A METHOD FOR DERIVING NORTHERN HEMISPHERE VEGETATION PHENOLOGY, LAND SURFACE WETNESS, AND OPEN WATER FRACTION FROM AMSR-E

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1. INTRODUCTION

Soil moisture and vegetation phenology are key variables determining surface fluxes of water and carbon. The in situ monitoring network for these variables is sparse, particularly at high latitudes. Vegetation and thermal inertia soil moisture information is often derived from satellite optical-IR remote sensing indices, such as the Normalized Difference Vegetation Index (NDVI) or land surface temperature (LST). However, cloud contamination, atmospheric aerosols, and solar illumination adversely impact optical-IR observations, limiting temporal repeat and spatial coverage. Optical-IR observations also have limited ability to penetrate vegetation canopies and as a consequence tend to saturate in high biomass conditions. Passive microwave instruments such as the Advanced Scanning Microwave Radiometer on EOS Aqua (AMSR-E) are sensitive to vegetation biomass and soil moisture, affording advantages over optical-IR observations by allowing observations in cloudy non-precipitating conditions, with greater ability to penetrate the vegetation canopy.

Several approaches exist for determining soil moisture from microwave instruments including change detection, multi-channel iterative, and single channel methods [6,7,4]. Water has a high dielectric constant and the presence of soil moisture or open water greatly increases the bulk surface reflectivity. Satellite passive microwave remote sensing at low frequencies (< 18 GHz) has relatively coarse spatial resolution (> 30 km) encompassing heterogeneous surface type and terrain information, therefore the presence of open water is a confounding factor when estimating soil moisture and vegetation properties from space-borne microwave instruments. Current approaches either ignore open water effects, apply various mitigation strategies such as static land cover classification, or apply a change detection approaches using microwave index (e.g. polarization ratios or channel gradients) time series to detect soil moisture changes relative to ‘baseline’ conditions. Many areas, particularly high latitudes, experience seasonal inundation leading to retrieval errors when static land cover maps are used to define open water areas. Current change detection approaches do not explicitly separate the impact of vegetation and open water on microwave indices leading to ambiguity in the interpretation of surface ‘baseline’ conditions. Although the NDVI is widely used to account for vegetation biomass effects on microwave soil moisture retrievals, detailed comparisons of the microwave canopy response relative to optical-IR wavelengths have focused on croplands and such information for the full range of Northern Hemisphere vegetation types is lacking. Interpolation schemes for gridding ancillary data introduce additional error in retrievals. In this study we develop a method for determining open water fraction, soil moisture, and vegetation optical depth from AMSR-E observations independent of ancillary data. The results are compared against independent satellite and in situ observations for a range of Northern Hemisphere land cover types.

2. METHODS

Our approach uses the familiar τ - ω radiative transfer equation and time-domain filters to sequentially estimate vegetation optical depth, open water fraction, and land surface wetness from AMSR-E L2A observations gridded to 25-km [1]. Daily surface temperature is derived from multi-frequency descending orbit AMSR-E observations [5]. The temperature retrievals are used to calculate effective H and V polarized emissivities for the 6.9 and 10.7 GHz frequency AMSR-E channels. Use of both channels allows mitigation of radio frequency interference. We assume that satellite retrievals over large regions encompass a mixture of emissivities from open water, and varying vegetation amount within the sensor field of view (FOV) and can be described by a linear relationship in V vs. H emissivity space. The line contains the H- and V- emissivities of open water (assumed constant) and the slope of the relationship can therefore be determined on a daily basis using the effective H and V emissivities. The slope varies seasonally with vegetation phenology. A moving window median filter is applied to reduce soil moisture dependence. The slope allows calculation of vegetation/roughness equivalent optical depth and baseline land fraction emissivity directly from the τ - ω equation, assuming vegetation properties are equivalent for V and H polarization. Daily effective V-emissivity is applied to calculate open water fraction from the baseline land fraction emissivity. The open water fraction is then smoothed using a moving window minimum filter to reduce soil moisture dependence. Land surface soil wetness is calculated from effective H-emissivity by inverting the τ - ω equation and a polynomial approximation of the Dobson model and Fresnel equations using the estimated vegetation optical depth and open water fraction [2]. The variance in estimated bare surface reflectivity (and hence surface wetness) increases in proportion to the amount of open water and the square of the exponential of vegetation biomass. We therefore dampen the variability in bare surface reflectivity relative to 'dry' conditions by multiplying the variance by an open water and vegetation biomass dependent factor. This technique improves surface wetness estimates under marginal retrieval conditions by reducing the dynamic range of the estimate. The wetness estimate represents the volumetric moisture of the soil surface (< 2 cm depth) that responds rapidly (i.e. on a daily to weekly timescale) to drying and wetting events. In order to test the algorithm, land surface wetness results are compared to in situ soil moisture and precipitation observations for North American flux towers and a subset of Northern Hemisphere WMO daily metrological stations. Vegetation optical depth is compared to MODIS 1-km 8-day LAI and NDVI gridded to 25-km spatial resolution. Open water fraction retrievals are compared to a MODIS 1-km IGBP land cover map gridded to 25-km spatial resolution.

3. RESULTS AND CONCLUSIONS

The AMSR-E land surface wetness retrievals are well correlated (up to 0.7) with in situ soil moisture (5 cm depth) data where the fraction of open water is less than 25 % of the FOV and vegetation optical depth is below 1.2 for 6.9 GHz. The surface wetness retrievals also correspond with the timing, but not necessarily the magnitude of in situ precipitation observations. Surface wetness results correlate with the AMSR-E Level 3 soil moisture product, but show increased dynamic range [6]. Vegetation optical depth retrievals correspond with MODIS LAI with the highest correlations (up to 0.8) in grassland, cropland, and savannah locations and somewhat lower but significant correlations (0.5) for tundra and forest. Individual sites show linear relations between optical depth and LAI with coefficients that vary by land cover type, although the overall pattern resembles a logarithmic relationship. These results also correspond well with results from SeaWinds Ku band observations and indicate that the canopy loss factor varies with vegetation type on a hemispheric scale [3]. AMSR-E typically estimates 5-10 % more open water area at each location relative to MODIS, which is attributed to the fact that water bodies existing within 1-km pixels classified as non-water can impact the FOV microwave signal. Seasonal variability in open water indicates increased inundation following spring melt in high latitude locations and may incorporate seasonal changes in soil water storage. This study provides a robust, relatively efficient algorithm for separating the effects of open water, vegetation phenology, and land surface wetness on satellite passive microwave observations relying only on information provided by the sensor itself. The approach can provide information for water and carbon flux models as well as an alternative algorithm for future passive microwave missions.

4. REFERENCES

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