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ТЕМАТИЧЕСКИЙ РЕФЕРАТИВНЫЙ СБОРНИК № 48-1

“Satellite SAR”
(«Спутниковые системы с синтезированной апертурой»)

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"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. [J1]

"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. [J2]

"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. [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]

"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. [J5]

"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. [J6]

"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. [J7]

"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. [J8]

"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. [J9]

"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. [J10]

"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. [J11]

"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. [J12]

"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. [J13]

"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. [J14]

"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. [J15]

"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. [J16]

"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. [J17]

"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. [J18]

"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. [J19]

"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). [J20]

"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. [J21]

"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. [J22]

"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. [J23]

"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. [J24]

"Wideband balanced folded dipole antenna with a dual-arm monopole structure for mobile handsets"

In this study, a balanced antenna for mobile handset applications with enhanced bandwidth performance, covering the bands from 1.8 to 2.45 GHz, is investigated. The antenna is a slot planar dipole with folded structure and a dual-arm on each half. The antenna impedance was investigated using a two-port S-parameter method. For the purpose of antenna power gain measurement, a wide bandwidth planar balun was employed to support a balanced feed from an unbalanced source. For validation, a prototype of the proposed antenna was fabricated and tested. The performance of the antenna was then verified in terms of return loss, radiation patterns and power gain. The calculated and measured results show good agreement and the results also confirm good wideband characteristics with low induced current in the ground plane, thus minimising performance variations and SAR. [J25]

"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. [J26]

"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. [J27]

"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. [J28]

"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. [J29]

"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. [J30]

"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. [J31]

"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. [J32]

"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. [J33]

"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. [J34]

"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. [J35]

"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. [J36]

"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. [J37]

"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. [J38]

"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. [J39]

"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. [J40]

"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. [J41]

"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. [J42]

"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. [J43]

"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. [J44]

"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. [J45]

"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. [J46]

"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. [J47]

"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. [J48]

"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. [J49]

"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. [J50]

"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. [J51]

"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. [J52]

"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. [J53]

"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. [J54]

"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. [J55]

"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. [J56]

"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. [J57]

"Block Analysis of a Voltage Supply Chain: Mixed Electromagnetic Modeling and Validation"

This paper describes an industry-oriented approach for the analysis of complex electronic systems. The typical constrains of an industry design flow such as limited time, limited computing resources, and the use of standard/commercial software tools are considered. The approach consists in partitioning the system in several functional blocks and studying each block separately. Different numerical techniques are employed, choosing the more appropriate, for characterizing each chain blocks. At the end, all the blocks are cascaded obtaining the overall system performances. The approach is applied to a voltage supply chain mounted on board of the SENTINEL 1-SAR satellite to verify the integrity of the voltage pulse propagating from the source to the high power amplifiers. The final results are validated by hardware measurements. [J58]

"Compact wideband balanced antenna for mobile handsets"

A novel miniature balanced mobile handset antenna is presented in this study, which covers digital communication system (DCS) (1710-1880-MHz), personal communication system (PCS) (1850-1990-MHz), universal mobile telecommunications system (UMTS) (1920-2170-MHz) and wireless local area network (WLAN) (2400-2484-MHz) frequency bands. The antenna is a built-in planar dipole with folded structure and with the addition of a dual arm on each half of the dipole. The performance of the antenna is analysed and optimised under certain design constraints. The stability performance of the proposed antenna against proximity effects is evaluated. The effects of the phone user-s hand on the return loss and radiation patterns have been characterised by simulation with a simple hand model. A prototype of the proposed antenna is fabricated and tested. A wide bandwidth planar balun is used to feed the wideband balanced antenna from an unbalanced source. The calculated and measured results show good agreement and confirm good wideband characteristics with multiband operation. The specific absorption rate (SAR) performance of the antenna is also studied experimentally by measuring near field exposure. The measured results have shown low induced current in the ground plane and thus confirm minimisation of performance variations and SAR. [J59]

"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. [J60]

"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). [J61]

"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. [J62]

"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. [J63]

"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. [J64]

"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. [J65]

"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. [J66]

"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. [J67]

"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. [J68]

"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. [J69]

"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. [J70]

"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. [J71]

"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. [J72]

"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. [J73]

"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. [J74]

"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. [J75]

"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. [J76]

"Cassini Radar Data: Estimation of Titan's Lake Features by Means of a Bayesian Inversion Algorithm"

The analysis derived from the Cassini SAR imagery reflects the complex Titan's surface morphology with a wide range of backscattering coefficients and peculiar features such as periodic structures and lakelike features, which were observed on July 22, 2006, when polar areas were first imaged, and are considered good candidates to be filled with liquid hydrocarbons. In this paper, the modeling description of lakes is addressed by means of a double-layer model which considers an upper liquid-hydrocarbon layer and a lower layer compatible with the radar response of the neighboring areas. This model is introduced into a Bayesian framework for the purpose of inferring the likely ranges of some parameters and, in particular, of the optical thickness of the hypothesized liquid-hydrocarbon layer and of the wind speed. The main idea is to use the information contained in the parameter probability density function, which describes how probability is distributed among the different values of parameters according to the various scenarios considered. The analysis carried out on lakes and surrounding areas on flybys T16 and T19 determines optical thickness values from 0.2 to 6. For T25 flyby, the inferred values of optical thickness indicate that a limit value of optical thickness may be 9. Considering that, beyond these values, the signal from the bottom layer is completely attenuated, information on the wind speed on the upper layer can be inferred. The found mean values of wind speed are around 0.2-0.3 m/s according to different hypotheses on the upper layer dielectric constant. [J77]

"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. [J78]

"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. [J79]

"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. [J80]

"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. [J81]

"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. [J82]

"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. [J83]

"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. [J84]

"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. [J85]

"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. [J86]

"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. [J87]

"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. [J88]

"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. [J89]

"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. [J90]

"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). [J91]

"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. [J92]

"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. [J93]

"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. [J94]

"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. [J95]

"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 . [J96]

"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. [J97]

"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. [J98]

"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. [J99]

"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. [J100]

"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. [J101]

"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. [J102]

"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. [J103]

"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. [J104]

"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. [J105]

"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. [J106]

"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. [J107]

"Bayesian Data Fusion for Adaptable Image Pansharpening"

Currently, most optical Earth observation satellites carry both a panchromatic sensor and a set of lower spatialresolution multispectral sensors. In order to benefit from both sources of information, several pansharpening methods have been developed to produce a multispectral image at the spatial resolution of the panchromatic band. The aim of this paper is to suggest a novel approach to the pansharpening problem within a Bayesian framework. This Bayesian data fusion (BDF) method relies on statistical relationships between the various spectral bands and the panchromatic band without suffering from restricting modeling hypotheses. Furthermore, it allows the user to weight the spectral and panchromatic information with respect to either visual or quantitative criteria, which leads to adaptable results according to users' needs and study areas. The performance of this approach was compared to existing methods based on markedly different subset images from very high spatial resolution IKONOS images. Results showed that BDF yielded the highest spectral consistency. Furthermore, small details were adequately added to the pansharpened images with little artifact as compared to those created using wavelet-based methods. Finally, the method was fast and easy to implement owing to its straightforward formulation. As it does not have any intrinsic limitations on the type of data to be processed or the number of bands to be merged, it also appears to be very promising for optical/SAR or hyperspectral image fusion. [J108]

"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. [J109]

"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. [J110]

"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. [J111]

"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. [J112]

"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. [J113]

"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. [J114]

"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. [J115]

"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. [J116]

"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. [J117]

"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. [J118]

"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. [J119]

"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. [J120]

"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. [J121]

"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. [J122]

"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. [J123]

"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. [J124]

"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. [J125]

"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. [J126]

"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. [J127]

"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. [J128]

"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. [J129]

"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. [J130]

"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. [J131]

"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. [J132]

"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. [J133]

"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. [J134]

"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. [J135]

"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 [J136]

"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 [J137]

"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 [J138]

"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. [J139]

"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. [J140]

"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. [J141]

"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 [J142]

"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 [J143]

"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 [J144]

"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 [J145]

"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 [J146]

"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 [J147]

"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 [J148]

"Satellite-Aided Search and Rescue (SAR) System"

To carry out search and rescue of people in distress on the distressed aircrafts/vessels on land, at sea, or in a remote mountainous region, there are a number of different search and rescue systems and methods that are being used by the different national search and rescue organizations worldwide. Herein, the main terrestrial search and rescue (SAR) systems that are in use are discussed in brief and a satellite-aided search and rescue (SAR) system-COSPAS-SARSAT is discussed in detail highlighting its benefits over other SAR systems. [J149]

"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. [J150]

"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. [J151]

"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. [J152]

"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. [J153]

"Mutual Coupling Between Box-Horn Elements of a Phased Array Terminated in Three-layered Bio-Media"

The ldquoplane wave spectral techniquerdquo is used to investigate theoretically the extent of mutual coupling between two box-horn elements of a phased array terminated in three-layered bio-media (skin, fat, and muscle layers). The results obtained have been validated against published results in the literature. Each box-horn of the array is assumed to be filled with water to provide good impedance match to the bio-media. Also, it reduces the dimensions of each box-horn which makes it suitable for array configuration. The effects of relative position of elements, spacing between elements, frequency, aperture size of each element, relative phase and amplitude of excitation of the elements on mutual coupling coefficients are numerically investigated and presented for an array of two box-horns terminated in bio-media. The specific absorption rate (SAR) distributions along the direction of the array axis in muscle layer of the bio-media in direct contact with a collinear array of two box-horns both with and without mutual coupling considerations are also computed and presented. The results of the present research work can provide useful design guidelines for the development of prototypes of box-horn array for hyperthermia treatment of tumors. Bio-media, box-horn, hyperthermia, mutual coupling, phased array, plane wave spectra. [J154]

"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. [J155]

"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. [J156]

"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. [J157]

"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. [J158]

"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. [J159]

"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. [J160]

"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. [J161]

"TerraSAR-X active radar ground calibrator system"

In April 2006, the TerraSAR-X satellite was launched. This paper describes the development of a novel and highly integrated, digitally-controlled active SAR system calibrator (DARC). It consists of both an active transponder path for absolute radiometric calibration and a calibrated receiver chain for antenna pattern evaluation of the satellite antenna. A total of 16 active transponder and receiver systems and 17 receiver-only systems will be fabricated for a calibration campaign in 2006. [J162]

"SAR programmes in JAXA: from JERS-1 to the future"

The author introduces the status of the Japan Aerospace Exploration Agency's synthetic aperture radar (SAR) programmes and their scientific returns from the last 20 years of activity. The Earth observation programme was started using active microwave sensors in the early 1990s. Spaceborne SAR aboard Japanese Earth Resource's Satellite-1 (JERS-1) was the pathfinder, and airborne polarimetric and interferometric SAR followed. The Advanced Land Observing Satellite will be launched to carry PALSAR as a follow-up high-resolution, high-performance SAR. [J163]

"TECSAR: design considerations and programme status"

TECSAR is designated to be the first Israeli space-based synthetic aperture radar (SAR) satellite. The system design considerations and the programme status are presented. TECSAR is defined as a space-borne SAR satellite technology demonstration programme. The programme's purpose is to develop and evaluate the necessary technologies required to achieve high-resolution images combined with large area coverages. These results can be achieved by designing a multi-mode operation, including innovative system and subsystems designed to cope with the special operational requirements and the weight/volume constraints. The TECSAR payload belongs to a family of SAR payloads, developed and produced by ELTA Systems. However, because of the demanding requirements imposed by the potential users and the need to fit into the satellite lightweight bus, TECSAR is unique as far as space SAR is concerned and exhibits the best performances in certain parameters. Mission requirements and system design are described here. The authors focus on the payload and its subsystems and also mention the possibility of multi-polarisation imaging. The TECSAR satellite development phase was completed at the end of 2005. [J164]

"Performance improvement for constellation SAR using signal processing techniques"

A new concept of spaceborne synthetic aperture radar (SAR) implementation has recently been proposed-the constellation of small spaceborne SAR systems. In this implementation, several formation-flying small satellites cooperate to perform multiple space missions. We investigate the possibility to produce high-resolution wide-area SAR images and fine ground moving-target indicator (GMTI) performance with constellation of small spaceborne SAR systems. In particular, we focus on the problems introduced by this particular SAR system, such as Doppler ambiguities, high sparseness of the satellite array, and array element errors. A space-time adaptive processing (STAP) approach combined with conventional SAR imaging algorithms is proposed which can solve these problems to some extent. The main idea of the approach is to use a STAP-based method to properly overcome the aliasing effect caused by the lower pulse-repetition frequency (PRF) and thereby retrieve the unambiguous azimuth wide (full) spectrum signals from the received echoes. Following this operation, conventional SAR data processing tools can be applied to focus the SAR images fully. The proposed approach can simultaneously achieve both high-resolution SAR mapping of wide ground scenes and GMTI with high efficiency. To obtain array element errors, an array auto-calibration technique is proposed to estimate them based on the angular and Doppler ambiguity analysis of the clutter echo. The optimizing of satellite formations is also analyzed, and a platform velocity/PRF criterion for array configurations is presented. An approach is given to make it possible that almost any given sparse array configuration can satisfy the criterion by slightly adjusting the PRF. Simulated results are presented to verify the effectiveness of the proposed approaches. [J165]

"SAR image coregistration based on isolated point scatterers"

This work considers a technique for fast and accurate coregistration of multipass synthetic aperture radar images based on isolated point scatterers analysis. Several tests, carried out on real data acquired by the European Remote Sensing and Envisat satellites, are presented to demonstrate the registration accuracy improvements with respect to standard cross-correlation techniques, carried out on extended image patches. Particularly relevant is the robustness of this technique also in presence of a large baseline span and in case of high temporal separation [J166]

"Improving the image quality of spaceborne multiple-aperture SAR under minimization of sidelobe clutter and noise"

As we know, a multiple-aperture radar carried by a group of formation-flying satellites can be used to improve the coverage and azimuth resolution of spaceborne synthetic aperture radar (SAR) simultaneously. However, in the case of the reconstruction of azimuth signal from a periodic nonuniform sampling sequence, the sidelobe clutter and noise may be amplified by tens of decibels in some cases, which makes the final SAR image blurry. In this letter, we present the analytical result of the amplification factor of sidelobe clutter and noise for the evaluation of the reconstruction performance. According to the result, we propose a method to reduce the sidelobe clutter and noise, which considerably improves the quality of SAR image. Computer simulation results confirm the effectiveness of the method [J167]

"Interferometric SAR coherence magnitude estimation using second kind statistics"

Coherence magnitude is a fundamental parameter for the analysis of applications using interferometric synthetic aperture radar (InSAR). The coherence magnitude estimators are biased and need bias removal. The sample coherence magnitude estimation, computed on a window basis, depends on the number of independent samples and theoretical coherence. It has been shown that the sample coherence magnitude estimator is the maximum-likelihood one. It is a biased estimator, especially for low coherence values. In this paper, we present a novel coherence magnitude estimator obtained from the method of moments using "second kind statistics". Classical methods (with regular statistics) for coherence computation are based on a probability density function (pdf) model for estimating regular moments (first kind statistics) defined with the Fourier transform. The proposed approach is based on the same pdf model to compute the second kind statistics defined with the Mellin transform (log-moment). Thus, it is shown that the estimated coherence given by the first log-moment is less biased. Moreover, it is shown that the coherence magnitude estimation from complex coherence maps (interferometric data) using second kind statistics is the optimal estimation procedure of interferometric coherence. It gives the smallest bias near zero comparing with existing estimators. The developed estimation approaches have been applied to obtain coherence measurements from tandem European Remote Sensing 1 and 2 satellite interferometric data, collected over varying terrain with a variety of ground cover types (agriculture field, forest, lake, urban area, sea) in Tunisia, France, and Nepal [J168]

"Performance analysis of multistatic configurations for spaceborne GMTI based on the auxiliary

beam approach"

In addition to powerful earth imaging and remote sensing, a multistatic spaceborne synthetic aperture radar (SAR) configuration offers the possibility of detecting efficiently the presence of slowly moving targets and surfaces as a result of the large baselines. Such a configuration can be achieved by a constellation of coherent passive satellites receiving the echoes of pulses transmitted by a separate SAR satellite and reflected from the earth. It also enables resolution of the design difficulty of space-based ground moving target indication (GMTI) systems caused by the severe spatial conditions. Owing to the additional degrees of freedom available in a multisatellite constellation compared with a monostatic system, the problem of blindness against certain directions of target motion can be overcome and the sensitivity can be extended to almost any direction of motion, depending on the configuration. For this purpose, non-classical algorithms have to be developed. Because of the high system complexity and the huge amount of data to be processed, only suboptimum methods can be implemented. A suboptimum method is proposed for multistatic spaceborne moving target detection based on the auxiliary beam approach. The main feature of this processing is estimation of both velocity and direction of target motion. According to this method, an analysis of multistatic SAR satellite configurations for their GMTI capability is carried out and the choice of the constellation baselines inferring directly on the expected GMTI sensitivity is discussed. [J169]

"Image autocoregistration and InSAR interferogram estimation using joint subspace projection"

In this paper, we propose a new method to estimate synthetic aperture radar interferometry (InSAR) interferometric phase in the presence of large coregistration errors. The method takes advantage of the coherence information of neighboring pixel pairs to automatically coregister the SAR images and employs the projection of the joint signal subspace onto the corresponding joint noise subspace to estimate the terrain interferometric phase. The method can automatically coregister the SAR images and reduce the interferometric phase noise simultaneously. Theoretical analysis and computer simulation results show that the method can provide accurate estimate of the terrain interferometric phase (interferogram) as the coregistration error reaches one pixel. The effectiveness of the method is also verified with the real data from the Spaceborne Imaging Radar-C/X Band SAR and the European Remote Sensing 1 and 2 satellites. [J170]

"Accuracy assessment of SAR data-based snow-covered area estimation method"

Employment of satellite radar-based remote sensing data for snow monitoring during the snow melt season has been widely studied by several investigators. Several methods for the estimation of snow-covered area (SCA) fraction have been developed for different types of regions. One common deficiency with the SCA estimation methods has been the lack of statistical accuracy analyses for them. In order to incorporate SCA estimates for operational use, one vital requisite is a thorough statistical analysis of the SCA estimation accuracy. This shortcoming has been addressed for boreal forest region, as an extensive statistical accuracy analysis has been carried out for the Helsinki University of Technology (TKK)-developed SCA method. The TKK SCA method was developed for boreal forest regions, and it is studied here with 24 European Remote Sensing 2 synthetic aperture radar intensity images, on a boreal-forest-dominated test area located in northern Finland. The performance of the SCA method is investigated by using reference data acquired through hydrological modeling. The accuracy analysis is carried out for several statistical variables, and the statistical interpretation is done with respect to several affecting parameters. The accuracy analysis shows a high correlation coefficient between the SCA estimates and the reference data and root mean square error values of 0.213 for open areas and 0.179 for forested areas. In addition, the TKK method employs two reference images for the SCA estimation, and the usability of multiyear reference image utilization was analyzed and proven feasible in this study. [J171]

"Analysis of the terrain displacement along a funicular by SAR interferometry"

An analysis of the terrain displacement along a funicular in Switzerland was performed by satellite synthetic aperture radar interferometry using ERS-1/2 data. An initial interferometric point target analysis was performed with images acquired before 1999 and excluding all winter acquisitions with snow cover. The line-of-sight profile of the displacement rate along the funicular shows maximum values of about 1.5 cm/year, with negligible displacements near the lower and upper stations. After the spring of 1999, when displacements of several decimeters occurred because of heavy rainfall, the analysis was continued with single interferograms on the previously identified point targets. With a series of interferograms with large baselines the displacement could be analyzed in 1999 and 2000 along parts of the funicular. [J172]

"Improved slope estimation for SAR Doppler ambiguity resolution"

The idea of using the Radon transform to measure the alignment of linear features in synthetic aperture radar (SAR) data has breathed new life into the "look displacement" class of Doppler ambiguity resolution algorithms.

