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Validation of the North American ASTER Land Surface Emissivity Database (NAALSED) version 2.0 using pseudo-invariant sand dune sites

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ABSTRACT

Knowledge of the Land Surface Emissivity (LSE) in the Thermal Infrared (TIR: 8–12 µm) part of the electromagnetic spectrum is essential to derive accurate Land Surface Temperatures (LSTs) from spaceborne TIR measurements. This study focuses on validation of the emissivity product in the North American ASTER Land Surface Emissivity Database (NAALSED) v2.0 — a mean seasonal, gridded emissivity product produced at 100 m spatial resolution using all Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) scenes from 2000 to 2008 over North America (http://emissivity.jpl.nasa.gov). The NAALSED emissivity product was validated over bare surfaces with laboratory measurements of sand samples collected at nine pseudo-invariant sand dune sites located in the western/southwestern USA. The nine sand dune sites cover a broad range of surface emissivities in the TIR. Results show that the absolute mean emissivity difference between NAALSED and the laboratory results for the nine validation sites and all five ASTER TIR bands was 0.016 (1.6%). This emissivity difference is equivalent to approximately a 1 K error in the land surface temperature for a material at 300 K in the TIR.

1. Introduction

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) was launched on the Terra satellite in December 1999 and has five bands in the Thermal Infrared (TIR) with a spatial resolution of 90 m. Remote sensing observations of narrowband surface emissivity in the wavelength range covered by ASTER TIR bands 10–14 centered on 8.3, 8.6, 9.1, 10.6, and 11.3 µm respectively range from ~0.65 to close to 1.0 for most natural Earth surfaces. Narrowband emissivities over arid and semi-arid areas in the 8–12 µm range typically have large variation due to the strong quartz absorption feature (Reststrahlen band) in the 8–9.5 µm region, whereas the emissivity of dense vegetation, water and ice cover is greater than 0.95 and constant in the 8–12 µm range. Changes in surface emissivity for most natural surfaces occur primarily due to variations in soil moisture (Mira et al., 2007), vegetation cover and type (French et al., 2008), and surface roughness (Mushkin & Gillespie, 2005), of which the influence of soil moisture is the least understood.

Land Surface Temperature and Emissivity products (LST&E) are generated by spaceborne sensors such as the Atmospheric Infrared Sounder (AIRS) (Susskind et al., 2003), the Moderate-Resolution Imaging Spectrometer (MODIS) (Wan, 2008) and ASTER (Gillespie et al., 1998; Hulley et al., 2008). Although these emissivity products produce the same measure, there are often discrepancies between them due to their varying spatial, spectral and temporal resolutions, and the different algorithms used to retrieve the surface emissivity.

LST&E products are key parameters used in land surface dynamics, climate modeling, and surface–atmosphere interactions. In climate modeling, recent sensitivity tests based on the NCAR Community Land Model (Bonan et al., 2002) indicate that an emissivity error of 0.1 (10%) in barren areas such as Northern Africa and the Arabian Peninsula will result in current climate models having errors of up to 6.6 W m^{-2} in their upward longwave radiation estimates (Jin & Liang, 2006; Zhou et al., 2003). This represents a much larger term than the surface radiative forcing due to an increase in greenhouse gases (~2–3 W m^{-2}), making accurate knowledge of the surface emissivity a critical component for climate change studies.

In surface–atmosphere interactions, errors in the retrievals of atmospheric temperature and moisture profiles from hyperspectral infrared radiances, such as those from AIRS, are strongly dependent on the accuracy of the surface emissivity (Kornfield & Susskind, 1977), particularly over arid and semi-arid regions where the variation in emissivity is large, both spatially and spectrally. Using a baseline-fit (BF) model based on laboratory measurements to fill in spectral gaps in the MOD11 emissivity product, Seemann eta l., (2008) found that the MOD07 total precipitable water (TWP) retrieval biases were reduced from 2.1 mm to 0.2 mm when using the BF method as opposed to assuming a constant emissivity of 0.95.

While the land surface temperature products from ASTER have been validated by several authors (Coll et al., 2005; Hook et al., 2007; Tonooka & Palluconi, 2005), far fewer authors have attempted to

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validate the surface emissivity product (Schmugge & Ogawa, 2006; Schmugge et al., 2003). In this study we have validated the North American ASTER Land Surface Database (NAALSED) v2.0 emissivity product over arid/semi-arid regions using nine pseudo-invariant sand dune sites in the western/southwestern USA. The emissivity of samples collected at each of the nine sites was determined in the laboratory using a Nicolet 520 FT-IR spectrometer (Baldridge et al., 2009) and convolved with the appropriate ASTER system response functions. Validation of emissivity data from space ideally requires a site that is homogeneous in emissivity at the scale of the imagery, allowing several image pixels to be validated over the target site. ASTER is able to meet this requirement due to its high spatial resolution of 90 m, making it unique amongst other spaceborne sensors that provide emissivity products at much coarser spatial resolutions. Validating the ASTER emissivity product with ground truth opens up the opportunity for validating other LST&E products from MODIS (5 km) and AIRS (45 km), by down-sampling the ASTER data over large homogeneous areas.

The nine sand dune validation sites chosen for this study were: Great Sands National Park, Colorado; White Sands National Monument, New Mexico; Kelso Dunes, California; Algodones Dunes, California; Stovepipe Wells Dunes, California; Coral Pink Sand Dunes, Utah; Little Sahara Dunes, Utah; Killpecker Dunes, Wyoming; and Moses Lake Basalt Dunes, Washington.

