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REMOTE SENSING OF EARTH TERRAIN

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SEMI-ANNUAL PROGRESS REPORT

Under the sponsorship of the NASA Contract NAG5-270, the publication list includes 2 books, 57 refereed journal and conference papers, and 10 recent technical reports for the research on the remote sensing of earth terrain.

A systematic approach for the identification of terrain media such as vegetation canopy, forest, and snow-covered fields is developed using the optimum polarimetric classifier. The covariance matrices for the various terrain cover are computed from theoretical models of random medium by evaluating the full polarimetric scattering matrix elements. The optimal classification scheme makes use of a quadratic distance measure and is applied to classify a vegetation canopy consisting of both trees and grass. Experimentally measured data are used to validate the classification scheme. Theoretical probability of classification error using the full polarimetric matrix are compared with classification based on single features including the phase difference between the VV and HH polarization returns. It is shown that the full polarimetric results are optimal and provide better classification performance than single feature measurements.

We modeled earth terrain covers as random media characterized by different dielectric constants and correlation functions. In order to model sea ice with brine inclusions and vegetation with row structures, the random medium is assumed to be anisotropic. A three-layer model will be used to simulate a vegetation field or a snow-covered ice field with the top layer being snow or leaves, the middle layer being ice or trunks, and the bottom layer being sea water or ground.

The strong fluctuation theory with the distorted Born approximation is applied to the solution of the radar backscattering coefficients. In order to take into account the polarimetric information, we relate the backscattered Stokes vector to the incident Stokes vector by the Mueller matrix, which completely describes the scattering (in amplitude, phase, frequency, and polarization) from the three-layer anisotropic random medium. The Mueller matrix properties, as well as the covariance matrix issues, relevant to the radar backscattering will be examined. It is shown that for an isotropic medium, eight of the sixteen elements of the Mueller matrix are identically zero. However, the tilted anisotropic permittivity of the middle layer (sea ice or trunks) generates a full nonzero Mueller matrix.

The Mueller matrix and polarization covariance matrix are studied for polarimetric radar systems. The clutter is modelled by a layer of random permittivity, described by a three-dimensional correlation function, with variance, and horizontal and vertical correlation lengths. This model is applied, using the wave theory with Born approximations carried to the second order, to find the backscattering elements of the polarimetric matrices. It is found that 8 out of 16 elements of the Mueller matrix are identically zero, corresponding to a covariance matrix with four zero elements. Theoretical predictions are matched with experimental data for vegetation fields.

The volume scattering effects of snow-covered sea ice are studied with a three-layer random medium model for microwave remote sensing. The strong fluctuation theory and the bilocal approximation are applied to calculate the effective permittivities for snow and sea ice. The wave scattering theory in conjunction with the distorted Born approximation is then used to compute bistatic coefficients and backscattering cross sections. Theoretical results are illustrated by matching experimental data for dry snow-covered thick first-year sea ice at Point Barrow. The radar backscattering cross sections are seen to increase with snow cover for snow-covered sea ice, due to the increased scattering effects in the snow layer. The results derived can also be applied to the passive remote sensing by calculating the emissivity from the bistatic scattering coefficients.

A general mixing formula is derived for discrete scatterers immersed in a host medium. The inclusion particles are assumed to be ellipsoidal. The electric field inside the scatterers is determined by quasistatic analysis, assuming the diameter of the inclusion particles to be much smaller than the wavelength. The results are applicable to general multiphase mixtures, and the scattering ellipsoids of the different phases can have different sizes and arbitrary ellipticity distribution and axis orientation, i.e., the mixture may be isotropic or anisotropic. The resulting mixing formula is nonlinear and implicit for the effective complex dielectric constant, because the approach in calculating the internal field of scatterers is self-consistent. Still, the form is especially suitable for iterative solution. The formula contains a quantity called the apparent permittivity, and with different choices of this quantity, the result leads to the generalized Lorentz - Lorenz formula, the generalized Polder - van Santen formula, and the generalized coherent potential - quasicrystalline approximation formula. Finally, the results are applied to calculating the complex effective permittivity of snow and sea ice.

We have used the strong fluctuation theory to derive the backscattering cross sections. The study of the strong fluctuation theory for a bounded layer of random discrete scatterers is further extended to include higher order co-polarized and cross-polarized second moments. The backscattering cross sections per unit area are calculated by including the mutual coherence of the fields due to the coincidental ray paths and that due to the opposite ray paths which are corresponding to the ladder and cross terms in the Feynman diagrammatic representation. It is proved that the contributions from ladder and cross terms for co-polarized backscattering cross sections are the same, while the contributions for the cross-polarized ones are of the same order. The bistatic scattering coefficients in the second-order approximation for both the ladder and cross terms are also obtained. The enhancement in the backscattering direction can be attributed to the contributions from the cross terms.

