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REMOTE SENSING OF EARTH TERRAIN

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1. Objective

The objective of this research is to develop theoretical models that are useful and practical in the remote sensing of the earth environment including the earth terrain, the lower and the upper atmospheres. We have been very successful in developing various models applicable to the microwave remote sensing of vegetation, snow-ice, and atmospheric precipitation. We shall extend such studies to the higher frequency range to unify the optical band and the microwave theoretical foundations. We shall also extend our study, which had an emphasis on vegetation canopy to include all terrain media, and the whole earth environment. A data base will be developed to generate scene radiation characteristics which will benefit the studies of global inhabitability, meteorological applications, and crop yield.

2. Technical Approach

The radiative transfer theory has been fully developed to treat the volume and rough surface scattering effects. The combined random rough surface and volume scattering effects have been studied by employing a Gaussian random surface and applying the small perturbation methods which are modified with the use of cumulant techniques. The rough surface effects are incorporated into the radiative transfer equations by modifying the boundary conditions for the intensities. The T-matrix method, which utilizes vector spherical wave functions for the expansion of incident, scattered, and surface fields is used to derive the extinction matrix and the phase matrix for the radiative transfer equations. Densely distributed spherical dielectric scatterers is studied with the quantum mechanical potential approach. The quasi-crystalline approximation is applied to truncate the hierarchy of multiple scattering equations and the Percus-Yevick result is used to represent the pair distribution function. The modified radiative transfer theory is studied with the Feynman diagrammatic representation. Atmospheric precipitation is also studied with the vector radiative transfer equations by making use of the Mie scattering phase functions and incorporating the rain-drop size distributions. To study scattering by anisotropic medium modelling sea ice and vegetation field with row structures, the dyadic Green's function is first derived and used in conjunction with the first-order Born approximation to calculate the backscattering coefficients.

3. Research Results

In active microwave remote sensing, a two-layer anisotropic random medium model has been developed to investigate the anisotropic effect of sea ice in which, due to the flow of sea water, the brine inclusions are tilted and to study the azimuthally anisotropic behavior of vegetation canopy which is attributed to the orientations of the vegetation stalks. In this scheme, the dyadic Green's function for a two-layer anisotropic medium is developed and used in conjunction with the first order Born approximation to calculate the backscattering coefficients. It is shown that strong cross-polarization occurs in the single scattering process and is indispensable in the interpretation of radar measurements of sea ice at different frequencies, polarizations, and viewing angles. The effects of anisotropy on angle responses of backscattering coefficients are also illustrated. For passive microwave remote sensing of a two-layer anisotropic random medium, the principle of reciprocity is invoked to compute the brightness temperatures. The bistatic scattering coefficients are first calculated with Born approximation and then integrated over the upper hemisphere to be subtracted from unity, in order to obtain the emissivity for the random medium layer. The theoretical results are illustrated by plotting the emissivities as functions of viewing angles and polarizations. They are used to interpret remote sensing data obtained from vegetation canopy where the aniostropic random medium model applies. Field measurements with corn stalks arranged in various configurations with preferred azimuthal directions are successfully interpreted with this model.

The problem of microwave scattering from periodic surfaces is solved by using a rigorous modal technique which conserves energy, obeys reciprocity, and takes into account the multiple scattering and shadowing effects. The theoretical results have been applied to the calculation of the radar backscattering cross sections in active remote sensing and the brightness temperatures in passive remote sensing, and used to match field data from soil moisture measurements. The angular behavior of the brightness temperatures has been explained with the threshold phenomenon by considering the appearance and disappearance of the various Floquet modes. The Kirchhoff approximation is used to study the scattering of electromagnetic waves from randomly perturbed quasi-periodic plowed fields. The narrow-band Gaussian random variation around the spatial frequency of the sinusoidal variation is used to introduce the quasiperiodicity. The physical optics integral is evaluated to obtain closed form solutions for coherent and incoherent bistatic scattering coefficients. In the geometrical optics limit, it is shown that the bistatic scattering coefficients are proportional to the probability of the occurrence of the slopes which will specularly reflect the incident wave into the observation direction. The theoretical results are illustrated for the various cases by plotting backscattering cross sections as a function of the incident angle. It is shown that there is a large difference between the cases where the incident wave vector is parallel or perpendicular to the row direction. When the incident wave vector is perpendicular to the row direction, the maximum value of the backscattering cross section does not necessarily occur at normal incidence. The scattering coefficients can be interpreted as a convolution of the scattering patterns for the sinusoidal and for the random rough surfaces. For the backscattering cross sections we observe the occurrence of peaks the relative magnitudes and locations of which are explained in terms of the scattering patterns for sinusoidal surfaces. The combined random rough surface and volume scattering effects have been studied by employing a Gaussian random surface and applying the small perturbation methods which are modified with the use of cumulant techniques. The rough surface effects are incorporated into the radiative transfer equations by modifying the boundary conditions for the intensities. The radiative transfer equations are then solved numerically using the Gaussian quadrature method and the results are illustrated and compared with experimental data.

