation. We consider a moving collector, with the sensor reflections creating a synthetic aperture radar (SAR)-like geometry. However, the collector must employ significant modifications to SAR signal processing for estimation of the location of the active sensors: noncoherent techniques similar to those in noncoherent radar tomography to account for the lack of carrier synchronization between sensor and collector nodes, and decision feedback mechanisms for estimation of the locations of multiple closely spaced active sensors. Measures for localization performance are defined, and the effect of system parameters such as bandwidth, beamwidth and signal-to-noise-ratio (SNR) on performance is investigated. [J899]

"Singularity-Spreading Phase Unwrapping"

How to process phase singular points (SPs), or residues, is a difficult problem in a 2-D phase-unwrapping process to generate digital elevation maps (DEMs). Although the minimum-cost network-flow method is an effective and widely used technique, some problems still remain. That is, the method often generates spikes in high SP-density areas and long clifflike artifacts for isolated SPs. It also takes a long time to unwrap phase data that contain many SPs. In this paper, we propose a new unwrapping method, namely, singularity-spreading phase unwrapping (SSPU), which solves these problems. In this method, we spread the singularity at SPs around to make the closely located positive and negative SPs combine gently with each other or make the isolated SPs fade away. Experiments demonstrate that the spreading process compensates the distortion in phase values in the vicinities of SPs appropriately for landscape reconstruction. The SSPU generates high-quality DEMs with smaller calculation costs than the conventional method. Besides the simple SSPU, we also present weighted SSPU where we utilize amplitude information to improve the performance further. In addition, we discuss the relationship between landscape characteristics and SSPU performance. [J900]

"Investigating Attenuation, Scattering Phase Center, and Total Height Using Simulated Interferometric SAR Images of Forested Areas"

The objective of this paper is to examine the link between the attenuation coefficients and the interferometric phase center heights, for several frequencies from P- to L-band, and to study the extent to which it depends on the canopy architecture and description. This paper relies on the use of a coherent and full polarimetric scattering model, which simulates the fields backscattered by a forested area. In the first part, we study the behavior with a frequency of the interferometric phase center heights, and in the second part, we focus on the attenuation coefficients. Then, we compare the behaviors of these two quantities, and we propose to empirically derive a relation between these two quantities and the mean forest height. Finally, we investigate if a change in the initial forest or radar configuration has an impact on the determination of this relation. [J901]

"Hybrid CramЙr-Rao Bounds for Crustal Displacement Field Estimators in SAR Interferometry"

This letter focuses on the performance achievable by spaceborne synthetic aperture radar interferometry (InSAR) in the estimation of line-of-sight crustal deformations from acquisitions over a distributed scatterer. Our model is suited for exploiting the hybrid Cramer-Rao bound (HCRB), where the unknowns are both deterministic parameters and stochastic variables. We take into account both target decorrelation and atmospheric phase screen (APS). This approach leads to a viable evaluation of InSAR performance as a function of system configuration, target decorrelation, and APS variance. [J902]

"Wideband Linear Frequency Modulated Waveform Compensation Using System Predistortion and Phase Coefficients Extraction Method"

This letter presents an effective method to compensate for the wideband linear frequency modulated waveform errors using system predistortion coefficients. The coefficients can be readily extracted by measuring and analyzing the changing rates of the period of non-constant beat frequencies generated from a nonlinear system in the time domain. The amplitude distortion components are examined using the polynomial curve-fitting method. In order to experimentally validate the practical feasibility of the waveform generator and the predistortion coefficients extraction module, the waveform's amplitude ripple, range resolution, and peak sidelobe ratios are measured and analyzed. The measured amplitude ripple at 5.3 GHz is improved from 1.835 to 0.333 dB and from 2.793 to 0.75 dB within 50 and 85 MHz bandwidth, respectively. Finally, the range resolution is improved from 4.102 to 3.103 m for 50 MHz bandwidth and the peak sidelobe ratio is improved from 7.78 to 20.55 dB for 85 MHz bandwidth with the applied predistortion. [J903]

"Comparison of Topography- and Aperture-Dependent Motion Compensation Algorithms for Airborne SAR"

This letter presents a comparison between three Fourier-based motion compensation (MoCo) algorithms for airborne synthetic aperture radar (SAR) systems. These algorithms circumvent the limitations of conventional MoCo, namely the assumption of a reference height and the beam-center approximation. All these approaches rely on the inherent time-frequency relation in SAR systems but exploit it differently, with the consequent differences in accuracy and computational burden. After a brief overview of the three approaches, the performance of each algorithm is analyzed with respect to azimuthal topography accommodation, angle accommodation, and maximum frequency of track deviations with which the algorithm can cope. Also, an analysis on the computational complexity is presented. Quantitative results are shown using real data acquired by the Experimental SAR system of the German Aerospace Center (DLR). [J904]

"Initial Images of the Synthetic Aperture Radiometer 2D-STAR"

Initial results are presented for the new synthetic aperture radiometer, 2D-STAR, which is a dual-polarized L-band radiometer that employs aperture synthesis in two dimensions. This airborne instrument is the natural evolution of the Electronically Scanned Thinned Array Radiometer, which employs aperture synthesis only in the across-track dimension, and represents a further step in the development of aperture synthesis for remote sensing applications. 2D-STAR was successfully tested in June 2003 and, then, participated in the SMEX03 and SMEX04 soil moisture experiments. A description of the instrument and initial results in the form of first images and a preliminary comparison with changes in soil moisture during SMEX03 are presented here. [J905]

"Sea-Ice Deformation State From Synthetic Aperture Radar Imagery-Part I: Comparison of C- and L-Band and Different Polarization"

In this paper, we present a quantitative comparison of L- and C-band airborne synthetic aperture radar imagery acquired at like- and cross-polarizations over deformed sea ice under winter conditions. The parameters characterizing the deformation state of the ice are determined at both radar bands and at different polarizations. The separation of deformed and level ice is based on a target detection technique. The threshold is set such that image pixels with intensities equal to or larger than the highest 2% of the level-ice intensity distribution are classified as deformed ice, independent of the radar configuration and ice conditions. Optical imagery of sufficient quality for comparison is available only in a very few cases. To characterize the deformation state, the areal fraction of deformation features and the average distance between these features are evaluated. The values obtained for both parameters are very sensitive to the radar frequency. Aeral fractions are larger, and average distances are smaller at L-band than at C-band because of the much higher intensity contrast between the deformed and level ice at L-band. The differences between polarizations at one radar band are smaller but not always negligible. In comparison to optical images, it was observed that deformed-ice areas can be distinguished from level ice over their whole length and extension at L-band, whereas at C-band, often, only

prominent parts are visible. [J906]

"A Novel Clutter Suppression Algorithm for Landmine Detection With GPR"

In this paper, we propose a new algorithm for the enhancement of plastic-cased antipersonnel mine detection using a video-impulse ground-penetrating radar (GPR). The algorithm is implemented as a nonlinear signal processor, which searches for the presence of a reference waveform in a 1D GPR echo return. The reference waveform represents a class of targets within a certain environment. The processor marks the presence of all responses similar to the reference waveform with a sharp mono-cycle. Simultaneously, responses with different waveforms, which presumably correspond to clutter, are suppressed. The reference waveform and other algorithm parameters are determined from training data sets acquired in a controlled environment. After training, the algorithm can be successfully applied at sites where soil, targets, and measurement scenarios are similar but not identical to those of the training site. The processor is integrated into an automated data processing and mine detection scheme as an additional clutter suppression step. The scheme consists of clutter suppression, synthetic aperture radar focusing, construction of a confidence map, and automated detection in it. The suggested algorithm is tested on experimental data, and its performance is compared against schemes where clutter suppression is organized by means of background removal and the cross correlation with a reference wavelet. The performance comparison is done in terms of receiver operating characteristic curves. It has been found that the suggested algorithm reduces the false alarm rate in about two and a half times in comparison to the cross-correlation-based clutter suppression. [J907]

"Template-Based Target Identification and Confusion Matrices [JAESS Tutorial IV]"

One-dimensional high-range-resolution (HRR) and two-dimensional range-Doppler-imaging (RDI) radar represent possible sensor technologies where template-based techniques can be applied to perform combat identification (CID). The majority of the research reported in these areas consists of empirical studies. This article provides a theoretical basis for understanding some of the fundamental trade-offs associated with these CID techniques, such as the following: What are the relative advantages of RDI over HRR radar or of finer versus coarser resolution in the HRR process? What is the relative advantage of coherent over noncoherent processing? How do target correlations, signal-to-noise ratio (SNR), and target scintillation affect the ability to identify targets? Because confusion matrices are often used to characterize the performance of CID systems, we provide analytical methods for calculating the entries in confusion matrices as a function of the issues cited above. These formulations provide analytical bases to guide system trade-off decisions. The organization of this paper is as follows. We begin with a short overview of HRR and RDI and then explore a number of ways to process the associated target templates that range from an ideal, theoretical approach to an approach that would be more feasible to implement within current-day radars. We first develop analytic template-based methodologies for constructing confusion matrix entries for nonscintillating targets for both coherent and noncoherent processing assumptions. The confusion matrix entries in these cases are conditional probabilities obtained from a simple rule: find the probability that among m (in general, correlated) random variables, each associated with a possible target, that any one is the largest. For the noncoherent case, the successful application of this rule requires the target template values to explicitly include the effects of thermal noise (noise-adjusted templates). We conclude by showing h--ow to calculate theoretically optimum results (e.g., using maximum likelihood techniques) for noncoherent processing of targets that exhibit uncorrelated Swerling 1 scintillation in ail resolution bins as a function of the SNR. This approach allows us to include overall target intensity (e.g., total radar cross section (RCS)) as a further factor in the target decision process. [J908]

"Visual Learning by Evolutionary and Coevolutionary Feature Synthesis"

In this paper, we present a novel method for learning complex concepts/hypotheses directly from raw training data. The task addressed here concerns data-driven synthesis of recognition procedures for real-world object recognition. The method uses linear genetic programming to encode potential solutions expressed in terms of elementary operations, and handles the complexity of the learning task by applying cooperative coevolution to decompose the problem automatically at the genotype level. The training coevolves feature extraction procedures, each being a sequence of elementary image processing and computer vision operations applied to input images. Extensive experimental results show that the approach attains competitive performance for three-dimensional object recognition in real synthetic aperture radar imagery. [J909]

"A Rapid and Automatic MRF-Based Clustering Method for SAR Images"

This letter presents a precise and rapid clustering method for synthetic aperture radar (SAR) images by embedding a Markov random field (MRF) model in the clustering space and using graph cuts (GCs) to search the optimal clusters for the data. The proposed method is optimal in the sense of maximum a posteriori (MAP). It

automatically works in a two-loop way: an outer loop and an inner loop. The outer loop determines the cluster number using a pseudolikelihood information criterion based on MRF modeling, and the inner loop is designed in a ldquohardrdquo membership expectation-maximization (EM) style: in the E step, with fixed parameters, the optimal data clusters are rapidly searched under the criterion of MAP by the GC; and in the M step, the parameters are estimated using current data clusters as ldquohardrdquo membership obtained in the E step. The two steps are iterated until the inner loop converges. Experiments on both simulated and real SAR images test the performance of the algorithm. [J910]

"Signal Representation and the Nonlinear Property of Phase Images"

