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RADAR SCENE GENERATION FOR TACTICAL DECISION AIDS

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RADAR SCENE GENERATION FOR TACTICAL DECISION AIDS

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FINAL REPORT

Under the sponsorship of the NASA Contract NAG5-769, we have published 23 refereed journal and conference papers and 6 technical reports for the research on the Radar Scene Generation For Tactical Decision Aids.

We have studied the Mueller matrix and polarization covariance matrix 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.

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.

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. 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.

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.

PUBLICATIONS SUPPORTED BY NASA CONTRACT NAG-5-769

REFEREED JOURNAL AND CONFERENCE PAPERS

Radar cross section prediction using a hybrid method (C. Lee and R. T. Shin), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9-13, 1986.

Radar cross section prediction for coated perfect conductors with arbitrary geometries (S. W. Rogers and R. T. Shin), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9-13, 1986.

Polarimetric microwave remote sensing of anisotropic earth terrain with strong fluctuation theory (M. Borgeaud, J. A. Kong, and R. T. Shin), *IGARSS 87 and URSI Meeting*, University of Michigan, Ann Arbor, MI, May 18-21, 1987.

Theoretical models for active and passive microwave remote sensing of snow-covered sea ice (F. C. Lin, J. A. Kong, and R. T. Shin), *IGARSS 87 and URSI Meeting*, University of Michigan, Ann Arbor, MI, May 18-21, 1987.

Theoretical models for polarimetric radar clutter (M. Borgeaud, R. T. Shin, and J. A. Kong), *Journal of Electromagnetic Waves and Applications*, vol. 1, no. 1, pp. 73-89, 1987.

Electromagnetic Wave Theory (J. A. Kong), Wiley-Interscience, New York, 696 pages, 1986.

On the resonant ionospheric heating at the electron gyrofrequency (M. C. Lee, J. A. Kong, and S. P. Kuo), *Proceedings of the International Symposium on Modification of the Ionosphere by Powerful Radio Waves*, 111, Suzdal/Moscow, U.S.S.R., September 9-12, 1986.

Enhanced ionospheric modifications by the combined operation of HF and VLF heaters (M. C. Lee, J. A. Kong, and S. P. Kuo), *Proceedings of the International Symposium on Modification of the Ionosphere by Powerful Radio Waves*, 146, Suzdal/Moscow, U.S.S.R., September 9-12, 1986.

Parametric excitation of whistler waves by HF heater (S. P. Kuo and M. C. Lee), *Proceedings of the International Symposium on Modification of the Ionosphere by Powerful Radio Waves*, 109, Suzdal/Moscow, U.S.S.R., September 9-12, 1986.

Microwave remote sensing of snow-covered sea ice (M. Borgeaud, J. A. Kong, and F. C. Lin), *1986 International Geoscience and Remote Sensing Symposium*, Zürich, Switzerland, 8-11, September, 1986.

Polarimetric radar clutter modeling with a two-layered anisotropic random medium (M. Borgeaud, J. A. Kong, and R. T. Shin), *International Union of Radio Science Commission F Open Symposium*, University of New Hampshire, Durham, New Hampshire, July 28-August 1, 1986.

Remote sensing of snow-covered sea ice (F. C. Lin and J. A. Kong), *International Union of Radio Science Commission F Open Symposium*, University of New Hampshire, Durham, New Hampshire, July 28-August 1, 1986.

Nonlinear EM wave interactions with the neutral atmosphere (S. Nghiem, M. C. Lee, and J. A. Kong), *International Union of Radio Science Commission F Open Symposium*, University of New Hampshire, Durham, New Hampshire, July 28–August 1, 1986.

Effective permittivity of dielectric mixtures (A. Sihvola and J. A. Kong), *International Union of Radio Science Commission F Open Symposium*, University of New Hampshire, Durham, New Hampshire, July 28–August 1, 1986.

Modified radiative transfer theory for a two-layer anisotropic random medium (J. K. Lee and J. A. Kong), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9–13, 1986.

Theoretical modeling of polarimetric radar clutter (M. Borgeaud, R. T. Shin, and J. A. Kong), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9–13, 1986.

A new formula for partial fraction expansion of a transfer matrix (C. F. Chen and G. Freeman), *Comp. & Maths. with Appls.*, vol. 12A, no.9, 963-968, 1986.

Radar cross section prediction using a hybrid method (C. Lee and R. T. Shin), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9–13, 1986.

Radar cross section prediction for coated perfect conductors with arbitrary geometries (S. W. Rogers and R. T. Shin), *National Radio Science Meeting*, Philadelphia, Pennsylvania, June 9–13, 1986.

Stimulated backscattering of lower hybrid waves (S. P. Kuo and M. C. Lee), *Physics of Fluids*, 29(4), 1024-1028, April 1986.

Backscattering and propagation of radar pulses in earth terrain media (F. C. Lin, J. A. Kong, R. T. Shin, and Y. E. Yang), *IEEE IMTC/86 Meeting*, Boulder, Colorado, March 24–27, 1986.

Resonant electron diffusion as a saturation process of the synchrotron maser instability (M. C. Lee and S. P. Kuo), *Journal of Plasma Physics*, vol. 35, part 1, 177-184, 1986.

Theory of Microwave Remote Sensing (L. Tsang, J. A. Kong, and R. T. Shin), Wiley-Interscience, New York, 613 pages, 1985.

EWT REPORTS

Radar cross section prediction for coated perfect conductors with arbitrary geometries (S. W. Rogers and R. T. Shin), Technical Report No. EWT-RS-92-8606, MIT, 1986.

Polarimetric radar clutter modeling with a two-layer anisotropic random medium (M. Borgeaud, J. A. Kong and R. T. Shin), Technical Report No. EWT-RS-94-8608, MIT, 1986.

Dielectric properties of geophysical media (A. Sihvola and J. A. Kong), Technical Report No. EWT-RS-96-8608, MIT, 1986.

Effective permittivity of dielectric mixtures (A. Sihvola and J. A. Kong), Technical Report No. EWT-RS-97-8608, MIT, 1986.

Theoretical models for polarimetric radar clutter (M. Borgeaud, R. T. Shin and J. A. Kong), Technical Report No. EWT-RS-99-8608, MIT, 1986.

Theoretical Models for Microwave Remote Sensing of Snow-Covered Sea Ice (F. C. Lin, J. A. Kong, and R. T. Shin), Technical Report No. EWT-RS-102-8705, MIT, 1987.