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

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"GMTI along-track interferometry experiment"

Synthetic aperture radar (SAR) along track interferometry (ATI) has been used extensively to measure ocean surface currents. Given its ability to measure small velocities (10 cm/s) of relatively radar-dark water surfaces, there is great potential that this technique can be adapted for ground moving target indication (GMTI) applications, particularly as a method for detecting very slow targets with small radar cross-sections. In this paper we describe preliminary results from an ATI GMTI experiment. The SAR data described herein were collected by the dual-frequency NASA/JPL airborne radar in its standard dual-baseline ATI mode. The radar system imaged a variety of control targets including a pickup truck, sport utility vehicles, passenger cars, a bicycle, and pedestrians over multiple flight passes. The control targets had horizontal velocities of less than 5 m/s. The cross-sections of the targets were not purposely enhanced, although the targets' reflectivities may have been affected by the existence of the GPS equipment used to record the targets' positions. Single-look and multiple-look interferograms processed to the full azimuth resolution were analyzed. In the data processed to date, all of the targets were observed by visual inspection in at least one of the four combinations of dual-frequency, dual-baseline interferometric data. This extremely promising result demonstrates the potential of ATI for GMTI applications. [J995]

"March 2006 Disfinguished Lecturers Program"

{no data available} [J996]

"On center-beam approximation in SAR motion compensation"

This work provides a geometrical analysis to assess the effects of center-beam approximation, crucial for efficient airborne raw data focusing, on the final image. [J997]

"Incoherent SAR polarimetric analysis over point targets"

In this letter, we show that the polarimetric behavior of point targets is preserved even in the case of multipolarization incoherent acquisitions. Point targets are defined as targets embedded in one image pixel and presenting a very stable backscatter during the integration time. We discuss in particular how the polarimetric response restoration can be helpful for point target detection and analysis from such acquisitions (e.g., ASAR Alternate Polarization mode of ENVISAT), but also for permanent scatterers interferometry applications. [J998]

"Considerations about antenna pattern measurements of 2-D aperture synthesis radiometers"

Accurate measurement of the antenna voltage patterns of large-aperture synthesis radiometers is critical in order to achieve good radiometric accuracy, and a very time consuming and expensive task. Measurement requirements and a tradeoff study relating radiometric accuracy degradation and number of elements to be measured are presented. [J999]

"Monitoring and surveillance potentialities obtained by splitting the antenna of the COSMO-SkyMed SAR into multiple sub-apertures"

The authors discuss the potentialities obtained by splitting the antenna of the COSMO-SkyMed synthetic aperture radar (SAR), developed by Alenia Spazio under contract to the Italian Space Agency and Italian Ministry of Defence, into multiple sub-apertures. The modified sensor has the capability to detect slowly moving ground targets that compete with the clutter Doppler spectrum. Special attention is devoted to a preliminary analysis of the signal processing techniques to be used. Moreover their capabilities for surveillance purposes are characterised based on theoretical and simulated results. Moreover the modified sensor is shown to allow sea current/wave monitoring by along-track SAR interferometry, relocation of moving targets in high resolution SAR images, and fully polarimetric imaging. Some practical implementation issues related to the possible modification

are also briefly discussed. [J1000]

"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. [J1001]

"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. [J1002]

"Editorial: Advances in synthetic aperture radar"

This special issue includes papers selected from EUSAR 2004. The publisher suggested including the top 10% of the EUSAR 2004 programme. As we had 280 presented papers including posters we came up with a selection of 26 papers. Because of the large number of pages this special issue has therefore been published in two parts. With EUSAR a unique, worldwide forum for everyone working in the SAR field-scientists, system designers, teachers and users-was established. Each EUSAR conference represents the most recent state-of-the-art in SAR in the world and exhibits perspectives for future activities. The selection of papers included in this double issue reflects these intentions. [J1003]

"Spaceborne imaging radar-C/X-band synthetic aperture radar (SIR-C/X-SAR): a look back on the tenth anniversary"

The spaceborne imaging radar-C, X-band synthetic aperture radar (SIR-C/X-SAR) missions have resulted in important scientific discoveries and provided new insights into Earth system processes. Analyses of SIR-C/X-SAR engineering-mode data have also led to new measurement and mission concepts. The multifrequency, multipolarisation capability provided by SIR-C/X-SAR is unsurpassed from a spaceborne system, making the data set valuable for algorithm development and assessment of optimal imaging parameters more than a decade after the missions were flown. [J1004]

"Sea ice monitoring by L-band SAR: an assessment based on literature and comparisons of JERS-1 and ERS-1 imagery"

Spaceborne single-polarization C-band synthetic aperture radar (SAR) imagery is widely used to gather information about the state of the sea ice cover in the polar regions. C-band is regarded as a reasonable choice for all-season monitoring capabilities. For specific mapping tasks, however, other frequency bands can be more suitable. In the first part of this paper, the summary of a literature study dealing with the utilization of L-band

SAR imagery for sea ice monitoring is presented. Investigations reveal that if deformation features such as ice ridges, rubble fields, and brash ice are to be mapped, L-band radar is superior in a number of cases. The second part of this paper addresses the comparison of JERS-1 and ERS-1 SAR images that were acquired over sea ice east of Svalbard and along the east coast of Greenland. The effects of the different frequencies, polarizations, and incidence angles of the two SAR systems are discussed. It is demonstrated that the images of both sensors complement one another in the analysis of ice conditions, resulting in a more detailed view of the sea ice cover state. [J1005]

"Polarimetric and interferometric characterization of coherent scatterers in urban areas"

In this paper the concept of point-like coherent scatterers (CSs) in urban areas is introduced. The detection of CSs in single and quad-polarized images is addressed and applied on polarimetric and interferometric high-resolution airborne SAR data at L-band. For the detection of CSs two different approaches are proposed and their individual performance is analyzed. The properties of the detected CSs and their polarimetric and interferometric characteristics are assessed. The role of polarimetry on the detection of the CSs is evaluated and the potential of extracting the orientation and dielectric properties of individual CSs is finally addressed. [J1006]

"Using a priori information to improve soil moisture retrieval from ENVISAT ASAR AP data in semiarid regions"

This paper presents a retrieval algorithm that estimates spatial and temporal distribution of volumetric soil moisture content, at an approximate depth of 5 cm, using multitemporal ENVISAT Advanced Synthetic Aperture Radar (ASAR) alternating polarization images, acquired at low incidence angles (i.e., from 15° to 31°). The algorithm appropriately assimilates a priori information on soil moisture content and surface roughness in order to constrain the inversion of theoretical direct models, such as the integral equation method model and the geometric optics model. The a priori information on soil moisture content is obtained through simple lumped water balance models, whereas that on soil roughness is derived by means of an empirical approach. To update prior estimates of surface parameters, when no reliable a priori information is available, a technique based solely on the use of multitemporal SAR information is proposed. The developed retrieval algorithm is assessed on the Matera site (Italy) where multitemporal ground and ASAR data were simultaneously acquired in 2003. Simulated and experimental results indicate the possibility of attaining an accuracy of approximately 5% in the retrieved volumetric soil moisture content, provided that sufficiently accurate a priori information on surface parameters (i.e., within 20% of their whole variability range) is available. As an example, multitemporal soil moisture maps at watershed scale, characterized by a spatial resolution of approximately 150 m, are derived and illustrated in the paper. [J1007]

"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. [J1008]

"Monitoring flood condition in marshes using EM models and Envisat ASAR observations"

This paper discusses the contribution of multipolarization radar data in monitoring flooding events in wetland areas of the Delta of the Paranar' River, in Argentina. The discussion is based on the comparison between radiative transfer model simulations and ENVISAT Advanced Synthetic Aperture Radar observations of two types of marshes: junco and cortadera. When these marshes are flooded, the radar response changes significantly. The differences in radar response between the flooded and nonflooded condition can be related to changes in the amount of emerged biomass. Based on this, we propose a vegetation-dependent flooding prediction scheme for two marsh structures: nearly vertical cylinders (junco-like) and randomly oriented discs (cortadera-like). [J1009]

"Feature fusion to improve road network extraction in high-resolution SAR images"

This letter aims at the extraction of roads and road networks from high-resolution synthetic aperture radar data. Classical methods based on line detection do not use all the information available; indeed, in high-resolution data, roads are large enough to be considered as regions and can be characterized also by their statistics. This property can be used in a classification scheme. Therefore, this letter presents a road extraction method which is based on the fusion of classification (statistical information) and line detection (structural information). This fusion is done at the feature level, which helps to improve both the level of likelihood and the number of the extracted roads. The proposed approach is tested with two classification methods and one line extractor. Results on two different datasets are discussed. [J1010]

"Computing the double-bounce reflection coherent effect in an incoherent electromagnetic scattering model"

One of the main limitations of electromagnetic incoherent vegetation models based on the radiative transfer theory concerns their inability to take into account the coherent effect occurring in a double-bounce scattering mechanism. This is particularly important for low-frequency synthetic aperture radar applications over forested areas, where large branch and trunk contributions may be preponderant. In this letter, an easily computable solution based on the reciprocity theorem is proposed. The coherent effect contribution is obtained directly from the radiative transfer incoherent solution through a straightforward correction algorithm. Compared to the classical vector radiative transfer first-order solution, this method provides the exact cross-polarized contribution to the radar cross section or to the polarimetric parameters computation. The theoretical developments are illustrated using electromagnetic full-wave and approximate scattering models. [J1011]

"Coseismic fault rupture detection and slip measurement by ASAR precise correlation using coherence maximization: application to a north-south blind fault in the vicinity of Bam (Iran)"

Using the phase differences between satellite radar images recorded before and after an earthquake, interferometry allows mapping the projection along the line of sight (LOS) of the ground displacement. Acquisitions along multiple LOS theoretically allow deriving the complete deformation vector; however, due to the orbit inclination of current radar satellites, precision is poor in the north-south direction. Moreover, large deformation gradients (e.g., fault ruptures) prevent phase identification and unwrapping and cannot be measured directly by interferometry. Subpixel correlation techniques using the amplitude of the radar images allow measuring such gradients, both in slant-range and in azimuth. In this letter, we use a correlation technique based on the maximization of coherence for a radar pair in interferometric conditions, using the complex nature of the data. In the case of highly coherent areas, this technique allows estimating the relative distortion between images. Applied to ASAR images acquired before and after the December 26, 2003 Bam earthquake (Iran), we show that the near-field information retrieved by this technique is useful to constrain geophysical models. In particular, we confirm that the major gradients of ground displacement do not occur across the known fault scarp but approximately 3 km west of it, and we also estimate directly the amplitude of right lateral slip, while retrieving this value from interferometry requires passing through the use of a model for the earthquake fault and slip. [J1012]

"Orientation angle preserving a posteriori polarimetric SAR calibration"

Fully polarimetric synthetic aperture radar (SAR) data analysis has found wide application for terrain classification, land-use, soil moisture, and ground cover classification. Critical to all analyses and applications is accurate calibration of the relative amplitudes of and phases between the various polarimetric channels. Here we propose an a posteriori method imposing only the weakest of constraints, scattering reciprocity, on the polarimetric data. Calibration parameters are self-consistently estimated from full 4Ч4 polarimetric covariance matrices. Whilst the complete set of calibration parameters is underdetermined, we give several reasonable heuristic methods to provide a complete calibration. Stronger constraints reduce the number of independent parameters and provide an overdetermined set of equations but at a cost-the loss of polarimetric fidelity when the underlying assumptions are violated. Without recourse to in situ calibration targets, the extent of the polarimetric distortion that results from polarimetric calibration remains unknown. We apply our new method to simulated data, anechoic chamber data and polarimetric SAR imagery. We also present comparisons with alternate calibration methods and different approximate solutions of the new technique. [J1013]

"Geometric symmetry in the quadratic fisher discriminant operating on image pixels"

This correspondence examines the design of Quadratic Fisher Discriminants (QFDs) that operate directly on image pixels, when image ensembles are taken to comprise all rotated and reflected versions of distinct sample

images. A procedure based on group theory is devised to identify and discard QFD coefficients made redundant by symmetry, for arbitrary sampling lattices. This procedure introduces the concept of a degeneracy matrix. Tensor representations are established for the square lattice point group (8-fold symmetry) and hexagonal lattice point group (12-fold symmetry). The analysis is largely applicable to the symmetrization of any quadratic filter, and generalizes to higher order polynomial (Volterra) filters. Experiments on square lattice sampled synthetic aperture radar (SAR) imagery verify that symmetrization of QFDs can improve their generalization and discrimination ability [J1014]

"Correction to "An investigation of bistatic calibration Objects""

Weizu Xiong provides a correction on the paper "An investigation of bistatic calibration objects" by Bradley et al., see ibid., vol.43, no.10, p.2177 (1990). [J1015]

"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. [J1016]

"Reply to correction to "An investigation of bistatic calibration objects""

The authors provide a reply to the correction by Weizu Xiong, see ibid., vol.44. no.6, p.1692 (2006), on their paper "An investigation of bistatic calibration objects", see ibid., vol.43, no.10, p.2177 (1990). [J1017]

"Derivation and comparison of SAR and frequency-wavenumber migration within a common inverse scalar wave problem formulation"

Two common Fourier imaging algorithms used in ground penetrating radar (GPR), synthetic aperture radar (SAR), and frequency-wavenumber (F-K) migration, are reviewed and compared from a theoretical perspective. The two algorithms, while arising from seemingly different physical models: a point-scatterer model for SAR and the exploding source model for F-K migration, result in similar imaging equations. Both algorithms are derived from an integral equation formulation of the inverse scalar wave problem, which allows a clear understanding of the approximations being made in each algorithm and allows a direct comparison. This derivation brings out the similarities of the two techniques which are hidden by the traditional formulations based on physical scattering models. The comparison shows that the approximations required to derive each technique from the integral equation formulation of the inverse problem are nearly identical, and hence the two imaging algorithms and physical models are making similar assumptions about the solution to the inverse problem, thus clarifying why the imaging equations are so similar. Sample images of landmine-like targets buried in sand are obtained from experimental GPR data using both algorithms. [J1018]

"Intensity-driven adaptive-neighborhood technique for polarimetric and interferometric SAR parameters estimation"

In this paper, a new method to filter coherency matrices of polarimetric or interferometric data is presented. For each pixel, an adaptive neighborhood (AN) is determined by a region growing technique driven exclusively by the intensity image information. All the available intensity images of the polarimetric and interferometric terms are fused in the region growing process to ensure the validity of the stationarity assumption. Afterward, all the pixels within the obtained AN are used to yield the filtered values of the polarimetric and interferometric coherency matrices, which can be derived either by direct complex multilooking or from the locally linear minimum mean-squared error (LLMMSE) estimator. The entropy/alpha/anisotropy decomposition is then applied to the estimated polarimetric coherency matrices, and coherence optimization is performed on the estimated polarimetric and interferometric coherency matrices. Using this decomposition, unsupervised classification for land applications by an iterative algorithm based on a complex Wishart density function is also applied. The method has been tested on airborne high-resolution polarimetric interferometric synthetic aperture radar (POL-InSAR) images (Oberpfaffenhofen area-German Space Agency). For comparison purposes, the two estimation techniques (complex multilooking and LLMMSE) were tested using three different spatial supports: a fix-sized symmetric neighborhood (boxcar filter), directional nonsymmetric windows, and the proposed AN. Subjective and objective performance analysis, including coherence edge detection, receiver operating characteristics plots, and bias reduction tables, recommends the proposed algorithm as an effective POL-InSAR postprocessing technique. [J1019]

"SAR image segmentation by stochastic complexity minimization with a nonparametric noise model"

We analyze the generalization of a parametric segmentation technique adapted to Gamma-distributed synthetic aperture radar (SAR) images to nonparametric noise models. This approach is based on a polygonal grid which can have an arbitrary topology and whose number of regions and regularity of its boundaries are obtained by minimizing the stochastic complexity of a quantified version on Q levels of the image. It thus leads to a criterion without parameters to be tuned by the user and adapted to different noise models. We analyze the influence of the quantization scheme and of the optimization procedure on the quality of the partitioning. We then compare the performance of the proposed approach to the parametric one on synthetic images. Finally, we show results obtained on real images and compared with a standard segmentation algorithm of SAR images [J1020]

"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 [J1021]

"An analysis of gradient-induced distortion in ATI-SAR imagery of surface currents"

This paper summarizes an analysis of gradient-induced distortions in the surface current estimates generated by along-track interferometric SAR (ATI-SAR) systems. In the presence of spatial current gradients, an effect akin to velocity bunching can cause distortion in the measured current profiles. This distortion is caused by variation in the azimuthal displacement induced by the current itself. Up to a point, these distortions can be removed by a straightforward, spatial remapping of the interferogram pixels based upon their phase values. However, there is a critical current gradient beyond which the true surface current field is not recoverable. This mechanism is compounded in dual-beam ATI-SAR systems designed to estimate the surface current vector using only a single aircraft pass. In such systems, interferograms from two squinted beams, one squinted forward of broadside and the other squinted aft by the same amount, are combined to measure the full surface current vector. However, when the current vector does not bisect the angle between the two beams, the along-track component of the current induces unequal azimuthal displacements in the fore- and aft-squinted interferograms. As a result, the two interferograms will not be spatially registered, in that corresponding pixels in the fore- and aft-interferograms will be related to currents at spatially distinct points on the water surface. Additional vector distortions will, therefore, occur in and around the gradient region. These effects are explored through an approximate, linear analysis as well as through an ATI-SAR model that accounts for nonlinearity and finite spatial resolution, using the current gradients present in rivers as an example [J1022]

"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. [J1023]

"Extended PGA for range migration algorithms"

The phase gradient autofocus (PGA) algorithm is extended to work for synthetic aperture radar (SAR) spotlight images processed with range migration (w-k) algorithms. Several pre-processing steps are proposed for aligning the range-compressed phase-history data needed for successful autofocusing of the data. The proposed algorithm gave good results for both data with large point targets and data without point targets. [J1024]

"First Polish SAR trials"

Recent research on synthetic aperture radars (SARs) in Poland is presented. The research started in 2002 and resulted in the first focused SAR image being obtained in the following year. The Telecommunication Research Institute and the Warsaw University of Technology have carried out the trials in order to work out efficient algorithms for radar imaging in different radar modes. The experiment consisted of two main stages. During the first stage, different SAR algorithms were tested using simulated data generated by a raw radar data simulator. During the second stage, real-life data were collected during the flight of an aircraft using a modified non-coherent radar. The collected data were processed offline. During the experiment, three techniques were tested: Doppler beam sharpening, unfocused SAR and focused SAR. The experiment was accomplished successfully and the obtained results allowed the start of research into the real-time implementation of imaging algorithms. [J1025]

"X-band experimental airborne radar-Phase II: synthetic aperture radar and ground moving target indication"

Defence Research and Development Canada, Ottawa, has completed Phase II of a multifunction X-band wideband experimental airborne radar. The system consists of a high average power transmitter, a digital waveform generator, two wideband 8-bit channels for synthetic aperture radar (SAR)/inverse synthetic aperture radar and two narrowband 14-bit channels for ground moving target indication (GMTI). The reflector antenna uses a novel multimode feedhorn to derive two phase centres displaced in azimuth. The radar was designed to support research into SAR imaging of fixed and moving targets (ocean and land), time-frequency analysis of moving targets, clutter suppression for GMTI radar and ocean surveillance for small and large target detection. Highlights of the data collection capabilities, include a swath width 16 K points wide in the single-channel SAR modes, 8 K points wide in the two-channel integrated SAR-GMTI modes and 4 K points wide in the GMTI surveillance modes. The architecture of the radar, its modes of operation with respect to the SAR and GMTI data collection capabilities, the MATLAB-based GMTI processor, and the real-time kernel developed for the SAR processor are discussed; and results from its high resolution stripmap, landspot, seaspot and GMTI modes are presented from trials in July 2003. [J1026]

"Ultra-lightweight synthetic aperture radar based on a 35 GHz FMCW sensor concept and online raw data transmission"

With the increasing number of small-size unmanned aerial vehicles (UAVs) for remote sensing, reconnaissance and surveillance applications, the demand for miniaturised and low weight synthetic aperture radar (SAR) sensor systems for these platforms has increased. Because of the extreme payload weight restrictions of unmanned platforms, size, weight and power (SWP) characteristics actually become dominating design drivers for UAV SAR developments. The author focuses on the development of a highly miniaturised SAR (MISAR) sensor that was especially designed for UAVs with stringent payload SWP constraints. The paper gives an overview of the design considerations for the MISAR sensor system. The realisation of the sensor is described and the results of test flights in fixed-wing aircraft, rotary-wing aircraft and in UAVs are presented. [J1027]

"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. [J1028]

"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. [J1029]

"Gauss–Markov Model for Wavelet-Based SAR Image Despeckling"

This letter presents synthetic aperture radar (SAR) image despeckling using dyadic wavelet transform. Maximum a posteriori (MAP) estimation is used to despeckle a SAR image in the wavelet domain. A wavelet transformed speckle-free image is approximated with a Gauss–Markov random field, and a Gaussian model is chosen to approximate speckle in the wavelet domain. A speckle-free wavelet coefficient is estimated with Bayesian inference using image and noise model parameters, which produce the highest evidence. The experimental results showed that the despeckling algorithm removes speckle noise in the homogeneous areas better than the state-of-the-art methods, which operate in the wavelet and image domain. The proposed method is very simple and computationally not demanding. [J1030]

"SAR amplitude probability density function estimation based on a generalized Gaussian model"

In the context of remotely sensed data analysis, an important problem is the development of accurate models for the statistics of the pixel intensities. Focusing on synthetic aperture radar (SAR) data, this modeling process turns out to be a crucial task, for instance, for classification or for denoising purposes. In this paper, an innovative parametric estimation methodology for SAR amplitude data is proposed that adopts a generalized Gaussian (GG) model for the complex SAR backscattered signal. A closed-form expression for the corresponding amplitude probability density function (PDF) is derived and a specific parameter estimation algorithm is developed in order to deal with the proposed model. Specifically, the recently proposed "method-of-log-cumulants" (MoLC) is applied, which stems from the adoption of the Mellin transform (instead of the usual Fourier transform) in the computation of characteristic functions and from the corresponding generalization of the concepts of moment and cumulant. For the developed GG-based amplitude model, the resulting MoLC estimates turn out to be numerically feasible and are also analytically proved to be consistent. The proposed parametric approach was validated by using several real ERS-1, XSAR, E-SAR, and NASA/JPL airborne SAR images, and the experimental results prove that the method models the amplitude PDF better than several previously proposed parametric models for backscattering phenomena. [J1031]

"Curvature effects in ocean surface scattering"

Curvature effects in EM scattering from ocean surface are described using a generalized curvature expansion of the fields at an elevated nonperfect conducting surface. The new expansion formalism allows us to describe analytically and in general, without separating into different scales, the scattering of EM waves from an undulated ocean surface. The model is exact to first order in curvature for nonshadowing imaging geometry, and obeys the law of reciprocity and tilt invariance. Explicit expressions for EM fields at the surface, including both the projection and the self induced fields, are derived up to first order in surface curvature. Analytic closed form expressions for the scattered fields are derived from the surface field solutions, and applied to the case of backscattering, providing a general expression for the normalized radar cross section. The analytic expression for the normalized radar cross section is implemented for a linear surface model using both the Eulerian and the Lagrangian frame of reference. The results show that the model is capable of describing the expected dependency on polarization, incidence angle, and wind field with minimal restrictions in terms of range of validity. Comparison of polarization ratio shows good agreement between the model and measurements from the Envisat ASAR instrument [J1032]

"Demonstration of advanced reconnaissance techniques with the airborne SAR/GMTI sensor PAMIR"

PAMIR (Phased Array Multifunctional Imaging Radar) is an experimental airborne radar system that has been designed and built by the Research Institute for High Frequency Physics and Radar Techniques (FHR) of Forschungsgesellschaft fьr Angewandte Naturwissenschaften (FGAN). The goal is to meet the growing demands for future reconnaissance systems with respect to flexibility and multi-mode operation by the use of an electronically steerable phased array antenna. The X-band system with a bandwidth of 1.8 GHz serves as a platform for different tasks. One of the main objectives is to demonstrate synthetic aperture radar (SAR) imaging at a very high resolution and for a long range. The fine resolution will also be applied for inverse SAR (ISAR) imaging of ground moving targets. Moreover, five parallel receiving channels allow array processing techniques like ground moving target indication (GMTI) via space-time adaptive processing, electronic counter-counter-measures and interferometric SAR with a very high 3D-resolution. A multi-channel scan-MTI mode with a range resolution adapted to the target size allows for a wide area GMTI operation that can be complemented by target tracking. Together with the predecessor system AER-II, operating at a frequency band contained in that of PAMIR, the possibility of experimental investigation of bistatic SAR is given. SAR images of large urban areas and ISAR images of moving objects, both with finest resolution down to the sub-decimetre scale, are presented. Results of GMTI in a wide area scanning mode and broadband bistatic experiments including true bistatic SAR processing are shown as well. [J1033]

"Airborne X-band SAR imaging with 10 cm resolution: technical challenge and preliminary results"

The bandwidth of RAMSES, an airborne synthetic aperture radar (SAR) system was recently increased to 1.2 GHz in X- and Ku-bands, yielding (unweighted) 3 dB range resolution of 11 cm. The synthesis of SAR images with matching cross-range resolution requires long integration times, and this disqualifies the temporal-domain back-projection synthesis algorithm as impractically slow. The wider relative bandwidth also disqualifies simplified range/Doppler types of algorithms, as the hypothesis of proportionality between Doppler and squint is no longer valid. Therefore the authors implemented a fast-frequency domain synthesis algorithm (Ω-k or range-migration algorithm) and designed a new deterministic motion and antenna pattern compensation method for it. As the required accuracy on carrier trajectory exceeded the performance of the differential GPS-hybridised inertial navigation unit, the authors implemented an autofocus based on the phase-tracking of several isotropic point-like echoes. [J1034]

"Range resolution improvement of airborne SAR images"

This letter proposes an algorithm to improve the range resolution in airborne synthetic aperture radar (SAR) data by coherently combining an interferometric image pair, i.e., two images acquired with slightly different viewing angles. This algorithm is based on the wavenumber shift principle. In contrast to other methods, developed for application to spaceborne SAR data, the proposed algorithm takes the nonlinear effects due the strong variations in incidence angle in airborne SAR data into account. The proposed method is applied to SAR data of German Aerospace Center (DLR)'s E-SAR sensor. Quantitative verification results are obtained by measuring the resolution of several corner reflectors placed in the area under study, as well as the resolution of speckle of different areas. It is demonstrated that a resolution improvement of almost a factor of two can be achieved by incorporating a second interferometric image, which can be acquired easily with an airborne sensor. [J1035]

"Refined estimation of time-varying baseline errors in airborne SAR interferometry"

The processing of airborne synthetic aperture radar (SAR) data requires a precise compensation of the deviations of the platform movement from a straight line. This is usually carried out by recording the trajectory with a high-precision navigation system and correcting them during SAR focusing. However, due to the lack of accuracy in current navigation systems, residual motion errors persist in the images. Such residual motion errors are mainly noticeable in repeat-pass systems, where they are causing time-varying baseline errors, visible as artefacts in the derived phase maps. In this letter, a refined method for the estimation of time-varying baseline errors is presented. An improved multisquint processing approach is used for obtaining robust estimates of higher order baseline errors over the entire scene, even if parts of the scene are heavily decorrelated. In a subsequent step, the proposed method incorporates an external digital elevation model for detection of linear and constant components of the baseline error along azimuth. Calibration targets in the scene are not necessary. [J1036]

"Analytical optimization of a DInSAR and GPS dataset for derivation of three-dimensional surface motion"

A revised method for derivation of three-dimensional surface motions maps from sparse global positioning system (GPS) measurements and two differential interferometric synthetic aperture radar (DInSAR) interferograms based on a random field theory and Gibbs-Markov random fields equivalency within Bayesian statistical framework is proposed. It is shown that the Gibbs energy function can be optimized analytically in the absence of a neighboring relationship between sites of a regular lattice. Because the problem is well posed, its solution is unique and stable, and additional regularization in the form of smoothness is not required. The proposed algorithm is simple in realization, does not require extensive computer power, and is very quick in execution. The results of inverse computer modeling are presented and show a drastic improvement of accuracy when both GPS and DInSAR data are used. [J1037]

"A locally adaptive filter of interferometric phase images"

We propose an adaptive filtering approach for interferograms, which is a modification to the Lee adaptive complex filter. Based on local frequency estimates, we compute the normal orientation of local phase fringes. A directionally dependent filtering window is aligned perpendicular to the normal orientation of local phase fringes (i.e., along local phase fringes) by interpolation, making the pixels included in the filtering window have approximately more homogeneous values. Moreover, the computation of the filter parameter does not require local phase unwrapping in the real plane. This filter minimizes the loss of signal and reduces the level of noise. By using two sets of simulated data, its effectiveness can be seen in terms of the fidelity to noise-free phases, fringe preservation, and residue reduction. [J1038]

"Modified range-Doppler processing for FM-CW synthetic aperture radar"

The combination of compact frequency-modulated continuous-wave (FM-CW) technology and high-resolution synthetic aperture radar (SAR) processing techniques should pave the way for the development of a lightweight, cost-effective, high-resolution, airborne imaging radar. Regarding FM-CW SAR signal processing, the motion during the transmission of a sweep and the reception of the corresponding echo were expected to be one of the major problems. In FM-CW SAR, the so-called stop-and-go approximation is no longer valid due to the relatively long sweeps that FM-CW radars transmit. The main effect of the continuous motion is a Doppler frequency shift throughout the SAR observation time. This Doppler frequency shift can be compensated for by modifying the range migration compensation. [J1039]

"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. [J1040]

"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. [J1041]

"Varying complexity in tree-structured image distribution models"

Probabilistic models of image statistics underlie many approaches in image analysis and processing. An important class of such models have variables whose dependency graph is a tree. If the hidden variables take values on a finite set, most computations with the model can be performed exactly, including the likelihood calculation, training with the EM algorithm, etc. Crouse et al. developed one such model, the hidden Markov tree (HMT). They took particular care to limit the complexity of their model. We argue that it is beneficial to allow more complex tree-structured models, describe the use of information theoretic penalties to choose the model complexity, and present experimental results to support these proposals. For these experiments, we use what we call the hierarchical image probability (HIP) model. The differences between the HIP and the HMT models include the use of multivariate Gaussians to model the distributions of local vectors of wavelet coefficients and the use of different numbers of hidden states at each resolution. We demonstrate the broad utility of image distributions by applying the HIP model to classification, synthesis, and compression, across a variety of image types, namely, electrooptical, synthetic aperture radar, and mammograms (digitized X-rays). In all cases, we compare with the HMT. [J1042]

"The maximum phase error of a reflected signal in an active coded transponder"

This letter is devoted to investigate the active coded transponder (ACT), which is designed to add a phase shifter to an active transponder (AT). Since a phase shifting error of a phase shifter is inevitable, there is additional phase error in reflected signal from ACT to synthetic aperture radar (SAR). This letter presents the theoretical study of the phase error of reflected signal. A method is proposed to determine the maximum phase error of the reflected signal. Moreover, images of ACT with different maximum phase errors are simulated. Peak-value and integral methods are used also to evaluate the accuracy of SAR radiometric calibration. [J1043]

"Backscatter change on fire scars in Siberian boreal forests in ENVISAT ASAR wide-swath images"

The objective of this letter was to investigate the performance of the C-band Advanced Synthetic Aperture Radar (ASAR) instrument onboard the European ENVISAT satellite for mapping fire scars in boreal forest ecosystems. The Wide Swath Mode (WSM) of the cloud and haze-penetrating ASAR instrument with a spatial resolution of 150 m would be ideal to support nearly real-time fire monitoring and impact assessment over the vast and sparsely populated circumpolar forest belt. We found that: (1) the ASAR WSM backscatter signal was sensitive to fire disturbance; (2) the backscatter change correlated mainly with snow-melt and rainfall; and (3) the backscatter varied as a function of the incidence angle with a higher backscatter occurring at shallower incidence angles. The results suggest ASAR WSM data could be used to support operational fire impact monitoring in boreal forests of Siberia. Multitemporal datasets are required because environmental conditions strongly influence the backscatter signal. [J1044]

"An interferometric coherence optimization method in radar polarimetry for high-resolution imagery"

This paper investigates to what extent a new interferometric coherence optimization in radar polarimetry allows the separation of point scatterers located in the same resolution cell according to their interferometric phases. An interferometric coherence definition called the single-mechanism coherence is introduced, and the corresponding optimization method is briefly discussed. This method was first validated theoretically when no volume decorrelation occurs. Then, it has been applied to simple target measurements acquired in an anechoic chamber, and to an X-band polarimetric and interferometric synthetic aperture radar image containing man-made targets. In both cases, the single-mechanism coherence optimization enables to resolve the interferometric phases of several scattering centers inside the same resolution cell. [J1045]

"Scattering-model-based speckle filtering of polarimetric SAR data"

A new concept in polarimetric synthetic aperture radar (POLSAR) speckle filtering that preserves the dominant scattering mechanism of each pixel is proposed in this paper. The basic principle is to select pixels of the same scattering characteristics to be included in the filtering process. To achieve this, the algorithm first applies the Freeman and Durden decomposition to separate pixels into three dominant scattering categories: surface, double bounce, and volume, and then unsupervised classification is applied. Speckle filtering is performed using the classification map as a mask. A single-look or multilook pixel centered in a 9 Ч 9 window is filtered by including only pixels in the same and two neighboring classes from the same scattering category. This filter is effective in speckle reduction, while perfectly preserving strong point target signatures, and retains edges, linear, and curved features in the POLSAR data. The effect of speckle filtering on scattering characteristics, such as entropy, anisotropy, and alpha angle, will be discussed. [J1046]

"Generation of speckle-reduced phase images from three complex parts for synthetic aperture

radar interferometry"

Interferometric synthetic aperture radar (InSAR) has applications in many fields. However, decorrelation speckle noise hinders the wider application of InSAR. In this letter, we propose an innovative method termed contoured correlation interferometry to generate speckle-noise-reduced phase images. This method only needs three part images of the two complex images instead of four for the conventional method, which is a significant advantage if processing synthetic aperture radar images on satellites. It proves an efficient tool that reduces speckle noise while preserving the phase derived, which is one of most difficult problems in InSAR data processing. The proposed method can serve as an alternative to generate better InSAR interferograms, whose physical meaning is clearer. [J1047]

"The influence of target acceleration on velocity estimation in dual-channel SAR-GMTI"

This paper investigates the effects of target acceleration on estimating the velocity vector of a ground moving target from single-pass dual-channel synthetic aperture radar data. Although vehicles traveling on roads and highways routinely experience acceleration, the majority of estimation algorithms assume a constant velocity scenario, which may result in erroneous estimates of target velocity. It is shown that under most conditions, acceleration has only minor effects on the estimation of across-track velocity using along-track interferometric phase. However, under the assumption of constant velocity, acceleration may significantly bias the estimate of along-track velocity. The influence of both along-track and across-track accelerations is examined through simulations of an airborne geometry and experimental data from Environment Canada's airborne CV 580 dual-channel synthetic aperture radar system. [J1048]

"Study of the SAR signature of internal waves by nonlinear parametric autoregressive models"

In this paper, we propose a method for estimating the nonlinear differential equation governing the propagation of internal waves (IWs) in a stratified water column of the ocean. This estimation of the kind of nonlinear differential equation and the coefficients of this equation is performed from profiles of the synthetic aperture radar signature at the ocean surface. Theoretically, the equation is based upon the Korteveg-de Vries (KdV) equation or one of its improved versions. The estimation of the differential equation version is based on nonlinear polynomial autoregressive models up to the third order. The estimation of the parameters of these models is performed simply by solving a set of linear equations using higher order statistics. This general approach allows us to identify the best model of propagation, i.e., the kind of nonlinearity as well as the structure of each kernel (linear, quadratic, cubic), without determining an analytic solution to the equation of propagation. Moreover, the physical oceanic parameters (such as the thermocline depth) are deduced from the estimated coefficients of the KdV equation (assuming an underlying model of the water column). Results on simulated profiles generally lead to an exact model identification (i.e., the one used for simulation with the exact order of nonlinearity and the exact structure of each kernel) and lead to satisfying geophysical parameter estimates. Finally, the geophysical parameters estimated from three sets of ERS-1 profiles are generally coherent with the parameters observed in the IW propagation mechanism but have not been validated by "in situ" measurements. [J1049]

"Analysis of a microwave backscattering mechanism from a small urban area imaged with SIR-C"

We analyzed the Spaceborne Imaging Radar C (SIR-C) imagery of a small urban area to characterize backscattering mechanisms. The results were compared with the building density so that we could relate the polarimetric backscattering characteristics with urban structures. Relative contributions of odd-bounce, double-bounce, and cross-polarized scatterings were evaluated as a function of the building density for small and large incidence angles. Their behaviors were characterized with respect to urban structures at small and large incidence angles. [J1050]

"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. [J1051]

"Comparison and application of near-field ISAR imaging techniques for far-field Radar cross

section determination"

Inverse synthetic aperture radar (ISAR) imaging is a powerful tool for the characterization of scattering properties of radar targets. In particular, near-field techniques allow for short distance imaging with results comparable to those of standard far-field ISAR techniques. The resulting near-field images can be used to extract the far-field radar cross section (RCS) of the target overcoming the need for long-range measurement setups. This paper compares different near-field imaging techniques and reveals an in-depth insight into the imaging process, especially with regard to the subsequent RCS extraction. The performance of the different techniques together with processing improvements are demonstrated by means of numerical target models as well as by measured data of test objects and a scaled aircraft model. [J1052]

"Dictionary-based stochastic expectation-maximization for SAR amplitude probability density function estimation"

In remotely sensed data analysis, a crucial problem is represented by the need to develop accurate models for the statistics of the pixel intensities. This paper deals with the problem of probability density function (pdf) estimation in the context of synthetic aperture radar (SAR) amplitude data analysis. Several theoretical and heuristic models for the pdfs of SAR data have been proposed in the literature, which have been proved to be effective for different land-cover typologies, thus making the choice of a single optimal parametric pdf a hard task, especially when dealing with heterogeneous SAR data. In this paper, an innovative estimation algorithm is described, which faces such a problem by adopting a finite mixture model for the amplitude pdf, with mixture components belonging to a given dictionary of SAR-specific pdfs. The proposed method automatically integrates the procedures of selection of the optimal model for each component, of parameter estimation, and of optimization of the number of components by combining the stochastic expectation-maximization iterative methodology with the recently developed "method-of-log-cumulants" for parametric pdf estimation in the case of nonnegative random variables. Experimental results on several real SAR images are reported, showing that the proposed method accurately models the statistics of SAR amplitude data. [J1053]

"Signal subspace change detection in averaged multilook SAR imagery"

This paper addresses change detection in averaged multilook synthetic aperture radar (SAR) imagery. Averaged multilook SAR images are preferable to full-aperture SAR reconstructions when the imaging algorithm is approximation-based (e.g., polar format processing) or when motion data are not accurate over a long full aperture. We examine the application of a SAR change-detection method, known as signal subspace processing, which is based on the principles of two-dimensional adaptive filtering, and we use it to recognize the addition of surface landmines to a particular area under surveillance. We describe the change-detection problem as a trinary hypothesis testing problem, and define a change signal and its normalized version to determine whether: 1) there is no change in the imaged scene; 2) a target has entered the imaged scene; or 3) a target has exited the imaged scene. A statistical analysis of the error signal is provided to show its properties and merits. Results are presented for averaged noncoherent multilook and coherent single-look X-band SAR imagery. [J1054]

"The efficiency of crop recognition on ENVISAT ASAR images in two growing seasons"

The aim of the presented project was to assess the efficiency of crop recognition based on microwave Advanced Synthetic Aperture Radar (ASAR) images acquired from ENVISAT-1. Investigations were conducted during two consecutive growing seasons, in 2003 and 2004. The agrometeorological conditions during the selected seasons differed markedly, which induced year-to-year variations regarding the relevant characteristics of crop canopy. Multitemporal series of ASAR alternating polarization images were used for crop differentiation. Classification was performed using a neural network classifier trained separately for each year. Field observations conducted in the western part of Poland supplied datasets for training, validation, and testing of the classifier. Despite some differences noted in the classifier performance on two datasets, the results obtained for 2003 and 2004 showed high mutual consistency. [J1055]

"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. [J1056]

"C-band polarimetric indexes for maize monitoring based on a validated radiative transfer model"

This paper assess the possibilities of the synthetic aperture radar (SAR) sensors currently in orbit for the maize monitoring defining the configurations (polarization and incidence angles at C-band) maximizing the sensitivity to plant growth and reducing the impact of the soil moisture on the signal. Temporal evolution of the signal was simulated in all the possible configurations using the radiative transfer model developed by the University of Rome "Tor Vergata." The input parameters came from an intensive field campaign providing a detailed description of maize crop over the Belgian Loamy site all along the 2003 growing season. The model was validated for vertical (VV) and horizontal (HH) polarization using ERS, ENVISAT, and RADARSAT observations. The C-band SAR signal in single polarization was found to be sensitive to crop growth till the leaf area index (LAI) reached 4.6 m2/m2, while the soil moisture influenced the signal for sparsely vegetated fields (LAI2/m2). Dual-polarizations indexes were found sensitive to maize growth and less sensitive to soil moisture variations. The VV/VH polarization ratios computed from signal recorded at high incidence angle (35° to 45°) could be considered to assess the crop growth till LAI reached 4.9 m2/m2with low sensitivity to soil moisture. At the beginning of growth, the emergence of maize plants could be detected using the copolarized ratio (VV/HH) computed at low incidence angle. These indexes allow discriminating various crop conditions at a given date between fields of a same region. [J1057]

"Indoor wide-band polarimetric measurements on maize plants: a study of the differential extinction coefficient"

A study of the wide-band polarimetric backscatter of maize plants, measured in laboratory conditions, is presented. The backscatter slant-range profiles in both linear (H-V) and Pauli basis manifest a higher extinction coefficient in the vertical channel due to the dominant vertical orientation of the structure of corn plants. The difference between the horizontal and vertical range profiles as the wave penetrates into the volume is employed to retrieve the differential extinction coefficient. In addition, the polarimetric target decomposition, as proposed by Cloude and Pottier, is used to obtain range profiles of alpha, entropy, and anisotropy. All these results reveal important features to be accounted for in the retrieval of the biophysical parameters of agricultural crops by means of polarimetric synthetic aperture radar interferometry. [J1058]

"Indoor C-band polarimetric interferometry observations of a mature wheat canopy"

We present results from experiments carried out in the ground-based synthetic aperture radar (GB-SAR) facility at the University of Sheffield to ascertain the role of polarimetric interferometry in crop height retrieval. To this end, a mature wheat canopy, grown in outdoor conditions, was reassembled inside the GB-SAR chamber and imaged at C-band using a two-dimensional scan. This allowed fully polarimetric tomography and interferometry. Interferometry using the VV, HH, and VH polarization states shows that the HH and VH interferograms retrieve a height close to the top of the soil layer for all angles of incidence considered, whereas the height retrieved from the VV interferogram increases with angle of incidence. The use of a Pauli basis gives poor results, due to the different location of the scattering phase centers in the VV and HH channels. The use of arbitrary polarization states shows that the top of the soil can be very accurately estimated using left-circular polarization, whereas, for angles of incidence close to 45°, a polarization state similar to VV can be used to retrieve the top of the canopy; hence crop height can be recovered as the difference of these two interferometric heights. Polarimetric coherence optimization techniques are also studied. Unconstrained coherence optimization gives very unstable results, due to the small number of available samples. Constrained optimization results in stable retrieved heights, and the retrieved polarization states agree well with the polarization synthesis results. [J1059]

"Predicting backscatter-biomass and height-biomass trends using a macroecology model"

This study describes the use of a plant structure model from the field of macroecology to make generalized predictions about backscatter-biomass and height-biomass trends from synthetic aperture radar data over forests. A theoretical relationship between canopy height and biomass density is derived. The predicted values of the height exponent are comparable with those from the remote sensing literature. A radiative transfer model parameterized by the macroecology model is also used to predict trends in P-band backscatter. The results imply that backscatter can saturate even for low-opacity canopies and decreasing basal area results in backscatter saturating at lower biomass levels. The theoretical analysis is supported by reference to a range of published results. [J1060]

"Derivation of surface soil moisture from ENVISAT ASAR wide swath and image mode data in agricultural areas"

Water and energy fluxes at the interface between the land surface and atmosphere are strongly dependent on surface soil moisture content, which is highly variable in space and time. It has been shown in numerous studies that microwave remote sensing can provide spatially distributed patterns of surface soil moisture. In order to use remote-sensing-derived soil moisture information for practical applications as, for example, flood forecasting and water balance modeling in mesoscale areas, frequent large-area coverage is a prerequisite. New sensor generations such as ENVISAT Advanced Synthetic Aperture Radar (ASAR) or RADARSAT allow for image acquisitions in different imaging modes and geometries. Imaging modes with the capability of large-area coverage, such as the Wide Swath Mode of ENVISAT ASAR, are of special interest for practical applications in this context. This paper presents a semiempirical soil moisture inversion scheme for ENVISAT ASAR data. Different land cover types as well as mixed-image pixels are taken into account in the soil moisture retrieval process. The inversion results are validated against in situ measurements, and a sensitivity analysis of the model is conducted. [J1061]

"Forest height retrieval from commercial X-band SAR products"

This paper assesses the accuracy and reliability of tree height retrieval over coniferous plantations using X-band interferometry. Factors such as crown shape, density, tree height, incidence angle, and slope have been assessed and quantified using a simple polarimetric radar interferometry simulator to determine their impact on height retrieval. Results from model simulation show that the most important factors are: crown shape, plantation density, and tree height. Variation in viewing angle and small slopes ([J1062]

"A coherent model of forest scattering and SAR imaging in the VHF and UHF-band"

We present a coherent scattering model to determine the forest response to an illuminating plane wave in the frequency band 20-300 MHz. In this frequency band, at low frequencies, it is well-known that the waves penetrate the canopy and allow the detection of a hidden target. We have developed a model based on a domain integral representation of the electric field. A decoupling hypothesis is stated and validated, allowing to significantly reduce the numerical complexity of the problem inherent to integral representations. The simulated scattered field is used in a standard synthetic aperture radar (SAR) imaging algorithm to build horizontal and vertical SAR images of a set of trunks and a concealed target. [J1063]

"Capabilities of a forest coherent scattering model applied to radiometry, interferometry, and polarimetry at P- and L-band"

The interpretation of radar data would ideally require extensive and numerous observations. However, the number of observations is limited by the difficulty and the cost of acquiring ground truth and radar data. On the other hand, numerical models can provide a wide range of situations, both in inputs and in outputs. More precisely, they have to provide radiometric, polarimetric, and interferometric simulations and be applicable to various forested areas (high density, high/low moisture, inhomogeneous area, etc.) and radar configurations (low/high frequency, bistatic observation, etc.). This paper is dedicated to the presentation of the capabilities of a descriptive coherent scattering model (COSMO) applied to the electromagnetic study of the backscattering by forested areas. Improvements have been implemented in order to produce in output a radar image, which can be treated with the same polarimetric and interferometric tools as those applied to real synthetic aperture radar images. Thus, comparisons are possible. COSMO has been widely tested from P- to L- bands, over temperate and tropical forests and applied to radiometry, polarimetry, and interferometry. It appears finally as an efficient simulating tool to carry out parametric studies and to analyze how the total scattered field is built from canonical mechanisms and individual scatterer contributions. [J1064]

"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. [J1065]

"Compensating the effects of target acceleration in dual-channel SAR-GMTI"

The authors examine the influence of uncompensated target acceleration on the focusing of moving targets in airborne synthetic aperture radar (SAR) imagery and present one method of detecting and compensating for its effects. Although vehicles travelling on roads and highways routinely experience acceleration, the majority of ground moving target indication algorithms assume a constant velocity scenario, which may result in a defocused target response. Both along-track and across-track accelerations are examined through simulations and experimental data from Environment Canada's airborne CV 580 dual-channel SAR system. Acceleration can have severe effects on focusing and may result in azimuthal shift, azimuthal smearing and a significant loss in peak power in the SAR image. Having determined the effects of acceleration, time-frequency (TF) analysis implementing the pseudo-Wigner-Ville distribution is used to improve target focusing and to detect the presence of significant acceleration. Accelerating targets in experimental airborne data are presented and are identified as such by their non-linear TF histories. Estimations of the instantaneous frequency of the signals yield reconstructed target phase histories, which may be used to identify the presence of certain acceleration components and to obtain a focused image of each target. However, estimates of a target's acceleration and velocity vector may not be uniquely determined using only two receive channels. [J1066]

"Advances in non-linear apodization"

Selected new methods and applications of non-linear apodization for irregularly-shaped and parse coherent apertures and arrays are presented. The benefits include unproved impulse response performance, i.e., reduced peak sidelobes and integrated sidelobe power, along with improved mainlobe resolution, compared to classic windowing techniques. Nonlinear apodization (NLA) techniques can also serve as powerful engines for effective superresolution and bandwidth extrapolation of coherent data for filling sparse apertures. The sparse aperture filling property of superresolution algorithms for radar data forms the basis for a new concept which is introduced here: synthetic multiple aperture radar technology (SMART). Increased swath and/or reduced antenna size are some of the benefits postulated for SMART applied to synthetic aperture radar (SAR) systems. The benefits of these new methods and applications for nonlinear apodization are then demonstrated for two specific applications: 1) sidelobe control for Y-type synthetic aperture radiometers, such as the European Soil Moisture and Ocean Salinity (SMOS) system (Kerr et al.) and JPL's proposed GeoSTAR (Lambrigsten) concept; and, 2) filling of sparse synthetic aperture radar data by exploiting the bandwidth extrapolation properties of nonlinear apodization based superresolution techniques. The methods that have been developed and demonstrated herein have potential application to a wide range of passive and active microwave remote sensing and radar systems. [J1067]

"PolInSAR analysis of X-band data over vegetated and urban areas"

This paper investigates the polarimetric and polarimetric interferometric synthetic aperture radar (PolInSAR) information contained in the high-resolution X-band data acquired by the RAMSES airborne SAR system over an area around Avignon, France containing bare surfaces, vegetation, and urban areas. The interferometric coherences are computed over natural and urban areas for all possible baseline copolar polarizations. In the complex plane, the obtained regions of coherence corresponding to most vegetation areas display small angular extents, meaning that if penetration occurs in the foliage, it is shallower than the system height accuracy. To quantify the PolInSAR information, an analysis of the interferometric height accuracy is first performed, and the results are compared with those associated with a theoretical and an empirical model. Concerning vegetation, a 6-m height difference is measured between the different polarimetric phase centers over a sparse pine forest, probably due to the presence of holes in the canopy. Crop study reveals also that wheat-type fields present oriented media properties at X-band due to their vertical structure. Over urban areas, in most cases, building height can be accurately obtained by using Pauli polarimetric phase center information. [J1068]

"Unsupervised change detection on SAR images using fuzzy hidden Markov chains"

This work deals with unsupervised change detection in temporal sets of synthetic aperture radar (SAR) images. We focus on one of the most widely used change detector in the SAR context, the so-called log-ratio. In order to deal with the classification issue, we propose to use a new fuzzy version of hidden Markov chains (HMCs), and thus to address fuzzy change detection with a statistical approach. The main characteristic of the proposed model is to simultaneously use Dirac and Lebesgue measures at the class chain level. This allows the coexistence of hard pixels (obtained with the classical HMC segmentation) and fuzzy pixels (obtained with the fuzzy measure) in the same image. The quality assessment of the proposed method is achieved with several bidate sets of simulated images, and comparisons with classical HMC are also provided. Experimental results on real European Remote Sensing 2 Precision Image (ERS-2 PRI) images confirm the effectiveness of the proposed approach. [J1069]

"Motion measurement errors and autofocus in bistatic SAR"

This paper discusses the effect of motion measurement errors (MMEs) on measured bistatic synthetic aperture radar (SAR) phase history data that has been motion compensated to the scene origin. We characterize the effect of low-frequency MMEs on bistatic SAR images, and, based on this characterization, we derive limits on the allowable MMEs to be used as system specifications. Finally, we demonstrate that proper orientation of a bistatic SAR image during the image formation process allows application of monostatic SAR autofocus algorithms in postprocessing to mitigate image defocus. [J1070]

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

{no data available} [J1071]

"Dual-speed SAR imaging of moving targets"

In conventional synthetic aperture radar (SAR) systems, the image of a moving target is usually mislocated. This is because the Doppler shift of the moving target is determined not only by its geometric location but also by its velocity. After range compression and auto-focusing, the Doppler frequency of the moving target is still time varying and the Doppler centroid is shifted. As a result, the SAR image of a moving target is smeared and the image location of the target may not reflect its true geometric location. In this paper, a dual-speed SAR imaging approach, i.e., the radar platform flies with two different speeds in the radar observation time duration, is proposed to resolve the above two problems, especially mislocation of a moving target. [J1072]

"In This Issue-Technically"

For a successful enemy maneuver, their most important action is the ability to identify, locate, and track their correct target. High-resolution imaging sensors such as the inverse synthetic aperture radar perform this action in the most effective way and are especially useful against low radar cross-section targets. Once the correct target is acquired and identified, the decision to engage is made and the weapons are selected. Counter-targeting is the attempt to prevent (or degrade) the engage-and-launch-weapons decision by the enemy. This paper describes an all-digital image synthesizer technique capable of generating realistic false-target images for counter-targeting using modern digital radio frequency memory technology. Uses in counter-lock on for coherent seekers in the terminal mode are also discussed. Examples of the output false target image capability are presented. [J1073]

"SAR-ECCM using phase-perturbed LFM chirp signals and DRFM repeat jammer penalization"

First Page of the Article [J1074]

"AMTA Corner"

{no data available} [J1075]

"SAR Minimum-Entropy Autofocus Using an Adaptive-Order Polynomial Model"

A new algorithm is presented for autofocus in synthetic aperture radar imaging. Entropy is used to measure the focus quality of the image, and better focus corresponds to smaller entropy. The phase response of the focus filter is modeled as a specially designed polynomial, and the coefficients of this polynomial are adjusted in sequence to minimize the entropy of the image. Because the order of this polynomial is adaptive, this algorithm applies more widely than the minimum-entropy algorithms with a fixed-order polynomial model [J1076]

"Supervised SAR Image MPM Segmentation Based on Region-Based Hierarchical Model"

This letter presents a novel method of supervised multiresolution segmentation for synthetic aperture radar images. The method uses a region-based half-tree hierarchical Markov random field model for multiresolution segmentation. To form the region-based multilayer model, the watershed algorithm is employed at each resolution level independently. The nodes of a quadtree in the proposed model are defined as regions instead of pixels. The relationship over scale is studied, and the region-based upward and downward maximization of posterior marginal estimations are deduced. The experimental results for the segmentation of homogeneous areas prove the region-based model much better in terms of robustness to speckle and preservation of edges compared to the pixel-based hierarchical model and the Gibbs sampler with the single-resolution model [J1077]

"An Adaptive and Iterative Method of Urban Area Extraction From SAR Images"

This letter presents a new method for unsupervised urban area extraction from synthetic aperture radar (SAR) images based on the ffmax algorithm proposed by C. Gouinaud specially for acquiring urban areas in SPOT imagery. According to the statistical characteristics of urban areas, an adaptive and iterative method based on the low-level extraction given by the ffmax algorithm using a large window is proposed. Experimental results on real SAR images show that the proposed automatic method works quickly and can preserve the borders of urban areas as well as avoid the disturbance of other classes and the extractions of urban areas are reliable and precise [J1078]

"The Exact Distribution of the Multilook Magnitude"

Gierull provides a statistical analysis of multilook synthetic aperture radar interferograms. Various expressions for the probability density function, cumulative distribution function, and the moments of associated statistics are derived. It appears, however, that most of these expressions are based on some approximation. In this letter, the corresponding expressions are derived in their exact form, including some elementary representations for certain expressions given by Gierull. A numerical comparison of the exact and approximate expressions is provided [J1079]

"In Search of the Statistical Properties of High-Resolution Polarimetric SAR Data for the Measurements of Forest Biomass Beyond the RCS Saturation Limits"

The purpose of this letter is to present the results on the study of searching effective parameters that describe the relation between high-resolution synthetic aperture radar (SAR) images and forest parameters. The study is based on the non-Gaussian texture analysis of the polarimetric airborne Pi-SAR data over coniferous forests in Hokkaido, Japan. The radar cross section (RCS) in terms of a forest biomass is first analyzed. It is found that the L-band RCS increases steadily with the biomass and saturates at approximately 40 tons/ha. These results are similar to the previous studies. The probability density function of the image amplitude is then investigated, and among Rayleigh, log-normal, Weibull, and K-distributions, the K-distribution is found to fit best to the L-band data of all polarizations, although the Weibull distribution fits equally well. Further, the correlation between the tree biomass and the order parameter of the K-distribution in the cross-polarization images is found to be very high, and the order parameter increases consistently with the biomass to approximately 100 tons/ha, which is well beyond the saturation limit of the L-band RCS. Thus, the order parameter of the K-distribution can be a promising new parameter to estimate the forest biomass from high-resolution polarimetric SAR data in a much wider range than the conventional RCS method [J1080]

"A Comment on “Homomorphic Wavelet-Based Statistical Despeckling of SAR Images”"

Explicit expressions are derived for the cumulants and the cumulant-generating function of the log-transformed radar cross section considered by Solbo and Eltoft. Some computational issues are also discussed [J1081]

"Ultra-wideband synthetic aperture radar time-frequency representation image formation"

In ultra-wideband synthetic aperture radar (UWB SAR) imaging, scatterers often perform the frequency- and aspect angle-dependent reflectivity characteristic, which is usually neglected in traditional imaging processing. A novel UWB SAR time-frequency representation image formation (TFRIF) is proposed to retrieve the frequency- and aspect angle-dependent information, which is valuable in target detection. Based on the TFRIF, two fusion schemes are studied: pixel level fusion (PLF) and decision level fusion (DLF). Based on the analytical expressions, it is concluded that TFRIF can extract the reflectivity pattern information with high precision and little sacrifice of the spatial resolutions. Quantitative analyses of spatial resolutions and detectability improvement of the proposed fusion schemes are tested on airborne UWB SAR data. The real data results validate the proposed TFRIF and its associated PLF and DLF schemes [J1082]

"The Potential of Low-Frequency SAR Systems for Mapping Ionospheric TEC Distributions"

Ionospheric propagation effects have a significant impact on the signal properties of low-frequency synthetic aperture radar (SAR) systems. Range delay, interferometric phase bias, range defocusing, and Faraday rotation are the most prominent ones. All the effects are a function of the so-called total electron content (TEC). Methods based on two-frequency global positioning system observations allow measuring TEC in the ionosphere with coarse spatial resolution only. In this letter, the potential of broadband L-band SAR systems for ionospheric TEC mapping is studied. As a basis, the dispersive nature of the ionosphere and its effects on broadband microwave radiation are theoretically derived and analyzed. It is shown that phase advance and group delay can be measured by interferometric and correlation techniques, respectively. The achievable accuracy suffices in

mapping small-scale ionospheric TEC disturbances. A differential TEC estimator that separates ionospheric from tropospheric contributions is proposed [J1083]

"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 [J1084]

"Polarimetric Analysis of Radar Signature of a Manmade Structure"

Identification of manmade structures from radar images has always been a difficult task, especially for single-polarization radar. Fully polarimetric radar, however, can provide detailed information on scattering mechanisms that could enable the target or the structure to be identified. Complexity remains stemming from overlaps of single-bounce scattering, double-bounce scattering, and triple- and higher order bounce scattering from various components of a manmade structure, which makes physical interpretation a challenge. In this letter, an interesting example using polarimetric synthetic aperture radar (PolSAR) data of the Great Belt Bridge, Denmark, was presented to illustrate the capability of PolSAR in analyzing radar signatures. Polarimetric target decomposition is used to differentiate the multiple-bounce scatterings contained in the PolSAR images. Two C-band Danish EMISAR data takes, with the first obtained during the bridge's construction and the second after its completion, are used to extract the scattering characteristics of the bridge deck, bridge cables, and supporting structures [J1085]

"Junction-aware extraction and regularization of urban road networks in high-resolution SAR images"

A general processing framework for urban road network extraction in high-resolution synthetic aperture radar images is proposed. It is based on novel multiscale detection of street candidates, followed by optimization using a Markov random field description of the road network. The latter step, in the path of recent technical literature, is enriched by the inclusion of a priori knowledge about road junctions and the automatic choice of most of the involved parameters. Advantages over existing and previous extraction and optimization procedures are proved by comparison using data from different sensors and locations [J1086]

"Generalized minimum-error thresholding for unsupervised change detection from SAR amplitude imagery"

The availability of synthetic aperture radar (SAR) data offers great potential for environmental monitoring due to the insensitiveness of SAR imagery to atmospheric and sunlight-illumination conditions. In addition, the short revisit time provided by future SAR-based missions will allow a huge amount of multitemporal SAR data to become systematically available for monitoring applications. In this paper, the problem of detecting the changes that occurred on the ground by analyzing SAR imagery is addressed by a completely unsupervised approach, i.e., by developing an automatic thresholding technique. The image-ratioing approach to SAR change detection is adopted, and the Kittler and Illingworth minimum-error thresholding algorithm is generalized to take into account the non-Gaussian distribution of the amplitude values of SAR images. In particular, a SAR-specific parametric modeling approach for the ratio image is proposed and integrated into the thresholding process. Experimental results, which confirm the accuracy of the method for real X-band SAR and spaceborne imaging radar C-band images, are presented [J1087]

"Dependence between standard deviation and measurement length for C-band backscattering signatures of the Baltic Sea ice"

This paper studies whether the standard deviation (std) of the Baltic Sea ice backscattering coefficient (sigmadeg) depends on the length of measurement (l). For many kinds of surfaces, especially for a fractal one, this is the case. The study was conducted using one-dimensional C-band helicopter-borne scatterometer data

and ENVISAT synthetic aperture radar (SAR) images. The results with both data sets indicate mostly a strong linear dependence between ln(I) and ln(std(sigmadeg)) up to a distance of at least a few kilometers. Based on the analysis of empirical and simulated data (fractal and nonfractal profiles), it seems that sea ice sigmadeg as a function of l is not completely described either by fractional Brownian motion or by a process with a single-scale autocorrelation function. Neither can the values of sigmadeg be regarded as samples from only one probability distribution. The regression coefficients describing the dependency of ln(I) versus ln(std(sigmadeg)) do not discriminate various ice types better than just mean and std of sigmadeg. However, the use of regression coefficients instead of mean and std is preferred due to their scale-invariant comparability with the results of other studies. The dependence of std(sigmadeg) on l should also be taken generally into account in the data analysis, e.g., when constructing classifiers for sea ice SAR data [J1088]

"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 [J1089]

"Azimuth fractional transformation of the fractional chirp scaling algorithm (FrCSA)"

The fractional chirp scaling algorithm (FrCSA) is based on the use of the fractional Fourier transform (FrFT) within the chirp scaling algorithm (CSA). In this paper, a closed-form expression for the azimuth FrFT of the FrCSA is mathematically derived and analyzed from the high-resolution synthetic aperture radar imaging point of view. The azimuth-FrFT expression of the FrCSA is compared to that of the classical fast Fourier transform (FFT)-based CSA. As the FFT is a special case of the generalized FrFT, the derived expression is found to be in total agreement with that of the FFT-based CSA when the transformation order is equal to unity; that is the angle of rotation is equal to pi/2 [J1090]

"High-Voltage Rectifier Diodes Used as Photoconductive Device for Microwave Pulse Generation"

Generation of unipolar and bipolar pulses by using high- and medium-voltage silicon rectifier diodes is achieved. These components are provided by the French Atomic Energy Commission (CEA). Furthermore, these devices work in the linear mode of photoconducting switches. Generation of electrical unipolar pulses with an amplitude of 10.7 kV and a full-width at half-maximum of 300 ps by using only 1.2 mJ of optical power is demonstrated. This energy value is 10-100 times less than usually published during the past decades. Furthermore, the linear mode running of these devices permits to synchronize several generators with a precision as low as 2 ps. This low timing jitter is useful for bipolar generators in order to control their spectrum with high precision, i.e., bipolar pulses of 3 kV peak-to-peak have been generated with a cycle duration of 400 ps and an optical energy of 1 mJ [J1091]

"Nonstationary Spatial Texture Estimation Applied to Adaptive Speckle Reduction of SAR Data"

This letter proposes a new model for the second-order statistics of spatial texture in synthetic aperture radar images. The autocovariance function is locally approximated by a two-dimensional anisotropic Gaussian kernel (AGK) to characterize texture by its local orientation and anisotropy. The estimation of texture parameters at a given scale is based on the gradient structure tensor operator and does not require the explicit computation of the autocovariance. Finally, a new filter called AGK minimum mean square error (MMSE) that takes into account this spatial information is introduced and compared with the refined MMSE filter. The proposed filter has better performance in terms of texture preservation and structure enhancement [J1092]

"Multiresolution MAP Despeckling of SAR Images Based on Locally Adaptive Generalized Gaussian pdf Modeling"

In this paper, a new despeckling method based on undecimated wavelet decomposition and maximum a

posteriori (MAP) estimation is proposed. Such a method relies on the assumption that the probability density function (pdf) of each wavelet coefficient is generalized Gaussian (GG). The major novelty of the proposed approach is that the parameters of the GG pdf are taken to be space-varying within each wavelet frame. Thus, they may be adjusted to spatial image context, not only to scale and orientation. Since the MAP equation to be solved is a function of the parameters of the assumed pdf model, the variance and shape factor of the GG function are derived from the theoretical moments, which depend on the moments and joint moments of the observed noisy signal and on the statistics of speckle. The solution of the MAP equation yields the MAP estimate of the wavelet coefficients of the noise-free image. The restored SAR image is synthesized from such coefficients. Experimental results, carried out on both synthetic speckled images and true SAR images, demonstrate that MAP filtering can be successfully applied to SAR images represented in the shift-invariant wavelet domain, without resorting to a logarithmic transformation [J1093]

"Radar cross-section enhancement of dihedral corner reflector using fractal-based metallo-dielectric structures"

Effective use of fractal-based metallo-dielectric structures for enhancing the radar cross-section (RCS) of dihedral corner reflectors is reported. RCS enhancement of about 30 dBsm is obtained for corner reflectors with corner angles other than 90deg. This may find application in remote sensing and synthetic aperture radar [J1094]

"The Multidimensional Phase Unwrapping Integral and Applications to Microwave Tomographical Image Reconstruction"

Spatial unwrapping of the phase component of time varying electromagnetic fields has important implications in a range of disciplines including synthetic aperture radar (SAR) interferometry, MRI, optical confocal microscopy, and microwave tomography. This paper presents a fundamental framework based on the phase unwrapping integral, especially in the complex case where phase singularities are enclosed within the closed path integral. With respect to the phase unwrapping required when utilized in Gauss-Newton iterative microwave image reconstruction, the concept of dynamic phase unwrapping is introduced where the singularity location varies as a function of the iteratively modified property distributions. Strategies for dynamic phase unwrapping in the microwave problem were developed and successfully tested in simulations and clinical experiments utilizing large, high contrast targets to validate the approach [J1095]

"A -Band FMCW Radar Front-End With Adaptive Leakage Cancellation"

Monostatic frequency modulation continuous wave radars that use one antenna to simultaneously transmit and receive can result in compact and lightweight synthetic aperture radar systems. One of the greatest challenges in designing a continuous-wave monostatic radar is realizing enough isolation between the transmitter and the receiver. A novel real-time digital signal processing scheme is proposed to cancel the transmitter leakage at the receiver front-end and to achieve high isolation. With the digital implementation, the proposed scheme shows a much more precise control of the leakage cancellation when compared to conventional analog implementations. The dc-offset problem in analog mixers that affects the cancellation performance is eliminated. A radar test bed at 26 GHz has been built and tested in several radar modes. The measurement shows a leakage suppression of more than 30 dB over a 1.7-GHz sweeping bandwidth [J1096]

"Investigation into arc-type sideband responses in SAR and ISAR imagery"

Rihaczek and Hershkowitz have proposed that radar scattering from man-made targets is dominated by cavity-type reflectors that do not meet the assumptions of point scatterer theory. The effect of such dispersive scattering is to produce spurious bright responses in the radar image that can appear as a number of peaks lying along an arc. If such arc-type responses do exist in radar imagery then their removal would enhance the ability to focus moving target imagery and to perform automatic target recognition. Rihaczek and Hershkowitz have outlined a method for identifying such arc-type responses that use the image phase. Algorithms have been written to automate the outlined procedure and used to analyse a large number of synthetic and inverse synthetic aperture radar images. Arcs are present in most radar images of static and moving ground targets. To investigate whether the arcs are due to a physical mechanism or a chance occurrence, randomised target imagery was generated and also analysed. No significant differences are seen between the distributions of arc numbers obtained from randomised and real imagery. In conclusion, the arcs present in the real imagery are likely to occur by chance, rather than because of an underlying scattering mechanism [J1097]

