EVALUATION OF AMSR-E SOIL MOISTURE PRODUCT AS AN INPUT TO CLIMATE CHANGE MODELS

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KEYWORDS: Soil Moisture, AMSR-E, NDVI.

ABSTRACT:

Present study is an attempt to examine the suitability of soil moisture products available from Aqua-AMSR-E for their application in monsoon simulations at different temporal scales ranging from medium range to climate scales. For this purpose we have analysed the AMSR-E soil moisture products over 18 locations in India to evaluate their suitability for assimilation in numerical models. It has been found from the study that the AMSR-E soil moisture can be used as input to climate model over Indian region, except over mountainous region, coastal region and regions with dense vegetation.

1. INTRODUCTION

Soil moisture plays an important role in the hydrological cycle. It contributes significantly to the water and energy flux from the surface of the Earth. The movement of water from soil into the atmosphere helps in cooling the Earth's surface. The heat that is released into the atmosphere helps in driving the atmospheric circulation. It controls the proportion of rainfall that percolates into the soil, runoff and evaporation from land. It also contributes to photosynthesis in plants. Soil moisture is the major source of water for crops and hence plays a key role in the performance of the crop. Likewise, soil moisture is clearly important for the hydrologic applications such as flood and drought monitoring, weather forecast, climate forecast etc (Sahoo et al., 2008). Accurate weather forecasts require the rate of transfer of soil moisture to the atmosphere, whether by evaporation or transpiration. Koster et al (2004) identified central Indian region as one of the hot spot apart from regions over Southern USA and Central Africa, where soil wetness could play an important role in rainfall prediction using NWP models.

In spite of its uncontrolled modification and its feedback on both short and long term weather, climate, water supplies, crop production, biochemical cycles and the ecological balance of the biosphere, it is difficult to get the soil moisture information over a large area. The networks of agriculture station provide valuable distributed point measurements but they are insufficient to characterize the spatial and temporal variability of soil moisture at large scales (Njoku et al., 2003). The cost of direct observation of soil moisture is very high, so for global coverage, satellite monitoring of soil moisture is the only reasonable approach. Remote sensing observations from space, assimilated with in situ data into hydrologic models, can contribute beneficially to an integrated global soil moisture monitoring capacity.

Large scale dry and wet surface conditions have been observed to impart positive feedback on subsequent precipitation patterns, such as in the extreme conditions over central U.S. during the 1988 drought and the 1993 floods. Recently, Koster et al. (2004) have identified hot spots over central India, Southern USA and Central Africa, where soil wetness could play important role in rainfall prediction. Thapliyal (2003) used satellite derived soil wetness over Indian region to demonstrate that at large spatial scale there is a positive feedback mechanism in soil wetness anomaly and rainfall. Thapliyal et al. (2004) showed that observations from satellite microwave radiometers can provide valuable information on soil wetness over India, especially the central Indian region, where soil-atmospheric feedback processes are important. A detailed study using soil moisture products available from Aqua-AMSR-E is needed to examine the impact of soil wetness on monsoon simulation at different temporal scale ranging from medium range to climate scales. For this purpose we have analysed the AMSR-E soil moisture products over Indian region to evaluate their suitability for assimilation in numerical models. Present study highlights the findings of the comparison of AMSR-E derived products with actual in-situ measured soil moisture and discuss their suitability for numerical models.

The Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) onboard Aqua satellite is the latest passive microwave sensor in orbit since May 2002 (Njoku et al., 2003). However, AMSR-E soil moisture products contain uncertainties

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due to imperfect instrument calibration and inversion algorithms, geophysical noise, representativeness error, communication breakdowns, and other sources (Eymard et al., 1993; Zhan et al., 2004). Also, the presence of moderate vegetation obscures the soil moisture signals, impeding accurate satellite measurements (Sahoo et al., 2008). It is, therefore, essential that the accuracy of these remotely-sensed fields be evaluated for their use in critical research and applications.

In the present study, an attempt has been made to evaluate the global soil moisture product from AMSR-E sensor with in situ soil moisture at 18 meteorological stations over India during the years 2002, 2003 and 2004 southwest summer monsoon periods (May-August). The objectives of the study includes (1) assessment of AMSR-E soil moisture algorithm performance, (2) verification of AMSR-E soil moisture estimation accuracy, (3) investigation of the effects of vegetation, and topography on the soil moisture retrieval accuracy, and (4) determination of the regions where the AMSR-E soil moisture can be useful.

