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Validation of Emissivity Estimates from ASTER Data

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Abstract - The multispectral thermal infrared data obtained from the Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer have been shown to be of good quality. ASTER is on NASA's Terra satellite. It has 5 bands in the 8 to 12 micrometer waveband with 90 m spatial resolution, when the data are combined with the Temperature Emissivity Separation (TES) algorithm the surface emissivity over this wavelength region can be determined. This paper will present some quantitative emissivity results obtained over test sites in southern New Mexico, USA; the Jornada Experimental Range and the White Sands National Monument which are compared with ground measurements. The Jornada site is typical of a desert grassland where the main vegetation components are grass and shrubs with a large fraction of exposed soil. While the White Sands site is mainly dunes of gypsum sand which provides relatively good homogenous emissivity target. More than a dozen ASTER scenes over these New Mexico test sites have been acquired since the launch of Terra in December 1999. There were simultaneous field campaigns in May of 2000, 2001 and 2002 and September/October 2001 and 2002. Also, simultaneous MASTER (MODIS-ASTER airborne simulator) coverage was obtained for several of the dates. In spite of the 90 m resolution, the results appear to be in good quantitative agreement with laboratory measurements of the emissivity for the quartz rich soils of the Jornada with values < 0.85 for the 8 - 9 micrometer channels. For the longest wavelength channels little spatial variation of the emissivity was observed with values of 0.96 ± 0.005 over large areas. Emissivity values derived from several ASTER scenes for the gypsum at White Sands were in good agreement with field measurements and values calculated from the lab spectra for gypsum and with each other. Gypsum has a strong emissivity minimum centered on the ASTER 8.63 micrometer band, and the satellite results for this band agree within 0.01 of the value calculated from the laboratory spectra.

I. INTRODUCTION

The Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) [1] on the Terra satellite provides a new tool for studying the earth's surface. The multichannel thermal infrared (TIR) band makes it possible to extract both surface temperature and spectral emissivity for the data. The Temperature Emissivity Separation (TES) [2] algorithm is used to extract the temperature and 5 emissivities from the 5 channels of ASTER TIR data. TES makes use of an empirical relation between the range of observed emissivities and their minimum value. This approach will be demonstrated with data acquired over test sites in southern New Mexico: the Jornada

Experimental Range and the White Sands National Monument. Knowledge of the surface emissivity is important for determining the radiation balance at the land surface. Wilber et al. [3] have shown that uncertainties in the surface emissivity on the order of 0.1 can produce uncertainties in the longwave radiation balance up to 5 or 6 W/m^2 , which is comparable or greater than the effect of increased CO_2 . For heavily vegetated surfaces there is little problem since the emissivity is relatively uniform and close to one. However, for arid lands with sparse vegetation the problem is difficult because the emissivity of the exposed soils and rocks is highly variable. This is shown in Fig. 1, where laboratory measurements of emissivity for several relevant soils are presented. In particular note the strong variations of emissivity in the 8 to 9 μm region. The results we will present are from ASTER data acquired over the Jornada Experimental Range and the White Sand National Monument in New Mexico for several dates since the December 1999 launch. The Jornada site is typical of a desert grassland where the main vegetation components are grass and shrubs.

The thermally emitted radiance from any surface depends on two factors: 1) the surface temperature, which is an indication of the equilibrium thermodynamic state resulting from the energy