"Resolution of signal sources via spectral moment estimation"

In different practical situations it is desired to estimate the number of signal sources and their positions in space

or in frequency domain. The first problem is known as the detection or the order estimation and the second one as the resolution. For the resolution problem techniques such as nonlinear least squares (NLSM), high-order Yule-Walker method (HOYW), multiple signal classification (MUSIC), Pisarenko harmonic retrieval method, min-norm method, estimation of signal parameters by rotational invariance technique (ESPRIT), were proposed (Marple, 1987 and Stoica and Moses, 1997). All these high-resolution methods are based on the analysis of the signal covariance matrix. But the covariance matrix is not the only choice to represent the signal spectrum. In different applications (weather radars, synthetic aperture radar (SAR) signal processing, ultrasound imaging in medicine, atmospheric turbulence measurements) the signal spectrum can be modeled through its algebraic moments. Recently a number of efficient nonparametric methods have been proposed to estimate the algebraic spectral moments (Monakov, 1999). The presented paper is an attempt to solve the direction of arrival (DOA) problem via estimation of the algebraic spectral moments. A method proposed in the article is comparable in its accuracy with the MUSIC method. At the same time its computational burden is much lower. The method permits to estimate the signal power of sources easily to complete the full spectral line analysis. Additionally the method shows good robustness in situations when signal sources have noticeable spatial extend [J1098]

"On the Usage of GRECOSAR, an Orbital Polarimetric SAR Simulator of Complex Targets, to Vessel Classification Studies"

This paper presents a synthetic aperture radar (SAR) simulator that is able to generate polarimetric SAR (POLSAR) and polarimetric inverse SAR data of complex targets. It solves the electromagnetic problem via high-frequency approximations, such as physical optics and the physical theory of diffraction, with notable computational efficiency. In principle, any orbital monostatic sensor working at any band, resolution, and operating mode can be modeled. To make simulations more realistic, the target's bearing and speed are considered, and for the particular case of vessels, even the translational and rotational movements induced by the sea state. All these capabilities make the simulator a powerful tool for supplying large amounts of data with precise scenario information and for testing future sensor configurations. In this paper, the usefulness of the simulator on vessel classification studies is assessed. Several simulated polarimetric images are presented to analyze the potentialities of coherent target decompositions for classifying complex geometries, thus basing an operational algorithm. The limitations highlighted by the results suggest that other approaches, like POLSAR interferometry, should be explored [J1099]

"Filament Preserving Model (FPM) Segmentation Applied to SAR Sea-Ice Imagery"

Modeling spatial context constraints using a Markov random field (MRF) has been widely used in the segmentation of noisy images. Its applicability to synthetic aperture radar (SAR) sea-ice segmentation has also been demonstrated recently. However, most existing MRF models are not capable of preserving filaments, specifically leads and ridges for SAR sea ice, which are valuable for ship navigation applications and necessary for identifying certain ice types. In this paper, a new statistical context model is proposed that, within the same scene, can simultaneously preserve narrow elongated features while producing similar smooth segmentation results comparable to typical MRF-based approaches. Tested on one synthetic image and two SAR sea-ice scenes, this filament preserving model substantially improves classification accuracies when compared to standard Gaussian mixture and MRF-based segmentation algorithms [J1100]

"Separation of target rigid body and micro-doppler effects in ISAR imaging"

Micro-Doppler (m-D) effect is caused by moving parts of the radar target. It can cover rigid parts of a target and degrade the inverse synthetic aperture radar (ISAR) image. Separation of the patterns caused by stationary parts of the target from those caused by moving (rotating or vibrating) parts is the topic of this paper. Two techniques for separation of the rigid part from the rotating parts have been proposed. The first technique is based on time-frequency (TF) representation with sliding window and order statistics techniques. The first step in this technique is recognition of rigid parts in the range/cross-range plane. In the second step, reviewed TF representation and order statistics setup are employed to obtain signals caused by moving parts. The second technique can be applied in the case of very emphatic m-D effect. In the first step the rotating parts are recognized, based on the inverse Radon transform (RT). After masking these patterns, a radar image with the rigid body reflection can be obtained. The proposed methods are illustrated by examples [J1101]

"Coherence- and Amplitude-Based Analysis of Seismogenic Damage in Bam, Iran, Using ENVISAT ASAR Data"

The sensitivity of synthetic aperture radar (SAR) and interferometric SAR (InSAR) to surface properties, especially changes in height and roughness, combined with an all-weather capability, makes radar remote sensing a potential tool for mapping urban damage caused by earthquakes. With InSAR, surface displacement

has been mapped successfully and in detail, but for urban-damage mapping, results have so far been less conclusive. ENVISAT Advanced SAR images of Bam, Iran, that were acquired before and after the 2003 earthquake were used. Between preseismic and coseismic image pairs, coherence decreased with increasing damage levels. However, contrary to previous studies, earthquake damage caused both increases and decreases in amplitude. Therefore, its absolute value, which correlated with damage level, was used. Individually, coherence difference led to better results than absolute amplitude change, although still with limited accuracy. The combination of both resulted in an overall accuracy of 52%. Since vegetation causes decorrelation, a predisaster Advanced Spaceborne Thermal Emission and Reflection Radiometer image was used to mask out vegetated areas, which improved the accuracy by 4%. The ground-truth map showed damage levels per district instead of per pixel. Therefore, the ratio of pixels classified as “damage” and “nondamage” was calculated for each damage class of the map, and a clear relation was found. This shows that the aggregation level of the map partly explains the low-accuracy figures of the pixel-based evaluation. Although improvement was made, InSAR techniques for urban-damage mapping do not yet provide the accuracy levels needed for disaster mitigation. However, substantial improvements can be expected from instruments with higher spatial resolution, such as the recently launched Phased Array type L-band SAR and Terra SAR-X. [J1102]

"Radix-2 DIF fast algorithms for polynomial time-frequency transforms"

The polynomial time-frequency transform (PTFT) converts a one-dimensional polynomial-phase signal (PPS) into a multi-dimensional (MD) output array in the frequency domain from which the phase coefficients are estimated. To significantly reduce the prohibitive computational complexity to deal with high order PPSs, effective decomposition of the overall computational task is important for any practical applications. This paper derives a radix-2 decimation-in-frequency (DIF) fast algorithms for any order of the PPSs by using the periodic and symmetric properties of the PTFT. Compared with other reported fast algorithms, the proposed one is simple in concept and achieves a significant reduction of the required computational complexity [J1103]

"Synthetic aperture radar-moving target indicator processing of multi-channel airborne radar measurement data"

Coherent signal processing methods for combining the data that are collected via a multi-channel airborne radar system for moving target detection and image formation, are examined. Methods that convert multi-channel radar data into dual along-track monopulse synthetic aperture radar (SAR) signals of the radiated scene, are studied. A two-dimensional adaptive filtering method that projects the data in one synthesised SAR channel into the signal subspace of the other, is used for blind calibration of the monopulse SAR signals and generation of the moving target indication statistic. The merits of these algorithms are studied using the data from the multi-channel airborne radar measurement system that has been developed by the Air Force Research Laboratory at Rome, New York [J1104]

"Dual-band dual-polarised microstrip antenna array for SAR applications"

A novel dual-band dual-polarised microstrip antenna array for synthetic aperture radar applications with a dual-frequency ratio of about 1:3 is presented. Microstrip dipoles and square patches are used as the radiating elements at S- and X-bands, respectively. The measured bandwidth of VSWR<2 reaches 8.9% and 17% for S- and X-bands, respectively. The measured cross-polarisation levels are <-26 dB for the S-band and <-31 dB for the X-band [J1105]

"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 [J1106]

"Forest Structure Dependency of the Relation Between L-Band and Biophysical Parameters"

Biophysical parameters and L-band polarimetry synthetic aperture radar observation data were taken for 59 test

sites in Tomakomai national forest, which is located in the northern part of Japan. Correlations between the derived sigmaHH0, sigmaHV0, and sigmaVV0and the biophysical parameters are investigated and yield the following results. 1) The above-ground biomass-sigma0curves saturate above 50 tons/ha for sigmaVV0, 100 tons/ha for sigmaHH0, and over 100 tons/ha for sigmaHV0when all forest species are included in the curves. 2) The sigmaHH0-above-ground biomass curve for one forest species indicates a higher saturation level than that for the other forest species. Dependence on the forest species was absent for VV polarization and low for HV polarization. 3) A simple three-component scattering model indicates that volume scattering accounts for 80%-90% when the above-ground biomass exceeds 50 tons/ha. The surface-scattering components are up to ~20% for young stands, and the volume-scattering components are down to 70%. The origin of the dependency among the forest species was examined for the sigmaHH 0-above-ground biomass. It is concluded that a possible cause of the dependency is the different characteristics of the stands rather than forest species [J1107]

"Spatial Variability of Barrow-Area Shore-Fast Sea Ice and Its Relationships to Passive Microwave Emissivity"

Aircraft-acquired passive microwave data, laser radar height observations, RADARSAT synthetic aperture radar imagery, and in situ measurements obtained during the AMSR-Ice03 experiment are used to investigate relationships between microwave emission and ice characteristics over several space scales. The data fusion allows delineation of the shore-fast ice and pack ice in the Barrow area, AK, into several ice classes. Results show good agreement between observed and Polarimetric Scanning Radiometer (PSR)-derived snow depths over relatively smooth ice, with larger differences over ridged and rubbled ice. The PSR results are consistent with the effects on snow depth of the spatial distribution and nature of ice roughness, ridging, and other factors such as ice age. Apparent relationships exist between ice roughness and the degree of depolarization of emission at 10, 19, and 37 GHz. This depolarization would yield overestimates of total ice concentration using polarization-based algorithms, with indications of this seen when the NT-2 algorithm is applied to the PSR data. Other characteristics of the microwave data, such as effects of grounding of sea ice and large contrast between sea ice and adjacent land, are also apparent in the PSR data. Overall, the results further demonstrate the importance of macroscale ice roughness conditions such as ridging and rubbling on snow depth and microwave emissivity [J1108]

"Automatic ground target classification using forward scattering radar"

Experimental study is undertaken of the feasibility of forward scattering radar (FSR) and its application to automatic ground target classification. The radar itself, fundamental theoretical analysis, target recognition algorithm and the target's classification subsystem are introduced. For target recognition, the effect of shadow inverse synthetic aperture radar is used. The radar experimental set-up and experimentation results are discussed. For classification, a system is proposed, which extracts features from the radar measurements by using Fourier transform and principle component analysis and uses a nearest neighbour classifier. Speed estimation in FSR is also introduced. By analysing 850 experimentally obtained car signatures, the performance of the system is evaluated and the effectiveness of the system is confirmed. The limitations of the work and its future are also discussed [J1109]

"HFSWR based on synthetic impulse and aperture processing"

A novel high-frequency surface wave radar (HFSWR) has been proposed, which is based on the principles of synthetic impulse and aperture processing. It uses multiple omnidirectional transmit antennae to simultaneously transmit a set of orthogonal waveforms, and the echoed signals are received and processed by one or multiple reception arrays. Although the transmit beam pattern is omnidirectional, by proper processing, the received signal multiple equivalent directional transmit beam patterns can be simultaneously formed. The signal processing scheme to obtain equivalent directional transmit beam pattern is investigated in detail. Considerations for system parameter selection to achieve an overall best system performance are proposed and discussed. In particular, for the novel HFSWR, target range and angle estimates are coupled together due to the orthogonality of the transmitted waveforms. A necessary and sufficient condition on the transmit antenna array geometry and transmit frequencies, which ensures that target range and angle estimates are uncoupled, is presented [J1110]

"Conservative Polarimetric Scatterers and Their Role in Incorrect Extensions of the Cameron Decomposition"

The properties of conservative symmetric polarimetric scatterer scattering matrices are examined. It is shown that the unambiguous rotation angle for "conservative" symmetric polarimetric scatterers is the interval (-pi/4,+pi/4] as compared with (-pi/2,+pi/2] for nonconservative symmetric scatterers. Errors relating to the Cameron decomposition, which are recently introduced into the literature, are discussed. It is demonstrated that these

errors arise from a faulty symmetric scatterer scattering matrix distance measure. This, in turn, leads to an improper mapping of the symmetric scatterer unit disk to a hemisphere. The correct mapping of the symmetric scatterer unit disk to the symmetric scatterer unit sphere is described [J1111]

"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 [J1112]

"Bistatic Synthetic Aperture Radar Imaging: Theory, Simulations, and Validations"

A three-dimensional "full-polarized" model for arbitrary transmitter, receiver and target motions in bistatic synthetic aperture radar configurations is proposed. Qualitative validation of this model is presented through comparison with existing results and quantitative validation is obtained from proposed general analytical resolution equations. To take into account complex targets, geometric theory of diffraction based models are considered. Some numerical results are proposed in bistatic and monostatic configurations which permit to check the performance of the proposed model and to highlight the interest of the bistatic synthetic aperture radar imaging [J1113]

"Imaging Simulation of Polarimetric SAR for a Comprehensive Terrain Scene Using the Mapping and Projection Algorithm"

A novel approach to polarimetric image simulation for synthetic aperture radar (SAR) observation over comprehensive terrain scenes is developed based on mapping and projection principles. It incorporates penetrable and impenetrable objects, volumetric and surface scatterers in the imaging space with extinction, attenuation, shadowing, and multiple-scattering effects. Scattering of the vegetation canopy is modeled as a layer of random nonspherical particles by using the vector radiative transfer model, and scattering from the ground surface and building objects is calculated by using the integral equation method. As an example, polarimetric SAR images at L-band and C-band and the different spatial resolutions for a virtual terrain scene composed of tree canopies, farmland, buildings, rough land surface, hills, and rivers are simulated. The imaging simulation results demonstrate the feasibility of the mapping and projection approach and the potential utilities of SAR imaging simulation [J1114]

"High-Accuracy Urban DEM Using Permanent Scatterers"

The permanent scatterers (PS) technique is a powerful operational tool that exploits a long series of synthetic aperture radar data for monitoring ground deformations with millimeter accuracy on a high spatial density grid of pointwise targets. The technique has been applied successfully to a number of applications, from subsidence and volcano monitoring to slow-landslide detection. This paper aims to analyze and demonstrate the positioning capability of the PS technique applied to the generation of urban elevation maps. The problem of the univocal identification of the PS position (discarding pixel-dependent sidelobes, both far and near) is addressed, and an easy and efficient solution is proposed. The results obtained in the Milan site allow the appreciation of the very high quality of an urban digital elevation model retrieved with the PS technique. The ground level of the city is identified with submeter accuracy, and elevated targets, where present, reveal building profiles. The estimated city street level (ranging plusmn3m in 16times18 km2) is then compared to those obtained with the same technique using a descending parallel track and an ascending one. Furthermore, the estimated PS elevation with respect to the ground has been connected to temperature-dependent elongations of high structures [J1115]

"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 [J1116]

"Detecting scene changes using synthetic aperture Radar interferometry"

In repeat-pass interferometric synthetic aperture radar (SAR), man-made scene disturbances are commonly detected by identifying changes in the mean backscatter power of the scene or by identifying regions of low coherence. Change statistics such as the sample mean backscatter-power ratio and the sample coherence, however, are susceptible to high false-alarm rates unless the change in the mean backscatter power is large or there is sufficient contrast in scene coherence between the changed and unchanged regions of the image pair. Furthermore, as the sample mean backscatter-power ratio and sample coherence measure different properties of a SAR image pair, both change statistics need to be considered to properly characterize scene changes. In this paper, models describing the changed and unchanged regions of a scene are postulated, and the detection problem is expressed in a Bayesian hypothesis-testing framework. Forming the log-likelihood ratio gives a single sufficient statistic, encoding changes in both the coherence and the mean backscatter power, for discriminating between the unchanged- and changed-scene models. The theoretical detection performance of the change statistic is derived and shows a significant improvement over both the sample mean backscatter-power ratio and sample coherence change statistics. Finally, the superior detection performance of the log-likelihood change statistic is demonstrated using experimental data collected using the Defence Science and Technology Organisation's Ingara X-band airborne SAR [J1117]

"Polarimetric image segmentation via maximum-likelihood approximation and efficient multiphase level-sets"

This study investigates a level set method for complex polarimetric image segmentation. It consists of minimizing a functional containing an original observation term derived from maximum-likelihood approximation and a complex Wishart/Gaussian image representation and a classical boundary length prior. The minimization is carried out efficiently by a new multiphase method which embeds a simple partition constraint directly in curve evolution to guarantee a partition of the image domain from an arbitrary initial partition. Results are shown on both synthetic and real images. Quantitative performance evaluation and comparisons are also given [J1118]

"Impact of oscillator noise in bistatic and multistatic SAR"

This letter addresses the impact of limited oscillator stability in bistatic and multistatic synthetic aperture radars (SARs). Oscillator noise deserves special attention in distributed SAR systems since there is no cancellation of low-frequency phase errors as in a monostatic SAR, where the same oscillator signal is used for modulation and demodulation. It is shown that the uncompensated phase noise may cause a time-variant shift, spurious sidelobes, and a broadening of the impulse response, as well as a low-frequency phase modulation of the focused SAR signal. Quantitative estimates are derived analytically for each of these errors based on a system-theoretic model taking into account the second-order statistics of the oscillator phase noise [J1119]

"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 [J1120]

"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 [J1121]

"SAR Sensor Trajectory Deviations: Fourier Domain Formulation and Extended Scene Simulation of Raw Signal"

Synthetic aperture radar (SAR) raw signal simulation is a useful tool for SAR system design, mission planning, processing algorithm testing, and inversion algorithm design. A two-dimensional (2-D) Fourier domain SAR raw signal simulator, exploiting the efficiency of fast Fourier transform algorithms, has been presented some years ago and is able to generate the raw signal corresponding to extended scenes. However, it cannot account for the effects of sensor trajectory deviations with respect to the nominal straight-line path. This paper explores the possibility of extending the efficient Fourier domain simulation approach to the case of sensor trajectory deviations, which is more realistic for airborne SAR systems. We first of all obtain a general and compact Fourier domain formulation of the SAR raw signal in the presence of arbitrary trajectory deviations, and show that in this general case no efficient simulation scheme can be devised. However, we demonstrate that, if a narrow beam and slow trajectory deviation assumption is made, a full 2-D Fourier domain simulation can be used. This approach can be applied only to some SAR systems and/or trajectory deviations, but it has the advantage that processing time is practically not increased with respect to the nominal trajectory case. The validity limits of the approach are analytically evaluated. Some simulation results are finally presented in order to verify the effectiveness of the proposed simulation scheme. In another paper, which is the second part of this work, it will be shown that the narrow beam-slow deviation assumption can be relaxed, at the expense of computation efficiency, if a one-dimensional azimuth Fourier domain processing followed by a range time-domain integration is used [J1122]

"Integration of Radar Interferometry and Laser Scanning for Remote Monitoring of an Urban Site Built on a Sliding Slope"

The Alpine village of Lamosano, Belluno, Italy, located near a wide and active landslide, has been seriously threatened by ground instabilities since 1960. In this paper, the results obtained by two different remote-monitoring techniques, synthetic aperature radar interferometry and three-dimensional laser-scanner imaging, planned for Lamosano hazard assessment, are presented. Both techniques compare images taken at different times to map and classify changes that occurred on the imaged scenario. The radar and laser data are gathered at the same dates with about ten-month temporal separation. The displacements measured separately by each of the two techniques highlight a similar sliding motion on the Lamosano village area, providing a good validation to each other and contributing to the definition of the village instability hazard [J1123]

"SAR image filtering based on the heavy-tailed Rayleigh model"

Synthetic aperture radar (SAR) images are inherently affected by a signal dependent noise known as speckle, which is due to the radar wave coherence. In this paper, we propose a novel adaptive despeckling filter and derive a maximum a posteriori (MAP) estimator for the radar cross section (RCS). We first employ a logarithmic transformation to change the multiplicative speckle into additive noise. We model the RCS using the recently introduced heavy-tailed Rayleigh density function, which was derived based on the assumption that the real and imaginary parts of the received complex signal are best described using the alpha-stable family of distribution. We estimate model parameters from noisy observations by means of second-kind statistics theory, which relies on the Mellin transform. Finally, we compare the proposed algorithm with several classical speckle filters applied on actual SAR images. Experimental results show that the homomorphic MAP filter based on the heavy-tailed Rayleigh prior for the RCS is among the best for speckle removal [J1124]

"Effective bandwidth SF-CW SAR increase using frequency agility"

The use of a frequency-agile waveform is proposed as a way of providing significantly increased bandwidth for a stepped frequency continuous wave (SF-CW) SAR, than is provided by traditional imaging schemes. The range resolution is set by the bandwidth of the transmitted waveform, and is built up as a set of monotonically increasing stepped frequencies. As these frequencies are sampled sequentially, a constraint with SF-CW waveforms is the time restriction available to build up the bandwidth, imposed by the spatial sampling requirements along the aperture to avoid grating-lobe effects. To address this problem, an approach is outlined which allows the frequency spectrum to be greatly undersampled to provide a greater effective bandwidth. It was found that randomizing the set of frequencies omitted from sweep to sweep allowed significant thinning before the appearance of significant unwanted image artifacts due to the under-sampling. This scheme allows great flexibility in the choice of bandwidths that can be realized for a particular imaging scenario. Their application is considered from the point of view of operation from UAV SAR platforms [J1125]

"A broadband slotted ridge waveguide antenna array"

A longitudinally-slotted ridge waveguide antenna array with a compact transverse dimension is presented. To broaden the bandwidth of the array, it is separated into two subarrays fed by a novel compact convex waveguide divider. A 16-element uniform linear array at X-band was fabricated and measured to verify the validity of the design. The measured bandwidth of S11les-15 dB is 14.9% and the measured cross- polarization level is less than -36 dB over the entire bandwidth. This array can be combined with the edge-slotted waveguide array to build a two-dimensional dual-polarization antenna array for the synthetic aperture radar (SAR) application [J1126]

"Automobile-based SAR/InSAR system for ground experiments"

An automobile-based synthetic aperture radar (SAR) system named AutoSAR is described. It is an experimental SAR system operating on the ground, which was developed by the Pohang University of Science and Technology, Korea. AutoSAR can also operate as an interferometric SAR (InSAR) when one additional receiving antenna is used. The swath of AutoSAR is less than 1 km, and the azimuthal coverage is limited only by the storage capacity of the system. SAR and InSAR images obtained at a test site near Pohang, Korea, are presented. Being on an automobile, this system can easily obtain SAR data of any target area with a straight road nearby [J1127]

"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 [J1128]

"Dual-polarized SAR and Stokes parameters"

For a given transmission polarization, the four-element Stokes vector captures all of the information inherent to the dual-polarized backscattered signals. Stokes parameters are linear combinations of the like-polarized power, the cross-polarized power, and the cross product between the complex image amplitudes in the two receive channels. Most so-called dual-polarized synthetic aperture radar (SAR) systems provide only the like- and cross-product images, ignoring the cross product. In so doing, potentially valuable information is thrown away. For most dual-polarized SARs, data sufficient to generate the Stokes parameters can be generated with small marginal cost. A practical and sufficient output data format would be a mapping of the (complex) cross product between the two channels, as well as their respective images [J1129]

"A four-component decomposition of POLSAR images based on the coherency matrix"

A four-component decomposition scheme of the coherency matrix is presented here for the analysis of polarimetric synthetic aperture radar (SAR) images. The coherency matrix is used to deal with nonreflection symmetric scattering case, which is an extension of covariance matrix approach. The same decomposition results have been obtained. The advantage of this approach is explicit expressions of four scattering powers in terms of scattering matrix elements, which serve the interpretation of polarimetric SAR data quantitatively [J1130]

"Synthetic aperture radar imaging using a unique approach to frequency-modulated continuous-wave radar design"

Synthetic-aperture-radar (SAR) imaging is an expensive endeavor. It can be difficult for universities, small business, or individuals to experiment with SAR imaging and algorithm development on a low budget. For this reason, a uniquely inexpensive solution to frequency-modulated continuous-wave (FMCW) radar was developed and then utilized as an ultra-low-cost SAR imaging system. This unique approach to FMCW radar used a pair of low-cost Gunn-oscillator-based microwave transceiver modules, known as "Gunnplexers." These transceiver modules had stability and noise problems, causing them to be unsuitable for use in precise FMCW radar applications when just one module was used. In order to overcome this problem, a unique radar solution was developed that used a combination of two transceiver modules to create a precise and inexpensive FMCW radar system, capable of producing SAR imagery on a budget [J1131]

"Extended wavenumber-domain synthetic aperture radar focusing with integrated motion compensation"

First Page of the Article [J1132]

"Edge effects on tree height retrieval using X-band interferometry"

This letter investigates the edge effects on the tree height retrieval over coniferous plantations using X-band interferometry. A coherent version of the water cloud model is used to evaluate the influence of observation conditions such as incidence angle, tree height, and slope, each of which affects the extent of areas affected by edge effects. Results from the model simulation are discussed in the context of actual X-band data over pine plantations. A generic expression to indicate the extent of edge effects is described [J1133]

"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 [J1134]

"Improving urban road extraction in high-resolution images exploiting directional filtering, perceptual grouping, and simple topological concepts"

In this letter, the problem of detecting urban road networks from high-resolution optical/synthetic aperture radar (SAR) images is addressed. To this end, this letter exploits a priori knowledge about road direction distribution in urban areas. In particular, this letter presents an adaptive filtering procedure able to capture the predominant directions of these roads and enhance the extraction results. After road element extraction, to both discard redundant segments and avoid gaps, a special perceptual grouping algorithm is devised, exploiting colinearity as well as proximity concepts. Finally, the road network topology is considered, checking for road intersections and regularizing the overall patterns using these focal points. The proposed procedure was tested on a pair of very high resolution images, one from an optical sensor and one from a SAR sensor. The experiments show an increase in both the completeness and the quality indexes for the extracted road network [J1135]

"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 [J1136]

"Automatic identification of the number and values of decision thresholds in the log-ratio image for change detection in SAR images"

In this letter, we propose an extension of an automatic and unsupervised change-detection method for synthetic aperture radar images we presented earlier. By analyzing a properly defined cost function, the proposed method allows the automatic detection of the number (zero, one, or two) and the values of the decision thresholds associated with changes (if any) in the log-ratio image. This cost function is the minimum value of the criterion function adopted to select the decision threshold in the log-ratio image according to a modified double-thresholding Kittler-Illingworth algorithm (implemented under the generalized Gaussian assumption for changed and unchanged classes). Experimental results carried out both on real and simulated multitemporal synthetic aperture radar images proved the effectiveness of the proposed automatic method in detecting both the number of changes to be identified (the situation of no changes is also explicitly identified) and the related threshold values [J1137]

"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 [J1138]

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{no data available} [J1140]

"Integrated beam synthesis and performance analysis of a spaceborne SAR antenna"

A set of tools to accomplish beam synthesis for synthetic-aperture radar antennas is presented. The synthesis process optimizing the beam properties is guided by criteria of the radar performance in terms of range ambiguities and noise-equivalent backscattering coefficient. The tools implemented with MATLABP are validated with examples of beams generated by RADARSAT [J1141]

"Reply to Comments on “Compact Polarimetry Based on Symmetry Properties of Geophysical Media: The Mode”"

For original paper see Souyris et al., ibid., vol.43, no.3, p.634 (2005) and for comment see Weizu Xiong, ibid., vol.44, no.9, p.2617 (2006). In their paper Souyris et al. discussed the pi/4 mode of polarimetric SAR. In the comment Weizu Xiong felt that the calibration model used by Souyris et al. could be wrong and derived a calibration model using polar theory. Souyris responds to these remarks [J1142]

"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 [J1143]

"Late-Season Rural Land-Cover Estimation With Polarimetric-SAR Intensity Pixel Blocks and -Tree-Structured Near-Neighbor Classifiers"

Synthetic aperture radar (SAR) image classification for late-season rural land-cover estimation is investigated. A novel tree-structured nearest neighbor-like classifier is applied to polarimetric SAR intensity image pixel blocks. The novel tree structure, called a sigma-tree, is generated by an ordered summation of unweighted template refinements. Computation and memory costs of a sigma-tree classifier grow linearly. The reduced costs of sigma-tree classifiers are obtained with the tradeoff of a guarantee of nearest neighbor mappings. Causal-anticausal refinement-template design methods, combined with causal multiple-stage search engine structures, are shown to yield sequential search decisions that are acceptably near-neighbor mappings. The performance of a sigma-tree classifier is demonstrated for rural land-cover estimation with detected polarimetric C-band AirSAR pixel data. Experiments are conducted on various polarization/pixel block size combinations to evaluate the relative utility of spatial-only, polarimetric-only, and combined spatial/polarimetric classifier inputs [J1144]

"Comments on “Compact Polarimetry Based on Symmetry Properties of Geophysical Media: The Mode”"

For original paper see Souyris et al., ibid., vol.43, no.3, p.634 (2005). In their paper Souyris et al. discussed the pi/4 mode of polarimetric SAR. Weizu Xiong feels that the calibration model used by Souyris et al. may be wrong and derives a calibration model using polar theory [J1145]

"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 [J1146]

"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 [J1147]

"Efficient simulation of airborne SAR raw data of extended scenes"

In a previous paper, a two-dimensional Fourier domain synthetic aperture radar (SAR) raw signal simulator that exploits the efficiency of fast Fourier transform algorithms was presented. It accounts for the effects of sensor trajectory deviations and is able to generate the raw signal corresponding to extended scenes in a few seconds. However, a narrow-beam-slow-deviation assumption is made; hence, the approach can be applied only to some SAR systems and/or trajectory deviations. To overcome this limitation, in this paper, we show that the narrow-beam-slow-deviation assumption can be relaxed, at the expense of computation efficiency, if use is made of one-dimensional azimuth Fourier domain processing followed by range time-domain integration. The latter approach only requires some reasonable assumptions on the sensor motion and on the SAR system features; hence, it can be used for airborne SAR systems, and turns out to be still much more efficient than the time-domain one; hence, extended scenes can still be considered. Validity limits of the approach are also analytically evaluated, and several simulation results are finally presented to verify the effectiveness of the proposed simulation scheme [J1148]

"Enhanced Simulation of Radar Backscatter From Forests Using LiDAR and Optical Data"

Focusing on a forest dominated by Poplar Box (Eucalyptus populnea) near Injune in Queensland, Australia, light detection and ranging (LiDAR) and optical remote sensing data are integrated with tree- and stand-level information to parameterize a coherent L-band synthetic aperture radar (SAR) imaging simulation that models microwave penetration and interaction with the canopy, understory, and ground. The approach used LiDAR data to generate a three-dimensional representation of the distribution of tree components (leaves and small branches) by species (based on 1-m3voxels) and the ground surface. Tree trunks were mapped across a 7.5-ha forest stand using a LiDAR-derived height-scaled crown openness index. Primary and secondary branches were modeled as tapering cylinders and linked the canopy voxels to the LiDAR trunks. The dimensions of vegetation and soil components and their geometric and dielectric properties required by the model were calibrated with field-based measurements. Visual and numerical comparison between NASA JPL Airborne SAR data and the model simulation suggests the effective modeling of SAR imagery at L-band. The study provides a proof-of-concept approach for integrating LiDAR data in the parameterization of coherent SAR simulation models, and the model presents options for better understanding of the information content of SAR data in real forest situations [J1149]

"Bistatic SAR Processing and Experiments"

Bistatic synthetic aperture radar (SAR) uses a separated transmitter and receiver flying on different platforms to achieve benefits like exploitation of additional information contained in the bistatic reflectivity of targets, reduced vulnerability for military applications, forward-looking SAR imaging, or increased radar cross section. Besides technical problems such as synchronization of the oscillators, involved adjustment of transmit pulse versus receive gate timing, antenna pointing, flight coordination, and motion compensation, the development of a bistatic focusing algorithm is still in progress and not sufficiently solved. As a step to a numerically efficient processor, this paper presents a bistatic range migration algorithm for the translationally invariant case, where transmitter and receiver have equal velocity vectors. In this paper, the algorithm was successfully applied to simulated and real bistatic data. The real bistatic data have been acquired with the Forschungsgesellschaft fur Angewandte Naturwissenschaften (FGAN)'s X-band SAR systems, namely the Airborne Experimental Radar II and the Phased Array Multifunctional Imaging Radar, in October 2003 [J1150]

"Focusing of General Bistatic SAR Configuration Data With 2-D Inverse Scaled FFT"

This paper presents a bistatic focusing solution for the general case, when transmitter and receiver trajectories move along nonparallel trajectories with different velocities. The approach in this paper is based on the point target reference spectrum for an arbitrary bistatic configuration, derived from our previous publications. Based on various simulations, the validity of the formula for both airborne and spaceborne configurations is demonstrated. Focusing for special bistatic azimuth time-invariant configurations, "tandem" and "translationally invariant" constellations are accomplished. All focusing algorithms have been developed in an interactive data language and verified with adequate simulation results. The bistatic algorithm was further successfully applied to real bistatic data acquired by the German Research Establishment for Applied Natural Sciences' PAMIR and AER-II synthetic aperture radar systems. Processing in the general case turns out to be additionally truly azimuth time variant. It is solved by implementing a novel two-dimensional inverse-scaled fast Fourier transform algorithm [J1151]

"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 [J1152]

"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 [J1153]

"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 [J1154]

"Two-Dimensional Variation Algorithm for Fractal Analysis of Sea SAR Images"

This paper proposes a novel algorithm for estimating the fractal dimension of sea synthetic aperture radar (SAR) images. The algorithm is based on the variation method, and it is suitably designed for the analysis of sea SAR images. The SAR image fractal dimension is a feature that provides a measure of the image roughness. Such a feature can play an important role in the classification process for recognizing the presence of anomalies on the sea surface. The innovation aspects of this paper are listed as follows: (1) an extension of the variation method, which was proposed for the fractal analysis of one-dimensional signals, to the case of two-dimensional (2-D) functions; (2) a numerical formulation of the variation method, which is suitable for processing 2-D discrete signals; and (3) an optimization of the algorithm for sea SAR image analysis. The algorithm is tested and validated both on simulated and real ERS-1/2 Precision Image sea SAR images and compared with the classical estimation algorithm based on spectral analysis [J1155]

"High resolutio ISAR imaging of high speed moving targets"

Range-Doppler (RD) algorithms are idely used i inverse synthetic aperture radar (ISAR) imaging. I the standard RD algorithm, envelope alignment and autofocus are first applied to transform the original data into equivalent turntable target data, and the FFT is used for the image formation. Usually, the migratio through resolution cells (MTRCs) due to target rotatio is ignored. ith the improvement of resolutio or the increase of target size, MTRCs cannot be ignored and must be mitigated. For high speed moving targets, the most idely used 'stop-and-go' data model is violated. I this case, the mitigation of MTRCs becomes eve more complicated. I the paper, technical issues associated ith high resolutio ISAR imaging of high speed moving targets are addressed. A preprocessing algorithm is first proposed to convert the non-coherent ra ISAR data into coherent data, the a keystone formatting algorithm developed for the imaging of slo ground moving targets i SAR is applied to mitigate the MTRCs o ing to rotational motion, and, finally, a high resolutio time-frequency analysis based range-instantaneous Doppler (RID) algorithm is used to produce the focused ISAR image. Numerical examples are provided to illustrate the performance of the proposed approach. [J1156]

"Efficient classification of ISAR images"

In this paper, we propose a method to classify inverse synthetic aperture radar images from different targets. Our approach can provide efficient features for classification by the combined use of a polar mapping procedure and a well-designed classifier. The resulting feature vectors are able to meet the requirements that efficient features should have: invariance with respect to rotation and scale, small dimensionality, as well as highly discriminative information. Typical experimental examples of the proposed method are provided and discussed. [J1157]

"Evolutionary feature synthesis for object recognition"

Features represent the characteristics of objects and selecting or synthesizing effective composite features are the key to the performance of object recognition. In this paper, we propose a coevolutionary genetic programming (CGP) approach to learn composite features for object recognition. The knowledge about the problem domain is incorporated in primitive features that are used in the synthesis of composite features by CGP using domain-independent primitive operators. The motivation for using CGP is to overcome the limitations of human experts who consider only a small number of conventional combinations of primitive features during synthesis. CGP, on the other hand, can try a very large number of unconventional combinations and these unconventional combinations yield exceptionally good results in some cases. Our experimental results with real synthetic aperture radar (SAR) images show that CGP can discover good composite features to distinguish objects from clutter and to distinguish among objects belonging to several classes. The comparison with other classical classification algorithms is favorable to the CGP-based approach proposed in this paper. [J1158]

"High resolutio spaceborne INSAR simulatio ith extended scenes"

The inverse-EETF4 (extended exact transfer functio 4th order) is used to simulate ra data and a complete INSAR processing chai for high squint has bee developed. Phase differences for a spaceborne INSAR geometry are estimated and used as input to the inverse-EETF4 and the the [J1159]

"Visual learning by coevolutionary feature synthesis"

In this paper, a novel genetically inspired visual learning method is proposed. Given the training raster images, this general approach induces a sophisticated feature-based recognition system. It employs the paradigm of cooperative coevolution to handle the computational difficulty of this task. To represent the feature extraction agents, the linear genetic programming is used. The paper describes the learning algorithm and provides a firm rationale for its design. Different architectures of recognition systems are considered that employ the proposed feature synthesis method. An extensive experimental evaluation on the demanding real-world task of object recognition in synthetic aperture radar (SAR) imagery shows the ability of the proposed approach to attain high recognition performance in different operating conditions. [J1160]

"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. [J1161]

"Measurement of river surface currents with coherent microwave systems"

River surface currents have been measured using coherent microwave systems from a bridge, a cableway, several riverbanks, a helicopter, and an airplane. In most cases, the microwave measurements have been compared with conventional measurements of near-surface currents and found to be accurate to within about 10 cm/s. In all cases, the basis for the microwave measurement of surface current is the Doppler shift induced in the signal backscattered from the rough water surface. In this paper, we outline the principles of the measurements and the various implementations that have been used to make microwave measurements of surface currents. Continuous-wave (CW) microwave systems have been used from a bridge to make long-term measurements of surface currents; these are compared with current-meter measurements and with time series of stage. A compact CW system has been developed and used on a cableway to measure surface currents at various distances across a river; these measurements have been compared with acoustic ones. Pulsed Doppler radars have been used to measure river surface currents from a riverbank, a helicopter, and an airplane. In the

first two cases, comparisons with both current-meter and acoustic measurements have been made. We suggest that the CW system would be preferable to the pulsed Doppler radar to make such measurements from helicopters in the future. Finally, we consider the implications of our experiments for the measurement of surface currents from aircraft or satellites using interferometric synthetic aperture radars (INSARs). We find that a combination along-track, cross-track INSAR is necessary but that significant limitations are inherent in the technique. [J1162]

"Object detection via feature synthesis using MDL-based genetic programming"

In this paper, we use genetic programming (GP) to synthesize composite operators and composite features from combinations of primitive operations and primitive features for object detection. The motivation for using GP is to overcome the human experts' limitations of focusing only on conventional combinations of primitive image processing operations in the feature synthesis. GP attempts many unconventional combinations that in some cases yield exceptionally good results. To improve the efficiency of GP and prevent its well-known code bloat problem without imposing severe restriction on the GP search, we design a new fitness function based on minimum description length principle to incorporate both the pixel labeling error and the size of a composite operator into the fitness evaluation process. To further improve the efficiency of GP, smart crossover, smart mutation and a public library ideas are incorporated to identify and keep the effective components of composite operators. Our experiments, which are performed on selected training regions of a training image to reduce the training time, show that compared to normal GP, our GP algorithm finds effective composite operators more quickly and the learned composite operators can be applied to the whole training image and other similar testing images. Also, compared to a traditional region-of-interest extraction algorithm, the composite operators learned by GP are more effective and efficient for object detection. [J1163]

"Modified wavefront reconstruction imaging formation for stand-off GPEN SAR"

A modified wavefront reconstruction algorithm (MWRA) is proposed for imaging a subsurface layer for a vehicle- or air-borne SAR. The MWRA with refraction and dispersive effect compensation can improve image quality and locating accuracy compared with the traditional one. Associated with the relax-based depth estimation method, the MWRA can provide 3D location information of multiple buried targets. Some simulated results show the effectiveness of the modified algorithm. [J1164]

"An optimal determination of variable antenna height and power for in-orbit SAR operations"

An optimal power and antenna height determination over a wide range of incidence angles is proposed for in-orbit operations of the spaceborne stripmap synthetic aperture radar (SAR) with variable antenna height and variable radiating element power. The antenna height and the average transmitted radio-frequency power of a radiating element for each incidence angle are determined so that the mapping area can be maximized with the constraints on the signal-to-noise ratio, ambiguities, and swath width, given the SAR geometry (an altitude and incidence angles) and radar wavelength. With the receive-chain power consumption of one transmit/receive module (Pr=10 mW) and the SAR instrument power consumption without the phased array antenna (PI=5 W), the illustrative design example shows that the mapping area of the proposed SAR for the maximum incidence angle ($\eta max=75°$) is about 269.1% of that resulted from utilizing only the variable antenna height. The proposed optimization would have a more beneficial effect on applications that need the high-incidence-angle operations. [J1165]

"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. [J1166]

"Characterization and quantification of data voids in the shuttle Radar topography mission data"

The goal of this study was to characterize and quantify the occurrence of data voids in data from the Shuttle Radar Topography Mission (SRTM) for the conterminous United States. For this purpose, SRTM data and corresponding data from the national elevation data were downloaded in 21 samples spatially organized to cover the main topography of the U.S. Void locations in SRTM data were compared to terrain attributes and subsequently the area of individual data voids to the same attributes. It was found that data voids amounted to 0.3% of the total dataset. Data voids were found in all topographic settings but more often in slopes steeper than approximately 20° that face south (170°), and also in flat areas such as lakes and rivers. It was also found that more than 50% of all data voids were composed of connected pixels in groups less than six pixels. The largest data voids could be attributed to water bodies, while the rest could be explained by terrain-radar interaction characteristics. [J1167]

"The negative alpha filter: a new Processing technique for polarimetric SAR interferometry"

In this letter we develop a new concept, the negative alpha filter, which we suggest has application for quantitative estimation of surface parameters beneath vegetation using polarimetric synthetic aperture radar (SAR) interferometry (POLInSAR). We first derive the filter and then validate it using simulations of L-band coherent forest scattering. We then show initial results of applying the filter to airborne data from the German Aerospace Center's E-SAR L-band sensor. [J1168]

"Topography-dependent motion compensation for repeat-pass interferometric SAR systems"

This letter presents a new motion compensation algorithm to process airborne interferometric repeat-pass synthetic aperture radar (SAR) data. It accommodates topography variations during SAR data processing, using an external digital elevation model. The proposed approach avoids phase artifacts, azimuth coregistration errors, and impulse response degradation, which usually appear due to the assumption of a constant reference height during motion compensation. It accurately modifies phase history of all targets before azimuth compression, resulting in an enhanced image quality. Airborne L-band repeat-pass interferometric data of the German Aerospace Center experimental airborne SAR (E-SAR) is used to validate the algorithm. [J1169]

"Statistical resolution limits and the complexified Cramer'r-Rao bound"

Array resolution limits and accuracy bounds on the multitude of signal parameters (e.g., azimuth, elevation, Doppler, range, cross-range, depth, frequency, chirp, polarization, amplitude, phase, etc.) estimated by array processing algorithms are essential tools in the evaluation of system performance. The case in which the complex amplitudes of the signals are unknown is of particular practical interest. A computationally efficient formulation of these bounds (from the perspective of derivations and analysis) is presented for the case of deterministic and unknown signal amplitudes. A new derivation is given using the unknown complex signal parameters and their complex conjugates. The new formula is readily applicable to obtaining either symbolic or numerical solutions to estimation bounds for a very wide class of problems encountered in adaptive sensor array processing. This formula is shown to yield several of the standard Cramer'r-Rao results for array processing, along with new results of fundamental interest. Specifically, a new closed-form expression for the statistical resolution limit of an aperture for any asymptotically unbiased superresolution algorithm (e.g., MUSIC, ESPRIT) is provided. The statistical resolution limit is defined as the source separation that equals its own Cramer'r-Rao bound, providing an algorithm-independent bound on the resolution of any high-resolution method. It is shown that the statistical resolution limit of an array or coherent integration window is about 1.2·SNR-14/ relative to the Fourier resolution limit of 2pi/N radians (large number N of array elements). That is, the highest achievable resolution is proportional to the reciprocal of the fourth root of the signal-to-noise ratio (SNR), in contrast to the square-root (SNR-12/) dependence of standard accuracy bounds. These theoretical results are consistent with previously published bounds for specific superresolution algorithms derived by other methods. It is also shown that the potential resolution improvement obtained by separating two collinear arrays (synthetic ultra-wideband), each with a fixed aperture B wavelengths by M wavelengths (assumed large), is approximately (M/B)12/, in contrast to the resolution improv- ement of M/B for a full aperture. Exact closed-form results for these problems with their asymptotic approximations are presented. [J1170]

"Two-look roll compensation for aircraft-borne interferometric SAR without phase unwrapping"

The two-look method for data-driven roll compensation of aircraft-borne interferometric synthetic aperture radar (SAR) is useful for platforms such as unmanned aerial vehicles lacking accurate inertial navigation units due to limitations on weight or cost. The accuracy of this method can be improved by an iterative implementation in which residual roll errors are removed progressively on each pass. However, phase unwrapping is required, which is inconvenient and difficult to automate. Proposed is an efficient method for eliminating phase unwrapping, facilitating an automatic iterative implementation. [J1171]

"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. [J1172]

"Landcover classification in MRF context using Dempster-Shafer fusion for multisensor imagery"

This work deals with multisensor data fusion to obtain landcover classification. The role of feature-level fusion using the Dempster-Shafer rule and that of data-level fusion in the MRF context is studied in this paper to obtain an optimally segmented image. Subsequently, segments are validated and classification accuracy for the test data is evaluated. Two examples of data fusion of optical images and a synthetic aperture radar image are presented, each set having been acquired on different dates. Classification accuracies of the technique proposed are compared with those of some recent techniques in literature for the same image data. [J1173]

"Open water detection from Baltic Sea ice Radarsat-1 SAR imagery"

An algorithm for open water and sea ice discrimination for Radarsat-1 ScanSAR images is presented. The algorithm is based on segmentation and local synthetic aperture radar signal intensity autocorrelation. The algorithm performance is evaluated by comparing the results to operational digitized ice charts, in which the sea ice information is based on human interpretation of multiple data sources, including remote sensing data. The algorithm locates the open water of the digitized ice charts with about 90% accuracy. [J1174]

"Integration of optical and radar classifications for mapping pasture type in Western Australia"

In this study, independent classifications of Landsat Thematic Mapper imagery and Jet Propulsion Laboratory AirSAR were combined to create an integrated classification of pasture and other vegetation types for a study area in the agricultural zone of Western Australia. The resulting classification combines greenness and brightness information from optical data with structure and water content information from synthetic aperture radar (SAR). Field observations of vegetation type, botanical composition, ground cover percentage, wet and dry biomass, canopy height, and soil water content were collected at 34 sites representing a range of pastures, browse shrubs, and crops. An unsupervised version of the Complex Wishart classification procedure, based on preserving scattering characteristics from the Freeman and Durden backscatter decomposition, was applied to the C-, L-, and P-band polarimetric SAR data. The optical classification was carried out using a principle component analysis on the green, red, and near-infrared bands and clustering on the basis of a class centroid distance measure and knowledge of ground targets. These two classification results were then fused together. Assessment of a confusion matrix using the individual sites showed that identification of more uniform, dense, and structurally distinct canopies was better than that of more diverse, sparse, and structurally ambiguous canopies, as the former were better represented by the canopy height attribute used in the SAR classification component. The optical classification enabled correction of SAR misclassification of vegetation due to surface roughness and soil moisture effects, or similar backscatter responses from herbaceous or arboreal canopies. The results show that simplification of vegetation into groups based upon properties with sensitive responses in both the optical and SAR domains, and combination of separate SAR and optical classifications, has potential for improving classification of diverse and heterogeneous herbaceous and browse cover in grazing lands. However, collection of ground calibration data must be at an appropriate spatial scale and include canopy and surface measurements directly related to backscatter mechanisms and spectral sensitivity. [J1175]

"Signal detectability in SS-BSAR with GNSS non-cooperative transmitter"

Power budget analysis is considered for signal detection in bistatic synthetic aperture radar, with global navigation satellite systems acting as non-cooperative transmitters. The signal detection is analysed against thermal noise, in addition to interference introduced by the transmitting satellites sharing the same frequency bands. Two basic radar receiver configurations are considered: on an aeroplane; stationary on the ground. [J1176]

"On merging high- and low-resolution DEMs from TOPSAR and SRTM using a prediction-error filter"

High-resolution digital elevation models (DEMs) are often limited in spatial coverage; they also may possess systematic artifacts when compared to comprehensive low-resolution maps. Here we correct artifacts and interpolate regions of missing data in airborne Topographic Synthetic Aperture Radar (TOPSAR) DEMs using a low-resolution Shuttle Radar Topography Mission (SRTM) DEM. We use a prediction error (PE) filter to interpolate and fill missing data so that the interpolated regions have the same spectral content as the valid regions of the TOPSAR DEM. The SRTM DEM is used as an additional constraint in the interpolation. We use cross-validation methods to obtain the optimal weighting for the PE filter and SRTM DEM constraints. [J1177]

"Pol-InSAR observations from an Alpine glacier in the cold infiltration zone at L- and P-band"

In the frame of the Swiss Alpine Airborne SAR Experiment 2003 (SASARE), multitemporal/multibaseline polarimetric synthetic aperture radar (SAR) interferometry (Pol-InSAR) datasets were acquired with the German Experimental SAR (E-SAR) platform at L- and P-band in the region of the Aletsch glacier in Switzerland. For SASARE, several sub-test-sites had been selected below and significantly above the equilibrium line. We provide results from the analysis of the multibaseline Pol-InSAR L- and P-band measurements of the polarization-dependent complex interferometric coherence of an Alpine glacier in the cold infiltration zone. Interferometric volume decorrelation is demonstrated as a function of polarization. Conventional polarimetric decomposition techniques confirm the polarization-dependent backscattering properties of the analyzed snow and ice surfaces. [J1178]

"Slicks detection on the sea surface based upon polarimetric SAR data"

This letter proposes a generalized-likelihood ratio test-based edge detector to be fed by possibly polarimetric synthetic aperture radar (SAR) data. It can be used to detect dark spots on the sea surface and, hence, as the first stage of a system for identification and monitoring of oil spills. The proposed constant false alarm rate (CFAR) detector does not require secondary data (namely pixels from a slick-free area); remarkably, a preliminary performance assessment, carried out by resorting to real SAR recordings, shows that it guarantees detection capabilities comparable to those of previously proposed polarimetric CFAR detectors (which though make use of secondary data). The preliminary performance assessment also seems to indicate that processing polarimetric data does not ensure improved detection capabilities. [J1179]

"Building characterization using L-band polarimetric interferometric SAR data"

This letter proposes a building characterization technique for L-band polarimetric interferometric synthetic aperture radar (SAR) data. This characterization consists of building identification and height estimation. Initially, a polarimetric interferometric segmentation is performed to isolate buildings from their surroundings. This classification identifies three basic categories: single bounce, double bounce, and volume diffusion. In order to compensate for the misclassifications among the volume and the double-bounce classes, interferometric phases given by the high-resolution Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) method are analyzed. Once buildings are localized, a phase-to-height procedure is applied to retrieve building height information. The method is validated using E-SAR, German Aerospace Center (DLR) fully polarimetric SAR data, at L-band, repeat-pass mode, over the Oberpfaffenhofen, Germany, test site, with a spatial resolution of 1.5 m in range and azimuth. More than 80% of buildings are retrieved with acceptably accurate height estimates. [J1180]

"Suppressing coherent noise in radar applications with long dwell times"

A method for suppressing internally produced coherent noise in radar applications is presented and experimentally demonstrated. The technique enhances conventional coherent averaging and involves interpulse phase modulation that is introduced digitally in the transmit waveform and removed digitally following digitization in the receiver. Experimental demonstration of this concept resulted in an additional noise floor reduction of 15 to 20 dB (compared to the conventional coherent averaging alone) when the number of coherent averages was between 1000 to 100 000, beyond which no significant suppression was observed. [J1181]

"Coherence optimization using the polarization state conformation in PolInSAR"

A new coherence optimization algorithm is proposed for polarimetric synthetic aperture radar (SAR) interferometry applications by using the polarization state conformation algorithm based on the polarimetric basis transformation along with the polarization signatures. Through application of this algorithm, the resemblance between the scattering mechanisms of the same target in the repeat-pass polarimetric SAR (POLSAR) images is

maximized. Then, coherence maps between the repeat-pass POLSAR images, before and after application of the algorithm, are generated. The coherences obtained by this method represent the best coherences or optimized coherences between the POLSAR images. The effects predicted by the theory are confirmed by the POLSAR data acquired by the Jet Propulsion Laboratory Spaceborne Imaging Radar mission. [J1182]

"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. [J1183]

"A new wind vector algorithm for C-band SAR"

Ocean wind speed and wind direction are estimated simultaneously using the normalized radar cross sections σ0corresponding to two neighboring (25-km) blocks, within a given synthetic aperture radar (SAR) image, having slightly different incidence angles. This method is motivated by the methodology used for scatterometer data. The wind direction ambiguity is removed by using the direction closest to that given by a buoy or some other source of information. We demonstrate this method with 11 ENVISAT Advanced SAR sensor images of the Gulf of Mexico and coastal waters of the North Atlantic. Estimated wind vectors are compared with wind measurements from buoys and scatterometer data. We show that this method can surpass other methods in some cases, even those with insufficient visible wind-induced streaks in the SAR images, to extract wind vectors. [J1184]

"On the utility of SeaWinds/QuikSCAT data for the estimation of the thermodynamic state of first-year sea ice"

The thermodynamic state of sea ice is important to accurately and remotely monitor in order to provide improved geophysical variable parameterizations in sea ice thermodynamic models. Operationally, monitoring the thermodynamic state of sea ice can facilitate eased ship navigation routing. SeaWinds/QuikSCAT (QuikSCAT) dual-polarization [i.e., horizontal (HH) and vertical (VV)] active microwave data are available at a sufficiently large spatial scale and high temporal resolution to provide estimates of sea ice thermodynamics. This analysis evaluated the temporal evolution of the backscatter coefficient (σ°) and VV/HH copolarization ratio from QuikSCAT for estimating sea ice thermodynamics. QuikSCAT estimates were compared against RADARSAT-1 synthetic aperture radar (SAR) imagery and the Canadian Ice Service (CIS) prototype operational ice strength algorithm. In situ data from the Collaborative Interdisciplinary Cryospheric Experiment (C-ICE) for 2000, 2001, and 2002 were used as validation. Results indicate that the temporal evolution of σ° from QuikSCAT is analogous to RADARSAT-1. The QuikSCAT σ° temporal evolution has the ability to identify winter, snow melt, and ponding thermodynamic states. Moreover, the copolarization VV/HH ratio of QuikSCAT could provide a second estimate of the ponding state in addition to identifying the drainage state that is difficult to detect by single-polarization SAR. QuikSCAT detected thermodynamic states that were found to be in reasonable agreement to that of in situ observations at the C-ICE camp for all years. Operational implications of this analysis suggest QuikSCAT is a more effective and efficient medium for monitoring ice decay compared to RADARSAT-1 and can be utilized to provide more robust modeled ice strength thresholds. [J1185]

"Antoine roederer awarded doctorate honoris causa"

First Page of the Article [J1186]

"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. [J1187]

"Adaptive inverse synthetic aperture radar imaging for nonuniformly moving targets"

A novel adaptive inverse synthetic aperture radar (ISAR) imaging technique is proposed for targets with nonuniform motion. The proposed algorithm is referred to as the generalized range-Doppler (GRD) ISAR imaging technique and is based on the fractional Fourier transform (FRFT). By utilizing this technique, clear ISAR imaging can be achieved for nonuniformly moving targets without involvement of complex motion compensation. Simulation results have proved that the new algorithm is robust and also computationally efficient as compared with previously reported algorithms such as joint time-frequency (JTF) imaging. [J1188]

"Region-enhanced passive radar imaging"

The authors adapt and apply a recently-developed region-enhanced synthetic aperture radar (SAR) image reconstruction technique to the problem of passive radar imaging. One goal in passive radar imaging is to form images of aircraft using signals transmitted by commercial radio and television stations that are reflected from the objects of interest. This involves reconstructing an image from sparse samples of its Fourier transform. Owing to the sparse nature of the aperture, a conventional image formation approach, based on direct Fourier transformation, results in quite dramatic artefacts in the image, as compared with the case of active SAR imaging. The region-enhanced image formation method considered is based on an explicit mathematical model of the observation process; hence, information about the nature of the aperture is explicitly taken into account in image formation. Furthermore, this framework allows the incorporation of prior information or constraints about the scene being imaged, which makes it possible to compensate for the limitations of the sparse apertures involved in passive radar imaging. As a result, conventional imaging artefacts, such as sidelobes, can be alleviated. Experimental results using data based on electromagnetic simulations demonstrate that this is a promising strategy for passive radar imaging, exhibiting significant suppression of artefacts, preservation of imaged object features, and robustness to measurement noise. [J1189]

"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. [J1190]

"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. [J1191]

"Target geolocation using SAR"

The paper provides an analysis of SAR target geolocation accuracy due to aircraft motion errors. It studies the nature of errors in INS and GPS navigation systems and relates them to achievable SAR geolocation accuracy. The nature of the INS errors was found using a computer simulation. The GPS error characteristics were acquired from a stationary P-code receiver. The results of the study show that the target geolocation accuracy when using the INS alone is of the same order as the positional accuracy of the INS. The GPS study concluded that it is possible to have a geolocation accuracy of <4-5 m from stand-off ranges of 20-50 km, using a state of the art GPS receiver [J1192]

"Unsupervised classification of polarimetric synthetic aperture Radar images using fuzzy clustering and EM clustering"

Five clustering techniques are compared by classifying a polarimetric synthetic aperture radar image. The pixels are complex covariance matrices, which are known to have the complex Wishart distribution. Two techniques are fuzzy clustering algorithms based on the standard ℓ1and ℓ2metrics. Two others are new, combining a robust fuzzy C-means clustering technique with a distance measure based on the Wishart distribution. The fifth clustering technique is an application of the expectation-maximization algorithm assuming the data are Wishart. The clustering algorithms that are based on the Wishart are demonstrably more effective than the clustering algorithms that appeal only to the ℓpnorms. The results support the conclusion that the pixel model is more important than the clustering mechanism. [J1193]

"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. [J1194]

"Editorial"

The authors state that 2004 has seen a major change to the operation of IEE journals. The entire process of submitting, reviewing, and accepting papers for publication is now carried out online, through a software package called Manuscript Central. The new scheme was introduced in April 2004. The authors acknowledge the roles of various groups in the production of each issue of the IEE journals. They also offer their congratulations to Dr M. Kirscht (his paper entitled 'Detection and imaging of arbitrarily moving targets with single-channel SAR' has been awarded the 2004 Clarke-Griffiths Memorial Premium). [J1195]

"Unsupervised segmentation of synthetic aperture Radar sea ice imagery using a novel Markov random field model"

Environmental and sensor challenges pose difficulties for the development of computer-assisted algorithms to

segment synthetic aperture radar (SAR) sea ice imagery. In this research, in support of operational activities at the Canadian Ice Service, images containing visually separable classes of either ice and water or multiple ice classes are segmented. This work uses image intensity to discriminate ice from water and uses texture features to identify distinct ice types. In order to seamlessly combine image spatial relationships with various image features, a novel Bayesian segmentation approach is developed and applied. This new approach uses a function-based parameter to weight the two components in a Markov random field (MRF) model. The devised model allows for automatic estimation of MRF model parameters to produce accurate unsupervised segmentation results. Experiments demonstrate that the proposed algorithm is able to successfully segment various SAR sea ice images and achieve improvement over existing published methods including the standard MRF-based method, finite Gamma mixture model, and K-means clustering. [J1196]

"Adaptive removal of azimuth ambiguities in SAR images"

We introduce an innovative algorithm that is capable of suppression of strong azimuth ambiguities in single-look complex (SLC) synthetic aperture radar images, to be used both for detected products and for interferometric surveys. The algorithm exploits a band-pass filter to select that portion of the azimuth spectrum that is less influenced by aliasing, the one that corresponds to the s in the replicated azimuth antenna pattern. The selectivity of this filter adapts locally depending on the estimated ambiguity intensity: the filter is more selective in the presence of strong ambiguities and becomes all-pass in absence of ambiguities. The design of such filter frames in the Wiener approach with two different normalization options, depending on the use of the SLC image, either for getting multilook averaged detected products or for interferometric applications. Preliminary results achieved by processing ENVISAT Advanced Synthetic Aperture Radar sensor data are provided. [J1197]

"Compact polarimetry based on symmetry properties of geophysical media: the pi/4 mode"

We assess the performance of synthetic aperture radar (SAR) compact polarimetry architectures based on mixed basis measurements, where the transmitter polarization is either circular or orientated at 45°(pi/4), and the receivers are at horizontal and vertical polarizations with respect to the radar line of sight. An original algorithm is proposed to reconstruct the full polarimetric (FP) information from this architecture. The performance assessment is twofold: it first concerns the level of information preserved in comparison with FP, both for point target analysis and crop fields classification, using L-band SIRC/XSAR images acquired over Landes forest and Jet Propulsion Laboratory AIRSAR images acquired over Flevoland. Then, it addresses the space implementation complexity, in terms of processed swath, downloading features, power budget, calibration, and ionospheric effects. The polarization uniqueness in transmission of this mixed basis mode, hereafter referred to as the pi/4 mode, maintains the standard lower pulse repetition frequency operation and hence maximizes the coverage of the sensor. Because of the mismatch between transmitter and receiver basis, the power budget is deteriorated by a factor of 3 dB, but it can partly be compensated. [J1198]

"Human-centered concepts for exploration and understanding of Earth observation images"

The progress in information retrieval, computer vision, and image analysis makes it possible to establish very complete bases of algorithms and operators. A specialist in remote sensing or image processing now has the tools that allow him, at least in theory, to configure applications solving complex problems of image understanding. However, in reality, earth observation (EO) data analysis is still performed in a very laborious way at the end of repeated cycles of trial and error. To overcome this, we proposed a novel advanced remote sensing information processing system knowledge-driven information mining (KIM). KIM is based on human-centered concepts (HCCs), which implements new features and functions allowing improved feature extraction, search on a semantic level, the availability of collected knowledge, interactive knowledge discovery, and new visual user interfaces. We assess the HCC methodology for solving several difficult tasks in EO image interpretation, using a broad variety of sensor data, from meter-resolution synthetic aperture radar and optical images to hyperspectral data. [J1199]

"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. [J1200]

"Generation of wide-swath and high-resolution SAR images from multichannel small spaceborne SAR systems"

Future spaceborne synthetic aperture radar (SAR) systems will be required to produce high-resolution imagery over a wide area of surveillance. However, the minimum antenna area constraint makes it a contradiction to simultaneously obtain both unambiguous wide-area and high azimuth resolution. To overcome this limitation, a technique has been suggested that combines a broad illumination source with multiple receiving channels. Then, the coherent combination of the recorded multichannel signals will allow for the unambiguous SAR mapping of a wide ground area with fine azimuth resolution. This letter first gives an overview of current research work carried out about the generation of wide-swath and high-resolution SAR images from multichannel small spaceborne SAR systems, and then a space-time adaptive processing (STAP) approach combined with conventional SAR imaging algorithms is presented, which could be of help to overcome the existing difficulties in data processing. The main idea of the approach is to use a STAP-based method to properly overcome the aliasing affect caused by the lower pulse repetition frequency and thereby retrieve the unambiguous azimuth wide (full) spectrum signal from the received signal. Following this operation, conventional SAR data processing tools can be applied to fully focus the SAR images. The performance of the approach is also discussed in this letter. The approach has the advantages of simplicity, robustness, and high efficiency. [J1201]

"Spatial resolution and processing tradeoffs for HYDROS: application of reconstruction and resolution enhancement techniques"

Recent developments in reconstruction and resolution enhancement for microwave instruments suggest a possible tradeoff between computation, resolution, and downlink data rate based on postcollection reconstruction/resolution enhancement processing. The Hydrospheric State (HYDROS) mission is designed to measure global soil moisture and freeze/thaw state in support of weather and climate prediction, water, energy, and carbon cycle studies, and natural hazards monitoring. It will use an active and passive L-band microwave system that optimizes measurement accuracy, spatial resolution, and coverage. The active channels use synthetic aperture radar-type processing to achieve fine spatial resolution, requiring a relatively high downlink data rate and ground processor complexity. To support real-time applications and processing, an optional postcollection reconstruction and resolution enhancement method is investigated. With this option, much lower rate real-aperture radar data are used along with ground-based postprocessing algorithms to enhance the resolution of the observations to achieve the desired 10-km resolution. Several approaches are investigated in this paper. It is determined that a reconstruction/resolution enhancement technique combining both forward- and aft-looking measurements enables estimation of 10-km resolution or better backscatter values at acceptable accuracy. Key tradeoffs to achieve this goal are considered. [J1202]

"Interference suppression in synthesized SAR images"

Radio interferences are becoming more and more an important source for image degradation in synthetic aperture radar (SAR) imaging. Especially at longer wavelengths, interferences are often very strong, and their suppression is required during data processing. However, at shorter wavelengths, interferences are often not obvious in the image amplitude, and filtering is not performed in an operational way. Nevertheless, interferences might significantly degrade the image phase, and the estimation of sensitive parameters like interferometric coherence or polarimetric descriptors becomes imprecise. Interference suppression is usually performed on the raw data, which are in most cases not available to the end-user. In this letter, a new interference suppression method for focused SAR images is proposed. Its performance is tested on interferometric repeat-pass data acquired by the German Aerospace Agency's experimental SAR system (E-SAR) at L-band. [J1203]

"An unsupervised segmentation method based on MPM for SAR images"

An unsupervised segmentation method for synthetic aperture radar (SAR) images is proposed. It alternately approximates the maximization of the posterior marginals estimate of the pixel class labels and estimates all model parameters except the number of classes during segmentation. In this method, a multilevel logistic (MLL) model for the pixel class labels and Gamma distribution for the marginal distribution of each class in the observed SAR image are employed. In our implementation, the expectation-maximization algorithm is used to estimate parameters of the Gamma distributions, and the iterative conditional estimation algorithm is used to estimate the MLL model parameters. The segmentation results for synthetic and real SAR images show that the proposed method has a good performance. [J1204]

"A maximum-likelihood estimator to simultaneously unwrap, geocode, and fuse SAR interferograms from different viewing geometries into one digital elevation model"

This paper presents theory, algorithm, and results of a maximum-likelihood algorithm that is capable to fuse a number of heterogeneous synthetic aperture radar interferograms into a single digital elevation model (DEM) without the need for the critical phase-unwrapping step. The fusion process takes place in the object space, i.e., the map geometry, and considers the periodic likelihood function of each individual interferometric phase sample. The interferograms may vary regarding their radar wavelength, their baseline, their heading angle (ascending or descending), and their incidence angle. Geometric baseline error estimates and a priori knowledge from other estimates like existing DEMs are incorporated seamlessly into the estimation process. The presented approach significantly differs from the standard DEM generation method where each interferogram is first phase-unwrapped individually, then geocoded into a common map geometry, and finally averaged with DEMs generated from other interferograms. By avoiding the phase-unwrapping step, the proposed algorithm does not depend on gradients between samples and is therefore capable to reconstruct the arbitrary height of each single scatterer. Because the height of each DEM sample is determined individually, spatial propagation of phase-unwrapping errors is avoided. The algorithm is targeted to fuse an ensemble of interferometric multiangle or multibaseline observations in areas of rugged terrain or highly ambiguous data where algorithms based on phase unwrapping may fail. The algorithm is explained, and examples with real data from the Shuttle Radar Topography Mission are given. Conditions of future missions are simulated, and optimization criteria for the viewing geometry are discussed. [J1205]

"Tree height influence on ERS interferometric phase in boreal forest"

