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Radiometric normalization and image mosaic generation of ASTER thermal infrared data: An application to extensive sand sheets and dune fields

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Abstract

Data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) have a significant advantage over previous datasets because of the combination of high spatial resolution (15–90 m) and enhanced multispectral capabilities, particularly in the thermal infrared (TIR) atmospheric window (8–12 μm) of the Earth where common silicate minerals are more easily identified. However, the 60 km swath width of ASTER can limit the effectiveness of accurately tracing large-scale features, such as eolian sediment transport pathways, over long distances. The primary goal of this paper is to describe a method for generating a seamless and radiometrically accurate ASTER TIR mosaic of atmospherically corrected radiance and from that, extract surface emissivity for arid lands, specifically, sand seas. The Gran Desierto in northern Sonora, Mexico was used as a test location for the radiometric normalization technique because of past remote sensing studies of the region, its compositional diversity, and its size. A linear approach was taken to transform adjacent image swaths into a direct linear relationship between image acquisition dates. Pseudo-invariant features (PIFs) were selected using a threshold of correlation between radiance values, and change-pixels were excluded from the linear regression used to determine correction factors. The degree of spectral correlation between overlapping pixels is directly related to the amount of surface change over time; therefore, the gain and offsets between scenes were based only on regions of high spectral correlation. The result was a series of radiometrically normalized radiance-at-surface images that were combined with a minimum of image edge seams present. These edges were subsequently blended to create the final mosaic. The advantages of this approach for TIR radiance (as opposed to emissivity) data include the ability to: (1) analyze data acquired on different dates (with potentially very different surface temperatures) as one seamless compositional dataset; (2) perform decorrelation stretches (DCS) on the entire dataset in order to identify and discriminate compositional units; and (3) separate brightness temperature from surface emissivity for quantitative compositional analysis of the surface, reducing seam-line error in the emissivity mosaic. The approach presented here is valid for any ASTER-related study of large geographic regions where numerous images spanning different temporal and atmospheric conditions are encountered.

Keywords: ASTER; Radiometric normalization; Multispectral; Image mosaics; Thermal infrared; Emissivity; Gran Desierto

1. Introduction

1.1. TIR remote sensing of aeolian systems

Desertification, sand encroachment and dust storms are some of the geologic hazards related to increasing climate change and anthropogenic activity found in arid lands associated with aeolian systems (Nicholson et al., 1998; Nickling et al., 1998; Prospero et al., 2002). These systems are quite extensive, and sand is moved long distances via transport pathways as indicated by geochemical studies (Kasper-Zubillaga et al., 2007; Muhs et al., 2003; Zimbelman et al., 1995; Zimbelman & Williams, 2002) and remote sensing (Ramsey et al., 1999). Past studies have used the Landsat Thematic Mapper (TM) data to study small portions of the Namib Sand Sea (White et al., 1997), the Wahiba Sand Sea (Pease et al., 1999), and the Gran Desierto (Blount, 1988; Blount et al., 1990). Paisley et al. (1991) successfully used these data to distinguish between active and inactive sands, and Blount et al. (1990) demonstrated the use of a

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spectral unmixing model to discriminate surface compositions. These studies largely utilize the visible near-infrared (VNIR) and shortwave infrared (SWIR) wavelength regions (0.4–2.5 μm).

The percentage and chemical composition of surface materials is, however, not easily related to the spectral shape in this wavelength region (Blount et al., 1990). Practical limits are imposed on the quantitative interpretations of surface composition and especially abundance because of the non-linear mixing of reflected energy scattering among sand grains (Johnson et al., 1992; Ramsey et al., 1999). Sub-pixel information can be retrieved from the emitted TIR multispectral data by assuming that the fractional areal extent of mineral end-members is linearly proportional to the position and depth of spectral features (Clark et al., 1990; Ramsey & Christensen, 1998; Salisbury & D'Aria, 1992; Thomson & Salisbury, 1993; Vincent & Thomson, 1972). Limiting factors for the linear unmixing of TIR remote sensing data include the noise equivalent delta temperature (NEΔT) of the sensor, the range of temperatures and the spectral contrast of image pixels and end-member spectra. Previous studies clearly identified surface mineralogy and mixing patterns using TIR airborne data (Crowley & Hook, 1996; Edgett et al., 1995; Ramsey et al., 1999) and satellite data on Earth and Mars (Bandfield et al., 2000; Ramsey et al., 1999; Wright and Ramsey, 2006). Likewise, only TIR radiance allows for thermophysical properties such as kinetic temperature and apparent thermal inertia to be derived (Kahl, 1987; Martinez-Alonso et al., 2005; Ramsey, 2002).