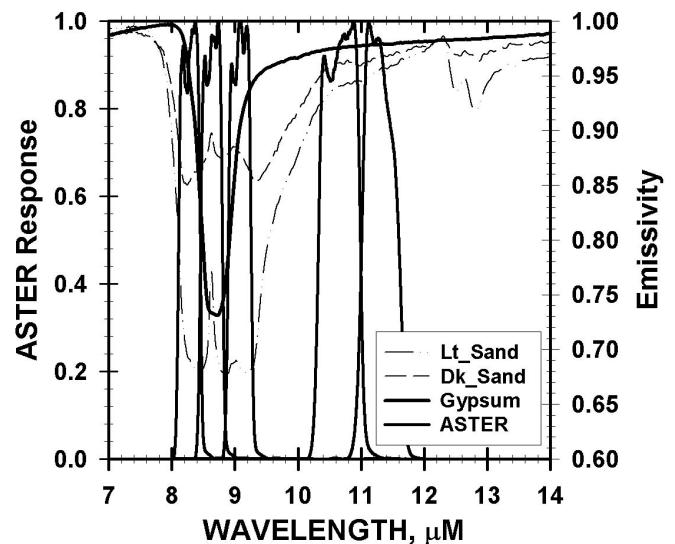


Fig. 1. Plots of spectral emissivity variation for 3 soils from New Mexico and the response functions for the 5 ASTER thermal infrared channels. Note that the emissivity curve for the light sand is the one that goes below 0.70.

balance of the fluxes between the atmosphere, surface and the subsurface soil; and 2) the surface emissivity, which is the efficiency of the surface for transmitting the radiant energy generated in the soil into the atmosphere. The latter depends on the composition, surface roughness, and physical parameters of the surface, e.g. moisture content. In addition, the emissivity generally will vary with wavelength for natural surfaces. Thus to make a quantitative estimate of the surface temperature we need to separate the effects of temperature and emissivity in the observed radiation. The TES algorithm used to extract the temperature and 5 emissivities from the 5 channels of ASTER data relies on an empirical relation between the range of observed emissivities and their minimum value. This approach will be demonstrated with data acquired over the Jornada Experimental Range in New Mexico.

II. JORNADA SITE

The Jornada Experimental Range lies between the Rio Grande flood plain (elevation 1190 m) on the west and the crest of the San Andres mountains (2830 m) on the east. The Jornada is 783 km² in area and is located 37 km north of Las Cruces, New Mexico on the Jornada del Muerto Plain in the northern part of the Chihuahuan Desert. The larger Jornada del Muerto basin is typical of the Basin and Range physiographic province of the American Southwest and the Chihuahuan Desert [4].

Five specific sites in the Jornada were chosen for intensive studies. Sites were selected to represent grass, shrub (mesquite, creosote, and tarbush), and the grass-mesquite transition areas. The grass site is in a fairly level area where black grama dominates and encompasses an enclosure where grazing has been excluded since 1969. Honey mesquite are on coppice dunes which vary in height from 1 to 4 m with honey mesquite bushes on each dune. Bare soil dominates the lower areas between these coppice dunes with most of this area covered by a darker soil with a consolidated crust. The transition site is between the grass and mesquite site and represents the degradation from a good grassland to the shrub dominated mesquite area. The creosote and tarbush sites are also fairly level with the shrubs being smaller and closer together than those at the mesquite site.

A portion of the interdunal area at the mesquite site is covered by a bright quartz-rich sand. Samples of these two soils were taken to the Jet Propulsion Laboratory for measurements of their emissivity spectra. The results are shown in Fig. 1 along with the ASTER spectral response functions and the emissivity spectra for the gypsum sand from the White Sands area. It is clear that there will be a significant variation of the emissivity for the 5 ASTER channels for these soils with the shorter wavelength ones ($8 < \lambda < 9.5\mu\text{m}$) having noticeably lower emissivities.

In contrast to the variability of the Jornada, the White Sands National Monument provides an opportunity to obtain data over a surface of relatively homogenous composition. The White Sands gypsum dunes cover an area of about 20 by 30 km and are northeast of the Jornada range. Both sites are frequently covered in the same ASTER scene so that we have a number of good observations covering the gypsum dunes.

III. ASTER

ASTER [2] has 5 thermal infrared channels between 8 and 12 μm as seen in Fig. 1. The central wavelengths of the channels are: 8.29, 8.63, 9.08, 10.66 and 11.29 μm . These channels have a spatial resolution of 90 m. The surface upwelling radiance, $L_j(\text{surf})$, is derived from the radiance at the satellite by:

$$L_j(\text{surf}) = (L_j(\text{sat}) - L_j(\text{atm}\uparrow)) / \tau_j \quad (1)$$

