Satellite Remote Sensing of Soil Moisture for Drought Applications

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1. Objective

The objective of this research is to assimilate soil moisture observations from NASA Earth satellite sensors into a national system for drought monitoring and drought early warning, such as the current U.S. Drought Monitor (USDM) that can be transitioned into the future National Integrated Drought Information System (NIDIS). The NASA sensors include the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) and the SeaWinds scatterometer aboard the QuikSCAT satellite (QSCAT).

2. AMSR-E Soil Moisture

The current USDM uses soil moisture calculated from a very simple model at the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC). The model makes indirect estimates of soil moisture based on prior surface observational data of precipitation and temperatures, and thus contains significant uncertainties. Currently, there are very few direct soil moisture observations available for input into the USDM. A few observations are provided from the U.S. Department of Agriculture Natural Resources Conservation Service (USDA/NRCS) Soil Climate Analysis Network (SCAN), but the data are generally too sparse and difficult for data assimilation. Similarly, there are soil-moisture observations from the SNOwpack TELemetry Network (SNOTEL) in the west, but these are not yet available routinely.

NASA soil moisture data measured by AMSR-E have been undergoing validation campaigns to evaluate accuracy, and it is expected that these data will provide a better representation of true soil moisture over much of the U.S. Because of the different vegetation cover conditions, we expect AMSR-E results to work better over the western U.S. than the eastern U.S. The AMSR-E soil moisture algorithm, implementation, and the validation program have been carried out.

Soil moisture is currently obtained from the AMSR-E radiometers on the NASA Earth Observing System (EOS) Aqua satellite. AMSR-E collects passive microwave data over the globe, allowing production of a global dataset of soil moisture in regions of low vegetation cover. The gridded Level-3 land surface product (AE_Land3) includes daily measurements of surface soil moisture. These measurements are derived from the sensitivity of the microwave surface emissivity to the moisture content of the top few centimeters of soil.

The full coverage of the conterminous United States (CONUS) can be obtained by AMSR-E in three days. This AMSR-E temporal resolution is ample compared to the weekly time scale of the USDM map product. The existing daily AMSR-E soil moisture product can be co-registered and merged to obtain averaged soil moisture products covering the entire CONUS over different time scales from weekly, to monthly, and seasonal periods. Figure 1 shows AMSR-E monthly soil moisture maps for August 2002. AMSR-E soil moisture results indicate dry conditions over the western U.S. that are consistent with the drought conditions there, according to the USDM drought map during the same time period. However, the drought conditions over the east in the USDM map are not seen in the surface soil moisture in Figure 1 over the eastern U.S. This is because high vegetation water content over the east in August (Figure 2), which is another AMSR-E product, masks AMSR-E surface soil moisture. Note that summertime is the peak vegetation period and the amount of vegetation water content can change significantly over different seasons.

Both AMSR-E soil moisture and vegetation water content products should be used together to select valid soil moisture values in order to obtain consistent results. In the peak vegetation season, large areas over CONUS may mask AMSR-E soil moisture measurements due to large values of vegetation water content (>2 kg·m^{-2}). In this case, AMSR-E and CPC soil moisture can be blended to obtain an optimum product with a full CONUS coverage. Weekly AMSR-E products are appropriate to be ingested into the USDM for monitoring purposes and for enhancing drought forecasts.