2. INSTRUMENT

The Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) is a passive microwave radiometer, which was launched aboard the National Aeronautics and Space Administration (NASA) Aqua Satellite on 04 May 2002. AMSR-E is modified from the Advanced Earth Observing Satellite-II (ADEOS-II) AMSR, designed and provided by NASDA. Aqua follows a sun-synchronous orbit with a descending equatorial crossing at approximately 1:30 Local Standard Time. This instrument measures brightness temperature at six frequencies ranging from 6.9 to 89.0 GHz with both horizontal and vertical polarizations at each frequency (total 12 channels). At a fixed incidence angle of 54.8^o and an altitude of 705 km, AMSR-E provides a conically scanning footprint pattern at the surface with a swath width of 1445 km. The mean spatial resolution ranges from 56 km at 6.9 GHz to 5 km at 89 GHz. The Earth-emitted microwave radiation is collected by an offset parabolic reflector 1.6 meters in diameter. During the 1.5 second scan period, the sub satellite nadir track moves approximately 10 km. Radiometer samples are recorded at equal intervals of 10 km along the scan (5 km for 89GHz channel). For AMSR-E, global swath coverage is achieved every two days or less, separately for ascending and descending passes, except for a small region near the poles.

3. DATASETS AND METHODOLOGY

3.1 AMSR-E Soil Moisture Data

In this study, the AMSR-E soil moisture product which is retrieved from AMSR-E brightness temperature (Njoku et al., 2003) has been used. The product is available in the NSIDC website (http://nsidc.org/data/amsre). This product includes daily retrievals of surface soil moisture of the top few centimeters of soil and vegetation water content, as well as brightness temperatures (at 6.9, 10.7, 18.7, 36.5, 89.0GHz with both horizontal and vertical polarization) and land surface temperature. The ancillary data include information on time, geo-location and observations quality control flag that can be used to remove the bad quality retrievals.

The format of the data set is Hierarchical Data Format-Earth Observing System (HDF-EOS), and the grid used is the 25 km Equal-Area Scalable Earth-grid (EASE-grid) in global cylindrical equal-area projection (true at 30^o N and 30^o S), with 1383 columns and 586 rows. The range of soil moisture measured is 0-0.5 g/cm^3, with an estimated accuracy of 0.06 g/cm^3 (Njoku et al., 2003). The level 3 products are derived by compositing level 2 parameters daily into global maps, separating ascending and descending passes so that diurnal effects can be evaluated.

The daily AMSR-E level-3 land surface data (AMSR_E_L3_DailyLand product) were obtained from NSIDC (1 file per day pertaining to ascending and descending pass) for the period May 18 to August 8, 2002; May 01 to August 08, of the year 2003 and 2004. However, for the present analysis only descending pass (1:30 AM) data are considered because at night, the soil moisture and temperature profiles are more uniform than in the early afternoon and the soil, vegetation temperature differences are smaller. Thus the 1:30 AM AMSR-E soil moisture data are expected to have less modeling error and will be more representative of the deeper-layer soil moisture than the 1:30 PM observations.

3.2 Modis Ndvi

For investigation of the effects of vegetation on the soil moisture retrieval, 16-day Normalized Difference Vegetation Index (NDVI) product which is derived from NIR (841-876nm) and red (620-670 nm) channel of the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA’s Terra satellite is used. The product is available in the NASA website (ftp://e4ft101u.ecs.nasa.gov/MOLT/) with two spatial resolutions (250 m and 1 km).

3.3 In-Situ Soil Moisture Data

For comparison purpose, in situ surface soil moisture data obtained from India Meteorology Department (IMD) over 18 stations distributed all over India (shown in figure 1) were used. IMD measures soil moisture by the gravimetric method once a week for two soil layers that is at the surface (surface to 5cm deep soil layer) and 7.5 cm depth (5-10 cm deep subsurface layers. However, the surface (surface to 5 cm deep soil layer) soil moisture data is used for the analysis as microwave radiometer can only detect moisture changes in the top few cm layer. In situ soil moisture is in gravimetric unit (kg/kg) and are converted to volumetric units (g/cm^3) by multiplying with the soil bulk density. Soil bulk density data has been taken from INFOCROP (Agrawal et al.).