where the values of τ_j and $L_j(\text{atm}\uparrow)$ can be calculated using an atmospheric radiative transfer model, e.g. MODTRAN-4, with atmospheric profile data from National Center for Environmental Prediction (NCEP) reanalysis product. The profile was adjusted for the surface temperature and humidity conditions. The remaining problem is to derive from these radiances the surface emissivity in the 5 ASTER channels without direct knowledge of the temperature, T_{grd} , using the relation:

$$L_j(\text{surf}) = \epsilon_j \text{BB}_j(T_{\text{grd}}) + (1 - \epsilon_j) \cdot L_j(\text{atm}\downarrow) \quad (2)$$

where $\text{BB}(T)$ is the Planck equation for the radiation from a black body. These radiance are used in the TES algorithm to extract the surface temperature and the 5 emissivities. TES has been successfully demonstrated with data from multispectral thermal infrared data from aircraft platforms for this site [5].

IV. RESULTS AND CONCLUSIONS

Since White Sands area provides the highest probability of observing a uniform surface, the radiances for a 2 by 2 pixel area (~ 180 by 180 m) were analyzed for several dates. The emissivity results are presented in Fig. 2 as the filled symbols, the lab results are the filled circles. The latter were obtained for each ASTER channel by integrating the product of the ASTER response and gypsum emissivity curve shown in Fig. 1. The ASTER results show excellent agreement with the laboratory results and with each other for the center 3 bands. The agreement is particularly clear for the low emissivity 8.6 μm channel. Bands 10 (8.29 μm) and 14 (11.29 μm) show the biggest differences. Band 10 is the one with the strongest atmospheric effects and the differences may indicate inadequate atmospheric correction. The cause for the band 14 differences is uncertain at the present time.

The open symbols are the results from a CIMEL CE312 [6] radiometer which has approximately the same 5 spectral bands as ASTER. The shortest wavelength band of the CIMEL is broader than that of the ASTER band and as a result shows a much lower emissivity than those observed by ASTER band 10. For the other channels the agreement is very good. CIMEL results for the bare soil at the other sites were also in good agreement with lab measurements. This agreement is an indication validity of TES for surfaces with large emissivity contrasts. The agreement of the ASTER results with both the CIMEL and lab measurements for the gypsum sands is a demonstration that these data can be

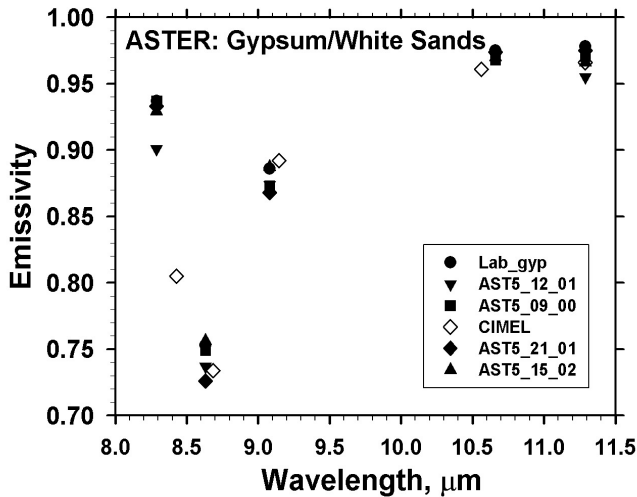


Figure 2. ASTER emissivity results for a gypsum site at the White Sands National Monument in New Mexico. The open symbols are for the ground measurements with the CIMEL radiometer and filled symbols are the ASTER results for four days.

used to estimate the surface emissivity over large areas. Additional results from the other sites also show good agreement with ground measurements and will be presented at the symposium.

These results indicate that the TES algorithm appears to work as well with the data from space as it did with the aircraft data presented earlier [5]. This is encouraging for the application of the technique for mapping emissivity over large areas. Examples of this are presented in the papers by Ogawa et al. [7], [8] where the window emissivity is mapped for a large (100 x 1200 km) desert area in North Africa.

We have also performed an ASTER/MODIS comparison for the Jornada site for the May 12, 2001 observation. This yielded an RMS temperature difference of 0.65 K, which is a further indication of the quality of the ASTER data [9].

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