This letter proposes a representation of pixel value in a phase image as a complex number, which implies that the phase image is a nonlinear field. Consequently, conventional linear filtering will not properly work. Local statistics filters (LSFs) are chosen as a special case of the signal-processing algorithm to show the significance of signal representation to filtering performance. First, relationships among various LSFs, namely, ordinary LSF, speckle LSF, and phasor LSF, are discussed. We found that they are related to each other, whose general form is a complex-valued LSF (CV-LSF). It is also realized that directional windowing for the CV-LSF is actually not required, which indicates that the complex-valued formulation (representation and algorithm) is the most suitable one for phase image filtering. We demonstrate that the linear filtering to a simulated complex-valued image and an actual interferometric synthetic aperture radar image will start to fail when the window size is subsequently enlarged due to the nonlinear nature of the phase image. [J911]

"A Beginner's Guide to Interferometric SAR Concepts and Signal Processing [JAESS Tutorial IV]"

Interferometric synthetic aperture radar (IFSAR, also abbreviated as InSAR) employs pairs of high resolution SAR images to generate high quality terrain elevation maps using phase interferometry methods. IFSAR provides an all-weather, day/night capability to generate measurements of terrain elevation on a dense grid of sample points with accuracies of ones of meters. Both spaceborne and airborne IFSAR systems are in use. In this paper we present a tutorial introduction to the concepts, techniques, and applications of IFSAR. After a brief introduction to digital elevation models (DEMs) and digital terrain elevation data (DTED), the fundamental IFSAR equation relating interferometric phase measurements to terrain elevation is derived from simple geometric considerations. The central section of the paper describes the major algorithmic steps required to form an IFSAR terrain map. Finally, variations of IFSAR for mapping terrain elevation or reflectivity changes are briefly described. A Web site at users.ece.gatech.edu/~mrichard/AESSJFSAR.htm provides access to color versions of many of the IFSAR images included in this paper. [J912]

"Variable Precision Two-Channel Phase, Amplitude, and Timing Measurements for Radar Interferometry and Polarimetry"

In this paper, we present a time-domain method for estimating the phase, amplitude, and timing of a test signal, referenced either to a theoretical version of the signal, or to another signal undergoing a similar transformation as the measured signal. The use of time-domain basis for this method allows for its direct application to data samples collected by a digital oscilloscope or a dedicated A/D converter, and precludes the need for conversion into in-phase and quadrature components. The estimation process described in this paper is based on a maximum likelihood formulation, which allows for the estimate performance to be related to errors associated with sampling and is shown to achieve the Cramer-Rao lower bound for variance. Measurements such as the ones described in this paper are important for characterizing interferometric and polarimetric radar systems, as well as for determining the number of observations necessary for achieving a given degree of accuracy in the measurement. By including a statistical description of the estimation process, we enable the ability for using the technique for evaluating hypotheses describing the measurement error model. This last point is critical because it creates a mechanism for accepting or rejecting system model scenarios based on the signal-to-noise ratio and the number of digitized samples. [J913]

"High-bandwidth 220 GHz experimental radar"

An experimental radar at 220 GHz has been developed which is capable of delivering an instantaneous bandwidth of 8000 MHz. The solid-state radar uses an FM-CW waveform. The development is based on experience with a 94 GHz broadband measurement radar. The data undergo an ISAR imaging process to derive high-resolution scattering centre distributions for targets measured in tower/turntable configuration. High-resolution processing algorithms have been developed which result in scattering centre distributions with a resolution better than 2 cm at ranges of and exceeding 200 m. The radar will be used for investigations on target signatures of small objects for stand-off detection of concealed weapons and other threat material. [J914]

"Inflight Antenna Pattern Measurement for Bistatic Synthetic Aperture Radar Systems"

Precise inflight antenna pattern should be known for synthetic aperture radar (SAR), so that an image pixel intensity is directly expressed in terms of the mean surface backscatter coefficient. For bistatic SAR (BiSAR), in which the transmitter and receiver are mounted on separate platforms, conventional passive calibrators are not applicable any more. As such, an approach is described on how to determine the inflight antenna patterns for BiSAR systems in this letter. This technique is suitable for high-resolution SAR due to the very high dynamic range. More importantly, this technique uses signal encoding to decouple the transponder from the background, which greatly improve the measurement performance. Theoretical analysis and simulation results also demonstrate its validity. [J915]

"Observations, Modeling, and Applications of ERS-ENVISAT Coherence Over Land Surfaces"

European Remote Sensing satellite (ERS) ENVISAT coherence is a new repeat-pass interferometric synthetic aperture radar product characterized by a very short repeat-pass interval between acquisitions (28min). In this paper, we investigate the properties of two 28-mins coherence images acquired over the regions of Paris, France, and Prague, Czech Republic, as well as a 35-day coherence image from Prague. Bare soils showed higher coherence compared to forests and urban areas. The range of coherence was larger for 28-min pairs, perpendicular baseline closer to 2km, and stable weather conditions between acquisitions. Coherence modeling shows that because of the long baseline: 1) significant surface decorrelation occurs when slopes are not accounted for in the common-band filtering and for variation of topography in the resolution cell and 2) volume decorrelation is significant. Temporal decorrelation seems to be relevant for vegetation even at the 28-min interval time scale. Observations and modeled coherence were found to be in good agreement. Land cover classification using coherence and backscatter has been tested for the Paris scene for mapping the four major classes. The classification accuracy was 86% when an edge-eroded version of the reference land cover map was used. It decreases to 68% when the full land cover map was used as reference because of local mismatches between the coherence image and the land cover map, and the reduced common band in range. The high coherence difference between forests and bare fields suggests the possibility to use the ERS-ENVISAT coherence for forest/nonforest mapping and estimation of biophysical properties of short vegetation. Coherence, decorrelation, ENVISAT Advanced Synthetic Aperture Radar (ASAR), European Remote Sensing satellite (ERS), land cover, synthetic aperture radar interferometry (InSAR). [J916]

"Unsupervised Classification of Scattering Mechanisms in Polarimetric SAR Data Using Fuzzy Logic in Entropy and Alpha Plane"

The eigenvalue-eigenvector-based approach for understanding the scattering mechanisms of polarimetric synthetic aperture radar (POLSAR) data leads to noisy classification results due to arbitrarily fixed zone boundaries in the H/alpha macr plane. In this paper, a new classification scheme that can address the inherent vagueness of class boundaries in the H/alpha macr plane was tested in order to improve the unsupervised classification of the microwave scattering mechanism by introducing concepts related to fuzzy sets. A 2-D fuzzy membership function was developed for the fuzzification of the 2-D H/alpha macr plane. The proposed fuzzy H/alpha macr classifier is composed of three steps: fuzzification of the H/alpha macr plane, iterative refinement of membership degrees using the c-means algorithm, and defuzzification for the final decision process. The performance of this new approach for the L-band NASA/Jet Propulsion Laboratory's Airborne SAR data obtained during the PACRIM-II experiment was shown to be consistently improved. This new classification technique can be applied to POLSAR data without any a priori information. The fuzzification of the zone boundaries can be further applied to the interpretation of the POLSAR data, e.g., multifrequency classification, retrieval of bio- and geophysical parameters, etc. In order to propose another implementation of the fuzzy boundary representation, we exploited the combination of the H/alpha macr state space and anisotropy information. [J917]

"Microwave Observatory of Subcanopy and Subsurface (MOSS): A Mission Concept for Global Deep Soil Moisture Observations"

The Microwave Observatory of Subcanopy and Subsurface (MOSS) is a mission concept for a spaceborne synthetic aperture radar (SAR) system that provides global observations of soil moisture under substantial vegetation cover (exceeding 20 kg/m2) and at useful depths (1-5 m). The concept was developed and a number of new required technologies were demonstrated through a National Aeronautics and Space Administration Earth Science Technology Office Instrument Incubator Program project. This very high frequency (VHF)/ultrahigh frequency (UHF) polarimetric SAR is designed to provide 7-10-day observations of soil moisture at 1-km resolution. The rapid repeat cycle mandates swath widths in the range of 300-400 km, which must be realized by a 30-m-long antenna. Conventional array implementations would result in a mass of more than 4000 kg, whereas with the technology proposed and demonstrated in this project, the total antenna mass is less than 500

kg. The antenna concept is a dual-stacked patch array feed illuminating a 30-m mesh reflector to synthesize the long apertures and achieve the wide swath. The feed system prototype was fabricated and its performance demonstrated. Other major project components were: (1) system-level SAR and mission design; (2) demonstration of science data and products, using a tower-based VHF/UHF radar; (3) spacecraft and mesh reflector antenna mechanical design; (4) developing mitigation strategies for ionospheric effects; and (5) assessing frequency interference effects. Experimental science data were generated from the tower radar for soil moisture profiling in Arizona and for forest penetration in Oregon. The soil moisture products were demonstrated through an integrated inversion-processing algorithm. This paper summarizes the results from the MOSS project and demonstrates the feasibility of the spaceborne mission. [J918]

"Robust SVA method for every sampling rate condition"

Linear apodization, or data weighting, is the traditional procedure to improve sidelobe levels in a finite sampled signal at the expense of resolution. New apodization methods, such as spatially variant apodization (SVA), apply nonlinear filtering to the signal in order to completely remove sidelobes without any loss of resolution. However, the results are strongly influenced by signal sampling rate. Some variations which improve results have been previously published, but sidelobe cancellation gets worse since sampling frequency is not settled at Nyquist (or a multiple). This paper presents a new and efficient technique based on SVA that drastically reduces sidelobe levels for every sampling rate condition. The algorithm is, essentially, a parameter optimization of a variant filter for each pixel of the image. A one-dimensional case and a two-dimensional generalization are presented, as well as some applications to target detection capability in a synthetic aperture radar (SAR) system. [J919]

"An Implementation of Synthetic Aperture Focusing Technique in Frequency Domain"

A new implementation of a synthetic aperture focusing technique (SAFT) based on concepts used in synthetic aperture radar and sonar is presented in the paper. The algorithm, based on the convolution model of the imaging system developed in frequency domain, accounts for the beam pattern of the finite-sized transducer used in the synthetic aperture. The 2D fast Fourier transform (FFT) is used for the calculation of a 2D spectrum of the ultrasonic data. The spectrum is then interpolated to convert the polar coordinate system used for the acquisition of ultrasonic signals to the rectangular coordinates used for the presentation of imaging results. After compensating the transducer lobe amplitude profile using a Wiener filter, the transformed spectrum is subjected to the 2D inverse Fourier transform to get the time-domain image again. The algorithm is computationally attractive due to the use of 2D FFT. The performance of the proposed frequency-domain algorithm and the classical time-domain SAFT are compared in the paper using simulated and real ultrasonic data. [J920]

"Fractional Chirp Scaling Algorithm: Mathematical Model"

In this paper, the new fractional chirp scaling algorithm (FrCSA) is mathematically derived and analyzed from high-resolution SAR imaging point of view. The FrCSA is based on the use of the fractional Fourier transform within the chirp scaling algorithm (CSA). The performance of the FrCSA is compared to that of the classical CSA that is based on the fast Fourier transform (FFT). Simulation results for airborne SAR systems show that the FrCSA offers enhanced signal-to-noise ratio (SNR), better focusing capabilities, sharpened main lobe with extra power concentration, and greater side-lobe reduction ratio (SLRR) and all of these, without the need for any additional focusing or enhancement techniques that are required in the classical FFT-based CSA. [J921]

"Radio Echo Sounding of Pine Island Glacier, West Antarctica: Aperture Synthesis Processing and Analysis of Feasibility From Space"