The European Remote Sensing 1/2 (ERS-1/2) "tandem" coherence has been shown to provide estimates of stem volume in boreal forest in agreement with in situ data. Tree height estimation from ERS interferometric phase represents a further step in the investigations concerning the retrieval of biophysical parameters using repeat-pass synthetic aperture radar (SAR) interferometry. At two test sites located in Sweden and Finland, sets of respectively nine and eight ERS "tandem" interferograms were available. Images acquired under stable winter weather conditions and during nighttime were found to be less affected by atmospheric artifacts. Reduction of atmospheric artifacts in interferograms was performed with a phase screen estimated over a dense grid of open areas. Nonetheless, at each test site, only a limited set of pairs was useful for tree height investigations. Under stable winter conditions, the interferometric tree height obtained from an inversion of the differential interferometric phase at stand level was found to be much lower than the true tree height. Spread and uncertainty in the interferometric tree height measurements were caused by phase noise and residual atmospheric artifacts. Using the semiempirical interferometric water cloud model (IWCM), the modeled interferometric tree height was generally in reasonable agreement with the measurements, showing the need of a phase term in interferometric modeling of forests. The inversion of the IWCM for tree height retrieval showed the strong effect of phase noise and atmospheric artifacts on the estimates. Hence, tree height retrieval from ERS repeat-pass SAR interferometry seems to have limited forestry applications. The results also indicate under what conditions the forest influence is small on digital elevation models derived from repeat-pass interferometry. [J1206]

"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. [J1207]

"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. [J1208]

"Generation of digital terrain models with a ground-based SAR system"

A novel technique for the retrieval of a digital terrain model (DTM) with a ground-based synthetic aperture radar (GB-SAR) system is described. A set of SAR images collected over a test site located at Salice d'Ulzio, Italy, is used to validate experimentally the proposed DTM retrieval technique. The topographic height is obtained using an algorithm specifically tailored for a GB-SAR system equipped with two receive antennas. The comparison with an existing DTM of the test site area shows that the retrieved DTM is accurate, with root mean square height differences between the two DTMs below 5 m. [J1209]

"Sea ice mapping method for SeaWinds"

A sea ice mapping algorithm for SeaWinds is developed that incorporates statistical and spatial a priori information in a modified maximum a posteriori (MAP) framework. Spatial a priori data are incorporated in the loss terms of a Bayes risk formulation. Conditional distributions and priors for sea ice and ocean statistics are represented as empirical histograms that are forced to conform to a set of expected histograms via principal component filtering. Tuning parameters for the algorithm allow adjustments in the algorithm's performance. Results of the algorithm exhibit high correlation with the Remund-Long sea ice mapping algorithm for SeaWinds and the Special Sensor Microwave/Imager National Aeronautics and Space Administration Team 30% ice edge, and are verified with RADARSAT-1 ScanSAR imagery. The resulting sea ice maps exhibit high edge detail, preserve polynyas and ice bodies disjoint from the primary ice sheet, and thus are suitable for use with wind retrieval and sea ice studies. Principles employed in the algorithm may be of interest in other classification studies. [J1210]

"Taylor expansion of the differential range for monostatic SAR"

The polar format algorithm (PFA) for spotlight synthetic aperture radar (SAR) is based on a linear approximation for the differential range to a scatterer. We derive a second-order Taylor series approximation of the differential range. We provide a simple and concise derivation of both the far-field linear approximation of the differential range, which forms the basis of the PFA, and the corresponding approximation limits based on the second-order terms of the approximation. [J1211]

"Velocity estimation of fast moving targets using a single SAR sensor"

A new methodology is presented to retrieve slant-range velocity estimates of moving targets inducing Doppler-shifts beyond the Nyquist limit determined by the pulse repetition frequency (PRF). The proposed approach exploits the linear dependence (not subject to PRF limitations) of the Doppler-shift with respect to the slant-range velocity, at each wavelength. Basically, we propose an algorithm to compute the skew of the two-dimensional spectral signature of a moving target. Distinctive features of this algorithm are its ability to cope with strong range migration and its efficiency from the computational point of view. By combining the developed scheme to retrieve the slant-range velocity with a methodology proposed earlier to estimate the velocity vector magnitude, the full velocity vector is unambiguously retrieved without increasing the mission PRF. The method gives effective results even when the returned echoes of the moving targets and the static ground overlap completely, provided that the moving targets signatures are digitally spotlighted and the signal-to-clutter ratio (SCR) is, roughly, greater than 14 dB. The effectiveness of the method is illustrated with simulated and real data. As an example, slant-range velocities of moving objects with velocities between 6 and 12 times the Nyquist velocity are estimated with accuracy better than 3%. [J1212]

"CFAR detection of extended objects in high-resolution SAR images"

This paper deals with the problem of constant false alarm rate detection of extended objects in high-resolution synthetic aperture radar (SAR) images. Starting from the receiver proposed by Guida and Longo, where some relevant properties of the location-scale distributions are exploited for ensuring constant false alarm against Weibull background, the authors consider the application of the algorithm to the case of spotlight SAR images collected by an airborne sensor developed by the Defense Evaluation and Research Agency laboratories. The algorithm has been reconceived for specific application to high-resolution SAR images where the reference window is order of magnitudes larger than in the usual radar case. As a first step, a careful analysis based on some real images has been made for testing the validity of the Weibull distribution hypothesis. Results are then presented for different values of the system parameters (censoring depth and size of the reference window) and

demonstrate that the proposed detector is able to operate under changeable conditions of the underlying background (vegetation and asphalt mixed with grass) and of the object size and shape. A little care, however, should be taken to avoid overload situations that occur when the object dimensions become comparable with the size of the reference window. Finally, real-time applications may be foreseen, since the computational charge of the processor is generally low and increases weakly with the number of samples used for parameter estimation. [J1213]

"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. [J1214]

"Accurate estimation of correlation in InSAR observations"

Interferometric synthetic aperture radar (InSAR) correlation, a measure of the similarity of two radar echoes, provides a quantitative measure of surface and subsurface scattering properties and hence surface composition and structure. Correlation is observed by comparing the radar return across several nearby radar image pixels, but estimates of correlation are biased by finite data sample size and any underlying interferometer fringe pattern. We present a method for correcting bias in InSAR correlation measurements resulting in significantly more accurate estimates, so that inverse models of surface properties are more useful. We demonstrate the value of the approach using data collected over Antarctica by the Radarsat spacecraft. [J1215]

"Wideband measurements of ice sheet attenuation and basal scattering"

We are developing a multifrequency multistatic synthetic aperture radar (SAR) for determining polar ice sheet basal conditions. To obtain data for designing and optimizing radar performance, we performed field measurements with a network-analyzer-based system during the 2003 field season at the North Greenland Ice Core Project camp (75.1 N and 42.3 W). From the measurements, we determine the ice sheet complex transfer function over the frequency range from 110-500 MHz by deconvolving out the system transfer function. Over this frequency range, we observe an increase in total loss of 8±2.5 dB using a linear regression to the log-scale data. With the ice sheet transfer function and an ice extinction model, we estimate the return loss from the basal surface to be approximately 37 dB. These measurements have broad applicability to interpreting radar-sounding data, which are widely used in glaciological studies of the polar ice sheets. These data have also been used in the link budget for the design considerations of the multifrequency multistatic SAR system. [J1216]

"Precise topography- and aperture-dependent motion compensation for airborne SAR"

Efficient synthetic aperture radar (SAR) processing algorithms are unable to exactly implement the aperture- and topography-dependent motion compensation due to the superposition of the synthetic apertures of several targets having different motion errors and potentially different topographic heights. Thus, during motion compensation, a reference level is assumed, resulting in residual phase errors that impact the focusing, geometric fidelity, and phase accuracy of the processed SAR images. This letter proposes a new short fast Fourier transform-based postprocessing methodology capable of efficient and precise compensation of these

topography- and aperture-dependent residual phase errors. In addition to wide beamwidth (very high resolution) SAR systems, airborne repeat-pass interferometry especially benefits from this approach, as motion compensation can be significantly improved, especially in areas with high topographic changes. Repeat-pass interferometric data of the E-SAR system of the German Aerospace Center (DLR) are used to demonstrate the performance of the proposed approach. [J1217]

"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. [J1218]

"Accuracy of differential shift estimation by correlation and split-bandwidth interferometry for wideband and delta-k SAR systems"

Estimation of differential shift of image elements between two synthetic aperture radar (SAR) images is the basis for many applications, like digital elevation model generation or ground motion mapping. The shift measurement can be done nonambiguously on the macro scale at an accuracy depending on the range resolution of the system or on the micro scale by employing interferometric methods. The latter suffers from phase cycle ambiguities and requires phase unwrapping. Modern wideband high-resolution SAR systems boast resolutions as small as a few tens of a wavelength. If sufficiently many samples are used for macro-scale shift estimation, the accuracy can be increased to a small fraction of a resolution cell and even in the order of a wavelength. Then, accurate absolute ranging becomes precise enough to support phase unwrapping or even make it obsolete. This letter establishes a few fundamental equations on the accuracy bounds of shift estimation accuracy for several algorithms: coherent speckle correlation, incoherent speckle correlation, split-band interferometry, a multifrequency approach, and correlation of point scatterers in clutter. It is shown that the performance of split-band interferometry is close to the Cramer'r-Rao bound for a broad variety of bandwidth ratios. Based on these findings, Delta-k systems are proposed to best take advantage of the available radar bandwidth. [J1219]

"Enhanced resolution in SAR/ISAR imaging using iterative sidelobe apodization"

Resolution enhancement techniques in radar imaging have attracted considerable interest in recent years. In this work, we develop an iterative sidelobe apodization technique and investigate its applications to synthetic aperture radar (SAR) and inverse SAR (ISAR) image processing. A modified noninteger Nyquist spatially variant apodization (SVA) formulation is proposed, which is applicable to direct iterative image sidelobe apodization without using computationally intensive upsampling interpolation. A refined iterative sidelobe apodization procedure is then developed for image-resolution enhancement. Examples using this technique demonstrate enhanced image resolution in various applications, including airborne SAR imaging, image processing for three-dimensional interferometric ISAR imaging, and foliage-penetration ultrawideband SAR image processing. [J1220]

"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. [J1221]

"ICARUS: imaging pulse compression algorithm through remapping of ultrasound"

In this work, we tackle the problem of applying to echographic imaging, those synthetic aperture focusing techniques (SAFT) in the frequency domain commonly used in the field of synthetic aperture radars (SAR). The aim of this research is to improve echographic image resolution by using chirp transmit signals, and by performing pulse compression in both dimensions (depth and lateral). The curved geometry present in the unfocused radio-frequency (RF) ultrasonic image is the main cause of inaccuracy in the direct application of frequency domain SAFT algorithms to echographic imaging. The focusing method proposed in this work, after pulse compression in the depth dimension, performs lateral focusing in the mixed depth-lateral spatial frequency domain by means of a depth variant remapping followed by lateral pulse compression. This technique has the advantage of providing a resolution that is uniform in nonfrequency selective attenuation media, and improved with respect to conventional time domain SAFT, without requiring the acquisition and processing of channel data necessary for the most advanced synthetic transmit aperture techniques. Therefore, the presented method is suitable for easy real-time implementation with current generation hardware. [J1222]

"Multiregion level-set partitioning of synthetic aperture radar images"

The purpose of this study is to investigate synthetic aperture radar (SAR) image segmentation into a given but arbitrary number of gamma homogeneous regions via active contours and level sets. The segmentation of SAR images is a difficult problem due to the presence of speckle which can be modeled as strong, multiplicative noise. The proposed algorithm consists of evolving simple closed planar curves within an explicit correspondence between the interiors of curves and regions of segmentation to minimize a criterion containing a term of conformity of data to a speckle model of noise and a term of regularization. Results are shown on both synthetic and real images. [J1223]

"Retrieval of biophysical parameters of agricultural crops using polarimetric SAR interferometry"

An existing two-layer model for forest height estimation is adapted for agricultural crops in order to develop a retrieval algorithm based on polarimetric synthetic aperture radar interferometry. This new inversion scheme is specifically tailored for vertically oriented agricultural crops, with extinction coefficients dependent on the wave polarization. Physical parameters of the vegetation scene are estimated from the location of the measured coherences in the complex plane. The proposed inversion scheme is validated experimentally with indoor wide-band polarimetric measurements on samples of corn and rice fields. Results show that the estimates of the thickness of the vegetation layer and the ground topography are reasonably accurate for a wide range of frequencies and baselines. Moreover, some interesting results are also obtained when using only dual-polarized data, which brings up new applications for present and future spaceborne missions. [J1224]

"Ambiguity-free Doppler centroid estimation technique for airborne SAR using the Radon transform"

In synthetic aperture radar (SAR) signal processing, the Doppler centroid estimation technique, called the "clutter-lock", is important because it is related to the signal-to-noise ratio, geometric distortion, and radiometric error of the final SAR image. Conventional algorithms have either ambiguity problems or somewhat high computational load. Using the fact that the Doppler centroid and the squint angle are directly related, we propose an ambiguity-free Doppler centroid estimation technique using Radon transform, named geometry-based Doppler estimator. The proposed algorithm is computationally efficient and shows good performance of estimating the absolute Doppler centroid. [J1225]

"Dual-polarization measurements at C-band over the ocean: results from airborne radar observations and comparison with ENVISAT ASAR data"

This paper presents an analysis of measurements of the normalized radar cross-section (NRCS) in vertical and horizontal polarizations over the ocean obtained from the C-band airborne radar STORM. The dataset was collected during the experiment called "Validation with a Polarimetric Airborne Radar of ENVISAT SAR over the Ocean (VALPARESO)", which took place during the calibration/validation phase of the ENVISAT Advanced Synthetic Aperture Radar (ASAR). From this dataset, the properties of the polarization ratio are discussed and in

particular its dependencies with radar geometry (incidence and azimuth angle) as well as with meteorological conditions (wind and sea state). The polarization ratio is found to be dependent on incidence and azimuth angles. Its dependence with incidence angle is found to be significantly different from empirical models previously proposed in the literature. It also exhibits some correlation with surface conditions (wind and wave) with a more important correlation with significant wave steepness. Two new analytical formulations are proposed to model the polarization ratio, one as a function of incidence angle only, the second one with additional dependence with azimuth angle. It is shown that it is necessary to consider an azimuth-dependent polarization ratio for incidence angles larger than 30°. Comparisons with the polarization ratio from ENVISAT ASAR images are used to assess this model. [J1226]

"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. [J1227]

"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. [J1228]

"Multi-aspect radar target recognition method based on scattering centers and HMMs classifiers"

A hidden Markov model (HMM)-based method for recognizing aerial targets according to the sequential high-range-resolution (HRR) radar signature is presented. Its recognition features are the location information of scattering centers extracted from the HRR radar echoes by the relax algorithm. The HMM is used to characterize the spatio-temporal information of a target. Several HMMs are cascaded in a chain to model the variation in the target orientation and used as classifiers. Computer simulations with the inverse synthetic aperture radar (ISAR) data are given to demonstrate that for an open-set recognition, average class-recognition rates of 84.50% and 89.88% are achieved, respectively, under two given conditions. [J1229]

"Wavelet transform-based interferometric SAR coherence estimator"

A novel method to estimate interferometric coherence in synthetic aperture radar interferometry is proposed. It is demonstrated that this approach is not affected by the terrain topography, contrary to multilook techniques. In addition, since the method is based on the two-dimensional discrete wavelet packet transform, it allows recovering coherence information with a high spatial resolution. Results derived from simulated and experimental ESAR-DLR X- and L-band interferograms corroborate the performance of the proposed technique. [J1230]

"Short Courses"

{no data available} [J1231]

"Time windowing for highly focused ISAR image reconstruction"

In several applications long recorded live inverse synthetic aperture radar (ISAR) data are used to obtain one or more ISAR images. In order to reconstruct a well-focused ISAR image, a suitable selection of the echoes to be coherently processed must be provided. Such a selection can be made by defining a time window. We propose a technique for the automatic selection of the position and length of the time window that provides the ISAR image with the highest focus. The technique, namely the maximum contrast based automatic time window selection (MC-ATWS), is based on the definition of image contrast (IC). Due to the fact that the IC is a measure of the image focus, the time window is selected by maximizing the IC. The technique effectiveness is tested by using simulated and real data. [J1232]

"Analysis of surface roughness and morphology of first-year sea ice melt ponds: implications for microwave scattering"

Variations in wind forcing over summer first-year sea ice (FYI) melt ponds occur at hourly to weekly scales and are a significant contributor to microwave backscatter (σ°) variability observed from spaceborne synthetic aperture radar (SAR) platforms (e.g., ENVISAT-ASAR and RADARSAT-1). This variability impairs our ability to use SAR to derive information on summer sea ice thermodynamic state and energy balance parameters such as albedo and melt pond fraction. The surface roughness contribution of FYI melt ponds in the Canadian Arctic Archipelago to like-polarized, C-band σ° estimates is analyzed through a spectral and statistical analysis of surface wave height profiles for varying wind speeds, upwind fetch lengths, and melt pond depths. A unique derivation of melt pond surface wave height spectra is presented based on digital video of melt pond surface wave trains. Significant scale surface roughness was observed even at wind speeds of 3 m·s-1, resulting in small perturbation model estimates of σ° (HH) ranging from -5 dB at 20° incidence to -22 dB at 50° incidence. Results from a multivariate linear regression analysis show that 53.5% of observed variance in σ° (HH or VV) can be explained by wind speed, upwind fetch from melt pond edges, and melt pond depth, with no appreciable difference in the relative contribution of explanatory variables. Modeled omnidirectional σ° as a function of wind speed and incidence angle for 100-m transects collected throughout the melt pond season act to elaborate the role of fetch and depth, as well as the modulating effect of hummocks, on σ°. [J1233]

"Timed arrays in a nutshell"

Timed arrays are the time-domain counterpart of phased arrays, where each array element is excited by wideband instead of narrowband signals. By referring to idealized, but meaningful canonical configurations, the array parameters in the transmit and receive mode are defined in a simple way, by following a purely time-domain intuitive analysis. Obtained results extend steady-state concepts of beamwidth, directivity, gain, effective receiving area, Fresnel and Fraunhofer regions to the case of transient excitation. Application is made to both real and synthetic arrays. The final main conclusion is that the role of the carrier wavelength associated with narrowband excitation is taken by the spatial width of the (carrierless) pulse. This result appears to be rather robust, because it turns out to be independent from the different norms used in the definition of the antenna parameters: it sheds light on the physics of the transient radiation and may be very useful for initiating a more technical analysis of the array performance. [J1234]

"Three-dimensional bistatic synthetic aperture radar imaging system: spatial resolution analysis"

A mathematical framework for analysing the spatial resolving capability of a general three-dimensional bistatic synthetic aperture radar imaging system, in which the transmitter, receiver and imaged object (or region of interest) may be non-coplanar and in which the transmitter and/or receiver may be moving, is presented. With Earth observation applications in mind, this framework is used to characterise quantitatively the two-dimensional ground-plane resolving capability of the three-dimensional imaging system. The theoretical results are confirmed via simulations. [J1235]

"Operational map-guided classification of SAR sea ice imagery"

This paper presents a map-guided sea ice classification system built to work in parallel with the Canadian Ice Service (CIS) operations to produce pixel-based ice maps that complement actual "egg code" maps produced by CIS. The system uses the CIS maps as input to guide classification by providing information on the number of ice types and their final label for specific regions. Segmentation is based on a modified adaptive Markov random field (MRF) model that uses synthetic aperture radar (SAR) intensities and texture features as input. The ice type

labeling is performed automatically by gathering evidences based on a priori information on one or two classes and deducing the other labels iteratively by comparing distributions of segments. Three methods for comparing the segment distributions (Fisher criterion, Mahalanobis distance, and Kolmogorov-Smirnov test) were implemented and compared. The system is fully described with special attention to the labeling procedure. Examples are presented in the form of two CIS SAR-based ice maps from the Gulf of Saint Lawrence region and one example from the Beaufort Sea. The results indicate that when the segmentation is good, the labeling attains best results (between 71% and 89%) based on evaluation by a sea ice analyst. Some problems remain to be assessed which are primarily attributable to discrepancies in the information provided by the egg code and what is actually visible in the SAR image. Subscale information on floe size and shape available to human analysts, but not in this classification system, also appear to be a critical information for separating some ice types. [J1236]

"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. [J1237]

"Stand age retrieval in production forest stands in New Zealand using C- and L-band polarimetric Radar"

Regressions of single-, dual-, quad-, and full-polarization L- and C-band synthetic aperture radar (SAR) against stand age from 403 radiata pine stands in Kaingaroa Forest, New Zealand have been carried out, using the National Aeronautics and Space Administration's Airborne SAR instrument. The regressions attempted to find products suitable for the separation of young (two years or less) from old stands (25 years or older), and for the estimation of stand age. Local incidence angle had no significant effect for C-band, but was always significant for L-band, giving a standard error reduction of 13% to 32% for log stand age. Stand density was highly significant for both bands, giving standard error reductions of 7% to 47%. Single- and dual-polarization products were severely biased, and it was impossible to separate young and old stands, except L-band horizontal-(HH)-plus-horizontal-vertical (HV). C-band quad-polarization gave less bias and lower error than for that L-band, when local incidence angle and stand density were excluded. C-band full-polarization using covariance magnitudes gave no improvement over C-band quad-polarization, but L-band did give a significant improvement. The C- and L-band full-polarization products with six polarimetric indices gave significant improvements in the standard error. The results show that regressions of SAR data with stand age are possible with full- and quad-polarization L- and C-band datasets, although the prediction limits increase rapidly with stand age. The smallest error in estimated stand age, with an RMS of 3.22 years, was for L-band full-polarization with six polarimetric indices, calculated from a validation dataset. Separation of young and old forest stands was only possible for full-, quad-polarization, and the L-band HH-plus-HV products. [J1238]

"Radar backscattering model for multilayer mixed-species forests"

A multilayer canopy scattering model is developed for mixed-species forests. The multilayer model provides a significantly enhanced representation of actual complex forest structures compared to the conventional canopy-trunk layer models. Multilayer Michigan Microwave Canopy Scattering model (Multi-MIMICS) allows overlapping layer configuration and a tapered trunk model applicable to forests of mixed species and/or mixed growth stages. The model is the first-order solution to a set of radiative transfer equations and includes layer interactions between overlapping layers. It simulates SAR backscattering coefficients based on input dimensional, geometrical, and dielectric variables of forest canopies. The Multi-MIMICS is an efficient realization of actual forest structures and can be shaped for specific interest of forest parameters. We present the model's application and validation in the paper. The model is parameterized using data collected from a 220,000-ha area of forests in central Queensland, Australia. Fifteen 50Ч50 m test sites representing the general forest diversity and growth stages are chosen as ground truth. Polarimetric backscattering airborne SAR (AIRSAR) data of the same area are acquired to validate the model simulations. The model predicts SAR backscattering coefficients of the test areas. Simulation results show a good agreement with AIRSAR data at most frequencies and polarizations. The simulated backscattering coefficient from the multilayer model and the standard MIMICS are also compared and significant improvements are observed. [J1239]

"A FARIMA-based technique for oil slick and low-wind areas discrimination in sea SAR imagery"

This paper introduces a new analysis technique, using the fractionally integrated autoregressive-moving average (FARIMA) model, to distinguish between low-wind and oil slick areas in high-resolution sea synthetic aperture radar (SAR) imagery. The method deals with the estimation of the fractional differencing and autoregressive-moving average parameters of the mean radial power spectral density of sea SAR images. The algorithm is applied and validated on dark areas corresponding to oil slicks, oil spills, and low-wind sea surface anomalies in European Remote Sensing 1 and 2 Precision Images of the Mediterranean Sea, North Sea, and Atlantic Ocean. [J1240]

"Sea surface velocity vector retrieval using dual-beam interferometry: first demonstration"

The dual-beam interferometer consists of two interferometric synthetic aperture radars (InSARs), one squinted at 20° forward of broadside, and the other 20° aft, to allow measurement of vector surface velocity with only a single aircraft pass. Estimates of surface velocity vectors in the coastal region during high tidal flow are presented. The data were gathered over the barrier islands west of Fort Myers, Florida, as part of a March 2004 deployment. Whereas no detailed bathymetry data were available, high-quality aerial photography appears to be a useful tool in inferring bottom topography and possible current obstructions. The retrieved velocity field clearly follows the expected outflow pattern. While comparisons with tidal current magnitudes predicted by the U.S. National Ocean Service do reveal discrepancies of up to 0.5 m/s, these differences are most likely due to the contribution of ocean surface waves to the overall InSAR velocity measurement. Velocity retrievals for the same area based on the data from different tracks show good consistency. The results constitute the first demonstration of vector retrieval of the surface velocity field with a single-pass InSAR system and confirm the robustness of the dual-beam interferometry principle. [J1241]

"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. [J1242]

"SAR PRF-ambiguity resolving by range diversity"

By exploiting the approximate linear relation of the absolute Doppler centroid against the slant range, a novel approach is proposed for resolving synthetic aperture radar (SAR) pulse repetition frequency (PRF)-ambiguity with high computational efficiency. Accuracy analysis and the experimental results with real data both demonstrate the effectiveness of the proposed method. [J1243]

"Very high bandwidth millimetre-wave radar"

An experimental radar at 94 GHz has been developed, which is capable of delivering an instantaneous bandwidth of 4 GHz. The radar uses an FM-CW waveform and is fully solid state. The data undergo an ISAR imaging process to derive high resolution scattering centre distributions for targets measured in tower/turntable configuration. The high resolution processing has to rely on an appropriate polar reformatting procedure, which is not necessary for ISAR imaging at millimetre waves with resolutions worse than 10 cm. [J1244]

"Earth observation image and DEM information aggregation for realistic 3-D visualization of natural landscapes"

This paper presents a system to integrate digital elevation model (DEM) enhancement and Earth Observation (EO) image analysis for realistic three-dimensional (3-D) rendering applications. There is an increasing interest in interferometric synthetic aperture radar (InSAR) data, principally due to the availability of the nearly global Shuttle Radar Topography Mission coverage. To remove artifacts and noise from an InSAR DEM, a nonstationary Bayesian filtering is applied that preserves structural information. Land-cover or man-made structures are easily recognized in an optical image. The corresponding geometry encapsulated in the DEM differs from our implicit perception and generally leads to unrealistic 3-D rendering. To improve this, DEM regularization is achieved using only the visualization dataset (optical image and DEM). It consists of extracting relevant information from the optical image and integrate them in the filtered DEM. To gather image information,

an object-based description of large optical EO images is obtained in two stages 1) an image is segmented to create a partition of regions and 2) a novel dynamical algorithm is proposed to extract the regions and encode them in a tree structure. Regions are modeled by objects primitives stored in a database. Spatial relationships between regions are reflected by the presented tree of regions. Using the object-based description generation, structures to be integrated into the DEM are interactively selected and classified among a set of user-thematic. Each thematic is associated with a corresponding elevation modeling and enables to estimate the region's 3-D structure. The proposed object line processing provides more realistic 3-D visualizations. [J1245]

"Identification of multiaspect radar signals based on the feature space trajectory concept"

Identification of radar targets has often been based on information gathered from only a single relative aspect between the radar and target. However, identification performances can be significantly improved, provided that radar signals at multiple aspects are simultaneously used to identify radar targets. In this paper, we investigate performances of various approaches to identification using multiaspect radar signals. In addition, some novel techniques based on the feature space trajectory concept are introduced to further enhance the identification performance of the conventional methods. All of these approaches are demonstrated using radar cross section (RCS) data of various aircraft models measured at compact range. Results show that the proposed methods via the FST concept can provide the most promising identification accuracy. [J1246]

"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. [J1247]

"A physical approach for the observation of oil spills in SAR images"

In this paper, a physical approach to support oil spills observation over synthetic aperture radar (SAR) images is presented. Electromagnetic model is based on an enhanced damping model that takes into account oil viscoelastic properties and wind speed. As a matter of fact, a multisensor approach is considered and a constant false alarm rate (CFAR) filter is used to minimize speckle effect. A set of experiments is presented and discussed. They show that oil spill processing is effective over single-look SAR images using mean input data. [J1248]

"Guest Editorial: Synthetic Aperture Radar Imaging of the Ocean Surface"

{no data available} [J1249]

"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). [J1250]

"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. [J1251]

"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. [J1252]

"Current measurements by airborne along-track InSAR: measuring technique and experimental results"

Since the first demonstration of high-resolution mapping of surface currents by airborne along-track interferometric synthetic aperture radar (along-track InSAR) in the late 1980s, theoretical models of the along-track InSAR imaging mechanism and recommendations for ideal instrument parameters, measuring strategies, and data processing and interpretation techniques have been discussed in a number of publications. However, due to the experimental nature of existing instruments and algorithms and a very limited reference database from actual experiments, potential users have not recognized the along-track InSAR as a readily available tool for current measurements until now. In order to promote the use of InSAR and to validate and demonstrate current measurements on the basis of instrument parameters and data processing techniques proposed earlier, the authors have carried out experiments with an airborne X-band along-track InSAR over spatially varying current fields at two test sites in the German Bight of the North Sea. In this paper, an overview of the experimental scenarios and the acquired data is given, and the newly implemented algorithms for the retrieval of two-dimensional (2-D) surface current fields from the InSAR raw data are described. Using acoustic Doppler current profiler (ADCP) data and predictions of a numerical circulation model as reference, a root mean square (rms) error of spatial variations in the InSAR-derived current fields on the order of 0.1 m/s at an effective resolution of about 100 m is obtained, which is consistent with theoretical expectations. Furthermore, it is shown that the proposed iterative correction scheme for nonlinearities of the InSAR imaging mechanism on the basis of numerical simulations works well and leads to a significant improvement. Altogether, it is concluded that the proposed technique for current measurements by along-track InSAR is efficient, robust, and sufficiently mature for applications that require high-resolut- ion snapshots of surface current fields within areas of some square kilometers, such as the monitoring of bathymetric changes in coastal waters. [J1253]

"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. [J1254]

"Extraction of coastal ocean wave fields from SAR images"

Wave spectra derived from synthetic aperture radar (SAR) images acquired by ENVISATs are compared to in situ measurements by seven sensors, deployed in a field experiment carried out on the French coast of La Manche (English Channel). The wave spectra inversion scheme is adapted for shallow water from the European Space Agency (ESA)'s operational processing techniques used for level 2 ocean wave products. Under the low to moderate wind speed observed conditions, overall good agreement is found between in situ and SAR observations over a wide range of wave heights and directions, including waves propagating in the radar azimuth direction and incidence angles different from the standard imagette products. [J1255]

"Motion compensation errors: effects on the accuracy of airborne SAR images"

This work addresses the study of the effect of residual uncompensated motion errors due to positioning measurement instrument and digital elevation model inaccuracies on the accuracy of airborne synthetic aperture radar (SAR) images. It is shown that these not only introduce phase errors following pure geometric considerations, but they also cause additional aberrations related to their interaction with the SAR processing procedure. Extension to the repeat pass airborne interferometry is also included to show their impact on the resulting interferograms. [J1256]

"Motion compensation errors: effects on the accuracy of airborne SAR images"

{no data available} [J1257]

"Polarimetric classification of land cover for Glen Affric radar project"

In recent years two polarimetric decompositions methods, the A/E method (Cloude and Pottier, 1997) and the three-component decomposition method (Freeman and Durden, 1998) have become the main methods of the polarimetric synthetic aperture radar data classification in radar imagery applications. In both methods the structural composition of the land cover is modelled using the main backscatter responses, as a function of the polarised channels, the level of energy received and the associated backscatter angles. To enhance the coherence in the polarimetric decompositions, data are generally multi-looked and de-speckled. The authors have applied and compared the 'Freeman' three-component decomposition followed by the Wishart complex classifier with the A/E decomposition algorithms to the de-speckled and edge-enhanced Glen Affric, fully polarimetric L-band radar data. The Glen Affric radar site was chosen for its extensive and diverse semi-natural woodlands of native Scots Pine, and its varied topography. The application results demonstrate the response of the radar classification from a semi-natural land cover on a rapid topography. [J1258]

"Change detection for low-frequency SAR ground surveillance"

Change detection using ultra-wideband synthetic aperture radar (SAR) images in the low end of the VHF band is shown to provide excellent performance for detection of vehicle-sized objects in forest concealment. Two different change detection algorithms are discussed and their performance evaluated. The two algorithms are based on similar statistical hypothesis testing, but differ in that one operates on complex (coherent change detection) whereas the other uses magnitude (incoherent change detection) image data. Algorithm evaluation is performed using radar data acquired with the airborne CARABAS-II SAR in northern Sweden. The data were collected during a change detection experiment with concealed vehicles in boreal forests (stand volume ca. 100 m3/ha). Results show that coherent change detection gives slightly better performance using full spatial resolution of the images, whereas the incoherent change detection gives better performance when spatial averaging (2Ч2 resolution cells) is included. A comparison with detecting vehicles using only single-pass images shows an increase of false alarms of one to two orders of magnitude at the same probability of detection. [J1259]

"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. [J1260]

"Ukraine institute of radio astronomy high-resolution radars"

A review is given of recent activities undertaken in the Institute of Radio Astronomy of the National Academy of Sciences of Ukraine for the development of high-resolution radars. The radars developed include 95- and 36-GHz cloud radars and an airborne, Ku-band SAR radar system. They are capable to perform real-time, high-resolution measurements. The set-up of these instruments, the novel technical solutions, and the signal processing technique introduced are discussed. The results obtained with such instruments during measurement campaigns are presented as well. [J1261]

"Short Courses"

{no data available} [J1262]

"ISAR imaging using an emulated multistatic radar system"

The use of a monostatic radar configuration limits the ability of an inverse synthetic aperture radar (ISAR) system to image targets in certain geometries. By employing multistatic geometries this limitation may be overcome. This paper discusses the emulation of multistatic geometries, via sea surface multipath reflections, using a monostatic system. This application capitalises on the advantages provided by both monostatic and bistatic systems. The possibility of obtaining ISAR images using these emulated multistatic radar configurations is first theoretically discussed and then verified using experimental results. [J1263]

"Multibaseline cross-track SAR interferometry using interpolated arrays"

{no data available} [J1264]

"Efficient Texture Analysis of SAR Imagery"

We address the problem of efficiency in texture analysis for synthetic aperture radar (SAR) imagery. Motivated by the statistical occupancy model, we introduce the notion of patch reoccurrences. Using the reoccurrences, we propose the use of approximate textural features in analysis of SAR images. We describe how the proposed approximate features can be extracted for two popular texture analysis methods—the gray-level cooccurrence matrix and Gabor wavelets. Results on image texture classification show that the proposed method can provide an improved efficiency in the analysis of SAR imagery, without introducing any significant degradation in the classification results. [J1265]

"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. [J1266]

"Automated georeferencing and orthorectification of Amazon basin-wide SAR mosaics using SRTM DEM data"

Frequently large synthetic aperture radar (SAR) mosaics are not precisely georeferenced because topographic distortions are not removed during the mosaicking process due to the lack of adequate digital elevation models (DEMs). The Shuttle Radar Topography Mission (SRTM) has recently provided high-resolution DEM data with

nearly global coverage and makes it possible to rectify SAR mosaics. Though techniques are available for rectifying individual scenes of SAR imagery using DEM data, these methods encounter difficulties when rectifying SAR mosaics because abrupt geometric discontinuities occur in SAR mosaics at scene boundaries. This paper introduces an automated method to removing topographic distortions from SAR mosaics and producing orthorectified mosaics, without accessing original SAR images. The procedures include SAR image simulation from DEMs, two-staged image matching between SAR mosaics and the simulated image, automated tie-point derivation and screening, piecewise image rectification for localized adjustment, and production of orthorectified mosaics. The method is used to orthorectify both high-water and low-water Global Rain Forest Mapping project SAR mosaics covering the entire Amazon basin. Validation results show that one-pixel (i.e., 92 m) positioning accuracy (root mean square error) was achieved in both cases, compared to 14-16 pixel errors (i.e., 1288-1472 m) of the original mosaics. [J1267]

"Statistical Assessment of Eigenvector-Based Target Decomposition Theorems in Radar Polarimetry"

The performance of quantitative remote sensing based on multidimensional synthetic aperture radars (SARs), and polarimetric SAR systems in particular, depends strongly on a correct statistical characterization of the data, i.e., on a complete knowledge of the effects of the speckle noise. In this framework, the eigendecompostion of the covariance or coherency matrices and the associated$H/underlinealpha/A$decomposition have demonstrated the potential for quantitative estimation of physical parameters. In this paper, we present a detailed study of the statistics associated with this decomposition. This analysis requires the introduction of mathematical tools that are not well known in the remote sensing community. For this reason, we include a review section to present them. Using this work, we then present an expression for the probability density function of the sample eigenvalues of the covariance or coherency matrix. The availability of this expression allows a complete study of the separated sample eigenvalues, as well as, the entropy H and the anisotropy A. As demonstrated, all these parameters must be considered as asymptotically nonbiased with respect to the number of looks. In order to reduce the biases for a small number of averaged samples, a novel estimator for the eigenvalues is proposed. The results of this work are analyzed by means of simulated and real airborne SAR data. This analysis permits us to determine in detail the effects of the number of averaged samples in the estimation of physical information in radar polarimetry. [J1268]

"International Radar Symposium 2005"

{no data available} [J1269]

"A new chirp scaling algorithm based on the fractional Fourier transform"

The fractional Fourier transform (FrFT), which is a generalized form of the well-known Fourier transform, has only recently started to appear in the field of signal processing. This has opened up the possibility of a new range of potentially promising and useful applications. In this letter, we develop a new FrFT-based chirp scaling algorithm (CSA) and compare its performance with the classical CSA based on the fast Fourier transform (FFT). Simulation results show that the FrFT-based CSA can offer significantly enhanced features compared to the classical FFT-based approach. [J1270]

"Modeling temporal evolution of junco marshes radar signatures"

In this work, multitemporal synthetic aperture radar (SAR) data in conjunction with an electromagnetic (EM) model and a vegetation growth model were used to monitor and explain burn-regrowth events of junco vegetation in a wetland environment. The data used were from Radarsat-1, ENVISAT Advanced Synthetic Aperture Radar (ASAR), and European Remote Sensing 2 (ERS-2) temporal series. The EM model is based on radiative transfer theory and describes junco vegetation as a set of vertical dielectric cylinders on a flat flooded surface. It was used, together with the vegetation growth model, to predict the temporal evolution of the radar response during a burn-regrowth event. This simulation was compared with the ERS-2 vertical (VV) data. It was observed a "bell-shaped" temporal trend that was confirmed by the simulated data with a mean error of 2.5 dB. Additionally, in view of current and future ENVISAT ASAR Alternating Polarization Mode Precision data, the horizontal (HH) SAR temporal response was also simulated giving as a result strong differences between simulated HH and VV temporal trends. These differences are in good agreement with the ones observed between Radarsat-1 HH and ERS-2 VV SAR data acquired at close dates and also with the same differences observed between HH and VV ENVISAT ASAR data. Electromagnetic modeling results provide a sound theoretical interpretation of these observations. [J1271]

"Multibaseline cross-track SAR interferometry: a signal processing perspective"

Synthetic aperture radar interferometry (InSAR) is a powerful and increasingly expanding technique for measuring the topography of a surface, its changes over both short- and long-time scale, and other changes in the detailed characteristics of the surface. We provide a tutorial description of recent results on multibaseline (MB) InSAR processing. The main focus is on the problem of retrieving both heights and radar reflectivities of natural layover areas by means of a cross-track InSAR (XTI-SAR) system with a uniform linear array (ULA). It is formulated as the problem of detecting and estimating a multicomponent signal corrupted by multiplicative noise-the speckle in the radar imaging jargon-and by additive white Gaussian noise. Application to the InSAR problem of both nonparametric and parametric modern spectral estimation techniques is described. The problem of estimating the number of signal components in the presence of speckle is also addressed. Finally, a brief mention is given to recent research trends on robust methods for nonperfectly calibrated arrays, on processing for non-ULA configurations, and on MB SAR tomography, which is an extension of MB SAR interferometry for the full 3D mapping of semitransparent volume scattering layers. The state of the art of other advanced multichannel interferometric techniques is also briefly recalled. [J1272]

"Contrast maximisation based technique for 2-D ISAR autofocusing"

An image contrast based algorithm for 2-D ISAR image autofocusing is proposed. The problem of ISAR image autofocusing is formulated analytically by defining geometry and dynamics of the radar-target system and by assuming a mathematical model for the received signal. The image focusing is then achieved by estimating the model parameters through the maximisation of the image contrast. The problem of the maximum search is solved numerically by means of an iterative search method. An algorithm able to produce an accurate initial guess is also developed by using the radon transform. The good accuracy of the initial guess guarantees the convergence of the optimisation problem solution to the global maximum. The performance of the proposed autofocusing technique is tested by comparing it to the point prominent processing (PPP) algorithm, the phase gradient algorithm (PGA) and the image entropy based technique (IEBT), through the use of real data. Results confirm the effectiveness of the proposed algorithm. [J1273]

"Dilation dependent matched filtering for SAR signal processing"

The relative motion between radar and targets in large time-bandwidth product synthetic aperture radar (SAR) induces serious dilation in the received signal. To process the received signal with serious dilation, a new technique called dilation dependent matched filtering (DDMF) is proposed to combine with the two-dimensional space frequency interpolation wavefront reconstruction (SFIWR) method. The DDMF-SFIWR method can effectively eliminate the impact of dilation when the illuminated area is relatively small, as verified by simulations and acoustic experiments. [J1274]

"Robust estimation of radar reflectivities in multibaseline InSAR"

We examine how to reliably exploit baseline diversity of a multichannel interferometric synthetic aperture radar (InSAR) system to overcome the layover problem. In practice, the baseline steering vectors will be imprecise, resulting in array miscalibration. We propose a nonparametric multilook approach based on robust Capon beamforming (RCB), allowing for uncertainty in the steering vectors. [J1275]

"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. [J1276]

"Generalized approach to resolution analysis in BSAR"

Bistatic synthetic aperture radars (BSARs) have been the focus of increasing research activity over the last decade. The generalized ambiguity function (GAF) of bistatic SAR is introduced here. First, the GAF for BSAR is represented in the delay-Doppler domain, and is then expanded to the spatial (coordinates) domain. From the GAF, comprehensive knowledge regarding the resolution of BSAR can be extracted, including the range and azimuth resolutions, as well as the area of a resolution cell of BSAR. These general results are also applied to the performance analysis of several particular BSAR geometries, including the space-surface-BSAR (SS-BSAR) system, to demonstrate the potential ability of this newly introduced system. [J1277]

"Four-component scattering model for polarimetric SAR image decomposition"

A four-component scattering model is proposed to decompose polarimetric synthetic aperture radar (SAR) images. The covariance matrix approach is used to deal with the nonreflection symmetric scattering case. This scheme includes and extends the three-component decomposition method introduced by Freeman and Durden dealing with the reflection symmetry condition that the co-pol and the cross-pol correlations are close to zero. Helix scattering power is added as the fourth component to the three-component scattering model which describes surface, double bounce, and volume scattering. This helix scattering term is added to take account of the co-pol and the cross-pol correlations which generally appear in complex urban area scattering and disappear for a natural distributed scatterer. This term is relevant for describing man-made targets in urban area scattering. In addition, asymmetric volume scattering covariance matrices are introduced in dependence of the relative backscattering magnitude between HH and VV. A modification of probability density function for a cloud of dipole scatterers yields asymmetric covariance matrices. An appropriate choice among the symmetric or asymmetric volume scattering covariance matrices allows us to make a best fit to the measured data. A four-component decomposition algorithm is developed to deal with a general scattering case. The result of this decomposition is demonstrated with L-band Pi-SAR images taken over the city of Niigata, Japan. [J1278]

"Initialization of Markov random field clustering of large remote sensing images"

Markov random field (MRF) clustering, utilizing both spectral and spatial interpixel dependency information, often improves classification accuracy for remote sensing images, such as multichannel polarimetric synthetic aperture radar (SAR) images. However, it is heavily sensitive to initial conditions such as the choice of the number of clusters and their parameters. In this paper, an initialization scheme for MRF clustering approaches is suggested for remote sensing images. The proposed method derives suitable initial cluster parameters from a set of homogeneous regions, and estimates the number of clusters using the pseudolikelihood information criterion (PLIC). The method works best for an image consisting of many large homogeneous regions, such as agricultural crops areas. It is illustrated using a well-known polarimetric SAR image of Flevoland in the Netherlands. The experiment shows a superior performance compared to several other methods, such as fuzzy C-means and iterated conditional modes (ICM) clustering. [J1279]

"Markov random field on region adjacency graph for the fusion of SAR and optical data in radargrammetric applications"

This paper deals with the estimation of an elevation model using a pair of synthetic aperture radar (SAR) images and an optical image in semiurban areas. The proposed method is based on a Markovian regularization of an elevation field defined on a region adjacency graph (RAG). This RAG is obtained by oversegmenting the optical image. The support for elevation hypotheses is given by the structural matching of features extracted from both SAR images. The regularization model takes into account discontinuities of buildings thanks to an implicit edge process. Starting from a good initialization, optimization is obtained through an iterated conditional mode algorithm. [J1280]

"Validation of the Shuttle Radar Topography Mission height data"

The Shuttle Radar Topography Mission (SRTM) provided data for detailed topographical maps of about 80% of the Earth's land surface. SRTM consisted of single-pass C- and X-band interferometric synthetic aperture radars (INSARs). In order to utilize SRTM data in remote sensing applications the data must be calibrated and validated. This paper presents The University of Michigan's SRTM calibration and validation campaign and our results using recently acquired C-band SRTM data of our calibration sites. An array of calibration targets was deployed with the intention of determining the accuracy of INSAR-derived digital elevation maps. The array spanned one of the X-band swaths and stretched from Toledo, OH to Lansing, MI. Passive and active targets were used. The passive targets included trihedrals and tophats. The locations in latitude, longitude, and elevation of the point targets were determined using differential GPS. We also acquired U.S. Geological Survey (USGS) digital elevation models (DEMs) to use in the calibration and validation work. The SRTM data used in this study are both Principal Investigator Processor (PI) data, which are not the refined final data product, and the ground data processing system (GDPS) data, which are a more refined data product. We report that both datasets for southeastern Michigan exceed the SRTM mission specifications for absolute and relative height errors for our point targets. A more extensive analysis of the SRTM GDPS data indicates that it meets the absolute and relative accuracy requirements even for bare surface areas. In addition, we validate the PI height error files, which are used to provide a statistical characterization of the difference between the SRTM GDPS and USGS DEM heights. The statistical characterization of the GDPS-USGS difference is of interest in forest parameter retrieval algorithms. [J1281]

"Effect of multiple scattering on the phase signature of wet subsurface structures: applications to polarimetric L- and C-band SAR"

We propose a two-layer integral equation model (IEM) model including multiple-scattering terms to reproduce the phase signature of buried wet structures that we observed on L-band synthetic aperture radar (SAR) images. We have good agreement between the extended (single+multiple scattering) IEM model and previous results obtained using a single-scattering IEM model combined with finite-difference time-domain simulations. We show that the multiple scattering not only significantly influences the copolarized phase difference but can also be related to the soil moisture content. In order to assess the validity of our extended model, we performed radar measurements on a natural outdoor site and showed that they could be fairly well fitted to the extended model. A parametric analysis presents the dependence of the copolarized phase difference on roughness parameters (rms height and correlation length) and radar parameters (frequency and incidence angle). Our study also shows that the phase signature should allow detection of buried wet structures down to a larger depth for C-band (3.8 m) than for L-band (2.6 m). This signature could then be used to map subsurface moisture in arid regions using polarimetric SAR systems. [J1282]

"Generalized ISAR-part I: an optimal method for imaging large naval vessels"

We describe a generalized inverse synthetic aperture radar (ISAR) process that performs well under a wide variety of conditions common to the naval ISAR tests of large vessels. In particular, the generalized ISAR process performs well in the presence of moderate intensity ship roll. The process maps localized scatterers onto peaks on the ISAR plot. However, in a generalized ISAR plot, each of the two coordinates of a peak is a fixed linear combination of the three ship coordinates of the scatterer causing the peak. Combining this process with interferometry will then provide high-accuracy three-dimensional location of the important scatterers on a ship. We show that ISAR can be performed in the presence of simultaneous roll and aspect change, provided the two Doppler rates are not too close in magnitude. We derive the equations needed for generalized ISAR, both roll driven and aspect driven, and test them against simulations performed in a variety of conditions, including large roll amplitudes. [J1283]

"Generalized ISAR-part II: interferometric techniques for three-dimensional location of scatterers"

This paper is the second part of a study dedicated to optimizing diagnostic inverse synthetic aperture radar (ISAR) studies of large naval vessels. The method developed here provides accurate determination of the position of important radio-frequency scatterers by combining accurate knowledge of ship position and orientation with specialized signal processing. The method allows for the simultaneous presence of substantial Doppler returns from both change of roll angle and change of aspect angle by introducing generalized ISAR ates. The first paper provides two modes of interpreting ISAR plots, one valid when roll Doppler is dominant, the other valid when the aspect angle Doppler is dominant. Here, we provide, for each type of ISAR plot technique, a corresponding interferometric ISAR (InSAR) technique. The former, aspect-angle dominated InSAR, is a generalization of standard InSAR; the latter, roll-angle dominated InSAR, seems to be new to this work. Both methods are shown to be efficient at identifying localized scatterers under simulation conditions. [J1284]

"Conference report-Radar 2005-A resounding success"

{no data available} [J1285]

"The Rician inverse Gaussian distribution: a new model for non-Rayleigh signal amplitude statistics"

In this paper, we introduce a new statistical distribution for modeling non-Rayleigh amplitude statistics, which we have called the Rician inverse Gaussian (RiIG) distribution. It is a mixture of the Rice distribution and the inverse Gaussian distribution. The probability density function (pdf) is given in closed form as a function of three parameters. This makes the pdf very flexible in the sense that it may be fitted to a variety of shapes, ranging from the Rayleigh-shaped pdf to a noncentral $\chi 2$-shaped pdf. The theoretical basis of the new model is quite thoroughly discussed, and we also give two iterative algorithms for estimating its parameters from data. Finally, we include some modeling examples, where we have tested the ability of the distribution to represent locale amplitude histograms of linear medical ultrasound data and single-look synthetic aperture radar data. We compare the goodness of fit of the RiIG model with that of the K model, and, in most cases, the new model turns out as a better statistical model for the data. We also include a series of log-likelihood tests to evaluate the predictive performance of the proposed model. [J1286]

"Analysis of geophysical networks derived from multiscale digital elevation models: a morphological

approach"

We provide a simple and elegant framework based on morphological transformations to generate multiscale digital elevation models (DEMs) and to extract topologically significant multiscale geophysical networks. These terrain features at multiple scales are collectively useful in deriving scaling laws, which exhibit several significant terrain characteristics. We present results derived from a part of Cameron Highlands DEM. [J1287]

"Observation of sea-ice thickness in the sea of Okhotsk by using dual-frequency and fully polarimetric airborne SAR (pi-SAR) data"

To investigate the possibilities of using dual-frequency, multipolarization synthetic aperture radar (SAR) data to monitor sea ice, we derived the relationship between various polarization characteristics and the physical parameters of sea ice. We discuss the frequency and polarization characteristics of the backscattering coefficients of sea ice and then characterize its thickness by comparing the corresponding backscattering coefficient for each polarization with the physical parameters of the ice. We first propose a methodology for classifying sea-ice types by using a polarimetric decomposition technique, before comparing an estimation of the sea-ice thickness with the corresponding dual-frequency, multipolarization SAR data. We utilized the backscattering ratio to estimate the thickness of the sea ice. This ratio canceled the effect of roughness on the backscattering. The method was validated using Pi-SAR (polarimetric and interferometric airborne SAR) observation data obtained at ground-truth sites. [J1288]

"Radiative transfer model for microwave bistatic scattering from forest canopies"

A bistatic forest scattering model is developed to simulate scattering coefficients from forest canopies. The model is based on the Michigan Microwave Canopy Scattering (MIMICS) model (hence called Bi-MIMICS) and uses radiative transfer theory, where the first-order fully polarimetric transformation matrix is used. Bistatic radar systems offer advantages over monostatic radar systems because of the additional information provided by the diversity of the geometry. By simulating the forest canopy scattering from multiple viewpoints, we can better understand how the forest scatterers' shape, orientation, density, and permittivity affect the canopy scattering. Bi-MIMICS is parametrized using selected forest stands with different canopy compositions and structure. The simulation results show that bistatic scattering is more sensitive to forest biomass changes than backscattering. Analyzing scattering contributions from different parts of the canopy gives us a better understanding of the microwave's interaction with the tree components. The ground effects can also be studied. Knowledge of the canopy's bistatic scattering behavior combined with additional synthetic aperture radar measurements can be used to improve forest parameter retrievals. The simulation results of the model provide the required information for the design of future bistatic radar systems for forest sensing applications. [J1289]

"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. [J1290]

"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. [J1291]

"Simulated Radar imagery of an ocean "Spiral Eddy""

Ocean submesoscale features appear to be widespread in the surface mixed layer and thus may be an important link in the energy pathway from large to small scales. An example is the "spiral eddy," for which several theories have been proposed. High-resolution radar imagery should be useful in testing these theories, but there have as yet been no simulations of radar imagery from first principles. As a step in this direction, we developed a capability to simulate imagery using a full-spectral calculation that includes the effects of both wave-current interaction and wave damping due to a surface film. A particular model of a spiral eddy is used to specify the surface velocity field and film distribution. Imagery is then simulated for a range of radar frequencies, wind speeds, initial film pressures, and relative radar view directions. For winds of 3-8 m/s and an initial film pressure of 0.5 mN/m, imagery for shorter radar wavelengths (X- and C-band) is dominated by the effects of film damping. For longer wavelengths (L- and P-band) wave-current interactions and film damping are of comparable magnitude; but for higher initial film pressures, the L- and P-band images also become dominated by film damping. L-band imagery, in particular, is highly sensitive to the initial value of film pressure, and such a result may have implications for determining properties of seawater films. Overall, the radar simulations produce surface patterns having characteristics that resemble radar imagery of real ocean spiral eddies. [J1292]

"Deorientation theory of polarimetric scattering targets and application to terrain surface classification"

Deorientation theory of polarimetric scattering targets is presented. Using a transformation of the target scattering vector, the target orientation is turned to a certain fixed state and polarimetric scattering of the transformed scattering vector shows the prominence of the generic characteristics of the target. A new set of parameters u, v, w, ψ is defined based on a deorientation of the target scattering vector. Numerical simulation of polarimetric scattering of nonspherical particles illustrates the meanings of the parameters u, v, w, ψ and the entropy H. An unsupervised classification scheme of the terrain surfaces is developed, which classifies the terrain surfaces using the set of u., v, H, and analyzes the orientation distribution of each class based on deorientation angle ψ. As examples, a SIR-C polarimetric image over China's Guangdong Hui-Yang district is classified into eight classes and a AirSAR polarimetric image over Canada's Boreal district is orientation-analyzed using our approach of deorientation and four parameters u, v, ψ, and H. [J1293]

"Current measurements by SAR along-track interferometry from a Space Shuttle"

We present one of the first studies on ocean current retrievals from interferometric synthetic aperture radar (InSAR) data acquired during the Shuttle Radar Topography Mission (SRTM) in February 2000. The InSAR system of SRTM was designed for high-resolution topographic mapping of the Earth's land surfaces, using two SAR antennas on a Space Shuttle with a cross-track separation of 60 m. An additional along-track antenna separation of 7 m resulted in an effective time lag of about 0.5 ms between the two images, which could theoretically be exploited for target velocity retrievals. However, the feasibility of ocean current measurements with SRTM has been questionable, since the time lag was much shorter than the theoretical optimum (about 3 ms at X-band) and the signal-to-noise ratio over water was quite low. Nevertheless, some X-band InSAR images of coastal areas exhibit clear signatures of tidal flow patterns. As an example, we discuss an image of the Dutch Wadden Sea. We convert the InSAR data into a line-of-sight current field, which is then compared with results of the numerical circulation model KUSTWAD. For tidal phases close to the conditions at the time of the SRTM overpass; we obtain correlation coefficients of up to 0.6 and rms differences on the order of 0.2 m/s. Furthermore we find that SRTM resolves current variations down to spatial scales on the order of 1 km. This is consistent with predictions of a numerical InSAR imaging model. Remaining differences between SRTM- and KUSTWAD-derived currents can be attributed mainly to residual motion errors in the SRTM data as well as to a limited representation of the conditions at the time of the SRTM overpass in the available KUSTWAD results. [J1294]

"Low VHF-band backscatter from coniferous forests on sloping terrain"

Low-frequency synthetic aperture radar (SAR) is a promising technique for stem volume retrieval, particularly for dense forests, due to the good penetration of forest canopies. However, it is well known that the dominant scattering mechanism, the trunk-ground dihedral interaction, decreases rapidly on sloping terrain. In this paper, we use low VHF-band SAR data, collected with CARABAS over dense coniferous forests in Sweden, to examine the effect of topography. Using flight passes with different headings, the effect of slope and aspect angle on backscatter is characterized. For tall trees (30 m), on the steepest slopes in the test-site (up to 12°), differences of up to 8 dB are observed between images acquired with different look directions relative to the slope. A physical model is developed to investigate the different scattering mechanisms and their sensitivity to

terrain slopes. The model shows that the trunk-ground scattering still dominates the response for large trees on moderate slopes, and a semiempirical model for the effect of topography on backscatter is proposed. The model shows good agreement with measurements, indicating the possibility of using it to compensate for the effects of sloping terrain when retrieving stem volume in coniferous forest. [J1295]

"Measurements on individual trees using multiple VHF SAR images"

Multiple VHF-band radar images from the airborne CARABAS-II system, retrieved with varying look direction to the imaged area, are coregistered and combined to improve spatial and radiometric resolution. Combined images over boreal forest in southern Sweden are used to identify and make backscatter measurements of individual trees. A coregistration scheme is proposed, and backscatter is compared to ground measurements of individual stem volume. It is found that the spatial resolution and radiometric precision could be significantly improved by combining the images coherently. A nearly linear relation between backscattered amplitude and individual stem volume for trees with a stem volume over 0.2 m3was found, which is in agreement with previous results at stand level. [J1296]

"Rectangular building extraction from stereoscopic airborne Radar images"

From the recent availability of images recorded by synthetic aperture radar (SAR) airborne systems, automatic results of digital elevation models (DEMs) on urban structures have been published lately. This paper deals with automatic extraction of three-dimensional (3-D) buildings from stereoscopic high-resolution images recorded by the SAR airborne RAMSES sensor from the French Aerospace Research Center (ONERA). On these images, roofs are not very textured whereas typical strong L-shaped echoes are visible. These returns generally result from dihedral corners between ground and structures. They provide a part of the building footprints and the ground altitude, but not the building heights. Thus, we present an adapted processing scheme in two steps. First is stereoscopic structure extraction from L-shaped echoes. Buildings are detected on each image using the Hough transform. Then they are recognized during a stereoscopic refinement stage based on a criterion optimization. Second, is height measurement. As most of previous extracted footprints indicate the ground altitude, building heights are found by monoscopic and stereoscopic measures. Between structures, ground altitudes are obtained by a dense matching process. Experiments are performed on images representing an industrial area. Results are compared with a ground truth. Advantages and limitations of the method are brought out. [J1297]

"The Rolling Radar"

In the search for a better rotating radar, a self-supporting array that rolls like a wheel can improve mechanical reliability and return higher-definition target resolution. The Rolling Radar concept evolved from the need to design and build a large rotating 3D radar as an alternative to multifaceted fixed radar installations, or large, expensive rotating radar systems. However, the physical act of rotating massive structures weighing many tons introduces a host of load bearing and other mechanical reliability problems. An alternative design needed to be conceptualized. The new concept places the radar array inside a large wheel attached to an axle. A smaller wheel affixed to the axle's other end provides support when both wheels simultaneously roll along electrified concentric rails in order to scan 360 degrees. The array wheel propels itself via a simple gravity drive consisting of a magnetic carriage that rides an electromagnetic rail around the inside circumference of the large array wheel. Displacement of its own weight causes the wheel (and the entire axle) to roll around the railed track with no visible external means of motion. The Rolling Radar achieves its initial objective-to improve mechanical reliability-because the array wheel is self-supporting, which eliminates the need for a large support structure and bearing. There is also no need for traditional electrical slip rings, rotating fluid couplers, motors or gearboxes. With fewer moving parts (compared with conventional rotating radars), reliability is increased and life cycle costs are reduced. Another important benefit is the Rolling Radar's electronic look back capability, and the ability to achieve higher spatial resolution than standard 3D radar. This occurs because the act of rolling about its axis and simultaneously rotating about a circumference sweeps an area larger than the array's physical aperture. The effect is similar to spotlight-mode synthetic aperture radar (SAR), a technique commonly used to produce high-resolution radar maps. The Rolling Radar concept was initially developed to address reliability, life cycle cost, and weight. Although still in the concept development phase, the Rolling Radar shows great promise of increasing functionality while improving resolution and- reliability, and in its simplicity of design. Both the reliability and performance gains are in the process of being evaluated. [J1298]

"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. [J1299]

"Quality map extraction for radar interferometry using weighted window"

Success of a phase unwrapping algorithm for radar interferometry depends on availability of a good quality map. Many quality map extraction algorithms are available, and most methods use a fixed window around each pixel. When there are noise corrupted pixels, the fixed window sometimes yield poor results, and so a weighted window is proposed for use for quality map extraction. [J1300]

"Ultra high resolution spaceborne SAR processing"

The accuracy requirements of the azimuth signal for spaceborne synthetic aperture radar (SAR) processing is analysed. Degradations of simulated extended scenes and point targets are studied at high squint or if erroneous Doppler parameters are used. At a resolution less than 1 m for X-band it is shown that the azimuth signal for spaceborne SAR geometry should be used. It is found that the fourth-order extended exact transfer function (EETF4) is a good candidate for demanding SAR processing. [J1301]

"Airborne high-resolution ISAR imaging of ship targets at sea"

We address the problem of airborne high resolution two-dimensional inverse synthetic aperture radar (ISAR) side-view imaging of ship targets. Using a simple model of the ship motions avoids the use of advanced joint-time frequency (JTF) transforms. A robust processing scheme including motion estimation and correction, optimal processing time and duration estimation and target shape extraction are developed. We stress the fact that the robustness of this processing leads to a single ISAR image analysis and that no merging of data from a set of radar images is necessary. [J1302]

"Analysis and statistical characterization of interferometric SAR signals based on the power spectral density function"

Interferometric signal analysis is applied in many fields including filtering, parameter estimation, and interferogram processing optimization. Sample applications include the determination of terrain and orbit parameters, interferogram phase estimation, and optimal processing of synthetic aperture radar (SAR) interferograms. In this communication, the relevance of the power spectral density to interferometric SAR mode exploration and interferogram multilooking or filtering is discussed. The interferometric SAR modes include strip-map, scansar, and spotlight. For the verification of the multilooking characteristics of SAR interferograms, two frequently used filters serve as empirical reference. Based on a simplified interferometric system model and Guassian distributed scatterers, the power spectral density description is developed. [J1303]

"Unifying regularization and Bayesian estimation methods for enhanced imaging with remotely sensed Data-part II: implementation and performance issues"

The fused Bayesian-regularization (FBR) method from a companion paper provides a rigorous theoretical formalism for optimal estimation of the power spatial spectrum pattern (SSP) of the wave field scattered from the probing surface as it is required for enhanced radar imaging of the remotely sensed scenes. Being nonlinear and solution-dependent, the optimal FBR method requires extremely complex nonlinear solution-dependent operator inversions and, therefore, cannot be recommended as a numerically realizable estimator of the SSP. Here, we design a family of robust easy-to-implement FBR algorithms, provide the relevant computational recipes, and discuss their performances. We comment on the practical aspects of the robustified FBR estimators, such as numerical implementation and improvement in the output SNR. The advantage in using the proposed robust FBR method is demonstrated through simulations of enhancing the SAR images formed using the conventional matched filtering of the trajectory signal. [J1304]

"Unifying regularization and Bayesian estimation methods for enhanced imaging with remotely sensed Data-part I: theory"

The problem of estimating, from one sampled realization of the remotely sensed data signal, the power spatial spectrum pattern (SSP) of the wave field scattered from the probing surface is treated as it is required for enhanced radar imaging of the remotely sensed scenes. Specifically, we propose to unify the Bayesian estimation strategy with the maximum-entropy (ME) information-theoretic principle for incorporating the prior knowledge through developing the fused Bayesian-regularization (FBR) technique for SSP estimation. The first aspect of the proposed approach concerns the ME-based incorporating the a priori information about the geometrical properties of an image to tailor the metrics structure in the solution space to the problem at hand. The second aspect alleviates the problem ill-posedness associated with preserving the boundary values, calibration, and spectral a priori fixed model properties of an image through the regularizing projection constraints imposed on the solution. When applied to SSP estimation without incorporating the metrics and regularization considerations, the procedure leads to the previously derived maximum-likelihood method. When such considerations are incorporated, the optimal FBR technique leads to a new nonlinear imaging algorithm that implies adaptive formation of the second-order sufficient statistics of the data, their smoothing, and projection applying the composite regularizing window operator. We provide analytical techniques to find these statistics and windows, and the optimal FBR estimator itself. Numerical recipes, performance issues, and simulation examples are treated in a companion paper. [J1305]

"Contrast definition for optical coherent polarimetric images"

We consider polarimetric images formed with coherent waves, such as in laser-illuminated imagery or synthetic aperture radar. A definition of the contrast between regions with different polarimetric properties in such images is proposed, and it is shown that the performances of maximum likelihood-based detection and segmentation algorithms are bijective functions of this contrast parameter. This makes it possible to characterize the performance of such algorithms by simply specifying the value of the contrast parameter. [J1306]

"River dike deformation measurement with airborne SAR"

Due to extremely high water levels or extremely dry periods, river dikes can deform and eventually burst. The deformation can be measured with repeat-pass synthetic aperture radar (SAR) interferometry. Two flights (5.5-day interval) with an airborne C-band SAR were carried out to verify a particular case. During the second flight, the dike was deliberately deformed. Interferogram analyses showed that the dike deformed by at most 2 mm on this day, in approximate agreement with tachymeter measurements. Corner reflector analysis showed a deformation of about 1 cm during the 5.5-day interval, in good agreement with ground measurements. [J1307]

"Migration through resolution cell compensation in ISAR imaging"

Range-Doppler (RD) processing is widely used in conventional inverse synthetic aperture radar (ISAR) imaging. The unwanted translational motion of moving targets is compensated by envelope alignment and autofocus. For existing ISAR imaging algorithms, the scatterers' migration through resolution cells (MTRC) caused by the rotational motion is usually ignored. With the improvement of resolution or the increase of target size, MTRC cannot be neglected. In this letter, the keystone formatting algorithm developed in SAR is used for the MTRC compensation in ISAR. Before the keystone formatting, coherent processing must be performed on the raw phase history data. An effective approach is proposed for this kind of coherent processing. Numerical examples are provided to demonstrate the performance of the proposed approach. [J1308]

"Maximum a posteriori estimation of height profiles in InSAR imaging"

We present a statistical method to solve the height estimation problem in interferometric synthetic aperture radar (InSAR) applications. It is based on the use of multifrequency SAR raw datasets obtained by partitioning in subbands the available raw data spectrum, and on a Bayesian estimator using Markov random fields to model the a priori distribution of the unknown images. The method allows recovering topographic profiles affected by strong height discontinuities and allows to perform efficient noise rejections. [J1309]

"Fuzzy-coded space-frequency quantization for SAR data compression"

In this letter, we propose a new image coding technique, which is a combination of space frequency quantization and a context-based modeling using fuzzy logic. The compression results showed that the proposed coder outperforms the state-of-the-art coders in the rate-distortion sense for compression of processed synthetic aperture radar amplitude data. [J1310]

"Design and implementation of near-field, wideband synthetic aperture beamformers"

A coarray-based near-field, wideband synthetic aperture beamformer using stepped-frequency signal synthesis and post-data acquisition processing is presented. While coarray techniques offer significant reduction in the number of array elements for a given angular resolution, the hybrid subarray-stepped frequency realization of wideband systems simplifies implementations and offers flexibility in beamforming. Proof of concept is provided using real data collected in an anechoic chamber for several pulse shapes and array weightings. [J1311]

"Detection, location, and imaging of fast moving targets using multifrequency antenna array SAR"

In this correspondence, we generalize the linear antenna array synthetic aperture radar (SAR) from transmitting single-wavelength signals to transmitting multiple-wavelength signals (called multifrequency antenna array SAR). We show that, using multifrequency antenna array SAR, not only the clutters can be suppressed but also the locations of both slow and fast moving targets can be accurately estimated: A robust Chinese remainder theorem (CRT) is developed and used for the location estimation of fast and slowly moving targets. Simulations of SAR imaging of ground moving targets are presented to show the effectiveness of the multifrequency antenna array SAR imaging algorithm. [J1312]

"A pod-based dual-beam SAR"

