USING TRMM SATELLITE C BAND DATA TO RETRIEVE SOIL MOISTURE ON THE TIBETAN PLATEAU

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ABSTRACT:

Soil moisture, through its dominance in the exchange of energy and moisture between the land and atmosphere, plays a crucial role in influencing atmospheric circulation. To identify the crucial role, it is a common agreement that knowledge of land surface processes and development of remote sensing techniques are of great important scientific issues.

This research uses TRMM satellite C band (10.65 GHz) data to retrieve soil moisture on the Tibetan Plateau in Mainland China. Two retrieval schemes that are implemented include the τ—ω model and the R model. The latter one is developed based on a land surface process and radiobrightness (R) model for bare soil and vegetated terrain. Compared with the in situ ground measurements, the soil moisture retrieved from the R model and the τ—ω model with vegetation information obviously appear more accurate than that derived from bare soil model.

Retrieved soil moisture contents from the two inversion models, R model and τ—ω model, have a similar trend, but the former appears to be superior in terms of correlation coefficient and bias compared with in situ data. In the future, we will apply the R model with the TRMM 10.65 GHz brightness temperature to monitor long-term soil moisture variation over Tibet Plateau.

KEY WORDS: Soil moisture, Microwave Remote sensing, Tibetan Plateau

1. INTRODUCTION AND OBJECTIVES

Soil moisture, through its dominance in the exchange of energy and moisture between the land and atmosphere, plays a crucial role in influencing atmospheric circulation. To identify the crucial role, it is a common agreement that knowledge of land surface processes and development of remote sensing techniques are of great important scientific issues. Because of the difficulty to measure soil moisture, soil moisture is usually ignored in the numerical weather modelling. However, with the development of remote sensing technique, soil moisture may be easily obtained by using microwave remote sensing (Wang and Schmugge, 1980; Schmugge et al. 1986; Liou and England, 1996, 1998a, 1998b; Liou et al. 2001; Liu et al., 2002).

This paper is intended to utilize TRMM satellite data to retrieve soil moisture over the Tibetan Plateau in Mainland China and to analyze the performance of different retrieval schemes based on emission models.

2. METHODOLOGY

2.1 Ground truth data

In this paper, we mainly collect non-freezing ground truth data to validate the developed retrieval models from July 1 to Aug 31, 2001. Nevertheless, the ground weather stations in Tibet are not well maintained, and even destroyed. It is often that there are data missing. Hence, we have limited options but only to use the MS3608 station (31.227°N, 91.78°E) as the ground truth data. The MS3608 station not only has surface temperature to be used as input data for the retrieval model but also has soil moisture data at depth of 4 cm to validate the retrieval results. The land cover over the MS3608 station is low density grass and the soil texture is mainly sandy loam.

2.2 Simulation data

The C band (10.65GHz) H-polarization brightness temperature data of TRMM TIM are used to retrieve soil moisture because C band is the longest wavelength (2.8 cm) for the TIM system. The longer the wavelength is the less the atmospheric effect is. Furthermore, the TRMM's orbit is circular with an inclination of 35 degrees to the Equator. Due to the nature of its non-sun-synchronous orbit we can get satellite data for different local time. Table1 shows the simulation data that we used in this research.

Table 1. Simulation data

Parameter	Value
Satellite	TRMM
Wavelength	2.8cm(10.65GHz)
Polarization	H
Look angle (Θ)	52.75°
Date	2001/07/01 ~2001/08/31
Vegetation type	grass
Vegetation parameter (b)	0.2039
Vegetation water content (W_V)	0.25 kg/m^2
Surface roughness parameter (h)	0.2
Polarization-mixing parameter (Q)	0.3
Scattering effect parameter(ω)	0.05
Canopy height	0.04 (X. Li, 2003)
Soil sand fraction	51.51%
Soil clay fraction	13.43%
Soil bulk density (ρ_b)	1.4 g/cm^3
Specific density(ρ_s)	2.65 g/cm^3
Temperature of soil	MS3608

2.3 Emission model

We mainly used surface emission model as a basis to retrieve soil moisture. The emission consists of brightness contributions from the surface soil, the canopy and the atmosphere.