2. The North American ASTER Land Surface Emissivity Database (NAALSED) v2.0

Using the results from the Temperature Emissivity Separation Algorithm (TES) (Gillespie et al., 1998), a mean seasonal ASTER LST&E database has been produced at 100 m spatial resolution and referred to as the North American ASTER Land Surface Emissivity Database (NAALSED) (Hulley & Hook, 2009b). The database can be ordered from http://emissivity.jpl.nasa.gov and covers the winter months of minimum vegetation cover (Jan–Mar) and summer months of maximum vegetation cover (Jul–Sep). Hulley et al. (2008) provide a detailed description of NAALSED (version 1.0) and initial results for California and Nevada, while Hulley and Hook (2008) describe a new methodology for ASTER cloud screening in NAALSED. In the two seasonal datasets the emissivity is calculated as the average emissivity of all clear-sky pixels for a given location from all scenes acquired in the season over the entire current period of acquisition of ASTER data (2000–2008). Fig. 1 shows the NAALSED summer emissivity product for ASTER band 12 (9.1 µm) covering USA and Mexico and generated by using a total of 50,075 ASTER scenes.

The NAALSED v2.0 product consists of eighteen bands: the mean and standard deviation of the surface emissivity (all five TIR ASTER bands), surface temperature, Normalized Difference Vegetation Index (NDVI), a Land-Water Map (LWM), the total yield, and geodetic latitude and longitude. Currently the database is available from 25 to 49° N, 125 to 66° W, and processing is currently underway for the rest of North America from 49 to 84° N, 169–52° W, including Alaska and Canada.

3. Sand dune field validation

The following sections describe the stability of the sand dune validation sites with regard to spatial uniformity and temporal stability; the methodology for collecting sand samples in the field and measuring the emissivity in the laboratory; and a comparison of NAALSED emissivities with the laboratory results is then discussed. Table 1 provides a summary highlighting the location, formation and basic geology of the nine dune sites used in the study.

3.1. Long-term stability

Pseudo-invariant ground sites such as playas, salt flats and claypans have been increasingly recognized as optimal targets for the long-term validation and calibration of visible, shortwave and thermal infrared data (Bannari et al., 2005; Cosnefroy et al., 1996; de Vries et al., 2007; Teillet et al., 1998). We have found that large sand dune fields are also useful for the validation of TIR emissivity data (Hulley & Hook, 2009a). Sand dunes have consistent and homogeneous mineralogy and physical properties over long time periods, they don't collect water for long periods as playas and pans might, and drying of the surface does not lead to cracks and fissures which could raise the emissivity due to cavity radiation effects (Mushkin & Gillespie, 2005). Furthermore, the mineralogy and composition of sand samples collected in the field can be accurately determined in the laboratory using reflectance and X-ray Diffraction (XRD) measurements.

The long-term temporal stability of the dunes is a critical aspect since NAALSED is a multi-year, mean seasonal emissivity product, and does not reflect inter-annual variations in emissivity other than in the standard deviation for a given pixel provided with the product. In general the dune sites should be spatially uniform and any temporal variability due to changes in soil moisture and vegetation cover should be minimal. Ideally the surface should always be dry, since any water on the surface can increase the emissivity by up to 0.16 (16%) in the 8.2–9.2 µm range depending on the type of soil (Mira et al., 2007).

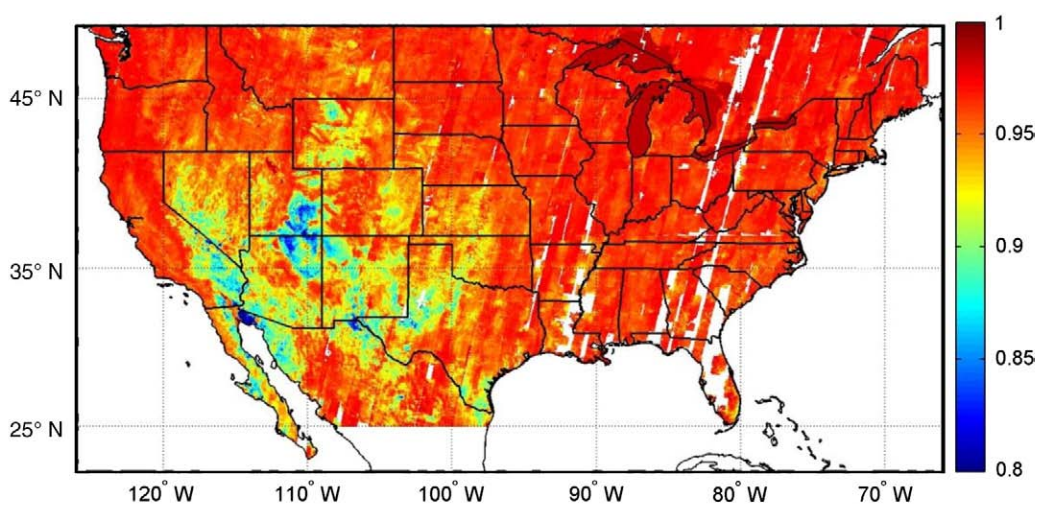

Fig. 1. NAALSED mean Summer (Jul–Sep) emissivity for band 12 (9.1 µm) using 50,075 ASTER scenes acquired from 2000 to 2008. White areas over land had no clear-sky coverage and plan to be filled during the 2009 Summer acquisition period.