STUDY FOR THE EFFECT OF SOIL MOISTURE CONTENT ON THE AGRICULTURAL VEGETATION USING ACTIVE MICROWAVE REMOTE SENSING

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ABSTRACT:

Dielectric constant values of the samples of soil of Alwar (at various moist states) have been calculated using wave guide cell method at a single microwave frequency 9.78 GHz at 33^0C. The Backscattering coefficients for rough and bare soil surfaces σ^0_{soil} are calculated by Small Perturbation Model (SPM). Fresnal reflectivity of the soil surfaces which is an input parameter for SPM is calculated using the values of dielectric constant of the soil (at different wetness) and observation angle as input parameters. The roughness of soil in SPM is characterized by RMS height and correlation length and isotropic Gaussian auto correlation function. The radar backscattering coefficient of vegetative soil surface is determined by water cloud model. The total back scattering coefficient is calculated adding the contribution of the vegetation, σ^0_{veg} and that of the modified effect of underlying soil. The effect of vegetation canopy on the backscattering from bare soil surface is modified by a parameter vegetation transmissivity τ. The present study reveals that radar backscattering coefficient for bare soil surface σ^0_{soil} and vegetative soil surface σ^0_{pp} has a respective correlation with SMC of the soil. Further, σ^0_{soil} and σ^0_{pp} decrease as the angle of observation increases.

1. INTRODUCTION

On earth's surface soil moisture content (SMC) and vegetation water content (VWC) are the important state variables which control most of physical processes dominant in the hydrosphere, atmosphere, geosphere, and biosphere (e.g. ecosystem dynamics, biogeochemical cycles). Knowledge of SMC is a fundamental requirement in so many applications of the field of Agriculture, forestry, water and soil management, drought and flood forecasting and civil engineering. SMC serves a critical role in shaping the ecosystem response to the physical environment. Near-surface soil moisture controls the partitioning of available energy at the ground surface into sensible and latent heat exchange with the atmosphere and thus linking the water and energy balances through the moisture and temperature states of the soil. Adequate knowledge of the distribution and linkage of soil moisture to evaporation and transpiration is essential to predict the reciprocal influence of the land surface processes to weather and climate. Thus, the climate and agricultural yield on earth's surface are inter- related to each other and the knowledge of SMC is essential to understand the relationship.

Microwave remote sensing is an important tool to monitor and measurement of SMC, VWC of agricultural field because SMC and VWC affect the dielectric properties of the soil and vegetation greatly. The basic observable parameter at the sensor in active microwave remote sensing is radar backscattering coefficient which a is strong function of dielectric properties of soil and vegetation. The sensitivity of microwave backscattering to soil moisture and vegetation biomass has been proved in several experimental and theoretical studies as given by Ulaby, et al (1986) and Paloscia. et al. (1999). In the present study the radar backscattering coefficient, at different volumetric SMC levels of soil and at VWC value corresponding to the growing stage of wheat crop are calculated using Small Perturbation Model developed by Engman and Wang (1987).

2. METHODOLOGY AND THEORY

Samples of soil are oven dried at 110^0 C for twenty four hours. Desired percentage of distil water is mixed with these oven dried samples corresponding to different SMC levels of soil varying from 0 to 40 % (volumetric).Time of setting was twenty-four hours. Dielectric constant values (real and imaginary parts) are determined at a single microwave frequency 9.78 GHz using the shift in minima of standing wave pattern in side the slotted section of rectangular wave guide excited in TE_{10} mode. The experimental set up theory and procedure for the present work is the same as is used earlier by Yadav and Gandhi (1992) and Jangid et al (1996) as shown in figure 1.

The dielectric constant (ε') and dielectric loss (ε'') values for soil samples are determined using the following equations (1) and (2) respectively

$$\varepsilon' = \left(\frac{\lambda_0}{\lambda_c}\right)^2 + \left(\frac{\lambda_0}{\lambda_d}\right)^2 \left[1 - \left(\frac{\alpha_d}{\beta_d}\right)^2\right] \qquad (1)$$

$$\varepsilon'' = 2\left(\frac{\lambda_0}{\lambda_d}\right)^2 \left[\frac{\alpha_d}{\beta_d}\right] \qquad (2)$$

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Where λ_0, λ_c, and λ_d are the free space wavelength, cut off wavelength (λ_c=2a) and wave length in the dielectric medium respectively for the wave-guide excited in TE_{10} mode. α_d is the attenuation introduced per unit length of the material (napers per meter). β_d is the phase shift introduced per unit length of material in radian per meter.

