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EXPERIMENTAL STUDY ON SOIL MOISTURE USING DUAL-FREQUENCY MICROWAVE RADIOMETER

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ABSTRACT: An experiment of measuring soil moisture was carried out by using dual-frequency microwave radiometer designed by the authors. The measured data were analyzed by using statistical regression method and the empirical regression model of retrieving soil moisture in L-band and C-band was developed. The soil moisture in a rainfall event was retrieved using the experiential regression model, which is consistent well with the field sampling value. The results show that when soil moisture is lower than 75%, the brightness temperature is linear with soil moisture. However, when soil moisture is higher than 75%, the brightness temperature is not linear with soil moisture, so it is difficult for microwave radiometer to measure the changes of soil moisture. The experiment verifies the effectiveness and feasibility of microwave remote sensing soil moisture. Although this method for linear regression based on the data measured with the radiometer is simple, and has strong adaptability, generally it has only local application value, and lacks universal applicability for different areas and different conditions.
KEY WORDS: soil moisture; dual-frequency microwave radiometer; brightness temperature

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1 INTRODUCTION

Soil is the basis of human's living. Soil moisture plays a significant role in studying the matter and energy exchanges in global hydrology sphere. The evaporation of soil moisture has an influence on the water vapor cycle. Meanwhile soil moisture is also one of the firsthand measurable parameters in crop yield estimation and water resources management (JACKSON et al., 1993). The influence of the interaction of land and atmosphere on soil moisture can bring about anomalous climatic changes (SHUKLA and MINTZ, 1982; DELWORTH and MANABE, 1989). If the parameter model of surface soil, vegetation cover and temperature characteristics is further perfected, numerical weather forecast model will be improved obviously (HURK et al., 1996) .

Microwave radiometer can predict soil moisture by measuring brightness temperature. In practical microwave remote sensing measurement, the influence of vegetation and soil surface roughness on surface brightness temperature has the frequency and polarization effects. In other words, under different frequency and polarization conditions, the response of surface brightness temperature to the same vegetation cover and soil surface roughness is different, which makes it possible to correct these influences using multi-band and multi-polarization data (WANG and SCHMUGGE, 1980; WIGNERON et al., 2001). The theoretical analysis and the remote sensing soil moisture experiment using spaceborne platform microwave radiometer show that L-band and C-band are optimal frequencies for retrieving soil moisture (SHI et al., 2003; MAGAGI et al., 2000). The device used in this experiment is the dual-frequency microwave radiometer designed by the authors, with two frequencies: L-band 1.4GHz and C-band 5.4GHz. The measurement temperature ranges are both 10- 350K, sensitivities are 0.2K and 0.15K respectively.

The method used for retrieving soil moisture is empirical algorithm in this experiment. Through empirical statistical description and correlation analysis to the observed data, the linear relationship between the brightness temperature of L/C-band and gravimetric soil moisture (weight percentage) is established. This model is also applied to rainfall event. The results from this rain

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fall event are well consistent with the actual values.

2 EXPERIMENT

2.1 Data Source

On July 20 to September 20, 2003 we carried out ground-based microwave soil moisture experiment at the Agricultural Demonstration Base of the Chinese Academy of Sciences, located in Dehui City, Jilin Province. The experimental soil consisted of sand 37%, silt 43% and clay 20%. The estimate of surface roughness is 1.45cm, and the initial soil moisture is 8%. The radiometer was mounted on a bracket that is 1.5m from ground, and incidence angle is 52%. The radiometer measured one group of data every second. Before the measurement, we carried out near-field integral calibration using the water body of fresh water pool in Northeast Institute of Geography and Agricultural Ecology, Chinese Academy of Sciences in Changchun City of Jilin Province. The water body surface temperature was 29.2℃ at that time. The calibration equations are:

1.4 GHz radiometer (H-polarization):

$$T_B=-63.06+0.1016V_{out} \tag{1}$$

1.4 GHz radiometer (V-polarization):

$$T_B=-88.43+0.1174V_{out} \tag{2}$$

5.4 GHz radiometer (H-polarization):

$$T_B=-79.72+0.1028V_{out} \tag{3}$$

5.4GHz radiometer (V-polarization):

$$T_B=-115.35+0.1264V_{out} \tag{4}$$

where T_B and V_{out} are the brightness temperature and voltage of the radiometer output respectively.

