Cross-Validation of AMSR-E Soil Moisture Retrievals, the Surface Soil Moisture Simulations from NASA's Global Land Data Assimilation System (GLDAS) and the field observations over SMEX04 region, Arizona

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Abstract: ***Soil moisture is a critical element for both global water and energy budget. Accurate measurements of this variable are thus required. Remote sensing is a widely used technique 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. Since measuring global soil moisture by any particular technique (e.g. satellite observations, ground measurements, global models etc.) is very difficult, data assimilation is a good technique to incorporate data from all the sources to produce an accurate global soil moisture map. A global soil moisture data product is currently steadily generated from the observations of the Advanced Microwave Scanning Radiometer onboard of NASA's Aqua satellite. The accuracy of this data product has not been yet validated globally and assessment of the product quality is required for its applications. In the limelight of cross-validation, I have used ground observed soil moisture data (SMEX02) as well as the GLDAS/LIS model soil moisture data to validate this AMSR-E satellite derived soil moisture product during my last summer internship program (GSSP 2004). So, this study includes very detailed comparison of the satellite, model and field soil moisture data with very high spatial and temporary resolution. Model soil moisture data were also compared to the precipitation forcing data to verify the validity of the model soil moisture product. The results indicate that there is reasonably good agreement among all the three datasets.***

Keywords: AMSR-E, GLDAS, LIS, SMEX04, soil moisture

1. Introduction

Soil moisture is a major component of water cycle, yet the most difficult component to measure accurately. Soil moisture affects the transfer of moisture into the atmosphere[8]. It is also linked to evaporation and thus to the distribution of heat fluxes from the land to the atmosphere. It divides the outgoing energy into latent heat and sensible heat. Many researchers have tried to measure soil moisture by satellites, models and field experiments. Satellites have deep penetration problem to measure the total soil moisture[10]. On the other hand, model soil moisture data is strongly influenced by the atmospheric forcing component like precipitation, incoming solar radiation etc. and clouds and precipitation are not well represented in model equations. Field observed soil moisture is somewhat accurate to the real soil moisture, but it's difficult to generalize the local scale soil moisture data for the global scale since the spatial variation of soil moisture is very high[11]. Advanced Microwave Scanning Radiometer (AMSR-E) aboard EOS-AQUA satellite has been deployed by NASA since 2002 to measure accurate global soil moisture field[7]. In this study, we have worked on the cross-validation of the AMSR-E soil moisture data product with the field experiment as well as with the NASA's Land Data Assimilation System simulation soil moisture product on a local scale. This study is a part of the long term objective to produce satellite derived global soil moisture product.

2. Background

I worked on part of this validation study last summer during the Graduate Summer Student Program (GSSP-2004)[2]. It was very preliminary work. I spent some time to get acquainted with the AMSR-E data, Land Data Assimilation System and the SMEX field experiment data. I used the already inbuilt AMSR-E soil moisture data processing tool to process the data last year. I produced global soil moisture data from the satellite and the model with coarse spatial (0.25 degree) and temporal (3 day composite for AMSR-E data and 3 hours for model data) resolution previously. This year, it's a continuation of last year's work with more extensive study. I am working on local scale with high spatial (0.25 degree for AMSR-E data, but 1 km or ~0.01 degree for model data) and temporal (1 day for AMSR-E data and 1 hour for model data) resolution in order to get soil moisture data as close as to the field observation.

3. Objective

The objective of this year's summer project was redefined on the basis of the previous results[2]. Last year's comparison study of soil moisture data from the AMSR-E data, field data and model data was very inconclusive. The satellite data was not at all in close range for the comparison study. Last year, we used 3-day composite data for the comparison study. But, we modified our approach this time and we took 1-day data instead of 3-day composite data. The field experiment and model data were chosen within an hour of the satellite passing time everyday over the study area. This will give us soil moisture data from 3 sources measured very close to each other which can be comparable with each other. We got many days with missing satellite data since the satellite covers the whole globe in 3 days. But at least, the data were comparable for the days we had satellite data. This year, we chose our study location in Arizona State which is a desert with very less rainfall. So, this will help us to avoid if any model biases exist in soil moisture data from precipitation. So, the current summer work plan is basically the same as that of the last year[2] with some modified approach.