1.2. Previous mosaicking methods for ASTER TIR

Satellite remote sensing data provide the synoptic view necessary to study large and commonly inaccessible aeolian systems. Without a mosaicking procedure, the geographical extent imposes practical limits on the choice of the data used. The Terra satellite carries two primary instruments for observing the Earth surface in the TIR: The Moderate Resolution Imaging Spectroradiometer (MODIS) and ASTER. MODIS is advantageous for global coverage utilizing eight bands in the TIR wavelength region at a spatial resolution of 1 km/pixel and a swath width of 2330 km. Spectral unmixing and classification of a mosaic of MODIS data was used for landform mapping in the Sahara (Ballantine et al., 2005), although it did not include multispectral TIR data. Even though sediment transport pathways are discernible over distances of hundreds of kilometers from MODIS data, a significantly higher spatial resolution is needed to quantify the composition and degree of mixing of small contributing areas of sand along paths of transport or the extent of dust source areas less than 1 km^2.

ASTER has a significant advantage in the remote sensing of geologic materials because of its higher spatial resolution than MODIS and enhanced spectral range (Fujisada et al., 1998; Yamaguchi et al., 1998). ASTER has proven useful for mapping key mineral groups, especially for discriminating silicates (Hewson et al., 2001; Rowan & Mars, 2003; Rowan et al., 2005). However, because the ASTER footprint is only 60 km × 60 km, it is necessary to combine multiple scenes into a mosaic for complete coverage of a large study region such as the Gran Desierto or Sahara Desert. Few published studies of ASTER data have been used in a multi-scene capacity. Ogawa et al. (2002) mosaicked the standard atmospherically corrected ASTER surface emissivity data product (Gillespie et al., 1998) for a 750,000-km^2 portion of the Sahara Desert to estimate broadband emissivity at 90 m/pixel spatial resolution. Hewson et al. (2005) described the generation of a seamless mosaic of normalized SWIR band-ratio data, but this emissivity data, generated from TIR radiance, were not normalized because spectra compared well with field observations and the emissivity product was found to mosaic well despite scan line noise and a relatively low signal to noise ratio (SNR). Seamlessness of a mosaic is a most obvious advantageous for display purposes, but the combination of radiometrically non-normalized scenes hinders spectral analysis and geologic interpretation (e.g., such as the delineation of surface composition). The thermal radiance received by the ASTER sensor is affected by the emissivity (composition) and the temperature of the emitting surface. Atmospheric correction and the separation of temperature from the desired surface composition information (emissivity) may not be adequate alone to achieve radiometric normalization. There has been no detailed description or evaluation of the pre-processing issues and mosaicking strategy for TIR radiance data.

The need to combine multispectral remote sensing data using a relative radiometric normalization approximated by linear functions is not a new concept, and a number of techniques have had varied success for Earth (Canty et al., 2004; Du et al., 2001, 2002; Furby & Campbell, 2001; Hall et al., 1991; Moran et al., 1992; Paolini et al., 2006; Schott et al., 1988) and Mars (Martinez-Alonso et al., 2005). For these techniques, it is assumed that an approximately linear relationship can be determined between the at-sensor radiance measurements within the area of the overlapping scenes that contain PIFs, as the models for the atmospheric and viewing-geometry effects on the recorded data are far more complex. Changes in the land surface through time may not have the same linear relation as the whole image scene and are problematic for image mosaicking. Canty et al. (2004) demonstrated a successful example of mosaicking by automatically selecting PIFs between bitemporal images using the multivariate alteration detection (MAD) technique (Nielsen et al., 1998), and they emphasize a number of unique characteristics that are important to their mosaicking technique:

- The selection of PIFs was not manual or subjective except for one decision threshold, based on scale-invariant criteria, and corresponded to physical characteristics of the land surface.
- Their results compared favorable with other manual methods, but their technique was fast and automatic.
- After testing, orthogonal linear regression of PIFs was preferred to ordinary least squares regression (OLS).

2. Location and primary objectives

An ideal location for creating an ASTER TIR mosaic and testing its science applications is a large sand sea of diverse surface composition with few complicating factors (*e.g.*, humid