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CROSS-VALIDATION OF SOIL MOISTURE DATA FROM AMSR-E USING FIELD OBSERVATIONS AND NASA'S LAND DATA ASSIMILATION SYSTEM SIMULATIONS

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ABSTRACT

Soil moisture is a critical hydrosphere state variable that often limits the exchanges of water and energy between the atmosphere and land surface, controls the partitioning of rainfall between evaporation and runoff, and impacts vegetation photosynthetic rate and soil microbiologic respiratory activities. Thus, accurate measurements of this variable are required for the global water and energy cycles as well as the carbon cycle. A global soil moisture data product is continuously generated from the observations of the Advanced Microwave Scanning Radiometer (AMSR-E) onboard NASA's Aqua satellite. The accuracy of this data product has not yet been validated and the assessment of the product quality is required for its various applications. A series of field experiments (SMEX02, Iowa; SMEX03, Georgia; SMEX04, Arizona; SMEX05, Iowa) have been conducted to address problems related to the hydrologic processes and validate AMSR-E soil moisture measurements. During these experiments, soil moisture values were obtained from both the Theta probes and gravimetric sampling from various surface layer depths for as many sites as possible that were selected to represent the footprints of the AMSR-E. A careful comparison between these observations and the corresponding AMSR-E retrievals has been carried out in this study. To further understand the quality of these soil moisture retrievals, the Noah land surface model in NASA's Land Data Assimilation System (LDAS) was run with the best available forcing data sets to produce the surface soil moisture data corresponding to the AMSR-E retrievals and the field observations. Results from comparing the AMSR-E retrievals, the LDAS simulations and the field observations are presented to demonstrate the characteristics of the current AMSR-E soil moisture data product.

1. INTRODUCTION

Soil moisture is a critical element for both global water and energy budget. Soil moisture has a great impact on climate change over land. It plays the same role over land as sea surface temperature plays over the ocean. It has a long memory (order of months) of storing the atmospheric signature/energy transferred to it through precipitation, in turn transferring them back to the atmosphere through evaporation and affecting the climate. It divides the outgoing energy into latent heat and sensible heat. Remote sensing technique is used lately to deal with large-scale spatial and temporal characterizations of soil moisture fields. However, satellite remote sensing data products contain uncertainties due to imperfect instrument calibration and inversion algorithms, geophysical noise, representativeness error, communication breakdowns, and other sources. It is therefore essential that the accuracy and credibility of these remotely-sensed fields be evaluated for their use in critical research and applications (Eymard et al., 1993). Therefore, several soil moisture field experiments have been conducted in the last few years to validate the satellite derived soil moisture product. The field experiment sites were chosen carefully so that the satellite data can be validated at different local climatic conditions, soil types and vegetation types. At the same time, many researchers have tried to validate the satellite soil moisture data using models because field experiments are very expensive, labor intensive and are limited to a certain region of the globe

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due to unavailability of the resources. Earlier, McCabe et al. (2005) used Land Surface Microwave emission Model (LSMEM) generated soil moisture data from AMSR-E brightness temperature and compared the model soil moisture data with SMEX02 in-situ measurements. This study discusses such soil moisture data comparisons study using AMSR-E satellite soil moisture data, Noah model simulated soil moisture data and in-situ measurements from SMEX02, SMEX03 and SMEX04 field experiments.

2. STUDY AREA

Figure 1 shows all the planned AMSR-E validation sites over USA. The current study is conducted over SMEX02 (Iowa), SMEX03 (Georgia) and SMEX04 (Arizona) field experiment sites. SMEX02 spans the area bounded by 41.7^0 N to 42.7^0 N latitudes and 93.8^0 W to 93.2^0 W longitudes; SMEX03 covers the area from 31.20^0 N to 31.82^0 N latitudes and 83.94^0 W to 83.43^0 W longitudes; SMEX04 covers the area 31.4^0 N to 32.1^0 N latitudes and 110.3^0 W to 109.7^0 W longitudes.