Airborne radio echo sounding of the West Antarctic Ice Sheet over Pine Island Glacier was performed in the austral summer of 2004/2005 under the National Science Foundation's West Antarctic Ice Sheet Initiative. The British Antarctic Survey flew its newly developed 150-MHz ice-sounding radar over Pine Island Glacier and collected approximately 35 000 km of sounding data. The synthetic aperture radar (SAR) technique was applied to process those data in order to enhance radar signatures from the bed. As a matter of fact, airborne ice-sounding radar systems are generally affected by surface clutter returns, masking the echoes of internal layers and ice-bedrock transition at a large depth. Focused and unfocused (Doppler filtering) SAR techniques were compared, and their respective advantages/disadvantages were analyzed. Enhancement of bedrock detection at a large depth (> 2000 m) through SAR processing is demonstrated. Finally, a simulation analysis was performed for assessing the feasibility of ice-sheet sounding from space. It is shown that the gain in bed detection threshold is marginal in the satellite sounding geometry. Airborne radar, Antarctica, ice sounding, satellite remote sensing, subglacial topography, synthetic aperture radar (SAR) processing, West Antarctic Ice Sheet. [J922]

"Polarimetric Calibration Using a Genetic Algorithm"

This letter presents a novel calibration approach to polarimetric synthetic aperture radar using distributed targets with known scattering characteristics. A genetic algorithm with complex-valued encoding is proposed to solve the overdetermined system of nonlinear equations associated with the polarimetric calibration problem. The proposed genetic algorithm is described in detail, and validation of the algorithm is performed by numerical simulations. [J923]

"A New Algorithm for Sparse Aperture Interpolation"

A new algorithm for filling sparse aperture synthetic aperture radar (SAR)/inverse SAR (ISAR) data, which applies for widely gapped apertures, is proposed in this letter. An Estimating Signal Parameter via Rotational Invariance Techniques(ESPRIT)-based parametric approach is first used to estimate the power distribution with the sparse data. With the estimated power spectrum as prior information, by minimizing a weighted norm as a constraint, the full aperture data can be estimated. Although the algorithm is proposed for the sparse aperture interpolation in SAR/ISAR, it can be applied to other gapped data spectral estimation problems as well. Both numerical and experimental examples are provided to demonstrate the performance of the proposed algorithm. [J924]

"Efficient Interpolation of SAR Images for Coregistration in SAR Interferometry"

An efficient polynomial interpolation method is proposed to reduce the computational burden of the coregistration of synthetic aperture radar images in interferometric processing. The method can be viewed as an application of the Farrow interpolator technique and requires a series of 2-D fast Fourier transforms (FFTs). Mainly, it has two advantages relative to the usual coregistration procedure. First, it does not require to compute or store in memory any kernel sample. Second, it involves less floating-point operations than the conventional coregistration, with a clear advantage if the image needs to be oversampled. The efficiency of the method is based on the fact that the complexity of one 2-D FFT is much smaller than the complexity of one spatial convolution. These advantages are demonstrated by both analyzing the interpolation procedure itself and by defining an efficient code implementation. [J925]

"Fitting a Two-Component Scattering Model to Polarimetric SAR Data From Forests"

Two simple scattering mechanisms are fitted to polarimetric synthetic aperture radar (SAR) observations of forests. The mechanisms are canopy scatter from a reciprocal medium with azimuthal symmetry and a ground scatter term that can represent double-bounce scatter from a pair of orthogonal surfaces with different dielectric constants or Bragg scatter from a moderately rough surface, which is seen through a layer of vertically oriented scatterers. The model is shown to represent the behavior of polarimetric backscatter from a tropical forest and two temperate forest sites by applying it to data from the National Aeronautic and Space Agency/Jet Propulsion Laboratory's Airborne SAR (AIRSAR) system. Scattering contributions from the two basic scattering mechanisms are estimated for clusters of pixels in polarimetric SAR images. The solution involves the estimation of four parameters from four separate equations. This model fit approach is justified as a simplification of more complicated scattering models, which require many inputs to solve the forward scattering problem. The model is used to develop an understanding of the ground-trunk double-bounce scattering that is present in the data, which is seen to vary considerably as a function of incidence angle. Two parameters in the model fit appear to exhibit sensitivity to vegetation canopy structure, which is worth further exploration. Results from the model fit for the ground scattering term are compared with estimates from a forward model and shown to be in good agreement. The behavior of the scattering from the ground-trunk interaction is consistent with the presence of a pseudo-Brewster angle effect for the air-trunk scattering interface. If the Brewster angle is known, it is possible to directly estimate the real part of the dielectric constant of the trunks, a key variable in forward modeling of backscatter from forests. It is also shown how, with a prioriknowledge of the forest height, an estimate for th- e attenuation coefficient of the canopy can be obtained directly from the multi-incidence-angle polarimetric observations. This attenuation coefficient is another key variable in forward models and is generally related to the canopy density. [J926]

"Spatially Variant Apodization for Squinted Synthetic Aperture Radar Images"

Spatially variant apodization (SVA) is a nonlinear sidelobe reduction technique that improves sidelobe level and preserves resolution at the same time. This method implements a bidimensional finite impulse response filter with adaptive taps depending on image information. Some papers that have been previously published analyze SVA at the Nyquist rate or at higher rates focused on strip synthetic aperture radar (SAR). This paper shows that traditional SVA techniques are useless when the sensor operates with a squint angle. The reasons for this behaviour are analyzed, and a new implementation that largely improves the results is presented. The algorithm is applied to simulated SAR images in order to demonstrate the good quality achieved along with efficient

computation. [J927]

"High-Resolution Forecast Models of Water Vapor Over Mountains: Comparison With MERIS and Meteosat Data"

Propagation delay due to variable tropospheric water vapor (WV) is one of the most intractable problems for radar interferometry, particularly over mountains. The WV field can be simulated by an atmospheric model, and the difference between the two fields is used to correct the radar interferogram. Here, we report our use of the U.K. Met Office Unified Model in a nested mode to produce high-resolution forecast fields for the 3-km-high Mount Etna volcano. The simulated precipitable-water field is validated against that retrieved from the Medium-Resolution Imaging Spectrometer (MERIS) radiometer on the Envisat satellite, which has a resolution of 300 m. Two case studies, one from winter (November 24, 2004) and one from summer (June 25, 2005), show that the mismatch between the model and the MERIS fields (rms = 1.1 and 1.6 mm, respectively) is small. One of the main potential sources of error in the models is the timing of the WV field simulation. We show that long-wavelength upper tropospheric troughs of low WV could be identified in both the model output and Meteosat WV imagery for the November 24, 2004 case and used to choose the best time of model output. [J928]

"Approach of Adaptive Synchronization for Bistatic SAR Real-Time Imaging"

The use of a novel synchronization link to compensate time, phase, and spatial synchronization errors is proposed, aiming at the development of a practical synchronization technique for bistatic synthetic aperture radar (BiSAR) real-time imaging. With the proposed technique, an amplitude-modulated signal emitting from the transmitter is received by a passive receiver and divided into two channels. One is passed through an envelope detector and then used to trigger the sampling clock, and the second is used to achieve spatial synchronization and phase synchronization. Finally, the residual time synchronization errors are compensated with a proposed high-precision range realignment method, and the residual phase synchronization errors are compensated with autofocus algorithms. This technique allows a passive receiver, which is teamed with an illuminator at a safe standoff distance, to receive the data reflected from potentially hostile areas of interest. Thus, this configuration, making real-time imaging possible, has a particular value in military applications. Simulation results show that successful adaptive synchronization for BiSAR real-time imaging is possible by using this dedicated synchronization link. [J929]

"Polarimetric Analysis of Bistatic SAR Images From Polar Decomposition: A Quaternion Approach"

This paper focuses on polar decomposition, which is based on the quaternion formalism, in single-look and multilook synthetic aperture radar polarimetry. Polar decomposition is used to decompose a bistatic or monostatic polarimetric scattering matrix into a product of a Hermitian matrix (boost) and a unitary matrix (rotation). After an overview of polar decomposition principle and quaternion properties, coherent (single-look complex) and incoherent (multilook) polar decompositions are discussed. In single-look polar decomposition, we introduce the boost parameter and the rotation parameter with the purpose of classifying scattering mechanisms of different natures. New relationships between these geometrical parameters and the scattering matrix elements are obtained. We also briefly reexamine the standard coherent polarimetric target decomposition algorithms in the light of quaternions. Next, an original use of polar decomposition for incoherent polarimetric imaging is proposed, which leads to the definition of the multilook boost parameter and of the degree of polarization dispersion. Subsequently, a new approach is presented, which consists in decomposing the scattering matrix into boost and rotation components before vectorization, then in averaging to generate boost and rotation coherency matrices separately. This leads to new inferred parameters: the boost and rotation entropies, and the concurrent dominant scattering mechanisms. The link between these new parameters and standard polarimetric invariants from the Cloude and Pottier decomposition is discussed. Eventually, the multilook extension of polar decomposition may allow this to be applied to the classification of remote sensing data. In this framework, a set of five parameters reducing to four in the monostatic case can be considered. [J930]

"Along-Track Focusing of Airborne Radar Sounding Data From West Antarctica for Improving Basal Reflection Analysis and Layer Detection"

This paper presents focused synthetic aperture radar (SAR) processing of airborne radar sounding data acquired with the High-Capability Radar Sounder system at 60 MHz. The motivation is to improve basal reflection analysis for water detection and to improve layer detection and tracking. The processing and reflection analyses are applied to data from Kamb Ice Stream, West Antarctica. The SAR processor correlates the radar data with reference echoes from subsurface point targets. The references are 1-D responses limited by the pulse nadir footprint or 2-D responses that include echo tails. Unfocused SAR and incoherent integration are included for comparison. Echoes are accurately preserved from along-track slopes up to about 0.5deg for unfocused SAR,

3deg for 1-D correlations, and 10deg for 2-D correlations. The noise/clutter levels increase from unfocused SAR to 1-D and 2-D correlations, but additional gain compensates at the basal interface. The basal echo signal-to-noise ratio improvement is typically about 5 dB, and up to 10 dB for 2-D correlations in rough regions. The increased noise degrades the clarity of internal layers in the 2-D correlations, but detection of layers with slopes greater than 3deg is improved. Reflection coefficients are computed for basal water detection, and the results are compared for the different processing methods. There is a significant increase in the detected water from unfocused SAR to 1-D correlations, indicating that substantial basal water exists on moderately sloped interfaces. Very little additional water is detected from the 2-D correlations. The results from incoherent integration are close to the focused SAR results, but the noise/clutter levels are much greater. [J931]

"Improved nonlinear frequency scaling algorithm for squint FMCW SAR"

An improved nonlinear frequency scaling algorithm is proposed to process squint frequency modulated continuous wave synthetic aperture radar data. The algorithm uses a decimation technique to decrease the bandwidth of the signal introduced by the frequency scaling operation, effectively removing the range frequency aliasing. Simulated results show the validity of the algorithm. [J932]

"Integration of synthetic aperture radar image segmentation method using Markov random field on region adjacency graph"

A novel approach to obtain precise segmentation of synthetic aperture radar (SAR) images using Markov random field model on region adjacency graph (MRF-RAG) is presented. First, to form a RAG, the watershed algorithm is employed to obtain an initially over-segmented image. Then, a novel MRF is defined over the RAG instead of pixels so that the erroneous segmentation caused by speckle in SAR images can be avoided and the number of configurations for the combinatorial optimisation can be reduced. Finally, a modification method based on Gibbs sampler is proposed to correct edge errors, brought by the over-segmented algorithm, in the segmentations obtained by MRF-RAG. The experimental results both on simulated and real SAR images show that the proposed method can reduce the computational complexity greatly as well as increase the segmentation precision. [J933]

