ASTER Thermal Infrared Observations over New Mexico

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Abstract - **Excellent scenes from the Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) on the Terra satellite were obtained over the Jornada Experimental Range test site along the Rio Grande and the White Sands National Monument in New Mexico. They were acquired on May 9, 2000, February 12, May 12, July 15 & 22, September 17, October 19 and November 11, 2001.There were simultaneous field campaigns for the 5/09/00, 5/12/01 and 9/17/01 scenes. Also, MASTER coverage was obtained for the 5/12/01 scene. The White Sands National Monument was also within several of the scenes. Emissivity values from the ASTER data from the 5/09/00 and 5/12/01 scenes for the gypsum sand at White Sands were in good agreement with values calculated from the lab spectra for gypsum and with each other, except for band 10. At both the mesquite and the grass sites the agreement amongst the ASTER results is excellent and in reasonable agreement with those calculated from the lab spectra and those observed with a field radiometer. These results indicate that ASTER and TES are working very well. The surface brightness temperatures from ASTER were in reasonable agreement with measurements made on the ground during the field campaigns mentioned above.**

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 from 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 the Jornada Experimental Range in New Mexico. Knowledge of the surface emissivity is important for determining the radiation balance at the land surface. 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 data we will present are early ASTER data acquired over the Jornada Experimental Range and the White Sands National Monument in New Mexico on 5/09/00, 5/12/01 and 9/17/01. The Jornada site is typical of a desert grassland where the main vegetation components are grasses and shrubs.

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 km^2 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.

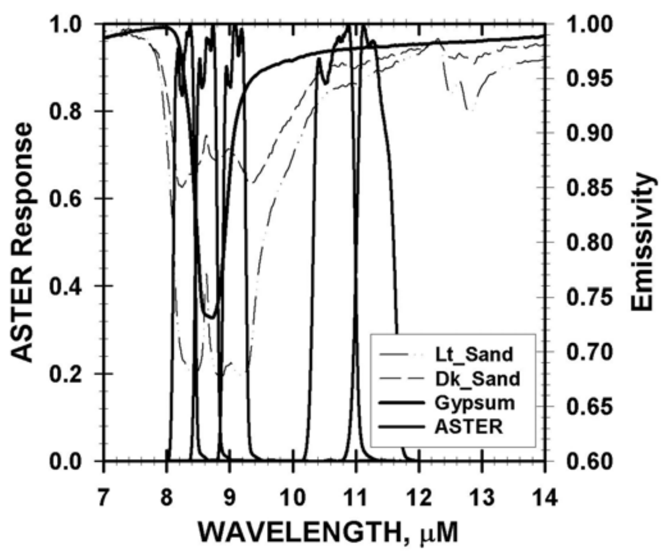

Fig. 1. Plots of spectral emissivity variation for 3 soils from New Mexico and the response functions for the 5 ASTER thermal infrared channels. Note that the emissivity curve for the light sand is the one that goes below 0.70.

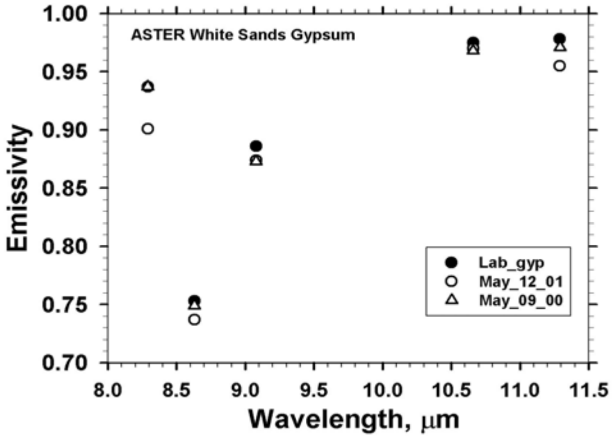

Fig. 2. ASTER emissivity results for a gypsum at the White Sands National Monument. The open symbols are the ASTER results and the closed are the lab results.