4. **Study Location**

The study area for this study extends from Hermosillo, Mexico, in the south to Tucson, Arizona, U.S. in the north[9]. Figure 1 shows the map of the study location. There were 40 soil moisture measuring stations within that study area. Figure 2 shows the locations of the 40 measuring station with the NLDAS $1/8^0$ grids for the same location as in the map.

Half of the study area had shrubby vegetation with acacia, tarbush, creosote brush and desert zinnia and other half had grasslands with sideoats grama, black grama, hairy grama and lehmann lovergrass[9].

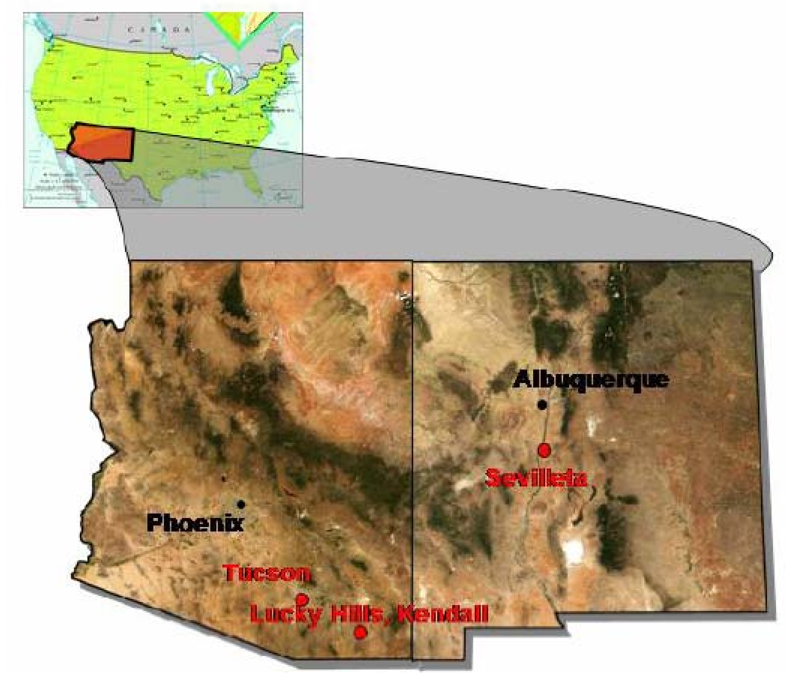

Figure 1 The figure shows the map of the Arizona/New Mexico region. The SMEX04 field experiment stations are around the Lucky Hill and Kendall areas[9]