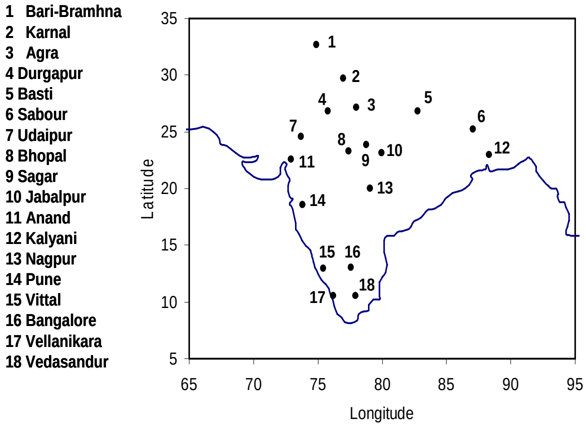


Figure 1. Locations of Insitu Soil Moisture Measurements

3.4 Description of Study Sites

The study area includes 18 locations distributed all over India where in situ soil moisture is measured by IMD. The different location has different irrigation as well as vegetation and topographic condition. During the study period, rice is the main crop that is grown in most of the region. In the month of May it is summer and almost all the fields over India are bare. With the onset of monsoon in June the sowing starts. By the month of July in most of the region crop grows to full canopy, which perturbs the microwave emission from soil. Therefore, for the present analysis the data is restricted until 1st week of August. The entire study region is divided into three categories which are plain, mountainous and coastal region. The central part of India falls under plain region. The locations Bhopal, Sagar, Jabalpur, Nagpur etc. falls under this category. Anand is also a plain region. Apart from being plain region the fields are irrigated naturally i. e. by rain. The location Karnal is also a plain region but the field soil moisture is mainly due to irrigation. The location Bari-Bramhna, Pune etc. falls under the mountaneous region with undulated terrain. Locations like Kalyani, Vittal, Vellanikara, Vedasandur and Kovilpatti etc. are in the costal region with strong presence of vegetation.

4. RESULTS AND DISCUSSIONS

The time series and point to point comparison of the AMSR-E and in situ soil moisture was carried out for all the stations falling in different region of India. Figure 2 shows the time series of AMSR-E soil moisture product over three different location i.e. Agra, Pune and Kalyani falling under different category. Agra located in the northern part of India with 27°10'N latitude, 78°02'E longitude. Topographically, it is in the plain region with very less undulation. Figure 2 shows the trend of the in situ soil moisture profiles from IMD and the corresponding soil moisture obtained from the AMSR-E surface soil moisture product at Agra station. Although the values of in situ and AMSR-E soil moisture are different, they follow the same trend. In all three years, the soil moisture in May and June are low (0.5-1.5 g/cm^3), in July and the first week of August the soil moisture become higher (0.2-0.3 g/cm^3). The deviation between in situ soil moisture and AMSR-E soil moisture is different in different year. The difference in 2003 is higher than in 2002 and 2004 for Agra. Even though the AMSR-E soil moisture is always higher that the in situ soil moisture at Agra, the correlation between the two is also found to be reasonably good (r= 0.75).

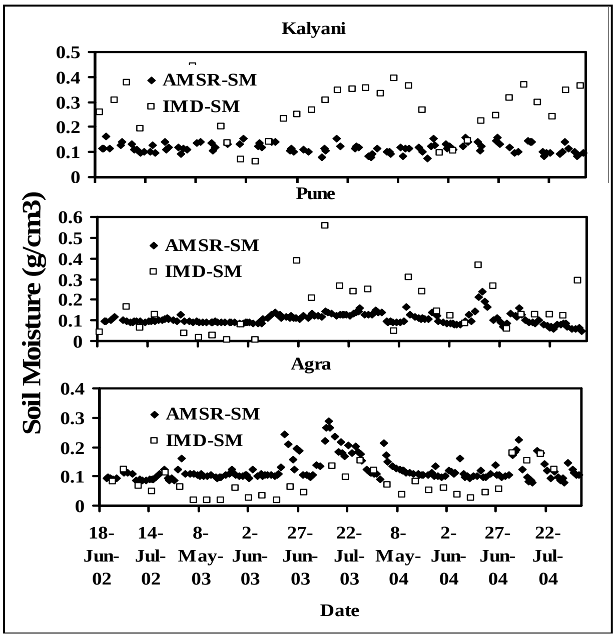


Figure 2. Temporal Variation of AMSR-E Soil Moisture and in Situ Soil Moisture Over Different Regions of India