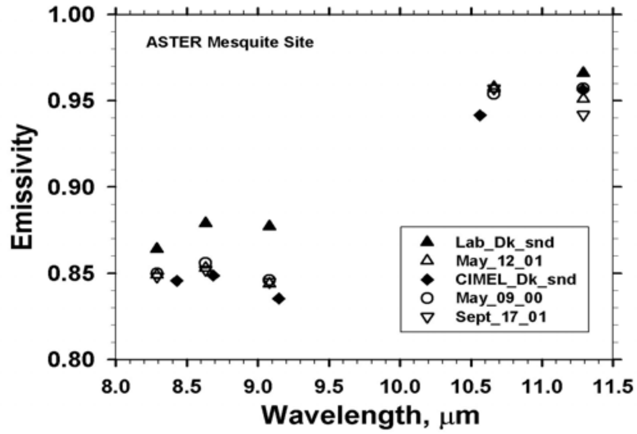

Fig. 3. ASTER emissivity results from the mesquite site for 3 dates. Again the open symbols are the ASTER results.

Two specific sites in the Jornada were chosen for analysis: grass and shrub (mesquite). The grass site is in a fairly level area where black grama grass dominates and encompasses an exclosure where grazing has been excluded since 1969. Honey mesquite on coppice dunes dominates the shrub site. The dunes 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. However a portion of the interdunal area 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 variation of the emissivity for the 5 ASTER channels for these soils with the longer wavelength ones ($8 < \lambda < 9.5\mu m$) having noticeably lower emissivities.

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 radiance at the satellite is given by

$$L_j(surf) = (L_j(a/c) - L_j(atm\uparrow)) / \tau_j \qquad (1)$$

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

$$L_j(surf) = \epsilon_j\, BB_j(T_{grd}) + (1 - \epsilon_j)\cdot L_j(atm\downarrow) \qquad (2)$$

where 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. The approach has been successfully demonstrated with data from multispectral thermal infrared data from aircraft platforms for this site [3].

RESULTS AND CONCLUSIONS

The radiances for a 2 by 2 pixel area (~180 by 180 m) from White Sands were analyzed for the May dates and the emissivity results are presented in Fig. 2 as the open symbols, the lab results are the filled circles. The ASTER results show excellent agreement with the laboratory results and with each other for the center 3 bands. 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 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. These are the bands with the strongest atmospheric effects and may indicate inadequate correction.

The results from the mesquite site for all 3 dates are given in Fig. 3 and show excellent agreement amongst the ASTER results for all 5 channels. In this case there is a small difference between the lab results and the ASTER results, e.g. < 0.03 for the 5 channels. At this site we made field measurements with a CIMEL 312 [4] radiometer which has approximately the same 5 spectral bands as ASTER. The CIMEL results also disagree with the lab calculations and we suspect that this may be due to the fact the lab measurements were made on a powdered sample of the soil while the field measurements were done on the consolidated surface. The other surprising thing is that the

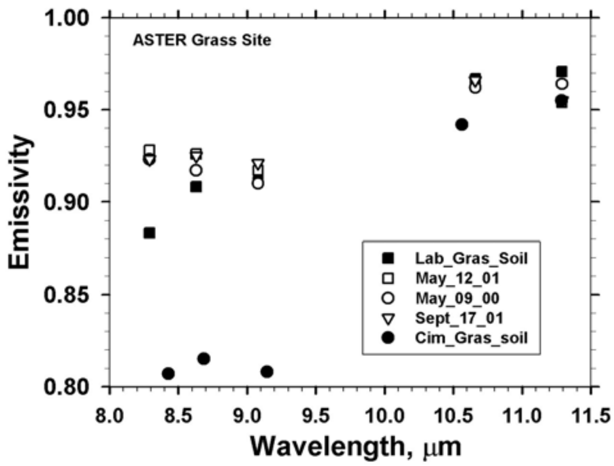

Fig. 4. ASTER emissivity results from the grass site for 3 dates. The open symbols are the ASTER data.

