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Inferring land surface parameters from the diurnal variability of microwave and infrared temperatures

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ABSTRACT

This study investigates the properties of the diurnal cycle of microwave brightness temperatures (TB), namely the phase and the amplitude, and their variability in time and space over the globe to infer information on key land surface parameters like changes in soil texture spatial distribution, soil moisture conditions, and vegetation density. The phase corresponds to the lag between Land Surface Temperature (LST) and TB diurnal cycles. The amplitude is determined as the difference between the maximum and the minimum of TB diurnal cycle. The diurnal cycle of TB was constructed using observations from the Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) and the Special Sensor Microwave/Imager (SSM/I). The latter offer a series of sensors, namely, F13, F14, and F15 that were used in this study for a higher temporal coverage and more accurate diurnal cycle determination. LST estimates, which are available every 3 h from the International Satellite Cloud Climatology Project (ISCCP) database were used to build the LST diurnal cycle. ISCCP LST data is an infrared-based temperature with almost no penetration and is the representative of top skin temperature.

The analyses of the diurnal cycles showed that the diurnal amplitude of TB decreases as the vegetation density increases, especially in the case of low frequencies which penetrate deeper into the canopy which makes them more sensitive to changes in vegetation density. The interannual variations of TB diurnal amplitudes were also in agreement with the seasonality of the vegetation cover. Over desert and rain forest regions where surface conditions do not vary significantly throughout the year, the changes in diurnal amplitudes were the lowest. A relationship between phase and amplitude values was established. It was found that the amplitude of TB diurnal cycle decreases when the phase lag increases. The spatial distribution of the determined diurnal properties, namely, phase and amplitude of TB, showed an agreement with lithology maps in desert areas. Lower TB amplitudes were observed over regions with loose siliceous rocks. Phase lag values between 1.5 and 3 h corresponded to 83% of the class "loose siliceous rocks" in the Sahara Desert, which corroborates the potential of using the diurnal properties of TB as an indicator of land surface parameters.

1. Introduction

Microwave brightness temperature (TB) is sensitive to key surface parameters, such as soil moisture, snow cover, freeze/thaw state, land surface temperature, and vegetation structure (e.g. Min et al., 2010; Njoku et al., 2003; Tedesco and Kim, 2006). The retrieval of these parameters typically requires running a radiative transfer model which uses TB observations from ascending or descending overpasses of a single polar orbiting satellite at the same specific time of the day. Then, the retrieved parameters should only correspond to the state of the land surface at acquisition time. Moreover, the retrieval of land surface parameters using radiative transfer models does not account for the diurnal variability of microwave TB with respect to other variables included

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in the model, like, Land Surface Temperature (LST), assuming a perfect sync between LST and TB may undermine the quality of the retrieval.

Nowadays, the considerable number of operational passive microwave sensors allows us to construct the diurnal cycle of TB and study its variability throughout the day. The diurnal variation of land surface temperature, atmospheric temperature, and water vapor profiles due to solar radiation affects the sensitivity of the microwave signal to other surface parameters, such as soil moisture, soil roughness, and vegetation optical depth (Choudhury, 1993) Relying on TB observations from a constellation of passive microwave sensors should improve our understanding of the diurnal variability of the signal and lead to a better retrieval of land surface parameters.

Operational polar orbiting satellites that are equipped with microwave radiometers provide at least two observations per day in most regions of the globe, except at higher latitudes, where the revisit time is shorter. Therefore, in order to construct the diurnal cycle of TB across the globe, observations from the existing operational satellites, which observe the surface of the Earth at different local times, should be aggregated. Over land, microwave TB is controlled mainly by surface emissivity and physical temperature (Choudhury, 1993). The changes in surface parameters affect land emissivity and physical temperature and, therefore the diurnal properties of TB.

The characteristics of skin temperature diurnal cycles from thermal infrared observations have been investigated using the Principal Component Analysis (PCA) approach (Aires et al., 2004). It was concluded that the first three components represent the diurnal amplitude, the phase, and the daytime duration of the diurnal variation (Aires et al., 2004). On the other hand, passive microwave TB affected by the depth of the originating soil layer that varies with frequency, surface type, soil moisture, and mineral types of the region (Prigent et al., 1999) exhibits a distinct diurnal variability. Grody and Weng (2008) showed that, in some desert regions, the difference between microwave TB at 19 and 37 GHz has a positive sign at 6:00 a.m., but changes to negative at 9:00 a.m., because observations in these frequencies originate from different layers. Recently, Temimi et al. (2014) analyzed the diurnal change in the performance of soil moisture retrieval using L-band TB measured throughout the day from a ground based radiometer and stated that the best performance was obtained in early afternoon and that the lowest performance was obtained when early morning TB were used. Prigent et al. (1999) used a physical model based on a semi-infinite heat transfer to simulate the effective temperature variation at different depths. They found that, for some surface types, such as sand dunes in desert regions, microwave temperature has much lower diurnal amplitude compared to the top surface physical temperature variation.