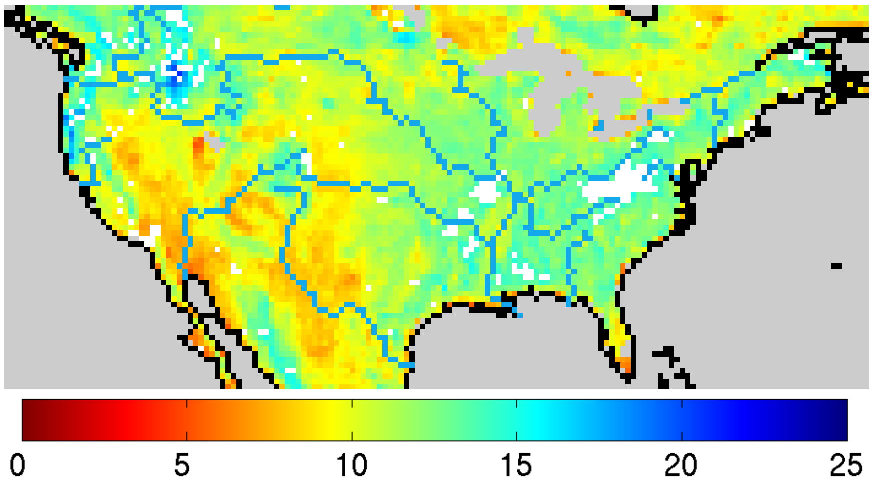

Figure 1. *AMSR-E monthly averaged soil moisture (volumetric %) for August 2002 showing dry conditions over the western U.S.*

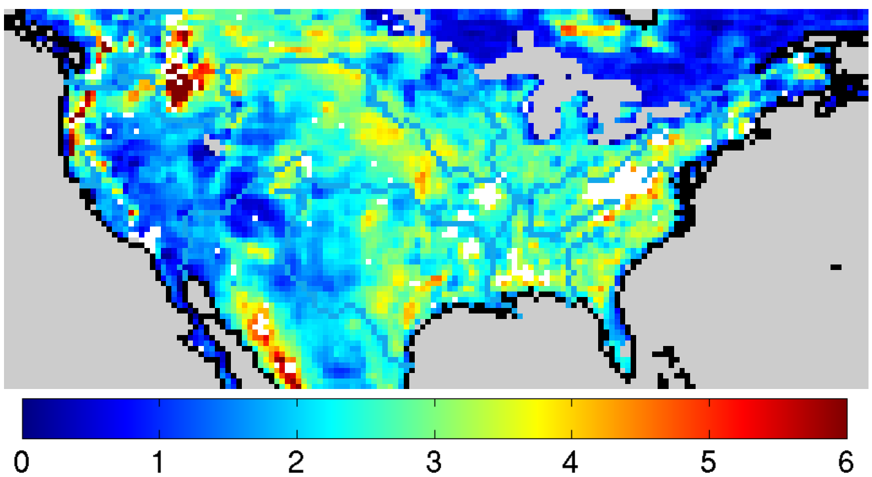

Figure 2. *AMSR-E monthly averaged vegetation water content (kg·m^{-2}) for August 2002 showing moist vegetation over the eastern U.S.*

3. QSCAT Precipitation Water on Land Surface

In the current USDM, the Standardized Precipitation Index (SPI) is used. SPI is based on preliminary precipitation data obtained from surface observations from the Climate Prediction Center and National Climatic Data Center (NCDC). It takes three to four months to assemble final, quality-controlled data. Preliminary data are based on measurements gathered from 450 to 550 stations nationwide each month. In the west, some climate divisions may have no stations reporting in a particular month or may lack a first- or second-order station altogether. The use of rain gauge data from stations (point measurements) is a hit-or-miss approach and may not be representative of regional rainfall amounts. In this regard, timely measurements of the water distribution from precipitation over large spatial extent (areal data rather than point data) will be crucial to improving the USDM.

Under the support of the NASA Hydrology Program (Global Water and Energy Cycles or GWEC), the Jet Propulsion Laboratory (JPL) has developed and produced results derived from the NASA SeaWinds scatterometer on the QuikSCAT satellite to map land surface water from precipitation. QSCAT acquires global data covering 93% of the world in one day. QSCAT surface water products are currently produced at JPL, and results compare well with in-situ soil moisture measurements, with precipitation data from NCDC Global Summary Of the Day (GSOD) stations in the U.S., and with the NASA Land Data Assimilation System (LDAS) over the domain of the NASA Soil Moisture EXperiment (SMEX), including Iowa and the surrounding states.

