MICROWAVE EMISSION STUDY OF ARABLE ROUGH SOIL SURFACE

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ABSTRACT

In view of passive microwave remote sensing microwave emissivity of smooth and bare arable soil surface is estimated by emissivity model. Fresnel reflectivity of soil surface is estimated using experimentally determined complex permittivity of soil and observation angle as the input parameters. The dielectric constants of soils (real and imaginary parts) are determined using wave guide cell method at a single microwave frequency 9.78 GHz. The roughness of the surface is characterized by the Root Mean Square (RMS) height. The rough surface emissivity is calculated using semi empirical model by taking into account the effects of RMS height.

INTRODUCTION

In passive microwave remote sensing electromagnetic radiation radiated from soil surfaces are detected at the distant radiometer. The microwave radiometer is one of the passive microwave sensors. The observable parameter at the sensor in passive microwave remote sensing is the microwave emissivity (e). Kirchhoff's reciprocity theorem relates the emissivity to the Fresnel reflectivity R of the surface if the subsurface temperature and dielectric profiles are uniform as given by equation (1)

$$e = 1 - R \qquad (1)$$

There have been several theoretical models[1-2] for microwave emission from soils, these models considered the emission from the soil for a range of moisture and temperature profiles and studied the effect of variations of these subsurface properties on the emission from the surface. Practically, the real soil surfaces are not smooth, the surface emissivity is significantly affected by soil surface roughness [3-4]. The effects of surface feature, such as, roughness produce large differences between the calculated and observed radio brightness of soil (upto30K). This roughness factor introduces fluctuation in the estimated values of emissivity and amounts of uncertainty into the actual results of remote sensing, thereby limiting the accuracy in the estimation. Further dielectric properties of soil are strong function of Soil Moisture Content (SMC), For smooth and bare soil surfaces, estimated values of microwave emissivities by model calculations lies between 0.3 to 0.9 depending on moistness of soil. But experimental observations carried out for emissivity of real soil surfaces using various techniques (radiometer mounted on the moving platform on surface experiment, a radiometer in aircraft or on satellites) shows that observed[5] values of emissivities are always more than 0.6 irrespective of the wetness of the soil. Such high values of observed emissivity are due to the effect of surface roughness[5]. Roughness of soil surface depends both on the observation wavelength of electromagnetic wave and surface characteristics. The term surface roughness in microwave region refers to the micro relief of the soil surfaces representing a scale range between millimeters to decimeter. For rough surfaces, geometrical variation of surface irregularities and volume discontinuities are similar to wavelength of microwaves. Roughness of the soil surfaces in decimeter to millimeter range affects the microwave remote sensing observations greatly. Hence, towards the shorter wavelength region of the microwave spectrum particularly at X-band ($\lambda \leq 3$ cm) the effects of roughness are dominant. The description of soil roughness can't be described clearly. A large range of roughness parameter defines the roughness of same surface when different measurement methodologies are used. The roughness of the surface is characterized by the various parameters, standard deviation of height[6], Root Mean square (RMS) height[7], correlation length[7], surface auto correlation function[7] etc. Here, in present investigation we have characterized the soil surface roughness by the Root Mean square (RMS) height. Chaudhery *et al*[8] develop a semi-empirical model for estimation of polarized rough surface reflectivity. Gross effect of the surface roughness on the reflected intensity can he incorporated by modifying the smooth surface reflectivity as given by following equations: (2) and (3).

$$R'_H(\theta) = R_H\,(\theta)exp(-hcos^2\theta) \quad (2)$$

$$R'_V(\theta) = R_V\,(\theta)exp(-hcos^2\theta) \quad (3)$$

Here R'_H and R'_V are rough surface reflectivities at horizontal and vertical polarization respectively. R_H and R_V are smooth surface reflectivities at horizontal and vertical polarization respectively.

