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Recent developments in satellite microwave remote sensing of soil moisture

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Abstract

Significant research developments in microwave remote sensing of soil moisture have occurred over the last ten years. These developments have been brought about largely through a combination of modelling and field studies. Field studies are usually instrument oriented, and typically consist of ground-based radiometer studies, aircraft missions, and often satellite studies. Modelling studies have been conducted both independently and in support of instrument programs. A number of key modelling studies have been conducted with retrospective satellite data sets. The Scanning Multichannel Microwave Radiometer (SMMR), which was carried on board the Nimbus-7 satellite, has provided an important 9-year (1978-1987) global data set of microwave observations, and has been the basis for a number of important microwave-based soil moisture studies. Results from several of these studies, along with results from some instrument field studies are presented.

Introduction

Surface moisture is an important link between the land surface and the atmosphere. It has direct influence on the exchange of heat and moisture between these two sinks, and as such is an important element in the global circulation process. Surface soil moisture has been identified as a parameter of significant potential for improving the accuracy of large-scale land surface-atmosphere interaction models. However, soil moisture is quite difficult to measure accurately both temporally and spatially, especially at large spatial scales. Soil moisture changes constantly, as a result of precipitation, evaporation processes (which includes extraction by vegetation), and redistribution within the soil. Soil moisture is highly variable at both small and large spatial scales, due largely to the variability of precipitation and the heterogeneity of the land surface (e.g. vegetation, soil physical properties, topography, etc.). While point sampling of soil moisture is generally thought to be the most accurate, the observed value is usually representative only of a relatively small area immediately surrounding the measurement. Subsequent spatial averaging of these measurements, especially at scales up to 10^2 - 10^3 km^2 or larger, will often introduce large errors. Since remotely sensed land surface measurements are already a spatially averaged value, they are a logical input parameter to regional or larger-scale land process models. Regular and improved estimates of soil moisture have been shown to significantly enhance the performance of GCM's and certain mesoscale models, such as flood forecast models [1].

Microwave remote sensing has been used to monitor surface soil moisture with increasing degrees of success. Both ground-based [2-5] and airborne radiometer experiments [6,7] have generally provided good results, largely because of good quality observations of supporting land surface properties such as soil moisture,

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vegetation, and surface temperature. These experiments are generally supported by intensive soil moisture measuring programs, to ensure optimum spatial representation for comparison. However, satellite-based studies [8-10] have historically been less successful. This is due to a great extent, to a general inadequacy of surface observations at the larger spatial scales. Traditional satellite remote sensing studies have relied heavily on either relatively sparse ground measurements of soil moisture or modelled data, primarily for calibration purposes. These approaches would typically use a radiative transfer model to first solve for the vegetation component, which then would be related to some measurable remote sensing parameter, such as the Normalized Difference Vegetation Index (NDVI).

Recently, however, a number new soil moisture retrieval techniques have been developed. These approaches partition the observed microwave signal into its component parts, and are somewhat unique in that they do not require ground observations of soil moisture or vegetation biophysical properties for calibration purposes. This paper will briefly present some basic microwave theory and then describe the results of several theoretical applied studies which have been conducted during the past several years.

Discussion and conclusions

Efforts to use remote sensing as a more consistent and cost effective method of monitoring the Earth and providing regular observations of various surface and atmospheric parameters has been highly successful. Certain parameters, such as vegetation biomass, snow cover, snow water equivalent, and land use classification, are reported regularly, and often in near real time through operational satellite monitoring programs. In many instances, historical global data-bases have been compiled, and have proven invaluable as validation tools.

Research in the area of microwave remote sensing has lead to important developments in recent years. A combination of field programs and modelling studies have aimed at improving the interpretation of passive microwave observations of the land surface. Developments in inverse modelling techniques have resulted in improved estimates of important land surface parameters such as soil moisture and vegetation canopy properties. Knowledge of vegetation properties such as single scattering albedo and optical depth is important because they tend to mask and distort the microwave signal. Their effect must be removed in order to obtain accurate estimates of soil moisture.

Surface soil moisture is a key factor in the partitioning of incoming radiation at the land surface. It is a common link between the moisture and energy balances, which are the physical bases for land surface modelling. While the importance of soil moisture is largely understood, independent spatial estimates at local to global scales are still largely unavailable. This lack of soil moisture information has had a negative affect on land process modelling efforts.

Passive microwave remote sensing presents the greatest potential for providing this information at regular spatial and temporal scales. Reliable estimates of surface moisture should provide the necessary input for improved predictions of global circulation. Real time estimates should also improve weather and climate modelling efforts, while the development of retrospective data sets will provide necessary information for simulation and validation of long term climate and global change studies. Additional applications of these data include desertification and drought monitoring, agricultural forecasting, and flood potential prediction.

Research results have demonstrated strong potential for deriving soil moisture from C-band microwave systems, and should provide a basis for further development and application of inverse modelling techniques at this frequency. This is especially important, in light of the upcoming launch of the NASA AQUA platform, and since the development of longer wavelength systems is still uncertain for the foreseeable future.

Plans are currently underway, to develop a more than 20-year database of historical global surface soil moisture. Because the Nimbus-7 SMMR data are available only through mid-1987, the data will be extended with Defense Satellite Mapping Program (DSMP) Special Sensor Microwave/Imager (SSM/I) observations from the beginning of August 1987. However, since the lowest frequency on the SSM/I is 19 GHz, which corresponds to a wavelength of only about 1.6 cm. the SSM/I data product will be somewhat degraded. Nevertheless, it should still be useful for hydrological modelling purposes. The dataset will again revert back to C-band, after the launch of the new AQUA satellite, currently scheduled for late 2001. The database will be in the form of daily global maps of soil moisture. Expected errors will be based on the calculated vegetation optical depth. The data product will be made available to the general public, through the Goddard Space Flight Center Distributed Active Archive Center (DAAC).