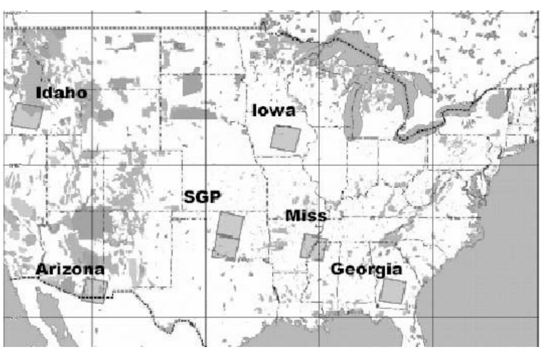


Figure 1: AMSR-E validation sites in the United States, located at agricultural watershed sites in Oklahoma, Georgia, Idaho and Arizona (after Njoku et al. (2003)).

3. DATA SOURCES AND PROCESSING

Soil moisture data from AMSR-E satellite, Noah model and field experiments (SMEX02, SMEX03 and SMEX04) have been used in this study.

3.1 AMSR-E Soil Moisture Data

The Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) is a passive microwave radiometer launched aboard NASA's Aqua Satellite on May 4, 2002. This conically scanning instrument senses microwave radiation (brightness temperatures) at 12 channels and 6 frequencies ranging from 6.9 to 89.0 GHz, horizontal and vertical polarized radiation measured separately at each frequency. Daily Level-2B and Level-3 (http://www.ghcc.msfc.nasa.gov/AMSR/) products are now available from the National Snow and Ice Data Center (NSIDC), beginning with dates from February 18, 2004. These derived geophysical AMSR-E products include measurements of rainfall, snow, sea ice and many other land and ocean geophysical variables.

The AMSR-E soil moisture data were collected from NSIDC (http://nsidc.org/data/). This product includes daily global soil moisture of the top 2 cm soil layer. Matlab software package was used to extract the data from the HDF-EOS files, to reproject the data from the 25km ease-grids to 0.25 degree lat-lon grids for comparing with the model simulation from the Land Information System.

3.2 Noah Land Surface Model Soil Moisture Data

The Global Land Data Assimilation System (GLDAS) (http://ldas.gsfc.nasa.gov/) has been developed jointly by scientists at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP) in order to provide forecast simulations that will lead to more accurate reanalysis and simulations by numerical weather prediction (NWP) models. GLDAS makes use of the new generation of ground and space-based observation systems, which provide data to constrain the modeled land surface states. Constraints are applied in two ways. First, by forcing the land surface models (LSMs) with observation based meteorological fields, biases in atmospheric model-based forcing can be avoided. Second, by employing data assimilation techniques, observations of land surface states can be used to curb unrealistic model states (Rodell et al., 2004).

The Land Information System (LIS) (http://lis.gsfc.nasa.gov/) is a high performance land surface modeling and data assimilation system, based on GSFC's Land Data Assimilation Systems. The LIS started with incorporating three LSMs in the beginning. Noah LSM was one of them. The Noah LSM simulates soil moisture (both liquid and frozen), soil temperature, skin temperature, snowpack water equivalent, snowpack density, canopy water content, and the traditional energy flux and water flux terms of the surface energy balance and surface water balance (Zhan et al., 2004). This model has been used and validated through many model inter-comparison studies. We used the North American Land Data Assimilation System (NLDAS) forcing for this model run. NLDAS incorporates in-situ gauge and radar information to produce the forcing data over the North American domain (Cosgrove et al., 2003).

The model was run twice in two different resolutions, first in 1 km resolution to compare with the in-situ field observation data and then in 1/8 degree resolution to compare with the 1/4 degree AMSR-E generated soil moisture data. In both the runs, the model was first run from October 1996 as spin-up since the NLDAS forcing is available from October 1996. After the spin-up, the model generated restart file was used to generate soil moisture during the study period. The post-processing was done in GrADS and Matlab for the comparison study.