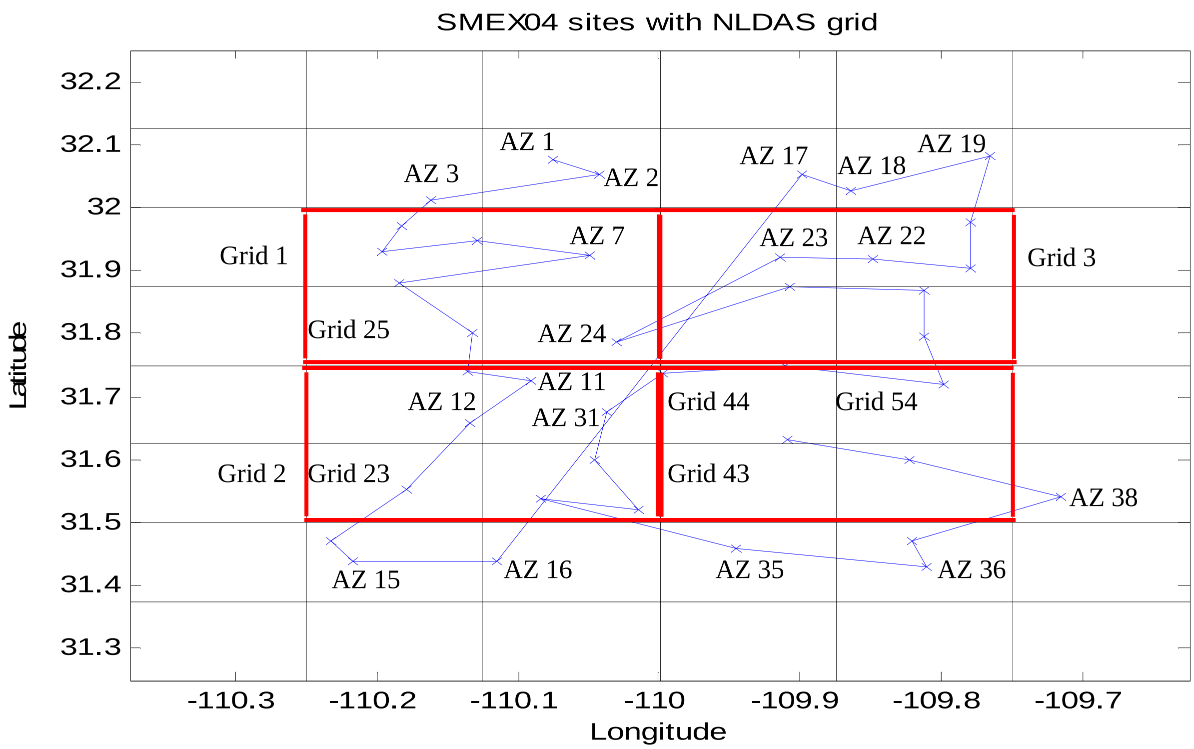

Figure 2 This figure shows the grid map with the station locations in the SMEX04 field experiment area. The longitude and latitude gives the position of all 40 stations (named as AZ1, AZ2…AZ40). The big red boxes are 0.25 grids matched with AMSR-E grid (Grid 1, grid 2, grid 3 and grid 4). Each 0.25 degree grid box includes four 0.125 degree NOAH land model grids (grid 23, grid 24…..grid 56).

We have used soil moisture data from AMSR-E aboard AQUA satellite, NASA's Land Data Assimilation System model and the SMEX04 field experiment for this comparison study.

5. AMSR-E Satellite instrument and soil moisture data

The details about the AMSR-E satellite instrument, performance characteristics and land data products have been described in my previous year's summer project report[2]. The AMSR-E global soil moisture product is a level 3 product with 25 km spatial resolution and 1 day temporal resolution[7].

6. Land Data Assimilation System

Land Data Assimilation Schemes (LDAS) are uncoupled land surface schemes, forced primarily by observations avoiding the model forcing biases. This research is implemented in near real time using existing LSMs collaboratively by many federal government organizations and universities at a 0.125^0 (about 10 km) resolution to evaluate the land-atmosphere science question as well as to improve the water and energy partitioning in the numerical weather prediction (NWP) models[3]. The near real-time LDAS at NASA GSFC is forced by NCEP Eta model analysis fields, along with observed precipitation and radiation fields to force several different land surface models in an uncoupled mode[1]. Model parameters are derived from the 1km global land cover classification map. First, the LDAS was implemented over the North America (North America LDAS (NLDAS)). Then it was extended for the whole globe (Global LDAS (GLDAS))[3].

There are many stand alone LSMs available in the LDAS. I used NOAH LSM for my study. NOAH has been developed by NCEP, Oregon State University, Air Force and Hydrologic research lab of National Weather Service[12]. NOAH simulates skin temperature, snow water equivalent, snow density, canopy water content soil moisture (both frozen and liquid) and soil temperature along with all traditional energy and water fluxes of the balance equations. NOAH model has been used in many validation and model inter-comparison studies[4, 13].

7. SMEX04 field experiment

This soil moisture experiment was conducted jointly with the North American Monsoon Experiment (NAME) from July 3 to July 26, 2004. SMEX04 followed the same type of work done in SMEX02 and SMEX03. The field experiment area for SMEX04 was from Hermosillo, Mexico, in the south to Tucson, Arizona, U.S. in the north. It provides soil moisture data (both gravimetric and theta probe) and some other land surface measurements.