In these algorithms, the slope of target energy is estimated to obtain the satellite beam pointing angle accurately enough to resolve the Doppler ambiguity. After explaining the method and adding some minor improvements, it is shown how it can work well on satellite SAR data. Then, an alternate method is developed that combines the ideas of the Radon and look displacement algorithms to obtain a computationally simpler and more accurate algorithm. In addition, the quality checks of the "spatial diversity" approach are used to increase the robustness of the algorithm. Even though the algorithm was conceived for high-contrast scenes, it works remarkably well in low to medium contrast scenes as well. [J173]

"TerraSAR-X technologies and first results"

TerraSAR-X is a satellite that is scheduled to be launched in October 2006 and is currently being built in the framework of a public-private partnership between the German Aerospace Centre (DLR) and EADS Astrium GmbH Germany and will carry an X-band synthetic aperture radar (SAR) instrument equipped with an active phased array antenna. Its operational flexibility will allow the use of the instrument for scientific and commercial applications. High amplitude and phase stability of the radar instrument is achieved by a carbon fibre reinforced plastic slotted waveguide radiator and a high precision transmit/receive module. Additionally, internal calibration hardware will allow for determination of the residual drifts. Precise central electronics controls the radar instrument, provides an arbitrary transmit chirp and receives the radar echo with selectable bandwidth and raw data compression ratio. The ground station's multimode SAR processor is supported by a novel satellite steering law to reduce the attitude-dependent mean Doppler shift. This article summarises the EUSAR 2004 TerraSAR-X contributions. [J174]

"Retrieving snowpack properties and accumulation estimates from a combination of SAR and scatterometer measurements"

This study combines two satellite radar techniques, low-resolution C-/Ku-band scatterometer and high-resolution C-band synthetic aperture radar (SAR) for glaciological studies, in particular mass-balance estimations. Three parameters expressing the mean backscattering and its dependency on azimuth and incidence angle are used to describe and classify the Antarctic ice sheets backscattering behavior. Simple linear regression analyses are carried out between ground truth accumulation data and the SAR backscattering coefficient along continuous profile lines. From this we parameterize the accumulation rate separately for certain snow pack regimes. We find that SAR data can be used to map mass-balance changes, however only within limited areas. Applying this method therefore generally requires accurate ground truth for regional calibration together with additional information regarding mean air temperature or elevation. This investigation focuses on the area of Dronning Maud Land, Antarctica. We present the first high-resolution accumulation map based on SAR data for the surrounding area of the EPICA deep ice core drilling site Kohnen, which is compared to reliable ground truth records as well as to a surface-mass-balance map interpolated from these at low resolution. [J175]

"Environmental effects on the interferometric repeat-pass coherence of forests"

The variability of C-band one-day tandem coherence measurements of forest is analyzed both statistically and with the aid of a soil-vegetation-atmosphere transfer model coupled to models for dielectric, backscattering coefficient, and coherence. Coherence depends strongly on both moisture and wind conditions. The dependence between coherence and moisture fluctuations in the soil and canopy is simulated using a simplified coherence model neglecting canopy coherence; trends are similar to those observed in measured coherence, but the range of variability observed in the satellite data is underestimated. Improved consistency with the data is achieved by using empirical estimates of canopy coherence derived from mature forest, but still with underestimated variability. The canopy coherence values cannot be predicted from the environmental model, and anomalous observations prevent the formulation of a reliable empirical predictor based on weather data; this could potentially be improved if higher time resolution wind data were made available. The study also suggests that canopy dielectric can vary rapidly in daylight, and that current models for dielectric may be inadequate to capture the effect of this behavior on coherence. [J176]

"Partially Supervised Oil-Slick Detection by SAR Imagery Using Kernel Expansion"

Spaceborne synthetic aperture radar (SAR) is well adapted to detect ocean pollution independently from daily or weather conditions. In fact, oil slicks have a specific impact on ocean wave spectra. Initial wave spectra may be characterized by three kinds of waves, namely big, medium, and small, which correspond physically to gravity and gravity-capillary waves. The increase of viscosity, due to the presence of oil damps gravity-capillary waves. This induces not only a damping of the backscattering to the sensor but also a damping of the energy of the wave spectra. Thus, local segmentation of wave spectra may be achieved by the segmentation of a multiscale decomposition of the original SAR image. In this paper, a semisupervised oil-slick detection is proposed by using

a kernel-based abnormal detection into the wavelet decomposition of a SAR image. It performs accurate detection with no consideration to signal stationarity nor to the presence of strong backscatters (such as a ship). The algorithm has been applied on ENVISAT Advanced SAR images. It yields accurate segmentation results even for small slicks, with a very limited number of false alarms [J177]

"Change Detection of Multitemporal SAR Data in Urban Areas Combining Feature-Based and Pixel-Based Techniques"

In this paper, the problem of change detection from synthetic aperture radar (SAR) images is addressed. Feature-level change-detection algorithms are still in their preliminary design stage. Indeed, while pixel-based approaches are already implemented into existing, commercial software, this is not the case for feature comparison approaches. Here, the authors propose a joint use of both approaches. The approach is based on the extraction and comparison of linear features from multiple SAR images, to confirm pixel-based changes. Though simple, the methodology proves to be effective, irrespectively of misregistration errors due to reprojection problems or difference in the sensor's viewing geometry, which are common in multitemporal SAR images. The procedure is validated through synthetic examples, but also two real change-detection situations, using airborne and satellite SAR data over the area of the Getty Museum, Los Angeles, as well as over an area around the city of Bam, Iran, stricken in 2003 by a serious earthquake [J178]

"Polarimetric Features of Oyster Farm Observed by AIRSAR and JERS-1"

The polarimetric features of an oyster farm in a coastal area are analyzed to verify the applicability of radar polarimetry and interferometry. L-band Airborne Synthetic Aperture Radar (AIRSAR) data and Japan Earth Resources Satellite (JERS-1) data are used to examine the unique structure of an oyster farm located in South Korea. A specific feature of the oyster farm is the presence of numerous arrays of structures of various orientations that consist of exercise-bar-shaped poles protruding above sea level. This paper demonstrates that tide level is strongly correlated with the double-bounce scattering power from the vertical pole structures. This phenomenon is also verified by laboratory measurements using a network analyzer. In the laboratory experiment, double-bounce scattering and total power showed increasing trends with increased height of the vertical poles. Single-bounce scattering is sensitive to the orientation of horizontal poles relative to antenna orientation. HH-polarization is the most effective technique for imaging oyster farms from L-band polarimetric AIRSAR data. The authors were able to use a three-component decomposition of the AIRSAR data to distinguish an exposed tidal flat from a submerged tidal flat. The characteristics of the exposed tidal flat are similar to those of the carbon sponge in the laboratory test, except that the double-bounce scattering power is slightly greater in the real-world example. The single-bounce scattering component in AIRSAR data is generally greater than that in laboratory measurements because of sea-surface conditions and oyster growth. When the horizontal pole was aligned normal to the radar look direction, single-bounce scattering was greater than the double-bounce scattering, even under water-covered conditions. While a difference in tide height of 10 cm contributed approximately 3.0 dB in the laboratory experiment, a difference in tide height of 20 cm contributed to only approximately 1.7 dB in the JERS-1 SAR-- image intensity. JERS-1 SAR image intensity for areas dominated by double- and single-bounce scattering was 0.78 and 0.56, respectively. Results confirm that polarimetric SAR data are useful in selecting areas dominated by double-bounce scattering in oyster farms [J179]

"Geometrical SAR image registration"

Accurate subpixel registration of synthetic aperture radar (SAR) images is an issue that is again growing interest since its initial developments related to two-pass interferometry. Recent progress in coherent (multichannel) SAR processing raises the need for accurate registration of data takes acquired with large baseline spans, high temporal coverage, and with different frequency and/or operational modes. In this paper, we discuss a SAR image-registration procedure, based on the use of external measures which allows obtaining a very accurate alignment of SAR images. The presented technique makes use of a digital elevation model and of the precise information about the acquisition flight tracks, to compute the warping functions that map the position of each pixel in the different takes, thus avoiding any approximation. The resulting algorithm is simple, robust, precise, and very efficient; as a matter of fact, it may achieve high accuracy even in critical areas, such as steep topography regions. Moreover, the availability of an analytical and exact model allows performing a detailed sensitivity analysis that can be useful in evaluating the applicability of this technique even to future high-precision satellite systems. Extensive testing, carried out on several real European Remote Sensing and ENVISAT datasets, clearly shows the effectiveness of such algorithm in registering critical SAR images [J180]

"Generation of Accurate DEMs Using DInSAR Methodology (TopoDInSAR)"

This letter presents a new methodology for the generation of digital elevation models (DEMs) by means of

differential interferometry (DInSAR) algorithms with no need for classical phase unwrapping. During the last years, several advanced DInSAR proposals have been published, most of them based on a linear deformation adjustment together with topographic error estimation. In those cases, the input data are composed of a set of differential interferograms with different temporal gaps. Consequently, interferograms are affected by severe problems of temporal decorrelation, and the estimation of the topography can only be performed over coherent pixels, which are sparsely spread over the image. The proposal presented in this letter consists in the usage of a set of highly coherent topographic interferograms as input data for an advanced DInSAR algorithm. Then, using classical linear model adjustment, a detailed DEM of the observed area is estimated. This methodology is presented jointly with results obtained by processing real data acquired by European Remote Sensing satellites 1 and 2 [J181]

"Assessment of the AMSR-E Sea Ice-Concentration Product at the Ice Edge Using RADARSAT-1 and MODIS Imagery"

Imagery from the C-band synthetic aperture radar (SAR) aboard RADARSAT-1 and the Moderate Resolution Imaging Spectroradiometer (MODIS) was used to evaluate the performance of the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) ice-concentration product near the sea ice edge in the Bering Sea for four days during March 2003, which is concurrent with the AMSRIce03 field/aircraft campaign. The AMSR-E products were observed to perform very well in identifying open-water and pack-ice areas, although the AMSR-E products occasionally underestimate ice concentration in areas with thin ice. The position of the ice edge determined from AMSR-E data using a 15% concentration threshold was found to be, on average, within one AMSR-E grid square (12.5 km) of the ice edge determined from the SAR data, with the AMSR-E edge tending to be outside the SAR-derived edge [J182]

"Imaging of Single and Double Scatterers in Urban Areas via SAR Tomography"

Microwave scattering is a rather complex mechanism, especially in urban areas. Three-dimensional (3-D) synthetic aperture radar (SAR) tomography is a technique that uses multiple views to map the scattering power at different heights, thus extending the capability of SAR sensors to fully image the scene in the 3-D space. This paper presents a first validation of spaceborne long-term SAR tomography by demonstrating the capability to resolve a simple layover case, i.e., to separate single- and double-scattering mechanisms within imaged pixels. Results obtained with real data acquired by the European Remote Sensing 1 and 2 (ERS-1 and ERS-2) satellites over the urban area of Napoli are presented. As an additional contribution, an innovative algorithm estimating residual topography and surface deformation, called the spatial-differencing technique, is also discussed in detail at the data calibration stage [J183]

"On the Extension of the Minimum Cost Flow Algorithm for Phase Unwrapping of Multitemporal Differential SAR Interferograms"

In this paper, an extension of the minimum cost flow (MCF) algorithm dealing with a sparse data grid, which allows the unwrapping of multitemporal differential synthetic aperture radar (SAR) interferograms for the generation of deformation time series, is presented. The proposed approach exploits both the spatial characteristics and the temporal relationships among multiple interferograms relevant to a properly chosen sequence. In particular, the presented solution involves two main steps: first of all, for each arc connecting neighboring pixels on the interferometric azimuth/range grid, the unwrapped phase gradients are estimated via the MCF technique applied in the temporal/perpendicular baseline plane. Following this step, these estimates are used as a starting point for the spatial-unwrapping operation implemented again via the MCF approach but carried out in the azimuth/range plane. The presented results, achieved on simulated and real European Remote Sensing satellite SAR data, confirm the effectiveness of the extended MCF unwrapping algorithm [J184]

"Performance prediction of a phase synchronization link for bistatic SAR"

Oscillator phase noise can dictate the performance of bistatic and multistatic synthetic aperture radar imaging. In this letter, the use of a dedicated synchronization link to quantify and compensate oscillator phase noise is investigated. Different synchronization schemes are presented, and their performance is analyzed. The error contribution of the synchronization link itself, which may suffer from receiver noise, aliasing, interpolation, and filter mismatch, is included in the analysis. The synchronization link performance is given in a frequency-domain closed integral form [J185]

"MST-based stepwise connection strategies for multipass Radar data, with application to coregistration and equalization"

This paper proposes a unified framework for predicting optimized pairing strategies for interferometric processing of multipass synthetic aperture radar data. The approach consists in a minimum spanning tree (MST) structure based on a distance function encoding an a priori model for the interferometric quality of each image pair. Using a distance function modeled after the interferometric coherence allows reproducing many "small baseline" strategies presented in the recent literature. A novel application of the method to the processing steps of image coregistration and equalization is illustrated, using a test European Remote Sensing Satellite dataset. Widespread methods used for these two operations rely on the computation of the amplitude cross correlation over a large number of corresponding tie patches distributed over the scene. Geometric shift and radiometric equalization parameters are estimated over the patches and used, respectively, within a polynomial warp model and a radiometric correction scheme. The number of reliable patches available behaves similarly to the interferometric synthetic aperture radar (InSAR) coherence with respect to the baselines, and can be assimilated to a quality figure for the derivation of the MST. Results show an improvement in the quality of the stepwise (SW)-processed image stack with respect to the classical single-master procedure, confirming that the SW approach is able to provide better conditions for the estimation of correlation-related InSAR parameters [J186]

"A SAR conjugate mirror"

A radar transponder was constructed, which modifies the received signal such that its complex conjugate is returned to the radar, qualities of the conjugate mirror used in optics and acoustics. For a monostatic synthetic aperture radar (SAR), a perfect conjugate mirror will reflect a signal back to the radar with no phase shift due to the propagation path. The signal received by the transponder is also decorrelated from other targets, enhancing the transponder signal in the SAR image. This letter describes a transponder operated as a SAR conjugate mirror and an experiment with the European Remote Sensing 1 satellite, demonstrating the feasibility and characteristics. The significance for transponder design is addressed and possible applications discussed [J187]

"Interferometry with ENVISAT wide swath ScanSAR data"

The possibility to get efficient topographic mapping and monitoring of large-scale motions with ScanSAR interferometry has been demonstrated with the Shuttle Radar Topography Mission and RADARSAT mission. The Environmental Satellite Advanced Synthetic Aperture Radar (ASAR) sensor has been designed to provide enhanced capabilities for interferometric applications. Different types of interferometric products can be obtained by combining the various ASAR modes as stripmap synthetic aperture radar [image mode (IM)] and ScanSAR [wide swath (WS) mode]. This letter deals with the possibility to use WS data to get either mixed-mode (IM/WS) or ScanSAR mode (WS/WS) differential interferograms. The impact of digital elevation model localization errors on IM/WS interferograms and of scan pattern synchronization on WS/WS interferograms is investigated. Experimental results are encouraging and show that ASAR ScanSAR data can be routinely used for interferometric applications in both cases [J188]

"Validating the SAR Wavenumber Shift Principle With the ERS–Envisat PS Coherent Combination"

Continuity of the European Remote Sensing Satellite Synthetic Aperture Radar (ERS SAR) archive by means of Envisat Advanced SAR (ASAR) data acquired from March 2002 has introduced the problem of the coherent combination of images coming from sensors with slightly different frequencies. The spectral shift principle states that in case of extended distributed targets, the frequency shift is equivalent to a change of looking angle. In this paper, the same principle is exploited to analyze the behavior of permanent scatterers (PSs) with an extension that is smaller than the ground resolution cell. The conditions under which the PSs identified by ERS can be continued by Envisat are then theoretically determined and experimentally validated. Moreover, this analysis shows that acquisitions characterized by different frequencies can be used to identify the slant-range position of scatterers with high subcell accuracy (tens of centimeters). From the processing side, a very precise images coregistration step is required to get the results described in this paper [J189]

"TOPSAR: Terrain Observation by Progressive Scans"

In this paper, a novel (according to the authors' knowledge) type of scanning synthetic aperture radar (ScanSAR) that solves the problems of scalloping and azimuth-varying ambiguities is introduced. The technique employs a very simple counterrotation of the radar beam in the opposite direction to a SPOT: hence, the name terrain observation with progressive scan (TOPS). After a short summary of the characteristics of the ScanSAR technique and its problems, TOPSAR, which is the technique of design, the limits, and a focusing technique are introduced. A synthetic example based on a possible future system follows [J190]

"Automated delineation of dry and melt snow zones in Antarctica using active and passive microwave observations from space"

This paper presents the algorithms and analysis results for delineating snow zones using active and passive microwave satellite remote sensing data. With a high-resolution Radarsat synthetic aperture radar (SAR) image mosaic, dry snow zones, percolation zones, wet snow zones, and blue ice patches for the Antarctic continent have been successfully delineated. A competing region growing and merging algorithm is used to initially segment the SAR images into a series of homogeneous regions. Based on the backscatter characteristics and texture property, these image regions are classified into different snow zones. The higher level of knowledge about the areal size of and adjacency relationship between snow zones is incorporated into the algorithms to correct classification errors caused by the SAR image noise and relief-induced radiometric distortions. Mathematical morphology operations and a line-tracing algorithm are designed to extract a vector line representation of snow-zone boundaries. With the daily passive microwave Special Sensor Microwave/Imager (SSM/I) data, dry and melt snow zones were derived using a multiscale wavelet-transform-based method. The analysis results respectively derived from Radarsat SAR and SSM/I data were compared and correlated. The complementary nature and comparative advantages of frequently repeated passive microwave data and spatially detailed radar imagery for detecting and characterizing snow zones were demonstrated [J191]

"Total zero Doppler Steering-a new method for minimizing the Doppler centroid"