Figure 3 (left panel) shows that QSCAT can consistently measure the increase in surface soil moisture due to precipitation on land surfaces, while point measurements at the Lonoke Station in Arkansas may not fully represent the areal precipitation. This is because the station may hit localized rain and may miss rains in surrounding areas, thus causing some mismatches between in-situ and QSCAT data. The QSCAT signature also shows the gradual decrease after each rain event, corresponding to and thus quantifying the drying time period. Furthermore, the seasonal averaged QSCAT trend represents the seasonal ecosystem dynamics and the seasonal averaged radiometer data represent seasonal soil moisture. Figure 3 (right panel) illustrates the QSCAT capability to detect drought in Great Falls, Montana.

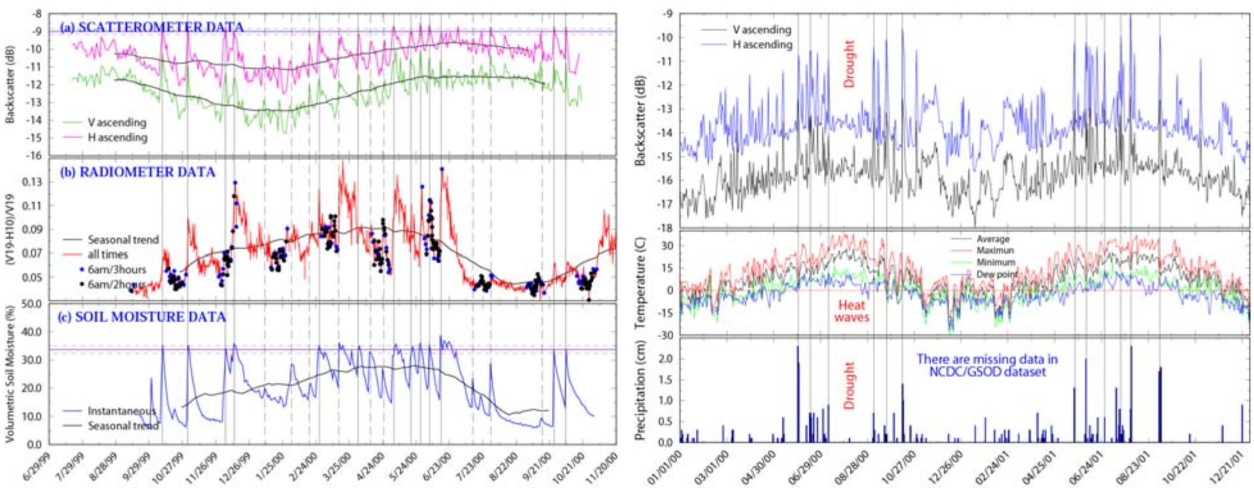

Figure 3. *QSCAT signatures: (a) Left panel shows QSCAT response to surface soil moisture in Lonoke, Arkansas; (b) Right panel shows QSCAT drought detection in Great Falls, Montana.*

The capability of QSCAT to measure transient responses to precipitation on the land surface and thus detect drought conditions over the entire CONUS allows a direct application to improve the USDM. QSCAT products for surface water distribution and precipitation occurrence frequency are currently produced daily at JPL with a typical delay of only one day. This can be improved when the near-real-time data (2-hour delay) are made accessible to us. Figure 4 shows daily QSCAT maps of large-scale precipitation water distribution in October 2004 that mostly erased the abnormally dry (D0) and moderate drought (D1) conditions in Oklahoma, Missouri, Arkansas, Louisiana, and Mississippi. Note that the QSCAT surface water maps indicate the lack of water from precipitation around the Great Lakes region and USDM maps show no improvement on the D0 and D1 drought classes there.

The color scale of the QSCAT maps in Figure 4 is for the increase of backscatter in dB above the bi-weekly averaged value (black-yellow for 0-1.4 dB backscatter increase). According to the initial calibration at Lonoke, Arkansas, an increase of 1 dB in backscatter is approximately equivalent to an increase in surface soil moisture (above the seasonal average soil moisture) of about 7% or 8% (volumetric soil moisture). QSCAT soil-moisture change products can be calibrated using LDAS soil moisture data over CONUS. The timely availability of LDAS soil moisture computations, together with QSCAT and AMSR-E results, are important to provide more accurate soil moisture data, both for transient responses to precipitation water distribution and for seasonal changes.