8. Data Processing

8.1. Model Setup and soil moisture data

We tried to use a reliable land surface model with best forcing and parameter data available to get a very realistic soil moisture data as close as to the field experiment. The specifications of the model setup have been given in Table 1. The NOAH model was first run from September 30, 1996 to April 30, 2004 for spin up with a cold start file with 6-hour model output. All the output variables and the forcing variables were written in the output file. It was run for the SMEX04 study area only with 1 km and $1/8^0$ spatial resolution. Then the model was run from April 30, 2004 to September 30, 2004 with a restart file with 1-hour model output for our comparison study. We used only the top layer soil moisture data (top 10 cm) for this study.

Land Surface Model (LSM)	NOAH
Base Forcing	NLDAS
Leaf Area Index (LAI)	AVHRR based LAI
Maximum number of tiles per grid	13
Time step of the run	15 minutes
Latitude Range	31.3125^0 N to 32.1875^0 N
Longitude range	110.3125^0 W to 109.6875^0 W
Output Data Resolution	1 km and 1/8 degree
Output interval to write the output files	1 hour
Output data format	Binary

Table 1 Experiment specifications for the GLDAS/LIS model run

8. 2. AMSR-E satellite data

AMSR-E soil moisture data processing was ordered from NSIDC site[5]. They were processed in the same manner as I did last year[2], but this time we used the matlab mathematical script language to read the data from the HDF file format and to change projection from ease-grid to geographic lat-lon projection with 25 km spatial resolution.

8. 3. SMEX04 observation data

I used the SCAN (Soil Climate Analysis Network) site data last year. But SCAN data is machine measured soil moisture data and it's not very reliable. So, I used the manually measured soil moisture data during the SMEX04 experiment time. There were 40 soil moisture measuring stations within the SMEX04 field experiment area. I used data from most of the locations for this comparison study[6].

9. Results and Discussion

The initial soil moisture retrieval algorithm got contaminated with radio frequency interference to C-band leading to erroneous AMSR-E soil moisture data. The algorithm got revised in December 2003 to use only X-band channel brightness temperature. So, the new AMSR-E global soil moisture product is continuously generated using the recent algorithm[13]. Figure 3 shows AMSR-E global soil moisture data for 2 days in July 2005 with both ascending and descending mode. The satellite covers the whole globe in 3 days. The soil moisture values range from 0 to 0.4 volume percentage, 0 being at all the deserts. The oceans and the big ice mass have been masked.

Before validating the AMSR-E soil moisture data, we wanted to check the model simulated soil moisture with the field observations. We first ran the NOAH land surface model with the best possible 1 km spatial resolution grid with 1/8 degree NLDAS forcing data. The LIS system itself interpolates the forcing data from 1/8 degree to the desired 1 km run domain using the elevation correction data and writes the

