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SEMI-ANNUAL PROGRESS REPORT

ON

MESOSCALE MONITORING OF THE SOIL FREEZE/THAW BOUNDARY FROM ORBITAL MICROWAVE RADIOMETRY

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1.0 INTRODUCTION

This progress report covers the work conducted under NASA Grant NAG5-852 during the time period from October 1, 1986 to January 31, 1988.

2.0 STATUS OF FIRST YEAR RESEARCH

The fundamental objectives of this research are to test the feasibility of delineating the lateral boundary between frozen and thawed conditions in the surface layer of soil from orbital microwave radiometry and secondly to examine the sensitivity of general circulation models to an explicit parameterization of this boundary condition. Prior to developing the freeeze/thaw boundary detection algorithm sought in this study, it has been necessary to (a) develop appropriate physical models that relate the radiation emitted by the scene to its physical properties, (b) develop an image simulation program that simulates SMMR data and (c) verify our understanding of the process as formulated by the models via comparison of simulations with actual SMMR data.

Under optimum conditions, where soil surfaces are unobscured by intervening vegetation canopies or snow, the detection problem reduces to differentiation of frozen and thawed conditions on the basis of the functional dependence of a soil's brightness temperature upon emissivity and physical temperature. In this case, the problem is complicated by the spatial heterogeneity of soil surfaces, in terms of soil texture, bulk density, and surface roughness, with respect to resolution cell size of the orbital instrumentation and by temporal variability, in terms of temperature and moisture, with respect to sensor revisit interval. For the non-optimum conditions imposed by the presence of intervening media (such as snow or vegetation), the sensitivity of brightness temperature to the state of soil moisture (frozen or thawed) is greatly diminished; and the variability of these conditions in both space and time further complicates the detection problem. Hence, in general, the detectability of frozen versus thawed soils is bounded by sensitivity of the technique over the possible range of surface conditions and by issues of scaling as related to scene heterogeneity within a resolution cell.

As a consequence, physical models have been developed to relate emissivity to scene properties and a simulation package has been developed to predict brightness temperature as a function of emissivity and physical temperature in order to address issues of heterogeneity, scaling, and scene dynamics.

2.1 Emission Models

Radiative transfer models have been developed for both bare soil surfaces and those obscured by an intervening layer of vegetation or snow. These models relate the emissivity to the physical properties of the soil (moisture content, density, physical temperature, soil composition and surface roughness) and to those of the snow or vegetation cover. These models have been developed to match the wavelengths (0.8 cm to 4.5 cm), polarizations (H and V), and angle of incidence of the SMMR sensors on Nimbus-7. The model developments involved some theoretical work as well as empirical relations based upon experimental data reported in the literature. Computer programs have been written to:

(a) Relate the dielectric constant of soil as a function of frequency to its temperature, moisture content, bulk density, and composition.

(b) Relate the dielectric constant of vegetation to its moisture content and temperature.

(c) Relate the dielectric constant of snow to its temperature, density, and wetness.

(d) Relate the emissivity of bare soil surfaces to the soil temperature, dielectric constant, and surface roughness as a function of frequency and polarization state.

(e) Relate the emissivity of a vegetation-covered soil surface to the soil and vegetation contributions as a function of frequency and polarization state.

(f) Relate the emissivity of a snow-covered soil surface to the soil and snow contributions as a function of the frequency and polarization state.

(g) Develop distribution functions to characterize the emission from water, ice, and man-made urban features as a function of frequency and polarization state.

2.2 SMMR Simulation

A SMMR simulation package has been developed to evaluate (1) the adequacy of the emission models and (2) the limiting effects of scaling for realistic scenarios incorporating spatially heterogeneous scenes with dynamic moisture and temperature gradients at the pixel scale. The simulation requires (1) the emission models previously described, (2) a model of the SMMR scanning mechanics and antenna on Nimbus-7, and (3) simulated surface conditions which drive the emission and temperature models.

The simulated region comprises an area roughly bounded by 80° to 110° W. longitude and 35° to 55° N. latitude. This area is subdivided into three test areas from west to east which can be generally characterized as grassland, mixed grass/herbaceous/and forest cover, and forest cover respectively. Consequently, these subareas also represent increasing spatial complexity of terrain conditions within the scene to be simulated. The two dimensional spatial distributions of bare soil, soil type, vegetation cover type, water bodies, and urban features are generated stochastically from density gradients derived from map-based information. The net result is a grid of pixels which is sub-resolution compared to SMMR data with each pixel characterized by a percent area occupied by given surface conditions. A two dimensional surface moisture and temperature gradient is then applied to these conditions to provide all of the requisite inputs for the emission models. The net emission and brightness temperature for each grid cell is calculated as the incoherent sum from each surface cover condition and its percent area. The observed antenna temperatures are next simulated by integrating over the appropriate beamwidth at each SMMR wavelength. The simulation has been tested, to date, with simplified linear gradients.

2.3 SMMR Data

Archival SMMR data products are required in order to verify the simulation procedure and to test multidate analytic techniques seeking to benefit from change-detection approaches. SMMR data has been requested from NSSDC to cover the fall and winter period of 1984-1985. A sample of this data was received in October 1987 and the data has been successfully read and reformatted for use in image display and analysis routines. The bulk of the data (20+ 6250 bpi CCTs) was received in early February 1988; and is in the process of being copied and reformatted. The size of the data set is being truncated to conform to the region of simulation (80° to 110° W. longitude and 35° to 55° N. latitude).

This time period for the SMMR data has been selected because of generally moist conditions prevalent in the fall time frame. Sensitivity studies based upon the emission models show that such conditions should yield the highest probability of detecting the soil freeze/thaw boundary.

3.0 FUTURE RESEARCH

The simulation package developed for SMMR data will be exercised for sub-areas of the midwestern North American continent. The simulation will incorporate a sequence of moisture and temperature gradients appropriate for selected time periods from late-summer 1984 to mid-winter 1985. These simulations will be compared to the actual SMMR data from this area and at these times to verify our mathematical understanding of the problem. On this basis the models will be modified where necessary.

Upon verification, the composite emission models will be used in sensitivity studies to define a small set of candidate retrieval algorithms and to explore the accuracies and limitations of these algorithms in the presence of spatial inhomogeneity in surface conditions and various types of surface conditions (i.e. snow cover and vegetation cover).

In addition, the archival SMMR data will be used to test these retrievals and to incorporate multi-date retrieval approaches, if possible, to help overcome some of the noted deficiencies via change detection methodology. The effective resampling interval of the SMMR for a given region is expected to play a critical role here and is the consequence of both orbital mechanics and duty cycle of the instrument.

Finally, research will be initated on the sensitivity of general circulation models to the availability and the expected accuracy limitations of satellite derived information on the soil freeze/thaw boundary.