2.2 Experiment Principles

The soil dielectric constant varies with the soil moisture, so does the brightness temperature. Therefore, microwave radiometer can retrieve the soil moisture by measured brightness temperature. The dielectric constant of water in soil not only lies on brightness temperature of water and electromagnetic wave frequency, but also is related to soil structure. When soil moisture is lower than the transition point moisture W_T, its dielectric behavior is similar to ice. When water moisture reaches or exceeds W_T, it will return to free liquid state (JIN et al., 1990). So the transition point moisture is a very sensitive parameter; W_T is generally 0.17- 0.33, which is related to soil structure and distribution of soil particle size. WANG and SCHMUGGE (1980) put forward an experiential analytic expression of soil dielectric constant. If sand content and clay content in soil are expressed as f_1 (%) and f_2 (%) respectively, soil structure parameter WP can be defined as follows:

$$WP=0.06774-0.00064f_1+0.00478f_2 \tag{5}$$

$$W_T=0.49WP+0.165 \tag{6}$$

The dry soil density can be expressed through the following empirical relationship:

$$\rho_b=3.4355/(25.1-0.21f_1+0.22f_2)^{0.3018} \tag{7}$$

Through calculation, W_T=0.20 and the dry soil density is 1.29g/cm³.

3 RESULTS AND ANALYSIS

On July 30, 2003 the soil moisture was changed through artificial watering mode, the soil specimens were sampled each half an hour, sampling depth was 0- 20cm, and sampling interval was 5cm. Fig. 1 and Fig. 2 show the curves of the relationships between brightness temperatures in L-band and C-band measured by dual-frequency microwave radiometer, and soil moisture, respectively.

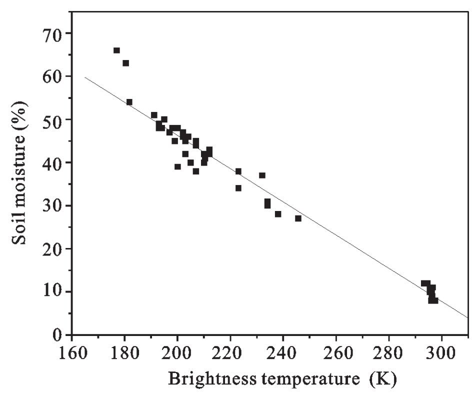

Fig. 1 Relationship between radiation brightness temperature in L-band and surface soil moisture

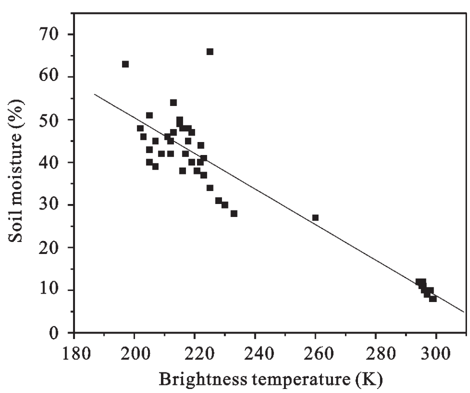

Fig. 2 Relationship between radiation brightness temperature in C-band and surface soil moisture

Through regression we got the linear relationship between the brightness temperatures T_B in L-band and C-band and the soil moisture (weight percentage) W_G:

L-band: $W_G(\%)=122.03-0.3803T_B$, $r=-0.987$ (8)

C-band: $W_G(\%)=133.38-0.4158T_B$, $r=-0.949$ (9)

A rainfall event was observed using dual-frequency microwave radiometer at 13:10 to 14:20 on August 20, 2003. The changes of soil moisture in the rainfall event gotten by regression equations are shown in Fig. 3.