Soil surface reflectivity may be computed from the knowledge of the dielectric constant of the medium and the surface boundary conditions. For a smooth and bare soil surface of uniform dielectric media, the polarized Fresnel reflectivities at horizontal and vertical polarized $R_H(\theta)$ and $R_V(\theta)$ using electromagnetic theory[9] are given by equation: (4) and (5) respectively:

$$R_H(\theta) = \frac{cos\,\theta - \sqrt{\varepsilon_r - sin^2\,\theta}}{cos\,\theta + \sqrt{\varepsilon_r - sin^2\,\theta}} \quad (4)$$

$$R_V(\theta) = \frac{\varepsilon_r\,cos\,\theta - \sqrt{\varepsilon_r - sin^2\,\theta}}{\varepsilon_r\,cos\,\theta + \sqrt{\varepsilon_r - sin^2\,\theta}} \quad (5)$$

where θ is the observation angle (measured from the surface normal) and ε_r is the complex dielectric constant (relative permittivity) of the soil. The reflectivity or the emissivity depend on the relative permittivity and observational or view angle and the polarization of the microwave (horizontal or vertical.

The root mean square (RMS) height describes the variation in surface elevation above an arbitrary plane. Obviously, the greater spread of height measurements means the greater value of RMS height. It represents the standard deviation of the distribution of surface heights. Thus, it is an important parameter to describe the surface roughness by statistical methods. This parameter is more sensitive than the arithmetic average height. It is an estimation of the variance of the vertical dimension in the test surface. For discrete one-dimensional surface roughness profiles consisting of N points with surface height z_i the RMS height (σ) is calculated using Equations (6) and (7) as given by Ulaby *et al*[10]:

$$\sigma = \left[\frac{1}{N}\left(\sum_{j=1}^{N} z_i^2 - N\bar{z}^2\right)\right]^{½} \quad (6)$$

$$\bar{z} = \frac{1}{N}\sum_{z=1}^{N} z_i \quad (7)$$

The RMS height (σ) of a surface can be measured by pin profilometer for agricultural areas[11] and its value generally is in the range 0.25 cm (sown fields) - 4.0 cm (ploughed fields). In the present investigations, the RMS height soil surface have not been measured experimentally, but the values determined by other workers[12] for agricultural soils have been used.

EXPERIMENTAL PROCEDURE AND THEORY

Soil of local profile of Alwar has been selected for experimentation. Texture of soil is determined as: Clay=14.10%, sand=52.60% and silt 33.30% respectively, using sieving and sedimentation methods. Soil sample is prepared and oven dried at 110 ^{0}C for twenty-four hours. Desired percentage of distil water is mixed with this oven dried samples corresponding to volumetric SMC level (0.026). Real and imaginary parts of Dielectric constant are determined at a single microwave frequency 9.78 GHz and at a constant temperature 32.5 ^{0}C using the shift in minima of standing wave pattern inside the slotted section of a rectangular wave guide excited in TE_{10} mode. The experimental set-up, theory and procedure for the present work are the same as is used earlier by another workers[13-14].

$$\varepsilon = \left|\varepsilon^{*}\right| = \left|\varepsilon' - j\varepsilon''\right| \tag{8}$$

In present investigation y smooth surface emissivities are calculated using Fresnel equations (2), (3) and emissivity model of Peake[15]. Further, we have used the semi empirical model developed by Chaudhery *et al*[3] for estimation of the emissivity of rough surfaces. Here we have used various values of RMS height σ as roughness parameter varying from 0 to 0.5 for representation of roughness, because these values are suitable for agricultural areas[16].

RESULT AND DISCUSSION

The variations of the rough surface emissivity, horizontal component (e_H) and vertical component (e_V) with respect to various agricultural soil surface areas roughness (RMS height σ) are shown in figures 1 and 2 respectively. The emissivities are estimated for various view angles (θ) ranging 0^0 to 60^0. It reveals from figure 1 that horizontal component of emissivity (e_H) respectively corelated with the roughness of the soil surface, further e_H decreases as the angle of observation increases. Here, Slope of the curves is almost independent of observation angle.

