Development of a Radiative Transfer Model for the Soil Media with Including Vertical Profile Effects and Its Application in AMSR2

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Abstract— Soil moisture plays an essential role in the Earth system. Reliable estimation of soil moisture, especially in regional and global scale, is important for climatic, meteorological and hydrological researches. This study presents a revised soil radiative transfer model (RTM) in which the vertical profile effects of soil temperature are included. In situ observations of soil moisture and temperature profile, measured during HIWater Experiment IOP, are used to formulate profile functions. The revised RTM is applied into the new AMSR2 soil moisture retrieval algorithm, in order to improve the algorithm performance in arid regions. By comparing the results of new algorithm against ground observations, the feasibility and capability of the revised algorithm and RTM were verified.

1. INTRODUCTION

Soil moisture is an essential variable in earth system science, playing a significant role in climate modeling, weather forecasting, hydrological and ecological process simulating and food production predicting. Soil moisture can be observed in point and local scales through in situ sensor networks and field survey. However, regional and global soil moisture information can be only derived from numerical model simulations or estimated from remote sensing observations. Passive microwave remote sensing has a more than 30 years history to provide earth observation which can be used to retrieve global surface soil moisture content (SMC). Beside the L-band observation provided by the current SMOS [1] and oncoming SMAP [2], the multi-band observations (C, X and K-band) provided by AMSR-E [3] and its successor AMSR2 [4] have been used to generate global SMC products from 2002 to now.

NASA, VUA and JAXA released AMSR-E SMC products independently, while JAXA is producing AMSR2 SMC data set now. The SMC retrieval algorithm of JAXA is relaying on a look up table (LUT). The SMC products of JAXA gives generally reasonable soil moisture estimate in global scale, while it overestimates soil moisture in desert regions. Figure 1 gives an example of AMSR2 SMC product over Africa continent. As shown in this figure, monthly averaged soil moisture in the Sahara desert regions (15N-35N) are higher than no desert regions in southern Africa. There are two main reasons for such unreasonable overestimation: current AMSR2 algorithm does not include the temperature profile effects and volume scattering effects which are aroused when microwave penetrates into dry soil. Such overestimations are generally occurred in mid to low latitude regions where have powerful solar radiation, and could lead to the energy imbalance for its further application in atmospheric and hydrological models.

2. THE REVISED SOIL RADIATIVE TRANSFER MODEL

In microwave region, the reflectivity of the air/soil interface is generally small. The downward radiation from vegetation and rainfall, which is reflected by the soil surface, therefore, is neglected. Moreover, for the lower frequencies region of microwave, the atmosphere is transparent. Finally, after neglecting all the downward radiation and parts of upward radiation from surroundings, the radiative transfer model is written as:

$$T_b = T_{bs}e^{-\tau_c}e^{-\tau_r} + (1-\omega_c)(1-e^{-\tau_c})T_c e^{-\tau_r} + \int (1-\omega_r(R))(1-e^{-\tau_r(R)})T_r(R)dR \qquad (1)$$

where T_{bs} is the emission of the soil layer, T_c is the vegetation temperature, T_r is the temperature of precipitation droplets, τ_c and ω_c are the vegetation opacity and single scattering albedo, and τ_r and ω_r are the opacity and single scattering albedo of precipitation.

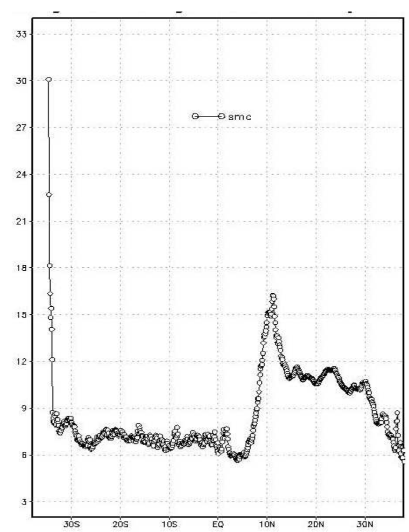

Figure 1: An example of overestimation-in-dry-religion problem of JAXA AMSR2 SMC product. Monthly averaged soil moisture over Africa continent was used to calculate the longitude average.

