SOIL MOISTURE MAPPING THE SOUTHERN U.S. WITH THE TRMM MICROWAVE IMAGER: PATHFINDER STUDY

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ABSTRACT

The Tropical Rainfall Measuring Mission (TRMM) was launched in November of 1997. TRMM Microwave Imager (TMI) provides a least a daily coverage over the southern Continental US (up to 38N latitude). The goal of this project is to develop a soil moisture pathfinder data set using the TMI observations. TMI provides multiple orbits over the southern US at varying times of observation. Methods to adjust for diurnal changes associated with this temporal variability and how to mosaic these orbits are required. The algorithm for deriving soil moisture and temperature from TMI observations is based on a physical model of microwave emission from a layered soil-vegetation-atmosphere medium. An iterative, least-squares-minimization method is employed in the retrieval algorithm. It is important to recognize that these high frequencies respond to a very shallow soil layer (~1-2 cm). Characterizing this layer is difficult and it can change rapidly. The significance of vegetation is very high at these frequencies. Based upon further validation and algorithm development, a five year daily soil moisture data set for applicable regions of the southern U.S. will be produced.

1. INTRODUCTION

There is a critical need in land surface hydrology to understand the feedback between the land surface and the atmosphere. Surface soil moisture may be one of the most important variables required to develop this information. There are no validated large scale or regional, long-term databases for this purpose. The goal of this project is to develop a soil moisture pathfinder data set for this research. This is the first attempt to map daily soil moisture from space over an extended period of time. Earlier attempts involved soil moisture mapping using airborne sensors over experimental areas (Jackson et al., 1995; Jackson et al., 1999).

Recognizing the limitations of past, current and near future microwave satellite systems, as well as the availability of adequate validation data, this project focuses on the use of the TRMM Microwave Imager (TMI) over the southern portion of the U.S. The goal is to develop a daily five-year soil moisture pathfinder data set using the TMI observations.

2. TRMM TMI

The Tropical Rainfall Measuring Mission (TRMM) has provided data since December of 1997. TRMM is in a sun asynchronous orbit with an angle of inclination of 35^o providing 16 orbits per day.

One of the satellite instruments is the TRMM Microwave Imager (TMI). TMI is a dual-polarization passive microwave conical scanning radiometer operating at 10.65, 19.4, 21.3, 37.0 and 85.5 GHz. It has a spatial resolution of about 50-km at 10.65 GHz.

TMI has a wide swath that can provide data between +/-38^o latitude. On a given day there will be multiple orbits over the southern U.S. at varying times of observation.

3. STUDY REGION

Several factors contributed to selecting and limiting the analyses to the southern U.S. These included the observation domain of the TMI, the effects of vegetation on algorithm performance, temporal variability, and available resources for ground based validation. Figure 1 shows the extent of the study region and the location of

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potential validation data. Validation will start with the Southern Great Plains (SGP), which has extensive in-situ observations, and then expand to ARS watershed and other networks.

4. SOIL MOISTURE ALGORITHM

The algorithm for deriving soil moisture and temperature from TMI observations is based on a physical model of microwave emission from a layered soil-vegetation-atmosphere medium. Dual polarization observations at 10.65 GHz are used in the retrieval. The land surface is modeled as an absorbing vegetation layer above soil. An iterative, least-squares-minimization method is employed in the retrieval algorithm. The algorithm is based on the multi-channel approach decribed in Njoku and Li, 1999; Bindlish and Barros, 2000; and Jackson and Hsu, 2001.

The relationship between brightness temperature (T_B) and soil moisture, surface roughness (Choudhury et. al, 1979) and vegetation water content (Jackson and Schmugge, 1991), is nonlinear. The method of soil moisture retrieval uses an iterative least-squares minimization algorithm based on the forward model developed to invert the measured brightness temperature and estimate the unknown variables. Soil moisture is most sensitive to the lowest TMI frequency (10.65 GHz), thus only the H and V polarization measurements at this frequency were used in the retrieval process.

The polarization ratio (T_{BH}/T_{BV}) is independent of soil temperature and is dependent only on soil moisture and vegetation water content (Paloscia et al., 1992). Whereas, the independent channel observations (H or V) are dependent on soil moisture, soil temperature and vegetation water content. Also, H polarization measurements have a higher sensitivity to soil moisture. Both surface roughness and vegetation have a similar relationship to brightness temperature (exponential), thus it is impossible to separate the two effects (unless one of them is known a priori). A fixed value of 0.1 was used for surface roughness and the remainder effect gets automatically coupled with the vegetation effect. Keeping these relationships in perspective, a least-squares minimization approach was adopted. The polarization ratio and the H and V band measurements (x) were used to obtain soil moisture, soil temperature and vegetation water content (y).