A dual-beam along-track interferometric synthetic aperture radar that is entirely self-contained within an aircraft pod has been developed by the University of Massachusetts to study sea surface processes in coastal regions. The radar operates at 5.3 GHz with a bandwidth of up to 25 MHz. System hardware is described. Initial test flights aboard the National Oceanic and Atmospheric Administration's WP-3D research aircraft were performed to evaluate system performance over land and water surfaces. Imagery were collected for fore and aft squinted beams, though no interferometric data were collected. Notable look-angle dependences are observed in the sea surface normalized radar cross section under very low wind conditions. [J1313]

"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. [J1314]

"Interpolation-free coregistration and phase-correction of airborne SAR interferograms"

This letter discusses the detection and correction of residual motion errors that appear in airborne synthetic aperture radar (SAR) interferograms due to the lack of precision in the navigation system. As it is shown, the effect of this lack of precision is twofold: azimuth registration errors and phase azimuth undulations. Up to now, the correction of the former was carried out by estimating the registration error and interpolating, while the latter was based on the estimation of the phase azimuth undulations to compensate the phase of the computed interferogram. In this letter, a new correction method is proposed, which avoids the interpolation step and corrects at the same time the azimuth phase undulations. Additionally, the spectral diversity technique, used to estimate registration errors, is critically analyzed. Airborne L-band repeat-pass interferometric data of the German Aerospace Center (DLR) experimental airborne SAR is used to validate the method. [J1315]

"The contribution of multitemporal SAR data in assessing hydrological parameters"

The sensitivity of radar backscattering to the principal hydrological parameters, such as vegetation biomass, soil moisture, and surface roughness, is discussed. Results obtained by using multifrequency synthetic aperture radar (SAR) data measured by the Jet Propulsion Laboratory Airborne Synthetic Aperture Radar, Spaceborne Imaging Radar-C, and European Remote Sensing 1/2 sensors are summarized. The sensitivity of L- and C-bands to spatial variations of plant and soil parameters is masked by the presence of surface roughness, which

in turn affects the radar signal. However, from the observation of data collected at different dates and averaged over a relatively wide area that includes several fields, the correlation to soil moisture and vegetation biomass is found to be significant, since the effects of spatial variations are smoothed. On the other hand, the sensitivity to surface roughness becomes appreciable when multitemporal data are averaged in time, thus reducing the effects of temporal moisture variations. [J1316]

"Generalized optimization of polarimetric contrast enhancement"

A generalized optimization of polarimetric contrast enhancement (GOPCE) is proposed in this letter. For this problem, it is not only necessary to find the optimal polarization states such that the received power ratio of a desired target and clutter is maximal, but also necessary to find three optimal coefficients such that the ratio of two factors associated with the desired target and clutter is maximal, where both the factors consist of three parameters, i.e., the Cloude entropy and two special similarity parameters. The optimal coefficients of the GOPCE are obtained by solving an eigenvalue problem. Using an example, we demonstrate that the GOPCE can be employed for detecting roads in a forest area by using polarimetric synthetic aperture radar data. [J1317]

"Ship detection based on coherence images derived from cross correlation of multilook SAR images"

A new simple technique is presented to extract ships from synthetic aperture radar (SAR) images. The procedure is to compute the cross-correlation values between two images extracted by moving windows of a small size from the multilook SAR intensity (or amplitude) images. A coherence image, consisting of the cross-correlation values of the intensity images, is then produced. Ships are deterministic targets, so that their interlook subimages possess higher degree of coherence than the uncorrelated random images of the surrounding sea surface. The main advantage of this method over the conventional constant false-alarm rate is its ability to detect, under favorable conditions, "invisible" images of ships embedded in the speckled image of the sea surface. The technique is tested using a RADARSAT-1 image in which one known and several unknown ships are present. The use of complex images and the exploitation of short decorrelation times of small-scale ocean waves to obtain an extra look are also discussed. [J1318]

"Special issue on synthetic aperture radar imaging of the ocean surface"

{no data available} [J1319]

"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. [J1320]

"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. [J1321]

"Boreal forest coherence-based measures of interferometric pair suitability for operational stem volume retrieval"

The performance of interferometric synthetic aperture radar (INSAR)-based boreal forest stem volume retrieval is strongly affected by weather conditions around the time of the SAR image acquisitions. Since weather conditions cannot be controlled, the suitability of a particular interferometric pair for stem volume retrieval can only be assessed afterward. In this letter, four objective measures based on observed forest coherence were compared

in assessing the suitability of interferometric pairs for stem volume retrieval. These suitability measures can be used to identify the best and worst pairs, i.e., the ones with the most and least favorable weather conditions. Stem volume retrievals were performed using single European Remote Sensing (ERS-1/2) Tandem interferometric pairs by inverting a backscattering-coherence model for boreal forests. A total of 14 ERS Tandem image pairs acquired in varying weather conditions were studied, and the stem volume retrieval performance was assessed against ground-based stem volume estimates on 134 boreal forest stands. Stem volume retrieval performance as measured by R2-values between INSAR-estimated stem volumes and ground truth was found to be directly proportional to boreal forest coherence. The interferometric coherence-contrast (ICC), i.e., the difference in coherence between sparsest and densest boreal forest stands was found to be the best of the four studied suitability measures. The ICC could be used as a suitability parameter in the selection of the best interferometric pairs for operational boreal forest stem volume retrieval. [J1322]

"Ground-based SAR interferometry for terrain mapping: theory and sensitivity analysis"

This short communication studies the problem of terrain mapping by means of the ground-based synthetic aperture radar (GB-SAR) interferometry technique. A phase-to-height relationship tailored for the GB-SAR interferometric configuration is introduced and verified by a simulated analysis. A sensitivity study is carried out aiming to optimize the use of a GB-SAR system for the terrain mapping and to derive the precision of this technique. [J1323]

"Multibaseline ATI-SAR for robust ocean surface velocity estimation"

An open problem of along-track interferometry (ATI) for synthetic aperture radar (SAR) sensing of ocean surface currents is the need of ancillary wind information for inversion of Doppler centroid measurements, that have to be compensated for the propagation velocity of advancing and/or receding Bragg scatterers. We propose three classes of estimators which exploit multibaseline (MB) ATI acquisition and Doppler resolution for robust data inversion under different degrees of a priori information about the wind direction and the value of the characteristic Bragg frequency. Performance analysis and comparison with conventional ATI show that the proposed MB estimators can produce accurate velocity estimates in the absence of detailed ancillary data. [J1324]

"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. [J1325]

"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. [J1326]

"Displaced ping imaging autofocus for a multi-hydrophone SAS"

The problems caused by random sway errors in the tow-path of a single hydrophone, synthetic aperture sonar (SAS) are well known. If these horizontal displacement errors are left uncorrected and the tow-path is assumed to be straight, they have a devastating effect on the quality of the reconstructed image. Although on-board navigation instruments can help measure the gross departures from the straight path, sub-wavelength residual sway errors still corrupt the imaging process. More recent SAS systems have an array of receiving hydrophones and are effected by both random sway and yaw errors and again navigation instruments cannot always estimate the yaw and sway to the accuracy required to remove the effects. Current autofocus (sometimes called 'micronavigation') techniques to estimate the sway and yaw from the raw (i.e. distorted) data rely on there being significant overlap of the hydrophone array between pings and so the SAS travels at much less than its maximum allowable speed (as determined by spatial sampling considerations). The requirement for significant overlap compromises the maximum achievable mapping rate. The authors show how the distorted raw data from a multi-hydrophone SAS can be used to estimate the sway and yaw even when the sonar is travelling at the maximum allowable speed. The mathematical framework is outlined using the wavenumber algorithm, modified for a multiple hydrophone-receiver SAS, as the final method of image reconstruction. The nub of the proposed autofocusing algorithm is the formation of individual images from each separate ping. These single-ping images from adjacent pings are then cross-correlated to determine how the sonar has moved between pings. Thus the differential yaw and differential sway can be estimated from a series of displaced single ping images and this process forms the basis of displaced ping imaging autofocus (DPIA). Using simulated, distorted SAS data as input, the proposed DPIA algorithm shows promise in that it can estimate yaw with sufficient accuracy to restore distorted SAS images close to their diffraction limit. [J1327]

"Acoustooptic correlation processing in random noise radar"

A new technique has been developed that permits coherent processing of backscatter data acquired by a radar system transmitting ultrawideband (UWB) random noise waveforms and processing the received signals using a heterodyne correlation receiver. This technique has been used in various applications, such as Doppler estimation, polarimetry, interferometry, buried-object detection, synthetic aperture radar (SAR) imaging, inverse SAR (ISAR) imaging, foliage penetration imaging, etc. One of the major advantages of the noise radar system is its inherent immunity to external interference. In such a radar system, the correlation receiver consists of a programmable variable-delay line, a mixer followed by a lowpass filter. One drawback of this type of receiver is that it sequentially processes the target returns, thus limiting the system response time and the dynamic detection range. We have recently integrated a novel heterodyning acoustooptic (AO) time-integrating correlation receiver that uses a traveling-wave AO deflector for wideband signal processing. The transmit waveform modulates the intensity of a laser diode that is multiplied by the traveling-wave modulation produced by the AO deflector, and the correlation is time-integrated on a charge-coupled device photodetector array. The principal advantages of this AO correlation receiver are its ability to generate a large range of variable delays, as well as to perform the signal correlation operation in parallel. Compared to the conventional sequential correlation receiver using a variable stepped delay line and correlator, implementation of the AO variable-delay line and heterodyning correlator can 1) reduce the processing time and greatly increase the processing gain due to the parallel correlation mechanism and 2) greatly increase the number of range cells depending on the number of resolvable spots of the AO deflector. This results in rapid data acquisition, longer integration time on parallel detector pixels (3000 pixels), and improved SNR. It is also shown that this radar has more range gates (up to 1000), which ultimately improves the detectable range resolution. Furthermore, several field experiments performed with different target arrangements demonstrate that the acoustooptic variable-delay line and c-orrelator is able to profile various targets instantaneously and with very high SNR. [J1328]

"Radar penetration imaging using ultra-wideband (UWB) random noise waveforms"

Ultra-wideband (UWB) radar has been proven to be a very powerful tool for high-resolution penetration imaging of obscured objects. The authors discuss a radar penetration imaging technique using UWB random noise waveforms. The theoretical foundations for random noise radar, the random noise radar imaging model, and the synthetic aperture radar (SAR) image formation algorithm are presented. Typical field test results using an experimental random noise radar system are demonstrated. [J1329]

"Flight path strategies for 3-D scene reconstruction from bistatic SAR"

Proper design of receiver flight paths allows three-dimensional information to be encoded in sensed bistatic SAR phase history data. The authors show how the flight path taken by the receiving platform determines the resolution of nonparametric scene reconstructions and determines the variance of three-dimensional scattering centre location parameter estimates. Based on these relationships, a bistatic SAR data collection strategy can be designed, involving a nonlinear receiver trajectory that allows preservation of three-dimensional scene information. [J1330]

"Estimation of three-dimensional motion parameters in interferometric ISAR imaging"

In most interferometric inverse synthetic aperture radar (InISAR) systems, the pixels between two ISAR images derived from corresponding antennas usually do not register properly. As such, correct phase difference between two ISAR images could not be obtained. A three-dimensional (3-D) motion compensation method, or 3-D focusing, is put forward in this paper. With a multiple antenna pair configuration, the angular motion parameters both in the azimuth and pitching directions are accurately estimated without the usual phase-unwrapping processing. As such, there is no phase ambiguity in the inteferometric systems. The angle motion trajectory measurement here is based on the range profiles (or spatial spectrum) so that the "angle scintillation" phenomenon can be effectively suppressed. The angular motion trajectory is then obtained by curve fitting of the spatial spectrum (range profile in the cross-range direction). The compensated ISAR images are registered accurately. Finally, the simulation data are used to illustrate the accuracy of the proposed method. [J1331]

"Terrain elevation mapping results from airborne spotlight-mode coherent cross-track SAR stereo"

Coherent cross-track synthetic aperture radar (SAR) stereo is shown to produce high-resolution three-dimensional maps of the Earth surface. This mode utilizes image pairs with common synthetic apertures but different squint angles allowing automated stereo correspondence and disparity estimation using complex correlation calculations. This paper presents two Ku-band, coherent cross-track stereo collects over rolling and rugged terrain. The first collect generates a digital elevation map (DEM) with 1-m posts over rolling terrain using complex SAR imagery with spatial resolution of 0.125 m and a stereo convergence angle of 13.8°. The second collect produces multiple DEMs with 3-m posts over rugged terrain utilizing complex SAR imagery with spatial resolutions better than 0.5 m and stereo convergence angles greater than 40°. The resulting DEMs are compared to ground-truth DEMs and relative height root-mean-square, linear error 90-percent confidence, and maximum height error are reported. [J1332]

"A STAP overview"

This tutorial provides a brief overview of space-time adaptive processing (STAP) for radar applications. We discuss space-time signal diversity and various forms of the adaptive processor, including reduced-dimension and reduced-rank STAP approaches. Additionally, we describe the space-time properties of ground clutter and noise-jamming, as well as essential STAP performance metrics. We conclude this tutorial with an overview of some current STAP topics: space-based radar, bistatic STAP, knowledge-aided STAP, multi-channel synthetic aperture radar and non-sidelooking array configurations. [J1333]

"A systematic comparison of QuikSCAT and SAR ocean surface wind speeds"

We performed a systematic comparison of wind speed measurements from the SeaWinds QuikSCAT scatterometer and wind speeds computed from RADARSAT-1 synthetic aperture radar (SAR) normalized radar cross section measurements. These comparisons were made over in the Gulf of Alaska and extended over a two-year period, 2000 and 2001. The SAR wind speed estimates require a wind direction to initialize the retrieval. Here, we first used wind directions from the Navy Operational Global Atmospheric Prediction System (NOGAPS) model. For these retrievals, the standard deviation between the resulting SAR and QuikSCAT wind speed measurements was 1.78 m/s. When we used the QuikSCAT-measured wind directions to initialize the inversion, comparisons improve to a standard deviation of 1.36 m/s. We used these SAR-scatterometer

comparisons to generate a new C-band horizontal polarization model function. With this new model function, the wind speed inversion improves to a standard deviation of 1.24 m/s with no mean bias. These results strongly suggest that SAR and QuikSCAT measurements can be combined to make better high-resolution wind measurements than either instrument could alone in coastal areas. [J1334]

"A fast physical optics (FPO) algorithm for high frequency scattering"

A novel algorithm referred as the fast physical optics (FPO) for computing the back-scattered field over a range of aspect angles and frequencies is presented. The computation is performed in the framework of the conventional physical optics approximation appropriate for the high frequency scattering regime. The proposed algorithm is, also, directly applicable to fixed angle bistatic configurations and a variety of single scattering formulations. The method comprises two steps. First, a decomposition of the scatterer into subdomains and computation of the pertinent scattering characteristics of each subdomain. Second, interpolation, phase-correction and aggregation of the scattering patterns of the subdomains into the final pattern of the whole body. A multilevel algorithm is formulated via a recursive application of the domain decomposition and aggregation steps. The computational structure of the multilevel algorithm resembles that of the FFT. The proposed method is especially suited for generation of synthetic data for radar imaging simulation. [J1335]

"A fast physical optics (FPO) algorithm for double-bounce scattering"

The fast physical optics (FPO) method for computing back-scattered fields over ranges of aspect angles and frequencies is extended to encompass double-bounce scattering. Computations are performed within the framework of the physical optics approximation appropriate in the high-frequency regime. The proposed algorithm is directly applicable to fixed angle bistatic configurations and a variety of double scattering settings. The method comprises two steps: 1) decomposition of the scatterer into subscatterers and computation of the scattering amplitudes of all pairs of subscatterers and 2) interpolation, phase correction, and aggregation of the scattering amplitude patterns of all subscatterer pairs into the pattern of the entire scatterer. The proposed method is especially suited for generating synthetic data for radar imaging simulations. [J1336]

"Retrievals of underlying surface roughness and moisture from polarimetric pulse echoes in the specular direction through stratified vegetation canopy"

The time-dependent Mueller matrix solution of vector radiative transfer for stratified random media of nonspherical scatterers is presented. Copolarized and cross-polarized bistatic scattering for a polarized pulse incidence are numerically simulated. Numerical results well demonstrate volumetric and surface scattering mechanism and depict the fraction distribution of random scatterers of stratified random media. The peak tails in polarized echoes due to wave reflections from the underlying surface can be identified. Its copolarized peaks in the specular direction are employed for simultaneous retrievals of the underlying surface roughness and moisture with the presence of stratified vegetation canopy. [J1337]

"The Bayesian hierarchical classifier (BHC) and its application to short vegetation using multifrequency polarimetric SAR"

Given an image of a scene comprised of a number of distinct terrain classes, the optimum Bayesian classifier (OBC) provides the highest possible classification accuracy of the imaged scene, provided we have a priori knowledge of the probability density function (pdf) of the sensor's output for each terrain class. If the imaging sensor consists of multiple channels, application of OBC requires knowledge of the joint pdf of the observations made by all the channels. In practice, the volume of data needed in order to generate an accurate multidimensional pdf far exceeds the size of available datasets. The data-size requirement may be relaxed by assuming the pdfs to be Gaussian in form, but such an assumption leads to suboptimum classification performance. This paper addresses the data size issue by (1) taking advantage of the maximum-entropy density estimation (MEDE) technique introduced in a companion paper and (2) using marginal pdfs in a hierarchical approach. Using multidate synthetic aperture radar observations, it was shown that the Bayesian hierarchical classifier introduced in this paper can classify short vegetation classes with an accuracy of 93%, without retraining, compared with an accuracy of 84% for the maximum-likelihood estimator (with Gaussian assumption) and only 74% with ISODATA. [J1338]

"Doppler centroid estimation for ScanSAR data"

We introduce a novel accurate technique to estimate the Doppler centroid (DC) in ScanSAR missions. The technique starts from the ambiguous DC measures in the subswaths and uses a method alternative to standard unwrapping to undo the jumps in estimates induced by modulo pulse repetition frequency (PRF) measures. The

proposed alternative is less error prone than the usual unwrapping techniques. Doppler Ambiguity is then solved by implementing a maximum-likelihood estimate that exploits the different PRFs used in different subswaths. An azimuth pointing of the antenna that does not change with subswaths, or that changes in a known way, is assumed. However, if the PRF diversity is strong enough, unknown small changes in azimuth pointing are tolerated and accurately estimated. This estimator is much simpler and more efficient, than those in the literature. Results achieved with both RADARSAT 1 and ENVISAT ScanSAR data are reported. [J1339]

"On neural network algorithms for retrieving forest biomass from SAR data"

We discuss the application of neural network algorithms (NNAs) for retrieving forest biomass from multifrequency (L- and P-band) multipolarization (hh, vv, and vv) backscattering. After discussing the training and pruning procedures, we examine the performances of neural algorithms in inverting combinations of radar backscattering coefficients at different frequencies and polarization states. The analysis includes an evaluation of the expected sensitivity of the algorithm to measurement noise stemming both from speckle and from fluctuations of vegetation and soil parameters. The NNA accomplishments are compared with those of linear regressions for the same channel combinations. The application of NNAs to invert actual multifrequency multipolarization measurements reported in literature is then considered. The NNA retrieval accuracy is now compared with those yielded by linear and nonlinear regressions and by a model-based technique. A direct analysis of the information content of the radar measurements is finally carried out through an extended pruning procedure of the net. [J1340]

"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. [J1341]

"Rank-order filters for FOPEN target detection"

Issues associated with the radar detection of military targets that are concealed or camouflaged by forest clutter are described. The specific sensor platform can be categorized as an ultrawideband (UWB) foliage penetration (FOPEN) synthetic aperture radar (SAR). The discussion illustrates the fact that many contemporary approaches to FOPEN target detection are computationally intensive and/or require the implementation of elaborate training procedures. Alternative approaches, based the application of a set of simple rank-order filters (alternately known as order statistical or L filters), are presented. Initial results indicate impressive performance levels (in terms of probability of detection as a function of false-alarm rate) with respect to baseline constant false-alarm rate computations. A number of avenues for future investigations are cited. [J1342]

"A generalized Lloyd-type algorithm for adaptive transform coder design"

In this paper, we establish a probabilistic framework for adaptive transform coding that leads to a generalized Lloyd type algorithm for transform coder design. Transform coders are often constructed by concatenating an ad hoc choice of transform with suboptimal bit allocation and quantizer design. Instead, we start from a probabilistic latent variable model in the form of a mixture of constrained Gaussian mixtures. From this model, we derive an transform coder design algorithm, which integrates optimization of all transform coder parameters. An essential part this algorithm is our introduction of a new transform basis-the coding optimal transform-which, unlike commonly used transforms, minimizes compression distortion. Adaptive transform coders can be effective for compressing databases of related imagery since the high overhead associated with these coders can be amortized over the entire database. For this work, we performed compression experiments on a database of synthetic aperture radar images. Our results show that adaptive coders improve compressed signal-to-noise ratio (SNR) by approximately 0.5 dB compared with global coders. Coders that incorporated the coding optimal transform had the best SNRs on the images used to develop the coder. However, coders that incorporated the discrete cosine transform generalized better to new images. [J1343]

"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. [J1344]

"Wheat cycle monitoring using radar data and a neural network trained by a model"

This paper describes an algorithm aimed at monitoring the soil moisture and the growth cycle of wheat fields using radar data. The algorithm is based on neural networks trained by model simulations and multitemporal ground data measured on fields taken as a reference. The backscatter of wheat canopies is modeled by a discrete approach, based on the radiative transfer theory and including multiple scattering effects. European Remote Sensing satellite synthetic aperture radar signatures and detailed ground truth, collected over wheat fields at the Great Driffield (U.K.) site, are used to test the model and train the networks. Multitemporal, multifrequency data collected by the Radiometer-Scatterometer (RASAM) instrument at the Central Plain site are used to test the retrieval algorithm. [J1345]

"Comparing cooccurrence probabilities and Markov random fields for texture analysis of SAR sea ice imagery"

This paper compares the discrimination ability of two texture analysis methods: Markov random fields (MRFs) and gray-level cooccurrence probabilities (GLCPs). There exists limited published research comparing different texture methods, especially with regard to segmenting remotely sensed imagery. The role of window size in texture feature consistency and separability as well as the role in handling of multiple textures within a window are investigated. Necessary testing is performed on samples of synthetic (MRF generated), Brodatz, and synthetic aperture radar (SAR) sea ice imagery. GLCPs are demonstrated to have improved discrimination ability relative to MRFs with decreasing window size, which is important when performing image segmentation. On the other hand, GLCPs are more sensitive to texture boundary confusion than MRFs given their respective segmentation procedures. [J1346]

"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. [J1347]

"Image registration by "Super-curves""

We solve the 2-D affine image registration problem by curve matching and alignment. Our approach starts with a super-curve, which is formed by superimposing two affine related curves in one coordinate system. We use B-spline fusion technique to find a single B-spline approximation of the super-curve and a registration between the two curves simultaneously. This approach achieves superior accuracy and efficiency in curve matching and alignment. We then address the occlusion problem by finding partial match between the curves segmented using

inflections and cusps, which are affine invariant. The combination of edge detection and curve alignment lead to accurate image registration. [J1348]

"Quantitative retrieval of soil moisture content and surface roughness from multipolarized radar observations of bare soil surfaces"

A semiempirical polarimetric backscattering model for bare soil surfaces is inverted directly to retrieve both the volumetric soil moisture content Mvand the rms surface height s from multipolarized radar observations. The rms surface height s and the moisture content Mvcan be read from inversion diagrams using the measurements of the cross-polarized backscattering coefficient σvh0and the copolarized ratio p(=σhh0/σvv0). Otherwise, the surface parameters can be estimated simply by solving two equations (σvh0and p) in two unknowns (Mvand s). The inversion technique has been applied to the polarimetric backscattering coefficients measured by ground-based polarimetric scatterometers and the Jet Propulsion Laboratory airborne synthetic aperture radar. A good agreement was observed between the values of surface parameters (the rms height s, roughness parameter ks, and the volumetric soil moisture content Mv) estimated by the inversion technique and those measured in situ. [J1349]

"Quantitative statistical assessment of conditional models for synthetic aperture radar"

Many applications of object recognition in the presence of pose uncertainty rely on statistical models-conditioned on pose-for observations. The image statistics of three-dimensional (3-D) objects are often assumed to belong to a family of distributions with unknown model parameters that vary with one or more continuous-valued pose parameters. Many methods for statistical model assessment, for example the tests of Kolmogorov-Smirnov and K. Pearson, require that all model parameters be fully specified or that sample sizes be large. Assessing pose-dependent models from a finite number of observations over a variety of poses can violate these requirements. However, a large number of small samples, corresponding to unique combinations of object, pose, and pixel location, are often available. We develop methods for model testing which assume a large number of small samples and apply them to the comparison of three models for synthetic aperture radar images of 3-D objects with varying pose. Each model is directly related to the Gaussian distribution and is assessed both in terms of goodness-of-fit and underlying model assumptions, such as independence, known mean, and homoscedasticity. Test results are presented in terms of the functional relationship between a given significance level and the percentage of samples that wold fail a test at that level. [J1350]

"Homomorphic wavelet-based statistical despeckling of SAR images"

In this paper, we introduce the homomorphic Γ-WMAP (wavelet maximum a posteriori) filter, a wavelet-based statistical speckle filter equivalent to the well known Γ-MAP filter. We perform a logarithmic transformation in order to make the speckle contribution additive and statistically independent of the radar cross section. Further, we propose to use the normal inverse Gaussian (NIG) distribution as a statistical model for the wavelet coefficients of both the reflectance image and the noise image. We show that the NIG distribution is an excellent statistical model for the wavelet coefficients of synthetic aperture radar images, and we present a method for estimating the parameters. We compare the homomorphic Γ-WMAP filter with the Γ-MAP filter and and the recently introduced Γ-WMAP filter, which are both based on the same statistical assumptions. The homomorphic Γ-WMAP filter is shown to have better performance with regard to smoothing homogeneous regions. It may in some cases introduce a small bias, but in our studies it is always less than that introduced by the Γ-MAP filter. Further, the speckle removed by the homomorphic Γ-WMAP filter has statistics closer to the theoretical model than the speckle contribution removed with the other filters. [J1351]

"Unsupervised terrain classification preserving polarimetric scattering characteristics"

In this paper, we proposed an unsupervised terrain and land-use classification algorithm using polarimetric synthetic aperture radar data. Unlike other algorithms that classify pixels statistically and ignore their scattering characteristics, this algorithm not only uses a statistical classifier, but also preserves the purity of dominant polarimetric scattering properties. This algorithm uses a combination of a scattering model-based decomposition developed by Freeman and Durden and the maximum-likelihood classifier based on the complex Wishart distribution. The first step is to apply the Freeman and Durden decomposition to divide pixels into three scattering categories: surface scattering, volume scattering, and double-bounce scattering. To preserve the purity of scattering characteristics, pixels in a scattering category are restricted to be classified with other pixels in the same scattering category. An efficient and effective class initialization scheme is also devised to initially merge clusters from many small clusters in each scattering category by applying a merge criterion developed based on the Wishart distance measure. Then, the iterative Wishart classifier is applied. The stability in convergence is much superior to that of the previous algorithm using the entropy/anisotropy/Wishart classifier. Finally, an

automated color rendering scheme is proposed, based on the classes' scattering category to code the pixels to resemble their natural color. This algorithm is also flexible and computationally efficient. The effectiveness of this algorithm is demonstrated using the Jet Propulsion Laboratory's AIRSAR and the German Aerospace Center's (DLR) E-SAR L-band polarimetric synthetic aperture radar images. [J1352]

"Statistical analysis of multilook SAR interferograms for CFAR detection of ground moving targets"

This paper examines the statistics of the phase and magnitude of multilook synthetic aperture radar (SAR) interferograms toward deployment of along-track interferometry (ATI) for slow ground moving-target indication (GMTI). While the known probability density function (pdf) of the interferogram's phase (derived under the assumption of Gaussian backscatter) is shown to agree almost perfectly for a wide variety of backscatter conditions, the corresponding magnitude's pdf tends to deviate strongly in most cases. Motivated by this discrepancy, a novel distribution is derived for the interferogram's magnitude. This pdf, called the polynomial or p-distribution, matches the real data much more accurately, particularly for heterogeneous composite terrain. For extremely heterogeneous terrain, such as urban areas, both pdfs for interferometric phase and magnitude fail and are extended. Based on these statistics, a completely automatic detection scheme with constant false-alarm rates (CFARs) for slow moving targets is proposed. All involved parameters required to determine the detection thresholds are estimated from the sample data. It is demonstrated, on the basis of experimental airborne SAR data, that this detector is capable of detecting slow moving vehicles within severe ground clutter. [J1353]

"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. [J1354]

"IRS 2003: International Radar Symposium in Dresden, Germany"

{no data available} [J1355]

"Special issue on synthetic aperture radar imaging of the ocean surface"

{no data available} [J1356]

"Optimum asymmetric half-plane autoregressive lattice parameter modeling of 2-D fields"

In this paper, we present a new optimum asymmetric half-plane (ASHP) autoregressive lattice parameter modeling of two-dimensional (2-D) random fields. This structure introduces 4N points into the prediction support region when the order of the model increases from (N-1) to N. Starting with a given data field, a set of four auxiliary prediction errors are generated in order to obtain the growing number of 2-D ASHP reflection coefficients at successive stages. The theory has been applied to the high-resolution radar imaging problem and has also been proven using the concepts of vector space, orthogonal projection, and subspace decomposition. It is shown that the proposed ASHP structure generates the orthogonal realization subspaces for different recurse directions. In addition to developing the basic theory, the presentation includes a comparison between the proposed theory and other alternative structures, both in terms of conceptual background and complexity. While the recently developed reduced-complexity ASHP lattice modeling structure requires O(4N3) lattice sections with N equal to the order of the error filter, the proposed configuration requires only O(2N2) lattice sections. [J1357]

"Radar "down under""

{no data available} [J1358]

"The effect of scene elevation on the coherence of wide-angle crossing-node SAR pairs"

The interference between two radar images, acquired from approximately the same location, has a number of uses. In particular, the literature abounds with examples of coherent change detection (CCD) and interferometric synthetic aperture radar (InSAR) uses that, respectively, enable the detection of small changes and the

extraction of terrain elevation. In almost all of these examples, collections have been deliberately constrained so that they have almost identical collection geometries. Details of the variation in geometry have been analyzed extensively but generally only with respect to variation in the mean grazing angle. Much of this variation is due to the angular variation in the scene reflectivity; however, when collection geometries differ in other respects, the reduction in performance cannot be entirely explained by angular variations alone. This paper identifies a source of performance degradation when the collection geometries are different for scenes containing local relief. The error is due to approximations during image formation that both the collection geometry and the terrain are flat. The effect of these errors is derived as a blurring kernel to the true scene. The impact of the blurring is then assessed in the interferometric case and broken into common and differential blurring terms to facilitate the impact of some special cases and to explain why the parallel-pass geometry works as well as it does even though the true three-dimensional nature of the collection and the ground are ignored. [J1359]

"Analysis of temporal backscattering of cotton crops using a semiempirical model"

To develop an operational methodology for estimating soil moisture and crop biophysical parameters and to generate a crop cover map, backscattering signatures of vegetation canopies are investigated using multitemporal Radarsat synthetic aperture radar (SAR) data over a predominantly cotton-growing area in India during low to peak crop growth stage. A simple parameterization of the water-cloud model with volumetric soil moisture content (mv) and leaf area idex (LAI) is used to simulate the microwave backscattering coefficient (σ0), as it is found to be a good candidate for operational purposes as demonstrated by several workers in past. The influence of crop height (H), LAI, and mvon σ0is investigated during peak crop growth stage. A linear relationship between LAI and crop height is derived semiempirically, and a linear zone is chosen for analysis during the peak crop-growing stage. Estimation of average volume fraction of leaves (V~l) and attenuation factor (L) by two different approaches is discussed: 1) using linear relationship between LAI versus crop height and 2) from the water-cloud model parameter (κ) estimation by iterative minimum least square error approach. It is observed that model-estimated parameters agree well with the measured values within an acceptable error limit. At lower soil moisture, mv 0.02(cm3·cm-3), the dynamic range of σ0is found to be about +5 dB for 0-70 cm of crop height but monotonously decreases to at a transition point, having mv≈0.38(cm3·cm-3). A positive correlation is found between backscattering coefficient and crop height till this transition point but shows a negative correlation beyond that, signifying the predominant attenuation by vegetation over soil. Differential moisture sensitivity (dσ0/dmv) of the backscattering coefficient decreases by half from 20.55 dB/(cm3·cm-3) for dry and bare-field conditions to 10.68 dB/(cm3·cm-3) for wet and crop-covered fields (mv=0.38cm3·cm-3, H=70cm), whereas differential crop height sensitivity (dσ0/dH) varies from-0.22-0.03 dB/cm for bare-field conditions to crop-covered fields with crop height 70 cm. It is found that the percentage of relative error is smallest (2.27%) for LAI and attenuation factor estimation using the value of V~l, from LAI models, whereas it is 4.25% when estimating from the attenuation coefficient (κ) from the model. [J1360]

"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. [J1361]

"First demonstration of surface currents imaged by hybrid along- and cross-track interferometric SAR"

This paper is concerned with the simultaneous measurement of terrain heights and currents using an airborne interferometric synthetic aperture radar (INSAR). For the first time, a hybrid two-antenna INSAR system with both along- and across-track baseline components is used to measure high-resolution digital elevation maps (DEMs) and current fields in a Wadden sea area. Coastal applications like the monitoring of sediment transport

or the numerical modeling of morphodynamic processes require measurements of topography and currents. Classical in situ measurements of these parameters are both expensive and time consuming, or even impossible if higher spatial resolution is required. Pure along-track interferometers (ATIs) have demonstrated their ability to provide information on ocean currents, while across-track interferometric systems (XTIs) have been successfully used to measure DEMs. In this paper, a hybrid system with both ATI and XTI components is used to acquire synoptic measurement for the first time. An experiment with an airborne system taking data over a Wadden sea area is presented demonstrating the potential of the technique. A geometrical model is developed for the interferometric phase of hybrid INSAR systems. This model combines ATI and XTI techniques using a baseline that spans between two antennas consisting of along-track and across-track components. In this model, both the effect of topography and the radial velocity of the water surface enter into the resulting interferometric phase. To separate both components, the system takes data of the respective scene flying two or more tracks with different flight directions, e.g., antiparallel tracks. This approach leads to a set of linear equations that has a unique solution for the along- and cross-track phase. Finally, an additional phase bias has to be considered due to the radial velocity and the influence of squint. This is caused by a misregistration effect between both antennas, which is related to cross-track imaging of surface motion. The new INSAR technique is tested with data acquired during a campaign in February 1997 over the Weser Estuary at the German coast. The airborne INSAR system AeS-1 was used. The interferometer configuration consists of two SAR antennas separated by a mixed alon- g-track and cross-track baseline. Two datasets acquired on antiparallel tracks are used. The calculated velocities were compared with a hydrodynamic model operated by the Federal Waterway Engineering and Research Establishment. The experimental results agree well with the numerical model. In particular, the mean velocity of 0.7 ms-1matches in both datasets. Deviations in the fine-scale structure of the current field are discussed. Topographic analysis and validation are performed in a separate investigation. The impact of surface gravity waves and wind drift, which are known to cause significant artifacts in the ATI phase under certain circumstances, is discussed. [J1362]

"Noise radar using random phase and frequency modulation"

Pulse compression radar is used in a great number of applications. Excellent range resolution and high electronic counter-countermeasures performance is achieved by wideband long pulses, which spread out the transmitted energy in frequency and time. By using a random noise waveform, the range ambiguity is suppressed as well. In most applications, the random signal is transmitted directly from a noise-generating microwave source. A sine wave, which is phase or frequency modulated by random noise, is an alternative, and in this paper, the ambiguity function and the statistical characteristics of the correlation output for the latter configuration are further analyzed. Range resolution is then improved because the noise bandwidth of the modulated carrier is wider than that of the modulating signal, and the range sidelobes are also further suppressed. Random biphase modulation gives a 4-dB (pi2/4) improvement, but much higher sidelobe suppression could be achieved using continuous phase/frequency modulation. Due to the randomness of the waveform, the output correlation integral is accompanied by a noise floor, which limits the possible sidelobe suppression as determined by the time-bandwidth product. In synthetic aperture radar (SAR) applications with distributed targets, this product should be large compared with the number of resolution elements inside the antenna main beam. The advantages of low range sidelobes and enhanced range resolution make frequency/phase-modulated noise radar attractive for many applications, including SAR mapping, surveillance, altimetry, and scatterometry. Computer algorithms for reference signal delay and compression are discussed as replacements for the classical delay line implementation. [J1363]

"Doppler aliasing artifact filtering in SAR imagery using randomised stepped-frequency waveforms"

A new technique for mitigating Doppler aliasing artifacts in synthetic aperture radar (SAR) imagery is demonstrated. The technique uses continuous-wave (CW) transmission of randomised stepped-frequency waveforms. Subsequent processing places Doppler aliasing artifacts in Doppler filter s, effectively removing them from the imagery. Simulated 2-D SAR images illustrate the effectiveness of the technique. [J1364]

"Polarization state conformation and its application to change detection in polarimetric SAR data"

For polarimetric SAR (POLSAR) images, it is ideal that scattering geometries of the same target should display resemblance between multidate images, which are used in change detection applications, since the scattering mechanisms may change due to the data acquisition geometry. However, sometimes it is difficult to achieve these conditions. An attempt is made to maximize the resemblance between the scattering geometries in multidate images for a specific target. An algorithm is developed based on the polarimetric basis transformation along with the polarization signatures. As a result, the resemblance between the scattering mechanisms of the same target in both images is maximized. The effects predicted by the theory are confirmed by the change detection analysis of POLSAR data acquired by the Jet Propulsion Laboratory Spaceborne Imaging Radar-C

mission. [J1365]

"Efficient Simulation of hybrid stripmap/spotlight SAR raw signals from extended scenes"

The hybrid stripmap/spotlight mode for a synthetic aperture radar (SAR) system is able to generate microwave images with an azimuth resolution better than the one achieved in the stripmap mode and a ground coverage better than the one of the spotlight mode. In this paper, time- and frequency-domain-based procedures to simulate the raw signal in the hybrid stripmap/spotlight mode are presented and compared. We show that a two-dimensional Fourier domain approach, although highly desirable for its efficiency, is not viable. Accordingly, we propose a one-dimensional (1-D) range Fourier domain approach, followed by 1-D azimuth time-domain integration. This method is much more efficient than the time-domain one, so that extended scenes can be considered. In addition, it involves approximations usually acceptable in actual cases. Effectiveness of the simulation scheme is assessed by using numerical examples. [J1366]

"Ambiguity resolution for permanent scatterer interferometry"

In the permanent scatterer technique of synthetic aperture radar interferometry, there is a need for an efficient and reliable nonlinear parameter inversion algorithm that includes estimation of the phase cycle ambiguities. Present techniques make use of a direct search of the solution space, treating the observations as deterministic and equally weighted, and which do not yield an exact solution. Moreover, they do not describe the quality of the estimated parameters. Here, we use the integer least squares estimator, which has the highest probability of correct integer estimation for problems with a multivariate normal distribution. With this estimator, the propagated variance-covariance matrix of the estimated parameters can be obtained. We have adapted the LAMBDA method, part of an integer least squares estimator developed for the ambiguity resolution of carrier phase observations in global positioning systems, to the problem of permanent scatterers. Key elements of the proposed method are the introduction of pseudo-observations to regularize the system of equations, decorrelation of the ambiguities for an efficient estimation, and the combination of a bootstrap estimator with an integer least squares search to obtain the final integer estimates. The performance of the proposed algorithm is demonstrated using simulated and real data. [J1367]

"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. [J1368]

"Parametric autofocus of SAR imaging-inherent accuracy limitations and realization"

In synthetic aperture radar (SAR) imaging, low scene contrast may degrade the performance of most of the existing autofocus methods. In this paper, by dividing a slow-time signal into three isolated components, namely target, clutter, and noise, in SAR imaging, a novel parametric statistical model is proposed during the coherent processing interval. Based on the model, Cramer-Rao bounds (CRBs) of the estimation of unknown parameters are derived. It is shown that the CRBs of the target parameter estimation strongly depend on the background, i.e., clutter and noise, and the CRBs of the background parameter estimation may be obtained regardless of the target component. Motivated from this result and using the estimated background parameters, a novel effective parametric autofocus method is developed, which is applicable to any scene contrast. In addition, a preprojection is also introduced to simplify the subsequent parameter estimation. Finally, the proposed model and the novel method are illustrated by some real SAR data. [J1369]

"Synthetic aperture Radar oil spill segmentation by stochastic complexity minimization"

We present a new algorithm for oil spill segmentation in synthetic aperture radar (SAR) images, using the minimum description length (MDL) principle and a polygonal active grid. This algorithm is based on two steps: a first partitioning step into homogeneous regions and a second classification step with an automatic MDL thresholding. The obtained method allows one to segment the different candidate oil spills in an image automatically and in a few seconds. [J1370]

"Azimuth positioning of moving targets in two-channel SAR by direction-of-arrival estimation"

Many present and future SAR systems that are also intended to measure and monitor moving objects on the ground will be restricted to only two parallel antenna apertures owing to the enormous costs involved for extra receiver channels. This is particularly true for space-based systems, such as RADARSAT-2 and TerraSAR-X. Classical techniques to simultaneously detect moving targets by rejecting the superimposed clutter and to estimate their correct locations subsequently via direction-of-arrival (DoA) estimates cannot be applied owing to the dual-receiver limitation. Proposed is an alternative method to retrieve clutter-suppressed target signals in the individual channels that allow the application of DoA-estimation and verifies its feasibility with measured airborne SAR data. [J1371]

"The speed and beam of a ship from its wake's SAR images"

Synthetic aperture radar (SAR) images of ships and their wakes frequently exhibit long dark and bright streaks. Some of them can be attributed to the Kelvin wavewake and others to the turbulent and bright narrow V-wake. The wakes contain information about the ship. The present work deals with estimates of the ship beam and its velocity by processing SAR images of the Kelvin and turbulent wakes. It is assumed that the ship moves along a straight path with constant speed. For the detection of the linear features of the ship wake, the fast discrete Radon transform is employed. Once the turbulent wake is detected, the ship beam is estimated by a novel method that exploits the expansion of the turbulent wake aft a ship. A semiempirical relation between the ship beam and the width of its turbulent wake is derived and analyzed. An algorithm for estimating the width of the turbulent wake in SAR images and the ship beam is developed. The spectrum of ship-generated waves along the Kelvin cusp-lines is discussed. Processing of the lines, pertaining to the Kelvin wake bounds, and analysis of the spectral peaks enables to estimate the ship speed. Numerical examples of processing of airborne SAR images are provided. [J1372]

"Beam characteristics of three-dimensional SAR in curved or random paths"

Interferometric synthetic aperture radar (InSAR) provides average height information by combining data from two parallel paths. True three-dimensional (3-D) SAR also detects the height distribution, which is of significant interest in airborne reconnaissance, forest inventory, and subsurface or wall-penetrating sensing applications as examples. In this paper, the beam performance of 3-D SAR is studied and compared for different curved line paths, such as circles, ellipses, and spirals ending up with random sampling. Curved path geometry reduces the ambiguity in height angle of traditional multipass SAR, and random path variation further improves the sidelobe suppression. The poor sidelobe suppression of a single circle path is significantly improved in near-range geometry in combination with high range resolution. By introducing a window function dependent on focus point and path position, high sidelobe suppression was achieved in an extended ground area below the circle path. [J1373]

"Proposed UWB radar terminology"

The term ultra-wideband (UWB) [which was formally defined by DARPA in 1990], for classifying an emerging technology in the field of radar and radio communications is synonymous with the following terms: baseband; video pulse; nonsinusoidal; carrierfree (carrierless); impulse; time-domain; super-resolution; ultra-high resolution; stealthy; spread spectrum; Rayleigh spectrum. The paper lists the terminologies that may be used for the emerging technology of UWB radar. [J1374]

"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. [J1375]

"Azimuth resolution of spaceborne P, VHF-band SAR"

A degradation of spatial resolution performance of spaceborne synthetic aperture radar (SAR) images, which is due to the atmospheric radio waves propagation effects, is considered in this letter. A special calculation procedure of spatial resolution performances, in particular of the SAR azimuth resolution, is offered. Herein, the analysis of a potential spatial resolution, resulting from the influence of the atmosphere, on SAR images is presented. [J1376]

"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. [J1377]

"Ground-based radar interferometry for landslides monitoring: atmospheric and instrumental decorrelation sources on experimental data"

The application of ground-based radar interferometry for landslide monitoring is analyzed: a case study based on an experimental campaign carried out in Italy during 2002 is discussed. Interferometric data obtained from coherent synthetic aperture radar (SAR) images acquired by means of C-band ground-based equipment are analyzed. The campaign was aimed at retrieving potential terrain movements of a small landslide observed hundreds of meters away. Critical aspects related to spatial and temporal decorrelation are discussed: the use of optical photogrammetry as a technique for evaluating mechanical stability and correcting geometric distortion is presented. Results also confirmed that the application of ground-based radar interferometry can be attractive and effective if the acquired SAR images maintain an adequate coherence on different dates. [J1378]

"Polar format algorithm for bistatic SAR"

Matched filtering (MF) of phase history data is a mathematically ideal but computationally expensive approach to bistatic synthetic aperture radar (SAR) image formation. Fast backprojection algorithms (BPAs) for image formation have recently been shown to give improved O(N2log2N) performance. An O(N2log2N) bistatic polar format algorithm (PFA) based on a bistatic far-field assumption is derived. This algorithm is a generalization of the popular PFA for monostatic SAR image formation and is highly amenable to implementation with existing monostatic image formation processors. Limits on the size of an imaged scene, analogous to those in monostatic systems, are derived for the bistatic PFA. [J1379]

"antenna-pattern correction for near-field-to-far field RCS transformation of 1D linear SAR measurements"

In a previous AMTA paper (B. E. Fischer, et al.), we presented a first-principles algorithm, called wavenumber migration (WM), for estimating a target's far-field RCS and/or far-field images from extreme near-field linear (one-dimensional) or planar (two-dimensional) SAR measurements, such as those collected for flight-line diagnostics of aircraft signatures. However, the algorithm assumes the radar antenna has a uniform, isotropic pattern for both transmitting and receiving. In this paper, we describe a modification to the (one-dimensional) linear SAR wavenumber migration algorithm that compensates for nonuniform antenna-pattern effects. We also introduce two variants to the algorithm that eliminate certain computational steps and lead to more efficient implementations. The effectiveness of the pattern compensation is demonstrated for all three versions of the algorithm in both the RCS and the image domains using simulated data from arrays of simple point scatterers. [J1380]

"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. [J1381]

"Fitting a statistical model to SIR-C SAR images of the sea surface"

A suite of statistical procedures aimed at assessing to what extent polarimetric and/or multifrequency synthetic aperture radar (SAR) images of the sea surface can be modeled in terms of spherically invariant random vectors and matrices (SIRVs and SIRMs) is presented. The proposed tests assume that images can be described by resorting to the compound-Gaussian model, but do not require any a priori knowledge about the actual first-order probability density function (pdf) of the texture. The tests have also been used to analyze three data sets from STR-C/X-SAR missions. [J1382]

"Near-field three-dimensional coherent imaging: Theory and simulations"

This work presents a rigorous mathematical derivation of an effective approximate solution to the three-dimensional inverse scattering/imaging problem that is applicable for all imaging zones ranging from the near to the far field. Simulation results for the point spread function illustrate the range and cross-range resolution as a function of the optical fnumber. The model system operates in a synthetic aperture type mode, where the coherent signals are transmitted, and the scattered signals are subsequently received at individual transmitters and receivers. Potential applications of this technology include: Medical ultrasound, foliage penetrating synthetic aperture radar, ground penetrating radar for land mine detection, and electromagnetic millimeter-wave scanning for concealed weapon detection. copyright 2004 American Institute of Physics. [J1383]

"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. [J1384]

"Sighted automation and fine resolution imaging"

First Page of the Article [J1385]

"IRS 2004: International Radar Symposium in Warsaw, Poland"

{no data available} [J1386]

"Ocean wave spectra from a linear polarimetric SAR"

Conventional horizontal or vertical polarization synthetic aperture radar (SAR) images seldom perform well in detecting azimuthally traveling ocean waves. However, theoretical analyses suggest that linear-polarimetric backscatter measurements may be more sensitive to these waves and, therefore, that a SAR with linear polarization is expected to give a better measurement of azimuthally traveling ocean waves. We derive the polarization-orientation modulation transform function and tilt modulation transform function of the linear-polarimetric SAR. Through numerical simulations based on these formulations, we examine the effects of radar and ocean wave parameters on linear-polarimetric SAR image spectra. We suggest a method to eliminate the 180° directional ambiguity in determining the true wave direction. Our numerical simulations show that the correlation between ocean wave spectra and SAR image spectra is improved for larger radar incidence angles and longer ocean waves. For real aperture radar, we suggest that the polarimetric modulation allows

measurement of waves traveling in the azimuth direction. Moreover, as suggested by Schuler et al., this may be the dominant modulation for many SAR aircraft measurements, particularly for moderate sea states. [J1387]

"Trained detection of buried mines in SAR images via the deflection-optimal criterion"

In this paper, we apply a deflection-optimal linear-quadratic detector to the detection of buried mines in images formed by a forward-looking ground-penetrating synthetic aperture radar. The detector is a linear-quadratic form that maximizes the output SNR (deflection), and its parameters are estimated from a set of training data. We show that this detector is useful when the signal to be detected is expected to be stochastic, with an unknown distribution, and when only a small set of training data is available to estimate its statistics. The detector structure can be understood in terms of the singular value decomposition; the statistical variations of the target signature are modeled using a compact set of orthogonal "eigenmodes" (or principal components) of the training dataset. Because only the largest eigenvalues and associated eigenvectors contribute, statistical variations that are underrepresented in the training data do not significantly corrupt the detector performance. The resulting detection algorithm is tested on data that are not in the training set, which has been collected at government test sites, and the algorithm performance is reported. [J1388]

"Volume decorrelation effects in polarimetric SAR interferometry"

Volume decorrelation is an aspect of synthetic aperture radar interferometry that is currently at stake. It stems from the distribution in height of the backscattering cross section in a imaged scene, and it widely affects interferometric coherence images, e.g., in the presence of forests or buildings. The interest in its reduction lies on the fact that "resolving" volume decorrelation and fixing the exact position of the scattering centers in a resolution cell may lead to an estimation of the height of the observed distributed scatterers. Indeed, the determination of the volume scattering contribution is determinant in digital elevation model generation as well as in biomass estimation. However, volume decorrelation itself may be a source of information on the mechanisms that originate it. In this paper, a distinction is made between the behavior of volume decorrelation due to random volumes and stationary distributed targets. The two cases are then studied by means of polarimetry: the response of such targets to different polarizations is considered by applying a series of decompositions of the scattering matrix, and a systematic analysis of the interferometric coherence characteristics is reported. [J1389]

"SAR image data compression using wavelet packet transform and universal-trellis coded quantization"

A wavelet packet image coding algorithm for synthetic aperture radar (SAR) image data compression is proposed in this paper. High rate-distortion (R-D) performance of this algorithm [wavelet packet quantization universal trellis-coded quantization (WPQUTCQ)] is achieved by incorporating the wavelet packet transform for representing the rich texture information of SAR image data, the quadtree technique for classifying the wavelet packet coefficients, and the universal trellis-coded quantization (UTCQ). For a typical SAR image, WPQUTCQ outperforms set partitioning in hiearchical trees and JPEG2000 by about 1.21 and 0.81 dB in peak signal-to-noise ratio (PSNR) at 2 bpp, respectively. The effect of best basis selection on the R-D performance of coding algorithm for SAR image data compression is also evaluated through comparing the effects of different cost functions (e.g., entropy, the texture energy, which is designed for SAR image data compression particularly, and the cost function, based on the actual coding strategy proposed by us) on the R-D performance of WPQUTCQ. The experimental results show the suitability of the cost function based on the actual coding strategy for SAR image data compression when compared with other cost functions. For a typical SAR image, the coding results by WPQUTCQ corresponding to the cost function based on the actual coding strategy achieve gains 0.59 and 0.49 dB on average in PSNR when compared with the coding results corresponding to entropy and the texture energy, respectively. [J1390]

"Migration based SAR imaging for ground penetrating radar systems"

The authors consider migration based synthetic aperture radar (SAR) imaging of surface or shallowly buried objects using both down-looking and forward-looking ground penetrating radar (GPR). The well known migration approaches devised to image the interior of the Earth are based on wave equations and have been widely and successfully used in seismic signal processing for oil exploration for decades. They have the potential to image underground objects buried in complicated propagation media. Compared to ray-tracing based SAR imaging methods, migration based SAR imaging approaches are more suited to imaging underground objects owing to their simple and direct treatment of oblique incidence at the air-ground interface and propagation velocity variation in the soil. The authors apply the phase-shift migration approach to both constant-offset and common-shot experimental data collected by PSI GPR systems. They address the spatial aliasing problems related to the application of migration to the GPR data and the spatial zero-padding approach to circumvent the problem

successfully. [J1391]

"Detection of land-mines using ultra-wideband radar data and time-frequency signal analysis"

The authors present a study of the backscattered signatures from various types of land-mines placed either on the Earth's surface or buried underground, and their time-frequency (t-v) distributions. A BoomSAR designed by the Army Research Laboratory (ARL) transmits ultra-wideband (UWB) signals to a test area to be inspected. The backscattered signals are used to form synthetic aperture radar (SAR) imagery and also the corresponding time-frequency distributions. The t-v plots are generated of the distributions of several mines and 'confusers' (i.e. undesirable debris that are similar to mines in terms of amplitude and shape). For both metal and plastic mines, SAR images are generated and the t-v distributions are obtained using the backscattered signals generated by an electromagnetic (EM) numerical model and are compared against the measured data. Time-frequency characteristics of mines and confusers that may be useful for demining purposes are investigated. Although measurements and EM predictions show good agreement in most cases, the main purpose of the work is to obtain the characteristics of the t-v distributions of the actual (dielectric and conducting) mines used, as well as those of the 'confusers' so that they can be distinguished from the true mines. This has been achieved in all cases shown, and many distinctive features of each have been identified. These could later be used for the development of automated algorithms for in-situ mine detection and could be combined with alternative approaches that have also shown promise for classification purposes, as planned for future research. [J1392]

"Capon-LS for model order selection of multicomponent interferometric SAR signals"

The authors address the problem of estimating the number of components in a multibaseline interferometric synthetic aperture radar (InSAR) signal, corrupted by complex correlated multiplicative noise, in the presence of the layover phenomenon. The appearance of multiplicative noise, termed 'speckle', makes this problem very atypical. In fact, all the approaches proposed in literature have been applied to constant amplitude sinusoidal signals. In particular, the information theoretic criteria (ITC) have been conceived for estimating the number of signal components embedded in additive white noise. In this case, the problem is equivalent to the estimation of the multiplicity of the smallest eigenvalues of the data covariance matrix. In the presence of multiplicative noise, the signal eigenvalues spectrum changes. Consequently, the classic ITC methods operate under model mismatch. In a previous work, the authors investigated their robustness to speckle. An ad hoc algorithm for model order selection, based on Capon and least squares methods is developed. Its performance is analysed via Monte Carlo simulation and compared with those of classic ITC. [J1393]

"Bayesian wavelet shrinkage with edge detection for SAR image despeckling"

In this paper, we present a wavelet-based despeckling method for synthetic aperture radar images and derive a Bayesian wavelet shrinkage factor to estimate noise-free wavelet coefficients. To preserve edges during despeckling, we apply a modified ratio edge detector to the original image and use the obtained edge information in our despeckling framework. Experimental results demonstrate that our method compares favorably to several other despeckling methods on test images. [J1394]

"A phase signature for detecting wet subsurface structures using polarimetric L-band SAR"

In this paper, we investigate the ability of L-band synthetic aperture radar (SAR) systems to penetrate soils to retrieve information about subsurface wet structures. Our experiment site, the Pyla dune, is a bare sandy area allowing high radar penetration and known to have large wet subsurface structures (paleosoils) at varying depths. Buried paleosoils, which act as moisture tanks, are detectable with radar, since they present a high permittivity due to their water content. By analyzing airborne polarimetric SAR data, we established that a phase signature is correlated to the buried wet palesoils: a phase difference of 23° between the horizontal (HH) and vertical (VV) channels was clearly observed. It allows detection of the paleosoil down to a larger depth (5.2 m) than when only considering HH and HV amplitude signals (3.5 m). In order to confirm this result, field measurements were performed that led to the same observed phase difference. We could fit our observations to the semiempirical model proposed by Oh and Sarabandi, and we reproduced the observed phenomenon using a two-layer integral equation method (IEM) model of the Pyla dune, which was completed by finite-difference time-domain (FDTD) numerical simulations. We show that the soil moisture significantly influences the radar response in terms of phase difference between the copolarized modes. Our study also shows that the single-scattering IEM model reproduces the observed phase difference fairly well for a natural outdoor site when combined to FDTD simulation results. This phase signature could be used as a new tool to map subsurface moisture in arid regions. [J1395]

"A simple and exact solution for the interferometric and stereo SAR geolocation problem"

This paper provides a closed-form solution to the geolocation problem arising in the generation of digital elevation models (DEMs) via both stereo and interferometric synthetic aperture radar techniques. The proposed solution is found with no approximations in an arbitrary Cartesian reference system, thus efficiently allowing the generation of DEMs in a chosen cartographic projection. Moreover, it is amenable of an easy and precise sensitivity analysis that exploits the full three-dimensional nature of the problem, thus being particularly useful when high-squinted and/or crossed-track acquisitions are considered. [J1396]

"Speckle filtering in polarimetric SAR data based on the subspace decomposition"

In this paper, a new approach to speckle filtering of synthetic aperture radar (SAR) data is presented. We define a parameter space consisting of two orthogonal subspaces-the signal subspace and the noise subspace. Then, the full polarimetric information from the signal subspace is obtained after speckle filtering. In this way, edges of different kinds of targets are preserved. The effectiveness of this method is demonstrated using the National Aeronautics and Space Administration Jet Propulsion Laboratory airborne L-band polarimetric SAR data. [J1397]

"Development of a ground-based polarimetric broadband SAR system for noninvasive ground-truth validation in vegetation monitoring"

We have developed a ground-based polarimetric broadband synthetic aperture radar (SAR) system for noninvasive ground-truth validation in polarimetric SAR remote sensing of terrestrial vegetation cover. This system consists of a vector network analyzer, one dual-polarized antenna, and an antenna positioner. It can be operated in a frequency range from 50 MHz to 20 GHz, with a scanning aperture of 20 m in the horizontal and 1.5 m in the vertical direction. Tests carried out with standard reflectors showed that the polarimetric measurement capabilities of this system are satisfactory. Using the polarimetric ground-based SAR (GB-SAR) system, we carried out measurements on a specific vegetation cover pertinent to the remote sensing of forested regions within Sendai City, consisting of three different kinds of trees common within the Kawauchi Campus of Tohoku University. Measurements were collected in spring, summer, and autumn. Three-dimensional (3-D) polarization-sensitive images were reconstructed from the acquired data. Analysis of the 3-D polarimetric images of each measurement found differences (at times strong differences) among the polarization signatures. There were stronger reflections in all of the HH, VH, VV images in the second (summer) measurement, especially in the VH image, due to the substantial growth of branches and leaves in summer. This ground-truth validation system provided valuable information about the scattering mechanisms of the three trees selected for analysis in different seasons, which can be detected by broadband polarimetric ground-based SAR measurements. The experimental results demonstrate the excellent polarimetric performance of the newly developed SAR imaging system, which should find many useful and immediate applications in noninvasive ground-truth validation of diverse terrestrial vegetation covers. [J1398]

"A time-domain raw signal Simulator for interferometric SAR"

In this paper, we present a time-domain (TD) raw signal simulator for an interferometric synthetic aperture radar (SAR). We consider the case of a spaceborne SAR operating in stripmap, spotlight, and hybrid modes, but the case of an airborne SAR can be considered as well. The spaceborne platform is considered as traveling on its nominal (Keplerian) orbit, and the targets are located on an ellipsoidal earth. We describe an accurate TD simulator, highlighting its usefulness in studying the effects on the SAR impulse response and on images from targets with limited extension due to operational conditions different from the nominal one. [J1399]

"Radiative transfer modeling of cross-polarized backscatter from a pine forest using the discrete ordinate and eigenvalue method"

Radiative transfer models have been widely used to interpret the radar backscatter from forested areas. Most of these models are based on an iterative solution of the radiative transfer equation, usually solved up to first or second order, thus taking into account single and double scattering. Although this method leads to results agreeing well with copolarized backscatter measurements, it produces less accurate estimates for horizontal-vertical (HV) polarization. This paper presents a radiative transfer backscatter model that accounts for multiple scattering by using the discrete ordinate and eigenvalue method applied to a layered medium. Using parameters derived from an architectural tree model, calculations at C- and L-band are compared with HV data acquired for a maritime pine forest in the southwest of France during the Spaceborne Imaging Radar-C missions. Good agreement is found at C-band for all values of forest biomass, and reasonable agreement at L-band for high biomass, when the soil backscatter plays a minor role. For low biomass, the L-band modeling is inadequate because of difficulties in estimating the soil backscatter. Comparison with calculations from a first-order radiative transfer model shows that multiple scattering is significant, especially at C-band. [J1400]

"A Bayesian filtering technique for SAR interferometric phase fields"

SAR interferograms are affected by a strong noise component which often prevents correct phase unwrapping and always impairs the phase reconstruction accuracy. To obtain satisfactory performance, most filtering techniques exploit prior information by means of ad hoc, empirical strategies. In this paper, we recast phase filtering as a Bayesian estimation problem in which the image prior is modeled as a suitable Markov random field, and the filtered phase field is the configuration with maximum a posteriori probability. Assuming the image to be residue free and generally smooth, a two-component MRF model is adopted, where the first component penalizes residues, while the second one penalizes discontinuities. Constrained simulated annealing is then used to find the optimal solution. The experimental analysis shows that, by gradually adjusting the MRF parameters, the algorithm filters out most of the high-frequency noise and, in the limit, eliminates all residues, allowing for a trivial phase unwrapping. Given a limited processing time, the algorithm is still able to eliminate most residues, paving the way for the successful use of any subsequent phase unwrapping technique. [J1401]

"Automatic detection and validity of the sea-ice edge: an application of enhanced-resolution QuikScat/SeaWinds data"

Sea-ice edge detection is an essential task at the different national ice services to secure navigation in ice-covered seas. Comparison between the Remund and Long ice mask image from enhanced-resolution QuikScat/SeaWinds (QS) products and the analyzed ice edge from high-resolution RADARSAT synthetic aperture radar has shown that the automatically determined QS ice mask underestimates the Arctic ice extent. QS data was statistically analyzed by colocating the data with ice charts around Greenland and with the National Aeronautics and Space Administration Team's Special Sensor Microwave/Imager (SSM/I) ice concentration algorithm over the whole Arctic region. All variables, i.e., the backscatter in vertical and horizontal polarization, the active polarization ratio (APR) and the daily standard deviation, are sensitive to ice types and are strongly correlated with ice concentration when the relationship is expressed in exponential form. Our study showed that the APR is especially suitable for ice-ocean separation, and a threshold of -0.02 was determined. An ice edge algorithm based on this APR threshold was developed using the other variables with conservative season-dependent thresholds to eliminate additional ocean noise. Also, the history of the ice cover is considered in order to detect single ice fields that are separated from the main Arctic pack ice. Validation with RADARSAT 1 and with the Advanced Very High Resolution Radiometer showed that the new algorithm successfully detects very low ice concentrations of about 10% during the entire year. The validity of the detected ice edge for near-real-time issues is also discussed in relation to the ice motion in the Marginal Ice Zone and the integration time necessary to produce the enhanced-resolution images. The new algorithm improves the automatic global ice edge resolution by a factor of two when compared to SSM/I products and could be used in both model initialization and data assimilation. [J1402]

"Baltic Sea ice SAR segmentation and classification using modified pulse-coupled neural networks"

A method for segmentation and classification of Baltic Sea ice synthetic aperture radar (SAR) images, based on pulse-coupled neural networks (PCNNs), is presented. Also, automated training, which is based on decomposing the total pixel value distribution into a mixture of class distributions, is presented and discussed. The algorithms have been trained and tested using logarithmic scale Radarsat-1 ScanSAR Wide mode images over the Baltic Sea ice. Before the decomposition into mixture of class distributions, an incidence angle correction, specifically designed for these Baltic Sea ice SAR images, is applied. Because the data distributions in the uniform areas of these images are very close to Gaussian distributions, the data are decomposed into a mixture of Gaussian distributions, using the Expectation-Maximazation algorithm. Only uniform image areas are used in the decomposition phase. The mixture of distributions is compared to the distributions of the Baltic Sea ice classes, based on earlier scatterometer measurements and visual video interpretations of the sea ice classes. The parameter values for the PCNN segmentation are defined based on this mixture of distributions. The PCNN segmentation results are also compared to the operational sea ice information of digitized ice charts and to visual interpretation of the sea ice class. [J1403]

"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. [J1404]

"Faraday rotation correction in the polarimetric mode of MIRAS"

This paper describes a new method to compensate the Faraday rotation in polarimetric radiometric measurements under the assumption that the polarimetric brightness temperature matrix of the target is diagonal. Simulations results of how this method can be used within the Soil Moisture and Ocean Salinity mission and the Microwave Imaging Radiometer with Aperture Synthesis imaging radiometer are presented. [J1405]

"On the detection of Faraday rotation in linearly polarized L-band SAR backscatter signatures"

The potentially measurable effects of Faraday rotation on linearly polarized backscatter measurements from space are addressed. Single-polarized, dual-polarized, and quad-polarized backscatter measurements subject to Faraday rotation are first modeled. Then, the impacts are assessed using L-band polarimetric synthetic aperture radar (SAR) data. Due to Faraday rotation, the received signal will include other polarization characteristics of the surface, which may be detectable under certain conditions. Model results are used to suggest data characteristics that will reveal the presence of Faraday rotation in a given single-polarized, dual-polarized, or quad-polarized L-band SAR dataset, provided the user can identify scatterers within the scene whose general behavior is known or can compare the data to another, similar dataset with zero Faraday rotation. The data characteristics found to be most sensitive to a small amount of Faraday rotation (i.e., a one-way rotation *)]. For a diverse, but representative, set of natural terrain, the level of distortion across a range of backscatter measures is shown to be acceptable (i.e., minimal) for one-way Faraday rotations of less than 5°, and 3° if the radiometric uncertainty in the HV backscatter is specified to be less than 0.5 dB. [J1406]

"Calibration of linearly polarized polarimetric SAR data subject to Faraday rotation"

A model for linearly polarized fully polarimetric backscatter measurements is used, incorporating the effects of system noise, channel amplitude, phase imbalance, crosstalk, and Faraday rotation. A step-by-step procedure is outlined for correction (or calibration) of fully polarimetric data subject to Faraday rotation, to recover the true scattering matrix. The procedure identifies steps for crosstalk removal and correction of channel imbalances that are robust in the presence of Faraday rotation. The final steps in the procedure involve a novel strategy for estimation and correction of Faraday rotation. Three approaches to estimate the (one-way) Faraday rotation angle Ω directly from linear (quad-) polarized synthetic aperture radar (SAR) backscatter data obtained by a spaceborne SAR system are described. Each approach can initially be applied to the signature of any scatterer within the scene. Sensitivity analyses are presented that show that at least one of the measures can be used to estimate Ω to within ±3° to 5°, with reasonable levels of residual crosstalk, noise floor, channel amplitude, and phase imbalance. Ambiguities may be present in the estimates of Ω of ±npi/2-the impact of this is discussed, and several approaches are suggested to deal with this possibility. The approach described in this paper is relevant for future L-band spaceborne SARs and removes one key obstacle to the deployment of even longer wavelength SARs (e.g., an ultrahigh frequency or P-band SAR) in Earth orbit. [J1407]

"Efficient algorithm for three-dimensional target feature extraction via CLSAR"

A lower dimensional position searching (LODIPS) algorithm is proposed for three-dimensional (3-D) target feature extraction via the curvilinear synthetic aperture radar (CLSAR) system. Compared with another similarly structured algorithm RELAX, the LODIPS algorithm dramatically reduces the computational load through the utilisation of lower dimensional FFTs. Simulation results show that the new algorithm can reach CRB at low SNR. [J1408]

"Distinguised lecturers program"

{no data available} [J1409]

"Simulation study of stochastic dark line features in correlated K-distributed images"

Intensity fluctuation of synthetic aperture radar (SAR) images, due to speckle and texture, statistically brings

series connections of dark pixels. Resolution enhancement of SAR systems can provide texture with correlation properties. In this paper, simulation studies are carried out to investigate the relation between the occurrence of the stochastic dark line features and texture correlation. [J1410]

