Microwave Radiometer Measurements of Soil Moisture Content

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Ground-based microwave radiometer experiments have been performed to investigate the effect of moisture on microwave emission from bare field. Measurements were made at 19.1 GHz using tower mounted dual polarized (vertical and horizontal) microwave radiometer to observe prepared soil site in the Gujarat University Campus, Ahmedabad. Increasing the soil moisture content from 5 to 20% by weight resulted in brightness temperature decrease of 40 K, depending, to a lesser extent, on polarization and viewing angle. The observed brightness temperatures over a bare field are higher than those calculated from an emissivity model.

1 Introduction
There is an active interest in research on microwave technique for remote sensing of soil moisture. In the past two decades, a number of experiments on remote sensing of soil moisture content using both active and passive microwave sensors\(^1\)\(^-\)\(^7\) have been conducted in the USA and Europe.

A programme of comprehensive study of emission properties of typical Indian soil in controlled conditions has been undertaken. Radiometric measurements were made over bare soil with different moisture contents at 19.1 GHz using horizontally polarized\(^8\) microwave radiometer during January-February 1984. In continuation of this work, an experiment was conducted over the same plot at 19.1 GHz using dual polarized microwave radiometer, and the results obtained are reported in this paper.

2 Experimental Details
Measurements were conducted on a test site in the Gujarat University Campus, Ahmedabad. A plot of 35 \(\times\) 20 m was prepared near the Physics Department of the Gujarat University and a dual polarized microwave radiometer was mounted on the top of the Physics Department building (height, 11 m) overlooking the plot. The field soil is sandy loam with an average texture (in the top 5 cm) of 64% sand, 29% silt and 7% clay, according to the US Standard classification. The plot is surrounded by grassland. The field was irrigated at the beginning of measurements and observations were made with the instrument during the soil drying cycle. About 40 soil samples were collected on each day from different locations distributed uniformly over the plot, at the time of radiometric measurements. The soil samples were sealed and weighed. Their moisture content was determined gravimetrically through oven drying at 105°C and they were reweighed. Soil bulk density was measured several times during the course of experiment. The average bulk density was used to convert the percentage moisture content by weight to moisture content by volume. The standard deviation of the gravimetric soil moisture field averages ran between 3 and 4%. This is due to the fact that measurement of soil moisture by weight suffers from some inconsistencies, e.g. it is very difficult to get exact layer of the soil when the soil under study is sandy loam, as by the time it is removed in chunks for weighing most of the water gets drained off. This inaccuracy is compounded by the conversion to the volumetric moisture, since the conversion requires a multiplication by another measured quantity, namely, bulk density. As a result volumetric moistures to which the radiometric measurements are being compared are only estimates and cannot be taken as exact ground truths. This is one problem that cannot be escaped, but it indicates that the correlation between radiometric antenna temperature and soil moisture may be even better if the soil moisture measurements are more accurate.

A 19.1 GHz radiometer, which is an engineering model version of the Satellite Microwave Radiometer (SAMIR) System which was flown on Bhaskara II, the
second Indian Satellite for Earth’s observation, was used. The radiometer system was designed and developed at the Space Application Centre (ISRO), Ahmedabad. The radiometer was realized in the conventional Dicke configuration. The system specifications are given in Table 1. The radiometer measures the brightness temperature of the target in horizontal and vertical polarization. Measurements over the field were made with incidence angles varying from 10 to 50° from nadir in steps of 5°. Sky temperature measurements were made at zenith at the end of each viewing. The radiometer was calibrated by simulating different brightness temperatures at the radiometer input by connecting a liquid nitrogen cooled termination followed by a precision variable attenuator maintained at ambient temperature. The calibration of the radiometer for an external target was checked by aiming the antenna to the targets of known brightness. These targets were clear sky and Eccosorb absorber. Based on these calibration results, the estimated accuracy of the radiometric measurements was about ±5 K.

3 Results and Discussion

Fig. 1 shows the moisture contents measured at 0-1 cm depth during the four days period (soil drying cycle). The corresponding brightness temperature is shown in Fig. 2.