This letter presents a new method, called total Zero Doppler steering, to perform yaw and pitch steering for spaceborne synthetic aperture radar (SAR) systems. The new method reduces the Doppler centroid to theoretically 0 Hz, independent of the range position of interest. Residual errors are only due to pointing inaccuracy or due to approximations in the implementation of the total zero Doppler steering law. This letter compares the new method with currently applied methods. The attitude angles and the residual Doppler centroid frequencies are calculated and depicted exemplarily for the parameters of TerraSAR-X, for which the new method will be implemented and used. The new method provides a number of advantages. The low residual Doppler centroid and the reduced variation of the Doppler centroid over range allow a more accurate Doppler centroid estimation. Due to the low residual Doppler centroid, the synthetic aperture radar (SAR) processing can be alleviated, since the range cell migration is reduced and the Doppler frequencies are low. This facilitates the use of very efficient processing algorithms, which are based on approximations whose quality is better for low Doppler frequencies. The new method will furthermore optimize the overlap of the azimuth spectra of SAR image pairs for cross-track interferometry. Low Doppler centroids will also reduce the impact of coregistration errors on the interferometric phase. Furthermore, scalloping corrections in the ScanSAR processing are alleviated due to the low variation of the Doppler centroid over range. [J192]

"A novel algorithm for ship detection in SAR imagery based on the wavelet transform"

Carrying out an effective control of fishing activities is essential to guarantee a sustainable exploitation of sea resources. Nevertheless, as the regulated areas are extended, they are difficult and time consuming to monitor by means of traditional reconnaissance methods such as planes and patrol vessels. On the contrary, satellite-based synthetic aperture radar (SAR) provides a powerful surveillance capability allowing the observation of broad expanses, independently from weather effects and from the day and night cycle. Unfortunately, the automatic interpretation of SAR images is often complicated, even though undetected targets are sometimes visible by eye. Attending to these particular circumstances, a novel approach for ship detection is proposed based on the analysis of SAR images by means of the discrete wavelet transform. The exposed method takes advantage of the difference of statistical behavior among the ships and the surrounding sea, interpreting the information through the wavelet coefficients in order to provide a more reliable detection. The analysis of the detection performance over both simulated and real images confirms the robustness of the proposed algorithm. [J193]

"Small-scale structure on the poleward edge of a stable auroral red arc"

Here we present all-sky images of a stable auroral red arc collocated with the low-density trough. Small-scale, dynamic structure is observed on the poleward edge of the arc that may be caused by a crossed density/temperature gradient or by a collisional Kelvin-Helmholtz shear-flow instability in conjunction with a sufficient density gradient. [J194]

"A noise model for estimated synthetic aperture radar look cross spectra acquired over the ocean"

It is well known that look cross spectra processed from synthetic aperture radar (SAR) contain valuable information on ocean waves. With the launch of the European satellite ENVISAT, SAR look cross spectra (SLCS) have become available on an operational basis. Activities therefore exist at different European weather centres to use the data for assimilation into numerical wave models. Furthermore there is scientific interest in SLCS, e.g., concerning the estimation of the phase speed of ocean waves. For the estimation of ocean wave

parameters, it is important to have information about the accuracy of SLCS. In this paper, errors of estimated SLCS due to SAR image speckle, spectral estimation errors, and image pattern decorrelation associated with ocean wave motion are analyzed. A probability model is proposed for the estimated SLCS based on the respective cross-spectrum coherence. The model is used to calculate signal-to-noise ratios and confidence limits for the SLCS phase and magnitude, as well as the real and imaginary part. The coherence is factored into a component describing look decorrelation due to SAR image speckle and a second factor describing the effect of sea surface motion. It is shown that the ocean-wave-dependent decorrelation can be simulated using existing nonlinear integral transforms for the look variance spectrum and the SLCS. The decorrelation effect associated with speckle noise is related to SAR system parameters, e.g., the spatial SAR resolution. The probability model is used to investigate the optimal choice of look processing parameters like the look separation time. A statistical analysis based on a global dataset of a reprocessed dataset of European Remote Sensing 2 satellite SLCS is presented confirming the applicability of the probability model. The implications of the results for the retrieval of two-dimensional wave spectra from SLCS are summarized. Possible future applications of the model like, for example, the investigation of the turbulent air flow over waves, are discussed. [J195]

"Permanent scatterers analysis for atmospheric correction in ground-based SAR interferometry"

Ground-based synthetic aperture radar (GB-SAR) interferometry has already been recognized as a powerful tool, complementary or alternative to spaceborne SAR interferometry, for terrain monitoring, and for detecting structural changes in buildings. It has been noted that, in spite of the very short range, compared with the satellite configuration, in GB-SAR measurement the disturbances due to atmospheric effects cannot be neglected either. The analysis of the interferometric phases of very coherent points, called permanent scatterers (PSs), allows the evaluation of the atmospheric disturbance and the possibility of removing it. In this paper, the PS analysis is carried out both on a test site facility and on a real campaign (Citrin Valley, Italy) that provided data with a temporal baseline of about ten months. [J196]

"Investigations of polarization purity and specific absorption rate for two dual-band antennas for satellite-mobile handsets"

A study of the effects of human proximity on the polarization purity of two types of circularly-polarized handset antennas for personal satellite communications was investigated using the hybrid method of moments (MoM)/finite-difference time-domain technique. Associated with this, assessments of specific absorption rate in the head were made. The method gave stable results, in accordance with physical expectations; good agreement with the pure Method of Moments was shown in simplified cases omitting the head. The quadrifilar spiral antenna (QSA) was shown to be a propitious design for personal satellite communications. [J197]

"Multitemporal repeat pass SAR interferometry of boreal forests"

Multitemporal interferometric European Remote Sensing 1 and 2 satellite tandem pairs from a forest test site in Finland are examined in order to determine the stem volume retrieval accuracy. A form of multitemporal filtering is introduced to investigate what forest stands show a multitemporal consistency in coherence. It is found that a large stand size is a major factor to obtain accurate retrievals. The effect of heterogeneity of forest stands is also discussed. Based on the stands showing highest multitemporal consistency different models for scattering and coherence are compared. The interferometric water cloud model is chosen for stem volume retrieval. The variation of the model parameters with meteorological parameters is investigated and the results illustrate that the best imaging conditions are obtained for subzero temperatures and windy conditions. It is shown that for the 20 stands showing highest multitemporal consistency the stem volume can be retrieved with a relative error of 21%, deteriorating when the number of testing stands is increased, e.g., for 80 stands the error is 48%. For 37 large forest stands representing 48% of the investigated area the relative stem volume error is 26%. With experience from another site in Sweden we may conclude that the error level for a multitemporal interferometric synthetic aperture radar evaluation of stem volume for large forest stands (>2 ha) in a well managed and homogeneous boreal forest may be expected to be in the 15% to 25% range, deteriorating for small and heterogeneous stands and for images acquired under nonwinter conditions. [J198]

"Computation of specific absorption rate in the human body due to base-station antennas using a hybrid formulation"

A procedure for computational dosimetry to verify safety standards compliance of mobile communications base stations is presented. Compared with the traditional power density method, a procedure based on more rigorous physics was devised, requiring computation or measurement of the specific absorption rate (SAR) within the biological tissue of a person at an arbitrary distance. This uses a hybrid method of moments/finite difference time domain (MoM/FDTD) numerical method in order to determine the field or SAR distribution in complex penetrable

media, without the computational penalties that would result from a wholly FDTD simulation. It is shown that the transmitted power allowed by the more precise SAR method is, in many cases, between two and five times greater than that allowed by standards implementing the power flux density method. [J199]

"A wavelet-based algorithm to estimate ocean wave group parameters from radar images"

In recent years, new remote sensing techniques have been developed to measure two-dimensional (2-D) sea surface elevation fields. The availability of these data has led to the necessity to extend the classical analysis methods for one-dimensional (1-D) buoy time series to two dimensions. This paper is concerned with the derivation of group parameters from 2-D sea surface elevation fields using a wavelet-based technique. Wave grouping is known to be an important factor in ship and offshore safety, as it plays a role in dangerous resonance phenomenons and the generation of extreme waves. Synthetic aperture radar (SAR) data are used for the analysis. The wavelet technique is introduced using synthetic ocean surfaces and simulated SAR data. It is shown that the group structure of the ocean wave field can be recovered from the SAR image if the nonlinear imaging effects are moderate. The method is applied to a global dataset of European Remote Sensing satellite (ERS-2) wave mode data. Different group parameters including the area covered by the largest group and the number of groups in a given area are calculated for over 33 000 SAR images. Global maps of the parameters are presented. For comparison, classical 1-D grouping parameters are calculated from colocated wave model data showing good overall agreement with the wavelet-derived parameters. ERS-2 image mode data are used to study wave fields in coastal areas. Waves approaching the island of Sylt in the North Sea are investigated, showing the potential of the wavelet technique to analyze the spatial wave dynamics associated with the bottom topography. Observations concerning changes of wavelength and group parameters are compared to linear wave theory. [J200]

"Information-theoretic heterogeneity measurement for SAR imagery"

A heterogeneity feature, calculable from synthetic aperture radar (SAR) images on a per-pixel basis, but relying on global image statistics, is defined and discussed. Starting from the multiplicative speckle and texture models relating the amount of texture and speckle to the local mean and variance at every pixel, such a feature is rigorously derived from Shannon's information theory as the conditional information of local standard deviation to local mean. Thanks to robust statistical estimation, it is very little sensitive to the noise affecting SAR data, and thus capable of capturing subtle variations of texture whenever they are embedded in a heavy speckle. Experimental results carried out on two SAR images with different degrees of noisiness demonstrate that the proposed feature is likely to be useful for a variety of automated segmentation and classification tasks. [J201]

"Differential tomography: a new framework for SAR interferometry"

A new interferometric mode crossing the differential synthetic aperture radar (SAR) interferometry and multibaseline SAR tomography concepts, that can be termed differential SAR tomography, is proposed. Its potentials, coming from the joint elevation-velocity resolution capability of multiple scatterers, are discussed. Processing is cast in a bidimensional baseline-time spectral analysis framework, with sparse sampling. The use of a modern data-dependent bidimensional spectral estimator is proposed for joint baseline-time processing. Simulated results are reported for different baseline-time acquisition patterns and two motion conditions of layover scatterers, showing that this new challenging interferometric technique is promising. [J202]

"Observation and characterization of radar backscatter over Greenland"

Characterization of the microwave signature of the Greenland snow surface enables delineation of the different snow facies and is a tool for tracking the effects of climate change. A new empirical observation model is introduced that uses a limited number of parameters to characterize the snow surface based on the dependence of radar backscatter on incidence angle, azimuth angle, spatial gradient, and temporal rate of change. The individual model parameters are discussed in depth with examples using data from the NASA Scatterometer (NSCAT) and from the C-band European Remote Sensing (ERS) satellite Advanced Microwave Instrument in scatterometer mode. The contribution of each model term to the overall accuracy of the model is evaluated. The relative contributions of the modeled dependencies vary by region. Two studies illustrating applications of the model are included. First, interannual changes over the Greenland ice sheet are investigated using nine years of ERS data. Surface changes are observed as anomalies in the σ° model parameters. Second, intraannual variations of the surface are investigated. These changes are observed in the average backscatter normalized to a given observation geometry. The results indicate that the model can be used to obtain a more complete understanding of multiyear change and to obtain low-variance high temporal resolution observations of intraannual changes. The model may be applied for increased accuracy in scatterometer, synthetic aperture radar (SAR), and wide-angle SAR studies. [J203]

"Three-dimensional multipass SAR focusing: experiments with long-term spaceborne data"

Synthetic aperture radar (SAR) interferometry is a modern efficient technique that allows reconstructing the height profile of the observed scene. However, apart for the presence of critical nonlinear inversion steps, particularly crucial in abrupt topography scenarios, it does not allow one to separate different scattering mechanisms in the elevation (height) direction within the ground pixel. Overlay of scattering at different elevations in the same azimuth-range resolution cell can be due either to the penetration of the radiation below the surface or to perspective ambiguities caused by the side-looking geometry. Multibaseline three-dimensional (3-D) SAR focusing allows overcoming such a limitation and has thus raised great interest in the recent research. First results with real data have been only obtained in the laboratory and with airborne systems, or with limited time-span and spatial-coverage spaceborne data. This work presents a novel approach for the tomographic processing of European Remote Sensing satellite (ERS) real data for extended scenes and long time span. Besides facing problems common to the airborne case, such as the nonuniformly spaced passes, this processing requires tackling additional difficulties specific to the spaceborne case, in particular a space-varying phase calibration of the data due to atmospheric variations and possible scene deformations occurring for years-long temporal spans. First results are presented that confirm the capability of ERS multipass tomography to resolve multiple targets within the same azimuth-range cell and to map the 3-D scattering properties of the illuminated scene. [J204]

"An unsupervised approach based on the generalized Gaussian model to automatic change detection in multitemporal SAR images"

We present a novel automatic and unsupervised change-detection approach specifically oriented to the analysis of multitemporal single-channel single-polarization synthetic aperture radar (SAR) images. This approach is based on a closed-loop process made up of three main steps: (1) a novel preprocessing based on a controlled adaptive iterative filtering; (2) a comparison between multitemporal images carried out according to a standard log-ratio operator; and (3) a novel approach to the automatic analysis of the log-ratio image for generating the change-detection map. The first step aims at reducing the speckle noise in a controlled way in order to maximize the discrimination capability between changed and unchanged classes. In the second step, the two filtered multitemporal images are compared to generate a log-ratio image that contains explicit information on changed areas. The third step produces the change-detection map according to a thresholding procedure based on a reformulation of the Kittler-Illingworth (KI) threshold selection criterion. In particular, the modified KI criterion is derived under the generalized Gaussian assumption for modeling the distributions of changed and unchanged classes. This parametric model was chosen because it is capable of better fitting the conditional densities of classes in the log-ratio image. In order to control the filtering step and, accordingly, the effects of the filtering process on change-detection accuracy, we propose to identify automatically the optimal number of despeckling filter iterations [Step 1] by analyzing the behavior of the modified KI criterion. This results in a completely automatic and self-consistent change-detection approach that avoids the use of empirical methods for the selection of the best number of filtering iterations. Experiments carried out on two sets of multitemporal images (characterized by different levels of speckle noise) acquired by the European Remote Sensing 2 satellite SAR sensor confirm the effectiveness of the proposed unsupervised approach, which results in change-detection accuracies very similar to those that can be achieved by a manual supervised thresholding. [J205]

"A new functional model for determining minimum and maximum detectable deformation gradient resolved by satellite radar interferometry"

In this paper, a functional model for determining the minimum and maximum detectable deformation gradient in terms of coherence for synthetic aperture radar (SAR) sensors is presented. The model is developed based on a new methodology that incorporates both real and simulated data. Sets of representative surface deformation models have been simulated, and the associated phase from these models introduced into real SAR data acquired by European Remote Sensing 1 and 2 satellites. Subsequently, interferograms were derived, and surface deformation was estimated. A number of cases of surface deformation with varying magnitudes and spatial extent have been simulated. In each case, the resultant surface deformation has been compared with the "true" surface deformation as defined by the deformation model. Based on these comparisons, a set of observations that lead to a new functional model has been established. Finally, the proposed model has been validated against external datasets and proven viable. Although the major weakness of the model is its reliance on visual interpretation of interferograms, this model can serve as a decision-support tool to determine whether or not to apply satellite radar interferometry to study a given surface deformation. [J206]

"Interlook cross-correlation function of speckle in SAR images of sea surface processed with partially overlapped subapertures"

In the present paper, a general integral expression is derived and discussed for the cross-correlation function (CCF) of speckle patterns in synthetic aperture radar (SAR) images processed by using partially overlapped subapertures of arbitrary Doppler center frequencies (or equivalent azimuth times). It is shown that, under the white noise approximation for the backscattered field, the CCF of the interlook speckle intensity patterns is given by the squared modulus of the autocorrelation function of the amplitude weighting function of subapertures where the time lag is the center time difference. It is also shown that the CCF of the interlook speckle patterns is independent of the surface coherence time of sea surface. The integral expression for the intensity CCF is then evaluated for a rectangular weighting function, and comparison is made with Japanese Earth Resources Satellite-1 (JERS-1) L-band and RADARSAT-1 C-band SAR images of sea surface to test the theory. The CCFs computed from the JERS-1 SAR data show excellent agreement with the theory, and good agreement is obtained with the RADARSAT-1 data. [J207]

"SAR-Derived coastal and marine applications: from research to operational products"

The synthetic aperture radar (SAR) has now successfully demonstrated its capacity to uniquely provide valuable high-resolution information for coastal applications (oil-spill monitoring, ship detection, shallow-water bathymetry mapping, sea-ice monitoring, high-resolution wind fields, coastal wave fields). However, it appears that the operational use of SAR-derived products still remains limited, particularly in Europe. Although costs and sampling rate are often invoked to explain this limitation, it also appears that the SAR-instrument capabilities are generally poorly known within the operational community. Consequently, no real initiative currently involves the sustainable use of SAR in the main European projects for operational oceanography nor meteorology. Conversely, other countries such as Norway and United States are now moving into the use of SAR on an operational basis for coastal ocean monitoring. Significant efforts are being led by these countries to develop and harmonize such a monitoring system and extend the number of locations. In order to promote the potential of SAR to routinely scrutinize our coastal environment, the objective of this paper is to provide an overview of current SAR-related issues, including a brief technical system description (coverage, revisit time, etc.) and qualitative and quantitative descriptions of operational marine products. The prospects for achieving true operational usage and improving these products will then be considered in terms of requirements (satellite receiving station, revisit time, low data costs). [J208]

"Performance of spaceborne bistatic synthetic aperture radar"

This paper reports on a model developed for evaluating major system performance of a spaceborne bistatic synthetic aperture radar (SAR) for remote sensing applications. The procedure accounts for formation flying aspects. It is particularly aimed at comparison of monostatic and bistatic cases, and, as a test case, it is applied to study a novel configuration, based on a small satellite equipped with a receiving-only antenna orbiting in tandem with a large, noncooperative transmitting spacecraft, the Italian COSMO-SkyMed mission. Numerical results and plots show the effectiveness of the procedure as a mission design tool and put in evidence key issues and characteristics of the proposed spaceborne bistatic formation. [J209]

"A detail-preserving scale-driven approach to change detection in multitemporal SAR images"

This paper presents a novel approach to change detection in multitemporal synthetic aperture radar (SAR) images. The proposed approach exploits a wavelet-based multiscale decomposition of the log-ratio image (obtained by a comparison of the original multitemporal data) aimed at achieving different scales (levels) of representation of the change signal. Each scale is characterized by a different tradeoff between speckle reduction and preservation of geometrical details. For each pixel, a subset of reliable scales is identified on the basis of a local statistic measure applied to scale-dependent log-ratio images. The final change-detection result is obtained according to an adaptive scale-driven fusion algorithm. Experimental results obtained on multitemporal SAR images acquired by the ERS-1 satellite confirm the effectiveness of the proposed approach. [J210]

"Operational oil-slick characterization by SAR imagery and synergistic data"

