Development and validation of TMI algorithms for soil moisture and snow

TOSHIO KOIKE, HIDEYUKI FUJII, TETSU OHTA & EITA TOGASHI
Department of Civil Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
e-mail: tkoike@hvdra.t.u-tokyo.ac.jp

Abstract Land surface hydrological conditions are considered to play an important role in global and regional climate variability. Soil moisture and snow are especially key parameters, which should be observed at the global scale and included in global and regional models. In this study, new algorithms based on radiative transfer theory are developed for soil moisture and snow using passive microwave sensors. These are applied to data from the TRMM Microwave Imager and evaluated by using the field data obtained during the GAME-Tibet Intensive Observing Period. The estimated hydrological parameters, surface soil moisture, soil surface temperature and water content of vegetation and snow temperature show good correspondence to the observed data.

Key words Asian monsoon; GEWEX; microwave radiometer; passive microwave remote sensing; snow; soil moisture; surface temperature; Tibetan Plateau; TMI; TRMM

INTRODUCTION

Microwave remote sensing can directly measure dielectric properties, which are strongly dependent on liquid water content. Their longer wavelength is one of the advantages of microwaves. It is long enough to reduce the scattering effect of cloud particles making microwave sensors a useful all-weather tool. Wavelengths in the microwave region have sensitivity to the scattering effect of snow grains and leaves. Microwave remote sensing, therefore, has potential for measuring snow water equivalent and vegetation water content (VWC). The independence of the sun as a source of illumination is also one of the important reasons for using microwaves, allowing one to acquire data at night. This advantage is more important in the case of non-sunsynchronous observation.

In this study, new algorithms for soil moisture, vegetation water content, soil surface temperature, snow depth and snow physical temperature obtained by using passive microwave sensors are developed, based on microwave radiative transfer theory. They are applied to the satellite data from the TRMM Microwave Imager (TMI) and validated by using ground data obtained in the Intensive Observing Period (IOP) of the Tibetan Plateau project of the Global Energy and Water Cycle Experiment (GEWEX)/Asian Monsoon Experiment (GAME-Tibet), which it has been suggested plays an important role in the variation of the Asian summer monsoon.

ALGORITHM BASIS

The microwave brightness temperature observed by satellites is expressed by the radiative transfer equation, and consists of the soil surface radiation attenuated by a
vegetation layer, and the radiation from vegetation. Passive microwave sensor algorithms based on radiative transfer theory for snow and soil moisture are proposed, and are based on the effects of vegetation on the observed brightness temperature.

In the soil moisture algorithm, vegetation is considered as an absorption and radiation layer over the surface soil which is characterized by its mixed dielectric constant, which strongly depends on soil moisture. The vegetation layer is characterized only by optical thickness, which is related to the VWC (Jackson, 1997). Dobson's equation is applied to estimate land surface dielectric constant (Dobson et al., 1985). To incorporate the effects of surface roughness, the reflectivity is calculated by using a polarization-mixing parameter and a roughness parameter (Wang & Choudhury, 1981). A Soil Wetness Index (Koike et al., 1996) and Polarization Index (Paloscia & Pampaloni, 1988), are introduced to estimate surface soil moisture and VWC. These two indices can remove the effect of the physical temperature, resulting in a more stable relationship with soil moisture and VWC than the direct solution of the radiative transfer equations at different frequencies and polarizations. To obtain a look-up table, which shows the relationship between soil moisture, VWC, and the two indices, a numerical inversion technique is applied to the results of forward calculation of the two indices by putting soil moisture and VWC into the radiative transfer equations. Soil moisture and VWC are then estimated by putting observed brightness temperature into the look-up table. Soil temperature is estimated by putting the estimated soil moisture and VWC into the radiative transfer model.