"A new statistical model for Markovian classification of urban areas in high-resolution SAR images"

We propose a classification method suitable for high-resolution synthetic aperture radar (SAR) images over urban areas. When processing SAR images, there is a strong need for statistical models of scattering to take into account multiplicative noise and high dynamics. For instance, the classification process needs to be based on the use of statistics. Our main contribution is the choice of an accurate model for high-resolution SAR images over urban areas and its use in a Markovian classification algorithm. Clutter in SAR images becomes non-Gaussian when the resolution is high or when the area is man-made. Many models have been proposed to fit with non-Gaussian scattering statistics (K, Weibull, Log-normal, Nakagami-Rice, etc.), but none of them is flexible enough to model all kinds of surfaces in our context. As a consequence, we use a mathematical model that relies on the Fisher distribution and the log-moment estimation and which is relevant for one-look data. This estimation method is based on the second-kind statistics, which are detailed in the paper. We also prove its accuracy for urban areas at high resolution. The quality of the classification that is obtained by mixing this model and a Markovian segmentation is high and enables us to distinguish between ground, buildings, and vegetation. [J1411]

"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. [J1412]

"Segmentation of textured polarimetric SAR scenes by likelihood approximation"

A hierarchical stepwise optimization process is developed for polarimetric synthetic aperture radar image segmentation. We show that image segmentation can be viewed as a likelihood approximation problem. The likelihood segment merging criteria are derived using the multivariate complex Gaussian, the Wishart distribution, and the K-distribution. In the presence of spatial texture, the Gaussian-Wishart segmentation is not appropriate. The K-distribution segmentation is more effective in textured forested areas. The validity of the product model is also assessed, and a field-adaptable segmentation strategy combining different criteria is examined. [J1413]

"Microwave scattering from mixed-species forests, Queensland, Australia"

The potential of synthetic aperture radar (SAR) data for retrieving the above-ground and component (e.g., branch, trunk) biomass of mixed-species forests (including woodlands) typical to subtropical Queensland, Australia, was evaluated using a wave scattering model based on that of Durden et al. (1989). The model was parameterized using field data collected for nine forest types, which were selected through combined analysis of 1: 4000 aerial photographs and light detection and ranging data. The simulated SAR backscatter data demonstrated a good correspondence at most frequencies and polarizations with Airborne SAR data. Analysis of scattering mechanisms revealed dominance of C-band horizontal-vertical (HV) volume scattering and increases with small-branch/foliage biomass, dominance of L- and P-band HH trunk-ground scattering and increases with trunk biomass, and dominance of L-band HV volume (branch) scattering and increases with large-branch biomass. The study concluded that above-ground biomass estimated using empirical relationships with selected SAR channels will be more reliable for forests of similar structural form due to dominance of microwave interaction with particular biomass components and the strength and consistency of relationships between these and the affiliated components that represent the total. In mixed-species forests, retrieval will be compromised by interaction with a greater diversity of structures and variability in relationships between structural components. Although empirical relationships with selected combinations of channels (e.g., L-band HH/HV) might allow retrieval of component and total biomass of forests containing trees of similar form (e.g., as mapped using Landsat sensor data), the use of SAR inversion models was considered a more appropriate route for retrieving

the biomass of forests containing a mix of structural forms. [J1414]

"Spatiotriangulation with multisensor VIR/SAR images"

The objectives of this research study was to evaluate the spatiotriangulation applied to multisensor satellite images, which enabled the simultaneous geometric processing of a large number of images and strips together to reduce the control point requirement. The spatiotriangulation is based on the three-dimensional physical models developed for multisensor images at the Canada Centre for Remote Sensing, Natural Resources Canada and on a least squares block bundle adjustment process with orbital constraints. The spatiotriangulation was applied to 49 images in six blocks (Landsat-7 ETM+, panchromatic SPOT-4 HRV, multiband ASTER, multimode radar RADARSAT-1, and ERS-1) acquired over the Rocky Mountains, Canada, from different viewing/look angles. The first results of least squares block bundle adjustments showed that the same error residuals (around 20 m) were obtained with the different image blocks whether independently or simultaneously processed. In addition to ground control points (GCPs), elevation tie points (ETPs), with a known elevation value, instead of normal tie points were used in the overlaps because the viewing/look-angle differences of overlapping images were generally small (8°). The second and most important results were related to simultaneous bundle adjustments of the largest "master" Landsat-7 block (600 km Ч 500 km) using 25 GCPs in the two outer strips and the smallest "slave" block(s) using no GCP but only ETPs. The errors, verified by a large number of independent check points (ICPs) in the "slave" blocks, were between 15-35 m (1.5-2 resolutions), depending on the "slave" block. However, the combined image pointing and map errors of ICPs (25-30 m) are included in these 15-35-m error results, and the internal accuracy of the blocks should, thus, be better (around one resolution). The research study demonstrated, thus, the possibility to use the largest block with a reduced number of GCPs to simultaneously adjust single image(s)/strip(s) or smallest block(s) with only ETPs, and with no degradation in the accuracy. [J1415]

"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. [J1416]

"Models and useful relations for bistatic SAR processing"

The paper derives a vectorial model for expressing transmitter and receiver trajectories for arbitrary transmitter and receiver motion (nonidentical velocity vectors) in a bistatic synthetic aperture radar constellation. The point target response is first modeled in the space-time domain and then transformed to the frequency domain by the method of stationary phase giving the point target reference spectrum. In the reference spectrum, two phasor functions can be identified, the first one resembling some quasi-monostatic contribution and the second one being a bistatic deformation phasor transforming into an elliptic arc in the spatial domain. The multiplication of the two phasors in the frequency domain transforms into a convolution like operation in the space-time domain, indicating that the bistatic dataset can be expressed as a convolution like (range and azimuth variant) mapping of a monostatic dataset. In this regard, the paper extends the solution for the constant offset case known from the geophysical literature (associated with "Rocca's smile operator") showing that this case is a specialization of the more general one considered in this work. [J1417]

"Stochastic geometrical modeling for built-up area understanding from a single SAR intensity image with meter resolution"

To investigate the limits and merits of information extraction from a single high-resolution synthetic aperture radar (SAR) backscatter image, we introduce a model-based algorithm for the automatic reconstruction of building areas from single-observation meter-resolution SAR intensity data. The reconstruction is based on the maximum a posteriori estimation by Monte Carlo methods of an optimal scene that is modeled as a set of mutually interacting Poisson-distributed marked points describing parametric building objects. Each of the objects

can be hierarchically decomposed into a collection of radiometrically and geometrically specified object facets that in turn get mapped into data features by ground-to-range projection and inverse Gaussian statistics. The detection of the facets is based on a likelihood ratio. Results are presented for airborne data with resolutions in the range of 0.5-2 m on urban scenes covering agglomerations of buildings. To achieve robust results for building reconstruction, the integration with data from other sources is needed. [J1418]

"Interference level evaluation in SS-BSAR with GNSS non-cooperative transmitter"

Space-surface bistatic synthetic aperture radars (SS-BSAR) can effectively utilise non-cooperative transmitters (NCTs). For continuous wave NCTs, the desired reflected signals are fundamentally received at the background of direct path interference (DPI). Proposed is the method of signal-to-interference ratio (SIR) evaluation. It is shown that the improvement in SIR is achieved due to the specific ambiguity functions of the radiated signals, as well as the phase history of both the signal and DPI. [J1419]

"Three-dimensional SAR imaging of a ground moving target using the InISAR technique"

In this paper, a three-dimensional (3-D) interferometric synthetic aperture radar (ISAR) imaging method for moving targets is presented. This imaging method is based on the ISAR principle and the simple observation that all scatterers on a moving target move in tandem. The angular motion parameters in the cross-range directions could be estimated using the overall range profile of the moving target. Registration of the respective complex images at the two (or more) interferometric antennas can then be achieved via compensating the respective echoes at the raw data level, thus avoiding phase-unwrapping processing and image-resampling processing as required by conventional methods. Finally, a 3-D image of the moving target can then be reconstructed from the 3-D spatial coordinates of these scatterers. Furthermore, the method works well even for a target moving in heavily cluttered environments. [J1420]

"Boundary-constrained agglomerative segmentation"

Automated interpretation of remotely sensed data poses certain demands to image segmentation algorithms, regarding speed, memory requirements, segmentation quality, noise robustness, complexity, and reproducibility. This paper addresses these issues by formulating image segmentation as source channel coding with side information. A cost function is developed that approximates the expected code length for a hypothetical two-part coding scheme. The cost function combines region-based and edge-based considerations, and it supports the utilization of reference data to enhance segmentation results. Optimization is implemented by an agglomerative segmentation algorithm that iteratively creates a tree-like description of the image. Given a fixed tree level and the output of the edge detector, the cost function is parameter-free, so that no exhaustive parameter-tuning is necessary. Additionally, a criterion is presented to reliably select an adequate tree level with high descriptive quality. It is shown by statistical analysis that the cost function is appropriate for both multispectral and synthetic aperture radar data. Experimental results confirm the high quality of the resulting segmentations. [J1421]

"Sparse frequency transmit-and-receive waveform design"

A computationally efficient algorithm derives complex digital transmit and receive ultra-wideband radar and communication waveforms with excellent arbitrary frequency band suppression and range sidelobe minimization. The transmit waveform minimizes a scalar function penalizing weighted spectral energy in arbitrary frequency bands. Near constant power results from another penalty function for deviations from constant power, or constant power is enforced by a phase-only formulation. Next, a least squares solution for the receive waveform minimizes a weighted sum of suppressed band spectral energy and range sidelobes (for pulse and continuous wave operation), with a mainlobe response constraint. Both waveforms are calculated by iterative algorithms whose updates require only linear order in memory and computation, permitting quick calculation of long pulses with thousands of samples. [J1422]

"Detection of moving targets in wideband SAR"

A likelihood ratio is proposed for moving target detection in a wideband (WB) synthetic aperture radar (SAR) system. WB is defined here as any systems having a large fractional bandwidth, i.e., an ultra wide frequency band combined with a wide antenna beam. The developed method combines time-domain fast backprojection SAR processing methods with moving target detection using space-time processing. The proposed method reduces computational load when sets of relative speeds can be tested using the same clutter-suppressed subaperture beams. The proposed method is tested on narrowband radar data. [J1423]

"Results on bistatic synthetic aperture radar"

The interest in bistatic synthetic aperture radar (SAR) has increased rapidly in recent years. This is founded in the specific advantages of bistatic SAR configurations. The calculation of the resulting bistatic resolution is quite different from the monostatic case. A general vectorial calculation in three-dimensional space is presented. Furthermore, first experimental results from a bistatic flight campaign are shown. [J1424]

"Radar imaging of moving targets in foliage using multifrequency multiaperture polarimetric SAR"

Because of the low signal-to-clutter ratio, it is a difficult problem to detect and image moving targets in foliage. In this paper, a multifrequency multiaperture polarimetric synthetic aperture radar (MFMA POLSAR) system is proposed for imaging of moving targets in foliage. The MFMA POLSAR extends the multifrequency antenna array SAR (MF-SAR) system to multiple polarizations. Full polarization is used in MFMA POLSAR to achieve an optimal polarization adaptive to the environment such that the images obtained by different apertures are of the best coherence that is used to obtain the highest accuracy of the phase estimation. It is also shown that the MFMA POLSAR cannot only accurately locate both the slow and the fast moving targets but also reveal moving targets in foliage. [J1425]

"Contribution of the fractal dimension to multiscale adaptive filtering of SAR imagery"

Radar images can show great variability from pixel to pixel, which is an obstacle to effective processing. This variability, due to speckle created by the radar wave coherence, necessitates the use of more adapted filters. Previous studies have shown that multiresolution wavelet analysis yields better results but produces artefacts due to multiscale decomposition. This paper proposes a method that reduces these effects by introducing the fractal dimension. The resultant filter combines wavelet decomposition and variance change model based on the level of variance estimated by studying the fractal dimension of the image. [J1426]

"Synthetic aperture inversion for arbitrary flight paths and nonflat topography"

The paper considers synthetic aperture radar (SAR) and other synthetic aperture imaging systems in which a backscattered wave is measured from positions along an arbitrary (known) flight path. The received backscattered signals are used to produce an image of the terrain. We assume a single-scattering model for the radar data, and we assume that the ground topography is known but not necessarily flat. We focus on cases in which the antenna footprint is so large that the standard narrow-beam algorithms are not useful. We show that certain artifacts can be avoided if the antenna and antenna footprint avoid particular relationships with the ground topography. We give an explicit backprojection imaging algorithm that corrects for the ground topography, flight path, antenna beam pattern, source waveform, and other geometrical factors. For the case of a non-directional antenna, the image produced by the above algorithm contains artifacts. For this case, we analyze the strength of the artifacts relative to the strength of the true image. The analysis shows that the artifacts can be somewhat suppressed by increasing the frequency, integration time, and the curvature of the flight path. [J1427]

"Minimum description length synthetic aperture radar image segmentation"

We present a new minimum description length (MDL) approach based on a deformable partition-a polygonal grid-for automatic segmentation of a speckled image composed of several homogeneous regions. The image segmentation thus consists in the estimation of the polygonal grid, or, more precisely, its number of regions, its number of nodes and the location of its nodes. These estimations are performed by minimizing a unique MDL criterion which takes into account the probabilistic properties of speckle fluctuations and a measure of the stochastic complexity of the polygonal grid. This approach then leads to a global MDL criterion without an undetermined parameter since no other regularization term than the stochastic complexity of the polygonal grid is necessary and noise parameters can be estimated with maximum likelihood-like approaches. The performance of this technique is illustrated on synthetic and real synthetic aperture radar images of agricultural regions and the influence of different terms of the model is analyzed. [J1428]

"SAR image denoising via Bayesian wavelet shrinkage based on heavy-tailed modeling"

Synthetic aperture radar (SAR) images are inherently affected by multiplicative speckle noise, which is due to the coherent nature of the scattering phenomenon. This paper proposes a novel Bayesian-based algorithm within the framework of wavelet analysis, which reduces speckle in SAR images while preserving the structural features and textural information of the scene. First, we show that the subband decompositions of logarithmically transformed SAR images are accurately modeled by alpha-stable distributions, a family of heavy-tailed densities. Consequently, we exploit this a priori information by designing a maximum a posteriori (MAP) estimator. We use the alpha-stable model to develop a blind speckle-suppression processor that performs a nonlinear operation on the data and we relate this nonlinearity to the degree of non-Gaussianity of the data. Finally, we compare our proposed method to current state-of-the-art soft thresholding techniques applied on real SAR imagery and we

quantify the achieved performance improvement. [J1429]

"Foreword to the special issue on the retrieval of bio- and geophysical parameters from sar data for land applications"

First Page of the Article [J1430]

"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. [J1431]

"Road vectors update using SAR imagery: a snake-based method"

The paper presents an approach for roads detection based on synthetic aperture radar (SAR) images and road databases. The vectors provided by the database are refined using active contours (snakes). In this framework, we firstly develop a restoration filter based on the frost filter achieving an acceptable compromise between speckle elimination and lines preserving. This is followed by a line plausibility calculation step which is used to deform the snake from its initial location toward the final solution. The snake is reformulated using finite elements method. The setting of the snake parameters is not an obvious problem especially when they are tuned by trial-and-error process. We propose a new automatic computational rule for the snake parameters. Our approach is validated by a series of tests on synthetic and SAR images. [J1432]

"Effect of dielectric properties of moist salinized soils on backscattering coefficients extracted from RADARSAT image"

This paper presents the experimental results regarding changes in the dielectric properties of artificially moistened and salinized soils and on soil samples taken from a salt lake. The complex dielectric constants of soil samples were measured using a microwave network analyzer. We evaluated the real and imaginary parts of dielectric constants of artificially moistened and salinized soil samples prepared in the laboratory as a function of microwave frequency, salinity, and water content. The soil moisture strongly affected the real part of dielectric constant ε'. The frequency and the salinity of soils have little influence on the real part of dielectric constant ε'. The imaginary part of the dielectric constant ε" is strongly affected by both the salinity and moisture of soil samples, especially at low frequencies. When f0backscattering coefficients extracted from a RADARSAT image (C-HH) that was acquired at same time with the soil sampling at the Jilantai Salt Lake area. We discovered that the correlation coefficient between σ0extracted from the RADARSAT image and ε" measured in the soil sample is 0.70, whereas the correlation coefficient of σ0and ε' is 0.27. The correlation coefficient between σ0and the soil sample salinity is 0.69. This suggests that soil salinity has a significant contribution to the backscattering coefficient σ0recorded in a synthetic aperture radar (SAR) image. Consequently, a SAR image can be a useful tool for monitoring soil salinity. [J1433]

"Estimation of azimuth phase undulations with multisquint processing in airborne interferometric SAR images"

Presents a technique to detect and correct phase errors appearing in interferometric airborne synthetic aperture radar (SAR) systems due to the lack of precision in the navigation system. The technique is based on a multisquint processing approach, i.e. by processing the same image pairs with different squint angles we can combine the information of different interferograms to obtain the desired phase correction. Airborne single-pass interferometric data from the Deutsches Zentrum fьr Luft- und Raumfahrt (DLR) experimental airborne SAR is used to validate the method. [J1434]

"Terrain analysis using radar shape-from-shading"

This paper develops a maximum a posteriori (MAP) probability estimation framework for shape-from-shading (SFS) from synthetic aperture radar (SAR) images. The aim is to use this method to reconstruct surface topography from a single radar image of relatively complex terrain. Our MAP framework makes explicit how the recovery of local surface orientation depends on the whereabouts of terrain edge features and the available radar reflectance information. To apply the resulting process to real world radar data, we require probabilistic models for the appearance of terrain features and the relationship between the orientation of surface normals and the radar reflectance. We show that the SAR data can be modeled using a Rayleigh-Bessel distribution and use this distribution to develop a maximum likelihood algorithm for detecting and labeling terrain edge features. Moreover, we show how robust statistics can be used to estimate the characteristic parameters of this distribution. We also develop an empirical model for the SAR reflectance function. Using the reflectance model, we perform Lambertian correction so that a conventional SFS algorithm can be applied to the radar data. The initial surface normal direction is constrained to point in the direction of the nearest ridge or ravine feature. Each surface normal must fall within a conical envelope whose axis is in the direction of the radar illuminant. The extent of the envelope depends on the corrected radar reflectance and the variance of the radar signal statistics. We explore various ways of smoothing the field of surface normals using robust statistics. Finally, we show how to reconstruct the terrain surface from the smoothed field of surface normal vectors. The proposed algorithm is applied to various SAR data sets containing relatively complex terrain structure. [J1435]

"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). [J1436]

"On the possibility of aperture synthesis with a single mobile antenna in radio astronomy"

The classic aperture synthesis widely used in radio astronomy, synthetic aperture radar, and remote sensing is based on the measurement of the degree of spatial coherence in the diffraction pattern of a radio emission source. All these applications imply correlation with a coherent reference signal. The possibility of obtaining the same information from the autocorrelation of a signal recorded on a single, mobile antenna is considered. Comparison of the output of an ordinary cross-correlation two-element radio interferometer and the autocorrelation output of a mobile antenna shows a similarity that allows extraction of information about the radio source spatial coherence in the latter case. The limitations of this method of aperture synthesis are considered. [J1437]

"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. [J1438]

"Estimating lava volume by precision combination of multiple baseline spaceborne and airborne interferometric synthetic aperture radar: the 1997 eruption of Okmok volcano, Alaska"

Interferometric synthetic aperture radar (InSAR) techniques are used to calculate the volume of extrusion at Okmok volcano, Alaska by constructing precise digital elevation models (DEMs) that represent volcano topography before and after the 1997 eruption. The posteruption DEM is generated using airborne topographic synthetic aperture radar (TOPSAR) data where a three-dimensional affine transformation is used to account for the misalignments between different DEM patches. The preeruption DEM is produced using repeat-pass European Remote Sensing satellite data; multiple interferograms are combined to reduce errors due to atmospheric variations, and deformation rates are estimated independently and removed from the interferograms used for DEM generation. The extrusive flow volume associated with the 1997 eruption of Okmok volcano is 0.154±0.025 km3. The thickest portion is approximately 50 m, although field measurements of the flow margin's height do not exceed 20 m. The in situ measurements at lava edges are not representative of the total thickness, and precise DEM data are absolutely essential to calculate eruption volume based on lava thickness estimations. This study is an example that demonstrates how InSAR will play a significant role in studying volcanoes in remote areas. [J1439]

"Estimation of rock glacier surface deformation using SAR interferometry data"

The detection and quantification of surface deformation of an active rock glacier using the differential synthetic aperture radar (SAR) interferometry (D-InSAR) technique is presented. An average deformation rate of -6 mm/35 days in the radar line of ight was estimated for the summer of 1992. The maximum deformation rate, -18 mm/35 days, was identified at the upper part of the rock glacier, whereas the deformation rate at the snout of the rock glacier was about -10 mm/35 days. The spatial distribution of the surface deformation in the D-InSAR displacement map is smooth and supports the idea that ice is the stress-transferring medium in rock glaciers. [J1440]

"Airborne differential SAR interferometry: first results at L-band"

In recent years, differential interferometry using spaceborne synthetic aperture radar (SAR) sensors has become an established technique for detecting and monitoring centimetre-scale deformations of the Earth's surface, as well as glacier flows and landslides. Although often very efficient, the use of spaceborne SAR data has several drawbacks, namely phase artifacts caused by atmospheric effects and very low coherence due to long data acquisition intervals and the short radar wavelength of the sensor. Most important, current spaceborne sensors are not able to ensure flexible monitoring of critical regions. Airborne sensors may overcome most of the problems mentioned above, but up to now, the operational use of airborne differential SAR interferometry has been prevented by insufficiently accurate motion compensation of the platform. In this letter, first results of airborne differential interferometry using the German Aerospace Center (DLR) experimental SAR system (E-SAR) in the interferometric repeat-pass mode are addressed. This includes an analysis of long-term decorrelation behavior in L-band and, particularly, the correction of residual motion errors in heavily decorrelated interferograms. A first differential interferogram of agricultural and forested areas is presented and analyzed. [J1441]

"Detection of wave groups in SAR images and radar image sequences"

The properties of individual wave groups in space and time utilizing synthetic aperture radar (SAR) images and nautical radar image sequences are studied. This is possible by the quantitative measurement and analysis of wave groups both spatially and spatio-temporally. The SAR, with its high spatial resolution and large coverage, offers a unique opportunity to study and derive wave groups. In addition to SAR images, nautical radar image sequences allow the investigation of wave groups in space and time and, therefore, the measurement of parameters such as the group velocity. The detection of wave groups is based on the determination of the envelope function, which was first adopted for one-dimensional (1-D) time series by Longuet-Higgins. The method is extended from 1-D to spatial and spatio-temporal dimensions to derive wave groups in images and image sequences. To test the algorithm, wave groups are derived from SAR images and two radar image sequences, recorded at locations in deep and shallow water. It is demonstrated that the algorithm can be employed for the determination of both location and size of wave groups from radar images. Investigating the detected wave groups in radar image sequences additionally allows the measurement of the spatial and temporal development of wave groups and their extension and phase velocities. Comparison of measured wave group velocities in shallow and deep water gives a deviation of the average value from the group velocities resulting from linear wave theory and shows a clear oscillation of the group velocities in two dimensions. [J1442]

"The application of wavelets correlator for ship wake detection in SAR images"

The detection of the wake can provide substantial information about a ship, such as its size, direction, and speed of movement. In general though, ship-generated wakes in synthetic aperture radar images are associated with

high sea clutter, which will cause some deterioration in the detection performance. Therefore, a wavelet correlator, based on an orthogonal basis function, is adopted. Three highpass images-horizontal, vertical, and diagonal direction-are generated for each resolution scale, followed by a process to correlate among the moduli of different scale modulus images formed from the three highpass images. The output of the correlation process is highly representative at the ship's wake edges. Comparisons with other methods indicate the superior performance of the present approach, in that not only can the wakes be detected, but their V-shaped pattern is well preserved. The second stage involves the application of the Radon transform technique to an estimation of the V-opening angle from the detected ship wakes. Ship-generated wake edges are found to be the local maxima in the wavelet transform method of several adjacent scales, and hence, the wake edge will be enhanced in the reconstructed data. The background noise is also greatly reduced. In particular, the process of spatial correlation is found to be critical. Compared to a direct Radon transform, the proposed scheme is demonstrated to be much more effective in terms of efficiency, as well as reliability, for ship wake detection in noisy backgrounds. [J1443]

"A comparison between soil roughness statistics used in surface scattering models derived from mechanical and laser profilers"

The objective of this paper is to quantify the impact of the type of surface-profiling instrument on the roughness measurements in radar remote sensing studies. Particularly, the use of mechanical profilers as compared to more precise laser profilers is investigated. The motivations for this study are twofold. First, simple and inexpensive mechanical profilers will probably still be used extensively for in situ ground measurements in the next few years, e.g., to investigate the use of multipolarization, multiincidence angle satellite data, i.e., Advanced Synthetic Aperture Radar (ASAR) onboard the European Space Agency Environmental Satellite. Second, a great amount of roughness data have been acquired in the past by means of mechanical profilers and, to date, a quantification of the error budget affecting these measurements is still missing. The paper focuses on modeling and quantifying the measurement errors associated with profiles a few meters long. To determine the errors, we compare soil roughness measurements obtained using laser and mechanical profilers over agricultural surfaces with different roughness characteristics. The analyzed datasets consist of roughness measurements acquired over the Matera site (Italy) and the Marestaing site, near Toulouse (France), in 1998 and 2000, respectively. Analytical expressions for first and second statistical moments of roughness parameters as a function of different sources of measurement errors are derived and compared to experimental values. The results show that mechanical measurements, once appropriately calibrated, are in overall good agreement with laser measurements. Practical indications of the most appropriate profiler length and number of independent measurements to be recorded are also derived in the paper. [J1444]

"Subsurface imaging in south-central Egypt using low-frequency radar: Bir Safsaf revisited"

We present the capabilities of low-frequency radar systems to sound the subsurface for a site located in south-central Egypt, the Bir Safsaf region. This site was already intensively studied since the SIR-A and SIR-B orbital radars revealed buried paleodrainage channels. Our approach is based on the coupling between two complementary radar techniques: the orbital synthetic aperture radar (SAR) in C and L bands (5.3 and 1.25 GHz) for imaging large-scale subsurface structures, and the ground-penetrating radar (GPR) at 500 and 900 MHz for sounding the soil at a local scale. We show that the total backscattered power computed from L-band SAR and 900-MHz GPR profiles can be correlated, and we combined both data to derive the geological structure of the subsurface. GPR data provide information on the geometry of the buried scatterers and layers, while the analysis of polarimetric SAR data provides information on the distribution of rocks in the sedimentary layers and at the interface between these layers. The analysis of 500-MHz GPR data revealed some deeper structures that should be detected by lower frequency SARs, such as a P-band system. [J1445]

"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. [J1446]

"Joint statistical properties of RMS height and correlation length derived from multisite 1-m roughness measurements"

This paper aims to establish the joint roughness statistics for rms height s and correlation length l for agricultural bare soil fields and a variety of tillage conditions. To do so, we make use of a unique pan-European database of profile measurements covering five different sites and containing approximately 1.5 km of profile data. A preliminary assessment of the validity of the derived roughness statistics for electromagnetic scattering models is also carried out by comparing σ0predictions obtained using the integral equation model with derived roughness statistics and European Remote Sensing 1 and 2 (ERS 1/2) synthetic aperture radar observations. The results are then summarized within the overall context of roughness description and we discuss the implications in terms of forward modeling and inversion. The limitations of s and l parameters as roughness descriptors are also underlined. [J1447]

"SAR monitoring of progressive and seasonal ground deformation using the permanent scatterers technique"

Spaceborne differential radar interferometry has proven a remarkable potential for mapping ground deformation phenomena (e.g., urban subsidence, volcano dynamics, coseismic and postseismic displacements along faults, as well as slope instability). However, a full operational capability has not been achieved yet due to atmospheric disturbances and phase decorrelation phenomena. These drawbacks can often be-at least partially-overcome by carrying out measurements on a subset of image pixels corresponding to natural or artificial stable reflectors [permanent scatterers (PS)] and exploiting long temporal series of interferometric data. This approach allows one to push the measurement precision very close to its theoretical limit (in the order of 1 mm for C-band European Remote Sensing (ERS)-like sensors). In this paper, the detection of both time-uniform and seasonal deformation phenomena is addressed, and a first assessment of the precision achievable by means of the PS Technique is discussed. Results highlighting deformation phenomena occurring in two test sites in California are reported (Fremont in the Southern Bay Area and San Jose in the Santa Clara Valley). [J1448]

"Digital beamforming in SAR systems"

The rapid progression in digital hardware and signal processing capabilities stimulates the development of radar systems. The tendency is to move the digital interface toward the antenna, replacing, whenever possible, analog RF-hardware. Based on software codes, these digital systems are more flexible and easier to reconfigure than RF-hardware. This letter illustrates the general concept for digital beamforming (DBF) in synthetic aperture radar systems and investigates their principle capabilities, limitations, and performance parameters. It is shown that using DBF a simultaneous improvement in azimuth coverage and resolution can be achieved. [J1449]

"Analysis of multistatic configurations for spaceborne SAR interferometry"

Spaceborne bistatic and multistatic SAR configurations are an attractive approach to acquire along-track and cross-track interferograms on a global scale. An efficient realisation of such systems may be achieved by a set of low-cost, passive receivers onboard a constellation of microsatellites which simultaneously record the backscattered signals transmitted by a conventional spaceborne radar. The authors introduce several multistatic SAR configurations suitable for global single-pass interferometry and discuss their advantages and limitations. The achievable interferometric performance is analysed in detail, taking into account thermal noise, block adaptive quantisation, range and azimuth ambiguities, and geometric decorrelation for both surface and random volume scatterers. Based on the estimated interferometric phase errors, the relative height accuracies for three illuminators (PALSAR, ASAR, TerraSAR-X) are derived. The achievable height accuracies are of the order of 2 m for PALSAR and ASAR, and of the order of 1 m for TerraSAR-X. However, it turns out that for vegetated areas, volume decorrelation may become a limiting factor for configurations with large interferometric baselines. These restrictions can be overcome by making the interferometric configuration fully polarimetric and/or increasing the number of available baselines. [J1450]

"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. [J1451]

"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. [J1452]

"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. [J1453]

"Toward precision forestry: plot-level parameter retrieval for slash pine plantations with JPL AIRSAR"

During an EOCAP-SAR project, Airsar P-, L-, and C-band data were used to test the capability of synthetic aperture radar (SAR) to predict biometric parameters which are frequently used by timber managers as inputs to growth, harvest, and yield models. Test site was a commercially managed area in Jesup, southeastern Georgia, with stands owned by Plum Creek Timber Company. A biometric survey data set from 118 cluster plots in two thinned and two unthinned slash pine stands was used to determine the correlation with the Airsar data at the plot level. A statistical model was used to test all possible scenarios of polarimetric and frequency combinations. Using a weighted least squares linear regression model, PHVproved to be the single most significant band/polarization combination to correlate with dominant height, basal area, and volume at adjusted squared correlation coefficients of 0.70, 0.80, and 0.84, respectively. [J1454]

"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. [J1455]

"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. [J1456]

"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. [J1457]

"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. [J1458]

"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. [J1459]

"Methods and examples for remote sensing data assimilation in land surface process modeling"

Land surface process models describe the energy, water, carbon, and nutrient fluxes on a local to regional scale using a set of environmental land surface parameters and variables. They need time series of spatially distributed inputs to account for the large spatial and temporal variability of land surface processes. In principle many of these inputs can be derived through remote sensing using both optical and microwave sensors. New approaches in four-dimensional data-assimilation (4DDA) form the basis to combine remote sensing data and spatially explicit land surface process models more effectively. This paper describes basic techniques for 4DDA in land surface process modeling. Two case studies were carried out to demonstrate different successful approaches of remote sensing data assimilation into land surface process models. The assimilation of surface soil moisture estimates from European Remote Sensing (ERS) synthetic aperture radar data in a flood forecasting scheme is

presented, as well as the combination of a land surface process model and a radiative transfer model to improve the accuracy of land surface parameter retrieval from optical data [Landsat Thematic Mapper (TM)]. [J1460]

"High-resolution measurements of scattering in wheat canopies-implications for crop parameter retrieval"

Polarimetric X- and C-band measurements by the University of Sheffield ground-based synthetic aperture radar (GB-SAR) indoor system provide three-dimensional images of the scattering processes in wheat canopies, at resolutions of around a wavelength (3-6 cm). The scattering shows a pronounced layered structure, with strong returns from the soil and the flag leaves, and in some cases a second leaf layer. Differential attenuation at horizontal (H) and vertical (V) polarization, due to the predominantly vertical structure of the wheat stems, gives rise to marked effects. At both C and X bands, direct return from the canopy exceeds the soil return at large incidence angles for VV polarization, but is comparable to or less than the soil return in all other cases. At HV, the apparent ground return is probably due to a double-bounce mechanism, and volume scattering is never the dominant term. Direct sensing of the crop canopy is most effective at X band, VV, and large incidence angles, under which conditions the return is dominated by the flag leaf layer. Field measurements with the outdoor GB-SAR system suggest, however, that for sensitivity to biomass and reduced susceptibility to disturbances by rainfall, a two-channel C-band system operating at a medium range of incidence angles is preferred. [J1461]

"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. [J1462]

"Global range alignment for ISAR"

A new technique is developed for range alignment in inverse synthetic aperture radar (ISAR) imaging. The shifts made to the echoes are modeled as a polynomial, and the coefficients of this polynomial are chosen to optimize a global quality measure of range alignment. This technique is robust against noise and target scintillation, and avoids error accumulation. In addition, the shift in the time domain is implemented by introducing a phase ramp in the frequency domain, which removes the limitation of integer steps. [J1463]

"Two-dimensional evolutionary programming-based CLEAN"

In this work, we present a novel two-dimensional (2-D) scattering center extraction method, called 2-D evolutionary programming (EP)-based CLEAN. The 2-D EP-based CLEAN uses the ideal point scattering model and EP for optimization. Our algorithm has accuracy, robustness and better resolution than the fast Fourier transform (FFT)-based CLEAN. Further, it does not require the transformation of measured data from the polar frequency domain to the Cartesian frequency domain or to the image domain. Numerical simulations are performed to verify the characteristics of the proposed algorithm, such as resolution, robustness and accuracy. [J1464]

"3-D E-CSAR imaging of a T-72 tank and synthesis of its SAR reconstructions"

The results of three-dimensional (3-D) imaging of a T-72 tank using its angular azimuthal (turntable) and linear elevation synthetic aperture data at X band are presented. This is achieved using an accurate and computationally efficient wavefront (Fourier-based) reconstruction algorithm for elevation and circular (E-CSAR) data. The E-CSAR 3-D images are then used to synthesize 2-D spotlight and stripmap slant plane synthetic aperture radar (SAR) images of the target at a desired range and squint angle. For this purpose, a procedure is introduced that incorporates the spatially varying azimuthal and elevation Doppler signatures of individual reflectors on the target as well as the mean range, azimuth, and elevation of the flight path. Results using the E-CSAR images of the T-72 tank are provided. [J1465]

"Use of genetic algorithms in ISAR imaging of targets with higher order motions"

Genetic algorithms (GA) are proposed for inverse synthetic aperture radar (ISAR) imaging. GA is used for motion parameters search in place of exhaustive search in the adaptive joint time-frequency (AJTF) algorithm. While

maintaining the same accuracy, GA has lower computational complexity, especially for targets with higher order motions. [J1466]

"Detection and imaging of arbitrarily moving targets with single-channel SAR"

In synthetic aperture radar (SAR) images, moving targets cause imaging errors such as defocusing and/or displacement, depending on the direction of their motion. To obtain a correct and focused image of the moving targets, knowledge of the target parameters, position and velocity, is necessary. An algorithm for detection, parameter estimation, and imaging of ground-based targets, moving in arbitrary directions, is presented. The algorithm is based on evaluation of a sequence of single-look SAR images which is generated from conventional, single-channel SAR raw data. The position and velocity of the moving targets are estimated by applying two observation models, whereby aliasing due to a motion induced Doppler shift is considered. In this way, the moving targets can be detected almost independently of their moving direction. The estimated parameters are used to compensate for the imaging errors in the SAR images. Finally, the real motion of the targets in the scene is visualised in a compensated image sequence. [J1467]

"Three-dimensional focusing with multipass SAR data"

Deals with the use of multipass synthetic aperture radar (SAR) data in order to achieve three-dimensional tomography reconstruction in presence of volumetric scattering. Starting from azimuth- and range-focused SAR data relative to the same area, neglecting any mutual interaction between the targets, and assuming the propagation in homogeneous media, we investigate the possibility to focus the data also in the elevation direction. The problem is formulated in the framework of linear inverse problem and the solution makes use of the singular value decomposition of the relevant operator. This allows us to properly take into account nonuniform orbit separation and to exploit a priori knowledge regarding the size of the volume interested by the scattering mechanism, thus leading to superresolution in the elevation direction. Results obtained on simulated data demonstrate the feasibility of the proposed processing technique. [J1468]

"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. [J1469]

"Results of flight tests of a two-channel radar system with real-time MTI processing"

Space-time adaptive processing (STAP) in real-time is discussed for two applications: first, STAP can be used for suppressing clutter and jammers; moreover, clutter filter coefficients gained by STAP can be used for the purpose of the correct positioning of moving targets within SAR images. Results of this real-time STAP technique as well as the results of the moving-target repositioning technique are presented: the clutter-suppression quality and the moving target repositioning accuracy are demonstrated with real SAR data and moving targets recorded during a measurement campaign. [J1470]

"A generalized divergence measure for robust image registration"

Entropy-based divergence measures have shown promising results in many areas of engineering and image processing. We define a new generalized divergence measure, namely, the Jensen-Renyi (1996, 1976) divergence. Some properties such as convexity and its upper bound are derived. Based on the Jensen-Renyi divergence, we propose a new approach to the problem of image registration. Some appealing advantages of registration by Jensen-Renyi divergence are illustrated, and its connections to mutual information-based

registration techniques are analyzed. As the key focus of this paper, we apply Jensen-Renyi divergence for inverse synthetic aperture radar (ISAR) image registration. The goal is to estimate the target motion during the imaging time. Our approach applies Jensen-Renyi divergence to measure the statistical dependence between consecutive ISAR image frames, which would be maximal if the images are geometrically aligned. Simulation results demonstrate that the proposed method is efficient and effective. [J1471]

"Application of frequency correlation function to radar target detection"

Analysis of high-resolution 35 GHz synthetic aperture radar (SAR) imagery of terrain reveals that when point targets, such as vehicles, are viewed at angles close to grazing incidence, they are often difficult to distinguish from tree trunks because the radar cross section (RCS) intensities of the vehicles are comparable to the upper end of the RCS exhibited by tree trunks. To resolve the point target/tree trunk ambiguity problem, a detailed study was conducted to evaluate the use of new detection features based on the complex frequency correlation function (FCF). This paper presents an analytical examination of FCF and its physical meaning, the results of a numerical simulation study conducted to evaluate the performance of a detection algorithm that uses FCF, and the corroboration of theory with experimental observations conducted at 35 and 95 GHz. The FCF-based detection algorithm was found to correctly identify tree trunks as such in over 90% of the cases, while exhibiting a false alarm rate of only 3%. [J1472]

"Volume decorrelation resolution in polarimetric SAR interferometry"

Volume decorrelation is a phenomenon affecting the synthetic aperture radar (SAR) interferometric coherence images in the presence of forests or buildings. 'Resolving' this effect could lead to an estimation of the height of the observed distributed scatterers. An empirical method is suggested to distinguish volume decorrelation due to random volumes (such as trees) and stationary distributed targets (such as man-made artifacts) when polarimetric SAR data are used. [J1473]

"Classified pixel-based windowing algorithm for polarimetric SAR speckle filtering"

Two main purposes of synthetic aperture radar (SAR) speckle filtering are the preservation of the edge sharpness and the suppression of the speckle noise. However, most of the existing filtering techniques suppress the speckle noise while smearing edges. This problem is partly solved by using nonsquare windows, but it can also generate large errors in many applications. A new windowing algorithm that can overcome the defects of the nonsquare window, by discriminating the edges more precisely with a preliminary terrain classification result, is proposed. [J1474]

"GRS 2002: German Radar Symposium in Bonn, Germany"

The German Radar Symposium (GRS 2002), organized jointly by the German Institute of Navigation (DGON) and by the Information Technology Society (VDE-ITG), attracted wide interest in the international radar community. It was held from September 3-5, 2002, in Bonn, the former capital city of Germany. The GRS 2002 programme covered a large scale of important radar topics. All classical topics like air traffic control, CFAR, antenna technology, signal processing and simulation papers have been presented and new results were demonstrated. These topics were combined with new applications like meteorology, subsurface, and automotive to underline the increase of interest in radar technology. Phased array antennas are the key elements of high performance multi-function radar systems which are studied all over the world. SAR and ISAR are, nowadays, essential radar techniques for civil and military observation and monitoring. [J1475]

"Synthesis of microstrip reflectarrays as planar scatterers for SAR interferometry"

The use of printed reflectarrays as planar scatterers for SAR interferometry applications is proposed. A phase-only synthesis is applied to obtain a scattered field in a prescribed direction. A reflectarray working at ERS1/2 frequency (5.3 GHz) is simulated to validate the method. Measurements are performed on a 10 GHz size-reduced prototype. [J1476]

"Digital on-line compensation of errors induced by linear distortion in broadband LFM radars"

The problem of group delay distortion in last generation LFM (linear frequency modulation) radars has been identified as an important handicap for the development of high performance broadband systems. A simple digital calibration technique is now proposed to overcome this problem. Although it has been developed for pulsed synthetic aperture radars it can be easily applied to other LFM systems. [J1477]

"CFAR edge detector for polarimetric SAR images"

Finding the edges between different regions in an image is one of the fundamental steps of image analysis, and several edge detectors suitable for the special statistics of synthetic aperture radar (SAR) intensity images have previously been developed. In this paper, a new edge detector for polarimetric SAR images is presented using a newly developed test statistic in the complex Wishart distribution to test for equality of covariance matrices. The new edge detector can be applied to a wide range of SAR data from single-channel intensity data to multifrequency and/or multitemporal polarimetric SAR data. By simply changing the parameters characterizing the test statistic according to the applied SAR data, constant false-alarm rate detection is always obtained. An adaptive filtering scheme is presented, and the distributions of the detector are verified using simulated polarimetric SAR images. Using SAR data from the Danish airborne polarimetric SAR, EMISAR, it is demonstrated that superior edge detection results are obtained using polarimetric and/or multifrequency data compared to using only intensity data. [J1478]

"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. [J1479]

"Minimising the tie patch window size for SAR image co-registration"

Owing to the presence of relatively large amounts of noise, coregistration of synthetic aperture radar (SAR) images typically involves matching of local area based 'tie patches' rather than feature based 'tie points'. Some applications require small tie patch windows, e.g. stereo SAR. Small tie patch windows, however, can lead to poor estimates of the local co-registration parameters. A procedure to minimise the tie patch window size while retaining 'confidence' in the local co-registration result is proposed. Background theory to the procedure and the results of an experimental study are presented. [J1480]

"A test statistic in the complex Wishart distribution and its application to change detection in polarimetric SAR data"

When working with multilook fully polarimetric synthetic aperture radar (SAR) data, an appropriate way of representing the backscattered signal consists of the so-called covariance matrix. For each pixel, this is a 3Ч3 Hermitian positive definite matrix that follows a complex Wishart distribution. Based on this distribution, a test statistic for equality of two such matrices and an associated asymptotic probability for obtaining a smaller value of the test statistic are derived and applied successfully to change detection in polarimetric SAR data. In a case study, EMISAR L-band data from April 17, 1998 and May 20, 1998 covering agricultural fields near Foulum, Denmark are used. Multilook full covariance matrix data, azimuthal symmetric data, covariance matrix diagonal-only data, and horizontal-horizontal (HH), vertical-vertical (VV), or horizontal-vertical (HV) data alone can be used. If applied to HH, VV, or HV data alone, the derived test statistic reduces to the well-known gamma likelihood-ratio test statistic. The derived test statistic and the associated significance value can be applied as a line or edge detector in fully polarimetric SAR data also. [J1481]

"ISAR imaging in strong ground clutter using a new stepped-frequency signal format"

In this paper, a new easy-to-implement variant of the stepped-frequency signal format is presented for ground clutter cancellation application. A sequence of pulse-groups, where each pulse-group consists of two pulses of the same carrier frequency, is transmitted. The carrier frequency of each subsequent burst is stepped at Δf. Simple first-order cancellation of ground clutter can be carried out by comparing the returns of the two adjacent pulses, as the clutter movement (due to wind, etc.) can be assumed negligible within this interval (typically [J1482]

"A novel technique for the processing of short-dwell spotlight SAR data"

The range migration algorithm (RMA) is an accurate algorithm to process spotlight synthetic aperture radar (SAR) data. However, in applying the RMA to process the SAR data, especially for short-dwell data, the data length has to be extended in azimuth by zero-padding it to the length of the azimuth filter. On the other hand, the spectral analysis (SPECAN, which is a deramp followed by a fast Fourier transform) algorithm is efficient, since the data extension is unnecessary, but an assumption is made that all targets have the same FM rate and

the same range cell migration. A novel algorithm is introduced here to combine the accuracy of the RMA and the efficiency of SPECAN. It involves bulk azimuth uncompressing the RMA processed data with a single linear FM filter, and then refocusing the data using SPECAN, all done without the azimuth extension in the RMA. Localized artifacts generated can be removed easily. Point target simulations, including one with a high squint angle of 60°, were successfully performed to verify the algorithm. [J1483]

"A new interpolation kernel for SAR interferometric registration"

Estimation of digital elevation maps from electromagnetic signals received at an interferometric synthetic aperture radar (SAR) requires significant processing. In this framework, a key step is the interferometric registration, which can be mathematically framed as an interpolation procedure. A new interpolation kernel for SAR interferometric registration is presented and discussed in comparison with five classical ones. It is based on the Knab sampling window that has been successfully employed in various electromagnetic problems and which has been proposed as capable of best preserving the stochastic information. The numerical experiments show the superiority of the new interpolation kernel. [J1484]

"Ionospheric effects on SAR imaging: a numerical study"

There has been an increasing interest in the use of spaceborne very high frequency ultra high frequency (VHF-UHF) synthetic aperture radar (SAR) for measuring forest biomass and for detecting underground facilities. The propagation characteristics of the low-frequency electromagnetic wave are severely affected by the ionosphere. Recently, Faraday rotation effects and SAR image degradation have been studied using an analytical model and a homogeneous ionosphere. In this paper, a numerical model is developed to investigate the SAR image degradation caused by an inhomogeneous ionosphere. Both horizontal and vertical structures of the ionosphere are considered in this model. Three different cases are studied. The first is a vertically homogenous ionosphere, where the simulation condition is the same as in the analytical study by Ishimaru and others. The second is a vertical profile, which is introduced using the Chapman formula. The ray-bending effect is added for the ionosphere with a layered structure. Finally, both the vertical profile in electron density and the horizontal gradient in total electron content are considered in the simulation. Simulation results show good agreement with the theoretical analysis under the same conditions of the ionosphere. When both horizontal and vertical structures and the inhomogeneity of the ionosphere are considered in the model, the simulation result shows further image degradation and shift caused by the ray-bending effect. The simulation results also show the strong frequency dependence of the SAR image resolution. [J1485]

"SAR raw data compression by subband coding"

A technique for compressing synthetic aperture radar raw data using multiresolution representations and subband coding is considered. In particular, we present the performance of a transform coding compression method using wavelet basis, coupled with a threshold quantizer optimized for Gaussian statistics, as well as a proper subband bit allocation strategy. The performances achieved in terms of bit rate reduction and certain quality parameters computed on the images obtained by compressed data have been evaluated. These show an increased performance in the compression method with respect to conventional methods, albeit with a slightly increased complexity in the algorithm implementation. [J1486]

"Multiple moving target detection and trajectory estimation using a single SAR sensor"

A novel methodology is presented for determining the velocity and location of multiple moving targets using a single strip-map synthetic aperture radar (SAR) sensor. The so-called azimuth position uncertainty problem is therefore solved. The method exploits the structure of the amplitude and phase modulations of the returned echo from a moving target in the Fourier domain. A crucial step in the whole processing scheme is a matched filtering, depending on the moving target parameters, that simultaneously accounts for range migration and compresses two-dimensional signatures into one-dimensional ones without losing moving target information. A generalized likelihood ratio test approach is adopted to detect moving targets and derive their trajectory parameters. The effectiveness of the method is illustrated with synthetic and real data covering a wide range of targets velocities and signal-to-clutter ratios (SCRs). Even in the case of parallel to platform moving target motion, the most unfavorable scenario, the proposed method yields good results for, roughly, SCR >10 dB. [J1487]

"Two-dimensional scattering center extraction based on multiple elastic modules network"

The concept of scattering centers on a target is commonly used for radar signature modeling and data compression, as well as target recognition. In particular, two-dimensional (2-D) scattering centers are useful features in automatic target recognition, which uses a synthetic aperture radar system, because they are directly

related to physical scattering mechanisms and also have small dimensionality. We propose a new technique for estimating 2-D scattering centers using radar data in the frequency-aspect domain. The technique first estimates one-dimensional scattering centers at several aspects, and the multiple elastic modules network optimization is exploited to find 2-D locations and amplitudes of the target's scattering centers. Experimental results illustrate that the proposed method is efficient not only for estimating 2-D scattering centers on the target but also in computation. [J1488]

"Lossy predictive coding of SAR raw data"

In this paper, we propose to employ predictive coding for lossy compression of synthetic aperture radar (SAR) raw data. We exploit the known result that a blockwise normalized SAR raw signal is a Gaussian stationary process in order to design an optimal decorrelator for this signal. We show that, due to the statistical properties of the SAR signal, an along-range linear predictor with few taps is able to effectively capture most of the raw signal correlation. The proposed predictive coding algorithm, which performs quantization of the prediction error, optionally followed by entropy coding, exhibits a number of advantages, and notably an interesting performance/complexity trade-off, with respect to other techniques such as flexible block adaptive quantization (FBAQ) or methods based on transform-coding; fractional output bit-rates can also be achieved in the entropy-constrained mode. Simulation results on real-world SIR-C/X-SAR as well as simulated raw and image data show that the proposed algorithm outperforms FBAQ as to SNR, at a computational cost compatible with modern SAR systems. [J1489]

"The effect of modified Markov random fields on the local minima occurrence in microwave imaging"

The application of a maximum a posteriori estimation method for microwave imaging that makes use of a Markov random field (MRF) a priori statistical model is presented. In particular, the MRF family adopted is generalized for complex profiles, characterized by a quadratic energy function and "modified" such to make it possible to statistically represent spatial interactions between real and imaginary parts. Thanks to its peculiarities, the use of this approach simultaneously favors in many cases well posedness and robustness against local minima occurrence, as well as high quality in the reconstructed images. Numerical results show the performance of the method. [J1490]

"A least squares database approach for SAR interferometric data"

Presents a least squares (LS) approach for the retrieval of a temporal deformation sequence from a set of interferometric synthetic aperture radar images. The method uses a database of interferograms spanning different longand short-term intervals, and by solving all the deformations as a unique LS problem provides a chronologically ordered sequence, i.e. a picture of the development of the deformation pattern in time. The approach is illustrated in detail and discussed with respect to both the results of its application on a case study and to possible alternative methods. [J1491]

"Experimental validation of autofocus algorithms for high-resolution imaging of the seabed using synthetic aperture sonar"

The paper outlines the strengths and limitations of the phase gradient autofocus (PGA) algorithm and the displaced phase centre antenna (DPCA) algorithm when applied to synthetic aperture sonar imaging. The PGA algorithm was originally developed for radar, and care is required when implementing it for sonar. Due to the typically high fractional bandwidth of sonar chirp signals compared with radar, the problems of range migration are much more severe. This leads in some cases to a distribution of blur information over many range lines. Both algorithms are demonstrated in their application to seabed data collected at Brest Harbour, France, using a rail-based sonar system with a 15 m track. It is seen that PGA handles successfully an applied sinusoidal range error of 10 mm p-p amplitude (one carrier wavelength) repeating at intervals of 1 m. [J1492]

"Reflectivity estimation for multibaseline interferometric radar imaging of layover extended sources"

In recent years, there has been great interest in exploiting the advanced multibaseline operation of synthetic aperture radar interferometry (InSAR) for solving layover effects from complex orography, which can degrade both SAR and InSAR imagery of terrain radar reflectivity and height. In this work, the problem of retrieving radar reflectivity of layover areas is addressed. It is formulated as the problem of estimating a multicomponent sinusoidal signal corrupted by multiplicative complex correlated noise and additive white Gaussian noise. Application of nonparametric [e.g., Capon, amplitude and phase estimation filter (APES)], parametric [least squares, modern parametric RELAXation spectral estimator (RELAX)], and hybrid spectral estimators for

amplitude estimation is investigated for a multilook scenario. In particular, the multilook extensions of RELAX and APES are applied to the interferometric problem. Performance analysis is investigated through a Cramer-Rao lower bound calculation and Monte Carlo simulation. The method of least squares, coupled with Capon's approach to spatial frequency estimation, multilook APES, and multilook RELAX turn out to provide accurate reflectivity estimates for undistorted multibaseline image formation of layover areas. [J1493]

"Penetration depth as a DInSAR observable and proxy for soil moisture"

We use prior theory and experimental results to construct a quantitative relationship between soil moisture and the penetration depth of synthetic aperture radar (SAR) microwaves at L-, C-, and X-bands. This relationship is nonlinear and indicates that a change of 5% volumetric water content (VWC) can cause between 1 and 50 mm of change in C-band penetration depth depending on initial VWC. Because these depths are within the range of differential interferogram SAR (DInSAR) measurement capability, penetration depth may be a viable proxy for measuring soil moisture. DInSAR is unlikely to detect a measurable change in penetration depth above 30% VWC, though certain clay rich soils may continue to cause surface deformation above that level. The possibility of using clay swelling as a proxy for soil moisture was found to be less feasible than penetration depth. Soil moisture may also be a significant, and previously unrecognized, source of noise in the measurement of subtle deformation signals or the creation of digital elevation models using repeat-pass DInSAR. [J1494]

"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. [J1495]

"Multivariate MIMO FIR inverses"

The problem of computing exact finite impulse response (FIR) inverses for multivariate multiple-input multiple-output (MIMO) FIR systems is considered. Necessary and sufficient conditions for invertibility are given, along with computation techniques. Random systems and structured systems are defined. Necessary and sufficient conditions for the almost sure invertibility of structured random systems are derived. Bounds on the orders of the inverse filters are computed. [J1496]

"Inversion of surface parameters from polarimetric SAR"

Proposes a new model for the inversion of surface roughness and soil moisture from polarimetric synthetic aperture radar (SAR) data, based on the eigenvalues and eigenvectors of the polarimetric coherency matrix. It demonstrates how three polarimetric parameters, namely the scattering entropy (H), the scattering anisotropy (A), and the alpha angle (α) may be used in order to decouple surface roughness from moisture content estimation offering the possibility of a straightforward inversion of these two surface parameters. The potential of the proposed inversion algorithm is investigated using fully polarimetric laboratory measurements as well as airborne L-band SAR data and ground measurements from two different test sites in Germany, the Elbe-Auen site and the Weiherbach site. [J1497]

"Temporal analysis of a landslide by means of a ground-based SAR Interferometer"

A ground-based synthetic aperture radar (GB-SAR) interferometer is used to retrieve the velocity field of a landslide. High-resolution images are obtained by means of a time domain SAR processor. An in-depth analysis of the sequence of SAR interferograms enables the recognition of a slowly deforming upper scarp in the scene, and a debris flow that feeds the accumulation zone of the landslide, where a fast change in terrain morphology is observed. The estimated deformation map is in agreement with the available measurements obtained by means of Global Positioning System receivers. Results show that GB-SAR interferometry is a cost-effective solution for the monitoring of landslides. The proposed method is shown to be a valid complement to space- and airborne SAR and to the traditional geodetic instruments. [J1498]

"Physics-based detection of targets in SAR imagery using support vector machines"

Radar scattering from an illuminated object is often highly dependent on the target-sensor orientation. In

conjunction with physics based feature extraction, the exploitation of aspect-dependent information has led to successful improvements in the detection of tactical targets in synthetic aperture radar (SAR) imagery. While prior work has attempted to design detectors by matching them to images from a training set, the generalization capability of these detectors beyond the training database can be significantly improved by using the principle of structural risk minimization. In this paper, we propose a detector based on support vector machines that explicitly incorporates this principle in its design, yielding improved detection performance. We also introduce a probabilistic feature-parsing scheme that improves the robustness of detection using features obtained from a two-dimensional matching-pursuits feature extractor. Performance is assessed by considering the detection of tactical targets concealed in foliage, using measured foliage-penetrating SAR data. [J1499]

"Reflectivity estimation for SAR image compression"

Synthetic aperture radar (SAR) images suffer from speckle noise that degrades image quality. Also, speckle removal is needed for lossy image compression as such noise increases image entropy. Nevertheless, most lossy compression schemes act as lowpass filters that might not suit multiplicative noise reduction. In order to build a compression scheme that takes into consideration statistics of SAR images, a well-known reflectivity estimator is integrated into an JPEG 2000-like image compression strategy, so that image compression artifacts may be viewed as an adaptive despeckle filter instead of a simple lowpass filter. It yields a compression algorithm that acts in a similar way to the Lee (or Kuan) filter. [J1500]

"Perspectives and visions for future SAR systems"

It is shown how far new SAR techniques, technologies and system principles, which at present are under consideration or under development, respectively, will fulfil future user requirements. Starting from the status quo, the expected development of future SAR techniques and technology is presented, leading to the vision of an autonomous, global reconnaissance and remote sensing system with integrated communication and positioning capability. This system will have central illuminators together with a synchronised fleet of both airborne and spaceborne receivers, which enable continuous availability with a nearly global coverage, and dedicated information transfer to specific users in real time. [J1501]

"Super-resolution Fourier transforms by optimisation, and ISAR imaging"

5A method for super-resolution ISAR imaging, denoising, and error estimation is developed using a novel Fourier transform that exploits the a priori information that the image is sparse, i.e. contains relatively few bright points. The method applies nonlinear optimisation to the complex-valued pixels to estimate the image by minimising its l1-norm. Noiseless images require linear programming, while quadratic programming with logarithmic barriers is necessary when complex-valued Gaussian noise is present. The novel Fourier transform, which is referred to as the l1-FFT, works with 'missing' data points, making 'jackknife' estimates of the mean and variance of each pixel value possible. These estimates should aid in image classification. This work extends earlier work of Chen, Donoho and Saunders on basis pursuit and denoising to complex signals, by formulating and solving the corresponding complex-valued nonlinear optimisation problems [J1502]

"Time-frequency analysis for plastic landmine detection via forward-looking ground penetrating radar"

Time-frequency analysis techniques are used for buried plastic landmine detection with a forward-looking ground penetration radar (GPR) system. Several time-frequency distributions are considered to characterise and interpret the scattering phenomena of both targets and clutter. An ambiguity function based detector is also presented, which employs principal component analysis and feature selection for data dimensionality reduction and linear discriminant analysis for signal classification. Experimental results based on the SRI (Stanford Research Institute) experimentally measured forward-looking GPR data are presented, showing a significant detection performance improvement over the conventional detector [J1503]

"Analysis of SAR images by multidimensional wavelet transform"

The description and development are described of a multidimensional continuous wavelet transform for synthetic aperture radar (SAR) image analysis, especially for the analysis of 'dispersive' reflectors located on a ground illuminated by a SAR. The usual imaging process makes the assumption that the reflectors are isotropic (i.e. that they behave the same way regardless of the angle from which they are viewed) and white (they have the same properties within the emitted frequency bandwidth). New imaging capacities (offering large bandwidth, low band and large angular excursions of analysis, for example) make these assumptions obsolete. The goal is to present methods based on the multidimensional continuous wavelet transform which highlight these effects for target recognition or identification. Some examples of this analysis are given by processing real data collected in X-

band by the RAMSES airborne SAR facilities at ONERA [J1504]

"Wavelet-RELAX feature extraction in radar images"

In classical high-frequency radar imaging, like synthetic aperture radar imaging, man-made target contributions are often well described by decomposing their signature into a set of bright points. The basic model supposes that these elementary reflectors are independent of the relative angular aspect and of the observation frequencies. Many feature extraction methods, such as CLEAN/RELAX-based algorithms, are built on this hypothesis and so it is currently used in assisted/automatic target recognition algorithms (ATR). However, this simple model cannot describe the variability of the signatures one can observe in image databanks. The authors propose extending the target feature extraction capacities of the CLEAN/RELAX algorithm to dispersive scatterers using generalised wavelets [J1505]

"Micro-Doppler analysis of vibrating targets in SAR"

Vibrating targets cause phase modulation of the azimuth phase history for a SAR system. The phase modulation may be seen as a time-dependent micro-Doppler frequency. It is useful to analyse such signals with Cohen's (1995) class time-frequency methods due to their superior resolution potential. The method must be chosen with care, as the effective time integration window of the kernel should not be longer than about a cycle of the modulation signal. Using the adaptive optimal kernel method (AOK), the authors obtained good results from a controlled experiment where two oscillating corner reflectors were placed within a SAR scene collected by the US Navy APY-6 radar. The oscillation frequency and amplitude were calculated from the time-frequency distributions and the results agree well with available ground truth. To resolve the instantaneous frequencies, the kernel time extent had to be sufficiently short [J1506]

"A sparse data fast Fourier transform (SDFFT)"

A multilevel algorithm that efficiently Fourier transforms sparse spatial data to sparse spectral data with controllable error is presented. The algorithm termed "sparse data fast Fourier transform" (SDFFT) is particularly useful for signal processing applications where only part of the k-space is to be computed-regardless of whether it is a regular region like an angular section of the Ewald sphere or it consists of completely arbitrary points scattered in the k-space. In addition, like the various nonuniform fast Fourier transforms, the O(NlogN) algorithm can deal with a sparse, nonuniform spatial domain. In this paper, the parabolic reflector antenna problem is studied as an example to demonstrate its use in the computation of far-field patterns due to arbitrary aperture antennas and antenna arrays. The algorithm is also promising for various applications such as backprojection tomography, diffraction tomography, and synthetic aperture radar imaging. [J1507]

"A Markov random field approach to spatio-temporal contextual image classification"

Markov random fields (MRFs) provide a useful and theoretically well-established tool for integrating temporal contextual information into the classification process. In particular, when dealing with a sequence of temporal images, the usual MRF-based approach consists in adopting a "cascade" scheme, i.e., in propagating the temporal information from the current image to the next one of the sequence. The simplicity of the cascade scheme makes it attractive; on the other hand, it does not fully exploit the temporal information available in a sequence of temporal images. In this paper, a "mutual" MRF approach is proposed that aims at improving both the accuracy and the reliability of the classification process by means of a better exploitation of the temporal information. It involves carrying out a bidirectional exchange of the temporal information between the defined single-time MRF models of consecutive images. A difficult issue related to MRFs is the determination of the MRF model parameters that weight the energy terms related to the available information sources. To solve this problem, we propose a simple and fast method based on the concept of "minimum perturbation" and implemented with the pseudoinverse technique for the minimization of the sum of squared errors. Experimental results on a multitemporal dataset made up of two multisensor (Landsat Thematic Mapper and European Remote Sensing 1 synthetic aperture radar) images are reported. The results obtained by the proposed "mutual" approach show a clear improvement in terms of classification accuracy over those yielded by a reference MRF-based classifier. The presented method to automatically estimate the MRF parameters yielded significant results that make it an attractive alternative to the usual trial-and-error search procedure. [J1508]

"Application of adaptive chirplet representation for ISAR feature extraction from targets with rotating parts"

The problem of feature extraction from inverse synthetic aperture radar (ISAR) data collected from targets with rotating parts is addressed. In traditional ISAR imaging, rigid-body motion is usually assumed. When non-rigid-

body motions are present, it is not possible to obtain a focused image of both the target and the rotating part. To solve this problem, the radar signal is first parameterised using the adaptive chirplet signal representation. The signal from the body and that from the rotating part are then separated in the parameter space. Point-scatterer simulation results show that better geometrical features of the body and better micro-Doppler features of the rotating part can be extracted after the separation. The algorithm is also demonstrated using the measurement data from an in-flight aircraft and a walking person [J1509]

"X-band wideband experimental airborne radar for SAR, GMTI and maritime surveillance"

Defence Research and Development Canada-Ottawa has completed Phase I in the development of a new multimode X-band wideband experimental airborne radar (XWEAR) to support studies in synthetic aperture radar (SAR) imaging, inverse SAR (ISAR), ground moving target indication (GMTI) radar and maritime surveillance radar with particular focus on small target detection and long-range surface surveillance. Specific areas of interest include research into SAR imaging techniques for fixed and moving targets, time-frequency analysis of ocean and land moving targets, space-time adaptive processing for application to GMTI, investigation into the electromagnetic backscatter properties of the ocean surface, generation of signatures for automatic target recognition and feature extraction, and analysis on the immunity of wide bandwidth systems against electronic countermeasures. Phase I culminated with the flight trialling of the SAR and maritime surveillance modes. Phase II will see the trialling of the wide area surveillance GMTI (WAS GMTI) and integrated SAR-GMTI modes. A description of the experimental radar is given along with an overview of its data collection capability. Distinguishing features include operation at X-band, single-channel operation for SAR and maritime surveillance, and two-channel operation for WAS-GMTI and integrated SAR-GMTI. The new radar maximises the use of an existing digital scan converter as a controller, and commercially available components including the transmitter, A/D converters and computer boards. The timing circuitry, waveform generator, single- and dual-channel receivers are custom built [J1510]

"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. [J1511]

"Conceptual reconfigurable antenna for 35 GHz high-resolution spaceborne synthetic aperture radar"

An innovative Cassegrain antenna for spaceborne synthetic aperture radar (SAR) utilizes a reconfigurable feed array for scene grazing angles from 15° to 70° to produce the largest antenna beam footprints that are circular and to maintain high efficiency or the transmitter. The antenna has a beam waveguide input and the feed array is located in this waveguide. The feed array of transmit-receive modules is reconfigured to vary the illumination shape and area of the radiating portion of the antenna. Each transmit device operates at its full power for maximum efficiency, and the number of devices is determined by the required power. Single-point design for a 35 GHz SAR in a 700 km altitude orbit is presented to detect terrain with 0.1 m resolution. The antenna is a 19.6 m2elliptical reflector, the power density at the aperture is 25.5 W/m2, and 500 W maximum average power is required. Compared to X-band, 1) the 35 GHz design requires a much smaller antenna, 2) high resolution requires less percentage bandwidth, and 3) integration requirements are less demanding. For comparison, a 9 GHz SAR point design is included for grazing angles of 15° and 70°. [J1512]

"Synthetic-aperture radar processing using fast factorized back-projection"

Exact synthetic aperture radar (SAR) inversion for a linear aperture may be obtained using fast transform techniques. Alternatively, back-projection integration in time domain can also be used. This technique has the benefit of handling a general aperture geometry. In the past, however, back-projection has seldom been used due to heavy computational burden. We show that the back-projection integral can be recursively partitioned and an effective algorithm constructed based on aperture factorization. By representing images in local polar coordinates it is shown that the number of operations is drastically reduced and can be made to approach that of

fast transform algorithms. The algorithm is applied to data from the airborne ultra-wideband CARABAS SAR and shown to give a reduction in processing time of two to three orders of magnitude. [J1513]

"Propagation velocity uncertainty on GPR SAR processing"

To detect buried landmines, Planning Systems Incorporated (PSI) has developed a ground-penetrating synthetic aperture radar (GPSAR) system. Since the electromagnetic wave propagation velocity in the soil depends on many factors, velocity uncertainty is inevitable. However, we have observed that, unlike conventional airborne/spaceborne synthetic aperture radar (SAR) systems, the PSI GPSAR system is very robust against the velocity uncertainty under mild conditions. Theoretical analysis is provided to explain this observation. Although our discussion is based on the PSI GPSAR system, it applies to other GPR-based (ground-penetrating radar) landmine detection systems as well. [J1514]

"Spectral analysis of periodically gapped data"

We devise novel, interpolation-free, and computationally tractable extensions of the spectral analysis methods Capon and APES (amplitude and phase estimation) to periodically gapped data. Our methods are based on the observation that periodically gapped data usually have a structure that supports estimation of a relatively large number of covariance lags. The large signal-to-noise-ratio (SNR) behavior of the new algorithms is discussed, and numerical examples are provided to illustrate their performance. [J1515]

"Distortion in the inverse synthetic aperture radar (ISAR) images of a target with time-varying perturbed motion"