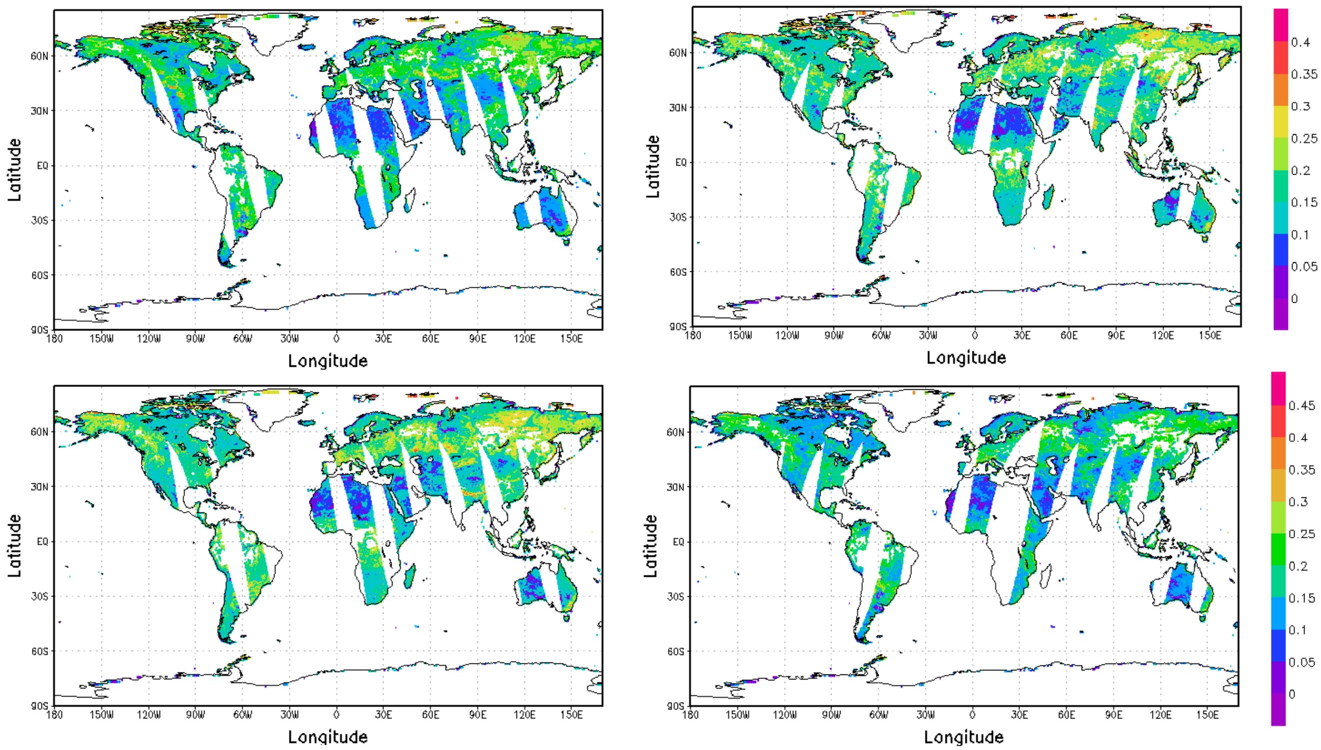

Figure 3 AMSR-E global soil moisture products for July 05, 2004 (top row) and July 20, 2005 (bottom row). Left figures are from ascending passes and right ones are descending passes. There are many missing data in daily passes

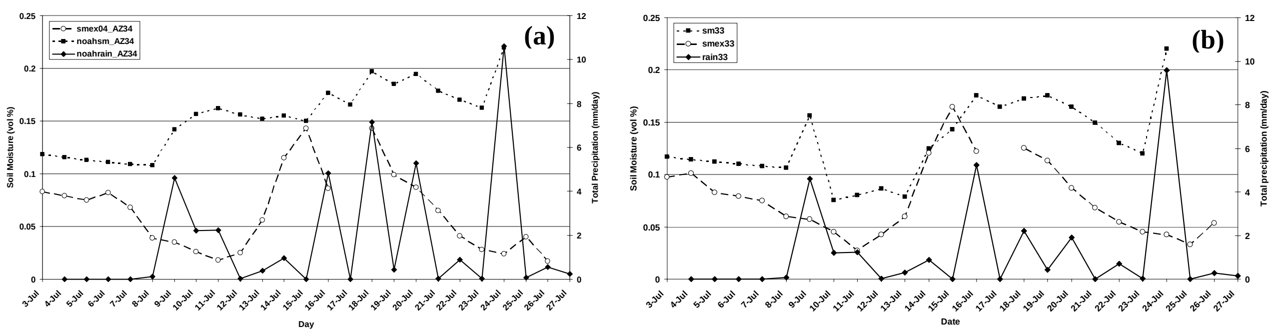

Figure 4 Daily time series of measured soil moisture, NOAH model generated soil moisture and NLDAS total precipitation forcing taken from NOAH output file with **(a)** 1 km grid size for the station AZ34 and **(b)** 1/8 degree grid size for the grid 33 which includes the station AZ34. Total precipitation is on the secondary y-axis. Both the soil moisture data don't agree very well in 1km whereas they are reasonably in good agreement in 1/8 degree.