A two-layer anisotropic random medium model is developed for the active and passive microwave remote sensing of ice fields. The dyadic Green's function for this two-layer anisotropic medium is derived. With a specified correlation function for the randomness of the dielectric constant, the backscattering cross sections are calculated with the Born approximation. It is shown that the depolarization effects exist in the single-scattering process. Treating sea ice as a tilted uniaxial medium, the observed strong cross-polarized return in the bistatic scattering coefficients is successfully predicted from the theoretical model. It is also shown that the backscattering cross section of horizontal polarization can be greater than that of vertical polarization even in the half-space case. The principle of reciprocity and the principle of energy conservation are invoked to calculate the brightness temperatures. The bistatic scattering coefficients are first calculated and then integrated over the upper hemisphere to be subtracted from unity, in order to obtain the emissivity for the random medium layer. It is shown that both the absorptive and randomly fluctuating properties of the anisotropic medium affect the behavior of the resulting brightness temperatures both in theory and in actual controlled field measurements. The active and passive results match favorably well with the experimental data obtained from the first-year and the multiyear sea ice as well as from the corn stalks with detailed ground-truth information.

The Feynman diagrammatic technique is used to derive the Dyson equation for the mean field and the Bethe-Salpeter equation for the correlation or the covariance of the field for electromagnetic wave propagation and scattering in an anisotropic random medium. With the random permittivity expressed in a general form, the bilocal and the nonlinear approximations are employed to solve the Dyson equation and the ladder approximation to the Bethe-Salpeter equation. The mean dyadic Green's function for a two-layer anisotropic random medium with arbitrary three-dimensional correlation functions has been investigated with the zeroth-order solutions to the Dyson equation under the nonlinear approximation. The effective propagation constants are calculated for the four characteristic waves associated with the coherent vector fields propagating in an anisotropic random medium layer, which are the ordinary and extraordinary waves with upward and downward propagating vectors.

A three-layer random medium model is adopted to study the volume scattering effects for the active and passive microwave remote sensing of snow-covered ice fields [13]. We simulate the snow layer by an isotropic random medium and the ice layer by an anisotropic random medium. In snow, the fluctuation of the permittivity and the physical sizes of the granular ice particles are characterized by the variance and two correlation lengths. In ice, the anisotropic effect is attributed to the elongated structures and the specific orientations of the air bubbles, the brine inclusions, and other inhomogeneities. Two variances are required to characterize the fluctuations of the permittivities along or perpendicular to the tilted optic axis. The physical sizes of those scattering elements are also described by two correlation lengths.

Nonlinear EM wave interactions with the upper atmosphere have been investigated on the following subjects: (1) the simultaneous excitation of ionospheric density irregularities and earth's magnetic field fluctuations, (2) the electron acceleration by Langmuir wave turbulence, and (3) the occurrence of artificial spread F. While processes (2) and (3) can be caused only by HF waves, process (1) occurs with EM frequencies as low as in the VLF band and as high as in the SHF band.

Radio measurements of Total Electron Content (TEC) and optical detection of airglow variations show that large scale plasma patches appearing in the high latitude ionosphere have irregular structures, evidenced by the satellite phase and amplitude scintillations. Whistler waves, intense quasi-DC electric fields, atmospheric gravity waves, and electrojets are potential sources of various plasma instabilities. The role of thermal effects in generating ionospheric irregularities by these sources have been investigated. A model has been developed to explain the discrete spectrum of the resonant ULF waves that have been commonly observed in the magnetosphere. The resonant electron diffusion is suggested to be an effective saturation process of the auroral kilometric radiation. The calculated intensity of the saturated radiation has a significantly lower value in comparison with that caused by the quasi-linear diffusion process as an alternative saturation process.

The vegetation canopy and snow-covered ice field have been studied with a three-layer model, an isotropic random medium layer overlying an anisotropic random medium. We have calculated the dyadic Green's functions of the three-layer medium and the scattered electromagnetic intensities with Born approximation. The backscattering cross sections are evaluated for active microwave remote sensing. The theoretical approach can be extended to derive the bistatic scattering coefficients. After integrating the bistatic scattering coefficients over the upper hemisphere and substracting from unity, we can also compute the radiometric brightness temperatures for passive microwave remote sensing by invoking the principle of reciprocity.

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