"Degrading effects of the lower atmosphere on long-range airborne synthetic aperture radar imaging"

The imaging performance of airborne synthetic aperture radar (SAR) systems has advanced to the point that the effects of clear-air refractive index perturbations cannot be ignored. Operating at long ranges, and low grazing angles, in particular, require propagation geometries through regions of the lower atmosphere that may cause noticeable and, sometimes, severe degradation of the images. The range of image anomalies that can be attributed to the atmospheric boundary layer (ABL) is illustrated, the pertinent characteristics of the ABL is discussed, a first-order SAR imaging model that incorporates the refractive index perturbations associated with the ABL is developed and the magnitude of the image anomalies resulting from measured refractive index perturbations is estimated. The model predictions correlate well with the observed image anomalies and measured properties of the ABL. On the basis of theory and measurements, it is expected that the degrading effect of clear-air atmospheric refractive index perturbations is much more common than previously thought and may be a limiting factor for long-range SAR imaging performance. [J934]

"Image-Driven Data Mining for Image Content Segmentation, Classification, and Attribution"

Image-driven data mining methods are described for image content segmentation, classification, and attribution, where each pixel location of an image-under-analysis is the center point of a pixel-block query that returns an estimated class label. Feature attribute estimates may also be mined when sufficient attribute strata exist in the data warehouse. Novel methods are presented for pixel-block mining, pattern similarity scoring, class label assignments, and attribute mining. These methods are based on a direct sum tree structure called a sigma-tree that is utilized with near-neighbor similarity scoring. The sigma-tree structure provides a solution to the challenge of high computation/memory costs of pixel-block similarity searching. The sigma-trees are integrated into warehouse subsystems that provide referential capability into feature attribute data, resulting in a foundation for data mining called Source Optimized, Labeled, DIgital Expanded Representations (SOLDIER). The variable depth "bit-plane" data representations produced by sigma-tree path selections provide an approach to image content segmentation, and provide a structure for formulation of Bayesian classification with data-adaptive Parzen classifiers with variably sized windows. Preliminary methods and results for postprocessing of mined feature-thematic layers for higher level scene understanding are also presented. Sample results are shown with synthetic aperture radar images and with high-resolution pan-sharpened satellite images of the Payagala, Sri Lanka area before the site was devastated by the 2004 Asian Tsunami. [J935]

"Phaseless characterisation of compact antenna test ranges"

Antenna characterisation and radar cross section measurements can be conveniently and successfully carried out by means of a compact antenna test range (CATR), whose performance is primarily assessed in terms of quiet zone size and field uniformity. CATR characterisation and diagnostics are usually performed by means of (amplitude and phase) field measurements in the quiet zone and are of timely interest either on CATR installation or on its periodic reassessments performed by manufacturers and/or users. This paper addresses CATR characterisation from amplitude-only data, an attractive topic because of the application of CATRs to the millimetre or sub-millimetre wave ranges. The approach is based on an appropriate strategy retrieving the missing quiet zone phase and facing the issue of the large electrical dimensions of the CATR. To take into account the characteristics of the collimating system as well as to keep as low as possible the number of unknowns to be sought for, it exploits the Jacobi-Bessel expansion of the aperture field. The performance of the algorithm has been tested through a wide numerical analysis against synthetic data generated by GRASP8-SE whose full version is routinely employed for CATR design. The main results related to a Gregorian dual offset reflector CATR, modelled on that proposed in the literature by Pistorius et ah, and to a single offset reflector CATR, inspired by the one available at the Queen Mary & Westfield College, London (UK), are reported. [J936]

"SAR Remote Sensing Analysis of the Sea Surface by Polynomial Filtering [JApplications Corner]"

Synthetic aperture radar (SAR) allows the observation of the sea surface over large areas regardless of weather conditions. In what follows we discuss a digital signal processing (DSP) formalism that makes use of polynomial filters such as Volterra models to extract the geophysical information from SAR images and to model several nonlinear transfer functions. Polynomial filters allow the extension of algorithms derived for the linear case to the nonlinear case. First, we will briefly discuss the types and sources of nonlinearities in SAR mapping of the ocean surface. Next, we will summarize the main characteristics of the Volterra filters and apply them to the understanding of hydrodynamic nonlinearities and instrumental nonlinearities. Then, we will combine their Volterra models to model the complete mapping process. Although we have only focused on the particular example of Volterra filters here, nonlinear autoregressive moving average (NARMA) models can also been applied to extract geophysical information from a nonlinear marine feature signature. [J937]

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{no data available} [J938]

"Correlation Properties of Signals Backscattered From Fractal Profiles"

A successful mathematical description of natural landscapes relies upon a class of random processes known as fractional Brownian motions (fBms), which may exhibit correlation with long-range dependence (LRD). In remote sensing applications, the sensor observes a certain real scene Band records data Ifor successive signal processing tasks. Assuming that B is modeled as an fBm, does the recorded signal Ipreserve the LRD character of B? More in general, can we relate the Hurst coefficient (an index of LRD) of the real scene to that of the recorded data? We address the problem in a simplified setup in which the data are related to (the slope of) the original scene through a zero-memory mapping. A mathematical framework is presented in which the above questions can be answered in the asymptotic regime of infinite data size. The effect of the finite sample size is also investigated. The mathematical model is also validated by real data, which are collected by a synthetic aperture radar that is mounted onboard of ERS-1/2 satellites. [J939]

"Application of the Deflection Criterion to Classification of Radar SAR Images"

An original application of the weighted deflection is proposed for radar target classification by quadratic filters. An explicit formulation of optimal filters is derived. We analyze the impact of the weighting parameter on real data recognition and show that performances are better when the deflection coincides with the Fisher ratio. [J940]

"SAR Image Autofocus By Sharpness Optimization: A Theoretical Study"

Synthetic aperture radar (SAR) autofocus techniques that optimize sharpness metrics can produce excellent restorations in comparison with conventional autofocus approaches. To help formalize the understanding of metric-based SAR autofocus methods, and to gain more insight into their performance, we present a theoretical analysis of these techniques using simple image models. Specifically, we consider the intensity-squared metric, and a dominant point-targets image model, and derive expressions for the resulting objective function. We examine the conditions under which the perfectly focused image models correspond to stationary points of the objective function. A key contribution is that we demonstrate formally, for the specific case of intensity-squared

minimization autofocus, the mechanism by which metric-based methods utilize the multichannel defocusing model of SAR autofocus to enforce the stationary point property for multiple image columns. Furthermore, our analysis shows that the objective function has a special separble property through which it can be well approximated locally by a sum of 1-D functions of each phase error component. This allows fast performance through solving a sequence of 1-D optimization problems for each phase component simultaneously. Simulation results using the proposed models and actual SAR imagery confirm that the analysis extends well to realistic situations. [J941]

"Target Detection and Texture Segmentation in Polarimetric SAR Images Using a Wavelet Frame: Theoretical Aspects"

Theoretical aspects of a technique for target detection and texture segmentation in synthetic aperture radar (SAR) imagery using a wavelet frame are presented. Texture measures consist of multiscale local estimates of the following: 1) normalized second moment of the backscattered intensity and 2) variance of the wavelet-frame coefficients. This work is an extension of a method proposed in the image-processing literature. Novel issues, which are considered in the passage to radar imagery, are the influence of speckle on texture measures afforded by the wavelet frame and their dependence on polarization states (polarimetric texture). Regarding speckle, estimators that decouple the influence of speckle over texture are introduced and characterized by their expected value and variance. The response of the wavelet frame to discontinuities, which is an important issue in target detection problems, is addressed in terms of signal-to-speckle-noise ratio. The notion of polarimetric texture is revisited, providing a theoretical model that explains the dependences of texture measures on the polarization states. For one-point statistics, such model calls for a mixture of diverse polarimetric scattering mechanisms within the texture estimator support. For two-point statistics, the difference in spatial correlation properties among the polarimetric channels is called into play. To analyze these effects in polarimetric SAR data, a novel tool is introduced that is called the Wavelet Polarimetric Signature. The tool encapsulates, in graphical form, the dependence on scale and polarization state of the texture measure afforded by the wavelet frame. The theory exposed here underpins a method that has been proven successful and computationally attractive in a selected number of SAR thematic applications. It also sets the stage for the exploitation of novel target detection and textural segmentation capabilities based on polarimetric diversity. [J942]

"Refraction and Dispersion Effects Compensation for UWB SAR Subsurface Object Imaging"

It is a trend to use airborne or vehicle-borne ultrawideband synthetic aperture radar (UWB SAR) to quickly detect subsurface objects, i.e., landmines or minefields, over large areas from a safe standoff distance. The traditional image formations without considering the refraction and dispersion of electromagnetic wave will lead to locating error and defocusing for subsurface objects. In this paper, an efficient refraction and dispersion effects compensation method is proposed, which can be integrated with the traditional three-stage automatic target detection framework for detection of subsurface landmines. The compensation method can focus and correctly locate multiple objects buried in different soils with different depths over large areas, which satisfies the operating requirement of an airborne or vehicle-borne UWB SAR system. The proposed method is proved efficient for subsurface object imaging by the field data collected by a UWB SAR system. [J943]

"Wavelet-Based Despeckling of SAR Images Using Gauss-Markov Random Fields"

In this paper, a wavelet-based speckle-removing algorithm is represented and tested on synthetic aperture radar (SAR) images. The SAR image is first transformed using a dyadic wavelet transform. The noise in the wavelet-transformed image is modeled as an additive signal-dependent noise with Gaussian distribution. The distribution of a noise-free image in a wavelet domain is modeled as a generalized Gauss-Markov random field (GGMRF). An unsupervised stochastic model-based approach to image denoising is represented. If the observed area is homogeneous, the parameters of the Gaussian distribution and GGMRFs are estimated from incomplete data using mixtures of wavelet coefficients. An expectation-maximization algorithm is used to estimate the parameters of both noisy and noise-free images. The unknown parameters are estimated using image and noise models that are defined in the wavelet domain for heterogeneous areas. Different inter-and intrascale dependences of wavelet coefficients were used to estimate the unknown parameters. The represented wavelet-based method efficiently removes noise from SAR images. [J944]

"Focused 70-cm Wavelength Radar Mapping of the Moon"

We describe new 70-cm wavelength radar images of the lunar near-side and limb regions obtained via a synthetic-aperture-radar patch-focusing reduction technique. The data are obtained by transmitting a circularly polarized pulsed waveform from the Arecibo telescope in Puerto Rico and receiving the echo in both senses of circular polarization with the Robert C. Byrd Green Bank Telescope in West Virginia. The resultant images in

both polarizations have a spatial resolution as fine as 320 m 450 m near the lunar limb. The patch-focusing technique is a computationally efficient method for compensating for range migration and Doppler (azimuth) smearing over long coherence times, i.e., 983 s, which is needed to achieve the required Doppler resolution. Three to nine looks are averaged for speckle reduction and to improve the signal-to-noise ratio. At this long wavelength, the radar signal penetrates up to several tens of meters into the dry lunar surface materials, thus revealing details of the bulk loss properties and decimeter-scale rock abundance not evident in multispectral and other remote-sensing data. Application of the new radar images to the analysis of basalt flow complexes in Mare Serenitatis shows that the long-wavelength radar data are sensitive to differences in both flow age and composition, and may be particularly useful for studies of smaller deposits that do not have robust crater statistics. The new 70-cm lunar radar data are archived at the National Aeronautics and Space Administration Planetary Data System. [J945]

