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AN EMPIRICAL RELATION FOR THE SOIL MOISTURE MEASUREMENT USING EMISSIVITY VALUES AT MICROWAVE FREQUENCY RANGE

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ABSTRACT

The potential of passive microwave radiometry for the soil moisture measurement is a well established one, especially in the long wave length regions due to its high penetrating capacity through vegetation. Radiometric data can be used as a mapping tool for classifying the crops, examining their health and viability and monitoring the farming practices. The radiometric data or the emission of microwave energy commonly referred as microwave brightness temperature T_B is proportional to the product of surface temperature and surface emissivity. The surface emissivity of soils is dependent on both water content and its physical characteristics . Hence these data are essential for the retrieval of soil moisture content from the remotely sensed satellite data. In this paper, we present the emissivity data of different Indian soils of different textures at various moisture levels in the frequency range 0.6GHz to 1.2GHz, calculated from the measured values of dielectric constants in the laboratory. The result indicate that the emissivity values are independent of frequency and texture but shows a strong dependence on the moisture content. On the basis of these results, an empirical relation is formulated for calculating the soil moisture content form emissivity values, which shows a good agreement with other reported radiometric measurements.

1 . INTRODUCTION

Microwave radiometry from space has been recognized as a powerful tool for the retrieval of several geophysical parameters especially the soil moisture content. (Newton and Rouse 1980, O'Neill 1985, Ulaby et al 1986, Rao et al 1987, 1990, Jackson 1990).The theory behind the microwave remote sensing of soil moisture is based on the large contrast between the dielectric properties of liquid water (~80) and dry soil (~4). Microwave emissivity of soil is dependent on both the water content and physical characteristics of the soil. The water holding capacity of wet soils is determined by its particle size distribution. Hence the emission properties need to be studied to extract the soil moisture information from emissivity data. In the Indian context little ground truth data are available for Indian soils to support the satellite data for retrieving geophysical parameters where different parts of the country have soils of different texture composition . Therefore we calculated the emissivity of soils collected form different parts of India for normal incidence at different moisture conditions in the frequency range 0.6GHz to 1.2GHz from the measured values of its dielectric constant. An empirical relation also formulated by using the emissivity values to predict the soil moisture content.

2. THEORETICAL BACKGROUND

The lumped element approach of Stuchly et al. (1974) was selected for measuring the reflection which is related to the characteristic impedance of the transmission line and that of the sensor probe. The impedance of the sensor is a function of the frequency and relative permittivity of the test sample.

Under quasi-static approximation the stationary formula for the aperture admittance of an open ended coaxial line terminated by a semi–infinite medium on a ground plane reduces to (Staebell et al.1990)

$$Y_L = j\frac{2wI_1}{[In(b/a)]^2}\in^{*} - j\frac{w^3 mI_2}{[In(b/a)]^2}\in^{*^2} + \frac{pw^4 m_o^{3/2}}{12}\,\frac{[b^2-a^2]^2}{[In(b/a)]^2}\in^{*5/2} \qquad (1)$$

Where a and b are the inner and outer radii of the coaxial cable respectively,μ is the complex permeability of free space $\in$ is the complex permittivity of the semi infinite medium, ω is the angular frequency of electromagnetic fields I_1, I_2 the two triple integrals dependent on the radii but constant otherwise.

The actual admittance of the aperture terminated by a sample from the measured reflection coefficient after calibrating the system with three standard materials as follows.

$$\frac{Ys - Y1}{Ys - Y2} \times \frac{Y3 - Y2}{Y1 - Y3} = \frac{\partial s1 \times \partial s2}{\partial s2 \times \partial s3} \quad (2)$$

Where Ys is the desired aperture admittance terminated by the sample material, $Y_{1,2,3}$ are aperture admittance in the standards respectively. By using a 4th standard, and noting the bilinear transformation characteristic of admittance, the aperture admittance can be written as

$$Y_L = \in_r^* + A_o \in_r^{*2} + A_1 \in_r^{*2.5} \quad (3)$$

$\in_r^*$ is the complex permittivity of the material Ao and A1 are the constants dependent on the frequency and dimensions of the aperture. Generally the radiation from the coaxial aperture can be neglected at lower frequencies.
Eqn (2) and Eqn (3) are used to determine the complex permittivity of the sample assuming that the 3rd standard used is a short circuit.
From the knowledge of permittivity we calculated the emissivity values for normal incidence by using the equation.

$$e = 1 - \left| \frac{1 - \sqrt{\in'}}{1 + \sqrt{\in'}} \right|^2$$

Where $\in$ is the real part of the dielectric constant.