This may be due to the fact that this region is rain fed and is moderately vegetated during the period of study. Figure 3 shows the variation of NDVI over different region during the period of study. However, in Pune the time series does not follow any particular trend. This region is mountainous and there is the effect of dense vegetation and polarization mixing. The scatter plot between the insitu soil moisture and the AMSR-E soil moisture (figure 4) shows that the correlation coefficient is as high as 0.87, but the slope is very less. At both the locations Agra and Pune, there appears to be bias between the in situ soil moisture and the AMSR-E soil moisture. In Kalyani which falls under the coastal region category it is observed that even though the actual measured soil moisture is very high the AMSR-E soil moisture shows hardly any change in the soil moisture value. This may be due to high vegetation cover in this region. The in situ soil moisture and the AMSR-E soil moisture shows negative correlation with correlation coefficient r=0.51. It is also observed that the minimum amount of soil moisture in AMSR-E is very high (0.1 g/cm^3) compared to that is observed (0.01 g/cm^3) in all the cases. The lowest value of soil moisture in the long time series may be taken as the wilting point, as in only very few cases, soil wetness is below wilting level (as discussed in Zabeline, 1998). Usually in such a situation a crust is formed at the top that prevents further evaporation and the moisture below the crust is preserved.

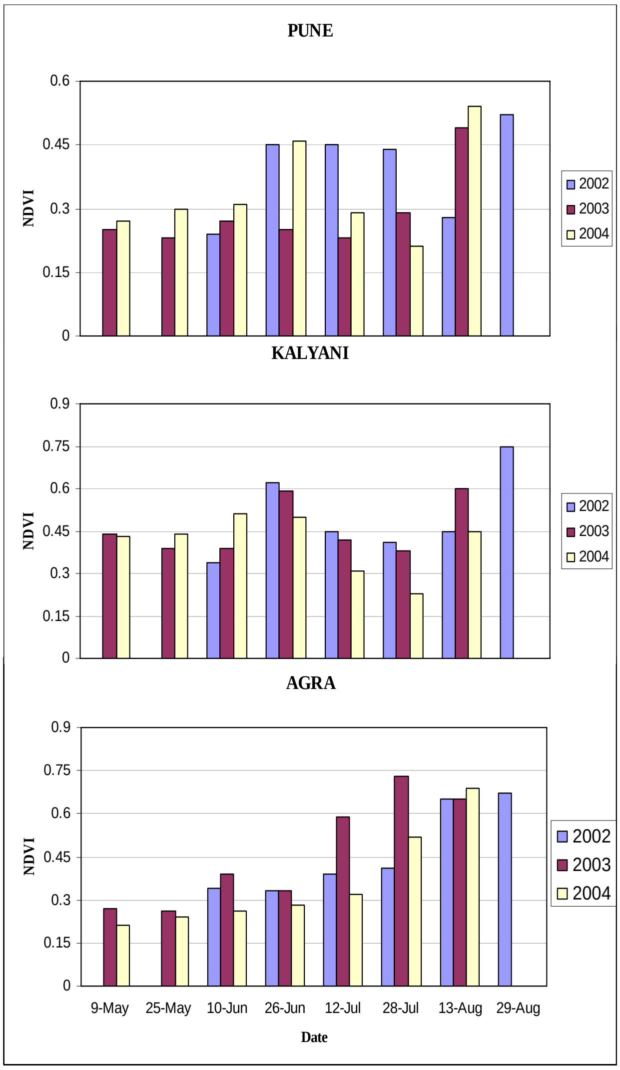
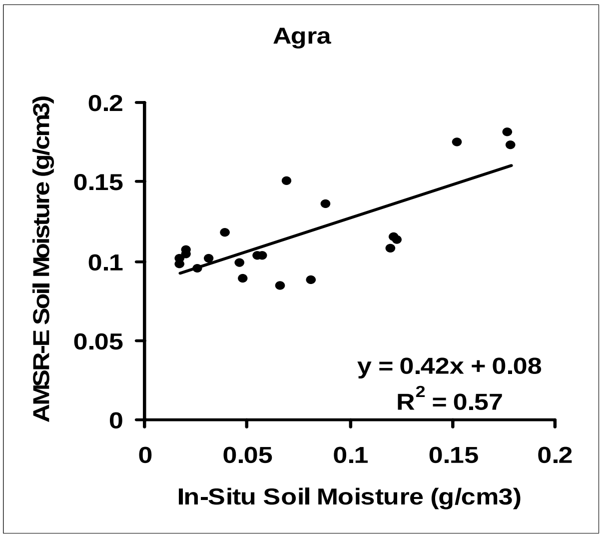
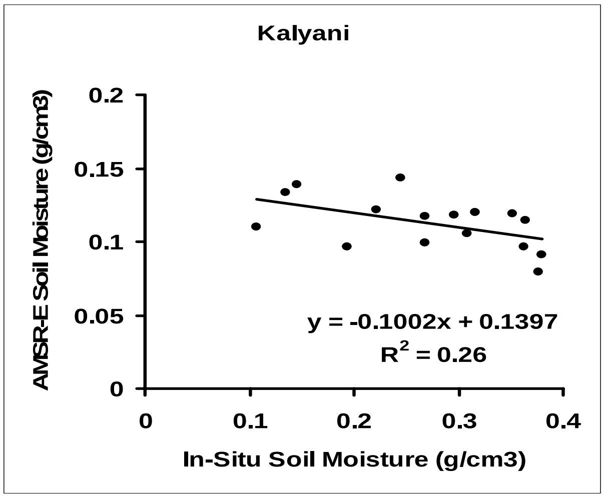