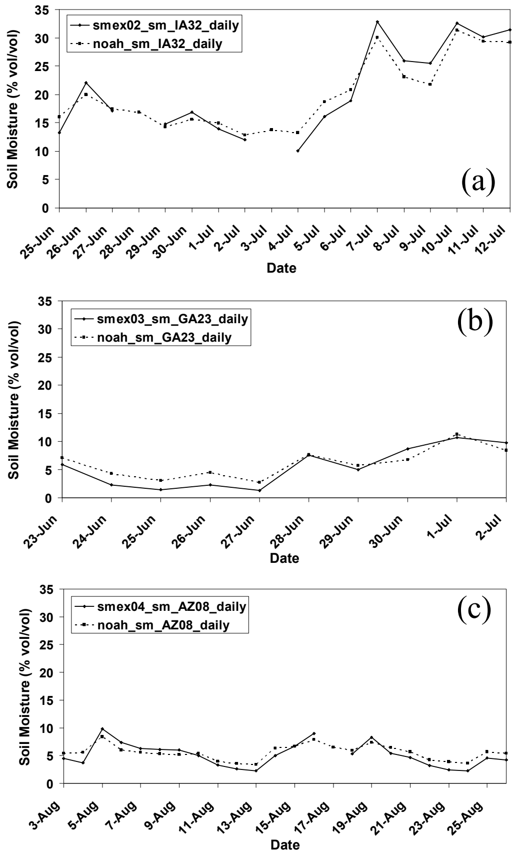
3.3 Field Experiment Soil Moisture Data

The SMEX field experiments have been conducted to study land-atmosphere interaction and validate the AMSR-E satellite derived soil moisture data product. SMEX02 (Iowa), SMEX03 (Georgia) and SMEX04 (Arizona) field experiments have been carried out from June 25 to July 12, 2002; June 23 to July 2, 2003 and August 3 to August 26, 2004 respectively. All the datasets are available from National Snow and Ice Data Center (NSIDC) website (http://www.nsidc.org/data/amsr_validation/soil_moisture/). The datasets basically include ground observed soil moisture and soil temperature from various surface soil layer depths, aerial photographs, vegetations data, meteorological data and ancillary data. The ground observed data were collected between 12 noon to 2 pm everyday to match with the AMSR-E overpass time during the field experiment. The datasets were available to the public in text files (Jackson et al. (2003, 2004); Bosch et al. (2004)). We processed the data in Matlab for comparison.

4. RESULTS AND DISCUSSION

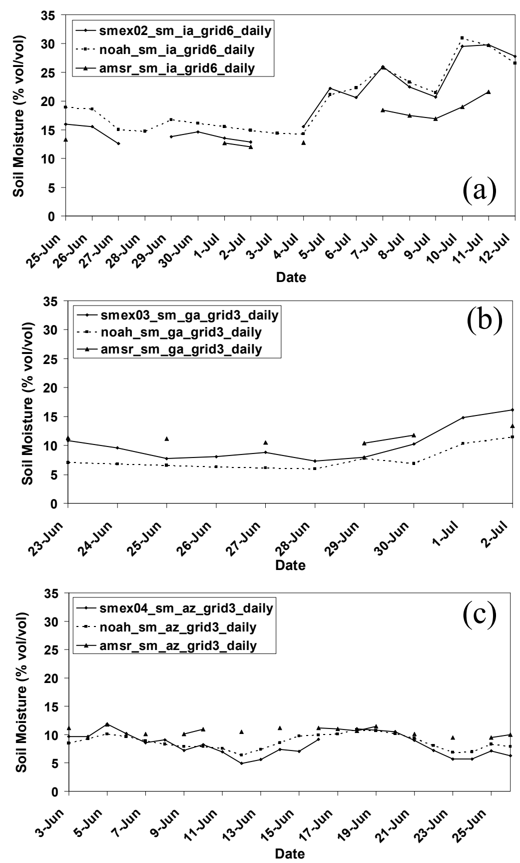
The soil moisture retrieval accuracy was assessed in two ways. First, the field experiment in-situ soil moisture data were compared with the Noah model 1 km retrieved soil moisture data. Second, the averaged field experiment in-situ and the averaged Noah retrieved soil moisture data over the 1/4 degree grid resolution were compared with the AMSR-E derived soil moisture data. Since the Noah model soil moisture was from the default top 10 cm soil layer, and the other two datasets were from top 2 to 3 cm soil layer. The Noah soil moisture data were linearly interpolated from 10 cm to 3 cm for this comparison study.