A methodology is proposed for the semiautomatic detection, characterization, and classification of slicks detected in C-band Synthetic Aperture Radar (SAR). For the first detection step, automatic algorithms were tested on Environmental Research Satellite (ERS) and Environmental Satellite (EnviSat) images acquired during the Prestige tanker accident. These tests reveal that simple filter or segmentation methods efficiently detect slicks with high contrasts and simple shapes, while a new and more complex multiscale method is able to detect a wider range of slicks. The characteristics of automatically detected slicks are then combined with meteooceanic data in order to eliminate slicks related to wind anomalies and current fronts. The data suggest that slicks in cold upwelling waters are natural, and confirm that slicks are heavy oils when high sea states are present. This

detection-classification methodology is validated with aircraft slick-tracking maps. In most cases, joint SAR and environmental data are sufficient to classify the slicks. [J211]

"Synthetic aperture radar imaging of axial convergence fronts in Cook Inlet, Alaska"

Axial fronts of tidal currents are observed in Cook Inlet, AK, on a RADARSAT-1 standard mode synthetic aperture radar (SAR) image taken at 16:31:47 coordinated universal time (UTC) on July 12, 2002. The longest front appears as a 100-km-long quasi-linear bright feature in the SAR image. This front is characterized by an increase in the normalized radar cross section (NRCS) of 7 dB in the C-band horizontal polarization (C-HH) RADARSAT-1 SAR image. Two other smaller fronts exist in the middle of the inlet. The NRCS modulations appear to be less, at about 5 dB. A diagnostic Cook Inlet tidal model is developed to calculate the current velocity fields of the inlet and to demonstrate that the variation in bottom friction caused by the bathymetry distribution generates axial convergence at different tidal stages. The model, using the actual bathymetry, is driven by predicted tides from six tidal stations along the inlet coast. The model results show that the tidal current flowed into the inlet at the time the SAR image was obtained. Tidal current along two transects in the inlet is extracted to show that there is a significant cross-channel convergence of the along-channel velocity component, with a magnitude of 4 to 6 times 10-4s-1near the observed front positions. In general, a higher velocity convergence from the model corresponds to higher NRCS return areas in this SAR image. [J212]

"Mapping offshore wind resources: synergetic potential of SAR and scatterometer data"

An accurate evaluation of the wind potential is needed to assess the economic reliability of an offshore wind project and to site wind farms, which need high-spatial-resolution wind fields with high repetitiveness. A measurement campaign is highly expensive, and the in situ data obtained are insufficient: the data time series are too short, and only defined at a single location. Moreover, the wind-flow models usually used, are unable to accurately extrapolate the data from the mast over the entire area of interest. Fortunately, wind fields at sea can be measured by active spaceborne sensors, such as synthetic aperture radar (SAR) and scatterometer sensors. This paper aims at evaluating the adequacy of wind data from space to the data requirements of the offshore wind industry. The different types of data available from space are described. The temporal sampling of the satellite data is evaluated compared to user needs. The adequacy of this set of information for Weibull-distribution estimation is demonstrated. A study area has been selected to illustrate the approach, namely the French Gulf of Lion area. [J213]

"Measurement of ocean surface winds using synthetic aperture radars"

A methodology for retrieving high-resolution ocean surface wind fields from satellite-borne synthetic aperture radar (SAR) data is introduced and validated. The algorithms developed are suited for ocean SAR data, which were acquired at the C band of either vertical (VV) or horizontal (HH) polarization in transmission and reception. Wind directions are extracted from wind-induced streaks that are visible in SAR images of the ocean at horizontal scales greater than 200 m. These wind streaks are very well aligned with the mean surface wind direction. To extract the orientation of these streaks, two algorithms are introduced, which are applied either in the spatial or spectral domain. Ocean surface wind speeds are derived from the normalized radar cross section (NRCS) and image geometry of the calibrated SAR images, together with the local SAR-retrieved wind direction. Therefore, several C-band models (CMOD IFR2, CMOD4, and CMODS) are available, which were developed for VV polarization, and have to be extended for HH polarization. To compare the different algorithms and C-band models as well as demonstrate their applicability, SAR-retrieved wind fields are compared to numerical-model results considering advanced SAR (ASAR) data from Environmental Satellite (ENVISAT), a European satellite. [J214]

"Leaf area index estimation of boreal forest using ENVISAT ASAR"

A method for retrieval of leaf area index (LAI) using ENVISAT Advanced Synthetic Aperture Radar vertical/horizontal (VV/HH) polarization ratio was derived for boreal forests. Five alternating polarization single-look complex images of the test site were acquired in summer 2003. The swath range from IS1-IS6 was studied. The VV/HH polarization ratio correlated quite well with the ground truth LAI values. The mean error of the LAI estimates was 0.27 for the test site with mixed forest when data from all images and stands were used without separating between species (or swaths). The respective mean LAI estimation error was 0.3 for Norway spruce (Picea abies (L.) Karst.) and 0.07 for Scots pine (Pinus sylvestris L.) dominated stands. [J215]

"On the generation of ERS/ENVISAT DInSAR time-series via the SBAS technique"

We exploit the small baseline subset (SBAS) algorithm for generating deformation time-series from SAR data acquired by sensors with different characteristics but with the same illumination geometry. In particular, our

approach is focused on the use of European Remote Sensing (ERS) and ENVISAT satellite data, the latter acquired by the Advanced Synthetic Aperture Radar sensor on the IS2 swath. The proposed solution is oriented to investigate large-scale displacements with a relatively low spatial resolution (about 100Ч100 m) and implements an easy but effective combination of ERS and ENVISAT multilook interferograms which benefits of the temporal overlap between the acquisitions of the two sensors. Moreover, the algorithm does not rely on specific hypothesis on the spatial or temporal characteristics of the investigated deformations. Presented results, achieved on a synthetic aperture radar dataset relevant to the Napoli city area (Italy), confirm the validity of the approach. [J216]

"Multisensor approach to automated classification of sea ice image data"

A multisensor data fusion algorithm based on a multilayer neural network is presented for sea ice classification in the winter period. The algorithm uses European Remote Sensing (ERS), RADARSAT synthetic aperture radar (SAR), and low-resolution television camera images and image texture features. Based on a set of in situ observations made at the Kara Sea, a neural network is trained, and its structure is optimized using a pruning method. The performance of the algorithm with different combinations of input features (sensors) is assessed and compared with the performance of a linear discriminant analysis (LDA)-based algorithm. We show that for both algorithms a substantial improvement can be gained by fusion of the three different types of data (91.2% for the neural network) as compared with single-source ERS (66.0%) and RADARSAT (70.7%) SAR image classification. Incorporation of texture increases classification accuracy. This positive effect of texture becomes weaker with increasing number of sensors (from 8.4 to 6.4 percent points for the use of two and three sensors, respectively). In view of the short training time and smaller number of adjustable parameters, this result suggests that semiparametric classification methods can be considered as a good alternative to the neural networks and traditional parametric statistical classifiers applied for the sea ice classification. [J217]

"An application of L-band synthetic aperture radar to tide height measurement"

A method for measuring the tide height near the coast from L-band synthetic aperture radar (SAR) data is presented. Twenty-one coherent interferograms have been successfully constructed from Japanese Earth Resources Satellite 1 (JERS-1) SAR data obtained over oyster sea-farming structures. A coherence analysis of the 21 interferometric pairs showed that a perpendicular baseline of less than 3 km, with a temporal baseline within 500 days, are required to obtain a coherent pair, with a coherence higher than 0.25, in the study area. The coherent phases preserved in the interferograms showed a close relation with the sea level. The problem of phase unwrapping to restore an absolute tide height was overcome by introducing normalized image intensities. The radar measurements estimated by the proposed method were verified using tide gauge data, and comparison of the two datasets yielded a correlation coefficient R2of 0.91, with a root mean square error of 5.76 cm. The results demonstrate that radar interferometry can be applied for a tide height measurement near the coast given sufficient structures that return off-nadir radar pulses to the antenna. The multipolarized L-band SAR system will provide better results, using only double-bounced signals, in the future. [J218]

"Three-dimensional surface reconstruction from multistatic SAR images"

This paper discusses reconstruction of three-dimensional surfaces from multiple bistatic synthetic aperture radar (SAR) images. Techniques for surface reconstruction from multiple monostatic SAR images already exist, including interferometric processing and stereo SAR. We generalize these methods to obtain algorithms for bistatic interferometric SAR and bistatic stereo SAR. We also propose a framework for predicting the performance of our multistatic stereo SAR algorithm, and, from this framework, we suggest a metric for use in planning strategic deployment of multistatic assets. [J219]

"Evaluation and perspectives of using multitemporal L-band SAR data to monitor deforestation in the Brazilian Amazo€nia"

Japanese Earth Resources Satellite 1 (JERS-1) synthetic aperture radar (SAR) data were evaluated to map areas of deforestation in a Brazilian Amazo€nia test-site. The results were compared with information derived from a Landsat TM multitemporal series. Unambiguous detection of deforested areas was observed only when the entire deforestation process (slash, burning, and terrain clearing) had already occurred. This result recommends further investigations on the effectiveness of horizontal polarization SAR data to map deforestation in a consistent basis. The cross-polarized (horizontal-vertical) channel designed to be in the ALOS/PALSAR system is expected to improve the distinction between forested and recently deforested areas. [J220]

"Digital elevation model of King Edward VII Peninsula, West Antarctica, from SAR interferometry and ICESat laser altimetry"

We present a digital elevation model (DEM) of King Edward VII Peninsula, Sulzberger Bay, West Antarctica, developed using 12 European Remote Sensing (ERS) synthetic aperture radar (SAR) scenes and 24 Ice, Cloud, and land Elevation Satellite (ICESat) laser altimetry profiles. We employ differential interferograms from the ERS tandem mission SAR scenes acquired in the austral fall of 1996, and four selected ICESat laser altimetry profiles acquired in the austral fall of 2004, as ground control points (GCPs) to construct an improved geocentric 60-m resolution DEM over the grounded ice region. We then extend the DEM to include two ice shelves using ICESat profiles via Kriging. Twenty additional ICESat profiles acquired in 2003-2004 are used to assess the accuracy of the DEM. After accounting for radar penetration depth and predicted surface changes, including effects due to ice mass balance, solid Earth tides, and glacial isostatic adjustment, in part to account for the eight-year data acquisition discrepancy, the resulting difference between the DEM and ICESat profiles is -0.57±5.88 m. After removing the discrepancy between the DEM and ICESat profiles for a final combined DEM using a bicubic spline, the overall difference is 0.05±1.35 m. [J221]

"An Automatic Image Registration for Applications in Remote Sensing"

This paper deals with a major problem encountered in the area of remote sensing consisting of the registration of multitemporal and/or multisensor images. In general, such images have different gray-level characteristics, and simple techniques such as those based on correlation cannot be applied directly. In this work, a new automatic satellite image registration approach is proposed. This technique exploits the invariant relations between regions of a reference and a sensed image, respectively. It involves an edge-based selection of the most distinctive control points (CPs) in the reference image. The search for the corresponding CPs in the sensed image is based on local similarity detection by means of template matching according to a combined invariants-based similarity measure. The final warping of the images according to the selected CPs is performed by using the thin-plate spline interpolation. The procedure is fully automatic and computationally efficient. The proposed algorithm for this technique has been successfully applied to register multitemporal SPOT and synthetic aperture radar images from urban and agricultural areas. The experimental results demonstrate the robustness, efficiency and accuracy of the algorithm. [J222]

"A spatially selective approach to Doppler estimation for frame-based satellite SAR processing"

When Doppler centroid estimators are applied to satellite synthetic aperture radar (SAR) data, biased estimates are often obtained because of anomalies in the received data. Typical anomalies include areas of low SNR, strong discrete targets, and radiometric discontinuities. In this paper, a new method of Doppler centroid estimation is presented that takes advantage of principles such as spatial diversity, estimator quality checks, geometric models, and the fitting of a "global" estimate over a wide area of a SAR scene. In the proposed scheme, Doppler estimates are made over small blocks of data covering a whole frame, so that all parts of the scene are potentially represented. The quality of each block estimate is examined using data statistics or estimator quality measures. Poor estimates are rejected, and the remaining estimates are used to fit a surface model of the Doppler centroid versus the range and azimuth extent of the scene. A physical model that relates the satellite's orbit, attitude, and beam-pointing-direction to the Doppler centroid is used to get realistic surface fits and to reduce the complexity (dimensionality) of the estimation problem. The method is tested with RADARSAT-1 and Shuttle Radar Topography Mission X-band SAR (SRTM/X-SAR) spaceborne data and is found to work well with scenes that do have radiometric anomalies, and in scenes where attitude adjustments cause the Doppler to change rapidly. [J223]

"Delta-K interferometric SAR technique for snow water equivalent (SWE) retrieval"

This letter describes the concept of using delta-K technique on interferometric synthetic aperture radar (InSAR) data for deriving the snow water equivalent (SWE) of dry snow-covered ground by utilizing the presence of scatterers in both datasets. The main scattering contribution from a dry snow cover is from the snow-ground interface. Thus, the interferometric phase of two SAR images, one with no snow and one with dry snow cover, contains information on the SWE. By performing a delta-K processing of the two SAR scenes followed by averaging, an estimation of the SWE can be achieved. The first step in the delta-K InSAR processing is to split the band into two nonoverlapping subfrequency band images. The resulting two subband images then contain two new carrier frequencies with a small delta frequency or delta-K separation. The next step is to multiply the two subband images together to obtain the delta-K image, one for summer and one for winter. Finally, the delta-K interferometric SAR image is generated by multiplying the two delta-K images from summer and winter together. In this letter, experimental results using European Remote sensing Satellite 1 (ERS-1) data from a summer and winter situation show that the delta-K phase can be estimated to a few degrees accuracy for an area of 10Ч10 km2corresponding to an SWE accuracy of approximately 100 mm. [J224]

"Measurement of 2-D sea surface elevation fields using complex synthetic aperture radar data"

A method is presented to derive two-dimensional sea surface elevation fields from complex synthetic aperture radar (SAR) data. Applied to spaceborne SAR data as acquired by European Remote Sensing 2 (ERS-2) or the Environmental Satellite (ENVISAT), the method allows to analyze the structure of ocean wave fields, e.g., wave grouping or individual wave heights on a global scale. The technique, thus, provides wave parameters not obtained with common SAR wave retrieval schemes, which are designed to estimate the 2-D wave spectrum, i.e., second-order statistical moments of the wave field. Estimates of sea surface elevation fields are obtained based on the existing theory of SAR ocean wave imaging, i.e., the modulation of the SAR image intensity due real aperture radar and motion-related effects. A power series expansion is derived for SAR intensity images that enables the analysis of nonlinear effects as well as to derive a quasi-linear approximation of the SAR imaging model in the spatial domain. A statistical analysis is performed based on a global dataset of 2D wave spectra provided by the European Centre for Medium-Range Weather Forecast. Distributions are given for the relative error of the quasi-linear approximation in the spatial domain. It is shown that the error can be reduced by smoothing the SAR image in the azimuthal direction at the cost of lower resolution. Smoothed elevation fields are retrieved by the minimization of a cost function defined in the Fourier domain based on the quasi-linear approximation of the imaging process. A multilook technique is applied to infer the information on wave propagation directions, which is required because the SAR transfer function is non-Hermitian, i.e., the SAR image is not determined by the "frozen" sea surface, but wave motion has a significant impact. The method is applied to simulated SAR images as well as to data acquired by ERS-2. The errors of the retrieved wave field due to image noise, uncertainties in the SAR imaging model, and bandwidth limitations are analyzed. In particular, the fact that the estimated elevation field is smoothed due to the finite system resolution and smearing effects associated with wave motion is discussed. A statistical test is proposed to check the homogeneity of the SAR image. T- he method makes sure that atmospheric effects are not misinterpreted as being caused by ocean waves. [J225]

"Diameters of the orbital tubes in long-term interferometric SAR surveys"

This letter studies the impact of the use of permanent scatterers (PS) on the distribution of the perpendicular baselines in long-term satellite interferometric synthetic aperture radar surveys. This letter also evaluates the relation between the radar center frequency and the dispersion of the estimates of the elevations of the PS as a function of noise and of the time jitter due to atmospheric disturbances. [J226]

"An advanced system for the automatic classification of multitemporal SAR images"

A novel system for the classification of multitemporal synthetic aperture radar (SAR) images is presented. It has been developed by integrating an analysis of the multitemporal SAR signal physics with a pattern recognition approach. The system is made up of a feature-extraction module and a neural-network classifier, as well as a set of standard preprocessing procedures. The feature-extraction module derives a set of features from a series of multitemporal SAR images. These features are based on the concepts of long-term coherence and backscattering temporal variability and have been defined according to an analysis of the multitemporal SAR signal behavior in the presence of different land-cover classes. The neural-network classifier (which is based on a radial basis function neural architecture) properly exploits the multitemporal features for producing accurate land-cover maps. Thanks to the effectiveness of the extracted features, the number of measures that can be provided as input to the classifier is significantly smaller than the number of available multitemporal images. This reduces the complexity of the neural architecture (and consequently increases the generalization capabilities of the classifier) and relaxes the requirements relating to the number of training patterns to be used for classifier learning. Experimental results (obtained on a multitemporal series of European Remote Sensing 1 satellite SAR images) confirm the effectiveness of the proposed system, which exhibits both high classification accuracy and good stability versus parameter settings. These results also point out that properly integrating a pattern recognition procedure (based on machine learning) with an accurate feature extraction phase (based on the SAR sensor physics understanding) represents an effective approach to SAR data analysis. [J227]

"ARKTOS: an intelligent system for SAR sea ice image classification"

We present an intelligent system for satellite sea ice image analysis named Advanced Reasoning using Knowledge for Typing Of Sea ice (ARKTOS). ARKTOS performs fully automated analysis of synthetic aperture radar (SAR) sea ice images by mimicking the reasoning process of sea ice experts. ARKTOS automatically segments a SAR image of sea ice, generates descriptors for the segments of the image, and then uses expert system rules to classify these sea ice features. ARKTOS also utilizes multisource data fusion to improve classification and performs belief handling using Dempster-Shafer. As a software package, ARKTOS comprises components in image processing, rule-based classification, multisource data fusion, and graphical user interface-based knowledge engineering and modification. As a research project over the past ten years, ARKTOS has

undergone phases such as knowledge acquisition, prototyping, refinement, evaluation, deployment, and operationalization at the U.S. National Ice Center. In this paper, we focus on the methodology, evaluations, and classification results of ARKTOS. [J228]

"A new hybrid-beam data acquisition strategy to support ScanSAR radiometric calibration"