forcing data, water and energy balance components in the output file with 1 km resolution. The precipitation rate was in kg.m^2/sec. We calculated the precipitation on hourly basis (kg.m^2/hr) for each hour from the hourly output and then added them all to get the daily total precipitation (kg.m^2/day). Figure 4a shows the daily time series plot of soil moisture and total precipitation data from the NOAH model and the corresponding soil moisture data from one of the measuring stations. From the figure, it's evident that the model soil moisture time series has mostly followed the precipitation forcing time series. But the model soil moisture time series is not at all in good math with the field station soil moisture observation data (correlation coefficient of 0.08 with 90% significance level). Since the original NLDAS forcing data was in 1/8 degree resolution grid, we decided to simulate the model again with 1/8 degree resolution to calculate the model soil moisture at the same resolution. To compare with the field observations, we took the averaged soil moisture for all the field observation sites over the same NOAH 1/8 degree grid. Figure 4b shows the same time series plot as that in figure 4a, but all the data here are in 1/8 degree resolution instead of 1 km resolution. We can clearly see the corresponding match between the nature of the NOAH soil moisture and field observed soil moisture data with a correlation coefficient of 0.65 with 90% significance level. The correlation is better when the region was dry in the beginning of the experiment period than the time the region became wet. The difference in the values may be attributed to the fact that the field observed soil moisture is from top 0-6 cm and model simulated soil moisture is from top 10 cm, as well as technicality issues in the model and field observations.

Figure 5 shows the AMSR-E as well as the NOAH model simulated soil moisture plot for the SMEX04 region for July 06, 2004. One thing we need to mention here is that AMSR-E plot is with 1/4 degree resolution and NOAH model soil moisture is with 1/8 degree resolution and AMSR-E measures soil moisture from top 2 cm whereas the NOAH model measures it from top 10 cm.. We can see that both the plots are though not very good matched, but still they are within the

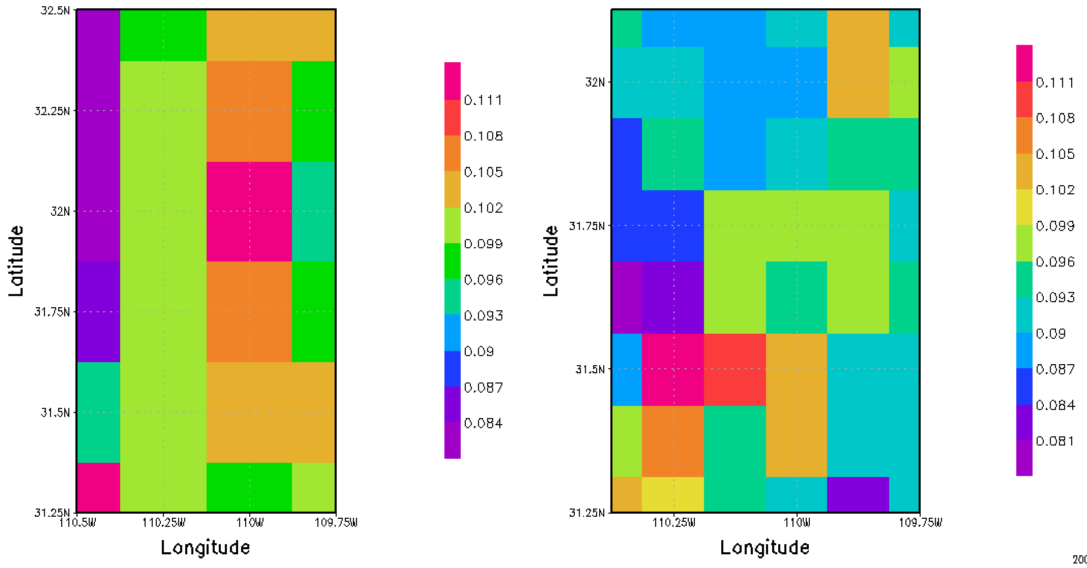

Figure 5 AMSR-E satellite and NOAH model simulated soil moisture maps for the SMEX04 region for July 06, 2004. Though the maps don't match very well, still they are within the same range of values. Note that AMSR-E grid size is 0.25 degree and NOAH model soil moisture grid size is 0.125 degree. Also AMSR-E measures soil moisture from top 2 cm where as the model measures from top 10 cm.