To compare the field experiment in-situ soil moisture data with the 1km Noah soil moisture data, 10 stations out of total 47 stations, 11 stations out of total 49 stations, and 10 stations out of total 40 stations were chosen from SMEX02, SMEX03 and SMEX04 field experiments respectively. The chosen stations were spatially diverse and they represented the whole study area very well. But comparison plots for just one station from each field experiment have been included in this study for analysis. Figures 2 (a), (b) and (c) show the daily soil moisture time series plots for the Noah model and SMEX02 (Station IA32), SMEX03 (Station GA23) and SMEX04 (Station AZ08) respectively. There are some missing values in the SMEX02 and SMEX04 station soil moisture data. The graph from SMEX02 (Iowa) shows high soil moisture values, possibly indicting some precipitation events in last few days (July 4 to July 12, 2002) of the field experiment. The soil moisture from SMEX04 (Arizona) shows low values. The same low soil moisture patterns were observed at all the stations from SMEX04. This is very obvious because of the dry hot environment in the SMEX04 region. All three plots illustrate that the Noah model captured the temporal evolution of the soil moisture parameter very well. The correlations between Noah model soil moisture and station observed soil moisture are 0.91, 0.88 and 0.86 for SMEX02 (station IA32), SMEX03 (station GA23) and SMEX04 (station AZ08) respectively. An extensive study indicates that the NLDAS precipitation forcing used in the Noah model were very accurate and captured the precipitation events very well. As a result, the Noah model produces accurate soil moisture data at this site (the results are not shown in this study).



Figures 2: Time series plot of the Soil Moisture data from Noah model 1 km output and **(a)** SMEX02 field experiment (June 25 to July 12, 2002), **(b)** SMEX03 field experiment (June 23 to July 2, 2003) and **(c)** SMEX04 field experiment (August 3 to August 26, 2004) respectively.

To compare the soil moisture data at AMSR-E 25-km spatial resolution, a couple of AMSR-E pixels were found capturing most of the soil moisture measuring stations at each field experiment area. Figures 3 (a), (b) and (c) illustrate the daily soil moisture time series plot from the AMSR-E, the Noah model and SMEX02, SMEX03 and SMEX04 field experiments for one AMSR-E 0.25^0 grid respectively. The AMSR-E pixels considered for analysis in this study capture 7 stations, 17 stations and 8 stations from SMEX02, SMEX03 and SMEX04 experiment area respectively. So, the data from all the stations representing the AMSR-E pixel were averaged to represent the AMSR-E equivalent grid from the field observations and were used for the comparison study with the AMSR-E data. Similarly, the data from four 0.125^0 Noah model output pixels corresponding to 0.25^0 AMSR-E pixel were averaged for the comparison study here. All the plots show many AMSR-E missing soil moisture values because of the 3-day revisit time of the instrument. There are also some missing data from the field experiment. From the AMSR-E soil moisture time series plots, it's evident that we can't infer the temporal evolution of the soil moisture parameter very well because of many missing values and shorter field experiment period. At 0.25^0 grid also, Noah model



Figures 3: Time series plot of the Soil Moisture data from AMSR-E instrument, Noah model and **(a)** SMEX02 field experiment (June 25 to July 12, 2002), **(b)** SMEX03 field experiment (June 23 to July 2, 2003) and **(c)** SMEX04 field experiment (August 3 to August 26, 2004) for the AMSR-E 25 km grid respectively.

simulated soil moisture show considerable accuracy compared with averaged field observed soil moisture data with correlation coefficients 0.89, 0.85 and 0.86 for SMEX02, SMEX03 and SMEX04 field experiment area respectively. In all the three graphs, AMSR-E soil moisture does not show much variation in values. It could not catch the sudden soil moisture increase due to the precipitation events in the last few days of SMEX02 experiment period. It also observed higher soil moisture than Noah model and field observed soil moisture over hot and dry SMEX04 area throughout the experiment period. This illustrates that the AMSR-E soil moisture retrieval algorithm is not very sensitive to the other climatic parameters affecting the soil moisture in local spatial and temporal scale. The correlation coefficients between AMSR-E soil moisture and SMEX02, SMEX03 and SMEX04 soil moisture are 0.68, 0.75 and 0.78 respectively. One of the reasons for low correlation coefficients might be because of the soil moisture field sampling patterns. During SMEX02, the sampling sites were in straight lines from north to south. So, the measuring sites in each AMSR-E pixel at SMEX02 do not represent the whole pixel evenly.