Assuming the forward model can be represented by Q(x), where x are the parameters soil moisture, soil temperature and vegetation water content. The solution for x is found iteratively. An initial guess for x is made based on the average value of the surface parameters. The sensitivity of each surface parameter (at iteration t) to the observation is computed by numerically perturbing the parameter by a small amount

$$[J_t]_{ij} = \left(\frac{\partial Q_i}{\partial x_j} \right)_t \tag{1}$$

A simple Newton-Raphson iteration is adopted to obtain convergence of these surface parameters.

5. ANCILLARY DATA

The algorithm in its current form requires several ancillary data sets for implementation: surface soil texture, land cover, and vegetation index (NDVI). The following summarizes the decisions and datasets selected for this process.

Surface Soil Texture. Soil properties do not change and, therefore, this data plane of ancillary data is constant. A multi-layer soil characteristics data set for the conterminous United States (CONUS-SOIL) has been developed at Penn State's Earth System Science Center (ESSC) (http://www.essc.psu.edu/soil_info/) and were adapted to this project.

Land Cover. Land cover can also be assumed to be a nearly constant data plane. We are using the 1-km scale product from the University of Maryland. Land cover is used in the algorithm to mask out water and other categories from further computations and to define vegetation parameters. An initial data set and parameter is available. It is anticipated that a seasonal table would be added to refine this decision rule.

Vegetation Index. Vegetation index is used to estimate the vegetation water content. Functions to perform this have yet to be developed. At the present time we are using NDVI products provided by the NASA DAAC.

6. TEMPORAL NORMALIZATION

TMI coverage over the southern U.S. is obtained on several orbits separated in time. In order to produce a synoptic product it is necessary to normalize these data to a single point in time. We developed a technique to mosaic these orbits based upon our experiences with aircraft mapping projects (Jackson et al. 1995 and 1999). On a given day, a single pass is selected as a reference. All passes on a day overlap this reference for some portion of the coverage.

These overlap areas are used to normalize the different passes. Figure 2 is one example of a merged and normalized data set.

7. VALIDATION STUDIES

Validation consists of a series of increasingly more comprehensive analyses. Initial efforts included an analysis of the TMI retrieval of soil moisture using the SGP99 data set (Jackson and Hsu, 2001). Satellite data collected by the TRMM Microwave Imager (TMI) were compared to soil moisture observations collected as part of the Southern Great Plains (SGP) 1999 Experiment. Data collection was conducted between July 8th and July 20th during which an excellent sequence of meteorological conditions occurred.

In order to broaden the validation dataset, we conducted a one week field experiment within the Little River Watershed located near Tifton, Georgia. The experiment was designed to provide spatially distributed surface soil moisture over a nominal TMI footprint area. It was timed for a morning sequence of TMI coverage between June 5 and 9, 2000. Soil moisture conditions included a wide range of values. Preliminary comparisons of TMI brightness temperature and soil moisture show patterns similar to those observed in SGP99.

8. SOIL MOISTURE RESULTS

The methodology used here estimates independent point estimates of soil moisture based on TMI observations. Figure 3a and 3b show the soil moisture estimates for July 8 and 10, 1999 respectively. During this 2 day period, northern Nevada, northern Texas, Oklahoma Tennessee received significant rainfall (~ 2.5 cm). The soil moisture estimates for CA show a dry-down during this period. The soil moisture estimates for Texas, Oklahoma, Tennessee and Georgia on July 10 are higher than July 8 estimates. On the contrary, estimates over Wyoming and Colorado also show a clear dry-down.

Retrieved variables represent area-averages over the 10.65 GHz footprints and also averages over the vertical sampling depth in the soil/vegetation medium. As the vegetation cover increases, the retrieval error increases. Uncertainties associated with land surface parameters (such as soil roughness, vegetation scattering and opacity coefficient, soil texture, etc.) propagate into the retrieval uncertainties for soil moisture and temperature.

ACKNOWLEDGEMENTS:

This work is supported by NASA Earth Science Enterprise Modeling and Data Analysis Research Program.

