RADIATIVE TRANSFER IN VERTICALLY STRATIFIED SOIL AND VEGETATION BOUNDARY

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ABSTRACT

This study presents a radiative transfer scheme for deriving microwave emissivity and reflectivity for a vertically stratified soil and vegetation boundary. The attenuation (or absorption) coefficients of each soil layer are derived from the conservation of the energy flux which allows for coupling and solving EM Poynting vector (Wilheit, 1978). In computations of soil attenuation coefficients at horizontal and vertical polarizations, soil dielectric constants are needed and parameterized as a function of soil and clay fraction, soil volumetric water content, soil and solid bulk volume density, and soil temperature so called mixing rule (Dobson et al., 1985). Brightness temperatures from multi-layer soil are based on the emission-based radiative transfer scheme and then used as a lower boundary condition for vegetation scattering medium. It is shown that two-stream radiative transfer scheme previously developed by Weng et al. (JGR,2001) simulates well brightness temperatures at microwave frequencies.

INTRODUCTION

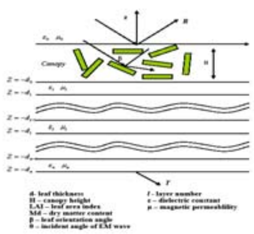
Variability of land surface emissivity and its spectra are not simulated well over many surfaces types. This uncertainty is continuing to be a major obstacle that affects satellite data assimilation over land and remote sensing of land surface properties such as soil moisture, snow, vegetation water content. In recent years, there have been numerous studies to explore the uses of satellite data to construct global emssivity atlas and to use the retrieved emissivity for data assimilation (Prigent et al, 2008; Ruston et al., 2008; Zhou et al., 2008; Trigo et al., 2008). However, retrievals of land emissivity are affected by the uncertainty in correcting the attenuation related to atmospheric gases and clouds and in surface skin temperature. Also the uncertainty may be associated with spatial inhomogeneity of land surface properties. Furthermore, the emissivity spectra can only be derived from satellites at specific viewing geometry and specific wavelengths

The modeling of emissivity over land is also progressing. Microwave emissivity spectra were simulated over a limited range of frequencies and surface conditions. For bare soil, emissivity was derived as a function of soil moisture, soil textural components (e.g., clay and sand), and surface roughness (Choudhury et al., 1979; Wang and Schmugge, 1980). The emissivity of vegetation canopy was also simulated using a simplified radiative transfer model and the canopy optical parameters were derived using small particle approximation (Mo et al., 1982), which is only valid at low frequencies like L-band. Recently, more sophisticated radiative transfer schemes were proposed to simulate the effects of the vegetation canopy on microwave emissivity (Wegmuller et al., 1995; Fung, 1994; Kerr and Njoku, 1990). For the snow-covered surfaces, where ice particles have a high fractional volume, the optical parameters were approximated using an effective wave propagation constant for the medium (Tsang et al., 1985). Alternatively, the Mie phase matrix used in the radiative transfer equation was modified to account for scattering interaction of closely-spaced scatterers (Fung, 1994).

In formulating the microwave land emissivity model (Weng et al., 2001), soil is considered as a semi-infinite and vertically homogeneous medium thus its reflectivity can be derived using a simple Fresnel equation. The model works well for microwave higher frequencies where the penetration depth is smaller. At L-C bands, microwave radiation may arise from deeper soil and requires much more sophisticated algorithms. This study integrates several radiative transfer components developed in the past with our previous microwave emissivity model for improved performance at all the microwave frequencies from 1 to 300 GHz.