5. CONCLUSION

The comparison study performed in this paper was to assess both the AMSR-E observed soil moisture as well as the Noah model simulated soil moisture data by comparing them with in-situ measured soil moisture data at different geographical regions representing different climatic conditions. Noah model simulations matched reasonably well with the soil moisture data both at 1 km and 0.25^0 resolutions at all the three field experiment sites (SMEX02, SMEX03 and SMEX04). AMSR-E soil moisture retrievals did not capture the sudden changes in soil moisture during SMEX02 due to precipitation events. It seems that the AMSR-E soil moisture algorithm is not very sensitive to the climatic parameters affecting the soil moisture parameter. Otherwise, it performed pretty well at all the three sites. Considering the field soil moisture measurement uncertainties, and uncertainties in model forcing and land parameters and the short field experiment time period, this comparison study indicates that the AMSR-E soil moisture retrievals need to be further evaluated before their applications.

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REFERENCES

Bosch, D., T. J. Jackson, V. Lakshmi, and J. Jacobs, 2004: *SMEX03 Georgia Regional Ground Soil Moisture Data*. Boulder, CO: National Snow and Ice Data Center. Digital media.

Cosgrove, B. A., D. Lohmann, K. E. Mitchell, P. R. Houser, E. F. Wood, J. C. Schaake, A. Robock, C. Marshall, J. Sheffield, O. Duan, L. Luo, R. W. Higgins, R. T. Pinker, J. D. Tarpley, and J. Meng, 2003: Real-time and retrospective forcing in the North American Land Data Assimilation System (NLDAS) project. *J. Geophys. Res.,* **108**, 8842, doi:10.1029/2002JD003118.

Eymard, L., R. Bernard, and J. Y. Lojou, 1993: Validation of microwave radiometer geophysical parameters using meteorological model analysis. *Int. J. Remote Sens.,* **14**, 1945-1963.

Jackson, T. J., M. H. Cosh, J. Famiglietti, and R. Bindlish, 2004: *SMEX04 Regional Soil Moisture Data, Arizona*. Boulder, CO: National Snow and Ice Data Center. Digital media.

Jackson, T., M. Cosh, and J. Famiglietti, 2003: *SMEX02 Iowa Regional Ground Soil Moisture Data*. Boulder, CO: National Snow and Ice Data Center. Digital media.

Li, L., E. G. Njoku, E. Im, P. Chang, and K. St. Germain, 2004: A Preliminary Survey of Radio-Frequency Interference Over the U.S. in Aqua AMSR-E Data. *IEEE Trans. Geosci. Remote Sens.,* **42**, 380-390.

McCabe, M. F., Wood, E. F. and Gao, H., 2005: Initial soil moisture retrievals from AMSR-E: Multiscale comparison using in situ data and rainfall patterns over Iowa. *Geophys. Res. Lett.,* **32**, L06403, doi:10.1029/2004GL021222.

Njoku, E.G., Jackson, T. J., Lakshmi, V., Chan, T. K. and Nghiem, S. V., 2003: Soil moisture retrieval from AMSR_E. *IEEE Trans. Geosci. Remote Sens.,* **41**, 215-229.

Rodell, M., P. R. Houser, U. Jambor, J. Gottschalck, K. Mitchell, C. J. Meng, K. Arsenault, B. Cosgrove, J. Radakovich, M. Bosilovich, J. K. Entin, J. P. Walker, D. Lohmann, and D. Toll, 2004: The global land data assimilation system. *Bull. Amer. Meteor. Soc.*, **85**, 381-394.

Zhan, X., P. R. Houser, J. P. Walker, and M. Rodell, 2004: Validation of AMSR-E Soil Moisture Product Using Data Assimilation Techniques. *COAA2004*, June 28-30, 2004, Beijing.