Large distortion in ISAR images of a moving target has been investigated and demonstrated under controlled experiments. The distortion is a result of small time-varying perturbed motion experienced by the target and is attributed to a modulation effect in the phase of the radar return from the target. The Doppler motion of the target, modulated by a time-varying perturbation, results in a broad smear in the phase of the radar signal. A numerical model of the distortion based on the phase modulation effect has been developed. Simulated ISAR images produced by this model are in good agreement with experimental results. The numerical and experimental studies described provide a better understanding of the distortion mechanism that affects the ISAR images of a target in motion [J1516]

"ISAR motion compensation using evolutionary adaptive wavelet transform"

Many time-frequency analysis techniques have been used for ISAR motion compensation. One of them, the adaptive wavelet transform (AWT), is cross-term free and has high resolution, but its accuracy is limited because it uses a bisection search method and fast Fourier transform (FFT) for parameter extraction. A novel time-frequency (T-F) analysis, called the evolutionary adaptive wavelet transform (EAWT), is used for ISAR motion compensation. The EAWT is more accurate than the conventional AWT. Using artificially created data from three time-frequency centres and simulated MIG-25 ISAR data, this algorithm is compared with the conventional AWT for accuracy. From the constructed ISAR image using AWT and EAWT, it is demonstrated that the EAWT algorithm can obtain a more clear motion-compensated ISAR image than the conventional AWT [J1517]

"Editorial: Time-frequency analysis for synthetic aperture radar and feature extraction"

First Page of the Article [J1518]

"Application of adaptive joint time-frequency algorithm for focusing distorted ISAR images from simulated and measured radar data"

An adaptive joint time-frequency algorithm has been applied and evaluated for focusing distorted ISAR (inverse synthetic aperture radar) images when the target motion is confined to a two-dimensional plane. It is shown that the adaptive joint time-frequency algorithm provides an effective method of achieving rotational motion compensation for ISAR imaging. Examples provided demonstrate the effectiveness of the adaptive joint time-frequency algorithm with both simulated and experimental ISAR data. Results show that if a target is moving smoothly, standard motion compensation generates a clear image of the target by using the conventional Fourier transform methods. However, when a target performs complex motion such as perturbed random motions, standard motion compensation is not sufficient to generate an acceptable image. In this case, the adaptive joint time-frequency algorithm provides an efficient candidate to resolve the image smearing caused by the time-varying behaviour and leads to a well focused ISAR image when the target motion is confined to a two-dimensional plane. The study also adds insight into the distortion mechanisms that affect the ISAR images of a target in motion [J1519]

"A new maximum-likelihood joint segmentation technique for multitemporal SAR and multiband optical images"

In this paper, we devise a new technique for the fusion of a sequence of multitemporal single-channel synthetic aperture radar (SAR) images of a given area with a single multiband optical image. Unlike for SAR, the availability of optical images is largely affected by atmospheric conditions, so that this is a case of practical interest. First, a statistical model for the joint distribution of SAR and optical data is provided. Then, a split-merge test based on this model is derived, and its performance is evaluated both analytically and using a Monte Carlo simulation. A new segmentation technique is introduced (OPT MUM), based on the test and on a region-growing scheme. The effectiveness of the proposed technique for the fusion of multitemporal SAR and multiband optical images is tested on synthetic and real images. Results show that the proposed scheme allows to both 1) discriminate characteristics that would be impossible to distinguish using only a single sensor and 2) increase the overall discrimination performance, even when each sensor has its own discrimination capability. [J1520]

"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. [J1521]

"DInSAR measurement of soil moisture"

Differential interferometric sythetic aperture radar (DInSAR) measurements using the European Remote Sensing 2 (ERS-2) satellite in a high-plains region of Colorado show intriguing spatial variations in millimeter-scale path-length change that may correspond to variations in soil moisture of a few percent by volume, in both farm fields and uncultivated terrain. The observed signal is hypothesized to result from both changes in penetration depth and the swelling of clay-rich soils, both due to changes in soil moisture. Comparisons with our field measurements of soil moisture cannot conclusively verify this, but strong support is found from prior and complementary research as well as the visual correlation with hydrological features such as stream channels and watershed boundaries on a 50-m scale. Detection of these subtle signals was facilitated using a digital elevation model with high vertical accuracy. If our interpretations are correct, C-band DInSAR is a promising new tool for the remote sensing of soil moisture in a variety of terrain. [J1522]

"Target decomposition analysis of SIR-C imagery for characterization of scattering mechanisms and their dependence on observation parameters"

Multitemporal Shuttle Imaging Radar C (SIR-C) images taken over the Sarobetsu test site were analyzed using target decomposition to characterize the scattering mechanisms and relate them with the target conditions. Analysis results indicate a change in the dominant scattering mechanism with a change in the observation parameters, which is reasonably related with the surface conditions estimated from aerial photographs. [J1523]

"On the use of complex SAR image spectral analysis for target detection: assessment of polarimetry"

The objective of this paper is to assess the joint use of the magnitude and the phase of a synthetic aperture radar (SAR) polarimetric image for point target detection and analysis. We first consider a single-look complex (SLC), single polarized radar image including point targets embedded in clutter. A series of sublooks are generated from this SLC image, both in azimuth and in range in order to analyze the inherent speckle effects. The two-looks internal Hermitian product (2L-IHP) is defined and is further shown to qualitatively increase the target/environment contrast. The processing of azimuth and range spectra preliminary to the 2L-IHP derivation (spectral whitening, generation and overlapping of sublooks) is described. A simulation tool is developed to model a point target behavior. Then, the polarimetric extension of the 2L-IHP is proposed, and the optimized polarimetric 2L-IHP is defined. The gain is twofold: in comparison with single polarization, polarimetry is shown to enhance detection capabilities, but also to provide additional information for target analysis. [J1524]

"Measurements of ocean surface waves and currents using L- and C-band along-track interferometric SAR"

Along-track interferometric synthetic aperture radar (ATI-SAR) is an active coherent imaging system, utilizing two antennas separated along the platform flight direction. The phase information of ATI-SAR from the Doppler shift of the backscattered signal represents the line-of-sight velocity of the water scatterers. While the advent of ATI-SAR provided us with a potentially powerful technique for ocean surface current and wave mapping, the surface current has not been measured exactly from the ATI-SAR velocity because the Doppler shift is not simply proportional to the component of the mean surface current. It also includes other types of contributions associated with the phase velocity of the Bragg waves and orbital motions of all ocean waves that are longer than Bragg waves. In this paper, we review how the phase difference measured by ATI-SAR is related to the mean Doppler frequency, and we develop a new and practically useful method to extract the surface current component utilizing simultaneously measured L- and C-band ATI-SAR data. Since the measured ATI-SAR velocity shows a different value at a different radar-frequency, we investigate the influence of Bragg-resonant waves and long ocean wave motions on the ATI-SAR velocity according to the radar frequency. The Bragg-wave phase velocity component, which is a significant source of error for extracting the surface current, can be effectively eliminated by using L- and C-band ATI-SAR. The method is applied to L- and C-band ATI-SAR measurements acquired at the Ulsan coast in the southeastern part of the Korean peninsula. The resulting ocean surface current vectors are compared with in situ measurements collected by recording current meter. We furthermore extract ocean surface wave information from the ATI-SAR phase image using a quasi-linear transform. [J1525]

"Feature enhancement and ATR performance using nonquadratic optimization-based SAR imaging"

We present an evaluation of the impact of a recently proposed synthetic aperture radar (SAR) imaging technique on feature enhancement and automatic target recognition (ATR) performance. This image formation technique is based on nonquadratic optimization, and the images it produces appear to exhibit enhanced features. We quantify such feature enhancement through a number of criteria. The findings of our analysis indicate that the new feature-enhanced SAR image formation method provides images with higher resolution of scatterers, and better separability of different regions as compared with conventional SAR images. We also provide an ATR-based evaluation. We run recognition experiments using conventional and feature-enhanced SAR images of military targets, with three different classifiers. The first classifier is template based. The second classifier makes a decision through a likelihood test, based on Gaussian models for reflectivities. The third classifier is based on extracted locations of the dominant target scatterers. The experimental results demonstrate that the new feature-enhanced SAR imaging method can improve the recognition performance, especially in scenarios involving reduced data quality or quantity. [J1526]

"Overview of an image-based technique for predicting far-field radar cross section from near-field measurements"

For the last 18 years, our group has been developing a variety of near-field-to-far-field transformations (NFFFTs) for predicting the far-field (FF) RCS of targets from monostatic near-field (NF) measurements. The most practical and mature of these is based on the reflectivity approximation, commonly used in ISAR imaging to model the target scattering. This image-based NFFFT is also the most computationally efficient because-despite its theoretical underpinnings-it does not explicitly require image formation as part of its implementation. This paper presents a formulation and implementation of the image-based NFFFT that is applicable to two-dimensional (2D) spherical and one-dimensional (1D) circular near-field measurement geometries, along with numerical and experimental examples of its performance. We show that the algorithm's far-field RCS pattern-prediction performance is quite good for a variety of frequencies, near-field measurement distances, and target geometries. In addition, we show that the predicted RCS statistics remain quite accurate under conditions where the predicted far-field patterns have significantly degraded due to multiple interactions and other effect. [J1527]

"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. [J1528]

"Recovering radar shadow to improve interferometric phase unwrapping and DEM reconstruction"

This letter presents a new approach to actively use radar shadow in order to unwrap and geocode objects that cannot be reconstructed by synthetic aperture radar interferometry alone. This new algorithm may significantly improve phase unwrapping and digital elevation model reconstruction in mountainous topography or in urban areas. The algorithm is explained and examples are given with data from the Shuttle Radar Topography Mission, where shadow is a serious problem in Alpine terrain. [J1529]

"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. [J1530]

"Measurement of glacier geophysical properties from InSAR wrapped phase"

A method is presented for calculating longitudinal glacier strain rates directly from the wrapped phase of an interferometric synthetic aperture radar (InSAR) interferogram assuming the ice flow path is known. This technique enables strain rates to be calculated for scenes lacking any velocity control points or areas within a scene where the phase is not continuously unwrappable from a velocity control point. The contributions to the error in the estimate of the strain rate are evaluated, and recommendations for appropriate SAR and InSAR parameters are presented. An example using Radarsat-1 InSAR data of an East Antarctic ice stream demonstrates the technique for calculating longitudinal strain rate profiles and estimating tensile strength of ice (186-215 kPa) from locations of crevasse initiation. The strain rate error was found to be 17% corresponding to a tensile strength of ice error of 5.3%. [J1531]

"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. [J1532]

"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. [J1533]

"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. [J1534]

"Super-resolution, degrees of freedom and synthetic aperture radar"

Super-resolution concepts offer the potential of resolution beyond the classical limit. This great promise has not generally been realised. The potential application of super-resolution concepts to synthetic aperture radar is investigated. The analytical basis for super-resolution theory is discussed. The application of the concept to synthetic aperture radar is investigated as an operator inversion problem. Generally, the operator inversion problem is ill posed. However, it is shown that it is the particular form of the eigenvalue spectrum of the associated operator that precludes any significant resolution enhancement of synthetic aperture radar images. A criterion for judging super-resolution processing of an image is presented. [J1535]

"A Bayesian transformation model for wavelet shrinkage"

Wavelet shrinkage estimators, in general, make the additive normal noise assumption and disregard the nonlinear nature of contamination. We develop Bayesian wavelet shrinkage estimators (based on the power transformations in the linear model) to accommodate a broad class of noise models in image processing applications. We intend to admit, under one roof, the widespread additive model, the product models common in imaging (such as in synthetic aperture radar (SAR) imagery), as well as noise that may exist amid these two extremes. Tactful prior elicitation in this model, such as the simultaneous assignment of mixture priors for wavelet coefficients and the transformation, imparts flexibility and ample insight into the underlying structure. The model permits estimation with unknown noise structure for reasonably unimodal and well-behaved (on the tails) distributions, wherein it can outperform common shrinkage estimators. Extensions with multiple transformations and Markov random field priors are also considered for adaptation to local variations in contamination. Modern Markov chain Monte Carlo (MCMC) Bayesian computation has been used for simulations and several examples are reported. [J1536]

"Segmentation of SAR images using multitemporal information"

The maximum likelihood method of SAR segmentation has the potential to retain single pixel accuracy without requiring heuristic decisions. Normally, a probabilistic measure is used to merge individual regions without assuming any prior knowledge for the underlying cross-sections. However, for a reasonable multitemporal scene, there may be considerable information available from the varying cross-sections over time. An example is given where this information can be extracted by an initial classification. It is then shown how the segmentation scheme can be modified to incorporate this information via an estimate of the multitemporal underlying class distributions. Using single-look Radarsat data at 8 m resolution, it is demonstrated how the final segment population can be significantly reduced. From a comparison with ground survey data and a high-resolution AirSAR image, the structural quality of the segmentation is shown to be improved. [J1537]

"Multichannel ATI-SAR with application to the adaptive Doppler filtering of ocean swell waves"

Multichannel along-track interferometric (MATI) SAR systems are discussed from the point of view of ocean remote sensing. It is shown that the signals scattered by range moving scatterers can be Doppler filtered using a MATI-SAR. Processing techniques are presented, including a phase screen method for the removal of phase

errors (including systematic errors and also those resulting from platform motion). A particular radar system (the ESR, enhanced surveillance radar) is described; this has a 3 cm wavelength MATI with two, three or four beams. It is used for investigating and exploiting Doppler effects in ocean radar scattering. It is demonstrated that, by applying adaptive Doppler filtering techniques, the MATI-SAR can significantly increase the imaging sensitivity of ocean features with respect to a conventional SAR. Examples illustrate the use of the ESR MATI-SAR system for imaging ship generated swell waves. Using three beams, the visibility of the wave images is increased by 9.5 dB looking downwind and 5.0 dB looking upwind for horizontal polarisation at grazing angles of 39° and 32°, respectively. Associated Doppler filter responses are shown which show that the scatterers modulated by the swell wave are located in the neighbourhood of the wave crests. [J1538]

"Multi-mode ENVISAT ASAR interferometry: techniques and preliminary results"

The paper focuses on the interferometric capabilities of current and future SAR systems, like ENVISAT, RADARSAT-2, etc. The authors introduce a technique to obtain interferometric surveys by combining two images, coming from any SAR mode, together with a digital elevation mode (DEM). The DEM is exploited during the interferogram generation to provide, at one time, effective noise removal and compensation for the topographic-dependent fringes. The final product is a 'differential' (topography-compensated) interferogram to be used for monitoring over landslides, upswelling, etc. An innovative technique is also discussed to estimate local coherence maps, to be used for classification and change detection. Such a technique exploits windows whose shapes and sizes adapt locally to the target features, to attain at one time the highest resolution and the best statistical confidence. Finally, applications involving the various ENVISAT ASAR modes are discussed. [J1539]

"Mixture multiscale autoregressive modelling of SAR imagery for segmentation"

A new and efficient multiscale model for the segmentation of synthetic aperture radar imagery, namely the mixture multiscale autoregressive (MMAR) model, is presented. The estimation of parameters is easily performed via expectation maximisation algorithm. Experimental results of the MMAR model are proposed and compared with those of previous methods. [J1540]

"Cross-calibration of interferometric SAR data"

Generation of digital elevation models from interferometric synthetic aperture radar (SAR) data is a well established technique. Achieving a high geometric fidelity calls for a calibration accounting for inaccurate navigation data and system parameters as well as system imperfections. Fully automated calibration techniques are preferable, especially for operational mapping. The author presents one such technique, called cross-calibration. Though developed for single-pass interferometry, it may be applicable to multi-pass interferometry, too. Cross-calibration requires stability during mapping, but not necessarily from map to map. It is based on natural distributed targets for which no a priori knowledge is needed. In particular, no DEM is required as in calibration techniques based on dedicated calibration scenes. To achieve absolute calibration, i.e. elimination of a constant elevation offset, a single ground control point is often needed. The paper presents the principles and mathematics of the cross-calibration technique and illustrates its successful application to EMISAR data. [J1541]

"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. [J1542]

"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. [J1543]

"SAR raw signal simulation for urban structures"

A synthetic aperture radar (SAR) raw signal simulator for urban scenes is presented along with models it employs to compute the backscattered field and to account for the imaging radar sensor characteristics. Urban areas are represented as a set of dielectric buildings placed over a random rough nonflat dielectric terrain. The adopted models allow evaluation of the raw signal on a sound physical and mathematical background: the scattering model employs the Kirchhoff approach appropriately extended to include multiple-reflection effects, and the radar model operates in the two-dimensional Fourier transformed domain. Details to assess how and why the simulator is also efficient with respect to the computational time are provided. In addition, relevant examples are discussed to show the simulator potentialities and assess the validity of the main results. It is shown that the simulator is able to quantitatively assess performances of SAR sensors over urban structures. The proposed simulator turns out to be also useful to train numerical schemes devoted to feature extraction, and to test any specific SAR processing technique. Comments for further developments of the simulation tool are presented. [J1544]

"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. [J1545]

"Optimum model-based segmentation techniques for multifrequency polarimetric SAR images of urban areas"

A new technique, named diagonal polarimetric merge-using-moments (DPOL MUM), is proposed for the segmentation of multifrequency polarimetric synthetic aperture radar (SAR) images that exploits the characteristic block diagonal structure of their covariance matrix. This technique is based on the newly introduced split-merge test, which has a reduced fluctuation error than the straight extension of the polarimetric test (POL MUM) and is shown to yield a more accurate segmentation on simulated SAR images. DPOL MUM is especially useful in the extraction of information from urban areas that are characterized by the presence of different spectral and polarimetric characteristics. Its effectiveness is demonstrated by applying it to segment a set of SIR-C images of the town of Pavia. The classification of the image segmented with DPOL MUM shows higher probability of correct classification compared to POL MUM and to a similar technique that does not use the correlation properties (MT MUM). [J1546]

"Information fusion for scene understanding from interferometric SAR data in urban environments"

We present a framework for scene understanding from interferometric synthetic aperture radar data that is based on Bayesian machine learning and information extraction and fusion. A generic description of the data in terms of multiple models is automatically generated from the original signals. The obtained feature space is then mapped to user semantics representing urban scene elements in a supervised step. The procedure is applicable at multiple scales. We give examples of urban area classification and building recognition of Shuttle Radar Topography Mission data and of building reconstruction from submetric resolution Intermap data. [J1547]

"Three-stage inversion process for polarimetric SAR interferometry"

The authors provide a new geometrical approach for the inversion of a two-layer coherent scattering model,

widely used for the interpretation of polarimetric interferometric SAR data. It has been shown in several recent publications that, by using interferograms in multiple polarisation channels, estimation of vegetation height, underlying ground topography and mean extinction is possible. Furthermore, this can be achieved with a single frequency sensor without the need for a separate reference DEM, other a priori information or the use of data-specific regression formulas. The authors first review the details of this approach and then develop a three-stage inversion procedure to illustrate the steps involved in parameter estimation. They then consider several possible sources of error in the inversion. In particular, they concentrate on the effects of vertical tree structure and on the effects of temporal decorrelation on inversion accuracy. It is shown that the former leads to errors, mainly in the extinction estimation, while the latter does not change the model structure but reduces the available parameter set and increases the variance of the parameter estimates. Finally, the new algorithm is applied to simulated vector coherent SAR data for a random canopy. [J1548]

"Polarisation orientation angle measurements of ocean internal waves and current fronts using polarimetric SAR"

Previous studies have shown that polarimetric synthetic aperture radar (POLSAR) data may be used to measure parameters such as bare surface roughness. Polarisation orientation angles, derived from POLSAR data, can be utilised to produce estimates of topography. Orientation angles have been used for SAR data compensation, in areas of rugged terrain, to ensure accurate estimation of geophysical parameters such as biomass and soil moisture. Orientation angles have also recently been investigated for use in measuring directional ocean wave spectra. Studies of these ocean features are conventionally done by measuring feature-related microwave backscatter intensity perturbations. In the work presented, a new approach is taken. Investigations have been made of changes in the polarisation orientation angle caused by ocean wave-current interaction features. The study uses airborne POLSAR data obtained in the New York Bight and in the Gulf Stream, east of Cape Hatteras. A model is used to determine the parametric dependencies of the orientation angle on internal wave current, wind-wave direction and wind-wave speed. An empirical relation is proposed to relate orientation angle perturbations to the underlying internal wave current strength. [J1549]

"Innovative technologies for space-based radars"

In previous years technology developments for SAR front-end and for on-board SAR data processing have been performed at Astrium GmbH, Germany. Remarkable progress has been made in the respective demonstrator projects DESA, EUCLID RTP 9.7, and TOPAS. A summary of the major results and achievements is presented. [J1550]

"Recent advances in extra-wide-band polarimetry, interferometry and polarimetric interferometry in synthetic aperture remote sensing and its applications"

The development of radar polarimetry and radar interferometry is advancing rapidly, and these novel radar technologies are revamping 'synthetic aperture radar imaging' decisively. The successive advancements are sketched eginning with the fundamental formulations and highlighting the salient points of these diverse remote sensing techniques. Whereas with radar polarimetry the textural fine-structure, target orientation and shape, symmetries and material constituents can be recovered with considerable improvements above that of standard 'amplitude-only polarisation radar'; with radar interferometry the spatial (in depth) structure can be explored. In 'polarimetric-interferometric synthetic aperture radar (POL-IN-SAR) imaging' it is possible to recover such co-registered textural plus spatial properties simultaneously. This includes the extraction of 'digital elevation maps (DEM)' from either 'fully polarimetric (scattering matrix)' or 'interferometric (dual antenna) SAR image data takes' with the additional benefit of obtaining co-registered three-dimensional 'POL-IN-DEM' information. Extra-wide-band POL-IN-SAR imaging-when applied to 'repeat-pass image overlay interferometry'-provides differential background validation and measurement, stress assessment, and environmental stress-change monitoring capabilities with hitherto unattained accuracy, which are essential tools for improved global biomass estimation and also for wetland assessment and monitoring. More recently, by applying multiple parallel repeat-pass EWB-POL-D(RP)-IN-SAR imaging along stacked (altitudinal) or displaced (horizontal) flight-lines will result in 'tomographic (multi-interferometric) polarimetric SAR stereo-imaging', including foliage- and ground-penetrating capabilities. In addition, various closely related topics of (i) acquiring additional and protecting existing spectral windows of the 'natural electromagnetic spectrum (NES)' pertinent to remote sensing; and (ii) mitigation against common 'radio frequency interference (RFI)' and intentional 'directive jamming of airborne and spaceborne POL-IN-SAR imaging platforms' are appraised. [J1551]

"Using topography statistics to help phase unwrapping"

Conventional techniques approach phase unwrapping (PU) as an optimisation problem, where figures of merit

like the total branch-cut length, the number of cuts, etc. are to be minimised. They disregard the properties of the field to be unwrapped: the topography, i.e. the DEM, projected in the SAR reference. The purpose of the paper is to fill this gap by providing statistics of the 'fringe maps'. The Woodward theorem is exploited to link the interferogram power spectrum density (PSD) with the probability density function (PDF) of the phase gradient that would result in a likely topography. A parametric model of the expected, unwrapped PG PDF is then derived by exploiting the fractal properties of topography. Its parameters can be accurately estimated given the wrapped PG. This model provides useful statistical information for phase unwrapping. It is then possible, for example, to estimate the number of residuals, to find the best azimuth presuming factor and to find the optimal interferogram range demodulation. Finally, the author exploits the second-order statistics of the PG field (as a fractal) to derive a suitable approximation for the expected length of the branch cuts. [J1552]

"PAMIR-a wideband phased array SAR/MTI system"

Air- and spaceborne imaging radar systems in forthcoming surveillance and reconnaissance tasks have to meet increasingly severe demands. The next generation of top-level synthetic aperture radar (SAR) systems will comprise, among others, high resolution and long-range imaging capabilities, highly sensitive ground moving target indication and a multitude of sophisticated operational modes. The variety of tasks can be fulfilled only by the use of a reconfigurable phased array antenna together with a comprehensive wideband system design and a multichannel capability. At FGAN a new experimental X-band radar has been conceived, which will possess in its final upgrade an electronically steerable phased array consisting of 16 autonomous and reconfigurable subapertures, five independent receive channels, and a total signal bandwidth of about 1.8 GHz. The sensor is called PAMIR (Phased Array Multifunctional Imaging Radar). It is envisaged to demonstrate SAR imaging at a very high resolution and for a long range. The fine resolution will also be achieved with inverse SAR (ISAR) imaging of ground moving objects. Furthermore, the number of receive channels will allow ground-moving target indication (GMTI) by space-time adaptive processing and single-pass interferometric SAR (IfSAR) with a very high 3-D resolution. In its current stage of extension PAMIR is operable with one receive channel and a mechanically steerable antenna array. The system design and the intended capabilities of PAMIR are described. Ground-based and airborne experimental results concerning high-resolution SAR and ISAR imaging are also presented. [J1553]

"Time-frequency analysis of vibrating targets in airborne SAR systems"

Vibrating targets may cause azimuth smearing in airborne synthetic aperture radar (SAR) images. Any motion of a reflector during the coherent integration time of a SAR image causes a phase modulation in the corresponding reflector phase history. For a sinusoidal motion, the phase modulation causes sidebands, often indistinguishable from stationary reflectors. The modulation is described in terms of a time-dependent Doppler frequency. Time-frequency methods are useful tools for such cases. Among the many possible time-frequency methods the authors chose the adaptive optimal kernel (AOK) method for the purposes of the present paper. With the AOK method they analysed an oscillating reflector within an airborne SAR image. The oscillation was clear and the oscillation parameters were estimated from the time-frequency distribution. The parameters agreed well with ground truth. In particular, the oscillation frequency agreed well, while the amplitude was less accurate, but still reasonable. [J1554]

"Extension of the chirp scaling algorithm to 3-D near-field wideband radar imaging"

The authors' objective is to develop an efficient algorithm to focus two-dimensional and three-dimensional SAR images under the following extreme conditions: large coherent integration angles and high bandwidth-to-centre-frequency ratios. These conditions constitute a common situation in wideband high-resolution SAR configurations, as in anechoic chambers and in ground-based systems. The algorithm presented is an extension of the well known chirp scaling algorithm (CSA). First, the original 2-D CSA is generalised by extending the formulation from data obtained with a linear aperture to data measured by a planar synthetic aperture. Moreover, a compact generalised formula of the impulse response function in the three-dimensional frequency domain is presented. These extensions enable the development of a 3-D algorithm under the aforementioned conditions. Finally, the algorithm has been implemented and tested with satisfying results. [J1555]

"Ultra-wideband multistatic SAR for the detection and location of landmines"

Techniques for improving the signal to clutter ratio of an ultra-wideband SAR designed to detect small mine-like objects in the surface of the ground were investigated. In particular, images were collected using different bistatic antenna configurations in an attempt to decorrelate the clutter with respect to the targets. The images were converted to a reference depression angle, summed, and then converted to ground coordinates. The resulting target strengths were then compared with the amplitude distribution of the ground clutter to show the

improvement obtained. While some improvement was demonstrated, this was for the relatively easy scenario of targets on the surface partially obscured by grass. Detection based on thresholding the raw RF signal (the bipolar response) rather than the envelope (baseband I2+Q2) was also considered to further enhance target-to-clutter ratios. [J1556]

"Urban building height variance from multibaseline ERS coherence"

Multibaseline European Remote Sensing (ERS) interferometric synthetic aperture radar coherence images from Cardiff, U.K. are investigated with respect to urban form. A model of spatial coherence, taking into account the vertical distribution of scatterers, is inverted to allow urban building height variance to be retrieved. Sixty-nine coherence maps are employed, generated from 20 ERS images. No a priori information is required in the analysis. However, realistic vertical scatterer distributions are retrieved, and Cardiff's central business district is automatically identified. This analysis demonstrates the utility of the urban decorrelation models employed. [J1557]

"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. [J1558]

"A comparison of two 85-GHz SSM/I ice concentration algorithms with AVHRR and ERS-2 SAR imagery"

Sea ice concentrations obtained with two algorithms from Special Sensor Microwave/Imager (SSM/I) data are compared to spaceborne visible/infrared and active microwave imagery for the Greenland Sea in spring. Both algorithms, the ARTIST Sea Ice algorithm (ASI) and the SEA LION algorithm (SLA), utilize 85-GHz SSM/I brightness temperatures with a spatial resolution of 15 km Ч13 km. Ice concentrations obtained from Advanced Very High Resolution Radiometer (AVHRR) infrared data in cloud-free areas are underestimated by SLA and ASI ice concentrations by 3.6% and 8.3% (correlation coefficients of 0.90 and 0.91). Ice concentrations estimated from texture classified ERS-2 synthetic aperture radar (SAR) images by assigning experience-based ice concentrations to ice-type classes are overestimated by SLA and ASI ice concentrations by 4.4% and 1.5% (correlation coefficients of 0.84 and 0.77). However, omitting low/high ice concentrations forming up to 80% (AVHRR) and 60% (SAR) of the entire dataset reveals a significantly different statistic. For instance, the correlation between AVHRR and SLA and ASI ice concentrations drops to 0.77 and 0.70, respectively. All presented techniques to obtain ice concentrations need improvement and future developments should involve larger datasets. However, with care, both algorithms can be used to obtain reasonable ice concentration maps with a 12.5 km Ч12.5 km grid-cell size. [J1559]

"Speckle filtering and coherence estimation of polarimetric SAR interferometry data for forest applications"

Recently, polarimetric synthetic aperture radar (SAR) interferometry has generated much interest for forest applications. Forest heights and ground topography can be extracted based on interferometric coherence using a random volume over ground coherent mixture model. The coherence estimation is of paramount importance for the accuracy of forest height estimation. The coherence (or correlation coefficient) is a statistical average of neighboring pixels of similar scattering characteristics. The commonly used algorithm is the boxcar filter, which

has the deficiency of indiscriminate averaging of neighboring pixels. The result is that coherence values are lower than they should be. In this paper, we propose a new algorithm to improve the accuracy in the coherence estimation based on speckle filtering of the 6Ч6 polarimetric interferometry matrix. Simulated images are used to verify the effectiveness of this adaptive algorithm. German Aerospace Center (DLR) L-Band E-SAR data are applied to demonstrate the improved accuracy in coherence and in forest height estimation. [J1560]

"Scene characterization using subaperture polarimetric SAR data"

In synthetic aperture radar (SAR) polarimetry, the measured polarimetric signatures are used to analyze physical scattering properties of the imaged media. It is generally assumed that the sensor has a fixed orientation with respect to the objects. However, SAR sensors operating at lower frequencies, like L- and P-band, have a wide azimuth beamwidth, i.e., during the formation of the synthetic aperture, multiple squint angles are integrated to build the full-resolution SAR image. Variations in the polarimetric properties with the azimuthal look angle remain unconsidered. In this paper, a fully polarimetric subaperture analysis method is introduced. Using deconvolution, synthesized SAR images are decomposed into subaperture datasets, which correspond to the scene responses under different azimuthal look angles. A statistical analysis of the polarimetric parameters permits to clearly discriminate media showing a nonstationary behavior during the SAR integration. Finally, a method is proposed, which eliminates the influence of azimuthal backscattering variations in conventional polarimetric SAR data analysis. The effectiveness of the new methods is demonstrated on fully polarimetric SAR data, acquired by the German Aerospace Center (DLR) airborne experimental SAR sensor (E-SAR) at L-band. [J1561]

"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. [J1562]

"Almost translation invariant wavelet transformations for speckle reduction of SAR images"

Two wavelet transformations are used for speckle reduction and enhancement of synthetic aperture radar (SAR) images. First, a discrete wavelet transformation (DWT) based on oversampled filter banks is used. The oversampled DWT is called a double-density DWT (DD-DWT) and is based on a single-scaling function (low pass) and two distinct wavelet functions (high pass). Second, a discrete wavelet transformation based on two dual real wavelet trees is applied. Each tree produces a set of real DWTs, which together form the complex wavelet transformation (CWT), i.e., a transformation with both real and imaginary parts. Both of these DWTs are almost translation invariant and are useful for speckle reduction through their subband images, and the speckle reduction is obtained by thresholding the subband image coefficients of the digitized SAR images. A thresholding method based on the use of nonlinear functions, which are adapted for each selected subband, is used. The nonlinear functions are based on sigmoid functions. The denoising method presented shows great promise for speckle removal and, hence, can provide good detection performance for SAR-based recognition. [J1563]

"Automated removal of ghost noise from SAR images using wavelet packet transform"

Due to interference caused by ground transmitters, so-called ghost noise occurs on images obtained from synthetic aperture radar (SAR). This letter proposes a scheme based on the wavelet packet transform to remove

this ghost noise from the SAR image. The wavelet packet transform is employed to decompose the SAR image with the ghost noise both in the spatial and in the spatial frequency domain. To automatically detect and remove the ghost noise, an energy detection method is developed in this letter. The performance of the proposed scheme is demonstrated by some experimental results on real SAR images. In addition, we point out that the proposed scheme is also useful for other applications of image processing and analysis. [J1564]

"Efficient spotlight SAR raw signal simulation of extended scenes"

Synthetic aperture radar (SAR) raw signal simulation is a powerful tool for designing new sensors, testing processing algorithms, planning missions, and devising inversion algorithms. In this paper, a spotlight SAR raw signal simulator for distributed targets is presented. The proposed procedure is based on a Fourier domain analysis: a proper analytical reformulation of the spotlight SAR raw signal expression is presented. It is shown that this reformulation allows us to design a very efficient simulation scheme that employs fast Fourier transform codes. Accordingly, the computational load is dramatically reduced with respect to a time-domain simulation and this, for the first time, makes spotlight simulation of extended scenes feasible. [J1565]

"Multitemporal/multiband SAR classification of urban areas using spatial analysis: statistical versus neural kernel-based approach"

In this paper, we derive two techniques for the classification of multifrequency/multitemporal polarimetric SAR images, based respectively on a statistical and on a neural approach. Both techniques are especially designed to exploit the spatial structure of the observed scene, thus allowing more stable classification results. Such techniques are useful when looking at medium- to large-scale features, like the boundaries between urban and nonurban areas. They are applied to a set of SIR-C images of a urban area, to test their effectiveness in the identification of the different classes that compose the observed scene. A lower and an upper bound to the classification performance are introduced to characterize their limits. They correspond respectively to pixel-by-pixel classification and to the joint classification of the pixels belonging to the different classes identified in the ground truth. The results achieved with the two approaches are quantitatively analyzed by comparing them to the ground truth. Moreover, a hybrid approach is presented, where the homogeneous regions identified through statistical segmentation are classified using a neurofuzzy technique. Finally, a quantitative analysis of the results achieved with all the proposed techniques is carried out, showing that their classification performance is much higher than the lower bound and reasonably close to the upper bound. This is a consequence of their effectiveness in the exploitation of the spatial information. [J1566]

"Linear and nonlinear terrain deformation maps from a reduced set of interferometric SAR images"

In this paper, an advanced technique for the generation of deformation maps using synthetic aperture radar (SAR) data is presented. The algorithm estimates the linear and nonlinear components of the displacement, the error of the digital elevation model (DEM) used to cancel the topographic terms, and the atmospheric artifacts from a reduced set of low spatial resolution interferograms. The pixel candidates are selected from those presenting a good coherence level in the whole set of interferograms and the resulting nonuniform mesh tessellated with the Delauney triangulation to establish connections among them. The linear component of movement and DEM error are estimated adjusting a linear model to the data only on the connections. Later on, this information, once unwrapped to retrieve the absolute values, is used to calculate the nonlinear component of movement and atmospheric artifacts with alternate filtering techniques in both the temporal and spatial domains. The method presents high flexibility with respect to the required number of images and the baselines length. However, better results are obtained with large datasets of short baseline interferograms. The technique has been tested with European Remote Sensing SAR data from an area of Catalonia (Spain) and validated with on-field precise leveling measurements. [J1567]

"A modification to the Goldstein radar interferogram filter"

We present a modification to the adaptive Goldstein radar interferogram filter which improves the quality of interferometry products. The proposed approach makes the Goldstein filter parameter alpha dependent on coherence, such that incoherent areas are filtered more than coherent areas. This modification minimizes loss of signal while still reducing the level of noise. [J1568]

"Feasibility of wide-area subdecimeter navigation with GALILEO and Modernized GPS"

Precise corrections with a three-dimensional voxel model of the ionosphere based on Global Navigation Satellite System (GNSS) data from a wide-area network of ground receivers can help resolve differential carrier-phase ambiguities over very long baselines of hundreds of kilometers in present two-frequency systems [Global Positioning System (GPS) and Global Orbiting Navigation Satellite System (GLONASS)] or in planned three-

frequency systems (GALILEO, Modernized GPS). A study based on simulated three-frequency data from a modified GNSS signal generator indicates that all the phase ambiguities could be resolved successfully more than 90% of the time. This should be useful in surveying large areas with instruments that require very precise geolocation (e.g. radar or lidar altimetry, interferometric synthetic aperture radar, interferometric sonar, etc.). [J1569]

"Texture and speckle statistics in polarimetric SAR synthesized images"

We investigate in this paper the one-point statistical properties of the backscattered power derived by polarization synthesis of polarimetric synthetic aperture radar (SAR) observations. In particular, we focus our attention on the normalized second moment of intensity and its dependency on the polarization state. For the analysis of this dependency, a novel graphical representation-an extension of the polarization response-is introduced: the polarimetric texture signature. The second moment of backscattered power characterizes statistically the variation of the radar signal due to speckle and the underlying radar cross section. The classical texture product model with a scalar radar reflectivity implies that the normalized second moment of intensity does not depend on the polarization state. However, such dependency is found in experimental observations, a fact that calls for further investigation of the phenomenon. Considering at first speckle statistics for homogeneous areas having no texture, it is demonstrated that correlation among the single-look speckle patterns, which are added on an intensity basis in a multilook operation, is responsible for a weak polarization dependency of the normalized second moment. Concerning the textural properties, a new model is proposed-the mixture model-where it is assumed that polarimetrically diverse scattering mechanisms contribute to the total return from an ensemble of resolution elements. Numerical simulations are used to reconstruct the texture signatures according to the mixture model, starting from simple assumptions related to scattering processes from natural targets. It is found that the polarimetric texture signature can be an interesting discriminator of weak targets against clutter, when only polarimetric diversity and not radiometric diversity plays a role. The effects predicted by the theory are confirmed by experimental analysis of polarimetric data acquired by the Jet Propulsion Laboratory AIRSAR sensor. Finally a classification scheme based on the polarimetric texture signature is proposed. [J1570]

"The use of fully polarimetric information for the fuzzy neural classification of SAR images"

Presents a method, based on a fuzzy neural network, that uses fully polarimetric information for terrain and land-use classification of synthetic aperture radar (SAR) image. The proposed approach makes use of statistical properties of polarimetric data, and takes advantage of a fuzzy neural network. A distance measure, based on a complex Wishart distribution, is applied using the fuzzy c-means clustering algorithm, and the clustering result is then incorporated into the neural network. Instead of preselecting the polarization channels to form a feature vector, all elements of the polarimetric covariance matrix serve as the target feature vector as inputs to the neural network. It is thus expected that the neural network will include fully polarimetric backscattering information for image classification. With the generalization, adaptation, and other capabilities of the neural network, information contained in the covariance matrix, such as the amplitude, the phase difference, the degree of polarization, etc., can be fully explored. A test image, acquired by the Jet Propulsion Laboratory Airborne SAR (AIRSAR) system, is used to demonstrate the advantages of the proposed method. It is shown that the proposed approach can greatly enhance the adaptability and the flexibility giving fully polarimetric SAR for terrain cover classification. The integration of fuzzy c-means (FCM) and fast generalization dynamic learning neural network (DLNN) capabilities makes the proposed algorithm an attractive and alternative method for polarimetric SAR classification. [J1571]

"Polarimetric speckle reduction using multi-texture maximum likelihood method"

A new speckle reduction approach, which estimates texture parameters simultaneously by the method of maximum likelihood under the assumption of multi-texture, is proposed. Comparison with the polarimetric whitening filter (PWF) shows that this approach preserves the polarimetric properties and reduces the couple between polarimetric channels. [J1572]

"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. [J1573]

"Polarimetric SAR speckle noise model"

Synthetic aperture radar (SAR) data are affected by speckle noise, originated by the SAR system's coherent nature. The problem of speckle noise in one-dimensional (1-D) data is already solved, as speckle has a multiplicative characteristic. SAR polarimetry represents an extension to multidimensional data by the use of polarization wave diversity. As a consequence of the existence of a correlation degree between the SAR images, the 1-D speckle noise model cannot be extended to multidimensional SAR data. This paper is devoted to present a completely new speckle noise model for the complex covariance matrix describing polarimetric SAR data in the distributed scatterers case. As is shown, this new model is able to identify which are the noise mechanisms in all the covariance matrix elements. The speckle noise model is validated by using real L-band polarimetric data acquired with the German E-SAR sensor. [J1574]

"Generalized multivariate analysis of variance-A unified framework for signal processing in correlated noise"

Generalized multivariate analysis of variance (GMANOVA) and related reduced-rank regression are general statistical models that comprise versions of regression, canonical correlation, and profile analyses as well as analysis of variance (ANOVA) and covariance in univariate and multivariate settings. It is a powerful and, yet, not very well-known tool. We develop a unified framework for explaining, analyzing, and extending signal processing methods based on GMANOVA. We show the applicability of this framework to a number of detection and estimation problems in signal processing and communications and provide new and simple ways to derive numerous existing algorithms. Many of the methods were originally derived "from scratch", without knowledge of their close relationship with the GMANOVA model. We explicitly show this relationship and present new insights and guidelines for generalizing these methods. Our results could inspire applications of the general framework of GMANOVA to new problems in signal processing. We present such an application to flaw detection in nondestructive evaluation (NDE) of materials. A promising area for future growth is image processing. [J1575]

"Role of processing geometry in SAR raw data focusing"

Synthetic aperture radar (SAR) systems require that a focusing operation be performed on the received backscattered echoes (raw data) to generate high-resolution microwave images. Either due to platform attitude instabilities, or to Earth rotation effects, the SAR raw data may be acquired in "squinted" geometries, i.e., with the radar beam directed with an offset angle (squint angle) from the broadside direction. This research investigates the impact of the focusing operation carried out on squinted raw data acquisitions performed by SAR sensors operating in the stripmap mode. To this end the 2D frequency SAR processing approach is generalized with respect to conical, i.e., nonorthogonal, reference systems. This allows analysis of the geometric, spectral, and phase aberrations introduced in the images by the chosen processing geometry with respect to the acquisition, and identification of the focusing procedure that minimizes these aberrations. The whole theory is validated by experimental results carried out on simulated data. Moreover, the extension of this analysis to the interferometric case where these aberrations may have a significant role is also investigated [J1576]

"Diffraction by a conducting half-plane with application to radar target shadowing"

The field received at a moving radar which illuminates a far-field point target is derived for the two-dimensional case when the target is shadowed by a perfectly conducting half-plane. This problem arises in radar imaging and in certain calculations of radar cross-section. The derivation is based on an approximate analysis of line source diffraction by a conducting half-plane using antenna aperture analysis and image theory. The approximate solution is the same as that obtained by integral equation techniques and, in particular, leads to the exact (Sommerfeld) expression for plane wave incidence on the half-plane. Results from the radar solution quantify errors in estimating the dimensions of target features when the features are in the vicinity of shadow boundaries during the imaging process [J1577]

"VLSI architecture for SAR data compression"

As a step towards a real-time signal aperture radar (SAR) correlator, custom very large scale integration (VLSI) architectures are developed. Considering the extremely short word length of the data, we derive three architectures with massive parallelism in bit space. Unlike frequency methods, no. degradation is introduced during convolution. Optimized for time and space, they are highly suited to VLSI implementation, and a small architecture with 80 taps operating at 10 MHz has been built using an FPGA [J1578]

"The evolution of digital signal processing for airborne radar"

The author presents his personal experience in the development and feasibility demonstration of signal processing for military radar systems [J1579]

"Quantitative SNR analysis for ISAR imaging using joint time-frequency analysis-Short time Fourier transform"

V.C. Chen recently presented an inverse synthetic aperture radar (ISAR) imaging technique using the joint time-frequency analysis (JTFA), which has been shown having a better performance for maneuvering targets over the conventional Fourier transform method. The main reason is because the frequencies of the radar returns of the maneuvering targets are time varying and a JTFA is a technique that is suitable for such signals, in particular a JTFA may concentrate a wideband signal, such as a chirp, while it spreads noise. We quantitatively study the signal-to-noise ratio (SNR) in the ISAR imaging using one of the typical JTFA techniques, namely the short time Fourier transform (STFT). We show that the SNR increases in the joint time-frequency (TF) domain over the one in the time or the frequency domain alone both theoretically and numerically. This quantitatively shows the advantage of the JTFA technique for the ISAR imaging [J1580]

"Performance complexity study of several approaches to automatic target recognition from SAR images"

A framework which allows for the direct comparison of alternate approaches to automatic target recognition (ATR) from synthetic aperture radar (SAR) images is described and applied to variants of several ATR algorithms. This framework allows comparisons to be made on an even footing while minimizing the impact of implementation details and accounts for variation in image sizes, in angular resolution, and in the sizes of orientation windows used for training. Alternate approaches to ATR are characterized in terms of the best achievable performance as a function of the complexity of the model parameter database. Several approaches to ATR from SAR images are described and the performance achievable by each for a range of database complexities is studied and compared. These approaches are based on a likelihood test under a conditionally Gaussian model, log-magnitude least squared error, and quarter power least squared error. All approaches are evaluated for a wide range of parameterizations and the dependence on these parameters of both the resulting performance and the resulting database complexity is explored. Databases for all of the approaches are trained using identical sets of images and their performance is assessed under identical testing scenarios in terms of probability of correct classification, confusion matrices, and orientation estimation error. The results indicate that the conditionally Gaussian approach outperforms the other two approaches on average for both target recognition and orientation estimation, that accounting for radar power fluctuation improves performance for all three methods, and that the conditionally Gaussian approach normalized for power delivers average performance that is equal or superior to all other considered approaches [J1581]

"A novel multifractal estimation method and its application to remote image segmentation"

Based on the gliding-box and relative differential box-counting algorithms, a novel method that estimates accurately the multifractal exponents, a distinct characteristics of gray-scale digital images, is proposed. Four natural texture images are used to test the performance of the novel multifractal measure. Comparisons with published methods show that the proposed method can efficiently describe texture images and can provide accurate classification results [J1582]

"Amplitude spectrum estimation for two-dimensional gapped data"

The amplitude and phase estimation (APES) approach to nonparametric spectrum estimation of uniformly sampled data has received considerable interest. We consider the extension of APES to gapped data, i.e., uniformly sampled data with missing samples. It has been shown that the APES estimate of the spectrum is the minimizer of a certain least-squares (LS) criterion, and our extension of APES is based on minimizing this LS criterion with respect to the missing data as well. A computationally efficient method for doing this based on cyclic minimization and the conjugate gradient algorithm is proposed. The new algorithm is called gapped-data APES (GAPES) and is developed for the two-dimensional (2-D) case, with the one-dimensional (1-D) case as a

special instance. Numerical examples are provided to demonstrate the performance of the algorithm and to show the advantages of 2-D data processing over 1-D (row or column-wise) data processing, as well as to show the applicability of the algorithm to synthetic aperture radar (SAR) imaging [J1583]

"Interrupted synthetic aperture radar (SAR)"

The severe timeline demands imposed by the multi-mode functions of modern airborne radars utilizing active array antennas, may result in interrupted SAR data collections and consequent corrupted images. To recover the image quality, we interpolate the missing data using the Burg algorithm, allowing interrupt ratios of up to 30% [J1584]

"Statistical properties of logarithmically transformed speckle"

In synthetic aperture radar (SAR) image processing and analysis, the logarithmic transform is often employed to convert the multiplicative speckle model to an additive noise model. However, this nonlinear operation totally changes the statistics of SAR images. In this communication, we first review the statistical properties of speckle noise in both the intensity and the amplitude formats. Then, we derive the probability density functions, the mean values, and the variances to characterize the log-transformed speckle. Finally we discuss the problems introduced by the logarithmic transform on statistical analysis of SAR images. The statistical models developed in this communication will facilitate subsequent SAR image processing tasks based on the additive noise model [J1585]

"A single-chip false target radar image generator for countering wideband imaging radars"

This paper describes the theory, design, implementation, simulation, and testing of an ASIC capable of generating false target radar images for countering wideband synthetic aperture and inverse synthetic aperture imaging radars. The 5.5 Ч 6.1 mm IC has 81632 transistors, 132 I/O pins, and consumes 0.132 W at 70 MHz from a 3.3-V supply. An introduction to the application and operation of the ASIC in an electronic attack system is also presented. The false target image is fully programmable and the chip is capable of generating images of both small and large targets, even up to the size of an aircraft carrier. This is the first reported use of all-digital technology to generate false target radar images of large targets [J1586]

"Effective imaging of buried dielectric objects"

Ultrawide-band CW radar have shown good potential for remote imaging of surface laid or shallow buried landmine-like objects. However when sensing fields near to the ground, a number of factors including direct antenna coupling, air/ground coupling, receiver noise floor, and effective dynamic range conspire to degrade or mask the scattered return, resulting in a loss of signal magnitude, range accuracy, and range resolution. The present paper addresses the latter problems using a near-field detection methodology and providing a thorough experimental and systems analysis of the signal-to-clutter issues. The method proves advantageous in sensing weak echoes in the vicinity of the sensor from objects of low dielectric contrast with their environment. To enhance image processing gains, an effective space frequency synthetic aperture technique applicable to the two-media problem is outlined. The algorithm is straightforward and robust enough to be implemented on compact GPR systems operating in real time. The remaining problem of object identification will not be addressed here. To demonstrate the utility of these combined techniques, field experiments, over different frequency bands, were conducted and their results are reported [J1587]

"Maximum likelihood signal processing techniques to detect a step pattern of change in multitemporal SAR images"

In this paper, we address the problem of deriving adequate detection and classification schemes to fully exploit the information available in a sequence of SAR images. In particular, we address the case of detecting a step reflectivity change pattern against a constant pattern. Initially we propose two different techniques, based on a maximum likelihood approach, that make different use of prior knowledge on the searched pattern. They process the whole sequence to achieve optimal discrimination capability between regions affected and not affected by a step change. The first technique (KSP-detector) assumes a complete knowledge of the pattern of change, While the second one (USP-detector) is based on the assumption of a totally unknown pattern. A fully analytical expression of the detection performances of both techniques is obtained, which shows the large improvement achievable using longer sequences instead of only two images. By comparing the two techniques it is also apparent that KSP achieves better performance, but the USP-detector is more robust. As a compromise solution, a third technique is then developed, assuming a partial knowledge of the pattern of change, and its performance is compared to the previous ones. The practical effectiveness of the technique on real data is shown by applying the USP-detector to a sequence of 10 ERS-1 SAR images of forest and agricultural areas,

which is also used to validate the theoretical results [J1588]

"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 [J1589]

"Comparison of C- and X-band InSAR data for 3D characterization of an urban area"

In this paper we offer an overview of a number of algorithms suitable for 3D characterization of an urban environment from interferometric SAR data. By means of these algorithms we compare fine resolution C- and X-band SAR measurements over the same area to understand what useful information can be derived from these measurements. In addition we examine the similarities and differences of these data sets that are acquired with different frequency bands, bandwidths, and radar look direction. These data sets are recorded over Los Angeles, California, by the C-band NASA/JPL AIRSAR system, and by X-band Intermap Star-3i system. We analyze the original range measurements as reconstructed after the phase unwrapping procedure, the bald earth topography that we were able to retrieve, and the 3D shapes of some of the buildings in the UCLA area. Our results show that both data sets provide useful information of urban 3D characteristics. The better ground resolution of the X-band system results in better building shape extraction. Lower resolution of the C-band data, surprisingly, was not a limiting factor for extraction of large building structures. We demonstrate that it is possible to extract the terrain elevation model (bald earth topography), and the heights of large building structures by means of our algorithms [J1590]

"Modeling non-Rayleigh speckle distribution in SAR images"

In non-Rayleigh distributed radar images, the number of scatterers can be viewed as a Poisson distributed random variable, with the mean itself random. When this mean is Gamma distributed, then the image classically satisfies the K distribution. We add three new possible distributions for this mean: inverse Gamma, Beta of the first kind, and Beta of the second kind. We show that new intensity distributions so obtained can be estimated, with the interest of the extension validated on a real image. [J1591]

"Semi-empirical model of the ensemble-averaged differential Mueller matrix for microwave backscattering from bare soil surfaces"

A semi-empirical model of the ensemble-averaged differential Mueller matrix for microwave backscattering from bare soil surfaces is presented. Based on existing scattering models and data sets measured by polarimetric scatterometers and the JPL AirSAR, the parameters of the co-polarized phase-difference probability density function, namely the degree of correlation α and the co-polarized phase-difference ς, in addition to the backscattering coefficients σvv0,σhh0and σvh0, are modeled empirically in terms of the volumetric soil moisture content mvand the surface roughness parameters ks and kl, where k=2pif/c, s is the rms height and l is the correlation length. Consequently, the ensemble-averaged differential Mueller matrix (or the differential Stokes scattering operator) is specified completely by σvv0,σhh0,σvh0,α, and ζ. [J1592]

"Quantitative analysis of RADARSAT SAR data over a sparse forest canopy"

This article studies the behavior of the backscattering coefficient of a sparse forest canopy composed of relatively short black spruce trees. Qualitative analysis of the multiangular data measured by the RADARSAT synthetic aperture radar (SAR) sensor shows a good agreement with surface and vegetation volume scattering fundamental behaviors. For a quantitative analysis, allometric equations and measurements of tree components collected within the framework of the Extended Collaboration to Link Ecophysiology and Forest Productivity

(ECOLEAP) project are used, in an existing multilayer radiative transfer model for forest canopies, to simulate the RADARSAT SAR data. In our approach, the fractional cover of trees estimated from aerial photographs is used as a weighting parameter to adapt the closed-canopy backscattering model to the sparse forest under study. Our objective is to analyze the sensitivity of the backscattering coefficient as a function of sensor configuration, soil wetness, forest cover, and forest structural properties in order to determine the suitable soil, vegetation, and sensor parameters for a given thematic application. For the entire incidence angle domain (20° to 50°) of the sensor, simulations show that over a sparse forest composed of mature trees the monitoring of the ground surface is possible only under very wet soil conditions. Therefore, this article informs about the ability of the RADARSAT SAR sensor in monitoring wetlands. [J1593]

"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. [J1594]

"PFA algorithm for airborne spotlight SAR imaging with nonideal motions"

The nonuniform-interpolation polar format algorithm is developed for processing spotlight SAR data with nonideal platform motions. Instead of two uniform interpolations for the conventional polar format algorithm (PFA), this algorithm employs a one-dimensional uniform interpolation in the range direction and a one-dimensional nonuniform interpolation in the azimuth direction to remove effects of nonideal motion. For azimuth-nonuniform interpolation, the output sample spacing depends on the pulse number, range and motion data, and can be easily computed. The output sample spacing can also be precomputed and stored in RAM. The computational load of azimuth-nonuniform interpolation is almost the same as azimuth-uniform interpolation, if the output sample spacing is precomputed and stored. The computational load is the same for both algorithms. Theoretically, for scatterers in the focus target plane (FTP), this algorithm can produce a SAR image with the same quality for the nonideal motion case as for the ideal motion case. Like conventional PFA, it is compatible with autofocus. Computer simulation results validate the algorithm [J1595]

"Virtual benchmarking and model continuity in prototyping embedded multiprocessor signal processing systems"

The complexity of hardware/software codesign of embedded real-time signal processing systems can be reduced by rapid system prototyping (RSP). However, existing RSP frameworks do not provide a sound specification and design methodology (SDM) because they require the designer to choose the implementation target before specification and design exploration and they do not work together coherently across development stages. This paper presents a new SDM, called MAGIC, that allows the designer to capture an executable specification model for use in design exploration to find the optimal multiprocessor technology before committing to that technology. MAGIC uses a technique called "virtual benchmarking," for early validation of promising architectures. The MAGIC SDM also exploits emerging open-standards computation and communication middleware to establish model continuity between RSP frameworks. This methodology has been validated through the specification and design of a moderately complex system representative of the signal processing domain: the RASSP Synthetic Aperture Radar benchmark. In this case study, MAGIC achieves three orders of magnitude speedup over existing virtual prototyping approaches and demonstrates the ability to evaluate competitive technologies prior to implementation. Transfer of this methodology to the system-on-a-chip domain using Cadence's Virtual Component Codesign infrastructure is also discussed with promising results. [J1596]

"High-resolution InSAR image simulation for forest canopies"

High-resolution interferometric airborne synthetic aperture radar (SAR) images of Indonesian tropical rain forests have been acquired during the European Space Agency (ESA) Indonesian Radar Experiment (INDREX) 1996

campaign. Research efforts are directed toward development of automated canopy reconstruction algorithms. In this paper, interferometric synthetic aperture radar (InSAR) image simulation is discussed as one of the tools to support development of such inversion algorithms. First, the relevant physics, observation geometry, and radar characteristics are described. It is assumed that a forest can be modeled as a cloud of uniformly distributed isotropically scattering elements located within crown volumes. These volumes were measured during a field experiment for a 7.2 ha plot. Simulated data comprise intensity, phase, as well as coherence images. These are compared, in a statistical sense, with real data acquired in C- and X-bands. The canopy attenuation was simulated over a range of values. The normalized second intensity moment, the mean coherence magnitude, the coherence histogram, and the autocorrelation function of coherence were taken as measures for comparison. It can be concluded that simulated and real C-band images compare well for an extinction coefficient in the range of 0.15-0.3 m-1. For X-band, the selected measures of agreement lead to contradictions, indicating that the physical assumptions made may be less valid than for C-band. [J1597]

"A comparison between different polarimetric measurement schemes"

The usefulness of polarization information in remote sensing applications has been clearly demonstrated in the last two decades. Land covers and meteorological targets are complex and their backscatter returns are time varying. Their polarimetric characteristics should be determined in terms of second order statistics of scattering matrix elements. These are contained. in the polarimetric covariance matrix. Estimation of polarimetric covariance matrix elements has been addressed by different authors based on different scattering matrix measurement methods. The most widely used and implemented method consists in the alternate transmission of two orthogonal polarizations while. receiving with both. Recently, a method that considers simultaneous transmission of two orthogonal polarizations, which are phase coded with orthogonal signals, has been proposed. Another method, specifically developed to obtain the polarimetric covariance matrix, is based on transmitting three different polarizations and receiving their corresponding co-polar and cross-polar counterparts. Different data sets result from each measurement technique and different estimators of polarimetric covariance matrix elements have been developed for the different data sets available. These various methods are investigated in here. Based on simulated data the performance of the different estimators under different working conditions are analyzed. Effects on the estimators of operation frequency, pulse repetition frequency (PRF) and temporal properties of targets are discussed [J1598]

"Interferometric alignment of the X-SAR antenna system on the space shuttle radar topography mission"

The on-orbit alignment of the antenna beams of both the X-band and C-band radar systems during operations of the shuttle radar topography mission/X-band synthetic aperture radar (SRTM/X-SAR) was a key requirement for achieving best interferometric performance. In this paper, we consider the X-SAR antenna beam alignment in azimuth. For a single-pass cross-track SAR interferometer, we establish the relation between yaw and pitch misalignment of the antenna beams and the resulting relative shift of the Doppler frequency bands. This relation is used to provide solutions for the mechanical adjustments of the outboard antenna and electronic beam steering to correct for azimuth misalignment. Furthermore, the effects of the X-SAR effective outboard antenna pattern on the azimuth beam alignment are analyzed. As a result, a so-called "relaxing" factor is derived, which increases the limit for the difference in antenna azimuth angle with respect to the requirement on spectral overlap, and hence spatial interferogram resolution. However, we also show that the alignment requirement is driven by the constraint on decreasing the azimuth ambiguity-to-signal ratio (AASR) for the effective outboard antenna pattern to reduce the resulting additional height error. The strategy for misalignment determination and correction is presented, and results of the analysis of the in-flight X-SAR antenna beam alignment are discussed [J1599]

"Design and applications of airborne radars in the VHF/UHF band"

The simultaneous need for ground penetration and high resolution dictates the use of frequencies less than 500 MHz for imaging ground penetrating radar (GPR) designs. It is possible to build such systems with good performance and yet not interfere with ground installations operating in the same bands. The total number of airborne GPR systems needed to saturate the market is small, (possibly less than ten), and so the buildup of noise in this spectral region occupied by these radars will be negligible. This is fortunate, since there is a clear need for such radars in such areas as humanitarian demining and unexploded ordnance (UXO) mapping. Some formal set of guidelines is needed beyond that given in Part 15 of the FCC regulations, which both recognizes the need for airborne UWB radar operations, and still protects licensed users in the band [J1600]

"Multilook APES for multibaseline SAR interferometry"

We extend the amplitude and phase estimation (APES) adaptive filter of Stoica et al. (see IEEE Signal Processing Lett., vol.6, p.205-206, Aug. 1999 and IEEE Trans. Signal Processing, vol.48, p.338-52, Feb2000.) to the multiple look scenario. Several important radar and sonar applications can benefit from the new multilook APES filter. The properties of the APES algorithm allow for the accurate solution of the layover problem and the undistorted estimation of radar reflectivity for topographic mapping by means of multibaseline interferometry [J1601]

"Biophysical forest type characterization in the Colombian Amazon by airborne polarimetric SAR"

Fully polarimetric C-, L-, and P-band data were collected by NASA's AirSAR system in May 1993 at the Araracuara test site, a well-surveyed forest reserve in the center of the Colombian Amazon. The area is characterized by a high diversity of forest types, soil types, and flooding conditions. In this paper a polarimetric classification technique is used to assess AirSAR's potential for forest structural type mapping and, indirectly, forest biophysical characterization. Field observations were made at 23 0.1 ha plots to obtain additional quantitative descriptions on forest structure and ground surface conditions, but also to assess the suitability of existing map legends for synthetic aperture radar (SAR) mapping. It could be shown that a new type of legend leads to physically better interpretable results. it method based on iterated conditional modes is introduced and is shown to yield radar-derived classifications with a high level of agreement with the landscape-ecological map, as well as with the ground observations. The following results may indicate the high level of accuracy obtained: 15 classes can be differentiated, the average radar classification agreement ranges from 68% to 94% (depending on the type of classification and approach), and for only a few classes the agreement is less than 70%. The relation between physical forest structure and polarimetric signal properties is studied explicitly using polarimetric decomposition. A new method is introduced based on the decomposition of polarimetric coherence, instead of power. It is based on simple physical descriptions of the wave-object interaction. The accuracy of the complex coherence estimation is described using the complex Wishart distribution. Thus, several interesting physical relations between polarimetric signal and forest structure can be revealed. The physical limitations of this technique and its relation with sample size are indicated. [J1602]

"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. [J1603]

"Multiplicatively processed antenna arrays for DBF radar applications"

Nonlinear multiplicative processing of receiving antenna arrays enables a significant reduction of elements (i.e. thinning), which becomes increasingly important for large digital beamforming (DBF) arrays. In the paper, several (conventional and multiplicative) array configurations are investigated experimentally with respect to DBF radar applications. Radar measurements were carried out at 5.5 GHz and 77 GHz using a flexible synthetic aperture set-up. The results from the multiplicative systems are compared with those obtained with conventional (fully filled) arrays with regard to imaging performance. Multiplicative systems allow thinning rates of the order of 80%, with minor degradations in image quality. Tolerance simulations indicate a higher sensitivity of multiplicative systems in the presence of amplitude and phase errors [J1604]

"Prescreening during image formation for ultrawideband radar"

Standard radar image formation techniques waste computational resources by full resolving all areas of the scene, even regions of benign clutter. We introduce a multiscale prescreener algorithm that runs as part of the image formation processing step for ultrawideband (UWB) synthetic aperture radar (SAR) systems. The prescreener processes intermediate radar data generated by a quadtree backprojection image former. As the quadtree algorithm iterates, it is resolving increasingly finer subpatches of the scene. After each quadtree stage, the prescreener makes an estimate of the signal-to-background ratio of each subpatch and applies a constant false alarm rate (CFAR) detector to decide which ones might contain a target of interest. Whenever the

prescreener determines that a subpatch is not near a detection, it cues the image former to terminate further processing of that subpatch. Using a small database of UWB radar field data, we demonstrate that the prescreener is able to decrease the overall computational load of the image formation process. We also show that the new multiscale prescreener method produces fewer false alarms than the conventional two-parameter CFAR prescreener applied to the completely formed image [J1605]

"Sequence CLEAN: a modified deconvolution technique for microwave images of contiguous targets"

High resolution range profiles usually suffer from range sidelobe artifacts which cause reduction in the dynamic range. The sidelobes can be greatly reduced by a deconvolution technique called Coherent CLEAN. The Coherent CLEAN algorithm is based on the assumption that the scene consists of isolated and independent targets. However, many real-life targets are contiguous. Even if we approximate the contiguous targets by very closely spaced point sources, they can hardly be assumed to radiate independently. The sidelobes and the mainlobes of these closely spaced point sources can interact constructively and destructively causing spurious peaks and peak mislocations. These problems are studied and a variation in the existing Coherent CLEAN algorithm, called Sequence CLEAN, is proposed. Sequence CLEAN is found to work well with actual targets [J1606]

"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 [J1607]

"Improved target classification using optimum polarimetric SAR signatures"

We present a new method for automatic target/object classification by using the optimum polarimetric radar signatures of the targets/objects of interest. The state-of-the-art in radar target recognition is based mostly either on the use of single polarimetric pairs or on the four preset pairs of orthogonal polarimetric signatures. Due to these limitations, polarimetric radar processing has been fruitful only in the area of noise suppression and target detection. The use of target separability criteria for the optimal selection of radar signal state of polarizations is addressed here. The polarization scattering matrix is used for the derivation of target signatures at arbitrary transmit and receive polarization states (arbitrary polarization inclination angles and ellipticity angles). Then, an optimization criterion that minimizes the within-class distance and maximizes the between-class metrics is used for the derivation of optimum sets of polarimetric states. The results of the application of this approach on real synthetic aperture radar (SAR) data of military vehicles are obtained. The results show that noticeable improvements in target separability and consequently target classification can be achieved by the use of the optimum over nonoptimum signatures [J1608]

"Computation of storm-surge damage using distributed models and remote sensing data: a case study for the super cyclone in Orissa State, India"

This paper describes two spatial distributed models based on one-dimensional (1-D) energy balance equation to assess land surface damage caused by a storm surge. IRS LISS III and RADARSAT SAR data were used to generate critical model input parameters. The model's performance was validated for the Orissa super cyclone storm surge, India [J1609]

"O(N/sup 3/ log N) backprojection algorithm for the 3-D Radon transform"

We present a novel backprojection algorithm for three-dimensional (3-D) Radon transform data that requires O(N3log2N) operations for reconstruction of an N\ЧN\ЧN volume from O(N2) plane-integral projections. Our algorithm uses a hierarchical decomposition of the 3-D Radon transform to recursively decompose the backprojection operation. Simulations are presented demonstrating reconstruction quality comparable to the standard filtered backprojection, which requires O(N5) computations under the same circumstances. [J1610]

"Measured and predicted synthetic aperture radar target comparison"

The DARPA Image Understanding program publicly released measured and predicted synthetic aperture radar (SAR) targets were compared by means of correlation. The training set consisted of three classes (BMP-2, T-72, and BTR-70) at 17 deg depression and 233 azimuths. The test set consisting of seven different serial-numbered targets at 15 deg depression was tested at 196 azimuths. After segmentation and normalization, each test image was correlated with all the training images to generate correlation and classification statistics. Measured correlation scores were higher and more consistent for same serial number training than variant training. The average in-class (0.837) and between-class (0.734) means for measured correlations were higher than both the average in-class (0.707) and between-class (0.675) means for predicted correlations; however, the corresponding variances for in-class (0.056) and between-class (0.048) predicted correlations were higher than in-class (0.026) and between-class (0.036) measured variances. The measured training data declared the target correctly almost 100% of the time; the T-72 and BTR-70 model-predicted data declared the target correctly 80% of the time. The correlation scores varied approximately sinusoidally with aspect. Correlation plots between a single orientation target and the entire training sets showed that a target was highly correlated at both the correct aspect angle and the correct angle rotated 180 deg [J1611]

"Radar images of rough surface scattering: comparison of numerical and analytical models"

