Spatial and temporal variability of soil moisture over India using IRS P4 MSMR data

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Available online: 22 Feb 2007

To cite this article: R. P. Singh Corresponding author, D. R. Mishra, A. K. Sahoo & S. Dey (2005): Spatial and temporal variability of soil moisture over India using IRS P4 MSMR data, International Journal of Remote Sensing, 26:10, 2241-2247

To link to this article: http://dx.doi.org/10.1080/01431160500043723
Spatial and temporal variability of soil moisture over India using IRS P4 MSMR data

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(Received 15 September 2004; in final form 20 December 2004)

The brightness temperature data measured by the multi-frequency scanning microwave radiometer (MSMR) data has been analysed over the Indian subcontinent to deduce the seasonal and monthly variations of soil moisture. The present results show the spatial variations of soil moisture over the Indian region which is affected by the monsoon and show strong variability over different geological terrains.

1. Introduction
Numerous efforts have been made to study the global soil moisture variability since the soil moisture has significant impact on the dynamics of the atmospheric boundary layer and its importance in hydrologic modelling, weather forecasting, climate prediction, flood and drought monitoring (Shukla and Mintz 1982, Delworth and Manabe 1982, Jackson et al. 1996, Fennessy and Shukla 1999). In the past, efforts have been made to prepare a brightness temperature map of India and study soil moisture using the limited data from Bhaskara satellite (Rao et al. 1986). The accurate assessments of the spatial and temporal variations of soil moisture are advantageous for numerous applications because of basic link between the hydrologic cycle and energy budget of land surfaces. Microwave remote sensing has proved to be a successful tool for quantitative evaluation of soil moisture. The multi-frequency scanning microwave radiometer (MSMR) sensors onboard Indian remote sensing satellite (IRS) P4 Oceansat-1 operational at 6.6, 10.65, 18 and 21 GHz provided global coverage in two days. Using MSMR brightness temperature various geophysical parameters (water vapour, ocean surface winds, cloud liquid water content and rain rate) have been estimated over the Indian subcontinent and also globally. These geophysical parameters are compared with similar geophysical data products from other satellites’ data (Varma et al. 2002a, b, Vasudevan et al. 2004). The present Letter deals with the variability of the average monthly soil moisture over the Indian subcontinent.

2. Theory
The microwave remote sensing mapping of soil moisture is based on the large contrast between the dielectric properties of water (~80) and dry soil (~4). The
dielectric properties of wet soil have been studied by several scientists (Wang and Schmugge 1980, Dobson et al. 1985, Ulaby et al. 1986). The change in water content induces change in the dielectric properties, which affects the emissivity and therefore the brightness temperature. This leads to a direct relationship between soil moisture and brightness temperature. The sensitivity to soil moisture decreases as frequency increases from L band (1 GHz). The radiometer measures the raw counts as the noise equivalent temperature that are converted into the brightness temperature. This brightness temperature consists of different contributions like upward atmospheric emission; downward atmospheric contribution reflected at the surface and attenuated by the atmosphere; contribution from the vegetation.

For radiometers working in shorter wavelength ranges, atmospheric attenuation and emission of the signal can be expressed as (Schmugge 1985, Engman 1991):

$$T_B = t(H) \left[ r T_{\text{sky}} + (1 - r) T_{\text{soil}} \right] + (1 - t(H)) T_{\text{atm}}$$

where $T_B$ is the microwave brightness temperature, $t(H)$ is the atmospheric transmission, $r$ is the surface reflectivity and $T_{\text{sky}}, T_{\text{soil}}$ and $T_{\text{atm}}$ are the temperatures of the sky, soil and atmosphere, respectively. For typical soil moisture applications using longer microwave wavelengths, atmosphere is transparent in most atmospheric conditions ($t(H) \approx 1$ K) and $T_{\text{sky}}$ is much less ($\approx 3.5$ K), hence these terms can be neglected. Therefore,

$$T_B = (1 - r) T_{\text{soil}} \approx e T_{\text{soil}}$$

where $e=(1-r)$ is the emissivity, which depends upon the dielectric constant of the medium (Wang and Schmugge 1980).

The soil moisture is a function of type of soil and surface temperature, which can be deduced from the brightness temperature data available from MSMR sensor. The main difficulty in estimating the soil moisture from brightness temperature is to account for the effect of surface roughness and vegetation cover. Although observations at all frequencies are subject to scattering and absorption, shorter wavelength bands are susceptible to vegetation influences (Owe et al. 2001). Studies with 6.6 GHz horizontally polarized data have also shown that the effect of soil roughness and vegetation cover in this frequency is minimal and can be neglected (Theis et al. 1984). The recent studies (Parde et al. 2003, Lee and Anagnostou 2004) have also shown that the longer wavelengths are not very much influenced by the sparse vegetation; if the vegetation is highly dense the estimation at 10 GHz may be highly affected.