"Knab Sampling Window for InSAR Data Interpolation"

Interferometric synthetic aperture radar processing requires interpolating a slave image onto a master one. Since the signals requiring interpolation are limited in both time and bandwidth, the Knab sampling window provides an almost optimal and viable interpolation kernel. Its performance in terms of coherence preservation and interferometric phase error as a function of the number of retained samples and oversampling factor are shown. [J946]

"Current Measurements in Rivers by Spaceborne Along-Track InSAR"

The global monitoring of river discharges is a technologically challenging problem, with important applications in a variety of disciplines. Due to the limited availability and/or quality of river runoff data from many regions, an increasing use of remote sensing techniques is highly desirable. Altimeter specialists have already demonstrated water level retrievals in rivers from available data. The along-track interferometric synthetic aperture radar [along-track InSAR (ATI)] capabilities of state-of-the-art imaging radars on satellites such as the German TerraSAR-X, which was launched on June 15, 2007, also permit high-resolution line-of-sight surface current measurements. In this paper, we evaluate the potential of current measurements in rivers by spaceborne ATI on the basis of fundamental theoretical considerations, existing spaceborne InSAR data from the shuttle radar topography mission (SRTM), and simulated TerraSAR-X data. We show that an SRTM-derived line-of-sight surface current field in the Elbe river, Germany, agrees well with numerical hydrodynamic model results. The data quality is sufficient to resolve characteristic lateral variations of the currents in the river around a pronounced main flow channel. Assuming that the flow direction is usually aligned with the river bed, even a quasi-2D total surface current field can be derived. Simulations indicate that TerraSAR-X was even better suited for current measurements in rivers. Depending on width, surface roughness, and relative flow direction of a river, current estimates with an accuracy better than 0.1 m/s were possible with an effective spatial resolution of a few hundred meters to kilometers. [J947]

"Urban-Target Recognition by Means of Repeated Spaceborne SAR Images"

The relative low resolution (~25 m times 5 m on the ground) of spaceborne C-band synthetic aperture radar (SAR) data as acquired, for example, by European Space Agency sensors ERS and Envisat, can be significantly increased (up to submeter precisions) by processing coherently long series of images. Moreover, by analyzing the amplitude of the radar signal and by exploiting polarization diversity, the main radar characteristics of urban targets can be estimated, and a system for automatic recognition of a set of scattering structures can be developed. In this paper, we study the variation of the amplitude of the received radar signal as a function of the acquisition geometry [normal baseline and Doppler centroid (DC)] to retrieve the extension of the targets in range and azimuth. The dependence of the radar amplitude on temperature at the time of acquisition has been discovered to be very useful to identify extended resonating targets. Dihedrals are discriminated from specular or trihedral reflectors through the phase of Envisat alternating polarization (AP) acquisitions. By means of all gathered radar measurements, the bases for the development of a system for the automatic recognition of six main typologies of urban SAR targets (ground-level and elevated backscatterers, simple and resonating dihedrals, poles and trihedrals) have been laid. Radar data are then combined with in situ surveys and aerial photos, allowing a first assessment of the methodology in urban area. [J948]

"SAR Sea-Ice Image Analysis Based on Iterative Region Growing Using Semantics"

Synthetic aperture radar (SAR) has been intensively used for sea-ice monitoring in polar regions. A computer-assisted analysis of SAR sea-ice imagery is extremely difficult due to numerous imaging parameters and environmental factors. This paper presents a system which, with some limited information provided, is able to perform an automated segmentation and classification for the SAR sea-ice imagery. In the system, both the

segmentation and classification processes are based on a Markov random-field theory and are formulated in a joint manner under the Bayesian framework. Solutions to the formulation are obtained by a region-growing technique which keeps refining the segmentation and producing semantic class labels at the same time in an iterative manner. The algorithm is a general-segmentation approach named iterative region growing using semantics, which, in this paper, is dedicated to the problem of classifying the operational SAR sea-ice imagery provided by the Canadian Ice Service (CIS). The classified image results have been validated by the CIS personnel, and the resulting classifications are quite successful using the same algorithm applied to diverse data sets. [J949]

"On the Existence of Coverage and Integration Time Regimes in Bistatic SAR Configurations"

Bistatic synthetic aperture radar (SAR) is an extension of traditional monostatic SAR, which increases the flexibility in designing SAR missions. We describe a scheme for the computation of integration time and azimuth coverage of bistatic SARs based on space-time diagrams. A classification of bistatic SAR configurations is introduced in terms of size and velocity on the ground of antenna footprints. Bistatic SAR regimes are also identified. [J950]

"Height Estimation of Boreal Forest: Interferometric Model-Based Inversion at L- and X-Band Versus HUTSCAT Profiling Scatterometer"

In this letter, we present results from the FinSAR project, where the E-SAR and Helsinki University of Technology Scatterometer (HUTSCAT) instruments were operated together in order to validate tree-height retrieval algorithms for boreal forest. The campaign was carried out in Finland in fall 2003. The main instruments of the campaign were the E-SAR airborne radar (operating at L- and X-band) and the HUTSCAT helicopter-borne profiling scatterometer (operating at X- and C-band). We compare and discuss forest height obtained from the inversion quad-pol polarimetric interferometric synthetic aperture radar (SAR) data sets at L-band and forest height obtained from the inversion of single-pol X-band in SAR data with forest height estimates from HUTSCAT scatterometer data. Our results show that the forest height values, which are estimated by means of two different radar instruments, are in good agreement. The correlation between HUTSCAT and E-SAR height estimates (at L-band and at X-band) underlines the good agreement between the results obtained by the two approaches. [J951]

"Polarimetric and Interferometric SAR Image Partition Into Statistically Homogeneous Regions Based on the Minimization of the Stochastic Complexity"

In this paper, we show that polarimetric and interferometric SAR (PolInSAR) images can be efficiently partitioned into homogeneous regions with a statistical technique based on minimization of a parameter-free criterion. This technique consists of finding a polygonal partition of the image that minimizes the stochastic complexity, assuming that the image is made of a tessellation of statistically homogeneous regions. The obtained results demonstrate that a global partition in statistically homogeneous regions of PolInSAR images can provide better results than a partition based on a single characteristic such as polarimetry or interferometry only. [J952]

"Improving River Flood Extent Delineation From Synthetic Aperture Radar Using Airborne Laser Altimetry"

Flood extent maps that are derived from synthetic aperture radar (SAR) images provide spatially distributed data for validating hydraulic models of river flood flow. The accuracy of such maps is reduced by a number of factors, including variation in backscatter from the different land cover types that are adjacent to the flood, changes in returns from the water surface that are caused by different meteorological conditions, and the presence of emergent vegetation. This paper describes how improved accuracy can be achieved by modifying an existing flood extent delineation algorithm to use airborne laser altimetry [light detection and ranging (lidar)] as well as SAR data. The lidar data provide an additional constraint that water line heights should vary smoothly along the flooded reach. The method was tested on a SAR image of a flood for which contemporaneous aerial photography existed, together with lidar data of the un flooded reach. The water line heights of the SAR flood extent that was conditioned on both SAR and lidar data matched the corresponding heights from the aerial photograph water line significantly more closely than those from the SAR flood extent that was conditioned only on SAR data. For water line heights in areas of low slope and vegetation, the root-mean-square error on the height differences reduced from 221.1 cm for the latter case to 55.5 cm for the former. [J953]

"Spatially Nonstationary Anisotropic Texture Analysis in SAR Images"

This paper deals with spatial analysis of texture in synthetic aperture radar (SAR) images. A new parametric

model for local two-point statistics of the image is introduced, in order to characterize the spatially nonstationary and anisotropic behavior of the image. The texture is first modeled by a nonstationary Gaussian process resulting from the convolution of a Gaussian white noise with a field of anisotropic Gaussian kernel with spatially varying parameters. Hence, under the hypothesis of locally stationary signal, the analytic expression of the local autocovariance is derived. It is then explained how to simulate nonstationary K-distributed random fields by combining the new model with an already existing simulation method. A method for parameter estimation is then introduced. This method, based on the statistical product model, first corrects the speckle contribution to the local autocovariance and estimates the parameters of the model by analyzing the shape of the autocovariance. The algorithm is then evaluated over simulated and experimental data. Stationary simulations permit to show that, for a sufficient sample size, the estimator is unbiased. A test over a nonstationary simulation proves the ability of the algorithm to capture the spatial fluctuations of the texture. Finally, the method is applied to the experimental SAR data, and it is shown that a large amount of spatial information may be retrieved from the data. [J954]

"On the Distribution of the Estimated Coherence"

The recent paper by Abdelfattah and Nicolas proposed a novel coherence magnitude estimator and studied its properties. Here, we derive simpler and more explicit expressions for four of the properties that were studied: 1) the probability density function; 2) moments; 3) Mellin transform; and 4) second-kind moments. We establish numerical efficiency of these expressions and provide simple Maple programs for inversion. We expect that the results presented here could enhance applicability of the new estimator. [J955]

"Ocean Mixed-Layer Depth and Current Variation Estimated From Imagery of Surfactant Streaks"

The ability of high-resolution imaging systems to resolve small-scale structure on the ocean surface suggests the possibility of using characteristics of Langmuir circulation to map the surface mixed-layer depth and near-surface current. We illustrate this using synthetic aperture radar and infrared imagery that are collected across the edge of the Gulf Stream (GS), which reveals surfactant streaks, or ldquowindrows,rdquo that are induced by Langmuir circulation. Based on changes in the windrow spacing and orientation, the mixed layer is estimated to deepen from 7 to 12 m across the edge of the GS and the current to increase from about 1 to 2 m/s. These spatial changes compare reasonably well with independent data, suggesting that the approach is plausible. It may also be possible to extract additional environmental information from the windrows. [J956]

"A Discrete Wavelet Transform Approach to Multiresolution Complex SAR Image Generation"

We present a signal processing approach using discrete wavelet transform (DWT) for the generation of complex synthetic aperture radar (SAR) images at an arbitrary number of dyadic scales of resolution. The method is computationally efficient and is free from significant system-imposed limitations present in traditional subaperture-based multiresolution image formation. Problems due to aliasing associated with biorthogonal decomposition of the complex signals are addressed. The lifting scheme of DWT is adapted to handle complex signal approximations and employed to further enhance the computational efficiency. Multiresolution SAR images formed by the proposed method are presented. [J957]

"Application of ENVISAT ASAR Data in Mapping Rice Crop Growth in Southern China"

This research letter presents preliminary results of mapping rice crop growth using ENVISAT advanced synthetic aperture radar (ASAR) alternating polarization HH/HV data. Four ASAR HH/HV images were collected in the early rice-growth cycle in the test site in 2006, and the temporal response of ASAR data to the rice field was analyzed. The height and biomass of rice were measured during acquisition of ASAR data, and empirical relationships were established between the backscattering coefficient and these two parameters. Based on the temporal variation of the radar response, a method for mapping a rice growth area was developed using the combination of ASAR HH and HV polarization data between two acquisition dates. The results confirm that C-band SAR data have great potential in the development of an operational system for monitoring rice crop growth in Southern China. [J958]

"Effect of Apodization on SAR Image Understanding"