The radiative transfer theory is applied to calculate the scattering by a layer of randomly positioned and oriented nonspherical particles. The scattering amplitude functions of each individual particle are calculated with Waterman's T-matrix method, which utilizes vector spherical wave functions for the expansion of incident, scattered, and surface fields. The orientation of the particles is described by a probability density function of the Eulerian angles of rotation and a rotation matrix is used to relate the T-matrix of the principal frame to that of the natural frame of the particle. The extinction and phase matrices for the radiative transfer equations are expressed in terms of the T-matrix elements. The extinction matrix for nonspherical particles is generally nondiagonal. It is shown that there are only two attenuation rates in a specified direction of propagation. The scattering of a plane wave obliquely incident on a half space of densely distributed spherical dielectric scatterers is studied with the quantum mechanical potential approach. The quasi-crystalline approximation is applied to truncate the hierarchy of multiple scattering equations and Percus-Yevick result is used to represent the pair distribution function. While results at high frequencies are calculated numerically, closed form solutions are obtained in the low frequency limit for the effective propagation constants, the coherent reflected wave and the bistatic scattering coefficients.

In the strong fluctuation theory for a bounded layer of random discrete scatterers, the second moments of the fields in the second order distorted Born approximation are obtained for co-polarized fields. The backscattering cross sections per unit area are calculated by including the mutual coherence of the fields due to the coincident ray paths, and those due to the opposite ray paths, corresponding to the ladder and cross terms in the Feynman diagrammatic representation. It is proved that the contributions from ladder and cross terms for the co-polarized backscattering cross sections are the same, while the contributions for the cross-polarized backscattering cross sections 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 contributions from the cross terms explain the enhancement in the backscattering direction.

Both passive and active remote sensing of atmospheric precipitation are studied with the vector radiative transfer equations by making use of the Mie scattering phase functions and incorporating the rain drop size distributions. For passive remote sensing we employ the Gaussian quadrature method to solve for the brightness temperatures, and for active remote sensing an iterative approach carryied out to second order in albedo is used to calculate the bistatic scattering coefficients and the backscattering cross sections per unit volume.

4. Significance of Results

The anisotropic medium model that has been developed is now able to account for the like as well as cross polarization measurements of the backscattering cross sections in active remote sensing of sea ice. The same model applies to the interpretation of data from the passive remote sensing of vegetation field. Extending this two-layer medium model to multilayered configuration will facilitate the interpretation for more complicated scene radiation characteristics.

The strong fluctuation theory has been successfully developed to account for the volume scattering effects, not only for earth terrain media such as vegetation and snow-ice fields, but also for the remote sensing of atmospheric precipitation. The periodic rough surface theory provides a rigorous approach that satisfies both the principle of reciprocity and the principle of energy conservation.

5. Next Major Steps

There are three major steps: 1) To extend our study to include the effects of the upper atmosphere such as the troposphere, the ionosphere, and the magnetosphere. Our initial success with the usage of the random medium model applied to atmospheric precipitation serves as a solid starting point. 2) To extend our study to other earth terrain medium configurations such as canopy-covered soil moisture investigation, snow-covered fields, and layered-medium model including both volume scattering and rough surface scattering effects. 3) To extend our study to unify the theoretical foundation for the microwave and the optical spectra. The starting point is the application of the radiative transfer theory, which has been developed in both frequency ranges rather independently.