Remote Sensing of Environment 123 (2012) 470–482

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Using microwave brightness temperature diurnal cycle to improve emissivity retrievals over land

Hamidreza Norouzi [a,b,*], William Rossow [b], Marouane Temimi [b], Catherine Prigent [c], Marzieh Azarderakhsh [b], Sid Boukabara [d], Reza Khanbilvardi [b]

[a] New York City College of Technology/CUNY, 300 Jay St., Brooklyn, NY 11201, USA
[b] NOAA-Cooperative Remote Sensing Science and Technology Center (CREST), The City College of New York, 160 Convent Ave, New York, NY 10031, USA
[c] Centre National de la Recherche Scientifique, Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique, Observatoire de Paris, 61 avenue de l'Observatoire, 75014 Paris, France
[d] National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS)/The Center for Satellite Applications and Research (STAR), 5200 Auth Road, Camp Springs, MD 20746, USA

ARTICLE INFO

Article history:
Received 4 January 2012
Received in revised form 3 April 2012
Accepted 14 April 2012
Available online 17 May 2012

Keywords:
Emissivity
Brightness temperature
Diurnal cycle
Land
Passive microwave
Effective temperature
Vegetation
Soil moisture

ABSTRACT

To retrieve microwave land emissivity, infrared surface skin temperatures have been used as surface physical temperature since there is no global information on physical vegetation/soil temperature profiles. However, passive microwave emissions originate from deeper layers with respect to the skin temperature. So, this inconsistency in sensitivity depths between skin temperatures and microwave temperatures may introduce a discrepancy in the determined emissivity. Previous studies showed that this inconsistency can lead to significant differences between day and night retrievals of land emissivity which can exceed 10%. This study proposes an approach to address this inconsistency and improve the retrieval of land emissivity using microwave observations from Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E). The diurnal cycle of the microwave brightness temperature (*Tb*) was constructed over the globe for different frequencies/polarizations using a constellation of satellites. Principal component analysis (PCA) was conducted to evaluate the spatial variation of the Tb diurnal cycle. The diurnal amplitudes of microwave temperatures observed in desert areas were not consistent with the larger amplitudes of the diurnal cycle of skin temperature. Densely vegetated areas with more moisture have shown smaller amplitudes. A lookup table of effective temperature (T_{eff}) anomalies is constructed based on the *Tb* diurnal cycle to resolve the inconsistencies between infrared and *Tb* diurnal variation. This lookup table of T_{eff} anomalies is a weighted average over the layers contributing to the microwave signal, for each channel and month. The integration of this T_{eff} in the retrieval of land emissivity reduced the differences between day and night retrieved emissivities to less than 0.01 for AMSR-E observations.

1. Introduction

Instantaneous measures of microwave brightness temperature, *Tb*, have been used in a variety of applications to estimate column water vapor abundance, rainfall rate, surface ocean wind speed, ocean salinity, soil moisture, freeze/thaw state, land surface temperature, inundation fraction, and vegetation structure (Boukabara et al., 2007; Entekhabi et al., 2010; Fily et al., 2003; Karbou et al., 2006; McCollum and Ferraro, 2005; Min et al., 2010; Njoku et al., 2003; Papa et al., 2006; Tedesco and Kim, 2006; Wilheit et al., 2003; Zhang et al., 2010). Land surface properties can be inferred accurately if physical temperature and emissivity variations can be separated (Prigent et al., 1997). Diurnal synoptic and variations of land surface temperature, as well as the atmospheric temperature and water vapor profiles, affect the observed *Tb*. The more frequent the observation of *Tb* throughout the day, the better understanding of the variability of retrieved parameters.

Microwave emissions can come from layers deeper than the surface skin depending on the frequency and the media, in particular its moisture. For instance, in vegetated areas, the 6.9 GHz (C band) passive microwave can provide some soil moisture information as it is less affected by vegetation (Njoku et al., 2003). The diurnal variation of the passive microwave *Tb* mainly depends on physical temperature variation at the depth of origination. For some dry and porous surfaces, such as sand dunes in deserts, microwave temperature exhibits much smaller diurnal amplitude than surface temperature variation (Prigent et al., 1999). In some desert regions at higher frequencies, where the penetration depth is smaller, the radiometric measurements display diurnal variations similar to those of the surface temperature, but conversely, at lower frequencies, where the penetration depth is larger, the radiation displays smaller diurnal variations than the surface temperature (Grody and Weng, 2008). Therefore, to retrieve microwave emissivities, estimates of the variation of physical temperatures with depth are

* Corresponding author. Tel.: +1 718 260 5410; fax: +1 718 260 5677.
E-mail address: hnorouzi@citytech.cuny.edu (H. Norouzi).

0034-4257/$ – see front matter
doi:10.1016/j.rse.2012.04.015

necessary. A physical model has been used to simulate the physical temperature variation at different depths based on a semi-infinite heat transfer equation (Grody and Weng, 2008; Prigent et al., 1999). This type of model shows decreasing diurnal amplitude and increasing phase lag with respect to the skin temperature with depth.

We found significant differences between land emissivities determined from AMSR-E daytime and nighttime overpasses (Norouzi et al., 2011), retrieved using the infrared thermal temperature as the physical temperature. The discrepancies between day and night emissivities have also been noticed in other studies (Moncet et al., 2011). Such large differences with a consistent feature (day to day) within one day, up to 0.1, seem unlikely for stable surface conditions. The proposed explanation is that the skin temperature, *Ts*, and *Tb*, do not originate from the same depth, so that their diurnal cycles are not the same. This assumption is supported by the variation of the discrepancy magnitude with surface type—more densely vegetated locations that are also moister showed much smaller discrepancies than arid regions. Moncet et al (2011) used the physical model proposed by Prigent et al (1999) to produce a monthly mean emissivity with consideration of microwave penetration depth effect. However, there is no available instantaneous emissivity product yet that has considered the effect of penetration depth in the retrieval.