This paper investigates the effect of apodization on the statistical properties of synthetic aperture radar (SAR) images and its impact on the capability of extracting information from homogeneous regions of apodized SAR images. The statistical model for the pixel complex amplitude of the apodized image is derived in terms of both probability density function and statistical moments. Knowledge of the statistical properties is then used to develop appropriate schemes for parameter estimation and supervised classification of homogeneous regions with different radar cross sections in apodized SAR images. The performance analysis shows that the new

techniques (properly derived for the apodized case) provide information extraction capabilities only slightly worse than those provided by the conventional techniques applied to the nonapodized case. This allows us to conclude that the use of nonlinear apodization yields sidelobe level reduction and main lobe resolution preservation that can be traded with the small losses above. A full characterization of the estimation and classification performance of these new techniques shows that nonlinear apodization globally introduces a performance degradation comparable to a reduction of the number of looks of a factor of 1.455 for a homogeneous region. [J959]

"Non-uniform rotation rate estimation for ISAR in case of slant range migration induced by angular motion"

Target rotation is the desired motion to obtain descriptive inverse synthetic aperture radar images. However, it can generate blurring effects: the migration through resolution cells. This blurring is more severe when the rotation rate is non-uniform. A method to estimate the non-uniform rotation rate (second-order model) for non-cooperative targets is addressed here. The technique considers the possibility of existence of slant range migration induced by angular motion, unlike other approaches. It needs a previous estimation of the range and radial velocity of two prominent points at two instants and minimises a function in order to estimate the motion parameters, which are used to polar format the radar data. The method is compared with the moving target imaging algorithm of Werness et al. and a time-frequency based technique. Simulated data are used to verify the approach and make the comparisons. [J960]

"Wavelet Based Deconvolution Algorithm for Time-Domain Near-Field ISAR Imaging"

Based on correlation receiver in communication theory, the measured backscattering waveform of a calibration conducting sphere is adopted as the system impulse response. This antenna-target system response is then approximated by the derivatives of a Gaussian function (DGF) as well as the Coiflets to restore the impulse response of the target and to reconstruct the ISAR images. Both the DGF and Coiflets are applied to the deconvolution and their results are compared. The Gaussian and Coiflet function parameters are derived by a best-fit to the measured time-domain system response. Employing the parametric fits, a lowpass filter has been automatically embedded which performs regularization of the conjugate gradient (CG) optimization and speeds up the CG convergence. Numerical results show that the image quality from the Coiflet system is similar to or better than from the DGF system. Owing to the continuity, smoothness, orthogonality and compact support of the Coiflets, the size of the system matrix has been reduced from 1024 times 1024 for DGF to 261 times 261, and the deconvolution process is accelerated more than 22 fold without sacrificing image characters. [J961]

"Novel Airborne Real-Time Survey System"

Although satellite imaging is widely used today, an airborne survey system is still more efficient and effective under certain circumstances. Airborne survey can successfully detect and transmit target information in real time that is useful and critical for related agencies, such as environmental management, natural-disaster monitor and control, etc. Using a real-time synthetic-aperture-radar image processing approach based on a distribution system, image data are synchronized with a global positioning system; a satellite-communication system of data transmission is designed and implemented; and a novel image-compression method, which is wavelet-based, is developed. The main idea of the proposed system is based on a function-distribution personal computer (PC) system: Data preprocessing, post processing, and extraction of images, data processing, image display, and image printing, are performed by different PCs. The method of image transmission proposed here is based on the satellite communication system. The proposed system has the advantage of low cost (both hardware prototype and maintenance) and rapid processing speed (only in several seconds; the disaster images from the air are processed and transmitted to the Disaster Reduction Center and to other users by the satellite communication system). The system has been applied to a real-time disaster monitor (such as a forest fire, a flood, etc.), real-time target tracking, large-scale topographic mapping, environmental survey, etc. [J962]

"A Chirp Transform Algorithm for Processing Squint Mode FMCW SAR Data"

Frequency-modulated continuous-wave (FMCW) synthetic aperture radar (SAR) is a lightweight cost-effective high-resolution airborne imaging radar. In squint case, the frequency scaling algorithm, which is suitable for processing nonchirped raw data, cannot be used directly in FMCW SAR data processing because of low system sampling frequency. On the other hand, the continuous antenna motion of FMCW SAR can cause serious distortions in the reconstructed images. In this letter, an improved algorithm called the chirp transform algorithm is proposed. When the effects of the residual video phase are negligible, the algorithm uses a chirp transform to perform the time scaling operation to alleviate the sampling frequency problem. It requires only fast Fourier transforms and multiplications. The range cell migration introduced by the continuous motion is also

compensated completely in range-Doppler domain. The algorithm performances are analyzed and are supported by point target simulation experiments. [J963]

"Improved Global Range Alignment for ISAR"

An improved global range alignment is presented for inverse synthetic aperture radar (ISAR) imaging. The shifts of the echoes are modeled as a polynomial, and the coefficients of this polynomial are chosen to optimize a quality measure of range alignment. The shift in the time domain is carried out by introducing a phase ramp in the frequency domain in order to remove the limitation of integer steps. Because the quality measure of range alignment is calculated directly in the frequency domain, this method is computationally more efficient than the original global method. [J964]

"HRR Detector for Slow-Moving Targets in Sea Clutter"

The radar detection of targets in the presence of sea clutter has historically relied upon the radial velocity of targets with respect to the radar platform either by exploiting the relative target Dopplers (for targets with sufficient radial velocity) or by discerning the paths targets traverse from scan to scan. For targets with little to no radial velocity component, though, it can become quite difficult to differentiate targets from the surrounding sea clutter. This paper addresses the detection of slow-moving targets in sea clutter using a high resolution radar (HRR) such that the target has perceptible extent in range. Under the assumption of completely random sea clutter spikes based on an epsiv-contaminated mixture model with the signal and clutter powers known, optimal detection performance results from using the likelihood ratio test (LRT). However, for realistic sea clutter, the clutter spikes tend to be a localized phenomenon. Based upon observations from real radar data measurements, a heuristic approach exploiting a salient aspect of the idealized LRT is developed which is shown to perform well when applied to real measured sea clutter. [J965]

"Moving Targets Processing in SAR Spatial Domain"

This paper presents a novel technique to estimate the initial coordinates and velocity vector of moving targets, including those with velocities above the Nyquist limit, using a single synthetic aperture radar (SAR) sensor without increasing the pulse repetition frequency (PRF). The basic reasoning is that, although the returned echoes may be undersampled in the azimuth direction, their phase and amplitude are informative with respect to the moving target trajectory parameters. Therefore, the so-called blind angle ambiguity, inherent to systems using a single SAR sensor, is overcome. The proposed method samples the data in the spatial domain, along the signature curve which depends on the moving target trajectory parameters. The resulting algorithm is a highly efficient (from the computational point of view) ID matched filter. The effectiveness of the proposed scheme is illustrated using simulated SAR data and real data from the MSTAR public release data set, corresponding to a static SAR scene and a static BTR-60 with simulated motion. [J966]

"Monitoring of an Alpine Glacier by Means of Ground-Based SAR Interferometry"

Spaceborne differential synthetic aperture radar (SAR) interferometry has been proven to be a powerful tool in monitoring environmental phenomena and, in particular, in observing glaciers and retrieving information about their surface topography and dynamics. In the last decade, the use of this technique has been successfully extended from space to ground-based observations as a tool for monitoring, on a smaller scale, single landslides, unstable slopes, and more recently, areas covered by snow but not yet glaciers. In this letter, the results of an experimental activity carried out to evaluate the potential of ground-based microwave interferometry to estimate the velocity of an unstable area belonging to a glacier is reported. This experiment demonstrated the possibility of remotely monitoring surface displacements of the monitored glacier up to a distance of about 3 km even if, due to the lack of ground truths on the observed area, the data interpretation must be carefully worked out. [J967]

"Location and Imaging of Moving Targets using Nonuniform Linear Antenna Array SAR"

By using a linear antenna array, velocity synthetic aperture radar (VSAR) can detect, focus, and locate slowly moving targets well. However, it may mis-locate fast moving targets in the azimuth (cross-range) direction. In this correspondence, we propose a synthetic aperture radar (SAR) with a nonuniform linear antenna array and give a design of the antenna arrangement. It is shown that our proposed nonuniform linear antenna array SAR (NULA-SAR) can locate both slowly and fast moving targets correctly. An integrated NULA-SAR algorithm for moving target imaging is also presented, and it is verified by some simulations. [J968]

"On Bistatic Inverse Synthetic Aperture Radar"

The use of multiple radar configurations can overcome some of the geometrical limitations that exist when obtaining radar images of a target using inverse synthetic aperture radar (ISAR) techniques. It is shown here how a particular bistatic configuration can produce three view angles and three ISAR images simultaneously. A new ISAR signal model is proposed and the applicability of employing existing monostatic ISAR techniques to bistatic configurations is analytically demonstrated. An analysis of the distortion introduced by the bistatic geometry to the ISAR image point spread function (PSF) is then carried out and the limits of the applicability of ISAR techniques (without the introduction of additional signal processing) are found and discussed. Simulations and proof of concept experimental data are also provided that support the theory. [J969]

"Bistatic Radar Imaging of the Marine Environment-Part II: Simulation and Results Analysis"

We present a bistatic, polarimetric, and real aperture marine radar simulator (MaRS) producing pseudoraw radar signals. The simulation takes the main elements of the environment into account (sea temperature, salinity, and wind speed). Realistic sea surfaces are generated using a two-scale model on a semideterministic basis to incorporate the presence of ship wakes. Then, the radar acquisition chain (antennas, modulation, and polarization) is modeled, as well as the movements of the sensors, on which uncertainties can be introduced, and ship wakes. The pseudoraw temporal signals delivered by MaRS are further processed using, for instance, bistatic synthetic aperture beamforming. The scene itself represents the sea surface as well as ship wakes. The main points covered here are the scene discretization, the ship wake modeling, and the computational cost aspects. We also present images simulated in various monostatic and bistatic configurations and discuss the results. This paper follows its companion paper, where much of the theory used here is recalled and developed in detail. a bistatic, polarimetric, and real aperture marine radar simulator (MaRS) producing pseudoraw radar signals. The simulation takes the main elements of the environment into account (sea temperature, salinity, and wind speed). Realistic sea surfaces are generated using a two-scale model on a semideterministic basis to incorporate the presence of ship wakes. Then, the radar acquisition chain (antennas, modulation, and polarization) is modeled, as well as the movements of the sensors, on which uncertainties can be introduced, and ship wakes. The pseudoraw temporal signals delivered by MaRS are further processed using, for instance, bistatic synthetic aperture beamforming. The scene itself represents the sea surface as well as ship wakes. The main points covered here are the scene discretization, the ship wake modeling, and the computational cost aspects. We also present images simulated in various--monostatic and bistatic configurations and discuss the results. This paper follows its companion paper, where much of the theory used here is recalled and developed in detail. [J970]

"Fusion of Support Vector Machines for Classification of Multisensor Data"

The classification of multisensor data sets, consisting of multitemporal synthetic aperture radar data and optical imagery, is addressed. The concept is based on the decision fusion of different outputs. Each data source is treated separately and classified by a support vector machine (SVM). Instead of fusing the final classification outputs (i.e., land cover classes), the original outputs of each SVM discriminant function are used in the subsequent fusion process. This fusion is performed by another SVM, which is trained on the a priori outputs. In addition, two voting schemes are applied to create the final classification results. The results are compared with well-known parametric and nonparametric classifier methods, i.e., decision trees, the maximum-likelihood classifier, and classifier ensembles. The proposed SVM-based fusion approach outperforms all other approaches and significantly improves the results of a single SVM, which is trained on the whole multisensor data set. [J971]

"Building Recognition From Multi-Aspect High-Resolution InSAR Data in Urban Areas"