2. SAMPLE COLLECTION

We collected samples from following agro ecological zones: North Eastern Hills, Deccan Plateau, Northern Plain and western coastal plain. (Table No.1)

3. EXPERIMENTAL PROCEDURE

Texture size was determined by mechanical fractionation and sedimentation techniques. Samples were dried in an oven at 100 C for 24hrs. Different levels of moisture conditions were obtained by adding double distilled water to the dry samples and allowing it to stand for 24 hrs to aid settling. Volumetric soil moisture content was calculated by multiplying the gravimetric soil moisture content with the oven dried bulk density. The experimental set up for measuring the reflection coefficient consists of Network Analyser (HP 8754A), reflection transmission test set (HP 8502A) and a coaxial cable sensor . All measurements were conducted at room temperature.

5. RESULTS AND DISCUSSION

The emissivity values for different Indian soils at different moisture levels were evaluated in the laboratory for normal incidence from the knowledge of the real part of the dielectric constant are shown in Table no.3 Textural values of different soils are given in Table No.2

It is found that the emissivity values decreases with an increase in moisture content. Also the analysis of the data indicate that the emissivity values for the normal incidence are i) independent of frequency variation , ii) independent on textural variation in dry and wet stage but iii) strongly dependent on the moisture content. The results show a very good agreement with the data available in the literature (Wagmuller et.al; 1994, Jackson et. al 1991)

The strong dependence of emissivity on moisture content and its independence with frequency and texture led us to formulate the following empirical relation to predict the amount of soil moisture from the emissivity values.

Soil moisture content = $-0.8317\, e^{-2} + 2.793\, e^{-1} - 2.04$
(Percent volume)
Co efficient of correlation for fitting the equation is 0.9095

We checked the validity of the relation by using the data published by Wagmuller et.al (1994) in the frequency region 2 –12 GHz for bare soil and found a good correlation.

6. CONCLUSION

The experiment indicates that the laboratory evaluated emissivity is almost identical to the emissivity obtained by other workers from radiometric measurements. Since the analysis conducted on the emistivity data proves its independence on texture and frequency it can be used for retrieving the soil moisture information.

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Table No.1

Zones	Soils Characteristics
North Eastern Hills	Shallow and Medium, red, yellow and lateritic soils
Deccan plateau	Deep loamy red soils and clayey black soils
Northern plain	Deep loamy, alluvium derived soils
Western coastal plains	Deep sandy and Coarse loamy soils

Table No.2

Sample No.	Soil Texture (%)		
	Clay	Silt	Sand
1	24.9	36.1	39.0
2	21.0	23.1	55.4
3	45.5	31.6	26.4
4	11.9	16.5	71.60
5	6.90	62.14	30.95
6	11.65	65.7	22.60
7	2.92	17.31	79.77
8	3.88	16.50	79.62

Table No.3
Emissivity values for normal incidence

Moisture Level % by volume	Sample No	Emissivity at			
		0.6 GHz	0.8GHz	1.0GHz	1.2GHz
Dry	1	0.93	0.92	0.93	0.93
	2	0.92	0.92	0.93	0.93
	3	0.94	0.95	0.93	0.93
	4	0.92	0.91	0.93	0.93
	5	0.92	0.92	0.93	0.93
	6	0.92	0.92	0.93	0.93
	7	0.91	0.91	0.93	0.93
	8	0.90	0.91	0.93	0.93
10%	1	0.81	0.82	0.83	0.85
	2	0.83	0.82	0.83	0.84
	3	0.81	0.83	0.83	0.84
	4	0.82	0.82	0.83	0.83
	5	0.78	0.81	0.82	0.82
	6	0.78	0.80	0.82	0.82
	7	0.80	0.80	0.81	0.81
	8	0.78	0.79	0.80	0.80
20%	1	0.73	0.75	0.77	0.77
	2	0.75	0.77	0.76	0.77
	3	0.73	0.75	0.77	0.77
	4	0.75	0.76	0.77	0.78
	5	0.73	0.74	0.74	0.75
	6	0.73	0.74	0.75	0.75
	7	0.73	0.73	0.74	0.75
	8	0.73	0.73	0.73	0.74
30%	1	0.64	0.64	0.64	0.64
	2	0.61	0.61	0.63	0.66
	3	0.61	0.61	0.62	0.64
	4	0.64	0.64	0.67	0.67
	5	0.63	0.64	0.64	0.65
	6	0.62	0.63	0.63	0.65
	7	0.64	0.64	0.64	0.64
	8	0.63	0.64	0.64	0.64