A typical variation of observed brightness temperature with soil moisture content \( W \) (per cent by weight) measured at the top 1 cm layer at an incidence angle \( \theta = 30° \) from nadir is shown in Fig. 3. Increasing the soil moisture content from 5 to 20% by weight resulted in brightness temperature decrease of 40 K. It is evident from Fig. 3 that in comparison to soil moisture content the brightness temperature is less dependent on polarization; similar results were obtained when brightness temperature was plotted against incidence angles from nadir for different moisture contents. The sensitivity to soil moisture, as indicated by the slopes of the plots, is greater at horizontal polarization than at vertical polarization. Fig. 4 gives the plot for brightness temperature against \( W \) for 1984 and 1985. For \( W \)'s between 5 and 20%, the measured brightness temperature in two different years fit nicely, indicating the consistency of the measurements. A linear regression analysis of the

<table>
<thead>
<tr>
<th>Table 1—Characteristics of the Radiometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>R F bandwidth</td>
</tr>
<tr>
<td>Integration time</td>
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<tr>
<td>r.m.s. sensitivity</td>
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<tr>
<td>Beam width</td>
</tr>
</tbody>
</table>

![Fig. 1—Variation of moisture content during drying period](image1)

![Fig. 2—Variation of brightness temperature during drying period](image2)

![Fig. 3—Observed brightness temperature versus moisture content for horizontally and vertically polarized emissions at 30° viewing angle](image3)
combined two year data gives a correlation coefficient $\approx 0.87$ between brightness temperature and $W$. 

Various theoretical models have been developed to compare microwave emission from surfaces. These models include emissivity model$^9$, radiative transfer model$^{10}$, and coherent model$^{11,12}$. The emissivity model is simplest to use with reasonable accuracy at higher microwave frequencies, where the radiation arises from within a region close to the surface. Since the present investigation was carried out at 19.1 GHz, the brightness temperature of the soil was calculated by emissivity model. In this model, the brightness temperature $T_{BP}$ observed outside the soil medium is given by

$$T_{BP}(\theta) = e_p(\theta) T + r_p(\theta) T_{SKY}$$  \hspace{1cm} (1)$$

where $T_{BP}(\theta)$ (subscript P can either be V for vertical polarization or H for horizontal polarization) is the brightness temperature, $e_p(\theta)$ the emissivity of surface layer, $T$ the surface temperature, $r_p(\theta)$ the reflectivity at the air-soil interface, and $T_{SKY}$ the brightness temperature equivalent of sky and atmospheric radiation incident on the soil. For a given surface layer, the sum of emissivity and reflectivity is unity$^{13}$.

Eq. (1) can be written as

$$T_{BP}(\theta) = [1 - r_p(\theta)] T + r_p(\theta) T_{SKY}$$  \hspace{1cm} (2)$$

In the case of smooth surface over a homogeneous medium, $r_p(\theta)$ is obtained from the Fresnel reflection coefficient $R_p(\theta)$ (Ref. 13) as

$$r_p(\theta) = |R_p(\theta)|^2$$  \hspace{1cm} (3)$$

and

$$R_p(\theta) = \frac{\cos \theta - \sqrt{K - \sin^2 \theta}}{\cos \theta + \sqrt{K - \sin^2 \theta}}$$  \hspace{1cm} (4)$$

for horizontal polarization, and

$$R_p(\theta) = \frac{K \cos \theta - \sqrt{K - \sin^2 \theta}}{K \cos \theta + \sqrt{K - \sin^2 \theta}}$$  \hspace{1cm} (5)$$

for vertical polarization

where $\theta$ is the angle of incidence from nadir, and $K$ the dielectric constant of soil. Eqs 3-5 can be used for the calculation of emissivity provided dielectric constants of soil with moisture contents are known.

The dielectric constants of soil in present work were calculated by dielectric permittivity model of Wang and Schmugge$^{14}$. From these values of dielectric constants, the emissivity of soil was calculated using Eqs 3-5. The brightness temperature was computed using Eq. 1. $T_{SKY}$ was measured by pointing the radiometer antenna towards the sky.

The calculated values of brightness temperature for incidence angle of 30° for both the polarizations are compared with the observed values in Fig. 5. The observed brightness temperatures are higher than the calculated ones. Examinations of 1984 data also indicates the similar trend (Fig. 5). One of the reasons could be roughness of the surface because although the field prepared was smooth, it might have had residual roughness which could have affected the observed brightness temperature at 19.1 GHz. It has been observed that a rough surface gives a higher brightness temperature than a smooth surface. Additional sources of uncertainty could come from imprecise measurements of soil bulk density, which directly affects the volumetric moisture content and therefore the soil dielectric permittivity.

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References