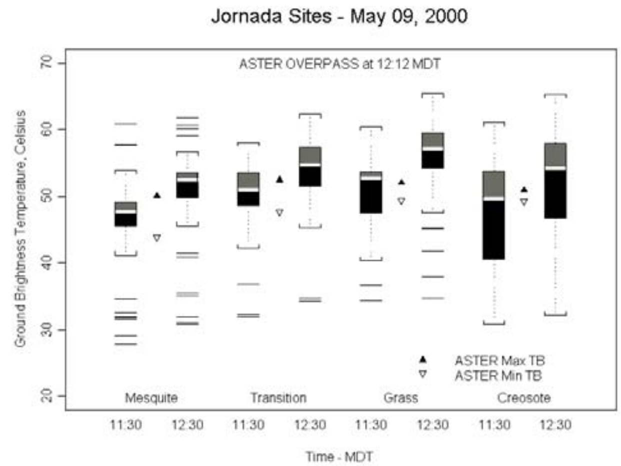

Fig. 5 Boxplots of ground measurements, the white bars are the medians and the boxes contain 50% of the points.

effects of the light sand with its low emissivity at 8 - 9 µm (see Figure 1) and the vegetation of the mesquite bushes are not apparent, perhaps because their effects are offsetting.

In Fig. 4 the results from the grass site for the 3 dates are presented as the open symbols. Again the agreement amongst the ASTER results is excellent. The results from the CIMEL measurements are shown as the solid circles and are much lower than the ASTER results. This is probably the result of the fact that much of the soil is covered by grass or senescent vegetation. whose flatter spectral response reduces the spectral variation observed at this site. The results calculated from the lab spectra show surprising agreement with the ASTER results and large disagreement with the CIMEL values. This difference is not understood at the present time.

Ground measurements of surface brightness temperature, T_B, were made on a 7 x 7 grid with 5 meter spacing using a broadband, 7 to 14 µm, radiometer at several sites. An example of the results is given in Fig. 5 for the May 9, 2000 ASTER overpass. The ground data are presented in boxplots at the times bracketing the overpass, i.e. 11:30 and 12:30 MDT, for the four sites. The range of T_B for the 5 ASTER channels is presented by the up and down triangles. It is expected that the broadband emissivity would be within the range of those for the 5 ASTER channels, and thus the average ground T_B should be within the ASTER T_B range as seen in Fig. 5.

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 [4]. This is encouraging for the application of the technique for mapping emissivity over large areas. There was also good agreement between the ASTER brightness temperatures and ground measurements

Acknowledgment

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References

[1] Y. Yamaguchi, A. B. Kahle, H. Tsu, T. Kawakami, and M. Pniel, "Overview of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)," *IEEE Transactions on Geoscience and Remote Sensing*, vol. **36**, pp. 1062-1071, 1998.

[2] A. Gillespie, S. Rokugawa, T. Matsunaga, J. S. Cothern, S. Hook, and A. B. Kahle, "A temperature and emissivity separation algorithm for Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images," *IEEE Transactions on Geoscience and Remote Sensing*, vol. **36**, pp. 1113-1126, 1998.

[3] T. Schmugge, A. French, J.C. Ritchie, A. Rango, and H.Pelgrum, "Temperature and emissivity separation from multispectral thermal infrared observations.," *Remote Sensing of Environment,* vol. 79, pp. 189 - 198, 2002.

[4] M. Legrand, C. Pietras, G. Brogniez, M. Haeffelin, N.K. Abuhassan and M. Sicard, "A High-accuracy multiwavelength radiometer for in situ measurements in the thermal infrared. Part 1: Characterization of the instrument," *Journal of Atmospheric & Oceanic Technology*, vol. **71**, pp. 1203-1214, 2000.