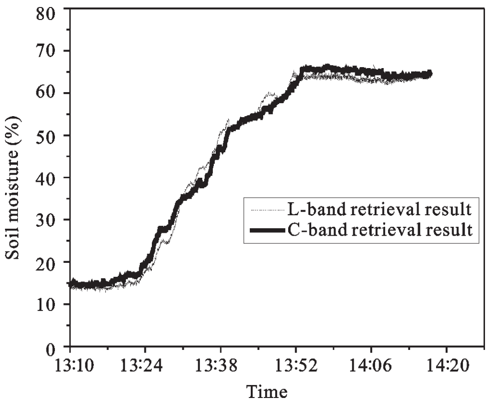

Fig. 3 Change of retrieved soil moisture in L-band and C-band along with rainfall

Fig. 3 shows that the soil moisture increased during the rainfall event. Fig. 4 presents the comparison between the retrieval results in the both bands, and the variance is 1.9%. The figure shows that the result of soil moisture is good consistent in both bands.

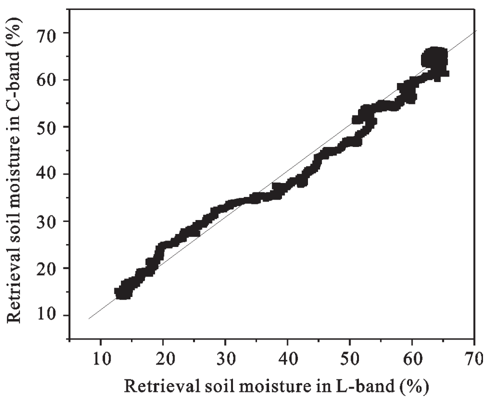

Fig. 4 Comparison between retrieval results in both bands

The comparison of retrieval result of soil moisture in L-band and the observed value of actual soil moisture is shown in Fig. 5, the variance is 2.8%.

The experimental results show that when soil moisture is lower than 75%, the brightness temperature is linear with soil moisture. However, when soil moisture is higher than 75%, the brightness temperature is not linear with soil moisture, so it is difficult for microwave radiometer to measure the changes of soil moisture. Retrieving soil moisture with this model in the rainfall event demonstrates that the result is good consistent with the practical sampling value. The empirical regression model developed in this paper only has good application value in experimental area.

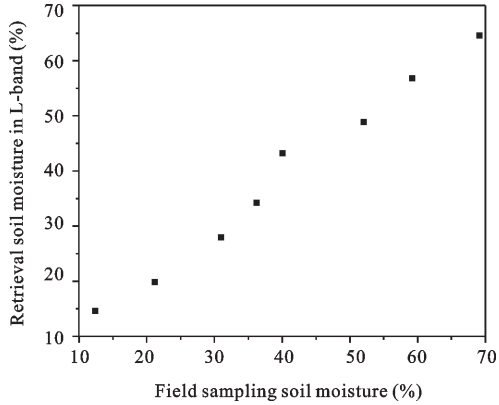

Fig. 5 Comparison of field sampling and retrieval results

4 CONCLUSIONS

The experiment of ground-based soil moisture using dual-frequency microwave radiometer verifies the effectiveness and feasibility of measuring soil moisture by microwave remote sensing. The empirical regression models in L-band and C-band were obtained. Retrieving soil moisture with this model in the rainfall event demonstrates that the result is good consistent with the practical sampling value. The results show that when soil moisture is lower than 75%, the brightness temperature is linear with soil moisture. However, when soil moisture is higher than 75%, the brightness temperature is not linear with soil moisture, so it is difficult for microwave radiometer to measure the changes of soil moisture. The results have good application value in the experimental area. There are several issues we should notice in future work:

(1) Although this method for linear regression based on the data measured with dual-frequency microwave radiometer is simple, generally it has only local application value, and lacks universal applicability for different areas and different conditions. Retrieving soil moisture using the theory of radiant transmission is a developing trend of the study on measuring soil moisture by microwave remote sensing.

(2) It is a difficulty and a hot-spot for present studies to develop the applicable retrieval approach of soil moisture at global scale, and to eliminate the influence of vegetation cover and surface roughness on retrieving soil moisture.

(3) The low frequency and low spatial resolution of the microwave radiometer may also greatly influence the effective utilization of data. This should be investigated in future work.

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