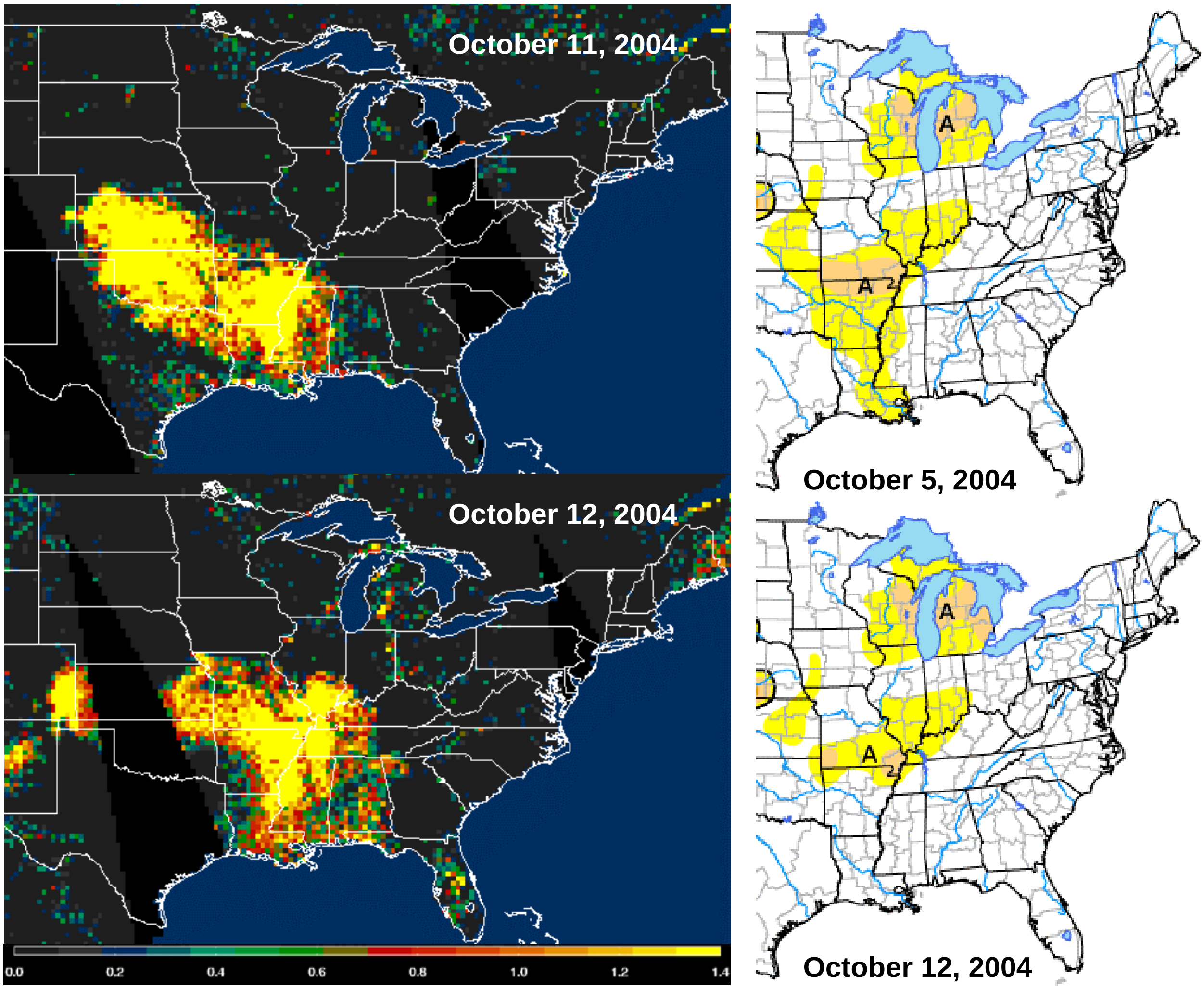

Figure 4. *Left panels are QSCAT daily maps of surface water increase due to precipitation, and right panels are USDM weekly drought maps showing changes in drought conditions.*