Microwave emission characteristics of land surface can be written as:

$$T_B = T_u + \exp(-\tau_a)[T_b + rT_d] \quad \ldots(1)$$

where T_B is the brightness temperature, T_u is the upward atmospheric apparent temperature, T_d is the downward-emitted atmospheric brightness temperature, T_b is the target apparent temperature, τ_a is the optical depth, r is the surface reflectivity.

In the study, the target brightness temperature is the soil brightness temperature. The soil brightness temperature is governed by the effective soil temperature, T_g, so that Eq (1) can be rewritten as

$$T_B = T_u + \exp(-\tau_a)[(1-r)T_g + rT_d] \quad \ldots(2)$$

The soil surface is assumed to be speciular so that its refractivity may be approximated by the Fresnel reflectivity, which is a function of soil dielectric constant. The Fresnel reflectivity is

$$r(\theta;h) = \left| \frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}} \right|^2 \quad \ldots(3)$$

where θ is the incidence angle of satellite, and ε is soil dielectric constant. Then, we chose an empirical model (Dobson et al, 1985) utilizing a dielectric mixing approach that was dependent upon readily measured soil characteristics to retrieve the soil moisture from the soil dielectric constant.

$$\varepsilon_m^\alpha = 1 + \frac{\rho_b}{\rho_s}(\varepsilon_s^\alpha - 1) + m_v^\beta \varepsilon_{fw}^\alpha - m_v \quad \ldots(4)$$

where m_v is soil moisture, ρ_s is soil bulk density, ρ_b is soil specific density, ε_s is the dielectric constant of soil solids, ε_{fw} is the dielectric constant of free water, and α is a shape parameter.

2.4 Vegetation models

A non-freezing period from July to August in 2001 is chosen for the current study. During this period, the land surface is covered with heavy grass. Hence, the effect of the canopy shall be considered when soil moisture is of interest by the developed retrieval algorithms. In this paper, two vegetation models, R model (Liou et al. 1999a) and τ—ω model (Wigneron et al. 2004) are used to correct the contribution of surface brightness temperature and their performances are compared.

2.4.1 R model

The R module from the LSP/R model of Liou et al. (1999a) is adopted. The R model is a forward model, and it is used to develop a backward scheme. In the R model, emission from the land surface consists of contributions from a layer of soil and a layer of canopy. Both layers are considered to be homogeneous.

The relative permittivity of a wet canopy based upon the dual-dispersion model of Ulaby and El Rayes is

$$\varepsilon_{wg} = \varepsilon_r + v_{fw}[4.9 + \frac{75}{1 + jf/18} - j\frac{18\sigma}{f}] + v_{bw}[2.9 + \frac{55}{1 + (if/0.18)^{0.05}}] \quad \ldots.(5)$$

where $\varepsilon_r = 1.7 - 0.74m_g + 6.16m_g^2$ is the residual dielectric constant, $v_{fw}=m_g(0.55m_g-0.076)$ is the volume fraction of free water in the grass, $\upsilon_{bw}= 4.64, m_g^2/(1+7.36m_g^2)$ is the volume fraction of bound water in the grass, and m_g is the gravimetric moisture constant of the wet grass.

The total model brightness is comprised of four components,

$$T_b = T_{bs} + T_{bc,d} + T_{bc,u} + T_{bsky} \ldots(6)$$

where $T_{bs} = T_{s,e}(1-r)e^{-\tau_0/\mu}$ is the soil brightness attenuated by one trip through the canopy, $T_{bc,d} = T_{c,e}(1-e^{-\tau_0/\mu})re^{-\tau_0/\mu}$ is the down-welling canopy brightness reflected by the soil and attenuated by one trip through the canopy, $T_{bc,u} = T_{c,e}(1-e^{-\tau_0/\mu})$ is the upwelling canopy brightness, $T_{bsky} = T_{sky}re^{-2\tau_0/\mu}$ is the sky brightness reflected by the soil and attenuated by two trips through the canopy, and μ is the cosine of the incidence angle.