MULTI-LAYER LAND EMISSIVITY MODEL

1. Model Description



Soil dielectric model:

Dobson et al. (1985) developed a mixing rule for soil dielectric constant (Weng et al., 2001) which is

$$\varepsilon_m^\alpha = 1 + \frac{\rho_b}{\rho_s}(\varepsilon_s^\alpha - 1) + m_v^\beta \varepsilon_w^\alpha - m_v, \quad (5.31)$$

where m_v is the soil volumetric moisture, ε_s is the dielectric constant of solids, and ρ_b is the density of soil, ρ_s is the density of solids, which are calculated from sand and clay fraction. The exponents, α, β are depending on soil type.

$$\alpha = 0.65 \quad (5.32)$$
$$\beta = 1.09 - 0.11S + 0.18C \quad (5.33)$$
$$\varepsilon_s = (1.01 + 0.44 * \rho_s)^2 - 0.062 \quad (5.34)$$

Vegetation dielectric model:

$$\varepsilon_{veg} = 1.7 - (0.74 - 6.16m_g)m_g + m_g * (0.55m_g - 0.076)[4.9 + 75.0/(1+y_i) - y_i] + 4.64m_g^2/(1+7.36m_g^2)[2.9 + 55.0/(1.0+\sqrt{y_i})] \quad (5.16)$$
$$y_i = i\nu/18.0$$

where y_i is a complex value, m_g is the gravimatric water content (g/kg), ν is the frequency in GHz.

A mixing formula was also derived and validated for leaves (Mätzler, 1994a) having a higher gravimetric water content (e.g. > 0.5) which is

$$\varepsilon_{veg} = (0.52 - 0.69m_d)\varepsilon_w + 3.84m_d + 0.51, \quad (5.17)$$

where m_d is the dry matter content and ε_w is the dielectric of water.

2. Simulated Brightness Temperature from Soil

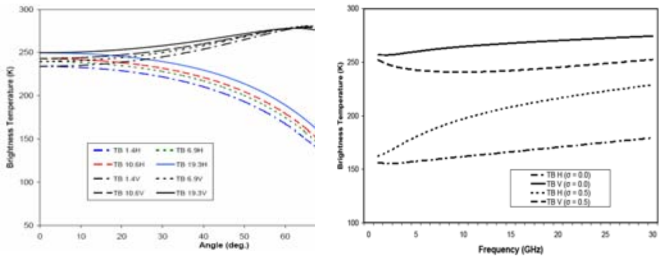


Figure 1. Brightness temperature at 1.4, 6.9, 10.7, and 19.3 GHz vs. (a) viewing angle and (b) frequency

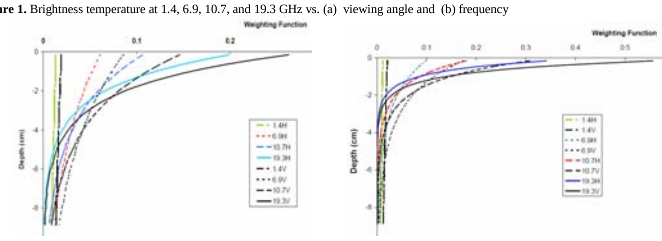


Figure 2. (a) Weighting function at 1.4, 6.9, 10.7, and 19.3 GHz in normal soil condition (m_v = 0.1) and (b) in wet soil condition (m_v = 0.3)

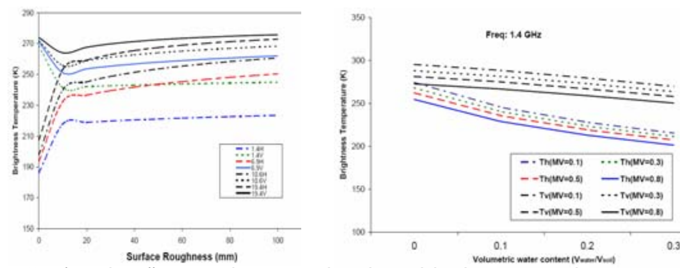


Figure 3. (a) Surface roughness effects on TBs with m_v = 0, view angle = 53 degree; and (b) Soil moisture impacts with m_v = 0.0, 0.3, 0.5 and 0.8 for 1.4 GHz

SYNTHETIC GLOBAL L-BAND SIMULATIONS USING NOAH MODEL OUTPUTS

1. NOAH Surface Model Outputs

GDAS land surface model (NOAH) outputs

GFS Data Assimilation System (GDAS) used at NCEP assimilates a variety of conventional data from radiosonde, buoy, ship, and airborne, satellite radiances, -derived produces. Global analyses are generated at four synoptic hours: 0000, 0600, 1200, and 1800 UTC. As part of GDAS, land surface parameters are also produced through its land data assimilation system called NOAH. The key NOAH parameters include skin temperature, soil volumetric water content, snow depth, soil temperature, global vegetation coverage, canopy water content, land surface vegetation type, surface wind vector at 10 m height, total precipitable water, temperature and relative humidity at 2 m height, and surface pressure.