3. Data used

India has launched its first ocean remote sensing satellite IRS P4 (Oceansat-1) on 26 May 1999, carrying a multi-frequency scanning microwave radiometer (MSMR) and ocean colour monitor (OCM) sensors. Oceansat-1 is a Sun-synchronous satellite with a global coverage period of two days. The MSMR provides microwave brightness temperature measurements at 6.6, 10.65, 18 and 21 GHz frequencies with dual polarization having spatial resolutions of 150, 75, 50 and 50 km, respectively. The operational algorithms for deriving various parameters from MSMR brightness temperature data in different grid schemes have been developed.
4. Algorithm used

The soil moisture (SM) has been estimated using 6.6 GHz horizontally polarized MSMR data using the following algorithm (Gohil 1999)

\[
SM = (-0.284 T_{B6.6H}) + 76.2
\]  

where SM is the total amount of water available (in % Vol) in the top 5 cm soil layer and \( T_{B6.6H} \) is the brightness temperature at 6.6 GHz frequency in horizontal polarization. This algorithm is validated in detail using soil moisture measured in the agricultural field, with the agro-metrological data and the observed brightness temperature using IRS P4 MSMR data. Since the validation of soil moisture product was very limited, it was rather difficult to test the algorithm for broad regions. Within the limitations, the algorithm given in equation (1) has been used to study the monthly and seasonal nature of soil moisture and its variations over different geological terrains. The soil moisture data computed for different geological terrains are taken over one pixel. Geologically, the Indian subcontinent is divided into: the Indo-Gangetic basin in the north, which is one of the highly fertile regions with high soil moisture; the central part of India which is covered by the shield region mainly characterized by igneous and metamorphic rocks; the desert region in the western part of India covered by mainly Rajasthan province; and the Deccan trap region covered by the state of Gujarat, Maharasthra and part of Madhya Pradesh. The central part of the region is covered by the shield region, which is characterized by very low porosity. While selecting a point for estimation of soil moisture data, geological and forest maps of India are considered. The area covered by dense forest is avoided and the efforts were made to choose a pixel which represents different geological terrains with minimum inhomogeneity.

5. Results and discussion

The monthly average variations of soil moisture (figure 1) over India have been deduced using 6.6 GHz MSMR data for the period January 2000–December 2000 (except September and October because of non-availability of data). The variation of moisture content over different land regions of India is mainly controlled by seasons and to a great extent by monsoon flow over India. The maximum moisture content of the soil varies in the range 16–20% Vol, which is restricted to limited areas in the rainy season. The lowest value of soil moisture over India is recorded in the month of April, which varies between 0 and 4% Vol. Looking at the general trend, it can be concluded that moisture content of soil increases after monsoon in the months June–August and gradually decreases during November–February and shows low values prior to monsoon during March–May. Figure 2(a) shows average monthly variations of soil moisture over different geological terrains of India. Soil moisture over the Indo-Gangetic basin and the Deccan trap region shows the highest value around 11% Vol in the month of July and lowest value (2% Vol) in the month of May, whereas the shield region shows the highest value (9% Vol) in October and the lowest value (2% Vol) in May. This is mainly due to the uneven distribution of precipitation over India. Generally, May is the hottest month in India, with the maximum temperature (35–45°C). The brightness temperature and surface temperature from figure 2(b) and 2(c) show highest values during May, which drastically reduces moisture content over the Indian region whereas in the rainy season, moisture content increases. The Indo-Gangetic basin and the Deccan
trap regions get maximum rain during July and August due to the south-west (SW) monsoon; as a result higher soil moisture is found. The shield region gets maximum rain due to the north-east (NE) monsoon during November, showing highest soil moisture in the shield region. The desert region shows higher values (around 5.5% Vol) of soil moisture during winter due to high concentration of dew. An effort has been made to study the seasonal variations of soil moisture over different geological terrains and river basins of India (figure 3). Significant soil moisture has been observed in the Indo-Gangetic basin in all seasons. The moisture content increases from west to east of the basin showing maximum values in the Bramhaputra–Ganges delta region. It has also been observed that moisture content along the coastal region is comparatively higher than those of other regions. Due to the coarse resolution of the data it was difficult to avoid the contamination of ocean with the coastal areas. The higher values of soil moisture along the coast may be highly biased by the contamination of ocean. Moreover, soil moisture is very much dependent on geology of the region showing lower values over the hard rock terrains.

6. Conclusion

Variations of soil moisture over India qualitatively show close agreement with the monsoon and rainfall pattern, showing the highest soil moisture during June–July and the lowest soil moisture during April–May. Along the coastal regions of India moisture content is generally found to be higher as compared to other regions. The soil moisture deduced in the present study may be biased with the presence of low and high dense vegetation. The resolution of the sensor (6.6 GHz) used for soil moisture is 150 km, at which soil moisture is averaged over a grid, therefore vegetation effect can be considered to be almost neglected at 6.6 GHz. The MSMR derived soil moisture data show close relation with the National Centers for
Environmental Prediction (NCEP) generated soil moisture data (figure 4) with the correlation coefficient 0.99. This further validates the soil moisture deduced from MSMR data. The results presented in this Letter are very crude since the resolution of data is very coarse but it gives qualitative information about the soil moisture variability over different geological terrains. The soil moisture discussed in this Letter is considered over the pixel dominance of soil/rock covers with sparse vegetation so it is assumed that the soil moisture may not be affected

Figure 2. Monthly variations of (a) soil moisture, (b) brightness temperature and (c) surface temperature in different geological terrains of India.
significantly. However, detailed analysis and field investigations are required to evaluate the effect of vegetation at 6.6 GHz.

**Acknowledgments**

The authors are thankful to the Space Application Centre, ISRO, Ahmedabad for providing MSMR data under Oceansat AO Project to Professor Ramesh P. Singh. The authors are grateful to Dr G. Foody, Letter Editor, and to two anonymous
reviewers for their comments which have helped to improve the earlier version of the manuscript.

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