The improved ground resolution of state-of-the-art synthetic aperture radar (SAR) sensors suggests utilizing SAR data for the analysis of urban areas. The appearance of buildings in SAR or interferometric SAR (InSAR) data is characterized by the consequences of the inherent oblique scene illumination, such as layover, occlusion by radar shadow, and multipath signal propagation. Therefore, particularly in dense built-up areas, building reconstruction is often impossible from a single SAR or InSAR measurement alone. But, the reconstruction quality can be significantly improved by a combined analysis of multi-aspect data. In this paper, two approaches are proposed to detect and reconstruct buildings of different size from multi-aspect high-resolution InSAR data sets. Both approaches focus on the recognition of buildings supported by knowledge-based analysis considering the mentioned SAR-specific effects observed in urban areas. Building features are extracted independently for each direction from the magnitude and phase information of the interferometric data. Initial primitives are segmented and afterward projected from slant-range into the world coordinate system. From the fused set of primitives of both flight directions, building hypotheses are generated. The first approach exploits the frequently observed lines of bright double-bounce scattering, which are used for building reconstruction in residential districts. In the case of larger buildings, such as industrial halls, often additional features of roof and facade elements are visible. Therefore, in a second approach, extended buildings are extracted by grouping primitives of

different kinds. The two approaches are demonstrated in an urban environment for an InSAR data set, which has spatial resolution of about 30 cm and was taken from two orthogonal flight directions. [J972]

"Analysis and Focusing of Bistatic Airborne SAR Data"

Bistatic synthetic aperture radar (SAR) processing requires precise knowledge about geometrical parameters of the flown bistatic constellation, whereas estimation of these parameters is even more important than in the monostatic case. As it is impossible to separate the individual semimonostatic parameters from the bistatic raw data, the searched parameters are derived from the tracks of the moving platforms. For this reason, global positioning system (GPS) and inertial navigation system (INS) position and velocity data of transmitter and receiver are combined in an optimal way by a Kalman filter approach. As a consequence of model-based interpolation, we can easily determine varying parameters like Doppler centroid frequency, azimuth velocity, and the bistatic parameters a2and a0referring to the illuminated scene at each time instant. Accurately determined position and velocity of the transmitter and receiver enable a first-order bistatic motion compensation (MC), which is also described in this paper. In verifying our approach, GPS/INS tracks and raw data of a bistatic airborne SAR experiment flown in 2003 were used, where the data were provided by Forschungsgesellschaft fu umlr Angewandte Naturwissenschaften e.V., Wachtberg, Germany. The focusing was done by a scaled inverse Fourier transformation processor for nearly parallel trajectories for transmitter and receiver. This paper focuses on analyzing the trajectories and antenna beams of bistatic missions to obtain accurate processing parameters and MC functions. [J973]

"Focusing Parallel Bistatic SAR Data Using the Analytic Transfer Function in the Wavenumber Domain"

In recent years, bistatic synthetic aperture radar (BiSAR) has attracted the attention of many radar researchers. It is well known that the slant range history of BiSAR is the sum of two square-rooted terms, which correspond to the transmitting and receiving slant ranges, respectively. For a point target in the SAR scene, it is quite difficult, if not impossible, to obtain an analytic formula to describe the target echo data in the 2-D frequency domain without any approximation by using the conventional stationary phase method, which makes it very difficult to develop fast-focusing algorithms for BiSAR. In this paper, based on the concept of an instantaneous Doppler wavenumber and by defining a new variable called half quasi-bistatic angle, an analytic formula of the point target response in the spectral domain is developed for BiSAR with parallel trajectory (referred to as parallel BiSAR for simplicity). Relying on a first-order Taylor expansion of the above formula with respect to the parameter called the sum of closest distances on the swath center, a bistatic range migration algorithm is proposed for any azimuth-shift-invariant BiSAR data processing. Simulation results have confirmed the effectiveness of the proposed novel approach. [J974]

"ALOS PALSAR: A Pathfinder Mission for Global-Scale Monitoring of the Environment"

The Advanced Land Observing Satellite (ALOS) is Japan's new-generation Earth Observation satellite, launched in January 2006 by the Japan Aerospace Exploration Agency. ALOS carries two optical instruments (Panchromatic Remote-sensing Instrument for Stereo Mapping and Advanced Visible and Near-Infrared Radiometer type 2) and, to maintain Japan's commitment to spaceborne L-band Synthetic Aperture Radar (SAR), the Phased Array L-band SAR (PALSAR). The successor to the SAR onboard the Japanese Earth Resources Satellite (1992-1998), the PALSAR instrument provides enhanced sensor characteristics, including full polarimetry, variable off-nadir viewing, and ScanSAR operations, as well as significantly improved radiometric and geometric performance. As important as the technical improvements and the reason PALSAR here is referred to as a pathfinder mission for global environmental monitoring is the systematic data-acquisition strategy which has been implemented for ALOS. With a priority second only to emergency observations, the PALSAR observation strategy has been designed to provide consistent, wall-to-wall observations at fine resolution of all land areas on the Earth on a repetitive basis, in a manner which has earlier been conceived only for coarse- and medium-resolution instruments. [J975]

"Model Limitations and Parameter-Estimation Methods for Agricultural Applications of Polarimetric SAR Interferometry"

Application of polarimetric synthetic aperture radar interferometry to the retrieval of geophysical parameters from vegetated scenes is based on simple direct models of such scenes. The first part of this paper presents an analysis of the correspondence between these simple models, namely, the random volume over ground and the oriented volume over ground (OVoG), and experimental data from samples of two agricultural crops (maize and rice) acquired in controlled conditions. Although an overall agreement between model and data is clear, some discrepancies have been found as a consequence of two assumptions in the model formulation: vertical

homogeneity of the vegetation volume and absence of multiple scattering effects inside the volume. This paper presents the shape and location of the visible region of the experimental coherences on the complex plane and compares it with the feasible region predicted by the model. This comparison has also pointed out the low sensitivity of the direct model to extinction coefficients. In the second part, two different strategies for a complete inversion (i.e., estimation of all model parameters) of the OVoG model are proposed and compared, using the same data set. The first one is based on a combination of geometrical and numerical approaches (genetic algorithms) and the second one on a dual-baseline configuration. In all cases, ground topography is accurately estimated, with a maximum error of 10 cm. Vegetation height estimates are accurate up to 30 cm, with some bands and baseline configurations providing errors below 15 cm. However, results obtained for the extinction coefficients are not stable with frequency and exhibit high variability. [J976]

"Hybrid-Polarity SAR Architecture"

A synthetic aperture radar (SAR) often is constrained to transmit only one polarization. Within this constraint, two aggressive measurement objectives are 1) full characterization and exploitation of the backscattered field, and 2) invariance to geometrical orientations of features in the scene. Full characterization implies coherent dual-polarization to support the four Stokes parameters. These are rotationally invariant with respect backscatterer orientation if and only if the transmission is circularly polarized. Given that the data products are the Stokes parameters, the receivers can use any orthogonal polarization basis. A SAR in hybrid-polarity architecture (CL-pol) transmits circular polarization and receives two orthogonal mutually coherent linear polarizations, which is one manifestation of compact polarimetry. The resulting radar is relatively simple to implement, and has unique self-calibration features and low susceptibility to noise and cross-channel errors. It is the architecture of choice for two lunar radars scheduled for launch in 2008. Data from a CL-pol SAR yield to decomposition strategies such as the m-delta method introduced in this paper. [J977]

"Processing of Bistatic SAR Data From Quasi-Stationary Configurations"

Standard synthetic aperture radar (SAR) processing algorithms use analytically derived transfer functions in the 2D frequency and range/Doppler domains. These rely on the assumption of hyperbolic range histories of monostatic SARs with straight flight paths. For bistatic SARs, the range histories are no longer hyperbolic, and simple analytic transforms do not exist. This paper offers two solutions for bistatic SAR data processing under the restriction of quasi-stationarity, i.e., sufficiently equal velocity vectors of transmitter and receiver. 1) Moderately bistatic configurations can be handled satisfactorily by using hyperbolic range functions with a modified velocity parameter, which is a solution already well known for the accommodation of curved orbits in the monostatic case. This "equivalent velocity" approach is shown to be of surprising range of validity even for pronounced bistatic situations. It is not to be confused with the "equivalent monostatic flight path" approximation, which is shown to be inapplicable for any practical case. 2) With increasing separation of transmitter and receiver, the equivalent velocity approximation deteriorates. To cope with extreme bistatic configurations, a general approach named "NuSAR" is proposed, where the involved transfer functions are replaced by numerically computed ones. This paper describes how the transfer functions are computed from the given orbits and the shape of the Earth surface. In any of these two cases, the bistatic SAR data can be processed by standard SAR processors; only the conventional transfer functions need to be replaced. Neither are there time-domain prefocusing or post focusing steps required nor complicated mathematical expansions involved. The presented algorithms are also applicable to very high resolution wide-swath (or squinted) SARs on curved orbits. [J978]

"Ultrawideband Synthetic Aperture Radar Landmine Detection"

In this paper, we consider landmine detection using ultrawideband synthetic aperture radar, where the two main challenges are feature extraction and discriminator design. The space-wavenumber processing is proposed to retrieve the frequency-and aspect-angle-dependent scattering features of suspected objects. In order to reduce the dimensionality of the input feature vector for a discriminator, the sequential forward floating selection method is used to choose efficient features. Based on the obtained feature vector, a fuzzy hypersphere support vector machine is designed to deal with the problem of detecting landmines in an unconstrained environment. The experimental results show that the proposed method can achieve a significant improvement in detection performance for antitank mines. [J979]

"ScanSAR-to-Stripmap Mode Interferometry Processing Using ENVISAT/ASAR Data"

Interferometric synthetic aperture radar (InSAR) images of geophysical events such as preeruptive volcano deformation or interseismic strain accumulation are often limited by phase distortions from the superimposed atmospheric signature. Additionally, the approximate monthly repeat cycle of many radar satellites cannot

accurately capture rapidly time-varying processes. The Scanning Synthetic Aperture Radar (ScanSAR) mode of the ENVISAT/ASAR instrument permits more frequent revisits of a given area, potentially overcoming both of these limitations. In particular, stripmap mode-to-ScanSAR images provide a denser time series of interferograms than is possible with conventional stripmap-to-stripmap mode InSAR. We present images of ENVISAT/ASAR data acquired over Hawaii in which data acquired roughly weekly in ScanSAR mode are combined with ENVISAT/ASAR conventional stripmap mode data to form interferograms at a much denser temporal spacing. The burst nature of ScanSAR data requires a new processing method to form the interferograms. We use traditional matched filtering for the range compression. For the azimuth processing, we compute the stripmap mode data on the ScanSAR sampling grid using a variation, consisting of different reference functions, of Lanari's modified SPECAN algorithm that is itself an adaptation of the chirp z-transform to readjust the azimuth pulse spacing. The resulting interferograms faithfully reflect the phase of conventional interferograms, but exhibit fewer looks and coarser resolution than those produced by fully stripmap mode data. For many problems, temporal density of the deformation observations is paramount, and the time series analysis and temporal averaging that were made possible using ScanSAR interferograms far outweigh the loss in looks and resolution. [J980]

"Statistical CLEAN Technique for ISAR Imaging"

