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Vegetation and surface roughness effects on AMSR-E land observations

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Abstract

Characteristics of the land surface including soil moisture, vegetation cover, and soil roughness among others influence the microwave emissivity and brightness temperature of the surface as observed from space. Knowledge of the variability of microwave signatures of vegetation and soil roughness is necessary to separate these influences from those of soil moisture for remote sensing applications to global hydrology and climate. We describe here a characterization of vegetation and soil roughness at the frequencies and spatial resolution of the EOS Aqua Advanced Microwave Scanning Radiometer (AMSR-E). A single parameter has been used to approximate the combined effects of vegetation and roughness. AMSR-E data have been analyzed to determine the frequency dependence of this parameter and to generate a global vegetation/roughness map and an estimate of seasonal variability. A physical model is used for the analysis with approximations appropriate to the AMSR-E footprint scale and coefficients calibrated empirically against the AMSR-E data. The spatial variabilities of roughness and vegetation cannot be estimated independently using this approach, but their temporal dynamics allow separation of predominantly static roughness effects from time-varying vegetation effects using multitemporal analysis. Global signals of time-varying vegetation water content derived from this analysis of AMSR-E data are consistent with time-varying biomass estimates obtained by optical/infrared remote sensing techniques.

Keywords: Vegetation; AMSR-E; Soil roughness

1. Introduction

The microwave emissivity of land surfaces is determined primarily by characteristics of the soil and vegetation, except for regions of water and snow cover. The primary soil characteristics affecting emissivity are the volumetric moisture content, surface roughness, and the volume structure and texture. Vegetation acts as an attenuating and emissive layer above the soil, with characteristics determined by its water content, geometric structure, and spatial distributions of stem (trunk, branch) and leaf components. A large number of parameters is typically required to model radiative transfer in the soil-vegetation medium, especially if the heterogeneity of vertical and horizontal vegetation structure over the sensor footprint is considered. Since satellite microwave radiometer footprints are large (typically ~10–60 km) as compared to the scales of surface heterogeneity, a reduced number of effective parameters is usually sought for geophysical retrieval purposes to model the aggregate effects of soil and vegetation characteristics on the land surface emission. The reduced set of parameters adopted for most passive microwave studies are those describing the opacity and single scattering albedo of the vegetation, the moisture, texture, and surface roughness of the soil, and the surface temperature. Though expressions for these effective parameters can be derived from physical principles, the expressions must usually be simplified and tuned empirically for remote sensing applications at the satellite footprint scale. Our objective here is to develop a method for estimating the combined spatial and temporal signatures of vegetation opacity and surface roughness in the multichannel AMSR-E data. These signatures can be used to monitor vegetation change and to provide corrections for soil moisture estimation using AMSR-E. The analysis provided here may also provide insights for algorithm development using other satellite instruments with similar frequencies and viewing characteristics.

The parameterization of surface roughness and vegetation used here was developed for estimating soil moisture from the Advanced Microwave Scanning Radiometer on the Earth Observing System (EOS) Aqua satellite (AMSR-E) (Njoku et

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al., 2003). AMSR-E is a dual-polarized radiometer operating at frequencies of 6.9, 10.7, 18.7, 23.8, 36.5, and 89 GHz. The instrument has a conically scanning antenna that provides multichannel observations at a constant incidence angle of 54.8° across a 1445-km swath (Kawanishi et al., 2003). The spatial resolution of AMSR-E varies from approximately 60 km at 6.9 GHz to 5 km at 89 GHz. Measurement of soil moisture, m_v, is a primary land surface hydrology objective of AMSR-E along with snow water equivalent and precipitation. Vegetation opacity, τ_c, is a limiting factor in obtaining accurate soil moisture retrievals since it reduces the observed microwave sensitivity to soil moisture. The surface temperature, T_s, soil surface roughness, soil texture, surface heterogeneity, and atmospheric water vapor and clouds (mostly at frequencies above ~15 GHz) are other significant factors affecting soil moisture retrieval. To retrieve soil moisture accurately, these factors must be estimated using ancillary data or as part of a multichannel microwave estimation. Even after correction, these factors contribute some residual error to the overall soil moisture retrieval error. The ability to estimate parameters such as τ_c and T_s, in addition to m_v, using a multichannel approach relies on the separability of the influences of m_v, τ_c, and T_s on the observed brightness temperatures at the frequencies and polarizations considered. The degree to which these influences are separable, and can be adequately modeled, determines the accuracy with which m_v, τ_c, and T_s can be simultaneously retrieved.