In the snow algorithm, the relationship between the land surface radiation and snow properties is obtained by radiative-transfer theory based on a scattering dielectric layer over a homogeneous half-space (England, 1975). The total land surface brightness temperature is the sum of the direct component and diffuse component, which corresponds to the reflected sky radiation and the thermal radio emission from the snowpack and soil, and the radiation scattered from the direct and diffuse fields respectively. By assuming snow grain size, snow density, and radiation from the soil-snow interface, brightness temperatures at two different frequencies are calculated by inputting snow depth and physical temperature. This forward model calculation was validated with data from aircraft observations (Koike & Suhama, 1993). To incorporate the vegetation effect on radiative transfer, a relationship between leaf area index (LAI) and VWC (Paloscia & Pampaloni, 1988) is introduced in addition to the relationship between optical thickness and VWC which is used in the proposed soil moisture algorithm in this paper. LAI is subsequently estimated by NDVI. To obtain a look-up table which shows the relationship between snow depth, snow physical temperature, and brightness temperature at the two different frequencies, the numerical inversion technique is applied to the results of the forward calculation at the two frequencies by inputting snow depth and snow physical temperature for each NDVI condition. We can then estimate snow depth and snow physical temperature by putting the observed brightness temperatures at the two frequencies into a look-up table.

In this paper, TMI data is used for the above two algorithms. For soil moisture, sensitivity is investigated using several combinations of frequencies: 10 and 19 GHz, 10 and 37 GHz, and 19 and 37 GHz. The snow algorithm is applied to the brightness temperature at 19 GHz and 37 GHz to estimate snow depth and snow physical temperature. The two algorithms are applied to the TMI orbit data geo-corrected to latitude-longitude coordinates.
VALIDATION DATA

It is suggested that the Tibetan Plateau plays an important role in the variation of the Asian summer monsoon through its atmospheric heating processes. To understand the processes of the hot air mass generation over the Tibetan Plateau in the summer and their seasonal and interannual variation, the land surface hydrological conditions and the precipitation should be observed at the plateau scale. The IOP was implemented in 1998 for the purpose of establishing satellite-based observing systems and clarifying the interactions between the land surface and atmosphere over the Tibetan Plateau. The following measurement systems were deployed and operated continuously during the IOP: 14 automatic weather stations (AWS), a planetary boundary layer (PBL) tower, two turbulent flux measurement systems, a radiosonde system, seven barometers, 20 raingauges, 3-D Doppler radar, a snow particle measurement system, a microwave radiometer, GPS receiver, eight soil moisture (Time Domain Reflectometry, TDR) and temperature measurement systems, and two river water level gauges.

RESULTS OF VALIDATION

Figure 1 shows that the estimated soil moisture corresponds reasonably to the soil moisture observed by the TDR sensor at 4 cm in depth. Just after the heavy rainfall, the satellite derived soil moisture is greater than the ground observations because the TMI only detects the surface moisture, which is much wetter than the observations at 4 cm depth. Conversely, during dryer periods the algorithm underestimates because the soil surface dries more rapidly. The monthly averaged diurnal cycle of the land surface physical temperature calculated by the proposed algorithm shows the same pattern as the ground observations, however with several K bias as shown in Fig. 2. The estimated water content of the vegetation also corresponds well to the observations, with an accuracy of 10% or less.

The estimated snow physical temperature is in good agreement with ground observations made with infrared thermometers (Fig. 3). Snow depth was not validated because of the lack of adequate ground observations.
Development and validation of TMI algorithms for soil moisture and snow

Fig. 2 The monthly averaged diurnal cycle of the land surface physical temperature. (solid line: observed, filled circle: estimated).

Fig. 3 The time series of the observed physical temperature of snow surface (solid line) and the values estimated by the TMI snow algorithm (filled circle).

Acknowledgements The data used in this paper were obtained by the GAME-Tibet project supported by the Ministry of Education, Science, Sport and Culture of Japan, the Science and Technology Agency of Japan, the National Space Development Agency of Japan, the Frontier Research System for Global Change, and the Chinese Academy of Science. This study is supported by the Core Research for Evolutional Science and Technology.

REFERENCES