Wide-swath synthetic aperture radar (SAR) coverage is provided by RADARSAT using a multiple-beam scanning strategy called ScanSAR. Each beam covers a different range, and is allocated a fixed period of time in which to transmit and receive radar pulses. During SAR processing, the data from each beam must be "stitched" together to form a complete image of the scanned area. This data must be radiometrically calibrated to compensate for antenna beam patterns. However, incorrect measurements of the satellite roll angle cause errors in radiometric calibration, and can lead to visible artifacts in the image (e.g. banding). A new ScanSAR data acquisition technique is proposed that improves roll angle estimation through the use of radar pulses, transmitted by one beam and received by another. The new data are called "hybrid beam data" and can be utilized with modified versions of existing roll estimation algorithms. This paper shows how the hybrid beam data are collected, accommodating pulse repetition frequency, range gate delay, and other timing changes as beams are switched. [J229]

"Evaluation of JERS-1 SAR images from a coastal wind retrieval point of view"

Wind retrieval from Japanese Earth Resources Satellite-1 (JERS-1) synthetic aperture radar (SAR) using an L-band model function in coastal regions is evaluated. It is known that JERS-1 SAR has excessive ambiguities. This paper also gives a quantitative evaluation of excessive ambiguities in coastal scenes of JERS-1 SAR. First, focusing on the cases where wind blows from the shore in Sagami Bay, we investigate phenomena of wind speed increase with offshore distance using European Remote sensing Satellite-1 (ERS-1) SAR-derived wind speeds. The relation between wind speed and offshore distance is well formulated, which indicates the transition of the atmospheric boundary layer from land to sea surface. Wind speeds derived from JERS-1 SAR should be overestimated due to the excessive ambiguity. Then, for observation time of each JERS-1 SAR capturing the cases that wind blows from the shore in Sagami Bay, the expected wind speed growth profile is derived from the wind speed growth formula and an in situ wind observation of Hiratsuka Experiment Station. We convert the wind-speed profile into the sigma-0 profile by an L-band model function. Finally, the profiles of JERS-1 SAR-observed and the estimated sigma-0 are compared, and the excessive ambiguity is estimated as the difference between them. As a result, the dynamic range of first azimuth ambiguity is as large as that of the wind-relating signal from the ocean surface. Moreover, higher order azimuth ambiguities and range ambiguity also may have a significant impact on near-shore wind retrieval. [J230]

"Directional analysis of SAR images aiming at wind direction"

Currently, the retrieval of wind fields from synthetic aperture radar (SAR) images suffers from inadequate knowledge of the wind direction. State-of-the-art spectral analysis works fine on open seas, but is limited in spatial resolution. The method described here is based on the local gradients computed with standard image processing algorithms. It handles image features not caused by wind and can be applied to irregularly shaped regions. The new method has already been applied to many images from the European Remote sensing Satellite SARs and RADARSAT-1 ScanSAR, usually supplying reasonable wind fields. The spatial sampling most frequently used was 20 Ч 20 and 10Ч10 km2. In some cases, samplings down to 1Ч1 km2were tested. This paper describes the local gradients method including the filtering of nonwind generated image features and gives some application examples. [J231]

"Modeling SAR images with a generalization of the Rayleigh distribution"

Synthetic aperture radar (SAR) imagery has found important applications due to its clear advantages over optical satellite imagery one of them being able to operate in various weather conditions. However, due to the physics of the radar imaging process, SAR images contain unwanted artifacts in the form of a granular look which is called speckle. The assumptions of the classical SAR image generation model lead to a Rayleigh distribution model for the histogram of the SAR image. However, some experimental data such as images of urban areas show impulsive characteristics that correspond to underlying heavy-tailed distributions, which are clearly non-Rayleigh. Some alternative distributions have been suggested such as the Weibull, log-normal, and the k-distribution which had success in varying degrees depending on the application. Recently, an alternative model namely the α-stable distribution has been suggested for modeling radar clutter. In this paper, we show that the amplitude distribution of the complex wave, the real and the imaginery components of which are assumed to be distributed by the α-stable distribution, is a generalization of the Rayleigh distribution. We demonstrate that the amplitude distribution is a mixture of Rayleighs as is the k-distribution in accordance with earlier work on modeling SAR

images which showed that almost all successful SAR image models could be expressed as mixtures of Rayleighs. We also present parameter estimation techniques based on negative order moments for the new model. Finally, we test the performance of the model on urban images and compare with other models such as Rayleigh, Weibull, and the k-distribution. [J232]

"Focusing bistatic synthetic aperture radar using dip move out"

The appearance of new synthetic aperture radar (SAR) acquisition techniques based on opportunity sources enhances interest in bistatic geometries. In seismic data acquisition, each source is currently accompanied by up to 10 000 receivers, and in the last two decades, the bistatic geometry has been carefully studied by scores of authors. Rather then introducing new focusing techniques, within the first-order Born approximation (no multiple reflections), seismic bistatic acquisitions are transformed into monostatic ones using a simple operator named "dip move out" (DMO). In essence, the elliptical locus of the reflectors corresponding to a spike in the bistatic survey is forward modeled as if observed in a monostatic one. The outcome of the model, the so-called smile, is a short operator, slowly time varying but space stationary. To transform a bistatic survey into a monostatic one, it is enough to convolve the initial dataset with this smile. Based on the well-known similarity between seismic and SAR surveys, DMO is first described in its simple geometric understanding and is then used in the SAR case. The same processing that is being used for movement compensation can be applied to the bistatic to monostatic survey transformation. Synthetic examples are also provided. [J233]

"Landsat ETM+ and SAR image fusion based on generalized intensity Modulation"

This work presents a novel multisensor image fusion algorithm, which extends panchrmomatic sharpening of multispectral (MS) data through intensity modulation to the integration of MS and synthetic aperture radar (SAR) imagery. The method relies on SAR texture, extracted by ratioing the despeckled SAR image to its low-pass approximation. SAR texture is used to modulate the generalized intensity (GI) of the MS image, which is given by a linear transform extending intensity-hue-saturation transform to an arbitrary number of bands. Before modulation, the GI is enhanced by injection of high-pass details extracted from the available panchrmomatic image by means of the "a`-trous" wavelet decomposition. The texture-modulated panchrmomatic-sharpened GI replaces the GI calculated from the resampled original MS data. Then, the inverse transform is applied to obtain the fusion product. Experimental results are presented on Landsat-7 Enhanced Thematic Mapper Plus and European Remote Sensing 2 satellite images of an urban area. The results demonstrate accurate spectral preservation on vegetated regions, bare soil, and also on textured areas (buildings and road network) where SAR texture information enhances the fusion product, which can be usefully applied for both visual analysis and classification purposes. [J234]

"Polarimetric Characteristics of sea ice in the sea of Okhotsk observed by airborne L-band SAR"

The Phased-Array L-Band SAR (PALSAR) aboard the Advanced Land Observing Satellite (ALOS) is capable of globally acquiring fully polarimetric data. In order to confirm the ability of L-band polarimetric synthetic aperture radar (SAR) to investigate sea ice before the ALOS launch, we conducted a field experiment using an airborne Polarimetric and Interferometric SAR (Pi-SAR) in the Sea of Okhotsk in 1999. This paper presents the analyzed results of data acquired in that experiment. The extracted polarimetric parameters of several ice types suggested that polarimetric coherences and phase differences between right-right (RR) and left-left (LL) are good candidates for discriminating ice types. The polarimetric anisotropy as well as the beta angle of the first eigenvector calculated in the polarimetric decomposition procedure are alternative parameters that are sensitive to ice type differences. Due to the low depolarization characteristics of open water, it could be discriminated from sea ice by scattering entropy in all incidence angle ranges. From the relation between ice thickness and the polarimetric parameters, we found that backscattering coefficients and vertical (VV) to horizontal (HH) backscattering ratio are highly correlated with ice thickness. Since the ratio is sensitive to ice surface dielectric constants, a simple simulation using the integral equation method surface model was conducted by using the physical parameters of typical sea ice. A two-dimensional ice thickness map was derived from an empirical relation between the VV-to-HH backscattering ratio and ice thickness. [J235]

"SAR and radiation performance of balanced and unbalanced mobile antennas using a hybrid computational electromagnetics formulation"

A procedure to reduce the effect of the mobile antenna on the handset by using balanced antennas has been investigated. Use of this type of antenna may degrade the antenna performance, such as bandwidth and gain, although it can cause less effect on the body to which they are adjacent. If the antennas are well designed, the maximum specific absorption rate (SAR) values are likely to be reduced when placed next to the head, since the coupling of such antennas to the body of the handset is very weak. A study on balanced and unbalanced

antennas for mobile handsets next to the human head is presented, using a hybrid electromagnetics method for the analysis. The method uses the hybridisation technique between the frequency-domain method of moments (MoM) and the finite-difference time-domain method (FDTD). The antenna was modelled using MoM whereas the head tissues were modelled using FDTD. Two antennas were designed and investigated with respect to the SAR and radiation performance for two different antenna positions on the top edge of a mobile handset. Radiation patterns are presented and compared, with and without the head, and the maximum SAR values and field distributions inside the head are discussed. The balanced antenna shows good improvements with respect to the unbalanced antenna in terms of the SAR values and variations of the input impedances. [J236]

"A case study of internal solitary wave propagation during ASIAEX 2001"

During the recent Asian Seas International Acoustics Experiment (ASIAEX), extensive current meter moorings were deployed around the continental shelf-break area in the northeastern South China Sea. Thirteen RADARSAT SAR images were collected during the field test to integrate with the in situ measurements from the moorings, ship-board sensors, and conductivity/temperatire/depth (CTD) casts. Besides providing a synoptic view of the entire region, satellite imagery is very useful for tracking the internal waves, locating surface fronts, and identifying mesoscale features. During ASIAEX in May 2001, many large internal waves were observed at the test area and were the major oceanic features studied for acoustic volume interaction. Based on the internal wave distribution maps compiled from satellite data, the wave crests can be as long as 200 km with an amplitude of 100 m. Environmental parameters have been calculated based on extensive CTD casts data near the ASIAEX area. Nonlinear internal wave models have been applied to integrate and assimilate both synthetic aperture radar (SAR) and mooring data. Using SAR data in deep water as an initial condition, numerical simulations produced the wave evolution on the continental shelf and compared reasonably well with the mooring measurements at the downstream station. The shoaling, turning, and dissipation of large internal waves at the shelf break have been studied and are very important issues for acoustic propagation. [J237]

"Unambiguous SAR signal reconstruction from nonuniform displaced phase center sampling"

The displaced phase center (DPC) technique will enable a wide-swath synthetic aperture radar (SAR) with high azimuth resolution. In a classic DPC system, the pulse repetition frequency (PRF) has to be chosen such that the SAR carrier moves just one half of its antenna length between subsequent radar pulses. Any deviation from this PRF will result in a nonuniform sampling of the synthetic aperture. This letter derives an innovative reconstruction algorithm and shows that an unambiguous reconstruction of a SAR signal is possible for nonuniform sampling of the synthetic aperture. This algorithm will also have great potential for multistatic satellite constellations as well as the dual receive antenna mode in Radarsat 2 and TerraSAR-X. [J238]

"On the use of permanent symmetric scatterers for ship characterization"

The symmetric scattering characterization method (SSCM) has been recently introduced for high-resolution characterization of certain targets under coherent conditions. SSCM is based on the Poincarer' sphere representation, which supports a high-resolution decomposition of symmetric target scattering, as well as assessment and validation of the backscatter coherence. In this paper, the SSCM is investigated for ship characterization using Convair-580 polarimetric synthetic aperture radar (SAR) data. It is shown that the target Poincarer' parameters permit identification of dominant scatterers with a significant symmetric scattering component. The polarization orientation angle of these quasi-symmetric scatterers is used to derive an estimate of the ship's pitch angle, under certain conditions. The effect of SAR system focus setting errors and Doppler centroid mistracking on the SSCM performance is investigated. It is shown that the SSCM is sensitive to the system focus setting and Doppler centroid shift. The first-order effects of these errors can be removed prior to the application of the SSCM method. [J239]

"A small-baseline approach for investigating deformations on full-resolution differential SAR interferograms"

This paper presents a differential synthetic aperture radar (SAR) interferometry (DIFSAR) approach for investigating deformation phenomena on full-resolution DIFSAR interferograms. In particular, our algorithm extends the capability of the small-baseline subset (SBAS) technique that relies on small-baseline DIFSAR interferograms only and is mainly focused on investigating large-scale deformations with spatial resolutions of about 100Ч100 m. The proposed technique is implemented by using two different sets of data generated at low (multilook data) and full (single-look data) spatial resolution, respectively. The former is used to identify and estimate, via the conventional SBAS technique, large spatial scale deformation patterns, topographic errors in the available digital elevation model, and possible atmospheric phase artifacts; the latter allows us to detect, on the full-resolution residual phase components, structures highly coherent over time (buildings, rocks, lava, structures,

etc.), as well as their height and displacements. In particular, the estimation of the temporal evolution of these local deformations is easily implemented by applying the singular value decomposition technique. The proposed algorithm has been tested with data acquired by the European Remote Sensing satellites relative to the Campania area (Italy) and validated by using geodetic measurements. [J240]

"Coregistration of multiangle fine spatial resolution SAR images"

Provides a first assessment of a coregistration technique suitable for multiangle fine spatial resolution synthetic aperture radar (SAR) images. The technique is based on crossroad and road junction extraction and matching and exploits recently introduced road extraction routines for SAR data. These features are matched using relational and geometrical analysis. Results are encouraging and show the possibility to exploit multiangle SAR available from future airborne and satellite missions. [J241]

"Application of log-cumulants to the detection of spatiotemporal discontinuities in multitemporal SAR images"

Multitemporal satellite synthetic aperture radar (SAR) images are a useful source of information for geophysicists to monitor changing regions. In this paper, a new approach is proposed to extract from multitemporal SAR images two kinds of information: temporal changes (flooded areas, coastline erosion, etc.) and stable spatial features (roads, rivers, etc.). The novelty of the proposed approach is to detect simultaneously these two kinds of discontinuities. In a first step, the contrast and the heterogeneity information is extracted by a "multitemporal" application of the ratio of local means and by new three-dimensional texture parameters based on the log-cumulants. In a second step, the resulting attributes that measure the time variability or the presence of spatial features are merged. An interactive fuzzy fusion approach is proposed to provide end-users with a simple and easily understandable tool for tuning the change-detection results. The performances of the proposed attributes and fusion technique are presented on a set of seven multitemporal SAR images acquired by the European Remote Sensing (ERS-1) satellite. [J242]

"Crop classification using multiconfiguration C-band SAR data"

This paper reports on an investigation aimed at evaluating the performance of a neural-network based crop classification technique, which makes use of backscattering coefficients measured in different C-band synthetic aperture radar (SAR) configurations (multipolarization/multitemporal). To this end, C-band AirSAR and European Remote Sensing Satellite (ERS) data collected on the Flevoland site, extracted from the European RAdar-Optical Research Assemblage (ERA-ORA) library, have been used. The results obtained in classifying seven types of crops are discussed on the basis of the computed confusion matrices. The effect of increasing the number of polarizations and/or measurements dates are discussed and a scheme of interyear dynamic classification of five crop types is considered. [J243]

"Herbaceous biomass retrieval in habitats of complex composition: a model merging SAR images with unmixed landsat TM data"

A remote sensing methodology for herbaceous areal above-ground biomass (AAB) estimation in a heterogeneous Mediterranean environment is presented. The methodology is based on an adaptation of the semiempirical water-cloud backscatter model to complex vegetation canopies combined with shrubs, dwarf shrubs, and herbaceous plants. The model included usage of the green leaf biomass volumetric density as a canopy descriptor and of cover fractions derived from unmixing Landsat Thematic Mapper image data for the three vegetation formations. The inclusion of the unmixed cover fractions improves modeling synthetic aperture radar backscatter, as it allows separation between the different radiation interaction mechanisms. The method was first assessed with reference to the reproduction of the backscatter from the vegetation formations. In the next phase, the accuracy of AAB retrievals from the backscatter data was evaluated. Results of testing the methodology in a region of climatic gradient in central Israel have shown a good correspondence between observed and predicted AAB values (R2=0.82). This indicates that the methodology developed may lay a basis for mapping important and more advanced ecological information such as primary production and contribute to better understanding of processes in Mediterranean and semiarid regions. [J244]

"Understanding C-band radar backscatter from wheat canopy using a multiple-scattering coherent model"

This paper describes a modeling approach to interpret the C-band synthetic aperture radar (SAR) data from wheat canopies as provided by European Remote Sensing (ERS) satellites, RADARSAT, and the forthcoming Environmental Satellite/Advanced Synthetic Aperture Radar (ENVISAT/ASAR) satellite. At a first step, the results

of a first-order modeling were compared to ERS data and scatterometer data over the growing season at two different test sites. The prediction by first-order approach was in disagreement with the data from stem extension stage to soft ripening stage. The first-order approach was found to overestimate the attenuation at vertical (V) polarization, resulting in a predicted backscattering coefficient one order of magnitude lower than that observed by the SAR system. To improve the prediction, a multiple-scattering modeling based on numerical solution of multiple-scattering Foldy-Lax equation was used. The multiple-scattering modeling provides better backscatter estimates at vertical-vertical (VV) polarization for both test sites. Then, the model is used to derive the prevailing interactions mechanisms at horizontal-horizontal (HH) and VV polarizations and 23° and 40° of incidence angle. Finally, the retrieval of crop parameters from C-band SAR data is addressed. [J245]

"Land-cover classification using multitemporal ERS-1/2 InSAR data"

In this study the potential of ERS-1/2 Tandem InSAR data for land-cover classification was investigated at a 2500 km2study area around the Helsinki metropolitan area in Southern Finland. A time-series of 14 ERS-1/2 SAR Tandem image pairs was processed into 28 five-look intensity images, 14 Tandem coherence images and two coherence images with a longer temporal baseline (36 and 246 days). All image data was coregistered and orthorectified into map coordinates using an InSAR DEM. A two-stage hybrid classifier method was employed, where the water-class was classified separately in the first classifier stage, and the remaining classes were classified with an ISODATA classifier. Temporal averaging and Principal Components Transformation (PCT) were used to reduce the number of images fed into ISODATA. Classification accuracy was assessed using high-resolution aerial orthophotos, digital base maps and the Finnish National Forest Inventory (NFI). The overall accuracy for six classes (Field/Open Land, Dense Forest, Sparse Forest, Mixed Urban, Dense Urban, Water) was found to be 90% with kappa coefficient of 0.86. Interferometric coherence carries more land-cover related information than the backscattered intensity. This study confirms that the ERS-1/2 Tandem archives could be exploited for land-cover classification. [J246]

"JERS SAR interferometry for land subsidence monitoring"

In this paper, the potential of L-band repeat-pass differential synthetic aperture radar (SAR) interferometry for land subsidence monitoring is evaluated using Japanese Earth Resources Satellite (JERS) SAR data. Bologna, Mexico City, and the Ruhrgebiet are selected as application sites representing slow to fast deformation velocities. The investigation includes feasibility aspects such as data availability, the temporal decorrelation over different landcover classes and the range of useful spatial baselines, an analysis of the achieved deformation accuracy, and considerations on the complementarity to European Remote Sensing satellite (ERS) SAR interferometry and leveling surveys. In spite of the rather limited data availability, land subsidence maps could be generated for the three selected application sites. In contrast to ERS C-band SAR data, JERS L-band interferometry permitted the retrieval of subsidence values over vegetated areas and forest when using interferograms of less than one year acquisition time interval and short baseline. In addition, the longer L-band wavelength was found to be superior in the case of large deformation gradients that lead to phase-unwrapping problems in C-band interferometry. [J247]