Polar orbiting satellites provide observations at most locations on the globe twice a day (except for Polar Regions which are observed more often). Since none of the available geostationary satellites is equipped with a passive microwave sensor, resolution of diurnal variations is not achievable for conical scanning sensors except by aggregating observations from multiple satellites. Several sensors, such as the Scanning Multi-channel Microwave Radiometer (SMMR) (Njoku et al., 1980) and the Special Sensor Microwave/Imager (SSM/I) (Colton and Poe, 1999), have provided passive microwave measurements of the earth surface since 1978. However, most of these satellites had local overpass times near 6:00 to 9:00 AM/PM. So they miss the daily maximum and minimum physical temperatures. In 2002, the Advanced Microwave Scanning Radiometer–Earth Observing System (AMSR-E) sensor on NASA's Aqua satellite was launched into an orbit with overpass times at 1:30 A.M./P.M. local solar time (Njoku et al., 2003). When combined with operational SSM/I instruments, better diurnal resolution can be obtained.

There are very few studies that have dealt with the characterization of the *Tb* diurnal variation over land. The diurnal variation of physical and brightness temperatures as a function of incident solar radiation has been modeled for the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) (Stephen et al., 2010). The characteristics of the skin temperature diurnal cycles as measured from IR over different land types were investigated using the Principal Component Analysis (PCA) approach applied to results from the International Satellite Cloud Climatology Project (ISCCP) (Aires et al., 2004). They found that the first three components represent the diurnal amplitude, the phase, and the seasonally and latitudinally varying daytime duration of the diurnal variation. In densely vegetated areas with more moisture, skin temperature exhibits a smaller diurnal variation than in arid and desert areas (Aires et al., 2004).

Our study builds on previous findings to develop a procedure to reduce globally the day-night discrepancies in land emissivity estimates for each overpass. First, the physical model proposed by Prigent et al (1999) is used globally to investigate the spatial variability of the penetration depth at different microwave frequencies. Secondly, we test another approach based on directly observed *Tb* diurnal variations to account for the discrepancies between day and night emissivity estimates. The *Tb* diurnal variation is constructed using *Tb* observed at different local times in similar channels of AMSR-E and SSM/I on multiple satellites. PCA is used to represent the spatial variation of microwave *Tb* diurnal cycles. A lookup table of effective temperature, T_{eff}, anomalies (i.e. a temperature that represents the vertical integration of microwave emissions over a profile of layer temperatures) diurnal variation for each frequency and month is constructed from the PCA results. These T_{eff} anomalies are used to reduce the differences between day and night estimates of land surface emissivity. Revised emissivities are estimated using the proposed lookup table.

2. Data sets

The AMSR-E L2A product (swath data) is obtained from National Snow and Ice Data Center (NSIDC). Data are originally resampled to be spatially consistent, and therefore are available at a variety of resolutions that correspond to the footprint sizes of the observations such as 56 km, 38 km, 24 km, 21 km, 12 km, and 5.4 km, for 6.925, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz respectively. Each swath is packaged with associated geolocation fields. For each frequency, we selected the resampled data having the closest spatial resolution to the original footprint at that frequency. In this study, all data sets are re-projected to an equal area grid (0.25° at equator). At this type of projection, the area of the map grid cells is maintained equal with latitude by adjusting the longitude interval based on a 0.25° cell area at the equator. Also, SSM/I observations from F13, F14, and F15 United States Air Force Defense Meteorological Satellite Program (DMSP) satellites provided by Global Hydrology Resource Center (GHRC) are mapped to the same grid and used to construct the diurnal cycle. More information such as crossing times, channels, and viewing angles for SSM/I and AMSR-E sensors are provided in Table 1.

Satellite infrared-based products from the International Satellite Cloud Climatology Project (ISCCP) are used for surface skin temperatures and cloud cover. The ISCCP-DX version provides information on skin temperature and cloud coverage every 3 h since 1983 (Rossow and Schiffer, 1999) at a ~30 km spatial resolution, based on merged observations from geostationary and polar-orbiting satellites. ISCCP products were resampled to match the 0.25° equal area grid adopted for the passive microwave observations. This skin temperature data set represents the top surface temperature; in the case of dense vegetation it may represent the top of the canopy.

Table 1
SSM/I and AMSR-E sensors information.

Sensor	Satellite	Temporal coverage	Equator crossing time (2005)	Channels (GHz)	Polarization	Spatial resolution (km)	Incidence angle
SSM/I	F13	May 1995–present	6:30 A.M./P.M.	19.35	V, H	69×43	53°
	F14	May 1997–Aug 2008	7:00 A.M./P.M.	22.235	V Only	60×40	
	F15	Jan. 2000–present	9:00 A.M./P.M.	37.0	V	37×28	
				85.5	V	15×13	
AMSR-E	Aqua	Jun. 2002–present	1:30 A.M./P.M.	6.925	V, H	75×43	55°
				10.65	V, H	51×29	
				18.7	V, H	27×16	
				23.8	V, H	32×18	
				36.5	V, H	14×8	
				89.0	V, H	6×4	