Rough surface scattering theories are investigated through analysis of radar images. Backscatter results from 10 GHz to 14 GHz under tapered wave illumination are considered for one-dimension (1D) random rough surface realizations which satisfy an impedance boundary condition. Back-projection tomography is applied to form two-dimensional (2D) synthetic aperture radar images from deterministic surface scattered field data at multiple incidence angles and frequencies. Numerical predictions of surface backscattered fields are obtained from an accelerated forward-backward (FB) method and the resulting images are compared with those obtained from approximate scattering theories such as the physical optics (PO) approximation, the small slope approximation (SSA), and the nonlocal SSA (NLSSA). The resulting radar images illustrate scattering sources associated with single and multiple scattering on the boundary, and a ray tracing analysis confirms the locations of time-delayed image points due to double reflections. For single scattering effects, the images demonstrate excellent agreement between analytical and numerical methods in both horizontal and vertical polarizations. For surfaces with RMS height 2.0 cm and correlation length 7.5 cm at normal incidence, multiple-scattering effects are observed and successfully captured when the lowest-order NLSSA is employed [J1612]

"The Z piM algorithm: a method for interferometric image reconstruction in SAR/SAS"

This paper presents an effective algorithm for absolute phase (not simply modulo-2-pi) estimation from incomplete, noisy and modulo-2pi observations in interferometric aperture radar and sonar (InSAR/InSAS). The adopted framework is also representative of other applications such as optical interferometry, magnetic resonance imaging and diffraction tomography. The Bayesian viewpoint is adopted; the observation density is 2-pi-periodic and accounts for the interferometric pair decorrelation and system noise; the a priori probability of the absolute phase is modeled by a compound Gauss-Markov random field (CGMRF) tailored to piecewise smooth absolute phase images. We propose an iterative scheme for the computation of the maximum a posteriori probability (MAP) absolute phase estimate. Each iteration embodies a discrete optimization step (Z-step), implemented by network programming techniques and an iterative conditional modes (ICM) step (pi-step). Accordingly, the algorithm is termed ZpiM, where the letter M stands for maximization. An important contribution of the paper is the simultaneous implementation of phase unwrapping (inference of the 2pi-multiples) and smoothing (denoising of the observations). This improves considerably the accuracy of the absolute phase estimates compared to methods in which the data is low-pass filtered prior to unwrapping. A set of experimental results, comparing the proposed algorithm with alternative methods, illustrates the effectiveness of our approach [J1613]

"Efficient radar signature prediction using a frequency-aspect interpolation technique based on adaptive feature extraction"

A radar cross section (RCS) interpolation technique in both frequency and aspect is proposed for the efficient prediction of radar signatures from computational electromagnetics data. Our approach is based on a multiple-arrival model for the induced current on the target. The model parameters are determined by an adaptive feature extraction (AFE) algorithm, which uses an iterative search-and-extract procedure to find the individual model features. Random frequency and aspect sampling is used to circumvent the ambiguity in selecting the features. Numerical examples are presented to test the interpolation algorithm. It is found that sufficient accuracy in the predicted radar features can be achieved even when the original computed data is sampled at 5:1 below the Nyquist criterion in either frequency or aspect. The algorithm is also applied to efficiently predict the radar images of the benchmark VFY218 airplane at UHF band with good results [J1614]

"Synthetic aperture imaging with arrays of arbitrary shape. Part I. General case"

The problem of synthesizing full-aperture resolution with linear transmitting and receiving arrays of arbitrary shape is considered. The arrays are assumed to lie in the same plane and can be open (e.g., curved or straight line segments) or closed (e.g., circles). It is shown that a full (area) aperture can be synthesized by suitably weighting the transmitted and received signals. This weighting turns out to be the Jacobian of a transformation that yields uniform coverage in the spatial-frequency domain. If the Jacobian is factorable, then full-aperture resolution can be achieved in a single transmission. The theory is illustrated with two annular arrays of different diameter: one that transmits and one that receives. If the radii of the annular arrays are a and b, then the synthesized point-spread function (PSF) is shown to be equivalent to that of a filled circular aperture of radius a+b. [J1615]

"Moving target detection and imaging using an X band along-track monopulse SAR"

Moving target detection and imaging results for an X band spotlight synthetic aperture radar (SAR) system that utilizes an along-track monopulse configuration for its data collection is presented. The theoretical foundation of the processing that is used on these data is based on our earlier work in which a two-dimensional signal subspace processing (adaptive filtering) method was used to calibrate the monostatic and bistatic radars of the monopulse SAR system. The blind calibration of the two channels enables the user to null the stationary scene, and detect the moving targets. Next, a measure that we call SAR ambiguity function is used to estimate the relative speed of a detected moving target. The resultant estimate is then used to image the moving target [J1616]

"High resolution 3-D imaging via multi-pass SAR"

Spaceborne/airborne synthetic aperture radar (SAR) systems provide high resolution two-dimensional terrain imagery. The paper proposes a technique for combining multiple SAR images, acquired on flight paths slightly separated in the elevation direction, to generate high resolution three-dimensional imagery. The technique could be viewed as an extension to interferometric SAR (InSAR) in that it generates topographic imagery with an additional dimension of resolution. The 3-D multi-pass SAR imaging system is typically characterised by a relatively short ambiguity length in the elevation direction. To minimise the associated ambiguities we exploit the relative phase information within the set of images to track the terrain landscape. The SAR images are then coherently combined, via a nonuniform DFT, over a narrow (in elevation) volume centred on the 'dominant' terrain ground plane. The paper includes a detailed description of the technique, background theory, including achievable resolution, and the results of an experimental study [J1617]

"Wavenumber domain reconstruction of SAR/SAS imagery using single transmitter and multiple-receiver geometry"

As synthetic aperture sonar and radar systems are operated at higher platform velocities, spatial undersampling becomes an increasing problem. This is most often countered by using an array of spatially separated receivers. Here, a modified form of the standard wavenumber (range mitigation algorithm, ω-k, seismic migration) algorithm to account for the increased number of receiver channels is reported [J1618]

"Subpixel variability of remotely sensed soil moisture: an inter-comparison study of SAR and ESTAR"

The representation of subpixel variability in soil moisture estimates from passive microwave data was investigated through sensitivity analysis and by comparison against the spatial structure of soil moisture fields derived from radar data. This work shows that the subpixel variability not represented in brightness temperature fields is directly associated with the spatial organization of soil hydraulic properties and the spatial distribution of vegetation. The significant implication of this result is that the physical connection between soil moisture

estimates at the pixel scale and local values within the pixel weakens strongly as the sensor resolution decreases. Subsequently, the application of scaling and fractal interpolation principles to downscale passive microwave data to the spatial resolution of radar data was investigated as a means to recover spatial structure. In particular, ESTAR soil moisture data was successfully downscaled from 200 to 40 m using only one radar frequency (e.g., L-band). This application suggests that the combined use of active and passive single-band microwave remote-sensing of soil moisture is a viable approach to improve the spatial resolution of soil moisture remote-sensing [J1619]

"Two-dimensional phase unwrapping using wavelet transform"

A method for solving the least squares two-dimensional phase unwrapping problem is presented. This technique is based on the multiresolution representation of a linear system using the discrete wavelet transform. By applying the wavelet transform to the original system, a better convergence condition of an equivalent new system can be achieved [J1620]

"Interferometric SAR image restoration using Monte Carlo metropolis method"

We present a novel method of interferometric synthetic aperture radar (InSAR) image restoration. An InSAR image is modeled as a complex-valued Markov random field (CMRF). Corrupted parts, which are indicated by residues in phase data, are restored by using the Monte Carlo Metropolis (MM) method based on their uncorrupted neighbor's CMRF parameter values. The system is implemented as a complex-valued neural network. The restoration process reduces the residue number, which is useful in the phase unwrapping process. The advantage of the method is demonstrated in the unwrapping process of an InSAR image that contains highly dense residues [J1621]

"Progressive space frequency quantization for SAR data compression"

The authors propose a new wavelet image coding technique for synthetic aperture radar (SAR) data compression called a progressive space-frequency quantization (PSFQ). PSFQ performs spatial quantization via rate distortion-optimized zerotree pruning of wavelet coefficients that are coded using a progressive subband coding technique. They compared the performances of zerotree-based methods: EZW, SPIHT, SFQ, and PSFQ with the classical wavelet-based method (CWM), which uses uniform scalar quantization of subbands followed by recency rank coding. The performances of the methods based on zerotree quantization were better than the CWM in the rate distortion sense. The embedded coding techniques perform better SNR results than the methods using scalar quantization. However, the probability density function (PDF) of the reconstructed amplitude SAR data compressed using CWM, better corresponded to the PDF of the original data than the PDF of the reconstructed data compressed using the zerotree based methods. The amplitude PDF of the reconstructed data obtained using PSFQ compression algorithm better corresponded to the original PDF than the amplitude PDF of the data obtained using the multilook method [J1622]

"Multisource data classification with dependence trees"

In order to apply a statistical approach to the classification of multisource remote-sensing data, one of the main problems to face lies in the estimation of probability distribution functions. This problem arises out of the difficulty of defining a common statistical model for such heterogeneous data. A possible solution is to adopt nonparametric approaches, which rely on the availability of training samples without any assumption about the related statistical distributions. The purpose of this paper is to investigate the suitability of the concept of dependence trees for the integration of multisource information through estimation of probability distributions. First, this concept, introduced by Chow and Liu (1968), is used to provide an approximation of a probability distribution defined in an N-dimensional space by a product of N-1 probability distributions defined in two-dimensional (2-D) spaces; this approximation corresponds, in terms of graph theoretical interpretation, to a tree of dependence. For each land cover class, a dependence tree is generated by minimizing an appropriate closeness measure. Then, a nonparametric estimation of the second-order probability distributions is carried out through the Parzen window approach, based on the implementation of 2-D Gaussian kernels. In this way, it is possible to reduce the complexity of the estimation, while capturing a significant part of the interdependence among variables. A comparison with other multisource data fusion methods, namely, the multilayer perceptron (MLP) method, the k-nearest neighbor (k-NN) method, and a Bayesian hierarchical classifier (BHC), is made. Experimental results obtained on multisensor [airborne thematic mapper (ATM) and synthetic aperture radar (SAR)] and multisource (experimental synthetic aperture radar (E-SAR) and a textural feature) data sets show that the proposed fusion method based on dependence trees is able to provide a classification accuracy similar to those of the other methods considered, but with the advantage of a reduced computational load [J1623]

"Adaptive noise reduction of InSAR images based on a complex-valued MRF model and its application t o phase unwrapping problem"

We propose a new adaptive noise reduction method for interferometric synthetic aperture radar (InSAR) complex-amplitude images. In the proposed method, we detect residues (singular points) in the phase image as well as their neighbors at first. Normal areas that contain no residue are used for the estimation of correct pixel values at the marked residues according to 5th order non-causal complex-valued Markov random field (CMRF) model. The process is performed block-wise with the assumption of a locally stationary condition of statistics. Using a CMRF lattice complex-valued neural-network, the error energy defined as the squared norm of distance between signal and estimated values is minimized by LMS steepest descent algorithm. Eventually, the number of residues is decreased. An application is also presented. An InSAR image around Mt. Fuji is processed by the proposed technique and then phase-unwrapped by the branch-cut method. It is found that after the application of the proposed method, a better phase unwrapped image can be obtained successfully [J1624]

"Surface roughness and slope measurements using polarimetric SAR data"

In this paper, the circular polarization coherence, ρRRLL, is investigated as a potential estimator of terrain surface roughness and small-scale slopes. The studies utilize microwave backscatter collected from 1) dielectric surfaces in an anechoic chamber and 2) a desert test site using P-, L-, and C-band NASA/JPL AIRSAR data. These experimental studies and supporting theory, indicate a sensitive decrease of |ρRRLL| with increasing surface roughness ks over a range 0 ⩽ ks ⩽ 1. For the present studies this decrease is caused largely by the depolarizing effects of small-scale surface slopes in the azimuth direction rather than by volume, or multiple scatter. For cases when the scatter is reflection symmetric, the value of |ρRRLL| depends on the surface roughness and on the local incidence angle. The dependence of |ρPRRLL| on the local incidence angle is supported by theory and experimental results. For these same scattering cases, however, |ρPRRLL| is independent of the surface dielectric constant. Estimation of the functional dependency of |ρPRRLL| versus ks, for a mid-range incidence angle, has been carried out using roughness estimates derived from an empirical model [J1625]

"Change detection for thematic mapping by means of airborne multitemporal polarimetric SAR imagery"

The paper addresses the detection of changes in multitemporal polarimetric radar images, focusing on small objects and narrow linear features. The images were acquired at C- and L-band by the airborne EMISAR system. It is found that the radar intensities are better suited for change detection than the correlation coefficient and the phase difference between the co-polarized channels. In the case of linear features, there is no obvious difference between the C- and L-bands, and slight variations of the flight tracks are acceptable at look angles larger than 35 degrees. Theoretical detection thresholds are evaluated from the statistical distribution of the intensity ratio due to speckle. For the linear features and for urban environments, the observed thresholds are larger than the theoretical predictions. This is interpreted as an effect of radar intensity variations on length scales smaller than the spatial image resolution. The signature of urban areas is very sensitive to deviations between the flight tracks, and the sensitivity is larger at C-band than at L-band. On the other hand, the intensity contrast between buildings and the urban background is smaller at L-band and larger at C-band. For change detection, thresholds may have to be chosen separately for each object class because the intensity ratios of different object classes vary differently as a function of time [J1626]

"Microwave underground propagation and detection"

The detection of buried targets has been a problem of significant interest for decades, with microwave-based sensing constituting an important tool. In this paper, we review the basic issues that characterize microwave-based subsurface sensing. Issues considered include the use of microwaves in the context of an airborne synthetic aperture radar, as well for radars deployed close to the air-soil interface. Rough-surface induced clutter is also discussed. Particular examples are presented for detection of land mines and unexploded ordnance [J1627]

"Unconstrained inversion of waveheight spectra from SAR images"

A procedure for inverting the nonlinear relationship between the waveheight spectrum and the SAR image spectrum is presented, and this procedure is evaluated using simulated data as well as actual ERS SAR data collected near Duck, NC. Results of this nonlinear inversion are compared with those obtained from a quasi-linear estimation procedure using simulated data, in order to illustrate the effects of nonlinearities in the imaging process. These effects include the well-known azimuth falloff effect as well as the generation of harmonics which appear in the background region of the spectrum. The nonlinear inversion technique is able to reproduce the

input image spectrum to high accuracy, although the wave spectrum obtained by this procedure is not necessarily the same as the input wave spectrum. In general, the estimated wave spectrum is quite similar to the portion of the input wave spectrum within the SAR passband region, but none of the energy outside the passband is recovered. The background signals due to nonlinear effects can cause large errors in the quasi-linear estimation procedure because these signals appear in regions of the spectrum where the SAR modulation transfer function (mtf) is small. Results using actual SAR data also indicate that energy within the passband is recovered fairly accurately, although energy outside the passband is clearly lost [J1628]

"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 [J1629]

"Exact closed-form geolocation for SAR interferometry"

Exact closed-form algorithms for InSAR-derived digital elevation model (DEM) geolocation are described. They are based on the knowledge of orbit parameters and time/Doppler frequency coordinates of each SAR image, as well as of their interferometric phase. The proposed scheme gives a simple framework for deriving the geolocation accuracy [J1630]

"Minimum mean square error space-varying filtering of interferometric SAR data"

This paper addresses the problem of filtering interferometric synthetic aperture radar (IFSAR) signals in presence of nonplanar topography to mitigate geometrical decorrelation effects. The problem is space-variant. The authors assume knowledge about the scene topography and derive an optimal, minimum mean square error (MMSE), filtering procedure. The algorithm is flexible and, beside the standard stripmap-stripmap interferometry, it may be applied to IFSAR data acquired in any operative mode. For instance, in scan-scan, scan-strip, and scan-spot interferometry. The scene topography contribution may be either derived from an external rough digital elevation model (DEM) or directly estimated from the SAR data. The filtering technique is extended to the azimuth direction to account for possible Doppler centroid decorrelation. Experimental results carried out on real data confirm the validity of the theory and show that this filtering procedure allows the authors to obtain a reduction of the interferometric noise content. Its gain is particularly marked in the cases of steep topography, where application of the standard common band filters could deteriorate the signal quality, or for large Doppler centroid shifts between the two acquisitions [J1631]

"Road detection in spaceborne SAR images using a genetic algorithm"

This paper presents a technique for the detection of roads in a spaceborne synthetic aperture radar (SAR) image using a genetic algorithm (GA). Roads in a spaceborne SAR image can be modeled as curvilinear structures that possess width. Curve segments, which represent the candidate positions for roads, are extracted from the image using a curvilinear structure detector, and the roads are accurately detected by grouping those curve segments. For this purpose, the authors designed a grouping method based on a GA, which is a global optimization method. They combined perceptual grouping factors with it and tried to reduce its overall computational cost by introducing a concept of region growing. In this process, a selected initial seed is grown into a finally grouped segment by the iterated GA process, which considers segments only in a search region. To detect roads more accurately, postprocessing, including noisy curve segment removal, is performed after grouping. The authors applied their method to ERS-1 SAR and SIR-C/X-SAR images that have a resolution of about 30 m. The experimental results show that our method can accurately detect road networks as well as single-track roads and is much faster than a globally applied GA approach [J1632]

"On the estimation of radar polarization orientation shifts induced by terrain slopes"

In recent studies, D. L. Schuler et al. (2000) applied polarimetric imaging radar-derived orientation angles to measure topography, and J. S. Lee et al. (2000) used orientation angles for polarimetric SAR data compensation, to ensure accurate estimation of geophysical parameters in rugged terrain areas. To support these applications, it is important to accurately estimate shifts in orientation angles induced by the azimuth slope variations. However, in many cases, inconsistency in the estimation of orientation angle shifts was encountered in several areas, introducing noisy and erroneous results. The present authors develop a unified analysis of estimation algorithms based on the circular polarization covariance matrix. The concept of reflection symmetry is used to explain the soundness of the circular polarization method and to show problems associated with other algorithms. L-band polarimetric synthetic aperture radar (SAR) images of Camp Roberts, CA, are used to substantiate this theory [J1633]

"Hierarchical network flow phase unwrapping"

The well-studied interferometric synthetic aperture radar (InSAR) problem for digital elevation map generation involves the derivation of topography from the radar phase. The topography is a function of the full phase, whereas the measured phase is known modulo 2pi, necessitating the process of recovering full phase values via phase unwrapping. This mathematical process becomes difficult through the presence of noise and phase discontinuities. This paper is motivated by research which models phase unwrapping as a network-flow minimization problem. A major limitation is that often a substantial computational effort is required to find solutions. Commonly, these phase images are huge (≫10 million pixels), and obviously the sheer size of the problem itself makes phase unwrapping challenging. This paper addresses the development of a computationally efficient hierarchical algorithm, based on a "divide-and-conquer" approach. We have shown that the phase-unwrapping problem can first be partitioned into independent phase-unwrapping subproblems, which can further be recombined to produce the unwrapped phase. Interestingly, the recombination step itself can be interpreted as an unwrapping problem, for which a modified network-flow solution applies! In short, this paper develops a parallelization of the network-flow algorithm, allowing images of virtually unlimited size to be unwrapped and leading to dramatic decreases in the algorithm execution time. [J1634]

"A new scattering mechanism enhancement scheme for polarimetric SAR images"

A new scattering mechanism enhancement scheme has been developed for natural (distributed) targets based on the eigenvalues and corresponding eigenvectors of the covariance matrix in order to identify different scattering events. First, three new vectors (v1, v2, and v3) were constructed from the eigenvectors of the covariance matrix with some modifications. Then, those modified vectors were weighted by the eigenvalues of the covariance matrix as a weighting function. Thus, three vertices (A, B, and C) could be obtained in the three-dimensional space. In order to utilize them equally, a triangle (ΔABC) was constructed by connecting these three vertices. The shape of the triangle may be changed due to the different scattering mechanisms because the vertices are obtained from the combination of eigenvalues and eigenvectors. The result indicated that different scattering mechanisms can be represented by using an exterior angle derived from the interior angles of the triangle. Results obtained from the newly developed scattering enhancement scheme, when compared with the results derived from existing schemes, were in agreement in terms of the dominant scattering mechanisms, including surface scattering, double-bounce scattering, and volume scattering. The experimental results with the Spaceborne Imaging Radar version C (SIR-C) L-band full polarimetric data demonstrate the effectiveness of the new scattering enhancement scheme. [J1635]

"Incidence angle dependence of the statistical properties of C-band HH-polarization backscattering signatures of the Baltic Sea ice"

Incidence angle dependence of three statistical parameters-the mean of the backscattering coefficient (σ°), standard deviation, and autocorrelation coefficient of texture (σTand ρT)-of the C-band horizontal-horizontal (HH) polarization backscattering signatures of the Baltic Sea ice are investigated using RADARSAT ScanSAR Narrow images and helicopter-borne Helsinki University of Technology Scatterometer (HUTSCAT) data. The analysis of the large amount of data shows that the relationship between the mean σ° in decibel scale and the incidence angle in the range from 19° to 46° is usually well described by a linear model. In general, the RADARSAT and HUTSCAT results agree with each other, and they are also supported by theoretical backscattering model calculations; the more deformed the ice, the smaller the slope between σ° and the incidence angle, and the higher the moisture content of snow or ice, the larger the slope. The derived σ° incidence angle dependencies can be used to roughly compensate the σ° incidence angle variation in the SAR images to help their visual and automated classification. The variability of σTand ρTwith the increasing incidence angle is insignificant compared to the variability within each ice type. Their average changes with the incidence angle are so small that, in

practice, their trends do not need to be compensated. The results of this study can be utilized when developing classification algorithms for the RADARSAT ScanSAR and ENVISAT HH-polarization Wide Swath images of the Baltic Sea ice. [J1636]

"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. [J1637]

"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. [J1638]

"Segmentation-based joint classification of SAR and optical images"

The authors devise a new data fusion technique for classification that exploits the information contained in single-channel SAR and optical images optimally. In fact, even though good classification performance can be achieved by using multiple optical channels, it is shown that classification results from a single optical channel are not appreciably better than those obtained with a single SAR image. The impact of fusion of SAR and optical images is investigated quantitatively. To characterise the limits that can be achieved, both lower and upper bounds to classification performance are introduced, corresponding respectively to single-pixel classification and joint classification of all pixels in the regions defined by the ground truth. First, an optimised technique for single-channel image segmentation followed by maximum likelihood (ML) classification is proposed. A significant performance improvement is demonstrated by classifying the homogeneous regions identified by segmentation, instead of single pixels or even small windows of 3Ч3 pixels. Indeed, the result consistently approaches the upper bound. Next, the proposed ML segmentation technique is extended to exploit the information available in SAR and optical images jointly to define the best set of segments. The segmented SAR and optical images are then used together to obtain the best possible classification of the segments, yielding a significant performance improvement with respect to using either sensor alone. Classification performance is again significantly better than with single pixels, or small windows, and approaches the upper bound. [J1639]

"Ultra-wideband continuous-wave random noise arc-SAR"

A coherent ultra-wideband random noise radar system operating in the 1-2-GHz frequency range has been developed at the University of Nebraska. A unique signal processing procedure based on heterodyne correlation techniques preserves phase coherence within the system, thereby enabling it to be used for synthetic aperture radar (SAR) imaging. Data acquisition is performed using a rotating boom with antennas installed atop a van containing radar equipment. This setup facilitates a simple and low-cost mobile SAR implementation, best suited for short-range quasi-stripmap Arc-SAR imaging. The use of ultra-wideband signals provides reasonable resolution of the obtained imagery. The amplitude and the phase response of the system are used to form the frequency-domain target scattering profile matrix, which are then transformed into a SAR image. The paper discusses the theory of SAR imaging using random noise signals and presents a detailed description of the radar and experimental imagery obtained using this system. [J1640]

"Modeling and reduction of SAR interferometric phase noise in the wavelet domain"

This paper addresses the problem of interferometric phase noise reduction in synthetic aperture radar interferometry. A new phase noise model in the complex domain is introduced and validated by using both simulated and real interferograms. This noise model is also derived in the complex wavelet domain, where a novel noise reduction algorithm, which is not based on a windowing process and without the necessity of phase unwrapping, is addressed. The use of the wavelet transform allows to maintain the spatial resolution in the filtered phase image and prevents to filter low coherence areas. By using both, simulated as well as real interferometric phase images, the performance of this algorithm, in terms of noise reduction, spatial resolution maintenance, and computational efficiency, is reported and compared with other conventional filtering approaches. [J1641]

"On shape, orientation, and structure of atmospheric cells inside wind rolls in two SAR images"

Synthetic aperture radar (SAR) images of the sea surface often show roll-vortex structures and other features which, in general, are spread out over several length scales and may present spatial periodicity as well as intermittence. Standard techniques, such as two-dimensional (2-D) Fourier analysis, are unsuitable both when it is of interest to detect intermittent phenomena and to analyze the spatial disposition of the backscatter structures inside the SAR images. For the above reasons, the 2-D continuous wavelet transform analysis has been applied to two European Remote Sensing mission SAR images over the Mediterranean Sea, showing wind rolls and atmospheric gravity waves. Through the evaluation of the wavelet variance map, which ideally corresponds to the 2-D Fourier spectrum, it has been possible to assess the presence of two main energy areas at large (from 7-28 km) and small (from 0.5-2 km) spatial scales. While the large-scale fluctuations may be ascribed to atmospheric gravity waves and other features induced by the surroundings, the small-scale fluctuations reveal the inner structure of the atmospheric wind rolls. The SAR-like maps, obtained by adding the wavelet coefficient maps pertaining to the small scales, have permitted us to highlight the high- and low-intensity backscatter cells associated with the wind rolls. These cells have been statistically characterized by means of the frequency distributions of the size of the cells maximum and minimum axes, of the orientation of the maximum axis, and of their area. The results indicate that high- and low-intensity backscatter cells have similar characteristics in both cases studied: they appear of elliptic shape, with the major axis along the wind roll direction; the average axes ratio is 2.5:1. The frequency distributions of the cell area indicate a continuous distribution of sizes, without significant gaps. [J1642]

"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. [J1643]

"Validation of surface scattering models across large footprints for global scatterometer applications"

Medium- to low-resolution active microwave sensors such as spaceborne scatterometers and wide-swath mode synthetic aperture radars have great potential as tools for long-term monitoring over land and ice. Their large area coverage and low data cost make them ideal for measuring mesoscale land-surface changes. One approach to the interpretation of such data is to employ a theoretical backscatter model that can be inverted to estimate some representative surface parameters. To optimize such a method, it is necessary to use scattering models that are applicable to large (>1 km) footprints that inevitably contain a range of surface characteristics. This paper investigates the validity of a number of surface scattering models for such a task. The analysis is carried out both from a theoretical modeling approach as well as through comparison with real data from the European Remote Sensing (ERS) scatterometer over nonvegetated areas. Modified models that incorporate surface heterogeneity through probability distributions are also introduced. It is shown than the ERS scatterometer data are better represented using these modified models than the standard theoretical models. Good results are also obtained using the semiempirical model by Oh et al. (1992) that seems to implicitly incorporate target heterogeneity. [J1644]

"ATR scheme based on 1-D HRR profiles"

A new automatic target recognition (ATR) scheme based on one-dimensional high range resolution profiles is presented, which features joint range alignment and classification. This method can also be used to form mean- or eigen-templates to further improve the ATR performance. Experimental results are provided to demonstrate the performance of the new algorithm. [J1645]

"A novel lacunarity estimation method applied to SAR image segmentation"

Based on the relative differential box-counting algorithm and the gliding-box algorithm, a novel method for estimating the lacunarity features of grayscale digital images is proposed. Four natural texture images are used to test the performance of the novel lacunarity measure. Comparisons with published methods show that the proposed method can efficiently describe texture images, and provide accurate classification results. Real synthetic aperture radar (SAR) images analyses are found to have different lacunarity values for different regions. We show that good results can be obtained with appropriate lacunarity parameters applied to SAR images segmentation. [J1646]

"Multifrequency InSAR height reconstruction through maximum likelihood estimation of local planes parameters"

A technique that is able to reconstruct highly sloped and discontinuous terrain height profiles, starting from multifrequency wrapped phase acquired by interferometric synthetic aperture radar (SAR) systems, is presented. We propose an innovative unwrapping method, based on a maximum likelihood estimation technique, which uses multifrequency independent phase data, obtained by filtering the interferometric SAR raw data pair through nonoverlapping band-pass filters, and approximating the unknown surface by means of local planes. Since the method does not exploit the phase gradient, it assures the uniqueness of the solution, even in the case of highly sloped or piecewise continuous elevation patterns with strong discontinuities. [J1647]

"Identification of ground targets from sequential high-range-resolution radar signatures"

An approach to identifying targets from sequential high-range-resolution (HRR) radar signatures is presented. In particular, a hidden Markov model (HMM) is employed to characterize the sequential information contained in multiaspect HRR target signatures. Features from each of the HRR waveforms are extracted via the RELAX algorithm. The statistical models used for the HMM states are formulated for application to RELAX features, and the expectation-maximization (EM) training algorithm is augmented appropriately. Example classification results are presented for the ten-target MSTAR data set. [J1648]

"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. [J1649]

"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. [J1650]

"A review of speckle filtering in the context of estimation theory"

Speckle filter performance depends strongly on the speckle and scene models used as the basis for filter development. These models implicitly incorporate certain assumptions about speckle, scene, and observed signals. In this study, the multiplicative and the product speckle models, which have been used for the development of most of the well-known filters, are analyzed, and their implicit assumptions with regard to the stationarity-nonstationarity nature of speckle are discussed. This leads to the definition of two categories of speckle filters: the stationary and the nonstationary multiplicative speckle model filters. The various approximate models used for the multiplicative speckle noise model are assessed as functions of speckle and scene characteristics to derive the requirements on scene signal variations for the validity of both the stationary and nonstationary multiplicative speckle models. Speckle filtering is then studied in the context of estimation theory, so as to develop a procedure for speckle filtering. It is shown that speckle filtering can be effective only in locally stationary scenes. Regions in which the signals are not stationary have to be filtered separately using a priori scene templates for the best matching of nonstationary scene features. The use of multiresolution techniques is crucial for accurate estimation of filter parameters. Under the guidance of the speckle filtering procedure, structural-multiresolution versions of the Lee (1980) and Frost et al. (1982) filters are developed for optimum application of these filters in the context of nonstationary scene signals. [J1651]

"Speckle removal from SAR images in the undecimated wavelet domain"

Speckle reduction is approached as a minimum mean-square error (MMSE) filtering performed in the undecimated wavelet domain by means of an adaptive rescaling of the detail coefficients, whose amplitude is divided by the variance ratio of the noisy coefficient to the noise-free one. All the above quantities are analytically calculated from the speckled image, the variance and autocorrelation of the fading variable, and the wavelet filters only, without resorting to any model to describe the underlying backscatter. On the test image Lena corrupted by synthetic speckle, the proposed method outperforms Kuan's local linear MMSE filtering by almost 3-dB signal-to-noise ratio. When true synthetic aperture radar (SAR) images are concerned, empirical criteria based on distributions of multiscale local coefficient of variation, calculated in the undecimated wavelet domain, are introduced to mitigate the rescaling of coefficients in highly heterogeneous areas where the speckle does not obey a fully developed model, to avoid blurring strong textures and point targets. Experiments carried out on widespread test SAR images and on a speckled mosaic image, comprising synthetic shapes, textures, and details from optical images, demonstrate that the visual quality of the results is excellent in terms of both background smoothing and preservation of edge sharpness, textures, and point targets. The absence of decimation in the wavelet decomposition avoids typical impairments often introduced by critically subsampled wavelet-based denoising. [J1652]

"Localization of step changes in multitemporal SAR images"

Deals with multitemporal sequences of synthetic aperture radar (SAR) images with regions possibly affected by step reflectivity patterns of change. Specifically, it addresses the problems of detecting a temporal step pattern with small reflectivity change against a constant pattern and of estimating the transition instant for the step. The statistically optimized signal processing techniques proposed in this work are most appropriate for the new generation of SAR systems with high revisit time that are currently under development. We propose two different techniques, based on the maximum likelihood (ML) approach, that make different use of prior knowledge on the radar cross section (RCS) levels of the searched pattern. They process the whole sequence to achieve optimal discrimination capability between regions affected and not affected by a step change and optimal estimation accuracy for the step transition instant. The first technique (known step pattern (KSP)-detector) assumes complete knowledge of the RCS levels of the searched pattern of change, while the second one (USP-detector) is based on the assumption of totally unknown step pattern. [J1653]

"Layover solution in multibaseline SAR interferometry"

In this work, spectral estimation techniques are used to exploit baseline diversity of a multichannel interferometric synthetic aperture radar (SAR) system and overcome the layover problem. This problem arises when different height contributions collapse in the same range-azimuth resolution cell, due to the presence of strong terrain slopes or discontinuities in the sensed scene. We propose a multilook approach to counteract the presence of multiplicative noise, which is due to the extended nature of natural targets; to this purpose we extend the RELAX algorithm to the multilook data scenario (M-RELAX). A thorough performance analysis of nonparametric (beamforming and Capon) and parametric (root MUSIC and M-RELAX) techniques is carried out based on Monte Carlo simulations and Cramer-Rao lower bounds (CRLB) calculation. The results suggest the superiority of parametric methods over nonparametric ones. [J1654]

"Application of the fractional Fourier transform to moving target detection in airborne SAR"

As a useful signal processing technique, the fractional Fourier transform (FrFT) is largely unknown to the radar signal processing community. In this correspondence, the FrFT is applied to airborne synthetic aperture radar (SAR) slow-moving target detection. For airborne SAR, the echo from a ground moving target can be regarded approximately as a chirp signal, and the FrFT is a way to concentrate the energy of a chirp signal. Therefore, the FrFT presents a potentially effective technique for ground moving target detection in airborne SAR. Compared with the common Wigner-Ville distribution (WVD) algorithm, the FrFT is a linear operator, and will not be influenced by cross-terms even if multiple moving targets exist. Moreover, to solve the problem whereby weak targets are shadowed by the sidelobes of strong ones, a new implementation of the CLEAN technique is proposed based on filtering in the fractional Fourier domain. In this way strong moving targets and weak ones can be detected iteratively. This combined method is demonstrated by using raw clutter data combined with simulated moving targets. [J1655]

"Polarimetric scattering indexes and information entropy of the SAR imagery for surface monitoring"

The Mueller matrix solution and eigenanalysis of the coherency matrix for completely polarimetric scattering have been applied to the analysis of synthetic aperture radar (SAR) imagery. Copolarized and cross-polarized backscattering for any polarized incidence can be obtained. The polarization index is usually defined as a parameter to classify the difference between polarized scattering signatures from the terrain surfaces. The eigenvalues of the coherency matrix and information entropy are derived to directly relate with measurements of the copolarized and cross-polarized indexes. Thus, it combines the Mueller matrix simulation, the information entropy of the coherence matrix, and two polarization indexes together and yields a quantitative evaluation for surface classification in the SAR imagery. This theory is applied to analysis of the AirSAR images and field measurements. [J1656]

"Characterization of target symmetric scattering using polarimetric SARs"

Cameron's coherent target decomposition (CTD) theory and the classification method that Cameron developed for operational use of his CTD are reconsidered. It is shown that Cameron's classification leads to a coarse scattering segmentation because of the large class dispersion that corresponds to a synthetic aperture radar (SAR) system with about ±8-dB channel imbalance. The application of Cameron's method within known SAR radiometric calibration requirements limits the utility of the classification. In addition, Cameron's classification is applied under the implicit assumption on the coherence nature of target scattering, and this might yield erroneous results within areas of noncoherent scattering. A new method, named the symmetric scattering characterization method (SSCM), is introduced to better exploit the information provided by the largest target symmetric scattering component in the context of coherent scattering. The Poincarer' sphere is used as the basis for a more complete representation of symmetric scattering than Cameron's unit disk, thus enabling the SSCM to generate better segmentation of target symmetric scattering with much higher resolution. In order to limit the application of the SSCM to targets of coherent scattering, new methods are developed for assessment and validation of the coherent nature of point and extended target scattering. [J1657]

"Comments on "Non-iterative quality phase-gradient autofocus (QPGA) algorithm for spotlight SAR imagery""

For original paper see ibid., vol.36, no.5, pt.1, p.1531-9 (1998). The quality phase-gradient autofocus (QPGA) technique was proposed to speed up the estimation convergence of phase-gradient autofocus by selectively increasing the pool of quality synchronization sources instead of selecting the "brightest" pixels within the image. It is now found that the QPGA, with its inherent scatter "growing" concept and target-filtering procedure, is also able to focus in environments with stationary and moving targets. [J1658]

"A wavelet transform coder supporting browsing and transmission of sea ice SAR imagery"

A wavelet-transform-based algorithm for sea ice synthetic aperture radar (SAR) image data compression is presented. Compression of the relatively low resolution (100 m) SAR data is necessary to enable the transmission of such images from the Finnish Ice Service to users in the Baltic Sea. On board the ships, the SAR images are used for navigation purposes. Hence, in the visual appearance of the compressed image, special attention must be paid to the sharpness of small details. Several target-dependent features are incorporated in the compression scheme developed. The addition of these features was motivated by an examination of the wavelet coefficient statistics for the SAR data. In the quantization phase, the sensitivity characteristics of the human visual system were taken into account. As a result, the proposed algorithm deviates

in several respects from the standard procedures used in wavelet-based compression. The algorithm requires the setting up of multiple user-defined parameters to satisfy the requirements of the users and data. This requires supervision of an expert, but also makes it flexible for many kinds of data and user requirements. The algorithm presented gives satisfactory results with a compression ratio of 20:1. Since only the location of ice-covered areas is of significance for ship traffic, the algorithm introduced contains an option to mask off open sea areas with the aid of an automatic open-water detection procedure. We also report the results of a user evaluation, in which the proposed algorithm is compared to the algorithm currently used by the Finnish Ice Service, as well as to the JPEG standard. The results of the evaluation favor the use of the proposed algorithm. [J1659]

"Road detection in dense urban areas using SAR imagery and the usefulness of multiple views"

This paper deals with the automatic extraction of the road network in dense urban areas using a few-meters-resolution synthetic aperture radar (SAR) images. The first part presents the proposed method, which is an adaptation of previous work to the specific case of urban areas. The major modifications are 1) the clique potentials of the Markov random field that extracts the road network are adapted and 2) a multiscale framework is used. Results on shuttle mission and aerial SAR images with different resolutions are presented. The second part is dedicated to road extraction combining two SAR images taken with different flight directions (orthogonal and antiparallel passes), and the obtained improvement is analyzed. [J1660]

"Topographic SAR interferometry formulation for high-precision DEM generation"

In repeat-pass synthetic aperture radar (SAR) interferometry, the approximations, allowing the phase-to-height conversion, prevent high-resolution mapped relief. In this paper, we present a more general and exact formulation giving a new relationship between the interferogram phase and the target height. It is based on the interferometric SAR geometry and on a better expansion of the path length difference between the sensor and the target. This formulation emphasizes the impact of baseline uncertainties on digital elevation model (DEM) accuracy. A quantitative assessment of the required baseline accuracy is computed. The impact of orbital parameters, used in the new formulation, on interferogram generation is studied. Thus, a new simulator algorithm is developed and tested on a set of reference and simulated DEM examples. Examples of interferogram simulation and DEM generation validate this new approach in the case of a mountainous area in Mustang (Nepal). [J1661]

"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. [J1662]

"On rewriting the imaging mechanism of underwater bottom topography by synthetic aperture radar as a Volterra series expansion"

Ocean surface current gradients can be imaged by real and synthetic aperture radar (RAR/SAR) due to the so-called hydrodynamic modulation mechanism. This is the reason why underwater bottom topography and internal waves are visible on radar images. Several physical models exist for this imaging mechanism. When trying to obtain current information from SAR images, a problem arises: the imaging mechanism can be nonlinear. We propose to rewrite the classical modeling of the SAR underwater bottom topography imaging mechanism by using a Volterra series expansion. The Volterra model can be seen as a tool allowing us to study whether the imaging mechanism can be inverted or not. It is a transposition of a well-studied physical problem into a more explicit expression. The conditions for the inversion of the Volterra model are presented and a scheme for estimating the bathymetry from SAR images is described. The main property of the inversion algorithm is its independence from the physical model used for the mechanism [J1663]

"A maximum-likelihood surface estimator for dense range data"

Describes how to estimate 3D surface models from dense sets of noisy range data taken from different points of view, i.e., multiple range maps. The proposed method uses a sensor model to develop an expression for the

likelihood of a 3D surface, conditional on a set of noisy range measurements. Optimizing this likelihood with respect to the model parameters provides an unbiased and efficient estimator. The proposed numerical algorithms make this estimation computationally practical for a wide variety of circumstances. The results from this method compare favorably with state-of-the-art approaches that rely on the closest-point or perpendicular distance metric, a convenient heuristic that produces biased solutions and fails completely when surfaces are not sufficiently smooth, as in the case of complex scenes or noisy range measurements. Empirical results on both simulated and real ladar data demonstrate the effectiveness of the proposed method for several different types of problems. Furthermore, the proposed method offers a general framework that can accommodate extensions to include surface priors, more sophisticated noise models, and other sensing modalities, such as sonar or synthetic aperture radar. [J1664]

"A simple model for SAR azimuth speckle, focusing, and interferometric decorrelation"

The phenomenon of speckle in synthetic aperture radar (SAR) images is well known as a characteristic grainy appearance of radar images. Speckle is frequently a significant obstacle to visual interpretations of radar data or target identification. In addition, it is usually the dominant noise source in SAR interferometry, since it is responsible for image decorrelation that degrades interferometric fringes, places severe constraints on orbits, and limits the accuracy of height measurements. This communication deals with the geometric sources of speckle. This conventional picture is extended to the case of vertically separated scatterers, and the formulation that results is applied to the structurally similar topics of azimuth focusing, interferometric decorrelation from defocusing, and atmospheric phase delays. [J1665]

"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 [J1666]

"Burst-mode and ScanSAR interferometry"

ScanSAR interferometry is an attractive option for efficient topographic mapping of large areas and for monitoring of large-scale motions. Only ScanSAR interferometry made it possible to map almost the entire landmass of the Earth in the 11-day Shuttle Radar Topography Mission. Also the operational satellites RADARSAT and ENVISAT offer ScanSAR imaging modes and thus allow for repeat-pass ScanSAR interferometry. This paper gives a complete description of ScanSAR and burst-mode interferometric signal properties and compares different processing algorithms. The problems addressed are azimuth scanning pattern synchronization, spectral shift filtering in the presence of high squint, Doppler centroid estimation, different phase-preserving ScanSAR processing algorithms, ScanSAR interferogram formation, coregistration, and beam alignment. Interferograms and digital elevation models from RADARSAT ScanSAR narrow modes are presented. The novel "pack-and-go" algorithm for efficient burst-mode range processing and a new time-variant fast interpolator for interferometric coregistration are introduced. [J1667]

"On the scattering mechanism of power lines at millimeter-waves"

The radar signature of power lines is of high importance in the design of systems for helicopter collision avoidance. Laboratory measurements have been reported previously, but field measurements at millimeter waves are missing. The present contribution describes measurements done in ground-based configuration with a real aperture scanning-beam radar operating simultaneously at 35 and 94 GHz. By scanning, an aspect angle interval of 60° was covered, including the broadside aspect. The narrow beam width allowed to discriminate between different wires separated horizontally. While these measurements were done under a very shallow incidence angle, assisting measurements were done with the same radar mounted into an aircraft using synthetic aperture radar techniques. The results for shallow and steep incidence are compared and show the significant

influence of this parameter on the signature of the power line. Additionally the measurement results are compared with those from model calculations. [J1668]

"SAR interferometric phase statistics in wavelet domain"

Synthetic aperture radar (SAR) interferometry is employed to obtain topographic information. Owing to noise, interferometric information has to be filtered. The wavelet transform can be employed to filter the interferometric phase, maintaining the spatial resolution, but new signal models have to be studied in this domain for further processing [J1669]

"Estimating the effective number of looks in interferometric SAR data"

The probability density function (pdf) of the multi-look interferometric phase between two complex synthetic aperture radar (SAR) images is parameterized by the number of looks and the complex correlation coefficient. In practice, adjacent pixels in a real SAR interferogram, are statistically dependent due to filtering, and hence, the number of looks is usually smaller than the number of samples averaged. It has been shown that compensation with an effective number of looks, rather than an intractable rederivation of the pdf, can account for the statistical dependence. This paper addresses the challenge of how to determine a suitable value for the effective number of looks. It is shown that an optimum value can be found via a maximum-likelihood estimator (MLE) based on the interferometric phase pdf. However, since such an MLE is computationally intensive and numerically unstable, an estimator based on the method of moments (MoM) possessing similar fidelity is proposed. MoM is fast and robust and can be used in operational applications, such as determining constant false alarm rate (CFAR) detection thresholds for moving-target detection in SAR along-track interferometry. [J1670]

"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. [J1671]

"Phase unwrapping for large SAR interferograms: statistical segmentation and generalized network models"

Two-dimensional (2-D) phase unwrapping is a key step in the analysis of interferometric synthetic aperture radar (InSAR) data. While challenging even in the best of circumstances, this problem poses unique difficulties when the dimensions of the interferometric input data exceed the limits of one's computational capabilities. In order to deal with such cases, we propose a technique for applying the statistical-cost, network-flow phase-unwrapping algorithm (SNAPHU) of Chen and Zebker (2001) to large datasets. Specifically, we introduce a methodology whereby a large interferogram is partitioned into a set of several smaller tiles that are unwrapped individually and then divided further into independent, irregularly shaped reliable regions. These regions are subsequently assembled into a full unwrapped solution, with the phase offsets between regions computed in a secondary optimization problem whose objective is to maximize the a posteriori probability of the final solution. As this secondary problem assumes the same statistical models as employed in the initial tile-unwrapping stage, the technique results in a solution that approximates the solution that would have been obtained had the full-size interferogram been unwrapped as a single piece. The secondary problem is framed in terms of network-flow ideas, allowing the use of an existing nonlinear solver. Applying the algorithm to a large topographic interferogram acquired over central Alaska, we find that the technique is less prone to unwrapping artifacts than more simple tiling approaches. [J1672]

"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. [J1673]

"Classification of pixels in a noisy grayscale image of polar ice"

Often, in synthetic aperture radar (SAR) images of polar ice, one encounters shadow-like features across the images. Such features make it difficult to classify pixels into ice and water. Accordingly, it becomes a challenge to determine the true size and boundaries of ice floes in an SAR image of polar ice. We develop a simple statistical procedure which classifies pixels of an image by eliminating the effects of shadow-like features. Methodology developed in this paper is illustrated using some noisy SAR images of ice floes in the Arctic sea. [J1674]

"A canonical problem in electromagnetic backscattering from buildings"

In this paper, a geometric and electromagnetic model of a typical element of urban structure is presented, in order to analytically evaluate in closed form its electromagnetic return to an active microwave sensor. This model can be used to understand what information on geometric and dielectric properties of a building can be extracted from microwave remote sensing data. The geometrical model consists of a rectangular parallelepiped whose vertical walls form a generic angle with respect to the sensor line of flight. The parallelepiped is placed on a rough surface. The radar return from such a structure can be decomposed into single-scattering contributions from the (rough) ground, the building roof (a plane surface in our model), and vertical walls and multiple scattering contributions from dihedral structures formed by vertical walls and ground. In our model, single-scattering contributions are evaluated by using either physical optics (PO) or geometrical optics (GO), depending on surface roughness. In order to account for multiple scattering between buildings and terrain, we use GO to evaluate the field reflected by the smooth wall toward the ground (first bounce) or the sensor (second or third bounce) and GO or PO (according to ground surface roughness) to evaluate the field scattered by the ground toward the wall (first or second bounce) or the sensor (second bounce). Finally, the above model is used to analyze the field backscattered from a building as a function of the main scene parameters; in particular, the angle between vertical walls and sensor line of night and the dependence on the look angle are analyzed. [J1675]

"Digital elevation map generation using VHF-band SAR data in forested areas"

The paper investigates digital elevation model (DEM) generation based on data from the ultra wideband coherent all radio band sensing (CARABAS) very high frequency (VRF)-band synthetic aperture radar (SAR). The results show excellent capability to penetrate forest areas, i.e., the generated DEMs are found to be close to the true ground height. A conventional DEM, based on stereo photography and surveying, and additional phase differential Global Positioning System (GPS) measurements have been used for comparison. The results in heavily vegetated areas (stem volume up to 600 m3/ha) show a mean height difference of less than 1.5 m and a root-mean-square (rms) error of less than 1.0 in compared to the conventional DEM. Stable backscattering properties allows us to use large baselines in order to obtain high height sensitivity. However, the amount of poor data due to low coherence increases with the increase of the baseline. The optimum baseline which balances these two effects is found to correspond to an incidence angle difference of 4°-8°. [J1676]

"SAR raw signal simulation of oil slicks in ocean environments"

Synthetic aperture radar (SAR) raw signal simulation is a powerful tool for design of oil slick detection and interpretation systems. In this paper, the ocean simulation issues are presented, and the main problems relating to the oil presence on the sea surface are treated. Attention is focused on the electromagnetic side of the problem, taking account of the sensor signatures, the dielectric, physical-chemical, and geometric nature of the oil slick, and the environmental conditions. The presented SAR simulator is based on an ocean model and an oil slick model. The former makes use of multiscale description of the ocean surface: the distributed surface model for the SAR-ocean interaction is considered by taking into account the nonlinear hydrodynamic effect for the water particle movement. The latter model implements a modification of the ocean spectrum, based on the Marangoni theory and accounting for the nonlinear wave interaction mechanism. However, the proposed SAR raw signal simulator is modular and flexible, thus allowing other possible physical models for modeling the oil slick effect over the ocean spectrum. Meaningful SAR simulation experiments are presented and discussed, elucidating the role of difference on pollutants, oil thickness, wind speed and direction, incident wavelength and angle and other radar parameters. Validation of the simulator is also presented by comparison with experimental data. A striking conclusion of the paper is that higher order moments (from the second on) of oil slick SAR image statistics are quite different compared to those pertinent to an equivalent wind speed decrease on the imaged area. This suggests a convenient way to define new appropriate oil slick signatures. [J1677]

"Nonuniform azimuth image shift observed in the Radarsat images of ships in motion"

This paper describes, for the first time to the authors' knowledge, the phenomenon of nonuniform azimuth image shift of a rigid body observed in the Radarsat synthetic aperture radar (SAR) images of cruising ships. The effect is caused by the different slant-range velocities of coherent scatterers across the hull associated with the ship motions. The slant-range velocity is estimated from the SAR image of an identified ship, and it is compared with that computed from a numerical model using the ship's specification and meteorological data. The result indicates that the dominant contribution to the nonuniform image shift is the pitching motion of the ship. Further comparison is made with the wave orbital velocity, and the results are shown to be in good agreement. Comparisons are also made between the SAR-derived slant-range velocities of two unknown ships and wave orbital velocities, and reasonable agreement is obtained. One of the ships' images exhibits not only nonuniform shift but also image skew. The latter skewing effect may be caused by rolling of the ship. [J1678]

"Forest variable estimation from fusion of SAR and multispectral optical data"

Radar and optical remote sensing data are used in a unified algorithm to estimate forest variables. The study site is the H. J. Andrews experimental forest in Oregon, which has significant topography and several mature and old-growth conifer stands with biomass values sometimes exceeding 1000 tons/ha. Polarimetric multifrequency Airborne Synthetic Aperture Radar (AIRSAR) backscatter, interferometric C-band Topographic Synthetic Aperture Radar (TOPSAR) coherence, and multispectral Landsat Thematic Mapper (TM) digital numbers are used in a regression analysis that relates them to forest variable measurements on the ground. Parametric expressions are derived and used to estimate the same variables(s) at other locations from the combination of AIRSAR and TM data. It is shown that the estimation accuracy is significantly improved when the radar and optical data are used in combination compared to estimating the same variable from a single data type alone. [J1679]

"Detection of storm-damaged forested areas using airborne CARABAS-II VHF SAR image data"

Strong winds cause severe damage worldwide to forested land every year. The devastating storms that struck large parts of Europe in late 1999 destroyed the equivalent of several years of normal forest harvesting, amounting to very large economical sums. Therefore, rapid mapping of damaged areas is of major importance for assessment of short-term actions as well as for long-term reforestation purposes. In this paper, the use of airborne CARABAS-II very high frequency (VHF) (20-90 MHz) synthetic aperture radar (SAR) imagery for high spatial resolution mapping of wind-thrown forests has been investigated and evaluated. The investigation was performed at a test site located in southern Sweden and dominated by Norway spruce forests. A regression model estimating radar backscattering amplitude prior to the storm was developed. The estimated amplitudes were compared to measured amplitudes after the storm. The results clearly show that the backscattering amplitude, at a given stem volume, is considerably higher for wind-thrown forests than for unaffected forests. Furthermore, the backscattering from fully harvested storm-damaged areas was, as expected, significantly lower than from unaffected stands. These findings imply that VHF SAR imagery has potential for mapping wind-thrown forests. However, to prevent ambiguities in increased backscattering caused by normal stem volume growth or wind-fellings, multitemporal change detection techniques using VHF SAR images acquired prior to and after wind-fellings would be preferable. [J1680]

"Mapping performance of curved-path SAR"

Synthetic aperture radar (SAR) mapping is usually performed along a straight path. Curved paths away from the target area will increase the mapping rate significantly. Drawbacks are more complex signal processing and decreased azimuth resolution due to the reduced dwell time. In this paper, curved SAR mapping is analyzed in more detail, including squinted beam geometry. Relationships are derived how the SAR resolution and mapping rate are influenced by the curved SAR path. The nonlinear phase error, which defocuses the SAR image, is more accentuated than for straight-line SAR, in particular at squinted observation angles. Simulation examples show how the nonlinear phase error depends on side acceleration and mapping geometry after scene center motion compensation. [J1681]

"Noniterative techniques for GPR imaging through a nonplanar air-ground interface"

It is often advantageous to acquire pulse-echo ground-penetrating radar (GPR) measurements from antennas that are offset from the air-ground interface by a nonnegligible distance, either because the ground's surface is rough, or because measurements must be collected remotely. This paper describes the effects of incorrectly estimating the location of the air-ground interface on GPR images created with the plane-to-plane backpropagation (PPB) method. To compensate for a nonplanar air-ground interface, the wideband time-domain synthetic aperture method is reviewed and reformulated, using Snell's law of refraction, to account for measurements taken some distance above an undulating interface. A modification of the PPB algorithm that accounts for a nonplanar interface is also formulated, and examples of imaging with both methods are given to validate, the algorithms' performance for surface variations that are relatively smooth with respect to the radar waveform wavelengths. Additionally, a method for inferring the surface topography from the radar returns is described. Finally, the modified PPB is demonstrated by imaging buried targets sensed in field-acquired data. [J1682]

"SAR speckle reduction using wavelet denoising and Markov random field modeling"

The granular appearance of speckle noise in synthetic aperture radar (SAR) imagery makes it very difficult to visually and automatically interpret SAR data. Therefore, speckle reduction is a prerequisite for many SAR image processing tasks. In this paper, we develop a speckle reduction algorithm by fusing the wavelet Bayesian denoising technique with Markov-random-field-based image regularization. Wavelet coefficients are modeled independently and identically by a two-state Gaussian mixture model, while their spatial dependence is characterized by a Markov random field imposed on the hidden state of Gaussian mixtures. The Expectation-Maximization algorithm is used to estimate hyperparameters and specify the mixture model, and the iterated-conditional-modes method is implemented to optimize the state configuration. The noise-free wavelet coefficients are finally estimated by a shrinkage function based on local weighted averaging of the Bayesian estimator. Experimental results show that the proposed method outperforms standard wavelet denoising techniques in terms of the signal-to-noise ratio and the equivalent-number-of-looks measures in most cases. It also achieves better performance than the refined Lee filter. [J1683]

"Observation of hurricane-generated ocean swell refraction at the Gulf Stream north wall with the RADARSAT-1 synthetic aperture radar"

We analyze the refraction of long oceanic waves at the Gulf Stream's north wall off the Florida coast as observed in imagery obtained from the RADARSAT-1 synthetic aperture radar (SAR) during the passage of Hurricane Bonnie on August 25, 1998. The wave spectra are derived from RADARSAT-1 SAR images from both inside and outside the Gulf Stream. From the image spectra, we can determine both the long wave's dominant wavelength and its propagation direction with 180° ambiguity. We find that the wavelength of hurricane-generated ocean waves can exceed 200 m. The calculated dominant wavelength from the SAR image spectra agree very well with in situ measurements made by National Oceanic and Atmospheric Administration National Data Buoy Center buoys. Since the waves mainly propagate toward the continental shelf from the open ocean, we can eliminate the wave propagation ambiguity. We also discuss the velocity-bunching mechanism. We find that in this very long wave case, the RADARSAT-1 SAR wave spectra should not be appreciably affected by the azimuth falloff, and we find that the ocean swell measurements can be considered reliable. We observe that the oceanic long waves change their propagation directions as they leave the Gulf Stream current. A wave-current interaction model is used to simulate the wave refraction at the Gulf Stream boundary. In addition, the wave shoaling effect is discussed. We find that wave refraction is the dominant mechanism at the Gulf Stream boundary for these very long ocean swells, while wave reflection is not a dominant factor. We extract 256-by-256 pixel full-resolution subimages from the SAR image on both sides of the Gulf Stream boundary, and then derive the wave spectra. The SAR-observed swell refraction angles at the Gulf Stream north wall agree reasonably well with those calculated by the wave-current interaction model. [J1684]

"Digital false-target image synthesiser for countering ISAR"

The paper presents the design of a pipelined, all-digital image synthesiser capable of generating false-target images from a series of intercepted inverse synthetic aperture radar (ISAR) chirp pulses to provide a novel RF imaging decoy capability. The image synthesiser modulates the phase samples from a phase-sampling digital RF memory (DRFM) that stores intercepted ISAR pulses. The synthesiser contains a parallel array of (identical) complex digital modulators with one modulator for each false-target range bin. The binary phase samples from each intercepted ISAR pulse are applied one at a time to the modulator array. To synthesise the image, each modulator requires a set of phase and gain coefficients that are derived from the range-Doppler description of the false-target to be synthesised. An ISAR image compression algorithm is presented to reconstruct the image using the synthesiser output pulses. A ship with 32 range bins is presented as an example of a false-target input, and simulations are used to quantify the image synthesis capability of the architecture. The image quality as a function of the number of ISAR pulses integrated is also numerically evaluated. The programmable design permits real-time alteration of modulation coefficients, allowing rapid and adaptive shifting among different types of targets offering a low-cost decoy capability using readily available DRFM technology. [J1685]

"Validation of SAR interferometric phase corrections in the squinted case for DEM quality enhancement"

The focus of this report is synthetic aperture radar (SAR) interferometric techniques for mapping applications, in the presence of possible high squint values. Theoretical and experimental analysis show the presence of limitations that are overcome by the proposed phase corrections. [J1686]

"A multiple-cascade-classifier system for a robust and partially unsupervised updating of land-cover maps"

A system for a regular updating of land-cover maps is proposed that is based on the use of multitemporal remote sensing images. Such a system is able to address the updating problem under the realistic but critical constraint that, for the image to be classified (i.e., the most recent of the considered multitemporal dataset) no ground truth information is available. The system is composed of an ensemble of partially unsupervised classifiers integrated in a multiple-classifier architecture. Each classifier of the ensemble exhibits the following novel characteristics: (1) it is developed in the framework of the cascade-classification approach to exploit the temporal correlation existing between images acquired at different times in the considered area; and (2) it is based on a partially unsupervised methodology capable of accomplishing the classification process under the aforementioned critical constraint. Both a parametric maximum-likelihood (ML) classification approach and a nonparametric radial basis function (RBF) neural-network classification approach are used as basic methods for the development of partially unsupervised cascade classifiers. In addition, in order to generate an effective ensemble of classification algorithms, hybrid ML and RBF neural-network cascade classifiers are defined by exploiting the characteristics of the cascade-classification methodology. The results yielded by the different classifiers are combined by using standard unsupervised combination strategies. This allows the definition of a robust and accurate partially unsupervised classification system capable of analyzing a wide typology of remote sensing data (e.g., images acquired by passive sensors, synthetic aperture radar images, and multisensor and multisource data). Experimental results obtained on a real multitemporal and multisource dataset confirm the effectiveness of the proposed system. [J1687]

"Parametric analysis of slot-loaded trapezoidal patch antennas"

Slot-loaded trapezoidal patch antennas are analyzed in order to achieve a multifrequency operation. A moment method formulation based on new analytical entire domain basis functions is developed and compared to the one involving the Rao-Wilton-Glisson (1982) RWG triangular discretization. The numerical results obtained through the new efficient implemented code are compared to the measurements showing a good agreement. A parametric analysis of such antennas is also presented leading to useful design graphs showing the main antenna properties (resonance frequencies, cross-polarization levels, matching, etc.) as a function of the patch geometrical dimensions, symmetric collocation of the slots on the patch, and slot dimensions. [J1688]

"Speckle reducing anisotropic diffusion"

This paper provides the derivation of speckle reducing anisotropic diffusion (SRAD), a diffusion method tailored to ultrasonic and radar imaging applications. SRAD is the edge-sensitive diffusion for speckled images, in the same way that conventional anisotropic diffusion is the edge-sensitive diffusion for images corrupted with additive noise. We first show that the Lee and Frost filters can be cast as partial differential equations, and then we derive SRAD by allowing edge-sensitive anisotropic diffusion within this context. Just as the Lee (1980, 1981,

1986) and Frost (1982) filters utilize the coefficient of variation in adaptive filtering, SRAD exploits the instantaneous coefficient of variation, which is shown to be a function of the local gradient magnitude and Laplacian operators. We validate the new algorithm using both synthetic and real linear scan ultrasonic imagery of the carotid artery. We also demonstrate the algorithm performance with real SAR data. The performance measures obtained by means of computer simulation of carotid artery images are compared with three existing speckle reduction schemes. In the presence of speckle noise, speckle reducing anisotropic diffusion excels over the traditional speckle removal filters and over the conventional anisotropic diffusion method in terms of mean preservation, variance reduction, and edge localization. [J1689]

"Multi-model SAR image despeckling"

A multi-model despeckling approach for SAR image is presented. The chi-squared test is used to segment the image into homogeneous and heterogeneous regions. Then, the heterogeneous regions are separated into subregions, each of which consists of the points with same edge orientations. Homogeneous regions and the separated subregions are despeckled according to their characteristics. Experimental results are reported. [J1690]

"Terrain mapping by ground-based interferometric radar"

The authors propose a ground-based interferometric synthetic aperture radar (SAR) technique for terrain mapping. It is based on a coherent continuous-wave step-frequency (CW-SF) radar moved along a linear horizontal rail. It works synthesising microwave holographic images taken from different points of view to obtain elevation maps by phase comparison. The focusing algorithm for imaging synthetic holograms and digital elevation models (DEM) is able to correct topographic distortion and phase wrap through an iterative multi-baseline procedure [J1691]

"Detection of urban structures in SAR images by robust fuzzy clustering algorithms: the example of street tracking"

The authors present a fuzzy approach to the analysis of airborne synthetic aperture radar (SAR) images of urban environments. In particular, they want to show how to implement structure extraction algorithms based on fuzzy clustering unsupervised approaches. To this aim, the idea is to segment first the sensed data and recognize very basic urban classes (vegetation, roads, and built areas). Then, from these classes, we extract structures and infrastructures of interest. The initial clustering step is obtained by means of fuzzy logic concepts and the successive analyses are able to exploit the corresponding fuzzy partition. As a possible complete procedure for urban SAR images, they focus on the street tracking and extraction problem. Three road extraction algorithms available in literature (namely, the connectivity weighted Hough transform (CWHT), the rotation Hough transform, and the shortest path extraction) have been modified to be consistent with the previously computed fuzzy clustering results. Their different capabilities are applied for the characterization of streets with different width and shape. The whole approach is validated by the analysis of AIRSAR images of Los Angeles, CA [J1692]

"InSAR for estimation of changes in snow water equivalent of dry snow"

This paper describes the theoretical relation between interferometric phase and changes in snow water equivalent (SWE) and show results from experiments using ERS-S tandem data. The main scattering contribution from a dry snow cover is from the snow-ground interface. However, the radar wave will be refracted in the snow. Thus, only small changes in the snow properties between two interferometric synthetic aperture radar (SAR) images will change the interferometric phase. This phase change is shown to introduce a significantly increase in the digital elevation model (DEM) height error, although no effects are observed on the degree of coherence. The phase change is also shown to affect the differential interferometric results and may wrongly be interpreted as range displacement. The presented theory and results implies that light snowfall and/or small changes in snow properties between interferometric SAR (InSAR) image acquisitions, may introduce significant height errors in DEM derived from glaciers, ice sheets, or bare ground, even in the case of high degree of coherence. Thus, meteorological observations in addition to degree of coherence must be considered when generating DEM in areas covered with snow or where snow fall is likely to have occurred [J1693]

"Focused synthetic aperture radar processing of ice-sounder data collected over the Greenland ice sheet"

The authors developed a synthetic aperture radar (SAR) processing algorithm for airborne/spaceborne ice-sounding radar systems and applied it to data collected in Greenland. By using focused SAR (phase-corrected coherent averaging), they improved along-track resolution by a factor of four and provided a 6-dB processing

gain over unfocused SAR (coherent averaging without phase correction) based on a point-target analysis for a Greenland ice-sounding data set. Also, They demonstrated that the focused-SAR processing reduced clutter and enabled them to identify bedrock-interface returns buried in clutter. Using focused-SAR technique, they processed data collected over a key 360-km-long portion of the 2000-m contour line of southwest Greenland. To the best of their knowledge, these are the first high-quality radar ice thickness measurements over this key location. Moreover, these ice-thickness measurements have been used for improving mass-balance estimates of the Greenland ice sheet [J1694]

"Global snow cover monitoring with spaceborne Ku -band scatterometer"

This paper presents a study to demonstrate the potential of a spaceborne Ku-band scatterometer to monitor global snow cover. Global Ku-band data were acquired by the NASA Scatterometer (NSCAT) operated on the Advanced Earth Observing Satellite (ADEOS) from September 1996 to June 1997. NSCAT backscatter patterns aver the northern hemisphere reveals boundaries between different snow classes, defined by the Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH, snow classification system at different times of the snow season. They show the evolution of the backscatter signature throughout the entire seasonal snow cycle. Within the snow extent determined by the National Oceanic and Atmospheric Administration (NOAA), Washington, DC, and Climate Prediction Center (CPC), operational snow product, Ku-band backscatter data expose detailed features and rapid changes as observed in in-situ snow depth data from surface weather stations in U.S., Canada, and Russia. Sensitivity of Ku-band backscatter to snow conditions is illustrated with the dramatic change over the U.S. northern plains and the Canadian prairie region corresponding to the snow event leading to the 1997 Flood of the Century. They discuss snow field experiments and data analysis plan to understand snow scattering mechanisms, to interpret snow backscatter, and to derive its relationship with snow physical parameters [J1695]

"Modeling the backscatter response due to salt crust development"

The ERS-1 synthetic aperture radar (SAR) is shown to be highly sensitive to temporal variations in the mineral surface of the Chott el Djerid playa, Tunisia. Field measurements and modeling results confirm that the primary control on the backscatter response is due to salt crust development. Brine-rich moisture exerts a secondary control. The effect of temperature, salinity, and mineralogy are negligible. An integral equation model (IEM) solution with mean parameters accurately represents the observed behavior [J1696]

"High-resolution autofocus techniques for SAR imaging based on fractional lower-order statistics"

The authors address the autofocusing problem in synthetic aperture radar imagery by introducing techniques that achieve robust image formation in the presence of severe heavy-tailed clutter and noise. Current state-of-the-art methods are extended, which are based on second-order moment theory, by employing fractional lower-order statistics (FLOS) of the phase-history data. The introduced FLOS-based methods perform a nonlinear transformation of the radar measurements, can mitigate the effects of impulsive additive clutter, and include the conventional algorithms as special cases. The benefits of the proposed approach are quantified by means of simulations, and the new FLOS-based methods are compared to current state-of-the-art processing with real synthetic aperture radar imagery data [J1697]

"Unsupervised classification of multifrequency and fully polarimetric SAR images based on the H/A/Alpha-Wishart classifier"

Introduces a new classification scheme for dual frequency polarimetric SAR data sets. A (6Ч6) polarimetric coherency matrix is defined to simultaneously take into account the full polarimetric information from both images. This matrix is composed of the two coherency matrices and their cross-correlation. A decomposition theorem is applied to both images to obtain 64 initial clusters based on their scattering characteristics. The data sets are then classified by an iterative algorithm based on a complex Wishart density function of the 6Ч6 matrix. A class number reduction technique is then applied on the 64 resulting clusters to improve the efficiency of the interpretation and representation of each class. An alternative technique is also proposed which introduces the polarimetric cross-correlation information to refine the results of classification to a small number of clusters using the conditional probability of the cross-correlation matrix. These classification schemes are applied to full polarimetric P, L, and C-band SAR images of the Nezer Forest, France, acquired by the NASA/JPL AIRSAR sensor in 1989 [J1698]

"Reduced bandwidth algorithm for near field imaging of tree targets using synthetic aperture radar"

An imaging algorithm which can generate high resolution near-field synthetic aperture radar images is presented. The algorithm requires only a small fractional bandwidth and is not computationally intensive. Images are

produced in a format familiar to the human visual system and provide a more complete characterisation of the polarimetric scattering distribution of a target. A new derivation of the algorithm is presented and its characteristics and limitations are described and formulated. The focusing process is validated by simulations and practical measurements on test targets. Sidelobe reduction is carried out by application of the SVA filtering algorithm. Finally, the technique is applied to the imaging of a small larch tree and the images presented clearly demonstrate the dependency of the target response on the system polarisation [J1699]

"Air and spaceborne radar systems an introduction [JBook Review]"

First Page of the Article [J1700]

"Quantitative comparison of classification capability: fully polarimetric versus dual and single-polarization SAR"

Addresses the land-use classification capabilities of fully polarimetric synthetic aperture radar (SAR) versus dual-polarization and single-polarization SAR for P-, L-, and C-band frequencies. A variety of polarization combinations are investigated for application to crop and tree age classification. Based on the complex Wishart distribution for the covariance matrix, maximum likelihood classifiers for all polarization combinations are used to assess quantitative classification accuracy. Thus, this allows optimally selecting the frequency and the combination of polarizations for various applications [J1701]

"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 [J1702]

"Detecting moving targets in SAR imagery by focusing"

A new method for detecting moving targets in a synthetic aperture radar (SAR) image is presented. It involves segmenting a complex-valued SAR image into patches, focusing each patch separately, and measuring the sharpness increase in the focused patch. The algorithm is sensitive to azimuth velocities and is exquisitely sensitive to radial accelerations of the target, allowing it to detect motion in any direction. It is complementary to conventional Doppler-sensing moving target indicators, which can sense only the radial velocity of rapidly moving targets. [J1703]

"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 [J1704]

"Sea surface imaging with an across-track interferometric synthetic aperture radar: the SINEWAVE experiment"

An across track interferometric synthetic aperture radar (InSAR) is used to image ocean waves. Across track InSAR data were acquired during the SAR INnterferometry Experiment for validation of ocean Wave imaging models (SINEWAVE) in the North Sea using an airborne X-band radar with horizontal polarization. A wind sea system was imaged at different flight levels and with different flight directions with respect to the ocean wave propagation direction. Simultaneously, ocean wave spectra were measured by a directional wave rider buoy. Thus, the experiment data comprises synthetic aperture radar (SAR) intensity, coherence, and phase images together with in situ measurements. As shown in a recent theoretical study by Schulz-Stellenfleth and Lehner (2001), across track InSAR provides distorted (bunched) digital elevation models (DEMs) of the sea surface.