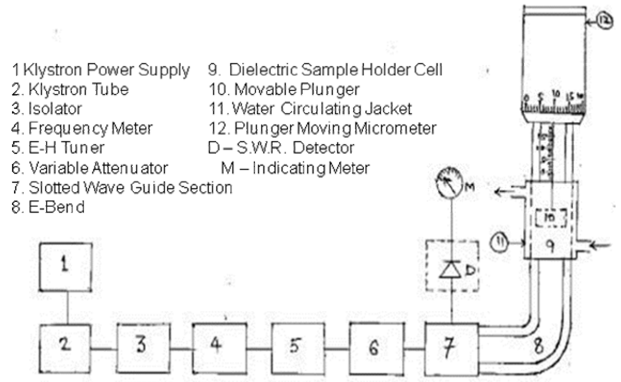

Figure 1. X-band Experimental Set-up

The surface reflectivity may be computed from the knowledge of the dielectric constant of the medium and the surface boundary condition. Here the $R_{hh}(\theta)$ is the Fresnel reflectivity of smooth soil surface for horizontal-horizontall polarization may be derived from electromagnetic theory as given by Kong (1990) and is represented by the following equation(3).

$$R_h(\theta) = \left[\frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}}\right]^2 \tag{3}$$

Where ε is the magnitude of the complex permittivity ε* followed by the equation (4).

$$\varepsilon = \left|\varepsilon^*\right| = \left|\varepsilon' - j\varepsilon''\right| \tag{4}$$

In our present investigation backscattering from slightly rough soil surface is calculated by Small Perturbation Model developed by Engman and Wang, 1987 as given by equation (5).

$$\sigma^0_{soil} = 4(ks)^2(kl)^2\cos^4\theta.\exp-(kl\sin\theta)^2\,|R_{hh}(\theta)| \tag{5}$$

where 'k' is wave number of microwave and's' is RMS height and 'l' is correlation length of the surface. $|R_{hh}(\theta)|$ is the horizontal-horizontal Fresnel reflectivity given by equation (3). Here $l^2/2.[\exp-(kl\sin\theta)^2]$ is the normalized roughness spectrum evaluated for isotropic surface, drive from the Bessel's transformation of correlation function $\rho(\xi) = \exp(\xi^2/l)$.

The radar backscattering coefficient of vegetative soil surface is determined by water cloud model. This is a first order canopy backscattering model developed by Attema and Ulaby (1978). Canopy is treated as water cloud consisting of a collection of identical water particles characterized by a uniform scattering phase function. Ignoring the second order contributions resulting from multiple scattering between the canopy particles and soil surface and assuming the scattering water particles to be uniformly distributed within the canopy volume Attema and Ulaby (1978) derived an expression for backscattering coefficient by integrating the backscattering contribution of thin strata between the air–vegetation boundary and vegetation-soil boundary.

According to the model, the total power scattered at a co-polarized channel pp, σ^0_{pp} is the incoherent sum of contribution of the vegetation (σ^0_{veg}) and that of the underlying soil (σ^0_{soil}), which is attenuated by the vegetation layer as given by equation (6).

$$\sigma^0_{pp} = \sigma^0_{veg} + \tau^2\sigma^0_{soil} \tag{6}$$

σ^0_{veg} is backscattering coefficient from vegetation which is calculated with help of vegetation dependent parameters "A" and "b" as given by below equations(7) and (8).

$$\sigma^0_{veg} = Am_v\cos\theta(1-\tau^2) \tag{7}$$

And $\tau^2 = \exp(-2bw_c\sec\theta)$ (8)

Where m_v is the volumetric SMC of the soil and τ^2 is called the two-way transmissivity of the vegetation layer which is also a function of vegetation parameter b, Wc and observation angle. τ^2 describes the attenuation that a wave experiences when it travels two times through the canopy.