We describe here a method for estimating the combined spatial and temporal signatures of vegetation opacity and surface roughness in the multichannel AMSR-E data. The approach does not require time-varying ancillary data inputs such as surface temperature and vegetation water content. Our objective, as a benchmark, is to rely on static ancillary data only, such as maps of surface type (including water bodies and urban areas), soil classes, topography, and estimates or climatologies of other less significant variables (at the frequencies considered here) such as atmospheric water vapor. In operational applications, masks for time-varying features such as snow cover and precipitation will be necessary. Alternate retrieval options of merging AMSR-E data with dynamic ancillary data such as forecast-modeled surface temperatures and optical/IR vegetation data can be evaluated separately against the microwave-only benchmark.

Analyses of vegetation cover, soil moisture, and surface water fraction using passive microwave satellite data at C-band (~6 GHz) and higher have been discussed previously in the literature (e.g., Choudhury et al., 1987; Fily et al., 2003; Gao et al., in press; Kerr and Njoku, 1990; Njoku and Li, 1999; Owe et al., 2001; Wang, 1985). These studies have demonstrated the multifrequency sensitivities of satellite microwave observations to soil moisture and vegetation. In the present study, we seek to tie specific parameters of the microwave model to satellite measurements at the ~60-km footprint scale as a means for more quantitative estimation by AMSR-E of global soil moisture and vegetation. A feature of the approach is the use of the polarization ratio, defined as proportional to the ratio of the first two Stokes parameters (i.e., the ratio of the difference of the vertical and horizontal brightness temperatures to their sum), as the observational quantity at each frequency. Use of the polarization ratio reduces significantly the dependence on surface temperature, T_s. Use of the polarization ratio for land retrievals has been discussed in earlier papers (Kerr & Njoku, 1990; Paloscia & Pampaloni, 1988).

The procedure adopted is as follows. In Section 2, the dependence of brightness temperature on m_v, τ_c, and T_s at the AMSR-E frequencies, polarizations, and incidence angle is formulated, using approximations to facilitate separation of the observed signal dependence on the three parameters. Surface roughness effects are included with the vegetation effects by defining a parameter g that describes to first order the combined effects of both vegetation and roughness. In Section 3, the frequency dependence of g is determined by considering AMSR-E data from a region with low to moderate values of g and relatively dry soil conditions. In Section 4, global estimates of g are derived and the seasonal variation is shown, related primarily to the time-varying vegetation water content. Although the effects of vegetation water content and surface roughness cannot be estimated independently in this approach, the temporal variability of g is seen to be predominantly due to vegetation. The temporal variations correlate closely with biomass changes observed by optical/infrared sensors. It is emphasized that the approach contains several approximations and may therefore only be generally applicable only to sensors with characteristics similar to AMSR-E. However, the principles of the analysis are extendable to other sensors, and the applicability of the results can be compared against other more rigorous parameterizations.

2. Formulation

The approach is based on simplified radiative transfer theory and the assumption of minimal influence (or available estimates) of atmospheric moisture. The method assumes that the multichannel sensor footprints are co-registered and processed to similar spatial resolution, as was done for the AMSR-E Level 2A data (Ashcroft & Wentz, 2000). The method also assumes that heterogeneous mixtures of vegetation and soil types within the footprints can be represented by effective or averaged quantities, i.e., the radiative transfer model maintains its validity using averaged parameters at the AMSR-E footprint scale. Using a common formulation (Kerr & Wigneron, 1995; Njoku et al., 2003), the surface brightness temperature, T_{bp}, for a vegetated surface, can be represented by:

$$T_{bp} = T_s\left\{e_{sp}\exp(-\tau_c) + \left(1-\omega_p\right)\left[1-\exp(-\tau_c)\right] \times \left[1+r_{sp}\exp(-\tau_c)\right]\right\}. \quad (1)$$

The subscript p refers to vertical or horizontal polarization, the soil emissivity e_{sp} and reflectivity r_{sp} are related by $e_{sp} = 1 - r_{sp}$, τ_c is the vegetation opacity along the observation path, and ω_p is the vegetation single scattering albedo that depends on vegetation structure and water content. Multiple scattering