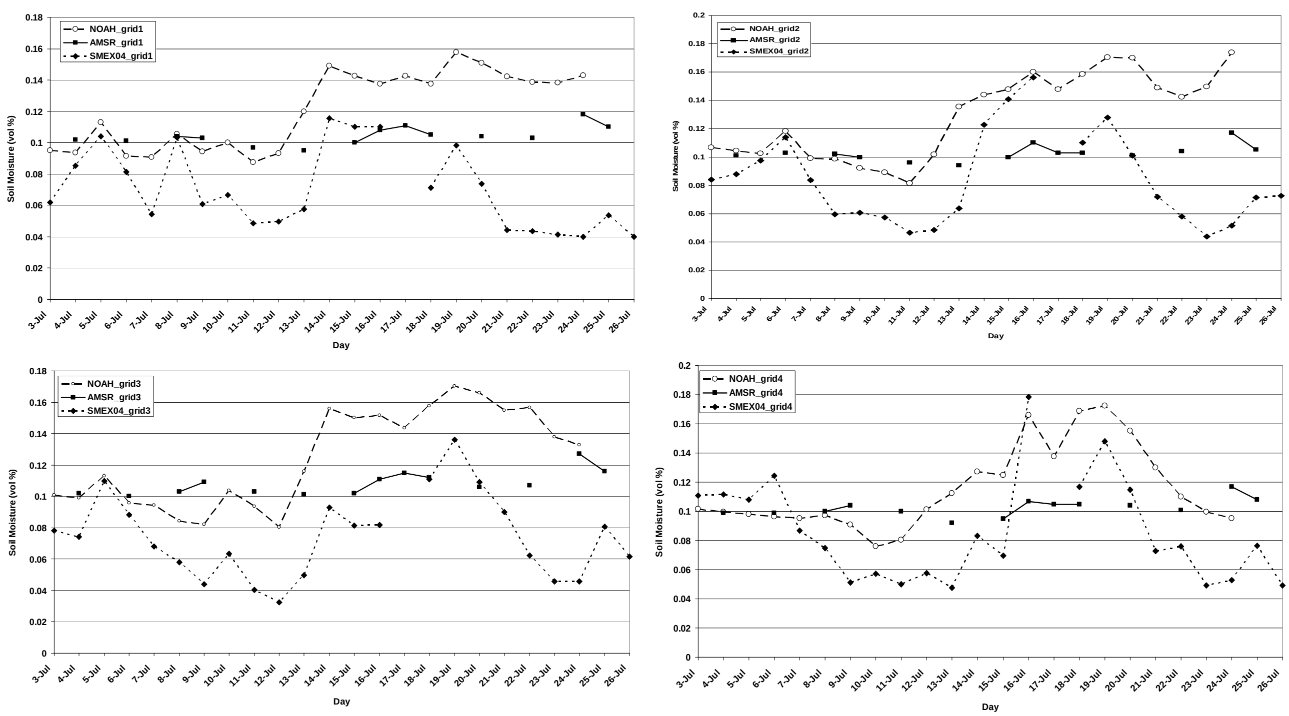

Figure 6 Daily time series of SMEX 04 and NOAH model simulated soil moisture averaged over 1/4 degree grids and AMSR-E 1/4 degree soil moisture data for all the 4 grids over the SMEX04 area. There are many missing AMSR-E soil moisture values in the daily data. Though there are differences among all the three soil moisture values, the nature of the time series agrees very well particularly when the region is dry in the beginning of the experiment time.

same range of values. Finally, the figure 6 shows the soil moisture time series plot from the AMSR-E sensor, the NOAH model and the SMEX04 field observation for grid 1, grid 2, grid 3 and grid 4. Since the AMSR-E covers the whole globe in 3 days only, there are many missing AMSR-E soil moisture data in the time series plot. In all the plots, the AMSR-E derived soil moisture is well within the range of the model soil moisture and the field observed soil moisture though the nature of the AMSR-E soil moisture time series is very difficult to infer because of so many missing data values.

10. Conclusion

From this study, it can be inferred that AMSR-E soil moisture can be compared with true soil moisture values (field experiment) as well as with the model simulations with some reasonable exceptions. Our earlier idea of AMSR-E producing very low soil moisture data couldn't be tested here since the SMEX04 region is mainly over a very dry region and the original field observed soil moisture values are very low. Also, this comparison study was to demonstrate the results at a local scale which can't be generalized for the whole globe. All the above questions can be answered after doing same kind of comparison studies at other places with different climatic regimes, soil types and vegetation types.

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