Since drought is a result of a depletion of water over time, the current QSCAT product for the occurrence frequency of precipitation surface water, defined as a percentage of the number of wet days when QSCAT detects a soil-moisture increase of more than 5% over the total number of days in the period of interest, is directly applicable to verify drought conditions. Figure 5 shows examples of the precipitation occurrence frequency computed between mid-May and mid-September accounting for QSCAT missing data days. QSCAT results over CONUS (mid-May to mid-September) in the last half-decade (1999-2003) reveal a highly recurrent precipitation pattern over the Midwest with a wet condition in year 2000 and a severe drought in 2003. In fact, QSCAT precipitation-water frequency results in Figure 5 show a decrease by a factor of 2 between years 2000 and 2003 over large regions in Iowa and other surrounding states.

The QSCAT precipitation surface water product actually represents water that accumulates on the land surface (not rain drops in the air), and is thus an integrated surface areal measurement. This product better represents regional water distributions than measurements from individual stations and therefore can be used to improve the USDM. QSCAT results are consistently measured by a stable and accurate instrument, avoiding cross-calibration problems among individual in-situ stations.

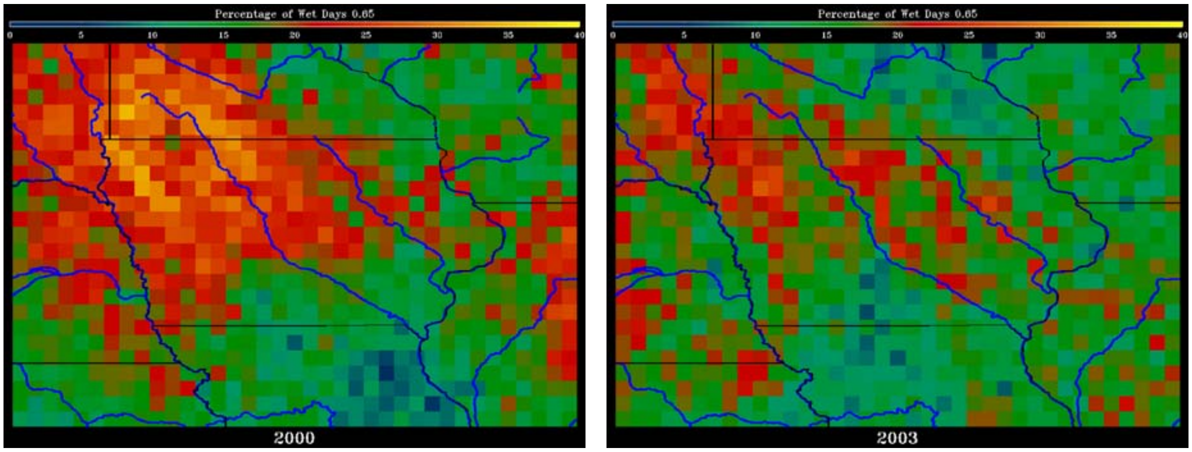

Figure 5. *QSCAT precipitation-water frequency maps over the Midwest for the period of mid-May to mid-September in the years 2000 (left) and 2003 (right). Between 2000 and 2003, the frequency value decreased by as much as a factor of 2 over some regions in the SMEX domain.*

4. Summary

The AMSR-E product can be used to characterize seasonal soil moisture, while the QSCAT product can monitor transient soil moisture changes due to rainfalls on land surface. Both of these NASA satellite products for soil moisture are complementary and are useful for drought monitoring over CONUS and other regions of the Earth. These products are to be integrated together with surface data and model results to improve the current USDM. Improved remote sensing of soil moisture, along with an expanded network of observations, will be an important step in the right direction. More accurate depictions of soil moisture distribution will benefit both the USDM and the U.S. Seasonal Drought Outlook, because improved characterizations of initial moisture conditions can lead to better forecasts. The use of NASA results to enhance the existing USDM drought monitoring and drought forecasts are expected to be transferable to the future NIDIS.

Acknowledgments

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