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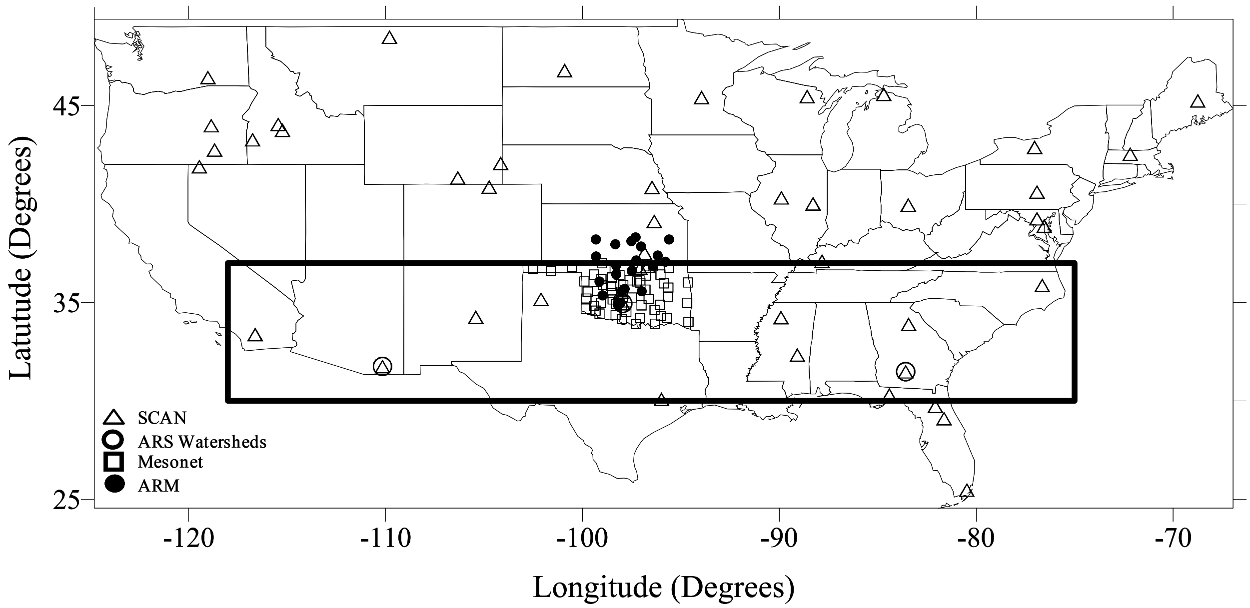

Figure 1. Schematic of Project Area and Study Sites

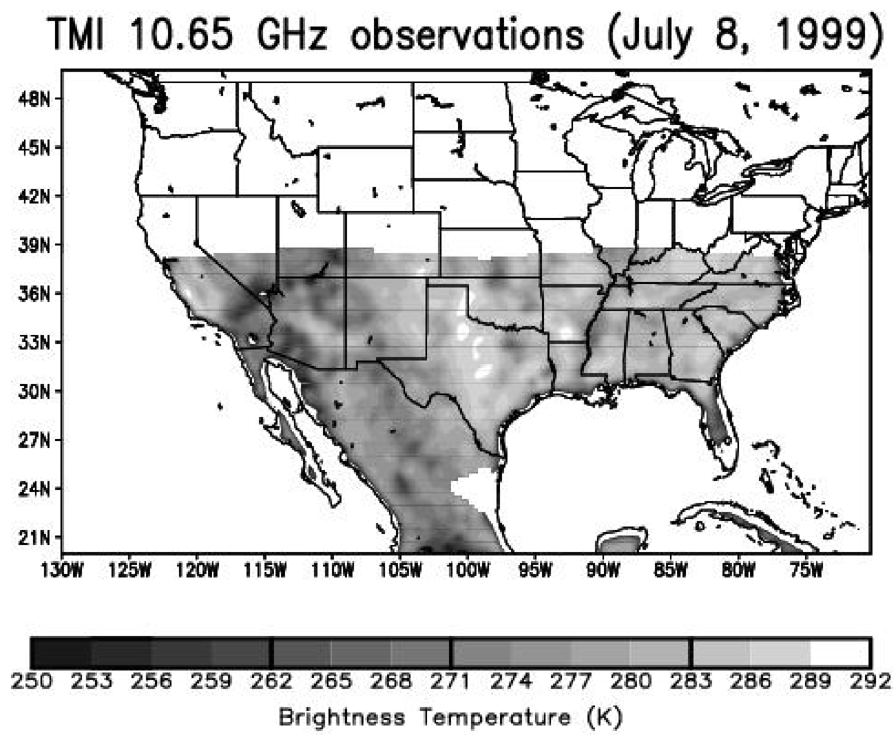

Figure 2. Normalized composite of TMI 10.65 GHz H data (July 8, 1999).