Here 'A' represents the vegetation scattering; b represents vegetation attenuation and w_c is the VWC. These parameters can be determined from remote sensing data or ground base experimental observations. In the present investigations these vegetation dependent parameters of agricultural vegetation are used according to Bindlish and Barros (2001) as replicated from the Washita' (1994) field data. Washita experiment was conducted during April 1994, for the site characterization and parameterization for both vegetated and bare soil areas, using radar data. This was a joint exercise by NASA, USDA, and Princeton University.

Values of vegetation parameters used in the semi empirical model for winter wheat crop are as A=0.0018,b=0.138, Particular value of Wc =1.38 is used in the present study as replicated by Bindlish and Barros (2001) by Washita'(1994) field data. The values of Wc varies between less than 1.0 kg/m^2 (light vegetation starting stage) to more than 4.0 kg/m^2 (full developed stage) for winter wheat crop as given by Hui et al. (2008).

3. RESULTS

The variation of radar backscattering coefficient of bare soil surface (σ^0_{soil}) at different observation angles varying from 0^0 to 80^0 is shown in the below figure 2.

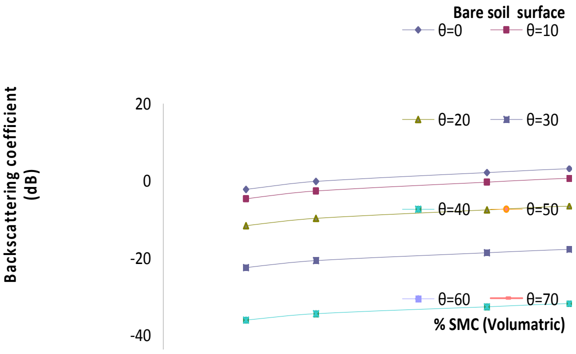

Figure 2. Variations of σ^0_{soil} w.r.t % SMC (Volumetric)

It reveals from fig 2 that the value of σ^0_{soil} increases slightly as SMC in soil increases and σ^0_{soil} decreases as the angle of observation increases. Variation is significant at lower observation angles. Hence, a good correlation exists between the variations of the backscattering coefficient and the corresponding values of the SMC.

The variation of radar backscattering coefficient of σ^0_{hh} vegetative soil surface for horizontal-horizontal polarization and at different observation angles varying from 0^0 to 80^0 is shown in the figure 3. It is evident from figure that the value of σ^0_{pp} or σ^0_{hh} increase as SMC in soil increases at all observation angles. Further, the value of σ^0_{hh} decreases as angle of observation increases.

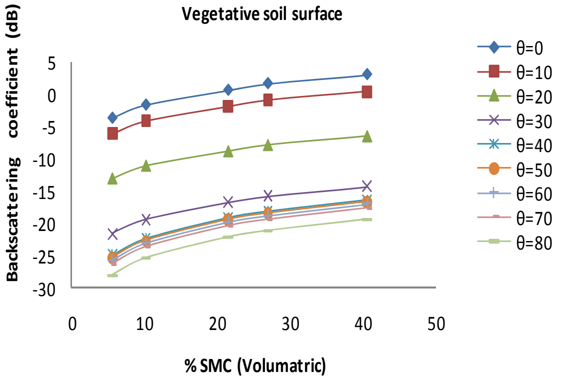

Figure 3. Variation of σ^0_{hh} w.r.t % SMC (Volumetric)

It is pointed out here that the sensitivity of σ^0_{pp} to vegetation biomass depends on crop type and observation parameters (frequency, polarization, incidence angle. Thus, a simple observation at a single-frequency single-polarization can be of little relevance.

However, once the crop type has been identified, vegetation biomass, represented by plant water content or leaf area index, can be retrieved.

CONCLUSION

The effect of a significantly vegetated surface is to increase the backscatter compared to a bare surface. Here this effect is relatively large at the higher observation angles for co-polarized channel. The degree to which vegetation affects the backscattering coefficient depends on several factors: SMC vegetation biomass, canopy type and configuration and crop condition. Thus, using a suitable retrieval algorithm these factors may be obtained by active microwave remote sensing data. The net effect of the vegetation is reducing the sensitivity of soil moisture to the back scattering. This effect increases as angle of observation increases. Hence the present study is very important. The drought monitoring and flood forecasting for a soil surface is possible by using active microwave remote sensing because dependency of back scattering coefficient on SMC.

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