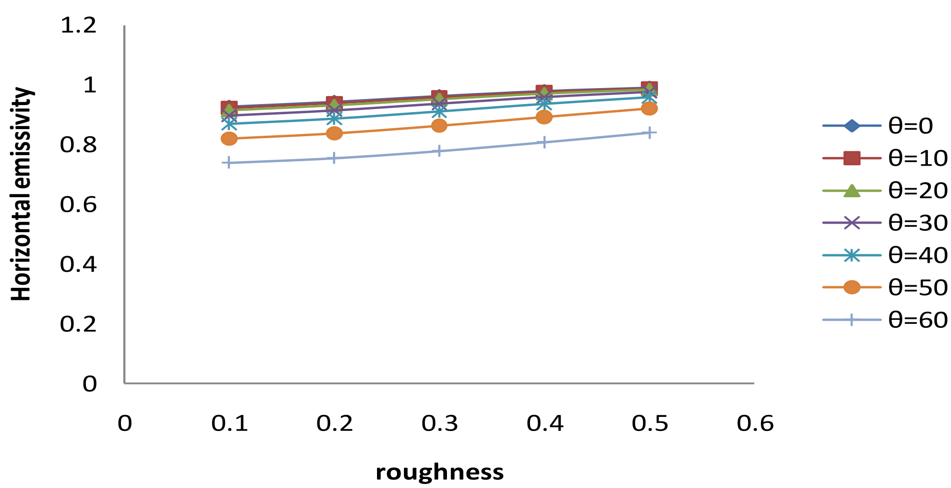

Figure 1: Variations of the (e_H) v/s roughness parameter (σ) of soil surface

It is evident from the figure 2 that vertical component of emissivity (e_V) increases with roughness of the surface but the behavior of increase is significantly dependent on the angle of observation. Curves become flat or slop reduces as (θ) increases. An increase in surface roughness decreases the difference between the vertically and horizontally polarized emissivities at each angle of observation. At higher roughness curves converges and surface becomes isotropic.

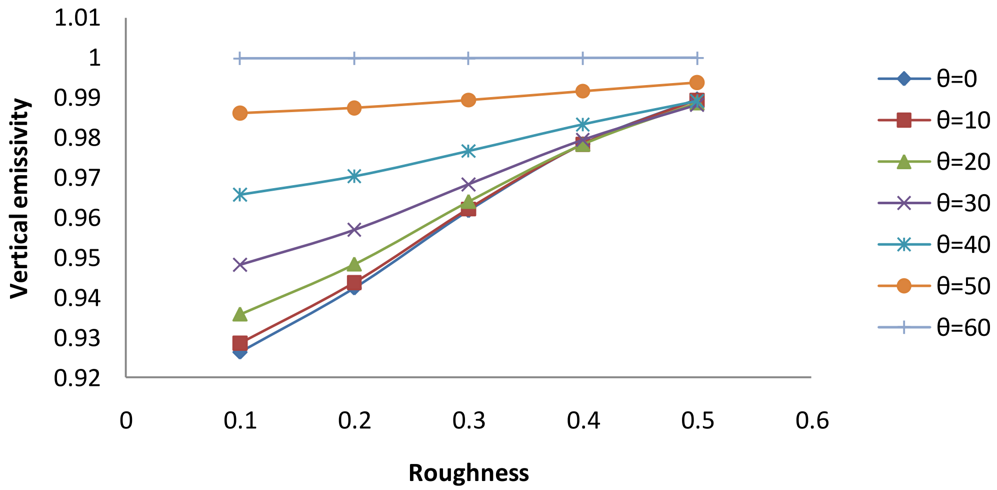

Figure 2: Variations of the e_V v/s roughness parameter (σ) of soil surface

The increase in of emissivity (e_H) and (e_V) with surface roughness can be attributed to the increase in emission area that interfaces with the air and thus, radiate the energy in environment. This is because of the fact that the enhancement of rough surface area. Further, horizontal emissivity (e_H) decreases as angle of observation increase due to obliquity. Further the roughness height increases as the standard height deviation increases and decreases as the observation angle increases. The vertical emissivity values at observation angle near to 60^0 shows different behavior due to Brewster angle effect. At higher roughness values the angular dependency of emissivities decreases.

CONCLUSIONS

From the present investigation we concluded that horizontal emissivity (e_H) and vertical emissivity (e_V) respectively corelated with surface roughness (ii) negatively corelated with obliquity of radiometer (iii) surface becomes isotropic at higher roughness.
Present investigation is very useful for the (i) intrinsic study of roughness of agricultural soil surface and (ii) for the perturbation produces by roughness on the various inferences of passive microwave remote sensing and (iii) for design of sensor for radiometer.

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