Soil moisture and vegetation parameters used for radiative transfer

m_v: Volumetric soil moisture content. W: Canopy water content (kg/m^2). Global distribution from NOAH is shown in Fig. 4. Simulated global L-band TB is generalized by allowing for all the other variables fixed with variable soil moisture and canopy water content from four NOAH layers.

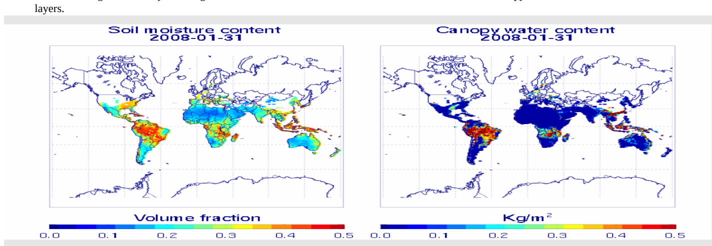


Figure 4. Global maps of soil moisture content (a) and canopy water content (b) from NOAH for Jan. 31, 2008. The cases are excluded if the snow depth from NOAH is larger than 0.

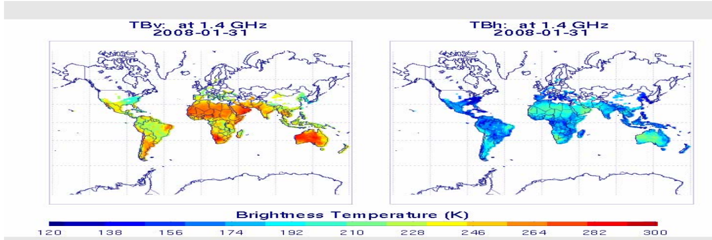


Figure 5. Global maps of simulated L-band TBv and TBh from NOAH model outputs for Jan. 31, 2008.

2. L-Band Correlation with Soil Moisture

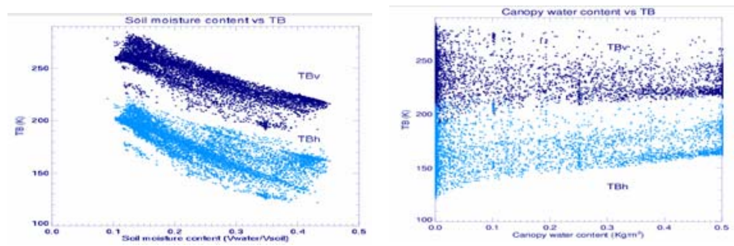


Figure 6. (a) Brightness temperature at 1.4 GHz vs. soil moisture content and (b) polarization difference vs. canopy water content

SUMMARY AND FUTURE WORK

Brightness temperatures at L-Band are simulated well from a multi-layer soil radiative transfer model and display sensitivity to several critical composition parameters such as sand and clay fraction, volumetric moisture content, and surface roughness. It is demonstrated that the polarization difference at L-C bands is a good indicator for vegetation canopy and surface roughness.

Currently, vegetation canopy is handled as a single layer scattering medium with an effective emissivity and reflectivity and surface skin temperature as a lower boundary condition. Optic parameters at L-band is parameterized as a function of volumetric (or gravimetric) canopy water content using the small particle theory at L/C bands and can also be computed directly from the geometric optics at high frequencies.

Our next studies will include 1) a full coupling of radiative transfer scheme among soil, vegetation and atmosphere and 2) development of an interface of land emissivity model with Community Radiative Transfer Model (CRTM) for improved radiance assimilation for L-C band radiometers.

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