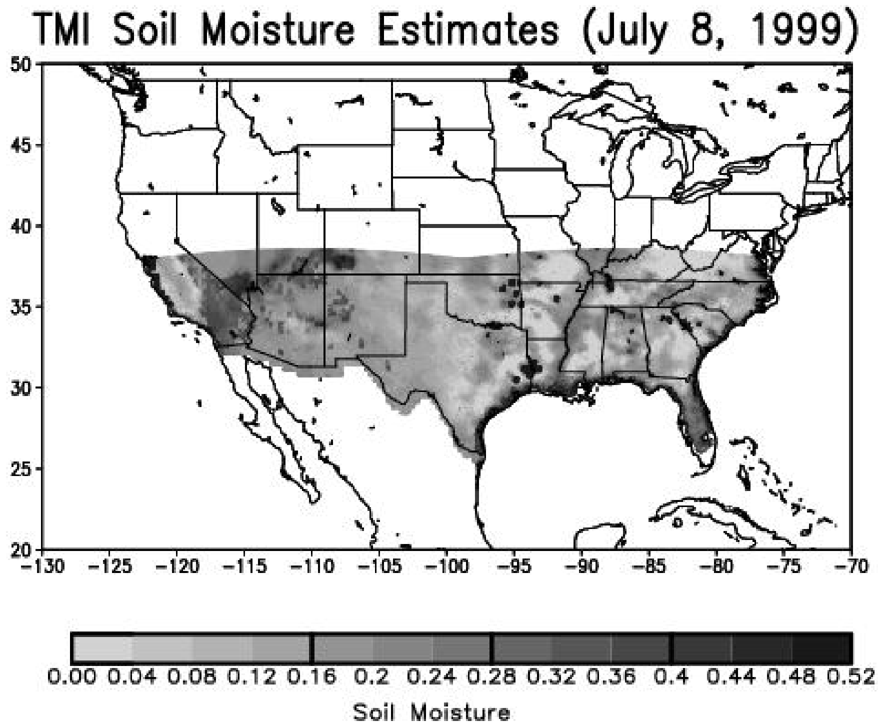

Figure 3a. TMI based soil moisture estimates over continental US for July 8, 1999.

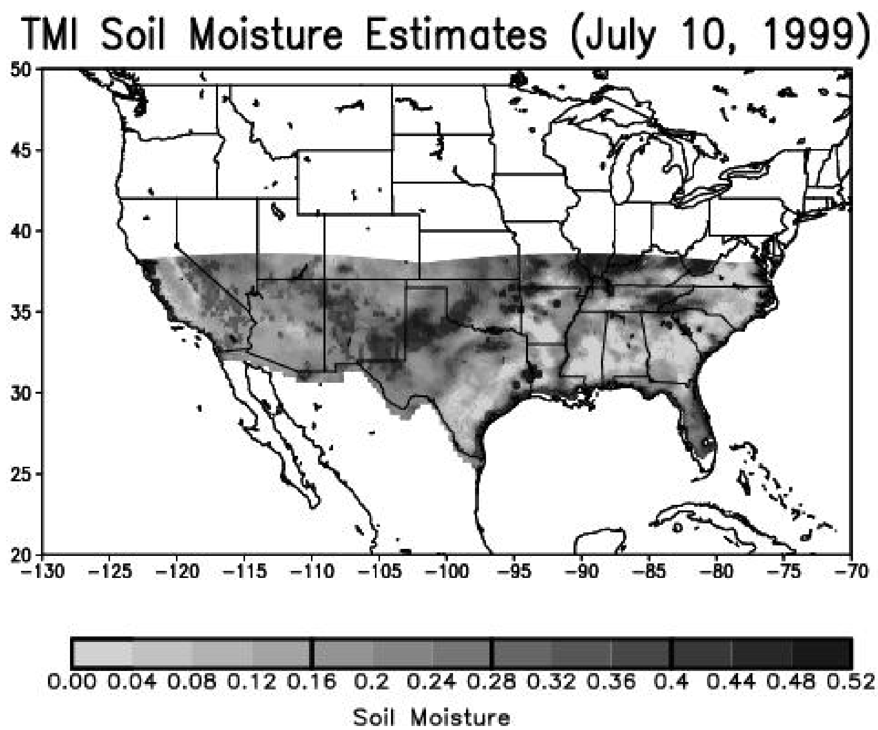

Figure 3b. TMI based soil moisture estimates over continental US for July 10, 1999.