"Evaporation of groundwater from arid playas measured by C-band SAR"

Salt-bearing groundwater evaporates within arid playas and roughens the surface during the summer months. We show that it is possible to infer the rates of evaporation of groundwater using radar backscatter measurements. Using an empirically derived relationship between backscatter coefficient and surface roughness, a model of how surface roughness changes with a continuous process of halite crystal efflorescence, and an assumed value for the salinity of the regional groundwater, we calculate the volumetric rate at which the groundwater must have evaporated. The method is illustrated with data from the European Remote Sensing 1 satellite synthetic aperture radar sensor that imaged the Chott el Djerid playa in southern Tunisia from 1992 to 1993. Independent measurements and calculations indicate that the radar method overestimates the rate of evaporation. The reasons for this probably lie in the assumptions about the salt budget of the groundwater or the model of how the salt crust roughens with time. [J248]

"Use of multiincidence angle RADARSAT-1 SAR data to incorporate the effect of surface roughness in soil moisture estimation"

The proposed study offers an approach to incorporate the effect of surface roughness in the estimation of soil moisture from space without actually measuring surface roughness conditions on ground. It is required to acquire synthetic aperture radar data at low and high incidence angles, such that the soil moisture changes are negligible between the two acquisitions. [J249]

"Multitemporal JERS repeat-pass coherence for growing-stock volume estimation of Siberian forest"

Multitemporal radar data from the Japanese Earth Resources Satellite (JERS) satellite from the period 1993 to 1998 have been used to investigate if L-band interferometric coherence with a 44-day temporal baseline is suitable for estimations of growing-stock volume in boreal forest. Two forest regions north of Krasnoyarsk in Siberia have been used as test areas. Seasonal variations in the repeat-pass coherence have been studied, and a comparison with C-band coherence from the European Remote sensing Satellite 1 and 2 (ERS-1/2) tandem missions in 1997 and 1998 has been done. JERS coherence from the winter shows a clear correlation with the forest growing-stock volume. For the summer scenes, the spread in the values is too large to give reliable results. Acquisitions from the spring and fall show large problems with decorrelation caused by temporal changes. The results indicate potential of repeat-pass interferometric L-band coherence in winter, as will be provided by the forthcoming Advanced Land Observing Satellite/Phased Array type L-band Synthetic Aperture Radar (ALOS/PALSAR) to map growing-stock volume in Siberia and boreal forests. [J250]

"Water quality retrievals from combined Landsat TM data and ERS-2 SAR data in the Gulf of Finland"

This paper presents the applicability of combined Landsat Thematic Mapper and European Remote Sensing 2 synthetic aperture radar (SAR) data to turbidity, Secchi disk depth, and suspended sediment concentration retrievals in the Gulf of Finland. The results show that the estimated accuracy of these water quality variables using a neural network is much higher than the accuracy using simple and multivariate regression approaches. The results also demonstrate that SAR is only a marginally helpful to improve the estimation of these three variables for the practical use in the study area. However, the method still needs to be refined in the area under study. [J251]

"An L-band geophysical model function for SAR wind retrieval using JERS-1 SAR"

An L-band geophysical model function is developed using Japanese Earth Resources Satellite-1 (JERS-1) synthetic aperture radar (SAR) data. First, we estimate the SAR system noise, which has been a serious problem peculiar to the JERS-1 SAR. It is found that the system noise has a feature common in all the SAR images and that the azimuth-averaged profile of noise can be expressed as a parabolic function of range. By subtracting the estimated noise from the SAR images, we can extract the relatively calibrated ocean signals. Second, using the noise-removed SAR data and wind vector data from the NASA Scatterometer and buoys operated by the Japan Meteorological Agency, we generate a match-up dataset, which consists of the SAR sigma-0, the incidence angle, the surface wind speed, and wind direction. Third, we investigate the sigma-0 dependence on incidence angle, wind speed, and wind direction. While the incidence angle dependence is negligible in the present results, we can derive distinct sigma-0 dependence on wind speed and direction. For wind speeds below 8 m/s, the wind direction dependence is not significant. However, for higher wind speeds, the upwind-downwind asymmetry becomes very large. Finally, taking into account these characteristics, a new L-band-HH geophysical model function is produced for the SAR wind retrieval using a third-order harmonics formula. Resultant estimates of SAR-derived wind speed have an rms error of 2.09 m/s with a negligible bias against the truth wind speed. This result enables us to convert JERS-1 SAR images into the reliable wind-speed maps. [J252]

"Texture-based characterization of urban environments on satellite SAR images"

We investigate the use of co-occurrence texture measures to provide information on different building densities inside a town structure. We try to improve the pixel-by-pixel classification of an urban area by considering texture measures as a means for block analysis and classification. We find some interesting hints concerning the optimal dimension of the window to be considered for texture measures, as well as the most useful measures. Moreover, we show that it is possible to use medium-resolution readily available satellite synthetic aperture radar images for a more refined urban analysis than previously shown. [J253]

"Watershed identification of polygonal patterns in noisy SAR images"

The paper describes a new approach to pattern recognition in synthetic aperture radar (SAR) images. A visual analysis of the images provided by NASA's Magellan mission to Venus has revealed a number of zones showing polygonal-shaped faults on the surface of the planet. The goal of the paper is to provide a method to automate the identification of such zones. The high level of noise in SAR images and its multiplicative nature make automated image analysis difficult and conventional edge detectors, like those based on gradient images, inefficient. We present a scheme based on an improved watershed algorithm and a two-scale analysis. The

method extracts potential edges in the SAR image, analyzes the patterns obtained, and decides whether or not the image contains a "polygon area". This scheme can also be applied to other SAR or visual images, for instance in observation of Mars and Jupiter's satellite Europa. [J254]

"Multitemporal C-band radar measurements on wheat fields"

This paper investigates the relationship between C-band backscatter measurements and wheat biomass and the underlying soil moisture content. It aims to define strategies for retrieval algorithms with a view to using satellite C-band synthetic aperture radar (SAR) data to monitor wheat growth. The study is based on a ground-based scatterometer experiment conducted on a wheat field at the Matera site in Italy during the 2001 growing season. From March to June 2001, eight C-band scatterometer acquisitions at horizontal-horizontal and vertical-vertical polarization, with incidence angles ranging from 23° to 60°, were taken. At the same time, soil moisture, wheat biomass, and canopy structure were collected. The paper describes the experiment and investigates the radar sensitivity to biophysical parameters at different polarizations and incidence angles, and at different wheat phenological stages. Based on the experimental results, the retrieval of wheat biomass and soil moisture content using Advanced Synthetic Aperture Radar data is discussed. [J255]

"Multitemporal repeat-pass SAR interferometry of boreal forests"

Multitemporal European Remote Sensing satellites 1 and 2 (ERS-1/2) and the Japanese Earth Resources Satellite 1 (JERS-1) interferometric synthetic aperture radar (InSAR) data from a boreal forest test site in Sweden (stem volumes up to 335 m3/ha, equivalent to above-ground dry biomass of 200 tons/ha) are studied in order to estimate stem volume using coherence and backscatter. The changes of JERS-1 backscatter and ERS-1/2 tandem coherence between images are consistent over the area studied, in contrast to ERS-1/2 backscatter. A model-based regression analysis has been performed, and the use of the model for inversion is discussed and compared with other approaches found in the literature. The model parameters are discussed in terms of their relation to wind speed and temperature. Results from the different acquisitions are combined to improve the stem volume estimation. The accuracy in terms of rms error (RMSE) for standwise estimated stem volume is ≈10 m3/ha using ERS-1/2 coherence. Using backscatter and coherence from JERS-1 we obtain an RMSE of ≈30-35 m3/ha. Finally, conditions for accurate retrieval of stem volume using multitemporal InSAR observations are discussed. We conclude that C- and L-band repeat-pass InSAR can provide stem volume estimates in boreal forests with accuracies similar to those of standard in situ measurements. [J256]

"Efficient simulation of SAR interferograms of large areas and of rugged terrain"

Interferometric synthetic aperture radar (InSAR) techniques are today applied in many areas of remote sensing, ranging from digital elevation model (DEM) generation to surface motion mapping and InSAR tomography. To enhance the understanding of the InSAR mapping process and to test new algorithms, accurate tools for the simulation of the topographic InSAR phase are necessary. Whereas the equations for the interferometric phase of a given DEM are well known, the actual implementation is tedious. Furthermore, a straightforward implementation would take far more computation time than all the other InSAR processing steps put together. This paper presents a novel algorithm for the efficient simulation of the InSAR phase, taking into account the special problems in mountainous terrain. Simulation results are compared to and illustrated with real data from the European Remote Sensing satellite (ERS-1/2) tandem mission and the Shuttle Radar Topography Mission (SRTM). Accuracy estimates for the phase simulation are given for different terrain types. The algorithm is described in enough detail that it can be implemented as a general-purpose tool for the accurate simulation of interferograms with virtually unlimited size, taking no more processing time than other InSAR processing steps. The algorithm in the presented form is used operationally within the interferometry software GENESIS to support the processing of SRTM/X-SAR data at the German Aerospace Center (DLR). [J257]

"Coherence estimation from multilook incoherent SAR imagery"

This paper presents an unsupervised method capable to provide estimates of temporal coherence starting from a pair of multilook detected synthetic aperture radar (SAR) images of the same scene. The method relies on robust measurements of the temporal correlation of speckle patterns between the two pass dates. To this end, a nonlinear transformation aimed at decorrelating the data across time while retaining the multiplicative noise model is defined as the pixel geometric mean and ratio of the two overlapped images. The temporal correlation coefficient (TCC) of speckle is analytically derived from the noise variances, measured in the transformed pair of images as regression coefficients of local standard deviation to local mean, calculated on homogeneous, i.e., nontextured, pixels. Such pixels are identified based on the observation that homogeneous areas produce clustered scatter-points that are aligned along the regression line. Experiments were carried out on two pairs of multitemporal SAR observations, from the European Remote Sensing 1/2 (ERS-1/2) tandem mission and from

the 1994 SIR-C mission. A good fit with the true coherence values was found, irrespective of the presence of textures; when the true coherence was unavailable, the estimated coherence results match the available ground truth data. [J258]

"Statistical and operational performance assessment of multitemporal SAR image filtering"

Multitemporal synthetic aperture radar (SAR) image filtering is a useful preprocessing step for many applications that require speckle reduction. Several multitemporal filters are now available with very different characteristics. In this paper, the performance of three multitemporal filters is assessed with respect to statistical and operational criteria. Statistical criteria include measures of bias, noise reduction, and preservation of both spatial and temporal information. Operational criteria evaluate the accuracy of manual detection of geographical features such as points, lines, and surfaces. This study was carried out with the help of ten photointerpreters. It uses a set of seven multitemporal SAR images from the European Remote Sensing 1 (ERS-1) satellite. It provides guidelines to select multitemporal filters according to the application and the subsequent processing. [J259]

"Resolution and synthetic aperture characterization of sparse radar arrays"

The concept of radar satellite constellations, or clusters, for synthetic aperture radar (SAR), moving target indicator (MTI), and other radar modes has been proposed and is currently under research. These constellations form an array that is sparsely populated and irregularly spaced; therefore, traditional matched filtering is inadequate for dealing with the constellation's radiation pattern. To aid in the design, analysis, and signal processing of radar satellite constellations and sparse arrays in general, the characterization of the resolution and ambiguity functions of such systems is investigated. We project the radar's received phase history versus five sensor parameters: time, frequency, and three-dimensional position, into a phase history in terms of two eigensensors that can be interpreted as the dimensions of a two-dimensional synthetic aperture. Then, the synthetic aperture expression is used to derive resolution and the ambiguity function. Simulations are presented to verify the theory. [J260]

"Linear features extraction in rain forest context from interferometric SAR images by fusion of coherence and amplitude information"

This paper presents an almost unsupervised fusion algorithm on linear features (LF) extraction in synthetic aperture radar (SAR) interferometric data, in particular for mangroves/shorelines and thin internal channels. The spatial information on LFs is first extracted in the coherence image, where they are wider and more visible: water regions (in particular thin internal channels) are dark areas (low coherence) due to the temporal decorrelation of backscattering signals in these and surrounding regions, whereas conventional vegetation regions are brighter areas (high coherence). These approximate locations of LFs are further refined by using the edge map coming from a semantic fuzzy fusion of the coefficient of variation (CV) and the ratio of local means (RLM) measured in the amplitude image. The final detection of LFs is then performed by merging the two fuzzy inputs: the spatial information and the edge location map. The membership degree statistics of CV and RLM semantic fusion measures are introduced in order to illustrate the location detection ability. The originality of this method in comparison with conventional approaches is in the fusion scheme that follows the interpreter behavior by using first the coherence image for a fuzzy detection where thin LFs are more visible, but have low location accuracy, and then the amplitude image where they are poorly visible, but with higher location accuracy, to obtain improved results. A quantitative performance evaluation is also presented. The method has been applied on real interferometric SAR images from European Remote Sensing satellites over the western part of Cameroon. [J261]

"Fast SAR image restoration, segmentation, and detection of high-reflectance regions"

An iterative filter that can be used for speckle reduction and restoration of synthetic aperture radar (SAR) images is presented here. This method can be considered as a first step in the extraction of other important information. The second step is the detection of high-reflectance regions and continues with the segmentation of the total image. We have worked in three-look simulated and real European Remote Sensing 1 satellite amplitude images. The iterative filter is based on a membrane model Markov random field approximation optimized by a synchronous local iterative method. The final form of restoration gives a total sum-preserving regularization for the pixel values of our image. The high-reflectance regions are defined as the brightest regions of the restored image. After the separation of this extreme class, we give a fast segmentation method using the histogram of the restored image. [J262]

"Faraday rotation effects on L-band spaceborne SAR data"

Several proposed near-future spaceborne radar missions, such as the Advanced Land Observing Satellite (ALOS) and TerraSAR, will include an L-band instrument. At such low frequencies, the Faraday rotation in the

ionosphere, which rotates the polarization plane of the radar signal, becomes an important consideration in instrument design. In this paper, both simple analytic approximations and numerical models are used to derive likely values of Faraday rotation and determine their impact on polarimetric imagery and derived products. One-way rotations exceeding 5° are likely to significantly reduce the accuracy of geophysical parameter recovery, such as forest biomass. On average, Faraday rotation can be neglected at solar minimum, but correction methods are needed at other times of the solar cycle and under disturbed conditions. Methods for implementing such corrections based on estimates of the Faraday rotation and prerotation of the transmitted signal are described. [J263]

"Measurements of soil compaction rate by using JERS-1 SAR and a prediction model"

The soil compaction rate in a reclaimed land has been estimated by using the Japanese Earth Resources Satellite 1 (JERS-1) synthetic aperture radar (SAR) two-pass differential interferometry (DInSAR) and magnetic probe extensometer (an accuracy of ±1 mm) from 42 ground stations. Twelve JERS-1 SAR interferometric pairs were acquired in the study area. We applied a soil compaction prediction model based on a hyperbolic method using the ground truth data and the DInSAR measurements. The hyperbolic model fitted well to the ground measurements with an rms error of 1.65 cm. The rms error of the model driven by DInSAR measurements was 2.24 cm. The two model results agreed well, showing a difference of 8.1% (12.9 cm) in permanent settlement that is defined as the amount of vertical subsidence as time goes to infinity. A two-dimensional (2-D) subsidence map was constructed from five qualified pairs. The correlation coefficient R between the radar measurements and the ground truth data was 0.87 with an rms error of 1.44 cm. The results demonstrate that the L-band DInSAR combined with a prediction model is useful for geotechnical applications. [J264]

"Texture analysis and classification of ERS SAR images for map updating of urban areas in The Netherlands"

In single-band and single-polarized synthetic aperture radar (SAR) image classification, texture holds useful information. In a study to assess the map-updating capabilities of such sensors in urban areas, some modern texture measures were investigated. Among them were histogram measures, wavelet energy, fractal dimension, lacunarity, and semivariograms. The latter were chosen as an alternative for the well-known gray-level cooccurrence family of features. The area that was studied using a European Remote Sensing Satellite 1 (ERS-1) SAR image was the conurbation around Rotterdam and The Hague in The Netherlands. The area can be characterized as a well-planned dispersed urban area with residential areas, industry, greenhouses, pasture, arable land, and some forest. The digital map to be updated was a 1:250000 Vector Map (VMap1). The study was done on the basis of nonparametric separability measures and classification techniques because most texture distributions were not normal. The conclusion is that texture improves the classification accuracy. The measures that performed best were mean intensity (actually no texture), variance, weighted-rank fill ratio, and semivariogram, but the accuracies vary for different classes. Despite the improvement, the overall classification accuracy indicates that the land-cover information content of ERS-1 leaves something to be desired. [J265]

"Phase and amplitude histories model adapted to the spaceborne SAR survey"

A model of relative movement of a SAR platform and imaged footprint is proposed. The model has been specially adapted to conditions of a spaceborne SAR survey. The main difference of this model from that used before is that it takes into account the SAR platform movement and Earth rotation in addition to commonly used calculations of satellite motion in the disturbed Earth gravitation field. It is shown that SAR motion could be considered as linear, but with velocity derived from orbital motion parameters. The proposed model could be easily applied to analysis of SAR processing algorithms and the influence of the orbit parameter estimation errors on the resulting image quality. Use of the model simplifies the parameter estimation of the SAR sensors intended for planetary investigations. [J266]

"Systematic data acquisitions-a prerequisite for meaningful biophysical parameter retrieval?"