Most of the abovementioned studies were based on observations from SSM/I, which are acquired early in the morning or late in the afternoon. Other sensors, like AMSR-E, which was operational from 2002 to 2011, offered additional observations closer to the daily maxima and minima as the sensor's overpass time over the Equator was around 1:30 a.m./p.m. Along with SSM/I measurements, AMSR-E observations allowed for better apprehension of TB diurnal variability and, therefore, accurately inferring changes in diurnal properties (Norouzi et al., 2012). The purpose of this study is to find the relationship between microwave Tb diurnal characteristics and land cover information and also to compare with skin temperature diurnal cycle using infrared observations. This study adds to previous investigations of diurnal variability of TB through integration of additional TB from AMSR-E and uses the constructed diurnal cycles of TB and LST to intercompare their diurnal parameters with respect to land cover classes on a global scale. The relationship between the diurnal variability of TB and soil texture is investigated, where bare soil conditions are prominent, specifically in desert regions. In addition, this study expands the scope of previous analyses (Aires et al., 2004) and places the focus on both LST and microwave TB diurnal cycles. We argue that the TB diurnal variability with respect to LST at different locations provides relevant information on soil texture and land cover type, particularly in desert areas.

2. Data and methodology

2.1. Background

Assuming that land surface is flat and specular and considering the atmosphere as a non-scattering plane-parallel medium, the emissivity can be written as:

$$Tb_{(p,\upsilon)} = \varepsilon_{(p,\upsilon)} \cdot e^{-\tau(0,H)/\mu} \cdot Ts + (1 - e^{-\tau(0,H)/\mu}) \cdot T^{\downarrow}_{atm} + T^{\uparrow}_{atm} \quad (1)$$

where $\varepsilon_{(p,\upsilon)}$ and $Tb_{(p,\upsilon)}$ are the land surface emissivity and the measured brightness temperatures at polarization p (horizontal, H, or vertical, V) and frequency μ, respectively. Ts is the skin temperature and $T^{\downarrow}_{atm}$ and $T^{\uparrow}_{atm}$ are the downwelling and upwelling brightness temperatures from the atmosphere

After removing the effect of the atmosphere, the land surface TB can be written as (Norouzi et al., 2012):

$$Tb_{(p,\upsilon)} = \varepsilon_{eff_{(p,\upsilon)}} . T_{eff} \quad (2)$$

where T_{eff} is the effective physical temperature and represents the temperature of the layer of soil that is contributing to the radiating microwave signal. Emissivity is a physical parameter, which depends on the characteristics, such as moisture, vegetation, surface roughness, and dielectric constant, as well as the sensor configuration (i.e. viewing angle and frequency). Therefore, for stable surface conditions in time, like in desert or rain forest regions, *TB* diurnal parameters are expected to be persistent and any variation in TB should be the result of changes in T_{eff} in space according to spatial variability of surface conditions. It is worth noting that the changes in T_{eff} that this study is capturing are not necessarily similar with changes in LST, essentially because of differences in the penetration depth that is known as the effective depth. In addition, we assume that surface conditions are stable diurnally. In other words, we expect that the physical and brightness temperatures should vary more rapidly than the surface properties represented by the emissivities over the day. The exceptions are produced by possible land surface variations due to precipitation, soil moisture, dew deposition over vegetated areas, and accumulation of snow.

In radiative transfer modeling, due to the lack of global effective temperature observations, LST is usually utilized to approximate T_{eff}. The penetration of the microwave signal into the soil determines the depth the soil layer is generating the microwave radiations. Over bare soils, the penetration depth should depend on the frequency, the soil texture, the soil temperature profile, and the moisture content. LST, on the other hand, reflects the radiating infrared signal of soil surface skin and unlike the microwave temperature does not penetrate deeper into the soil. The deeper sensing depth of the microwave signal leads to lower amplitude of the TB diurnal cycle and introduces a phase lag between TB and LST diurnal cycles. We expect that the difference between the diurnal cycles of LST and TB that is the result of the difference in their sensing depths and includes valuable information on the changing soil parameters.

To verify this assumption, we propose constructing diurnal cycles from TB and LST measures. Then, we assess the variability of the diurnal cycle of TB globally and analyzed over a number of specific land cover types. A vegetation and land use global data set compiled from a large number of published sources at 1° equal