For the frequencies less than 18 GHz, Equation (1) can be even simplified by omitting the precipitation layer, as:

$$T_b = T_{bs}e^{-\tau_c} + (1-\omega_c)\left(1-e^{-\tau_c}\right)T_c \tag{2}$$

For the dry regions, vegetation water content is generally very small and there is almost no vegetation attenuation effect. RTM can be further simplified as

$$T_b = T_{bs} = T_{eff}(1-R) \tag{3}$$

where R is the surface reflectivity and can be estimated by combing Fresnel function and roughness function, T_{eff} is the effective temperature, as:

$$T_{eff} = \int_0^{\varpi} T(z)\alpha(z)\exp\left[-\int_0^z \alpha(z')dz'\right]dz \tag{4}$$

$$\alpha(z) = (4\pi/\lambda)\varepsilon''(z)/2\sqrt{\varepsilon'(z)} \tag{5}$$

where $T(z)$ is soil temperature profile along the vertical direction z (cm), $\varepsilon(z)$ is the dielectric constant profile and can be estimate by inputting soil moisture and temperature profile into Dobson model.

3. STUDY REGION

We applied our RTM and algorithm [5] in the middle reach of Heihe river (38.7N-39.5N, 100.1E-100.8E), where the HIWater experiment conducted during June to September, 2012. Soil moisture and temperature at 0, 2, 4, 10 and 20 cm depth are recorded every 10 minute at Shenshawo station (38.79N, 100.49E). The location of this station is selected carefully to make it be representative for the surrounding desert. The recorded profiles are converted to three-month-averaged values and are used to calculate the effective temperature in Equation (4).

As shown in Figure 2(a), soil temperature changes obviously as depth increasing. Soil temperature profile in daytime differs from that in nighttime. After curve fitting, the soil temperature profiles shown in Figure 2(a) are formulated as:

$$T(z) = T_{surf} * [1.029 - 0.02893 * \exp(-0.355 * z)] \tag{6}$$

for descending overpass and

$$T(z) = T_{surf} * [0.9403 + 0.0595 * \exp(-0.7087 * z)] \tag{7}$$

for ascending overpass.

As shown in Figure 2(b), the soil moisture at different depths have almost same values. A uniform soil moisture profile, therefore, will be used in our RTM.

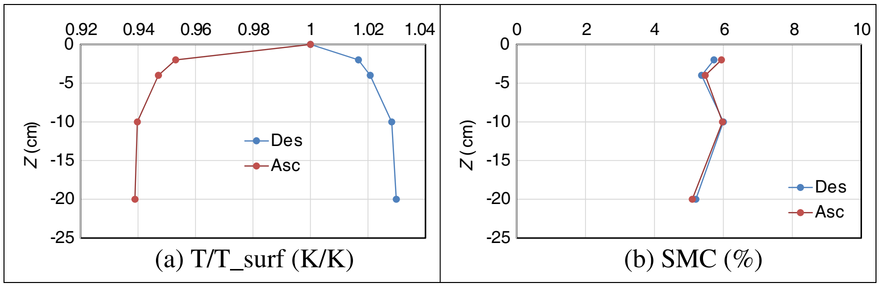

Figure 2: Averaged soil (a) temperature and (b) moisture, profile observed at Shenshawo station. "Des" denotes observations in at the time of descending overpass (around 02:00 local time); "Asc" for ascending overpass (around 13:00 local time).

4. RESULTS AND DISCUSSIONS

Figure 3 shows the comparison between soil moisture contents retrieved from new algorithm and those observed at the station. With using the new RTM, the wet-bias is partly mitigated and performance of soil moisture algorithm is improved, giving the RMSE of 4.69% with a R-square of 0.475.

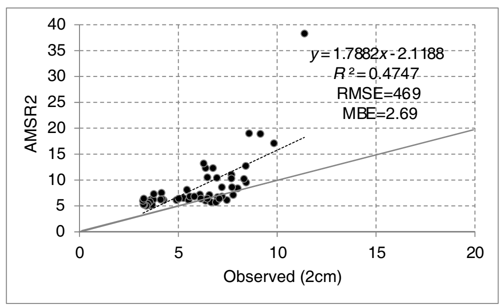

Figure 3: Comparison of retrieved soil moisture with ground observation at Shenshawo station.

5. CONCLUSION

A soil radiative transfer model with including temperature profile effects is developed to improve the accuracy of soil moisture estimation, especially in dry regions. By coupling the new RTM into AMSR2 soil moisture retrieval algorithm, algorithm performance can be improved. Further numerical and theoretical simulations will be studied.

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