Implementation of systematic Earth observation data acquisition plans over extensive regions, in which the spatial and temporal components of relevant ground targets are adequately taken into account, is a prerequisite for successful retrieval of bio- and geophysical parameters and imperative to accommodate extrapolation of locally developed models to regional scales as required in the context of terrestrial carbon cycle science. Straightforward in concept, but surprisingly uncommon in mission operations thus far, the key characteristics of such a systematic data acquisition strategy are outlined in this short communication. [J267]

"Improvements to urban area characterization using multitemporal and multiangle SAR images"

We present some improvements to urban area characterization by means of synthetic aperture radar (SAR) images using multitemporal and multiangle datasets. The first aim of this research is to show that a temporal sequence of satellite SAR data may improve the classification accuracy and the discriminability of land cover classes in an urban area. Similarly, a second point worth discussing is to what extent multiangle SAR data allows extracting complementary urban features, exploiting different acquisition geometries. To these aims, in this paper, we show results on the same urban test site (Pavia, northern Italy), referring to a sequence of European Remote Sensing Satellite 1/2 (ERS-1/2) C-band images and to a set of simulated X-band data with a finer spatial resolution and different viewing angles. In particular, the multitemporal data is analyzed by means of a novel procedure based on a neuro-fuzzy classifier whose input is a subset of the ERS sequence chosen using the histogram distance index. Instead, the multiangle dataset is used to provide a better characterization of the road network in the area, overcoming effects due to the orientation of the SAR sensor. [J268]

"Path Processing and block adjustment with RADARSAT-1 SAR images"

The objectives of this research study was to determine the conditions of experimentation and application of path processing and block adjustment with synthetic aperture radar (SAR) images when few controls are available. The path and block processing enabled the simultaneous adjustment of all images together to reduce the control point requirement. The method is based on the three-dimensional physical model developed for multisensor images at the Canada Centre for Remote Sensing, Natural Resources Canada. These processes were applied to 15 RADARSAT-1 SAR fine mode images (five paths by three rows) acquired over the Rocky Mountains, Canada from different look angles (F1 and F4) with a weak intersection geometry (6° angle). The first results of the least squares block adjustment showed that the same errors were obtained with image paths or block (20 m for three-image paths and five-path block) as with a single image (18 m). In addition to ground control points (GCPs), elevation tie points (ETPs), with a known elevation value, were used in the overlaps because the 6° look-angle difference of overlapping paths was small. However when using only GCPs in the outer paths for block adjustments, the error results deteriorated from 25 m in both directions for the three-path block to 270 m in X direction for the five-path block. This deterioration was a combination of the image pointing and cartographic errors of GCPs (25-30 m) and the weak 6° intersection angle. Consequently, GCP distribution every two paths was the solution with this dataset, and better results (35 m) was then achieved using a reduced number of GCPs in the outer paths (25 or even 10 GCPs) and middle path (six GCPs) and 20 ETPs in each overlap. However, the combined image pointing and cartographic errors of GCPs (25-30 m) are included in these 35-m error results, and the internal accuracy of the block should thus be better (around one resolution). Finally, the same minimum requirement of GCPs, as a function of their accuracy and the overlap intersection geometry, can be applied for an image, a path or a block. [J269]

"Global wind speed retrieval from SAR"

The global availability of synthetic aperture radar (SAR) wave mode data from the European Remote Sensing (ERS) satellites ERS-1 and ERS-2, as well as ENVISAT, allows for the investigation of the wind field over the ocean on a global and continuous basis. For this purpose, 27 days of ERS-2 SAR wave mode data were processed, representing a total of 34310 imagettes of size 10 km Ч5 km, available every 200 km along the satellite track. In this paper, two methods for retrieving wind speeds from SAR imagettes are presented and validated, showing the applicability of ENVISAT alike SAR wave mode data for global ocean wind retrieval. The first method is based on the well-tested empirical C-band scatterometer (SCAT) models, which describe the dependency of the normalized radar cross section (NRCS) on wind speed and direction. To apply C-band models to SAR data, the NRCS needs to be accurately calibrated. This is performed by a new efficient method utilizing a subset of colocated measurements from ERS-2 SCAT and model winds from the European Centre for Medium-Range Weather Forecast (ECMWF). SAR wind speeds are computed from the calibrated imagettes and compared to the entire set of colocated ERS-2 SCAT and ECMWF model data. Comparison to ERS-2 SCAT winds result in a correlation of 0.95 with a bias of -0.01 m s-1and an rms error of 1.0 m s-1. The second approach is based on neural networks (NNs), which allow the retrieval of wind speeds from uncalibrated SAR imagettes. NNs are trained using the mean intensity of ERS-2 SAR imagettes and colocated wind data from the ERS-2 SCAT and ECMWF model data. Validation of the NN-retrieved SAR wind speeds to ERS-2 SCAT and ECMWF model wind data result in a correlation of 0.96 with a bias of -0.04 m s-1and an rms error of 0.93 m s-1. [J270]

"Development of a retrodirective PARC for ALOS/PALSAR calibration"

Polarimetric radar calibration is a procedure that corrects the polarization distortion of a measured scattering matrix by referring to the scattering matrix of a known target. The present paper describes the principle, design, manufacture and measurement results of a novel retrodirective polarimetric active radar calibrator (PARC). It accommodates both the depolarization characteristic by using dual-polarized antennas and retrodirectivity with

the Van Atta array concept simultaneously. The PARC was designed for Phased Array L-band SAR (PALSAR) calibration based on the proposed principle. It consists of a 6Ч6-element antenna array with a 1-m-square aperture and four amplifiers with a 20-dB gain. The whole array is divided into four 3Ч3-element subarrays to form a two-dimensional (2-D) Van Atta array. Retrodirectivity extends the angular width, where the radar cross section exceeds 35 dBm2, which is a preliminary design goal, to almost twice the width of a conventional array reflector of the same size. However, it should be noted that the present design needs at least four times as many amplifiers as a conventional fixed-beam array reflector to be capable of 2-D source tracking. A prototype model of the present retrodirective PARC is manufactured in the L-band to allow Advanced Land-Observation Satellite (ALOS)/PALSAR calibration. The results we obtained through measurement agree well with the theoretical predictions, and substantiate the premise behind the present design of the retrodirective PARC for polarimetric SAR calibration. [J271]

"Orthorectification of 1960s satellite photographs covering Greenland"

This article presents a rigorous, high-precision model for geometric orthorectification of declassified intelligence satellite photography (DISP) imagery for the generation of a seamless, full-coverage mosaic of the Greenland ice sheet. This model integrates the bundle adjustment method and satellite orbital parameters, solving for interior orientation (including lens distortion) and exterior orientation parameters simultaneously. In addition, the techniques of adaptive filtering, bright-strip removal, radiometric balancing, and mosaic postprocessing are discussed. Two full-coverage mosaics of Greenland using 24 DISP images from eight orbits of the ARGON 9034A Mission of May 1962 and 36 images from 14 orbits of the 9058A/59A mission of October 1963 were created. The average planimetric accuracy (relative to the synthetic aperture radar (SAR) mosaic) is about 168 m from statistical measurements of 182 points in topographically flat areas and 186 m from statistical measurements of 201 points in mountainous areas. The two mosaic products have been delivered to the U.S. National Snow and Ice Data Center (NSIDC) for use by the research community. [J272]

"Spatial contextual classification and prediction models for mining geospatial data"

Modeling spatial context (e.g., autocorrelation) is a key challenge in classification problems that arise in geospatial domains. Markov random fields (MRF) is a popular model for incorporating spatial context into image segmentation and land-use classification problems. The spatial autoregression (SAR) model, which is an extension of the classical regression model for incorporating spatial dependence, is popular for prediction and classification of spatial data in regional economics, natural resources, and ecological studies. There is little literature comparing these alternative approaches to facilitate the exchange of ideas. We argue that the SAR model makes more restrictive assumptions about the distribution of feature values and class boundaries than MRF. The relationship between SAR and MRF is analogous to the relationship between regression and Bayesian classifiers. This paper provides comparisons between the two models using a probabilistic and an experimental framework. [J273]

"SAR-retrieved wind in polar regions-comparison with in situ data and atmospheric model output"

European remote sensing (ERS) satellites synthetic aperture radar (SAR) wind retrievals using CMOD-IFR2 are, for the first time, retrieved in the marginal ice zone (MIZ) and in Arctic coastal areas and compared with in situ observations from reseach vessels (RVs) and output from a high-resolution atmospheric model. The root mean squares (rms) of the comparisons were 1.6 m s-1and 2 m s-1, respectively. The spatial variation of the SAR wind fields established a decrease in wind speed close to the ice edge for the late summer situations where the wind was along the ice edge with the ice to the left. This decrease is believed to be due to changes in atmospheric stability, possibly through development of an internal boundary layer caused by the cold ice cover and melt water. Lower wind speed near the ice edge is confirmed by the atmospheric model and the in situ observations. Furthermore, good results are obtained from SAR wind retrieval in leads when compared with model output during a cold-air outbreak. Routine measurements in the MIZ are useful for estimating the wind stress, and therefore SAR may play an important role in this region. Finally, the identification of a jet out from Hinlopen Strait in the Svalbard region and low wind wakes along the coast in the SAR-retrieved wind field is confirmed by in situ observations as the RV moves through the region. The jet is also confirmed by the atmospheric model, which is able to reproduce the situation. [J274]

"Surface roughness characterizations of sea ice and ice sheets: case studies with MISR data"

This work is an examination of potential uses of multiangular remote sensing imagery for mapping and characterizing sea ice and ice sheet surfaces based on surface roughness properties. We use data from the Multi-angle Imaging SpectroRadiometer (MISR) to demonstrate that ice sheet and sea ice surfaces have characteristic angular signatures and that these angular signatures may be used in much the same way as

spectral signatures are used in multispectral classification. Three case studies are examined: sea ice in the Beaufort Sea off the north coast of Alaska, the Jakobshavn Glacier on the western edge of the Greenland ice sheet, and a region in Antarctica south of McMurdo station containing glaciers and blue-ice areas. The MISR sea ice image appears to delineate different first-year ice types and, to some extent, the transition from first-year to multiyear ice. The MISR image shows good agreement with sea ice types that are evident in concurrent synthetic aperture radar (SAR) imagery and ice analysis charts from the National Ice Center. Over the Jakobshavn Glacier, surface roughness data from airborne laser altimeter transects correlate well with MISR-derived estimates of surface roughness. In Antarctica, ablation-related blue-ice areas, which are difficult to distinguish from bare ice exposed by crevasses, are easily detected using multiangular data. [J275]

"Evaluation of late summer passive microwave Arctic sea ice retrievals"

The melt period of the Arctic sea ice cover is of particular interest in studies of climate change due to the albedo feedback mechanisms associated with meltponds and openings in the ice pack. The traditionally used satellite passive microwave sea ice concentration algorithms have deficiencies during the summer months due to the period's highly variable surface properties. A newly developed ice concentration algorithm overcomes some of these deficiencies. It corrects for low ice concentration biases caused by surface effects through the use of 85 GHz data in addition to the commonly used 19 and 37 GHz data and, thus, the definition of an additional ice type representing layering and inhomogeneities in the snow layer. This new algorithm will be the standard algorithm for Arctic sea ice concentration retrievals with the EOS Aqua advanced microwave scanning radiometer (AMSR-E) instrument. In this paper, we evaluate the performance of this algorithm for the summer period of 1996 using data from the special sensor microwave imager (SSM/I) which has frequencies similar to the AMSR instrument. The temporal evolution of summertime passive microwave sea ice signatures are investigated and sea ice concentration retrievals from the standard NASA team and the new algorithm are compared. The results show that the introduction of the additional sea ice type in the new algorithm leads to improved summertime sea ice concentrations. The SSM/I sea ice retrievals are validated using SAR-derived ice concentrations that have been convolved with the SSM/I antenna pattern to ensure an appropriate comparison. For the marginal ice zone, with ice concentrations ranging from 40% to 100%, the correlation coefficient of SAR and SSM/I retrievals is 0.66 with a bias of 5% toward higher SAR ice concentrations. For the central Arctic, where ice concentrations varied between 60% and 100%, the correlation coefficient is 0.87 with a negligible bias [J276]

"Detection of small objects in clutter using a GA-RBF neural network"

Detection of small objects in a radar or satellite image is an important problem with many applications. Due to a recent discovery that sea clutter, the electromagnetic wave backscatter from a sea surface, is chaotic rather than purely random, computational intelligence techniques such as neural networks have been applied to reconstruct the chaotic dynamic of sea clutter. The reconstructed sea clutter dynamical system which usually takes the form of a nonlinear predictor does not only provide a model of the sea scattering phenomenon, but it can also be used to detect the existence of small targets such as fishing boats and small fragments of icebergs by observing abrupt changes in the prediction error. We applied a genetic algorithm (GA) to obtain an optimal reconstruction of sea clutter dynamic based on a radial basis function (RBF) neural network. This GA-RBF uses a hybrid approach that employes a GA to search for the optimum values of the following RBF parameters: centers, variance, and number of hidden nodes, and uses the least square method to determine the weights. It is shown here that if the functional form of an unknown nonlinear dynamical system can be represented exactly using an RBF net (i.e., no approximation error), this GA-RBF approach can reconstruct the exact dynamic from its time series measurements. In addition to the improved accuracy in modeling sea clutter dynamic, the GA-RBF is also shown to enhance the detectability of small objects embedded in the sea. Using real-life radar data that are collected in the east coast of Canada by two different radar systems: a ground-based radar and a satellite equipped with synthetic aperture radar (SAR), we show that the GA-RBF network is a reliable detector for small surface targets in various sea conditions and is practical for real-life search and rescue, navigation, and surveillance applications [J277]

"Processing of multiple-receiver spaceborne arrays for wide-area SAR"

The instantaneous area illuminated by a single-aperture synthetic aperture radar (SAR) is fundamentally limited by the minimum SAR antenna area constraint. This limitation is due to the fact that the number of illuminated resolution cells cannot exceed the number of collected data samples. However, if spatial sampling is added through the use of multiple-receiver arrays, then the maximum unambiguous illumination area is increased because multiple beams can be formed to reject range-Doppler ambiguities. Furthermore, the maximum unambiguous illumination area increases with the number of receivers in the array. One spaceborne implementation of multiple-aperture SAR that has been proposed is a constellation of formation-flying satellites.

In this implementation, several satellites fly in a cluster and work together as a single coherent system. There are many advantages to the constellation implementation including cost benefits, graceful performance degradation, and the possibility of performing in multiple modes. The disadvantage is that the spatial samples provided by such a constellation will be sparse and irregularly spaced; consequently, traditional matched filtering produces unsatisfactory results. We investigate SAR performance and processing of sparse, multiple-aperture arrays. Three filters are evaluated: the matched filter, maximum-likelihood filter, and minimum mean-square error filter [J278]

"Use of ground observations to simulate the seasonal changes in the backscattering coefficient of the subarctic forest"

RADARSAT synthetic aperture radar (SAR) data acquired at C Band, HH polarization, and for the 20°-27° and 45°-49° incidence angle ranges were available over northern Quebec, Canada, (54°N, 72°12'W), in the fall of 1996, the winter of 1997, and the spring of 1997. The main land occupation of this area is sparse black spruce (Picea mariana) forests. Vegetation characteristics are jointly used with snow and soil observations coinciding with the satellite overpasses to simulate the seasonal changes in the backscattering coefficient of the subarctic forest. The aim of this study is twofold. First to evaluate the effects of the seasonal changes in vegetation on the RADARSAT SAR data, and second to use backscattering models as a tool for a better interpretation and understanding of the RADARSAT SAR data over snow-covered forested areas. Simulations show the importance of the surface-vegetation interaction term and the wet snow surface roughness on the discrimination between open forest and denser forest, and on the contrast between wet snow and dry snow covers. When comparing the simulations to the RADARSAT SAR data, the poorest results are obtained in the spring for a rough wet snow. It is shown that they are mainly due to a crude evaluation of the vegetation dielectric constant rather than to uncertainties introduced by the spatial variability in the wet snow surface roughness [J279]

"Unwrapping ground displacement signals in satellite radar interferograms with aid of GPS data and MRF regularization"

Synthetic aperture radar (SAR) images acquired by radar satellites at different times can be combined into interferograms that reveal information about the change in range from ground to satellite, wrapped into phase fringes corresponding to half the radar wavelength. We describe a methodology that uses Markov random field (MRF) regularization and simulated annealing optimization to unwrap such differential interferograms. Often, repeated Global Positioning System (GPS) geodetic measurements are available in an area covered by interferograms. Here, such repeated GPS observations are used to provide a complementary measurement of the unwrapped change in range at sparse locations. The process of unwrapping interferograms can be initialized and guided with such sparsely located "correct" values. Both interferograms and GPS observations may include several error factors, which are reduced before combining the two observations. GPS-measured range change is used to eliminate residual orbital error. In the unwrapping procedure, a vectorized lowpass filter is used to gain temporarily increased smoother variation of the phase. For the purposes of initializing the unwrapping process, virtual unwrapped interferograms are created by ordinary kriging of GPS-measured range change. The initial interferograms are then optimized further by using MRF regularization that incorporate the assumption of a smoothly varying displacement field and the relationship of the unwrapped images to the GPS observations. A simulated annealing optimization algorithm is used to find an optimal solution of the MRF regularization. The smoothed unwrapped interferograms are then used to construct unwrapped versions of the unfiltered input interferogram. Several additional image analyses methods are used in the optimization process to make the unwrapping more efficient and faster. The unwrapping technique is applied to unwrap interferograms from the Reykjanes Peninsula, in southwest Iceland. [J280]

"On current limits of soil moisture retrieval from ERS-SAR data"

Assesses the feasibility of retrieving soil moisture content over smooth bare-soil fields using European Remote Sensing synthetic aperture radar (ERS-SAR) data. The roughness conditions considered in this study correspond to those observed in agricultural fields at the time of sowing. Within this context, the retrieval possibilities of a single-parameter ERS-SAR configuration is assessed using appropriately trained neural networks. Three sources of error affecting soil moisture retrieval (inversion, measurement, and model errors) are identified, and their relative influence on retrieval performance is assessed using synthetic datasets as well as a large pan-European database of ground and ERS-1 and ERS-2 measurements. The results from this study indicate that no more than two soil moisture classes can reliably be distinguished using the ERS configuration, even for the restricted roughness range considered. [J281]

"Soil moisture estimation from ERS/SAR data: toward an operational methodology"

Previous studies have shown the possibility of using European Remote Sensing/synthetic aperture radar (ERS/SAR) data to monitor surface soil moisture from space. The linear relationships between soil moisture and the SAR signal have been derived empirically and, thus, were a priori specific to the considered watershed. In order to overcome this limit, this study focused on two objectives. The first one was to validate over two years of data the empirical sensitivity of the radar signal to soil moisture, in the case of three agricultural watersheds with different soil compositions and land cover uses. The slope of the observed relationship was very consistent. Conversely, the offset could change, making the soil moisture retrieval only relative (and not absolute). The second one was to propose an "operational" methodology for soil moisture monitoring based on ERS/SAR data. The implementation of this methodology is based on two steps: the calibration period and the operational period. During the calibration period, ground truth campaigns are performed to measure vegetation parameters (to correct the SAR signal from the vegetation effect), and the ERS/SAR data is processed only once a field land cover map is established. In contrast, during the operational period, no vegetation field campaigns are performed, and the images are processed as soon as they are available. The results confirm the relevance of this operational methodology, since no loss of performance (in soil moisture retrieval) is observed between the calibration and operational periods. [J282]

"SAR interferometry and statistical topography"

The paper introduces a parametric model for the power spectrum density of synthetic aperture radar (SAR) interferograms. This model is derived by assuming the interferogram as a stationary frequency-modulated process and by exploiting the statistical description of earth topography provided by multifractal fields. Despite the small number of parameters involved (three to six in most cases), the model has been proven robust and accurate in most of the cases tested. In particular, the parametric probability distribution assumed for ground terrain slopes fitted the actual histogram (derived from existing digital elevation models) in a range of three to five decades. Applications to blind baseline estimation and phase unwrapping are then briefly discussed. [J283]