Using SINEWAVE data the DEM bunching mechanism is verified with in situ ocean wave measurements available for the first time. It is shown that significant waveheight as well as one-dimensional (1D) wavenumber spectra derived from bunched DEMs and buoy data are in good agreement for small nonlinearities. Peak wave directions and peak wavelength detected in bunched DEMs and SAR intensity images are compared with the buoy spectrum. Peak rotations of up to 30° with respect to the buoy spectrum are found depending on flight direction and flight level. Two-dimensional (2D) spectra of bunched DEMs, corresponding coherency maps, and SAR intensity images are intercompared. The signal-to-noise ratio (SNR) of bunched DEM spectra is shown to be about 5 to 10 dB higher than the SNR of SAR intensity image spectra [J1705]

"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 [J1706]

"Predicting an upper bound on SAR ATR performance"

We present a method for predicting a tight upper bound on performance of a vote-based approach for automatic target recognition (ATR) in synthetic aperture radar (SAR) images. In such an approach, each model target is represented by a set of SAR views, and both model and data views are represented by locations of scattering centers. The proposed method considers data distortion factors such as uncertainty, occlusion, and clutter, as well as model factors such as structural similarity. Firstly, we calculate a measure of the similarity between a given model view and each view in the model set, as a function of the relative transformation between them. Secondly we select a subset of possible erroneous hypotheses that correspond to peaks in similarity functions obtained in the first step. Thirdly, we determine an upper bound on the probability of correct recognition by computing the probability that every selected hypothesis gets less votes than those for the model view under consideration. The proposed method is validated using MSTAR public SAR data, which are obtained under different depression angles, configurations, and articulations [J1707]

"Dual polarization stacked microstrip patch antenna array with very low cross-polarization"

This paper describes the development and performance of a wideband dual linear polarization microstrip antenna array used in the Danish high-resolution airborne multifrequency polarimetric synthetic aperture radar, EMISAR. The antenna was designed for an operating frequency of 1.25 GHz±50 MHz and was built as an array of 8Ч2 probe-fed stacked microstrip patches. The feeding network is constructed in microstrip and is capable of handling 6 kW of peak input-power at an altitude of 45000 ft (unpressurized). The impedance bandwidth (return loss better than -14 dB) of the antenna is 10%, the isolation between the horizontal and the vertical ports of the array is 50 dB and the cross-polarization suppression is 40 dB. A new design principle for simultaneously achieving very low cross-polarization and low side lobes in dual linear polarization antenna arrays has been applied [J1708]

"Extension of the 3-D range migration algorithm to cylindrical and spherical scanning geometries"

A near field three-dimensional (3-D) synthetic-aperture radar (SAR) algorithm specially tailored for cylindrical and spherical scanning geometries is presented. An imaging system with 3-D capability can be implemented by using a stepped-frequency radar which synthesizes a two-dimensional (2-D) aperture. Typical scanning geometries commonly used are planar, cylindrical, and spherical. The 3-D range migration algorithm (RMA) can be readily used with a planar scanning geometry. This algorithm is extremely accurate, preserves the phase, and corrects for the wavefront curvature. The RMA cannot be directly applied with nonplanar scanning geometries. However, as an alternative solution, we propose to backpropagate the backscattered data onto a planar aperture in the vicinity of the measurement aperture and then apply the 3-D RMA. The proposed imaging

algorithm is validated both numerically and experimentally [J1709]

"Joint target tracking and classification using radar and ESM sensors"

Bayesian target classification methods using radar and electronic support measure (ESM) data are considered. A joint treatment of target tracking and target classification problems is introduced. First, a method for target classification using radar data and class-dependent kinematic models is presented. Second, a target classification method using ESM data is presented. Then, a Bayesian radar and ESM data fusion algorithm, referred to as direct identity fusion (DIF), for target classification is presented. This algorithm exploits the dependence of target state on target class via the use of class dependent kinematic models but fails to exploit the dependence of target class on target state. We then introduce a method, referred to as joint tracking and classification (JTC), for treating target tracking and classification problems jointly, by exploiting the dependence of target class on target state via flight-envelope-dependent classes and the dependence of target state on target class via class dependent kinematic models. A two-dimensional example demonstrates the relative merits of these methods. It is shown that, while the incorporation of the two-way dependence between target state and class (i.e., JTC) promises some benefits over the method that incorporates only a one-way dependence (i.e., DIF), there are severe filter implementation difficulties for the former. The results also demonstrate that the fusion of information from radar and ESM sensors via the DIF approach results in improvements over classification methods based on either of the individual sensors [J1710]

"Robust autofocus algorithm for ISAR imaging of moving targets"

A robust autofocus approach, referred to as AUTOCLEAN (AUTOfocus via CLEAN), is proposed for the motion compensation in ISAR (inverse synthetic aperture radar) imaging of moving targets. It is a parametric algorithm based on a very flexible data model which takes into account arbitrary range migration and arbitrary phase errors across the synthetic aperture that may be induced by unwanted radial motion of the target as well as propagation or system instability. AUTOCLEAN can be classified as a multiple scatterer algorithm (MSA), but it differs considerably from other existing MSAs in several aspects: (1) Dominant scatterers are selected automatically in the 2D image domain; (2) scatterers may not be well isolated or very dominant; (3) phase and RCS information from each selected scatterer are combined in an optimal way; (4) the troublesome phase unwrapping step is avoided. AUTOCLEAN is computationally efficient and involves only a sequence of FFTs. Another good feature associated with AUTOCLEAN is that its performance can be progressively improved by assuming a larger number of dominant scatterers for the target. Numerical and experimental results have shown that AUTOCLEAN is a very robust autofocus tool for ISAR imaging [J1711]

"Time-frequency approaches to ISAR imaging of maneuvering targets and their limitations"

Inverse synthetic aperture radar (ISAR) imaging of the noncooperative maneuvering target is a challenging task because of its time variant orientation and rotation velocity which cannot be measured accurately. This correspondence investigates the principles of ISAR imaging of maneuvering targets, and proposes an algorithm for application in situations where the maneuverability is not too severe and the Doppler variation of subechoes from scatterers can be approximated as a first-order polynomial. The imaging results obtained by using real data show the effectiveness of the new method [J1712]

"Single-baseline polarimetric SAR interferometry"

Examines the application of single-baseline polarimetric SAR interferometry to the remote sensing and measurement of structure over forested terrain. For this, a polarimetric coherent scattering model for vegetation cover suitable for the estimation of forest parameters from interferometric observables is introduced, discussed and validated. Based on this model, an inversion algorithm which allows the estimation of forest parameters such as tree height, average extinction, and underlying topography from single-baseline fully polarimetric interferometric data is addressed. The performance of the inversion algorithm is demonstrated using fully polarimetric single baseline experimental data acquired by DLR's E-SAR system at L-band [J1713]

"FOPEN SAR imaging using UWB step-frequency and random noise waveforms"

The detection and identification of targets obscured by foliage have been topics of great interest. Several synthetic aperture radar (SAR) experiments have demonstrated promising images of terrain and man-made objects obscured by dense foliage, by using either linear frequency modulation (LFM) or step-frequency waveforms. We present here the methodology and results of a comparative study on foliage penetration (FOPEN) SAR imaging using ultrawideband (UWB) step-frequency and random noise waveforms. A statistical-physical foliage transmission model is developed for simulation applications. The foliage obscuring pattern is analyzed by means of the technique of paired echoes. The results of the comparative study demonstrates the

ability of a UHF band UWB random noise radar to be used as a FOPEN SAR. Advantages of the random noise radar system include covert detection and immunity to radio frequency interference (RFI) [J1714]

"High-resolution SAR imaging with angular diversity"

We propose to use the APES (amplitude and phase estimation) approach for the spectral estimation of gapped data and synthetic aperture radar (SAR) imaging with angular diversity. A relaxation-based algorithm, referred to as GAPES (Gapped-data APES), is proposed, which includes estimating the spectrum via APES and filling in the gaps via a least squares (LS) fitting. For SAR imaging with angular diversity data fusion, we perform one-dimensional (1-D) windowed fast Fourier transforms (FFTs) in range, use the GAPES algorithm to interpolate the gaps in the aperture for each range, apply 1-D inverse FFTs (IFFTs) and dewindow in range, and finally apply the two-dimensional (2-D) APES algorithm to the interpolated matrix to obtain the 2-D SAR image. Numerical results are presented to demonstrate the effectiveness of the proposed algorithm [J1715]

"Superresolution HRR ATR with high definition vector imaging"

A new 1-D template-based automatic target recognition (ATR) algorithm is developed and tested on high range resolution (HRR) profiles formed from synthetic aperture radar (SAR) images of targets taken from the Moving and Stationary Target Acquisition and Recognition (MSTAR) data set. In this work, a superresolution technique known as High Definition Vector Imaging (HDVI) is applied to the HRR profiles before the profiles are passed through ATR classification. The new I-D ATR system using HDVI demonstrates significantly improved target recognition compared with previous I-D ATR systems that use conventional image processing techniques. This improvement in target recognition is quantified by improvement in probability of correct classification (PCC). More importantly, the application of HDVI to HRR profiles helps to maintain the same ATR performance with reduced radar resource requirements [J1716]

"Signal processing of wide bandwidth and wide beamwidth P-3 SAR data"

This research is concerned with multidimensional signal processing and image formation with FOliage PENetrating (FOPEN) airborne radar data which were collected by a Navy P-3 ultra wideband (UWB) radar in 1995. The digital signal processors that were developed for the P-3 data commonly used a radar beamwidth angle that was limited to 35 deg. Provided that the P-3 radar beamwidth angle (after slow-time FIR filtering and 6:1 decimation) was 35 deg, the P-3 signal aperture radar (SAR) system would approximately yield alias-free data in the slow-time Doppler domain. We provide an analysis here of the slow-time Doppler properties of the P-3 SAR system. This study indicates that the P-3 database possesses a 50 deg beamwidth angle within the entire [215, 730] MHz band of the P-3 radar. We show that the 50-degree beamwidth limit is imposed by the radar (radial) range swath gate; a larger beamwidth measurements would be possible with a larger range swath gate. The 50-degree beamwidth of the P-3 system results in slow-time Doppler aliasing within the frequency band of [444, 730] MHz. We outline a slow-time processing of the P-3 data to minimize the Doppler aliasing. The images which are formed via this method are shown to be superior in quality to the images which are formed via the conventional P-3 processor. In the presentation, we also introduce a method for converting the P-3 deramped (range-compressed) data into its alias-free baseband echoed data; the utility of this conversion for suppressing radio frequency interference signals is shown [J1717]

"Multiple moving target feature extraction for airborne HRR radar"

This study considers the clutter suppression and feature extraction of multiple moving targets for airborne high range resolution (HRR) phased array radar. To avoid the range migration problems that occur in the HRR radar data, we divide each HRR profile into nonoverlapping low range resolution segments. No information is lost due to the division and hence no loss of resolution occurs. We show how to use a vector auto-regressive filtering technique to suppress the clutter. Then a relaxation-based parameter estimation algorithm is presented for multiple moving target feature extraction. Numerical results are given to demonstrate the effectiveness of the algorithm [J1718]

"Analysis of multiplicative speckle models for template-based SAR ATR"

It has been noted that signal aperture radar (SAR) imagery of clutter exhibits Rayleigh multiplicative noise due to speckle. We use a database of MSTAR target chips to verify that the noise is multiplicative rather than additive for all regions in the chip. Then, by examining histograms corresponding to the noise residuals, we show that a Weibull distribution that is almost Rayleigh best fits the data. However, when we restrict the analysis over the target region, the log-normal and Rayleigh models fit the noise equally as well. This can be attributed to scattering mechanisms that are unstable over five degrees of aspect angle [J1719]

"New approach for hybrid strip-map/spotlight SAR data focusing"

A new algorithm is presented for processing SAR data acquired in the hybrid strip-map/spotlight SAR configuration whose acquisition mode allows the generation of microwave images with an azimuth resolution better than that obtained in the strip-map case and with an imaged area larger than that achieved in the spotlight operation. The algorithm extends the focusing capability of conventional strip-map processing techniques to the hybrid SAR data; this result is achieved by generalising a previously proposed two-step focusing technique for spotlight SAR data processing, the spotlight mode being a particular case of the more general hybrid one. The key point of the procedure is the first filtering step which implements an azimuth convolution between the raw data and a chirp signal whose rate is selected, in the generalised approach, depending on the characteristics of the hybrid acquisition mode. Following this stage, standard strip-map processing procedures can be used to implement the second processing step, leading to fully focused SAR images. The algorithm, mainly oriented to spaceborne systems, is simple and efficient and allows the design of a generalised processing code suitable for data acquired in the hybrid strip-map/spotlight SAR configuration including the strip-map and spotlight modes as special cases. Experiments carried out on simulated data clarify the rationale of the method and confirm its validity [J1720]

"Time resolved synthetic aperture terahertz impulse imaging"

Using a well characterized terahertz (THz) impulse ranging system we demonstrate broad bandwidth imaging at THz frequencies using an inverse synthetic aperture deconvolution technique. The system demonstrates millimeter and submillimeter resolutions along the cross range and range axes, respectively. The range resolution, determined by the THz pulse bandwidth is 0.12 mm, while the cross range resolution is 1.2 mm; both resolutions agree well with theoretical predictions. Through imaging of cylindrical targets we demonstrate quantitative measurement of target position in the image plane within the experimental error of 0.2 mm. Imaging of geometrically scaled complex targets is demonstrated for a 1:2400 scale model ship (1 mm=24 m)corresponding to a full scale frequency bandwidth of 83-625 MHz at a distance of 840 m. copyright 2001 American Institute of Physics. [J1721]

"Parameter estimation for the K-distribution based on [Jz log(z)]"

A new method for estimating the order parameter of a K-distribution is presented which exploits the accuracy of log-based estimators while having a computationally efficient functional form which allows rapid calculation. The estimation accuracy of this new estimator is compared with previous estimators using an analysis technique based on asymptotic expansion of the estimator moments. The new estimator is found to have comparable accuracy to the normalised log estimator while having a much simpler implementation. SAR imaging is discussed as an example [J1722]

"Iterative MMSE method and recurrent Kalman procedure for ISAR image reconstruction"

This work presents a novel approximate iterative and recurrent approach for image reconstruction from inverse synthetic aperture radar (ISAR) data. Mathematical models of the quadrature components of the ISAR signal, reflected by an object with a complex geometry, are devised. Approximation matrix functions are used to describe deterministic signals reflected by point scatterers located at nodes of the uniform grid (model) during inverse aperture synthesis. Minimum mean square error (MMSE) equations and Kalman equations are derived. To prove the validity and correctness of the developed iterative MMSE method and recurrent Kalman procedure, numerical experiments were performed. The computational results demonstrate high resolution images, unambiguous and convergent estimates of the point scatterers' intensities of a target from simulated ISAR data [J1723]

"System-level microwave design projects"

The teaching laboratory can be an invaluable component of an undergraduate electromagnetics curriculum. This goal of this article is to illustrate several simple but effective microwave-design laboratory projects, involving both system- and component-level design experiences, based upon radar and wireless communications applications. The projects highlighted include a Doppler radar, a simple synthetic aperture radar (SAR), and wireless links using amplitude and frequency-modulation schemes. Students use modern computer-aided design (CAD) tools, coupled with planar technology [J1724]

"Fusing interferometric radar and laser altimeter data to estimate surface topography and vegetation heights"

Interferometric synthetic aperture radar (INSAR) and laser altimeter (LIDAR) systems are both widely used for

mapping topography. INSAR can map extended areas but accuracies are limited over vegetated regions, primarily because the observations are not measurements of true surface topography. The measurements correspond to a height above the true surface that depends on both the sensor and the vegetation. Conversely, topography from LIDAR is very accurate, but coverage is limited to smaller regions. The authors demonstrate how these technologies can be used synergistically. First, the authors determine surface elevations and vegetation heights from dual-baseline INSAR data by inverting an INSAR scattering model. The authors then combine sparse LIDAR observations with the INSAR inversion results to improve the estimates of ground elevations and vegetation heights. This is accomplished via a multiresolution Kalman Filter that provides both the estimates and a measure of their uncertainty at each location. Combining data from the two sensors provides estimates that are more accurate than those obtained from INSAR alone yet have dense, extensive coverage, which is difficult to obtain with LIDAR. Contributions of this work include (1) combining physical modeling with multiscale estimation to accommodate nonlinear measurement-state relationships and (2) improving estimates of ground elevations and vegetation heights for remote sensing applications [J1725]

"Sub-aperture algorithm for motion compensation improvement in wide-beam SAR data processing"

The effects of strong motion errors in wide-beam azimuth synthetic aperture radar (SAR) processing are analysed and discussed, using simulated data, as well as data collected by the airborne experimental SAR system of the Deutsches Zentrum fur Luft- und Raumfahrt e.V. (DLR) (E-SAR). A new sub-aperture approach for residual motion error compensation in wide-beam azimuth processing is proposed [J1726]

"Projection pursuit classification of multiband polarimetric SAR land images"

Results are presented for an experiment utilizing a pastoral land scene with a variety of eight classes, imaged by the NRL dual band (X and L) polarimetric synthetic aperture radar (NUWSAR) at a spatial resolution of 1.2 m. Projection pursuit (PP) statistical analysis tools were applied to a set of simultaneous L-band and X-band fully polarized images (six independent channels) to demonstrate the utility of land classification at high spatial resolution from a light aircraft using SAR. The statistical confusion matrix was used as a quantitative optimization measure of classification. Samples of eight classes from a portion of the scene were used to define a training set, then PP tools were used for classification. It is clear that L-band and X-band fully polarized data view the classes in a significantly different manner, and each brings independent information to the analysis. These results are not meant to be exhaustive at this time but to demonstrate the utility of applying PP tools to multiband and polarization SAR data and to give an indication of the quality of classification one can achieve with moderately high spatial resolution SAR data using a light plane platform [J1727]

"On the retrieving of forest stem volume from VHF SAR data: observation and modeling"

Investigates the relationships between VHF data and forest biomass using data acquired by the airborne imaging radar CARABAS over two different pine plantation forests in southern France. Data are analyzed using detailed ground truth measurements available on both sites. The backscattering coefficient is strongly correlated to characteristics of the tree trunk. Signal saturation is not observed up to 900 m3/ha. However, the sensitivity to the volume is high in the range of 0-500 m3/ha (e.g. 1 to 1.5 dB for 50 m3/ha), whereas it is reduced beyond 500 m3/ha (<0.5 dB for 50 m3/ha). The experimental analysis is supported by theoretical modeling using a coherent backscatter model based on the distorted Born approximation coupled with a tree growth model giving a fine and precise description of the trees at both sites. The modeling results show that the trunk is the main scatterer, but that, when the branch dimensions are not insignificant compared to trunk dimension, branch scattering needs to be accounted for. However, since the two species under study are both coniferous, branch dimensions are relatively small compared to trunk dimension. This explains no significant differences observed in the backscatter behavior between both sites, except for mature stands with low stem density. Finally, the effect of topography is investigated both experimentally, using a digital elevation model, and theoretically with the coherent model. The loss of sensitivity to stem volume due to slope is clearly demonstrated and explained by the decrease of the dihedral trunk-ground interaction as the slope increases [J1728]

"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 [J1729]

"High-resolution ISAR imaging of maneuvering targets by means of the range instantaneous Doppler technique: modeling and performance analysis"

Very high resolution inverse synthetic aperture radar (ISAR) imaging of maneuvering targets is a complicated task. In fact, the conventional range Doppler (RD) ISAR technique does not work properly when target motions generate terms higher than the first order in the phase of the received signal relative to each scatterer. This effect typically happens when at least one of these situations occur: (1) very high resolution images are required; (2) the target maneuvers; and (3) the target undergoes significant angular motions (roll, pitch, and yaw). A novel ISAR technique, named range instantaneous Doppler (RID), has been proposed for the reconstruction of very high resolution images of maneuvering targets. In this paper, we analytically show that the RID technique works properly when high-resolution ISAR images are required of maneuvering and/or rolling, pitching, and yawing targets; we also quantify the performance improvement of the RID technique with respect to the RD technique. The problem is tackled from an analytical point of view. First, we define a new model of the ISAR received signal that is valid for maneuvering targets, then we derive and compare the analytical expression of the point spread function (PSF) for the two techniques. Furthermore, we perform a statistical analysis to evaluate the improvement of the RID technique versus the RD technique in terms of spatial resolution. Finally, we prove the effectiveness of the RID technique by simulating the imaging process for two different targets: (1) a ship that undergoes roll, pitch and yaw motions and (2) a fast maneuvering airplane [J1730]

"Seasonal and short-term variability of multifrequency, polarimetric radar backscatter of Alpine terrain from SIR-C/X-SAR and AIRSAR data"

Signatures of glaciated and ice free areas were analyzed from polarimetric SAR data at C-, L-, and P-band and single polarization X-band data. The data base includes an AIRSAR scene from June 25, 1991, and SIR-C/X-SAR images from April and October 1994 (SRL-1 and SRL-2), acquired over the high Alpine test site Цtztal in Austria. The environmental conditions were different at the time of the three experiments. Ground measurements, meteorological observations, and backscattering modeling are the basis for interpreting the backscattering signatures. Seasonal differences are due mainly to the presence or absence of snow and due to changes of its properties. Short term variations of snow conditions can be monitored at C- and X-band. For unglaciated areas, the surface roughness has a dominant influence on backscattering in all seasons. The dependence of the mean backscattering and correlation coefficients on the incidence angle was analyzed. Spectral and depolarization ratios and the magnitude of the HHVV correlation coefficient were selected as components of the multidimensional feature vector for studying the target separability. Good separability was found between the accumulation and ablation areas on the glaciers, whereas on ice-free areas, the dominance of surface roughness limits the discrimination of different surface types. Short-term variations of backscattering have significant impact for the classification of accumulation and ablation areas on glaciers, as verified by comparisons with field data [J1731]

"A joint multicontext and multiscale approach to Bayesian image segmentation"

In this paper, a joint multicontext and multiscale (JMCMS) approach to Bayesian image segmentation is proposed. In addition to the multiscale framework, the JMCMS applies multiple context models to jointly use their distinct advantages, and we use a heuristic multistage, problem-solving technique to estimate sequential maximum a posteriori of the JMCMS. The segmentation results on both synthetic mosaics and remotely sensed images show that the proposed JMCMS improves the classification accuracy, and in particular, boundary localization and detection over the methods using a single context at comparable computational complexity [J1732]

"Forestry parameter retrieval from texture in CARABAS VHF-band SAR images"

Methods for retrieval of the stem volume, dominant tree height, and dominant tree diameter values using CARABAS images are presented. Both intensity and its texture can be used, but texture detects sparse, low stem volume forests overlooked by the intensity. The texture parameters used are the zero and first-order constants of the log-log regression of the standard deviation of the intensity and the distance over which it is determined. The accuracy of the stem volume estimates is of the order of the ground truth. The dominant diameter and height values are less accurate [J1733]

"Comparison of SAR-derived wind speed with model predictions and ocean buoy measurements"

As part of the Alaska synthetic aperture radar (SAR) Demonstration Project in 1999 and 2000, wide-swath RADARSAT SAR imagery has been acquired on a regular basis in the Gulf of Alaska and the Bering Sea. During 1998 and 1999, similar data were acquired off the East Coast of the United States as part of the StormWatch Project. The radar cross section measurements from these images were combined with wind direction estimates from the Navy Operational Global Atmospheric Prediction System model to produce high-resolution maps of the surface wind speed. For this study, 2862 SAR image frames were collected and examined. Averaged wind estimates from this data base have been systematically compared with corresponding wind speed estimates from buoy measurements and model predictions, and very good agreement has been found. The standard deviation between the buoy wind speed and the SAR estimates is 1.76 m/s. Details of the SAR wind extraction procedure are discussed, along with implications of the comparisons on the C-band polarization ratio [J1734]

"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 [J1735]

"Vector probability diffusion"

The basic motivation of this work is to introduce contextual information into image segmentation tasks by adding spatial coherence to the posterior probabilities corresponding to the classes present in the scene. A method for isotropic and anisotropic diffusion of vector probabilities in general, and posterior probabilities in particular, is introduced. The technique is based on diffusing via coupled partial differential equations restricted to the semi-hyperplane corresponding to probability functions. Both the partial differential equations and their corresponding numerical implementation guarantee that the vector remains a probability vector, having all its components positive and adding to one. Applying the method to posterior probabilities in classification problems, spatial and contextual coherence is introduced before the maximum a posteriori (MAP) decision, thereby improving the classification results [J1736]

"Observation of tropical rain forest trees by airborne high-resolution interferometric radar"

The Indonesian Radar Experiment (INDREX) Campaign was executed in Indonesia to study the potential of high-resolution interferometric airborne radar in support of sustainable tropical forest management. Severe cloud cover limits the use of aerial photography, which is currently applied on a routine basis to extract information at the tree level. Interferometric radar images may be a viable alternative once radar imaging at the tree level is sufficiently understood. It is shown that interferometric height images can contain large height and displacement errors for individual trees but that this problem can be solved to a large extent using models for the vertical distribution of backscatter intensity and an extension of the Van Cittert-Zernike theorem. The predicted loss of coherence in lay-over regions of emergent trees is shown to be in good agreement with the loss of coherence as observed in the high resolution radar data (Pierson correlation coefficient=0.94). Several correction methods for height and displacement errors are proposed. It is shown that a simple approach already gives a good correction. Semi-empirical correction models, which can be calibrated for forest structure, perform even better

[J1737]

"Extraction of moving ground targets by a bistatic ultra-wideband SAR"

The use of a bistatic antenna configuration for ground moving target indication in an ultra-wideband and widebeam synthetic aperture radar system is discussed. To suppress the strong clutter signal the radar channels have a strict requirement on equality. In a bistatic system they are not equal, and the author investigates how to compensate for the bistatic configuration. Bistatic effects on clutter scattering cannot be compensated, and an attempt is therefore made to estimate the bistatic scattering influence of the ground moving target indication. The bistatic to monostatic synthetic aperture inversion in a wide antenna beam is derived in both the time and the frequency domain. The mismatch between the radar channels will cause clutter leakage. The pulse compressed impulse response leakage is determined both for the time and frequency domains [J1738]

"Tomographic imaging of isolated ground surfaces using radio ground waves and conjugate gradient methods"

The ground surface of the Earth is usually mapped using microwave radar, and in particular synthetic aperture radar. A different technique is presented for the imaging of isolated ground surfaces, which may range from the order of a metre to a few kilometres in diameter, using radiowaves generated from antennas on the ground surface of the Earth. The technique is first formulated using groundwave propagation theory to solve the forward electromagnetic scattering problem of the isolated surface. Conjugate gradient methods are then used to solve the inverse problem to obtain the normalised surface impedance distribution in an iterative manner, with the establishment of a cost function of the measured and scattered fields around the surface. Numerical simulations at 0.5 MHz of two ground features, namely dry ground and dry-wet mixed ground surfaces confined within a diameter of 500 m and surrounded by seawater, show that the distributions of both real and imaginary parts of the normalised surface impedance can be well reconstructed using the technique. It is also shown that the Polak-Ribiere-Polyak conjugate gradient method gives a faster rate of convergence than the Fletcher-Reeves method. The simulation at 300 MHz of dry ground with a buried metallic object confined within a diameter of 50 cm shows that the metallic object and its position can be identified from the images of normalised surface impedance distribution. The study demonstrates a new technique for the tomographic imaging of isolated ground surfaces which may be useful in ground surface mapping, remote sensing and monitoring, and detection of buried metallic objects [J1739]

"Three-dimensional ISAR imaging of maneuvering targets using three receivers"

The conventional ISAR image is a two-dimensional (2-D) projection of a three-dimensional (3-D) object surface. The image (projection) plane is related to the motion of a target with respect to the line of radar sight (LOS). In general, the image plane and the image scale in the cross range direction can not be determined by the traditional ISAR system with one receiver unless the target motion knowledge is known. In this paper, we propose a new ISAR system with three receivers. Using the three-receiver ISAR system, 3-D images of maneuvering targets can be generated, where the knowledge of the target motion is not required [J1740]

"RFI suppression in ultra-wideband SAR systems using LMS filters in frequency domain"

A least-mean-square algorithm in the frequency domain, with amplitude normalisation, is proposed to remove narrowband radio frequency interference in low-frequency ultra-wideband synthetic aperture radar systems. The performance of the algorithm was tested on experimental data acquired with the CARABAS system [J1741]

"SAR image data compression using a tree-structured wavelet transform"

SAR image compression is very important in reducing the costs of data storage and transmission in relatively slow channels. The authors propose a compression scheme driven by texture analysis, homogeneity mapping and speckle noise reduction within the wavelet framework. The image compressibility and interpretability are improved by incorporating speckle reduction into the compression scheme. The authors begin with the classical set partitioning in hierarchical trees (SPIHT) wavelet compression scheme, and modify it to control the amount of speckle reduction, applying different encoding schemes to homogeneous and nonhomogeneous areas of the scene. The results compare favorably with the conventional SPIHT wavelet and the JPEG compression methods [J1742]

"Optimal “focusing” for low resolution ScanSAR"

Deals with the focusing of low resolution ScanSAR data, for both detected amplitude images and interferometric applications. The SAR reference is exploited to achieve ScanSAR focusing in conventional techniques. Such

techniques provide quite effective compensation of the azimuth antenna pattern (e.g. no scalloping) when the azimuth time-bandwidth product of the ScanSAR echo is large, but fail to do so as the burst shortens, being reduced to an ineffective weighting of the output. The result is an azimuth varying distortion of the focused impulse responses, a distortion that is partly compensated for in the multilook average (not available for interferometric applications) at the price of a reduction in the processed Doppler bandwidth. This paper proposes quite a different approach. A set of short kernels, each suitable for “focusing” at a specific azimuth bin, has been optimized to reconstruct source reflectivity in the minimum mean square error sense. That pseudoinversion converges to the “conventional” focusing when the burst extent is large and for short bursts, edge effects are accounted for. These azimuth-varying kernels can be suitably tuned to meet constraints in the resolution/sidelobes trade-off and have proved capable of providing fairly undistorted output and fine resolution. They better exploit the available Doppler bandwidth, maximizing the number of looks and the interferometric quality. A decomposition is suggested that implements the inverse operator as a fast preprocessing to be followed by a conventional ScanSAR processor [J1743]

"Contextual information in SAR target detection"

Established target detection schemes make a statistical decision as to whether the value of a test pixel is more likely to have arisen due to the presence of a target or of clutter. Subject to prior probabilities for the occurrence of targets or clutter. However, such schemes do not take into account the contextual information which is available. For example, it will be known that military vehicles may be more likely to be located in fields close to hedges and woodland edges to provide cover and will often travel in groups. It is demonstrated how such contextual information may be incorporated into a SAR target detection scheme, while maintaining the statistical rigour of established techniques. A theoretical framework is developed in which the prior probability for the presence of a target is modified by the contextual influences via conditional dependencies. The resulting detection scheme is applied to simulated SAR images to obtain target detection rates for various combinations of contextual information. An improvement in performance of about 13% is observed when the context is fully exploited [J1744]

"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 [J1745]

"Recognizing occluded objects in SAR images"

Recognizing occluded vehicle targets in synthetic aperture radar (SAR) images is addressed. Recognition algorithms, based on local features, are presented that successfully recognize highly occluded objects in both XPATCH synthetic SAR signatures and real SAR images of actual vehicles from the MSTAR data. Extensive experimental results are presented for a basic recognition algorithm, using SAR scattering center relative locations as features with the XPATCH data and for an improved algorithm, using scatterer locations and magnitudes with the real SAR targets in the MSTAR data. The results show the effect of occlusion on recognition performance in terms of probability of correct identification, receiver operating characteristic curves, and confusion matrices [J1746]

"Toward edge sharpening: a SAR speckle filtering algorithm"

This paper makes two contributions. It first introduces an algorithm for synthetic aperture radar (SAR) speckle reduction and edge sharpening. Existing speckle filtering algorithms can effectively reduce the speckle effect but unfortunately also, to some degree, smear edges and blur images. Even for unfiltered images, there is still a need for edge sharpening; since SAR sensors have limited bandwidths, leading to slow responses to sudden changes (smearing sharp edges). The proposed algorithm functions as an adaptive-mean filter. Edge crossing points are detected by using the second-order derivative of the Gaussian function as a wavelet transform

function. A proper dilation scale factor enables the wavelet transform function to detect only edge crossings and ignore the local oscillations. Then in a moving window the mean filter is applied if there is no edge crossing point. Otherwise, averaging is only applied to the part of the window separated by edge crossing points. Consequently, the algorithm smooths uniform areas while it sharpens and enhances edges. Edges of the filtered images are generally sharper than the original. Similarities between the proposed filter and other popular speckle filters, such as the Lee, Kuan, and Frost filters, designated for SAR multiplicative noise, are analyzed. Another contribution of the paper is the evaluation of popular filters from the viewpoint of texture preservation. The evaluation is carried out using the first and second-order histograms. Possible distortions caused by filters are explained [J1747]

"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 [J1748]

"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 [J1749]

"Feature-enhanced synthetic aperture radar image formation based on nonquadratic regularization"

We develop a method for the formation of spotlight-mode synthetic aperture radar (SAR) images with enhanced features. The approach is based on a regularized reconstruction of the scattering field which combines a tomographic model of the SAR observation process with prior information regarding the nature of the features of interest. Compared to conventional SAR techniques, the method we propose produces images with increased resolution, reduced sidelobes, reduced speckle and easier-to-segment regions. Our technique effectively deals with the complex-valued, random-phase nature of the underlying SAR reflectivities. An efficient and robust numerical solution is achieved through extensions of half-quadratic regularization methods to the complex-valued SAR problem. We demonstrate the performance of the method on synthetic and real SAR scenes [J1750]

"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 [J1751]

"SAR ATR performance using a conditionally Gaussian model"

A family of conditionally Gaussian signal models for synthetic aperture radar (SAR) imagery is presented, extending a related class of models developed for high resolution radar range profiles. This signal model is

robust with respect to the variations of the complex-valued radar signals due to the coherent combination of returns from scatterers as those scatterers move through relative distances on the order of a wavelength of the transmitted signal (target speckle). The target type and the relative orientations of the sensor, target, and ground plane parameterize the conditionally Gaussian model. Based upon this model, algorithms to jointly estimate both the target type and pose are developed. Performance results for both target pose estimation and target recognition are presented for publicly released data from the MSTAR program [J1752]

"Ocean wave extraction from RADARSAT synthetic aperture radar inter-look image cross-spectra"

This study is concerned with the extraction of directional ocean wave spectra from synthetic aperture radar (SAR) image spectra. The statistical estimation problem underlying the wave-SAR inverse problem is examined in detail in order to properly quantify the wave information content of SAR. As a concrete focus, a data set is considered comprising six RADARSAT SAR images co-located with a directional wave buoy off the east coast of Canada. These SAR data are transformed into inter-look image cross-spectra based on two looks at the same ocean scene separated by 0.4 s. The general problem of wave extraction from SAR is cast in terms of a statistical estimation problem that includes the observed SAR spectra, the wave-SAR transform, and prior spectral wave information. The central role of the weighting functions (inverse of the error covariances) is demonstrated, as well as the consequence of approximate (based on the quasilinear wave-SAR transform) versus exact linearizations on the convergence properties of the algorithm. Error estimates are derived and discussed. This statistical framework is applied to the extraction of spectral wave information from observed RADARSAT SAR image cross-spectra. A modified wave-SAR transform is used to account for case-specific geophysical and imaging effects. Analysis of the residual error of simulated and observed SAR spectra motivates a canonical form for the SAR observation error covariance. Wave estimates are then extracted from the SAR spectra, including wavenumber dependent error estimates and explicit identification of spectral null spaces where the SAR contains no wave information. Band-limited SAR wave information is also combined with prior (buoy) spectral wave estimates through parameterization of the wave spectral shape and use of regularization [J1753]

"Permanent scatterers in SAR interferometry"

Temporal and geometrical decorrelation often prevents SAR interferometry from being an operational tool for surface deformation monitoring and topographic profile reconstruction. Moreover, atmospheric disturbances can strongly compromise the accuracy of the results. The authors present a complete procedure for the identification and exploitation of stable natural reflectors or permanent scatterers (PSs) starting from long temporal series of interferometric SAR images. When, as it often happens, the dimension of the PS is smaller than the resolution cell, the coherence is good even for interferograms with baselines larger than the decorrelation one, and all the available images of the ESA ERS data set can be successfully exploited. On these pixels, submeter DEM accuracy and millimetric terrain motion detection can be achieved, since atmospheric phase screen (APS) contributions can be estimated and removed. Examples are then shown of small motion measurements, DEM refinement, and APS estimation and removal in the case of a sliding area in Ancona, Italy. ERS data have been used [J1754]

"Multi-aspect target detection for SAR imagery using hidden Markov models"

Radar scattering from an illuminated object is often highly dependent on the target-sensor orientation. In typical synthetic aperture radar (SAR) imagery, the information in the multi-aspect target signatures is diffused in the image-formation process. In an effort to exploit the aspect dependence of the target signature, the authors employ a sequence of directional filters to the SAR imagery, thereby generating a sequence of subaperture images that recover the directional dependence of the target scattering. The scattering statistics are then used to design a hidden Markov model (HMM), wherein the orientation-dependent scattering statistics are exploited explicitly. This approach fuses information embodied in the orientation-dependent target signature under the assumption that. Both the target identity and orientation are unknown. Performance is assessed by considering the detection of tactical targets concealed in foliage, using measured foliage-penetrating (FOPEN) SAR data [J1755]

"Ocean wave imaging using an airborne single pass across-track interferometric SAR"

An airborne single pass across-track interferometric synthetic aperture radar (InSAR) is used to image ocean waves. A theoretical model explaining the imaging mechanisms is developed, and simulations of the interferogram as well as the conventional SAR intensity image are presented for given ocean wave spectra. Distortions of digital elevation models (DEM) derived from InSAR data are explained by the motion of the sea surface. A Monte Carlo method based on forward simulations is used to estimate variance spectra of the distorted elevation models. It is shown that a straightforward estimation of wave height using the distorted InSAR

elevation model is in good agreement with true wave height for low amplitude swell with about 10% error depending on propagation direction and coherence time. However, severe underestimation of wave height is found for wind seas propagating in flight direction. Forward simulations show that the distorted InSAR DEM is less dependent an the model chosen for the real aperture radar mechanism than conventional SAR images. Data acquired during an experiment over the North Sea by a high precision InSAR system are compared with simulations [J1756]

"Multiscale MAP filtering of SAR images"

Synthetic aperture radar (SAR) images are disturbed by a multiplicative noise depending on the signal (the ground reflectivity) due to the radar wave coherence. Images have a strong variability from one pixel to another reducing essentially the efficiency of the algorithms of detection and classification. We propose to filter this noise with a multiresolution analysis of the image. The wavelet coefficient of the reflectivity is estimated with a Bayesian model, maximizing the a posteriori probability density function. The different probability density function are modeled with the Pearson system of distributions. The resulting filter combines the classical adaptive approach with wavelet decomposition where the local variance of high-frequency images is used in order to segment and filter wavelet coefficients [J1757]

"Estimation of terrain elevation by multifrequency interferometric wide band SAR data"

We present a phase unwrapping method using a maximum likelihood estimation technique together with frequency diversity information to reconstruct highly discontinuous ground elevation profiles. Frequency diversity can be obtained by considering the interferograms obtained by different couples of subband images [J1758]

"A technique for the identification and localization of SAR targets using encoding transponders"

Targets in SAR images can be tagged for unambiguous identification and localization by equipping them with transponders that encode the signal received from the SAR before it is retransmitted. The encoding technique described below requires no modification of the SAR. The SAR data can be processed to image the transponders with the background suppressed. The transponder response is suppressed in a conventionally processed SAR image. The encoding technique enables the transponder signal to be automatically detected in the SAR data [J1759]

"Edge location in SAR images: performance of the likelihood ratio filter and accuracy improvement with an active contour approach"

The likelihood ratio edge detector is an efficient filter for the segmentation of synthetic aperture radar (SAR) images. We show that this filter provides biased location of the edge, when the window does not have the same orientation as the edge. A phenomenological model is proposed to characterize this bias. We then introduce an efficient technique to refine edge location: the statistical active contour. The combination of these two methods permits to achieve accurate and regularized edge location [J1760]

"The ratio of the arithmetic to the geometric mean: a cross-entropy interpretation"

The ratio of the arithmetic mean to the geometric mean is often applied to synthetic aperture radar (SAR) imagery as a heuristic index of target homogeneity. It is shown that this ratio is equivalent to a cross entropy expression, and can therefore be interpreted as a measure of the information contained within the image [J1761]

"Segmentation and classification of vegetated areas using polarimetric SAR image data"

Classification of radar images based on the information provided by individual pixels cannot generally produce satisfactory results due to speckle. The classification based on area analysis is therefore expected to be more accurate, as a uniform area, which usually consists of multipixels, provides reliable measurement statistics and texture characteristics. However, the area analysis requires partitions of uniform areas to be performed first. In this paper, an approach to the classification of radar images is developed based on two steps. First an image is partitioned into uniform areas (segments), and then these segments are classified. Both segmentation and classification are achieved by using the Gaussian Markov random field model. Test images are classified to demonstrate the method [J1762]

"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 [J1763]

"Amazon floodplain water level changes measured with interferometric SIR-C radar"

The authors find that interferometric processing of repeat-pass L-HH-band shuttle imaging radar (SIR-C) data reveals centimeter-scale changes in the elevations of water surfaces within flooded vegetation. Because radar pulses reflect specularly from the water surface, interferometric observations of open water are incoherent. However, within flooded forests and inundated shrubs, the L-band radar pulse penetrates the vegetation canopy and follows a double-bounce travel path that includes the water and vegetation-trunk surfaces. In these environments, the returned radar energy and associated phase coherence are both stronger than the surrounding nonflooded terrain, permitting determination of the interferometric phase. Phase errors related to atmospheric water vapor are usually longer in wavelength and spatially distinct from phase signatures related to stage changes in tributaries and floodplain lakes. The interferometrically measured stage decreases match gauge data, providing further verification. Water level changes across 150 m to 2.75 km-wide water bodies containing inundated vegetation can be reliably measured. The authors' results suggest that if future interferometric L-HH-band SAR missions are implemented with short temporal baselines, it is possible to measure the hydrologic response of wetlands and inundated floodplains to changes in mainstem water level [J1764]

"Dual-beam interferometry for ocean surface current vector mapping"

The recent use of along-track interferometry (ATI) in synthetic aperture radar (SAR) has shown promise for synoptic measurement of ocean surface currents. ATI-SARs have been used to estimate wave fields, currents, and current features. This paper describes and analyzes a dual-beam along-track interferometer to provide spatially resolved vector surface velocity estimates with a single pass of an aircraft. The design employs a pair of interferometer beams, one squinted forward and one squinted aft. Each interferometric phase is sensitive to the component of surface Doppler velocity in the direction of the beam. Therefore, a proper combination of these measurements provides a vector surface velocity estimate in one pass of the aircraft. The authors find that precise measurements dictate widely spaced beams and that the spatial resolution for the squinted SAR is essentially identical to the sidelooking case. Practical instrument design issues are discussed, and an airborne system currently in development is described. Through computer simulation, they observe the azimuthal displacement of interferometric phases by moving surfaces identical to those of conventional SAR and find that such displacement can bias the estimated surface velocity [J1765]

"New sampling method for the improvement of the image reconstruction algorithm for the rotating object"

The proposed method is devised to reconstruct a focused radar image for a wide observation angle without an interpolation, and therefore, it improves the image quality and reduces the processing time. To evaluate the performance, it is compared with the conventional sampling method through simulation and experimental results. In the case of the proposed method, the computation time is improved more than 33% for the image size of 1024Ч1024 pixels [J1766]

"Estimation of the mean radar reflectivity from a finite number of correlated samples"

The authors compare estimators of the mean radar reflectivity on images with different spectral properties. By working on complex data rather than detected images, they can take the speckle correlation into account and thus obtain more accurate estimates. A robust and computationally efficient approximation of the optimal estimator is proposed [J1767]

"Analysis of topographic decorrelation in SAR interferometry using ratio coherence imagery"

Topographic decorrelation due to the local surface slope has been an obstacle to interferometric synthetic aperture radar (InSAR) applications. A modified spatial decorrelation function is derived as a function of the baseline and topography. This function explains the origin of the total topographic decorrelation phenomenon on the slopes directly facing radar illumination and layover, which may mislead InSAR coherence image interpretation. The authors define critical terrain slope (or critical incidence angle) as the angle for which two SAR signals completely decorrelate regardless of surface stability. It is found that the width of the critical terrain slope increases with the increase of the component of the baseline perpendicular to the radar look direction. A new analytical method, the ratio coherence imagery, is then introduced to highlight total topographic decorrelation against the temporal decorrelation features. The applications of this methodology are demonstrated in selected locations in the Sahara Desert, Algeria, and Almerıŕa, Spain, using ERS-1 and ERS-2 SAR data [J1768]

"Optical calibration phase locked loop for the Shuttle Radar Topography Mission"

The Shuttle Radar Topography Mission (SRTM) is an interferometric synthetic aperture radar system that flew on the space shuttle in February 2000, SRTM has an inboard antenna in the shuttle cargo bay and an outboard antenna at the end of a 60-m mast, extending from the cargo bay. In order to meet the elevation mapping accuracy requirement, the relative phase delay between the radar signals received via the outboard channel, compared with the inboard channel has to be known to within 80 at 5.3 GHz. This paper describes the design solutions and constraints, the devices, the analysis, and validation used to implement an optical calibration loop for SRTM. The calibration method involves injecting a tone into one panel of the inboard antenna, and sending an optical copy of the tone via a fiber-optic cable to be injected into the outboard antenna. A portion of the optical signal is reflected off an outboard partial mirror and travels back via the fiber to the inboard calibration system. There, it is converted back into a radio frequency tone and its phase is compared with the phase of the original tone. As the temperature of the mast fiber changes, a phase error is detected in the phase comparator. This error is used to control a custom designed optical phase shifter connected in series with the mast fiber. This phase-locked-loop guarantees that the phase of the calibration tone at the outboard stages within 1° relative to the phase of the calibration tone at the inboard antenna [J1769]

"High resolution 3D “snapshot” ISAR imaging and feature extraction"

We have developed a new formulation for three dimensional (3D) radar imaging of inverse synthetic aperture radar (ISAR) data based on recent developments in high resolution spectral estimation theory. Typically for non real-time applications, image formation is a two step process consisting of motion determination and image generation. The technique presented focuses on this latter process, and assumes the motion of the target is known. The new technique offers several advantages over conventional techniques which are based on the correlation imaging function. In particular, the technique provides for a direct 3D estimate (versus back projection to a 3D target grid matrix) of the locations of the dominant scattering centers using only a minimum set of independent 2D range-Doppler ISAR “snapshots” of the target. Because of the snapshot nature of the technique, it is particularly applicable to 3D imaging of sectors of sparse-angle data, for which the sidelobes of the correlation imaging integral become high. Furthermore, the technique provides for an estimate of amplitude and phase of each scattering center as a function of aspect angle to the target, for those aspect angles which encompass the set of 2D range-Doppler snapshots. Results illustrating the technique developed are presented for both simulated and static range data [J1770]

"Improved SAR target detection via extended fractal features"

The utility of the extended fractal (EF) feature is evaluated for the enhancement of the focus of attention (FOA) stage of a synthetic aperture radar (SAR) automatic target recognition (ATR) system. Unlike more traditional SAR detection features that distinguish target pixels from the background only on the basis of contrast, the EF feature is sensitive to both the contrast and size of objects. Furthermore, the structure for the EF feature computational algorithm lends itself to very fast implementation, and it can be shown that the new feature has a CFAR-like (constant false alarm rate) property. We demonstrate the improved performance using the new feature by testing a number of different detection approaches over two databases of SAR imagery [J1771]

"Integrated microstrip probe for phaseless near-field measurements on plane-polar geometry"

An integrated probe performing phaseless near-field measurements on a polar surface is presented. The unknown near-field phase is computed by an interferometric technique used in conjunction with the minimisation of a suitable functional. A microstrip patch antenna for synthetic aperture radar (SAR) applications is considered to validate the method [J1772]

"Support vector machines for SAR automatic target recognition"

Algorithms that produce classifiers with large margins, such as support vector machines (SVMs), AdaBoost, etc, are receiving more and more attention in the literature. A real application of SVMs for synthetic aperture radar automatic target recognition (SAR/ATR) is presented and the result is compared with conventional classifiers. The SVMs are tested for classification both in closed and open sets (recognition). Experimental results showed that SVMs outperform conventional classifiers in target classification. Moreover, SVMs with the Gaussian kernels are able to form a local “bounded” decision region around each class that presents better rejection to confusers [J1773]

"An analytic nonlinear approach to sidelobe reduction"

We propose an analytic technique for reducing sidelobe artifacts in synthetic aperture radar data. The technique, called leakage energy minimization (LEM), uses a spatially varying aperture function, the coefficients of which satisfy a simple optimality condition. The integrated sidelobe energy (or leakage energy) characterizing a given aperture weighting function is used as a metric for determining the likelihood of an aperture weighting. When applied to synthetic aperture radar data, the technique can effectively reduce sidelobe levels with negligible loss of resolution. The algorithm is computationally efficient, and its application requires no restrictions on the data sampling rate [J1774]

"SAR imaging of buried objects from MoM modelled scattered field"

Synthetic aperture radar (SAR) images of resonant buried objects are modelled in the presence of ground surface clutter. The method of moments (MoM) is used to model scattered fields from a resonant buried conductor and clutter is modelled as a bivariant Gaussian distribution. A diffraction stack SAR imaging technique is applied to the ultra-wideband waveforms to give a bipolar signal image. A number of examples have been computed to illustrate the combined effects of SAR processing with resonant targets and clutter. SAR images of different targets show differences which may facilitate target identification. To maximise the peak signal-to-clutter ratio, an image correlation technique is applied and the results are shown [J1775]

"ISAR imaging of targets at low elevation angles"

The problem of inverse synthetic aperture radar (ISAR) image reconstruction of targets at low elevation angle is considered. In this geometric condition the main causes affecting the reconstructed ISAR image are the multipath effect due to the reflection of the Earth's surface and the angular motions of the target produced by external action like wind, fast maneuvering, and sea waves as in the case of ships. The aim of this work is to analyze the effects that the multipath and the target angular motions jointly produce on the ISAR image. The results show that multipath generates some artifacts in the image whereas the target oscillations undergo a spatial-dependent blurring of the point spread function of the ISAR system. These theoretical results are validated by presenting some numerical examples relevant to aircrafts and ships in rectilinear or circular motion. A wide discussion on possible solutions of this problem is made in the conclusion [J1776]

"Unbiased coherence estimator for SAR interferometry with application to moving target detection"

A new maximum-likelihood estimator (MLE) for estimating the coherence between two synthetic aperture radar (SAR) channels is proposed. In contrast to conventional techniques, this estimator is unbiased for any number of samples and degrees of coherence. The performance of the new MLE is validated with results based on measured along-track interferometric data. It is demonstrated how such accurate coherence estimates can be used to define CFAR-detection thresholds for moving targets [J1777]

"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 [J1778]

"Theory of synthetic aperture radar imaging of a moving target"

Two novel image processing techniques have been developed to refocus a moving target image from its smeared response in the synthetic aperture radar (SAR) image which is focused on the stationary ground. Both approaches may be implemented with efficient fast Fourier transform (FFT) routines to process the Fourier spatial spectrum of the image data. The first approach utilizes a matched target filter that is derived from the signal history along the range-Doppler migration path mapped onto the SAR image from the moving target trajectory in real space. The coherent spatial filter is specified by the apparent target range in the image and the magnitude of the relative target-to-radar velocity. The second approach eliminates the range-dependence by reconstructing the moving target image from a spectral function that is obtained from the SAR image data spectrum via a spatial frequency coordinate transformation [J1779]

"Correction of residual motion errors in airborne SAR interferometry"

The main limitation for a wider applicability of airborne repeat pass interferometric SAR data is the presence of small uncompensated motion errors. The effect of residual motion compensation errors is addressed and a new technique to minimise their influence on the interferometric phase is proposed [J1780]

"Restoration of polarimetric SAR images using simulated annealing"

Filtering synthetic aperture radar (SAR) images ideally results in better estimates of the parameters characterizing the distributed targets in the images while preserving the structures of the nondistributed targets. However, these objectives are normally conflicting, often leading to a filtering approach favoring one of the objectives. An algorithm for estimating the radar cross-section (RCS) for intensity SAR images has previously been proposed in the literature based on Markov random fields and the stochastic optimization method simulated annealing. A new version of the algorithm is presented applicable to multilook polarimetric SAR images, resulting in an estimate of the mean covariance matrix rather than the RCS. Small windows are applied in the filtering, and due to the iterative nature of the approach, reasonable estimates of the polarimetric quantities characterizing the distributed targets are obtained while at the same time preserving most of the structures in the image. The algorithm is evaluated using multilook polarimetric L-band data from the Danish airborne EMISAR system, and the impact of the algorithm on the unsupervised H-α classification is demonstrated [J1781]

"Spotlight SAR data focusing based on a two-step processing approach"

The authors present a new spotlight SAR data-focusing algorithm based on a two-step processing strategy that combines the advantages of two commonly adopted processing approaches: the efficiency of SPECAN algorithms and the precision of stripmap focusing techniques. The first step of the proposed algorithm implements a linear and space-invariant azimuth filtering that is carried out via a deramping-based technique representing a simplified version of the SPECAN approach. This operation allows the authors to perform a bulk azimuth raw data compression and to achieve a pixel spacing smaller than (or equal to) the expected azimuth resolution of the fully focused image. Thus, the azimuth spectral folding phenomenon, typically affecting the spotlight data, is overcome, and the space-variant characteristics of the stripmap system transfer function are preserved. Accordingly, the residual and precise focusing of the SAR data is achieved by applying a conventional stripmap processing procedure requiring a minor modification and implemented in the frequency domain. The extension of the proposed technique to the case of high bandwidth transmitted chirp signals is also discussed. Experiments carried out on real and simulated data confirm the validity of the presented approach, which is mainly focused on spaceborne systems [J1782]

"Maximum likelihood approach to the detection of changes between multitemporal SAR images"

The authors introduce maximum likelihood techniques for optimised discrimination between agricultural and wooded regions, based on a multitemporal sequence of ERS images. The inherent resolution of the system is inadequate to make such a classification on an individual image. However, the different temporal change patterns of the two classes can be exploited. One approach uses joint annealed segmentation of the image sequence, providing optimised exploitation of the speckle model in determining the common set of region boundaries in the underlying radar cross-section. This is followed by maximum likelihood change detection using a normalised log temporal texture measure. This is shown to be superior to constructing the normalised log measure directly including speckle fluctuations, followed by a single annealed segmentation process. Finally, it is demonstrated how simple filtering of this normalised log measure can provide reasonable classification with greatly reduced computation load [J1783]

"The use of ERS-1/2 Tandem interferometric coherence in the estimation of agricultural crop heights"

In this study, the relationship between ERS-1/2 SAR Tandem interferometric coherence and the height of sugar beet, potato, and winter wheat is investigated using measurements of crop growth and coherence. The development of both coherence and crop height is observed to be approximately linear during the early growing season, and linear crop-specific relationships between Tandem coherence and the heights of the studied crops are derived. The coherence of all the studied crops decreases as the crop heights increase, a probable explanation for this is that as the crop grows, it screens the ground more effectively, and a greater part of the incident radar energy is backscattered from vegetation that decorrelates more rapidly than the more stable soil. The relatively dense canopies of the root crops sugar beet and potato screen the ground considerably more effectively than the cereal crop winter wheat. This study gives a strong indication that ERS-1/2 Tandem interferometric coherence is related to the height of agricultural crops, and that this relationship can be used to retrieve crop heights [J1784]

"A market-based conflict resolution approach for satellite mission planning"

A market-based system has been developed to assist in mission planning for an Earth orbiting synthetic aperture radar mission. This approach was chosen over more traditional systems based on a functional model used to compare the market-based system with a human-expert, thematic and geometric approaches. The market-based system enables participants to signal demands for spacecraft resources needed for data acquisitions by establishing a currency and “worth” for a particular data acquisition request. We compared a serial draft approach to two market-based approaches; a simple market and a priority market. The market systems utilized a planning period which ended when the value of the time-ordered data acquisition plan did not increase by 10% of the value of the previous round. The market-based approaches were superior to a serial draft approach and that a priority market had a 2% greater value than a simple market [J1785]

"Microwave detection of buried mines using non-contact, synthetic near-field focusing"

Existing ground penetrating radars (GPR) are limited in their 3-D resolution. For the detection of buried land-mines, their performance is also seriously restricted by `clutter'. Previous work by the authors has concentrated on removing these limitations by employing multi-static synthetic focusing from a 2-D real aperture. This contribution presents this novel concept, describes the proposed implementation, examines the influence of clutter and of various ground features on the system's performance, and discusses such practicalities as digitisation and time-sharing of a single transmitter and receiver. Experimental results from a variety of scenarios are presented [J1786]

"New applications of nonlinear chirp scaling in SAR data processing"

New applications of nonlinear chirp scaling (NLCS) have been found in processing monostatic and bistatic SAR data acquired in the strip-map mode. When the effects in impulse response broadenings due to quadratic range migration are negligible for short radar wavelengths, a time domain range cell migration correction (RCMC) can be applied. After the correction, the FM rates of targets confined in a range gate will differ from each other. A nonlinear chirp perturbation function can be applied to each range gate to equalize the targets' FM rates before azimuth compression. This algorithm is analyzed in the paper and is supported by point target simulation experiments [J1787]

"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 [J1788]

"A fast multilevel domain decomposition algorithm for radar imaging"

A novel algorithm for radar imaging is presented. The method comprises two steps. First, a decomposition of the radar data domain into subdomains and computation of pertinent low resolution images. Second, interpolation, phase correction and aggregation of the low resolution images into the final high resolution one. A multilevel algorithm is formulated via a recursive application of the domain decomposition and image aggregation steps. The computational cost of the proposed algorithm is comparable to that of the fast Fourier transform (FFT) based techniques while it appears to be considerably more flexible than the latter [J1789]

"A new subaperture approach to high squint SAR processing"

A high squint subaperture (HSS) algorithm was developed from the perspective of a strip map synthetic aperture radar (SAR) system and has the ability to focus SAR data at extremely high squint angle of 55° with less than 1.27% mainlobe expansion or even higher squint angles if larger mainlobe expansion can be tolerated. The unique characteristic of this algorithm is that the subapertures are formed by multiplying the received signal with a set of overlapped complex conjugated reference signals where the chirp rate varies in the azimuth direction. This is done to solve the range focus problem that arises after the azimuth input signal undergoes the range walk removal procedure. As the IISS algorithm only involves short fast Fourier transforms (FFTs) and avoids interpolation, it is computationally efficient and allows for small data buffers and facilitates hardware real-time implementation. The distinct feature of this algorithm is its simplicity of implementation, which is vital in real time processing and motion compensation when the squint angle may be changing continuously [J1790]

"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 [J1791]

"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 [J1792]

"A matched-filter-based reverse-time migration algorithm for ground-penetrating radar data"

Ground-penetrating radar (GPR) is a remote sensing technique used to obtain information on subsurface features from data collected over the surface. The process of collecting data may be viewed as mapping from the object space to an image space. Since most GPRs use broad beam width antennas, the energy reflected from a buried structure is recorded over a large lateral aperture in the image spare, migration algorithms are used to reconstruct an accurate scattering map by refocusing the recorded scattering events to their true spatial locations through a backpropagation process. The goal of this paper is to present a pair of finite-difference time-domain (FDTD) reverse-time migration algorithms for GPR data processing. Linear inverse scattering theory is used to develop a matched-filter response for the GPR problem. The reverse-time migration algorithms, developed for both bistatic and monostatic antenna configurations, are implemented via FDTD in the object space. Several examples are presented [J1793]

"Sea-wave fractal spectrum for SAR remote sensing"

A new model of the sea-wave directional spectrum based on fractals is proposed. An innovative aspect of the

work is the theoretical approach used to get the `fractal sea spectrum'. The common spectrum models are described by empirical expressions derived from fitting experimental data. Starting from a definition of a fractal model of the sea surface, the spatial autocorrelation function is calculated and the directional sea spectrum derived by taking its two-dimensional Fourier transform. The fractal spectrum explicitly accounts for the fractality of the sea. The spectrum theoretically explains why its slope in the equilibrium range depends on the fractal dimension D of the sea surface and can be expressed by the relationship 2D-7, as usually claimed from experimental data. The spectrum is validated by comparing it to the common spectra of Pierson-Moskowitz (1964) and JONSWAP and to real data of the Mediterranean Sea. New research directions offered by this spectrum model in SAR remote sensing are addressed [J1794]

"SAR interferometric phase noise reduction using wavelet transform"

The problem of synthetic aperture radar interferometric phase noise reduction is addressed. A new technique based on discrete wavelet transforms is presented. This technique guarantees high resolution phase estimation without using phase image segmentation. Areas containing only noise are hardly processed. Tests with synthetic and real interferograms are reported [J1795]

"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 [J1796]

"Real-time three-dimensional modular SAR preprocessor design"

The architecture design for a high-speed front-end video prefiltering is described, this being part of an effort to develop a real-time range-doppler digital SAR processor to produce image maps of the scanned area immediately as raw data are collected. The evolved architecture consists of three-dimensionally interconnected planes of modified transverse FIR parallel tapped elements. Both the range and azimuth prefilterings are performed simultaneously in a continuous input-output flow without the need to consider corner turning. The computation load has been reduced to one complex multiplication and two complex additions [J1797]

"Simulation of ISAR imaging of moving targets"

The simulation of inverse synthetic aperture radar (ISAR) imaging of moving targets is described and the effects of the target's rotations on ISAR imaging are analysed. The simulation of ISAR imaging of an aircraft with a circular motion is demonstrated. An ideal ISAR image of a target can be derived by projection of the target onto an image projection plane. Time-varying Doppler shifts induced by roll, pitch and yaw motions are analysed using the rotation matrix and the effective rotation vector. Through the simulation, the individual effect of roll, pitch and yaw motion on ISAR imaging is observed and studied [J1798]

"Segmentation-based technique for ship detection in SAR images"

A novel segmentation-based ship detection scheme is proposed to cope with the typical features of sea clutter. In particular, it is shown that the standard 2D-CFAR schemes applied to both low- and high-resolution SAR images do not allow adequate control of the false-alarm rate for nonhomogeneity and non-Gaussianity characteristics of backscattering from the sea. The introduction of an appropriate first segmentation stage allows standard CFAR techniques to be applied inside homogeneous areas. Moreover, the derived approximate CFAR performance against non-Gaussian clutter allows the detection threshold to be set to achieve the desired false alarm rate. The practical performance is demonstrated for both a set of low-resolution quick-look ERS-SAR images and a set of high-resolution single-look X-SAR/SIR-C images. This proved that the proposed segmentation-based scheme gives a very high ship detection capability for both sets, with a controlled number of false alarms in the presence of any structure or fluctuation of the background [J1799]

"Multi-aspect detection of surface and shallow-buried unexploded ordnance via ultra-wideband synthetic aperture radar"

An ultra-wideband (UWB) synthetic aperture radar (SAR) system is investigated for the detection of former bombing ranges, littered by unexploded ordnance (UXO). The objective is detection of a high enough percentage of surface and shallow-buried UXO, with a low enough false-alarm rate, such that a former range can be detected. The physics of UWB SAR scattering is exploited in the context of a hidden Markov model (HMM), which explicitly accounts for the multiple aspects at which a SAR system views a given target. The HMM is trained on computed data, using SAR imagery synthesized via a validated physical-optics solution. The performance of the HMM is demonstrated by performing testing on measured UWB SAR data for many surface and shallow UXO buried in soil in the vicinity of naturally occurring clutter [J1800]

"Subsurface structures detection by combining L-band polarimetric SAR and GPR data: example of the Pyla Dune (France)"

The authors investigate the penetration capabilities of microwaves, particularly at L-band, for the mapping of subsurface heterogeneities such as lithology variations, moisture or sedimentary structures. The experiment site, the Pyla Dune, is a bare sandy area allowing high signal penetration and presenting large subsurface structures (paleosoils) at varying depths. Several radar data sets over this area are available. A polarimetric analysis of airborne synthetic aperture radar (SAR) data as web as the ground penetrating radar (GPR) sounding experiment show that subsurface scattering occurs at several places. The SAR penetration depth is estimated by inverting a scattering model for which the subsurface structure geometric and dielectric properties are determined by the GPR data analysis. These results suggest that airborne radar systems in a lower frequency range (P-band) should be able to detect subsurface moisture down to several meters, leading to innovative Earth observation systems for hydrogeology in arid regions [J1801]

"Three-dimensional interferometric ISAR imaging for target scattering diagnosis and modeling"

Two-dimensional (2-D) inverse synthetic aperture radar (ISAR) imaging has been widely used in target scattering diagnosis, modeling and target identification. A major shortcoming is that a 2-D ISAR image cannot provide information on the relative altitude of each scattering center on the target. In this paper, we present an interferometric inverse synthetic aperture radar (IF-ISAR) image processing technique for three-dimensional (3-D) target altitude image formation. The 2-D ISAR images are obtained from the signature data acquired as a function of frequency and azimuthal angle. A 3-D IF-ISAR altitude image can then be derived from two 2-D images reconstructed from the measurements by antennas at different altitudes. 3-D altitude image formation examples from both indoor and outdoor test range data are demonstrated on complex radar targets [J1802]

"Polarimetric radar interferometry for improved mine detection and surface clutter rejection"

A recently developed technique, polarimetric radar interferometry, is applied to tackle the problem of the detection of buried objects embedded in surface clutter. An experiment with a fully polarimetric radar in an anechoic chamber has been carried out using different frequency bands and baselines. The processed results show the ability of this technique to detect buried plastic mines and to measure their depth. This technique enables the detection of plastic mines even if their backscatter response is much lower than that of the surface clutter [J1803]

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