Figure 3. Variation of NDVI over Different Locations of India





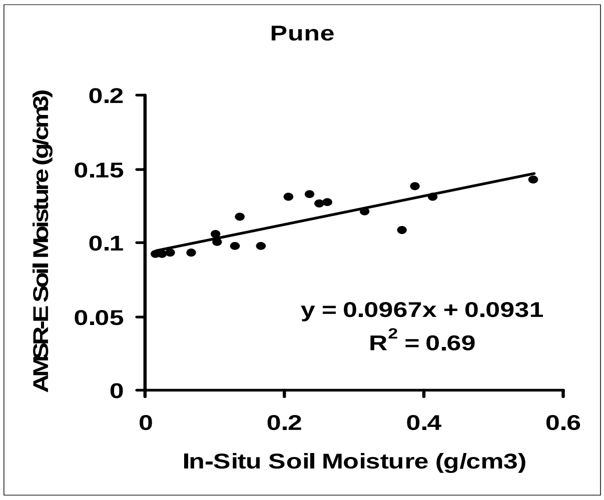


Figure 4. Correlation of in Situ Soil Moisture and AMSR-E Soil Moisture

Similar results are obtained for other locations falling under different category.

CONCLUSION

The AMSR-E soil moisture data is evaluated for 18 stations in India falling under different category like plain region, mountainous region and coastal region. Following are the few main points as conclusions of the present study:

- Present study shows that AMSR-E soil moisture products correlates well with the observed in-situ soil moisture for plain regions with low vegetation. Therefore, these products can be used as input to climate models over Indian plains with low vegetation.

- The wilting point (minimum soil moisture value below which the water from soil is not available to the plant) as shown by AMSR-E product is always high (~ 0.1 g/cm^3) in comparison to the actual soil moisture values as low as (0.01 g/cm^3).

- A refinement of the AMSR-E algorithm is required for the estimation of soil moisture over India giving special emphasis to the correction required for surface coverage especially vegetation.

ACKNOWLEDGEMENTS

The author wishes to thank NSCIDC for providing the AMSR-E soil moisture data and India Meteorological Department for providing in-situ soil moisture data.

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