Inverse synthetic aperture radar (ISAR) images are frequently used in target classification and recognition applications. Some classifiers often require features that can be more easily obtained by extracting scattering centers from ISAR data rather than by reconstructing ISAR images. An available method for scattering center extraction, namely, the CLEAN technique, was proposed in a recent paper by Yang et al. In this paper, an improvement of this CLEAN technique is proposed that introduces a new method for detecting scattering centers. The proposed technique is based on a Gaussianity test, and its effectiveness is first theoretically proven and then tested on real data. Moreover, a comparison with the technique proposed by Yang et al. is shown. [J981]

"Single-Pass Polarimetric SAR Interferometry for Vessel Classification"

This paper presents a novel method for vessel classification based on single-pass polarimetric synthetic aperture radar (SAR) interferometry. It has been developed according to recent ship scattering studies that show that the polarimetric response of many types of vessels can be described by trihedral- and dihedral-like mechanisms. The adopted methodology is quite simple. The input interferometric data are decomposed in terms of the Pauli basis, and hence, one height image is derived for each simple mechanism. Then, the local maxima of these images are isolated, and a 3-D map of scatters is generated. The correlation of this map with the scattering distribution expected for a set of reference ships provides the final classification decision. The performance of the proposed method has been tested with the orbital SAR simulator developed at Universitat Politecnica de Catalunya. Different vessel models have been processed with a sensor configuration similar to the incoming TanDEM-X system. The analysis of diverse vessel bearings, vessel speeds, and sea states shows that the map of scatters matches reasonably the geometry of ships allowing a correct identification even for adverse environmental conditions. [J982]

"Bistatic Radar Imaging of the Marine Environment-Part I: Theoretical Background"

We describe in detail the theoretical and practical implementation aspects of a simulation for marine radars which can, in particular, be used in multistatic configurations. Since the simulator is intended to deliver pseudoraw signals, it can be used later as a tool to benchmark and improve postprocessing algorithms such as bistatic synthetic aperture radar focusing algorithms and ship wake detection algorithms. The work is divided into two parts. This paper reviews and recalls theoretical prerequisites necessary in implementing such a simulator. Included are the full derivation of the bistatic radar equation from the transmitter to the receiver, accounting also for the transmit-receive time, a description of the sea state phenomenology, a review of the theory of electromagnetic scattering from the sea surface, and the presentation and validation of the method used in the simulation. A companion paper discusses the practical implementation aspects of the simulator as well as an analysis of our results. [J983]

"A Self-Initializing PolInSAR Classifier Using Interferometric Phase Differences"

This paper describes an unsupervised classifier for polarimetric interferometric synthetic aperture radar (PolInSAR) data. Expectation maximization is used to estimate class parameters that maximize the likelihood of observations in an input data set for a given number of classes. Polarimetric information, in the form of coherency matrices, and interferometric information, in the form of complex coherences, are taken into account. Differences in interferometric phase across different polarization states are explicitly modeled to make the

classifier sensitive to the vertical structure of the scene under observation, and the distribution over such phase differences is introduced. The classifier is self-initializing, in that it does not rely on decompositions or thresholds. Classification results obtained for real polarimetric interferometric data are presented and discussed. [J984]

"Analysis of Polarization Orientation Angle Shifts by Artificial Structures"

In this paper, the polarization orientation angle shifts induced by artificial structures were analyzed and attempted to combine target orientation information which characterizes an urban area with the polarization orientation angle information extracted by the circular-polarization method. In order to illustrate the characteristic of the polarization orientation angle shifts represented in an urban area, the X-band polarimetric synthetic aperture radar (SAR) datasets of Sendai City acquired by Pi-SAR were used. This paper is based on Kimura's idea that the variation of the polarization orientation angle shifts depends on the artificial structures, particularly for the target rotation angle. We found that the polarization orientation angle shift is also affected by the relative relationship between the target rotation angle and the flight direction. From these results, it is possible to estimate the target rotation angle via computation of the polarization orientation angle shift from polarimetric SAR data. [J985]

"Foreword to the Special Issue on Synthetic Aperture Radar (SAR) Technologies and Techniques"

{no data available} [J986]

"Signal Processing for FMCW SAR"

The combination of frequency-modulated continuous-wave (FMCW) technology and synthetic aperture radar (SAR) techniques leads to lightweight cost-effective imaging sensors of high resolution. One limiting factor to the use of FMCW sensors is the well-known presence of nonlinearities in the transmitted signal. This results in contrast- and range-resolution degradation, particularly when the system is intended for high-resolution long-range applications, as it is the case for SAR. This paper presents a novel processing solution, which solves the nonlinearity problem for the whole range profile. Additionally, the conventional stop-and-go approximation used in pulse-radar algorithms is not valid in FMCW SAR applications under certain circumstances. Therefore, the motion within the sweep needs to be taken into account. Analytical development of the FMCW SAR signal model, starting from the deramped signal and without using the stop-and-go approximation, is presented in this paper. The model is then applied to stripmap, spotlight, and single-transmitter/multiple-receiver digital-beamforming SAR operational mode. The proposed algorithms are verified by processing real FMCW SAR data collected with the demonstrator system built at the Delft University of Technology. [J987]

"A New Application for PolSAR Imagery in the Field of Moving Target Indication/Ship Detection"

Recent analysis of a polarimetric synthetic aperture radar (PolSAR) velocity experiment has shown that azimuth ambiguities can provide useful information for the detection of moving targets with an across-track velocity component in PolSAR images using cross-polarization clutter cancellation. This paper examines this phenomenon using theoretical analysis and simulations and illustrates its application with experimental results. It is shown that, for reciprocal scatterers, the phase difference between HV and VH images is zero, whereas for HV and VH ambiguities, the phase difference is pi. For land applications, clutter cancellation is essential for the detection of moving targets in PolSAR images. For maritime applications, it can be used to distinguish images from ambiguities. However, it is important to note that the underlying physical reasons for the performance of clutter cancellation are entirely different from ground moving target indication along-track interferometric SAR. It is also shown that cross-pol clutter cancellation is related to filtering of a double-rate-sampled single-channel SAR signal. [J988]

"TanDEM-X: A Satellite Formation for High-Resolution SAR Interferometry"

TanDEM-X (TerraSAR-X add-on for digital elevation measurements) is an innovative spaceborne radar interferometer that is based on two TerraSAR-X radar satellites flying in close formation. The primary objective of the TanDEM-X mission is the generation of a consistent global digital elevation model (DEM) with an unprecedented accuracy, which is equaling or surpassing the HRTI-3 specification. Beyond that, TanDEM-X provides a highly reconfigurable platform for the demonstration of new radar imaging techniques and applications. This paper gives a detailed overview of the TanDEM-X mission concept which is based on the systematic combination of several innovative technologies. The key elements are the bistatic data acquisition employing an innovative phase synchronization link, a novel satellite formation flying concept allowing for the collection of bistatic data with short along-track baselines, as well as the use of new interferometric modes for system verification and DEM calibration. The interferometric performance is analyzed in detail, taking into account the peculiarities of the bistatic operation. Based on this analysis, an optimized DEM data acquisition plan

is derived which employs the combination of multiple data takes with different baselines. Finally, a collection of instructive examples illustrates the capabilities of TanDEM-X for the development and demonstration of new remote sensing applications. [J989]

"An Unsupervised Segmentation With an Adaptive Number of Clusters Using the SPAN/H/α/A Space and the Complex Wishart Clustering for Fully Polarimetric SAR Data Analysis"

In this paper, an unsupervised segmentation is proposed for fully polarimetric synthetic aperture radar (SAR) data analysis. The backscattering power SPANcombined with H/alpha/Ais used to obtain the initial cluster centers. We use the Wishart test statistic to perform an agglomerative hierarchical clustering to obtain the segmentation results with different numbers of clusters. The appropriate number of clusters is automatically estimated using the data log-likelihood (Lm), and the resulting images with the estimated number of clusters are the final segmentation results. The experiments show that the SPANhas additional information that is not contained in H/alpha/A, and this information could be useful for the initialization. The number of clusters seems to be a crucial point for the segmentation, which will affect the segmentation performance. It is also shown that the data log-likelihood has the potential ability to reveal the inner structure of fully polarimetric SAR data. [J990]

"DEM Control in Arctic Alaska With ICESat Laser Altimetry"

Use of Ice, Cloud, and land Elevation Satellite (ICESat) laser altimetry is demonstrated for control of a digital elevation model (DEM) that is synthesized from repeat-pass ERS-1 and 2 synthetic aperture radar (SAR) imagery using interferomet-ric SAR (InSAR). Our study area is 15 650 km2of the Barrow, AK coastal plain adjacent to the Arctic Ocean; a vast expanse of tundra, lakes, and arctic wetlands of such low relief as to be nearly devoid of terrain features. The accuracy of the ICESat-derived elevation measurements is assessed by comparison with differential global positioning system (DGPS) data acquired along ICESat ground tracks. The ICESat-derived elevations have a mean accuracy, relative to the DGPS elevations, of -0.01 plusmn 0.18 m. ICESat-derived elevations on the Arctic coastal plain provide an excellent source for DEM control. We employ the ICESat-derived ground control points (GCPs) in two distinct InSAR processing steps: 1) selected points are used to perform baseline refinements, which improves the ERS-1 and 2 interfero-grams and 2) the ICESat-derived GCP position data (latitude, longitude, elevation) are then used as control in mosaicking multiple InSAR-derived DEMs. The resulting ICESat-controlled DEM has a mean accuracy of -1.11plusmn 6.3 m relative to an independent standard, which is a commercial airborne InSAR-derived DEM having 0.5 m rms accuracy. This easily meets DTED-2 standards and suggests that DEMs derived using only ICESat altimetry for ground control would meet similar standards in other regions of low relief. [J991]

"Results of a Space-Surface Bistatic SAR Image Formation Algorithm"

This paper reports progress in the development of an image formation algorithm suitable for stripmap space-surface bistatic synthetic aperture radar. A description of the proposed algorithm, which is a modification of the standard range-Doppler algorithm, is provided for the case when the transmitter and the receiver have parallel flight paths and unequal velocities. Both simulation and initial experimental results are presented to verify our analysis. [J992]

"Inverse Synthetic Aperture Secondary Radar Concept for Precise Wireless Positioning"

In this paper, the novel inverse synthetic aperture secondary radar wireless positioning technique is introduced. The proposed concept allows for a precise spatial localization of a backscatter transponder even in dense multipath environments. A novel secondary radar signal evaluation concept compensates for the unknown modulation phase of the returned signal and thus leads to radar signals comparable to common primary radar. With use of this concept, inverse synthetic aperture radar algorithms can be applied to the signals of backscatter transponder systems. In simulations and first experiments, we used a broadband holographic reconstruction principle to realize the inverse synthetic aperture approach. The movement of the transponder along a short arbitrary aperture path is determined with assisting relative sensors (dead reckoning or inertia sensors). A set of signals measured along the aperture is adaptively focused to the transponder position. By this focusing technique, multipath reflections can be suppressed impressively and a precise indoor positioning becomes feasible. With our technique, completely new and powerful options for integrated navigation and sensor fusion in RF identification systems and wireless local positioning systems are now possible. [J993]

"Retrieving 3-D Topography by Using a Single-Antenna Squint-Mode Airborne SAR"

In this paper, a novel method is proposed for retrieving 3-D topography of the ground surface by using a single-antenna squint-mode airborne synthetic aperture radar (SAR). The main idea of the method is based on the fact that the spatial 3-D location of a target can be found as the intersection of the range sphere, the Doppler cone,

and the elevation plane of the antenna pattern. An accurate estimation of the Doppler centroid for each resolution cell is required to realize this method. Experimental results obtained with a Ku-band airborne SAR are presented. The method calls for using a precise calibrated attitude determination unit. [J994]

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