2.4.2 τ—ω (Tau-Omega) model

The τ—ω model is developed by Wigneron et al. (2004). It used a single microwave band to retrieve the soil moisture. Compared with the R model, the effect of the canopy is determined by two parameters, τ and ω, where τ means the optical of canopy and can be written

$$\tau = VWC * b \ldots(7)$$

where VWC is vegetation water content , and b is a parameter, which is a constant that depends on vegetation type, operating frequency of the antenna, and ω is the scattering effect parameter within the canopy

3. RESULTS

3.1 Results of bare soil emission

First of all, we used the simplest emission model, bare soil emission model, to retrieve the soil moisture. Fig.1. shows the results with blue points representing the soil moisture retrieved by bare soil emission model using TRMM 10.65GHz data. The green line is the relative ground truth from MS3608 station.

The correlations between the model and the ground truth in July and in two months (July to Aug) are 0.75 and 0.63, respectively. The soil moisture retrieved from bare soil model is obviously lower by about 10% than the ground truth.

3.2 Results of considering the canopy effect

Because canopy also contributes to the observed brightness temperature in summer, we use the vegetation models including the R model and τ—ω model to correct the emission for improving the accuracy of retrieval of the soil moisture. The biases of R model and τ—ω model between the in situ ground truth are 0.013 and 0.027, respectively.

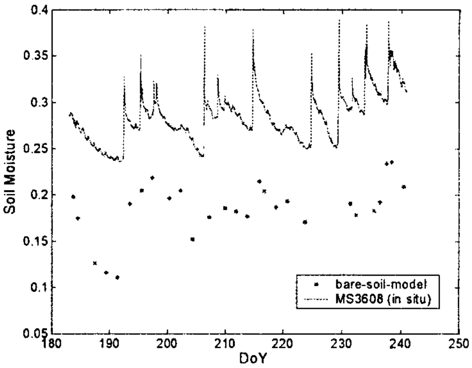

Fig.1. The relationship between the soil moisture from bare soil model and ground truth of MS3608 station

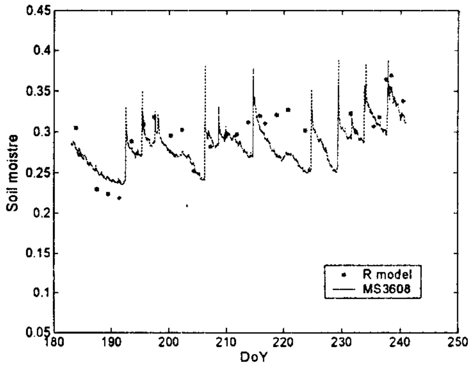

Fig.2. The relationship between the soil moisture from R model and ground truth of MS3608 station

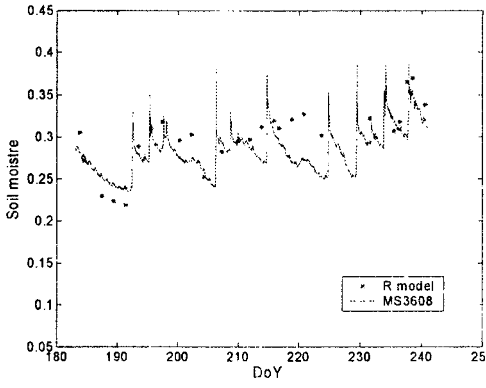

Fig.3. The relationship between the soil moisture from τ—ω model and ground truth of MS3608 station

4. CONCLUSIONS

This study used TRMM satellite C band (10.65 GHz) data to retrieve soil moisture on the Tibetan Plateau in Mainland China. Two retrieval schemes that are implemented include the τ—ω model and the R model. The latter one is developed based on a land surface process and radiobrightness (R) model for bare soil and vegetated terrain. Compared with the *in situ* ground measurements, the soil moisture retrieved from the R model and the τ—ω model with vegetation information obviously appear more accurate than that derived from bare soil model.

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