"Glacier motion estimation using SAR offset-tracking procedures"

Two image-to-image patch offset techniques for estimating feature motion between satellite synthetic aperture radar (SAR) images are discussed. Intensity tracking, based on patch intensity cross-correlation optimization, and coherence tracking, based on patch coherence optimization, are used to estimate the movement of glacier surfaces between two SAR images in both slant-range and azimuth direction. The accuracy and application range of the two methods are examined in the case of the surge of Monacobreen in Northern Svalbard between 1992 and 1996. Offset-tracking procedures of SAR images are an alternative to differential SAR interferometry for the estimation of glacier motion when differential SAR interferometry is limited by loss of coherence, i.e. in the case of rapid and incoherent flow and of large acquisition time intervals between the two SAR images. In addition, an offset-tracking procedure in the azimuth direction may be combined with differential SAR interferometry in the slant-range direction in order to retrieve a two-dimensional displacement map when SAR data of only one orbit configuration are available. [J284]

"Analysis of the SAR imaging process of the ocean surface using Volterra models"

The synthetic aperture radar (SAR) process of the ocean surface mapping is studied using a decomposition based on a Volterra model. By a mathematical expansion of the complex exponential of the complete SAR transform, these models decompose the nonlinear distortion mechanisms of the SAR spectrum over different spectra of polynomial interactions. Thus, they offer an alternative modeling (to the exact SAR transform) giving a theoretical separation between the SAR Fourier components linearly derived from the sea surface elevation and the artifacts created by nonlinearities of the SAR mapping of the ocean surface. The paper gives a systematic assessment of such an approximation of the ocean surface SAR imaging process. Higher order statistics (HOS) of the SAR transform and their calculus and implementation are presented. In fact, nonlinearity detection, location (in the Fourier domain) and quantification can only be performed by HOS, reduced to a second-order Volterra model. The Volterra expansion of the SAR imaging process opens new theoretical inversion schemes since under certain conditions on the linear part, Volterra models are easily invertible. Our method is first tested on simulated SAR images in order to validate the HOS tools. We then show results of this nonlinearity analysis performed on images from the ERS-1 satellite and we present cases of nonlinearity detection [J285]

"Preparing an urban test site for SRTM data validation"

In this paper, we describe a method to obtain a reliable set of elevation data suitable for data validation on the Shuttle Radar Topography Mission (SRTM), starting from laser scanning measurements on an urban test site: Pavia, Northern Italy. The elevation dataset is obtained through extraction of digital terrain models. The source digital surface model is first filtered by means of a lowpass or morphological kernel. Then, buildings are

suppressed through analysis of the height histogram. Finally, a lowpass filter suppresses the surviving elevation artifacts. We show that, starting from a digital surface model at 1-m ground resolution, we end up with a digital terrain model that can be used as a ground truth for SRTM topographic analysis of an urban area. [J286]

"A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms"

We present a new differential synthetic aperture radar (SAR) interferometry algorithm for monitoring the temporal evolution of surface deformations. The presented technique is based on an appropriate combination of differential interferograms produced by data pairs characterized by a small orbital separation (baseline) in order to limit the spatial decorrelation phenomena. The application of the singular value decomposition method allows us to easily "link" independent SAR acquisition datasets, separated by large baselines, thus increasing the observation temporal sampling rate. The availability of both spatial and temporal information in the processed data is used to identify and filter out atmospheric phase artifacts. We present results obtained on the data acquired from 1992 to 2000 by the European Remote Sensing satellites and relative to the Campi Flegrei caldera and to the city of Naples, Italy, that demonstrate the capability of the proposed approach to follow the dynamics of the detected deformations. [J287]

"A model-based approach to the automatic extraction of linear features from airborne images"

The authors describe a model-based method for the automatic extraction of linear features, like roads and paths, from aerial images. The paper combines and extends two earlier approaches for road detection in SAR satellite images and presents the modifications needed for the application domain of airborne image analysis together with representative results [J288]

"Analysis of ERS Tandem SAR coherence from glaciers, valleys, and fjord ice on Svalbard"

Interferometric satellite synthetic aperture radar (SAR) data was acquired from an area on Spitsbergen, Svalbard, during the European remote sensing satellite (ERS) Tandem mission in 1995-1996. Analyzing these data sets shows that the estimated SAR coherence is highly dependent on the satellite baseline length, and that corrections for this decorrelation effect is necessary if the baseline is a few hundred meters or more. Meteorological recordings are compared to SAR coherence estimates made at different seasons and surface categories: glaciers in motion, glacial forefields dominated by ice-cored moraines, lakes, rivers, and flat valleys with fine moraine materials like gravel and sand. It was found that temporal decorrelation effects are mainly due to changing surface conditions caused by precipitation and temperature variations around freezing, but that wind redistribution of snow also may play a role. Structures and cracks in the fjord ice as well as boundaries of lakes, rivers, and coastlines can be detected in SAR coherence images because of the contrast between high and low coherence areas. Low coherence is observed from those parts of moving glaciers that experience deformations shear, or zones of relative high velocity. The usefulness of 35-days interferometric SAR (e.g., the foreseen ENVISAT configuration) will be limited, even in sparsely vegetated areas like Svalbard, as compared to the ERS Tandem configuration [J289]

"Compression of SAR raw data through range focusing and variable-rate trellis-coded quantization"

There is an ever-growing interest in the compression of SAR data because of the huge resources required for storage and transmission. This is especially true for spaceborne sensors, given the limited capacity of the downlink channel. Unfortunately, SAR data lack the useful properties on which compression algorithms rely; indeed, these are present in the focused images, but focusing is too complex for on-board implementation at this time. Poggi et al. (2000) proposed to perform on the satellite only the low-complexity range focusing, which increases the data correlation and better concentrates their energy. These properties were then exploited by adopting a variable-rate vector quantizer, with a clear performance improvement with respect to reference techniques. However, vector quantization (VQ) is too complex for actual on-board implementation, and therefore, here we replace VQ with trellis-coded VQ. To limit complexity, only small vectors are used, which reduces VQ's ability to exploit data dependencies; on the other hand, trellis coding allows one to encode large blocks of data at once, and to obtain a better partition of the input space. Experiments on real SAR data show that the overall performance is comparable to that of Poggi et al., but the complexity is much lower, making on-board implementation possible [J290]

"The development of inflatable array antennas"

Inflatable array antennas are being developed to significantly reduce the mass, the launch vehicle stowage volume, and the cost of future spacecraft systems. Three inflatable array antennas, previously developed for spacecraft applications, are a 3.3 mЧ1.0 m L-band synthetic-aperture radar (SAR) array, a 1.0 m-diameter X-

band telecom reflectarray, and a 3 m-diameter Ka-band telecom reflectarray. All three antennas are similar in construction, and each consists of an inflatable tubular frame that supports and tensions a multi-layer thin-membrane RF radiating surface with printed microstrip patches, The L-band SAR array achieved a bandwidth of 80 MHz, an aperture efficiency of 74%, and a total mass of 15 kg. The X-band reflectarray achieved an aperture efficiency of 37%, good radiation patterns, and a total mass of 1.2 kg (excluding the inflation system). The 3 m Ka-band reflectarray achieved a surface flatness of 0.1 mm RMS, good radiation patterns, and a total mass of 12.8 kg (excluding the inflation system). These antennas demonstrated that inflatable arrays are feasible across the microwave and millimeter-wave spectrum. Further developments of these antennas are deemed necessary, in particular, in the area of qualifying the inflatable structures for space-environment usage [J291]

"Effects of stand size on the accuracy of remote sensing-based forest inventory"

The comparison of results of different forest studies is extremely difficult due to differences in test sites and studied stand characteristics, validation procedures, parameters used as an evaluation criteria, selection of stands, and the number of predictors used to name but a few. All these account for a large variation of the obtained accuracy. Additionally, in most reports inadequate information is given to convert statistically results from one study to the other. Since very few studies, such as Hyyprд et al.(2000), exist where various remote sensing data sources and methods are verified in the same test site, much of the knowledge of the applicability of various data sources and methods for forest inventory has to be obtained by studies carried out in different tests sites. However, there is a single parameter, stand size, affecting strongly comparisons of forestry inventory results. The effect of stand size on the accuracy of remote sensing-based standwise forest inventory has not been reported extensively. The most dramatic changes occur at the level where stands are small. Not surprisingly, stand size has been successfully utilized as an auxiliary parameter in some studies. This paper describes how the accuracy of estimation is influenced by the stand size. Both spaceborne and airborne data are used in order to show that the effect is not just based on large pixel sizes or the effects of border pixels in spaceborne data. The accuracy of the following remote sensing data, SPOT Pan and XS, Landsat TM, ERS-1/2 SAR PRI and SLC, and airborne data from imaging spectrometer (AISA) is verified as a function of stand size in the range 1 to 20 ha. The paper presents curves that assist in converting results from one stand size to another and compares results of some studies in different test sites. Stand size seems to explain most of the variability of the results; however, for detailed comparison, more carefully described results are needed. Recommendations to design future forest studies are given in order to help the statistical conversion of results from one study to another [J292]

"Investigations of polarisation purity and SAR for personal satellite communications antennas using a hybrid computational method"

Using a hybrid method of moments/finite difference time domain technique, a study of the effects of human proximity on the polarisation purify of circularly-polarised handset antennas for personal satellite communications was undertaken. Assessments of specific absorption rate in the head were also made. The method gave stable results, in accordance with physical expectations. Good agreement with the pure method of moments was shown in simplified cases [J293]

"Filtering of multichannel SAR images"

An explicit form of the linear multichannel synthetic aperture radar (SAR) intensity filter, which preserves radiometry while optimally reducing speckle is derived, together with a compact expression for the theoretical gain in equivalent numbers of looks (ENLs). The filter can be applied to mixed data types, which is demonstrated using a combination of ERS and JERS satellite data, and confirms the filter performance predicted by the theory. Tests indicate that a simplified form of the filter, which neglects correlation between images, gives an ENL only slightly less than optimal, while being much easier to implement. Exact analysis of the effect of estimating filter weights shows that the linear increase in ENL with the number of images predicted for the ideal filter does not occur. In practice, the ENL is affected by the window size used to estimate the weights and saturates as the number of images increases. An efficient recursive form of the filter is described, which is most naturally applied to multitemporal data for the practically important case where the current image is uncorrelated with previous images in a data sequence [J294]

"Spaceborne along-track SAR interferometry: performance analysis and mission scenarios"

A system study of a spaceborne along-track synthetic aperture radar (SAR) interferometer is presented. This sensor has been successfully experienced for detecting moving targets by using only airborne installations. Several key issues must be addressed when spaceborne configurations are envisaged. To this end, a quantitative evaluation of system performance and measurement accuracy has been conducted. First, the

identification of possible space configurations has been accomplished. In particular, the two antennas can operate on a single satellite or they can be carried along appropriate trajectories by two spacecrafts. Then, an error budget of radial velocity measurement accuracy has been performed. Finally, two possible mission scenarios are dealt in details, and numerical results are reported [J295]

"The seasonal behavior of interferometric coherence in boreal forest"

The capability of SAR interferometry has been previously demonstrated in various applications. In particular, the use of interferometric coherence has shown promising results in forest monitoring, however, mainly in discriminating forested and nonforested areas. The authors have collected ERS-1 and ERS-2 Tandem data from two boreal forest test sites in Finland. The data have been processed into interferometric coherence and intensity images. These images have been used to a) compare the behavior of interferometric coherence and intensity for various land-use and forest classes and b) extensive analysis on the behavior of interferometric coherence in boreal forests as a function of stem volume. Based on the observations and the use of a boreal forest semi-empirical backscattering model, they have developed an empirical model that describes interferometric coherence of boreal forests using backscattering information. The results indicate that coherence is more sensitive to the stem volume than the C-band backscattering intensity. However, the intensity and coherence data contain complementary information and therefore, the use of both data sources is beneficial in the observation of boreal forest [J296]

"A weighted least squares solution for space intersection of spaceborne stereo SAR data"

The use of stereoscopic SAR images offers an alternative to interferometric SAR for the generation of digital elevation models (DEMs). The stereo radargrammetric method is robust and can generate DEMs of sufficient accuracy to geocode SAR images. Previous work has shown that ground coordinates with accuracy of four times the resolution cell can be obtained from ERS data without using any ground control points (GCPs), where the high accuracy of the orbit and satellite position of the order of metres introduce insignificant errors into the intersection procedure. The orbit data for RADARSAT is not as accurate as that for ERS, and the perpendicular relationship between the resultant velocity vector and the resultant range vector is uncertain in terms of image geometry. Hence, it is necessary to refine the method to allow for possible errors. This paper introduces a weighted space intersection algorithm based on an analysis of the predicted errors. A radargrammetric error model for observation errors is also formulated to predict the accuracy of the algorithm. The revised method can be used without any GCPs, but this can lead to systematic errors due to less accurate orbit data, and it has been found that the use of two GCPs provides a reasonable solution. The method is insensitive to the spatial distribution of GCPs, which is often critical in traditional methods. The error statistics of the results generated from 32 independent check points, distributed through the entire SAR image, approach the predicted errors and give positional accuracy of 38 m in three dimensions [J297]

"Radically new design of SAR satellite: short vertical antenna approach"

The idea of this work is the use of a vertical antenna (antenna placed in the orbit plane) for a spaceborne radar. This surprising geometry is proven to work properly and to simplify the design of the instrument, particularly when it is associated with a short antenna length (<5 m, along speed vector). The number of antenna control points is greatly reduced, which saves cost and mass of an active antenna. A single pencil beam allows all the incidences and modes to be achieved. Viewing on both sides of the satellite track is enabled. Spotlight mode is no longer needed and therefore most of the operational constraints attached to high resolution are removed. Merits of the geometry are not limited to the instrument, a cascade of other innovations converges into a radically new design of the whole satellite for an ultimate goal of simplification and cost reduction, this is radar SAIL concept. The merits and cost savings of short vertical antenna are illustrated with a 1 m resolution X band mission, and the extra merits of the integrated SAIL architecture with respect to the standard satellite architecture are discussed [J298]

"Geometric calibration of ERS satellite SAR images"

Geometric calibration of the European Remote Sensing (ERS) Satellite synthetic aperture radar (SAR) slant range images is important in relation to mapping areas without ground reference points and also in relation to automated processing. The relevant SAR system parameters are discussed and calibrated by using the European Space Agency (ESA) transponders at Flevoland. The resulting accuracy of the slant range images corresponds to 10 m horizontally on the ground. The results are verified by using runway intersections and corner reflectors surveyed with differential GPS techniques. Based on a seven-year ERS-1 and a four-year ERS-2 time series, the long term stability is found to be sufficient to allow a single calibration covering the entire mission period. A descending and an ascending orbit tandem pair of the ESA calibration site on Flevoland,

suitable for calibration of ERS SAR processors, is described to allow other researchers to geometrically calibrate their processing systems [J299]

"An ERS-1 synthetic aperture radar image of a tropical squall line compared with weather radar data"

A radar image acquired by the C-band synthetic aperture radar (SAR) aboard the European Remote Sensing satellite ERS-2 over the coastal waters south of Singapore showing radar signatures of a strong tropical squall line (“Sumatra Squall”) is compared with coincident and collocated weather radar data. Squall line features such as the gust front, areas of updraft convergence, and rain areas are identified. Possible attenuation effects from the rain drops in the atmosphere under very heavy rain (rain rate >100 mm/h) is suggested. In addition, the possibility of extracting the associated geophysical parameters, i.e., rain rate and wind speed from SAR imagery is investigated. The rain rate is estimated from the attenuation signature in the SAR image. Comparison between the estimated rain rate and weather radar rain rate shows consistency. Wind speed associated with the squall line is estimated based on the CMOD4 wind scatterometer model. The estimated wind speed pattern appears to be in agreement with the observed squall line structure. Possible errors in the wind estimation due to effects of rain are suggested [J300]

"A two-dimensional Doppler-Radiometer for Earth observation"

Compared to synthetic aperture radars (SARs), the angular resolution of microwave radiometers is quite poor. Traditionally, it has been limited by the physical size of the antenna. However, the angular resolution can be improved by means of aperture synthesis interferometric techniques. A narrow beam is synthesized during the image formation processing of the cross-correlations measured at zero-lag between pairs of signals collected by an array of antennas. The angular resolution is then determined by the maximum antenna spacing normalized to the wavelength (baseline). The next step in improving the angular resolution is the Doppler-Radiometer, somehow related to the super-synthesis radiometers and the Radiometer-SAR. This paper presents the concept of a three-antenna Doppler-Radiometer for 2D imaging. The performance of this instrument is evaluated in terms of angular/spatial resolution and radiometric sensitivity, and an L-band illustrative example is presented [J301]

"The relationship between the backscattering coefficient and the biomass of narrow and broad leaf crops"

The influence of the shape and dimensions of plant constituents on the backscattering of agricultural vegetation is investigated. Multifrequency multitemporal polarimetric data, collected at C- and L-bands by means of airborne and satellite synthetic aperture radar (SAR), showed that the relations between the backscattering of crops and the vegetation biomass depend on plant type, and that there are different trends for “narrow” and “broad” leaf crops. In the latter crops, backscattering increases with an increase in the biomass, especially at L-band. This behavior is typical of media in which scattering is dominant, whereas on “narrow leaf” plants, the trend is flat or decreasing, denoting a major contribution of absorption. Theoretical simulations obtained with a discrete element radiative transfer model have confirmed that a different backscattering of crops with the same biomass may be due to plant geometry [J302]

"Self-similar texture modeling using FARIMA processes with applications to satellite images"

A texture model for synthetic aperture radar (SAR) images is presented. Specifically, a sea surface in satellite images is modeled using the two-dimensional (2-D) fractionally integrated autoregressive-moving average (FARIMA) process with a non-Gaussian white driving sequence. The FARIMA process is an ARMA type model which is asymptotically self-similar. It captures the long-range as well as short-range spatial dependence structure of an image with a small number of parameters. To estimate these parameters, an efficient estimation procedure based on a spectral fit is presented. Real-life ocean surveillance radar images collected by the RADARSAT sensor are used to evaluate the practicality of this FARIMA approach. Using the radial power spectral density, the new model is shown to provide a more accurate description of the SAR images than the conventional moving-average (MA), autoregressive (AR), and fractionally differenced (FD) models [J303]

""Flashing Fields" in nearly simultaneous ENVISAT and ERS-2 C-band SAR images"

Large differences are observed between radar backscatter measurements made by the ENVISAT and ERS-2 satellite synthetic aperture radars, within 30 min of each other over certain agricultural fields in Flevoland, The Netherlands. The differences appear to be caused by the presence of highly directive scattering combined with very small variations in the azimuth illumination angle of the two sensors at the degree or subdegree level. There is relatively little awareness of such sensitivity to illumination direction, and it is not predicted by models

for microwave interaction usually applied to soils and vegetation. It is, however, to be expected if there are significant contributions from coherent scattering extending over patches of the agricultural fields in question. We present analysis that supports such a conclusion. [J304]

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