Comparison of ASTER, MASTER, and ground-based hyperspectral reflectance measurements

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Abstract This study compares reflectance measured in the visible, near infrared, and short wave infrared wavelengths by the Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER), MODIS/ASTER Airborne Simulator (MASTER), and ground-based Analytical Spectral Devices Spectroradiometer (ASD) in a semi-arid area of the northern Chihuahuan desert in southern New Mexico, USA. This study provided a unique opportunity to compare remote sensing data collected for semi-arid rangelands from different platforms, at different scales, over different plant communities, and for different dates. ASD visible, near infrared, and shortwave infrared reflectance data (0.35 to 2.5 μm) for 12 May 2001, 6 October 2002, and 2 May 2003 were analysed and integrated to match the first 21 MASTER and first 9 ASTER bandwidths for three different vegetation communities (grass, shrub, and shrub-grass transition) and compared to MASTER and ASTER reflectance data collected for the same dates. A strong positive correlation between the measurements indicated that the three sensors were measuring similar reflectance values for the three dates and vegetation communities. Reflectance was highest from the shrub and shrub-grass transition communities and lowest from the grass community and was related to the amount of vegetation cover present. This has implications for the energy and water budgets in this region of the Chihuahuan desert where shrub communities with low ground cover are invading and replacing grass communities.

Key words ASTER; MASTER; reflectance; semi-arid grasslands; SWIR; VNIR

INTRODUCTION

Understanding land surface reflectance in the visible and near infrared (VNIR) and shortwave infrared (SWIR) wavelengths is fundamental for understanding land surface processes and properties affecting vegetation change and heat and waters balances across the landscape using remote sensing techniques. Data from Landsat, SPOT, and other satellites have been used to provide reflectance data for studying landscape processes and properties. With the launch of NASA's Earth Observation Satellite (EOS) TERRA Platform in December 1999, reflectance data in the VNIR and SWIR wavelengths became available from the Advance Spaceborne Thermal Emission Reflectance Radiometer (ASTER) instrument, providing a new source of information about the landscape surface.

The objective of this study was to compare VNIR and SWIR reflectance data collected by the ASTER instrument, the MASTER (MODIS/ASTER Airborne

Simulator) instrument on an airplane, and an ASD (Analytical Spectral Device spectroradiometer) instrument at ground level.

STUDY AREA

The United States Department of Agriculture (USDA) Agricultural Research Service (ARS) Jornada Experimental Range (Jornada) lies 37 km north of Las Cruces, New Mexico, USA on the Jornada del Muerto Plain in the northern part of the Chihuahuan Desert (Fig. 1). It is located between the Rio Grande flood plain (elevation 1186 m) on the west and the crest of the San Andres mountains (2833 m) on the east. The Jornada is typical of the Chihuahuan Desert and the Basin and Range physiographic province of the American Southwest (Havstad *et al*., 2006). The average monthly maximum temperature ranges from 13°C in January to 36°C in June. Precipitation, which averages 241 mm year^{-1}, mainly occurs as thunderstorms during July, August, and September. The study sites are located on Typic Haplargid and Paleargid soils. These soils are loamy to fine loamy, moderately deep with calcic horizons of varying thicknesses below the surface. Surface colours are typically light brown and reddish brown (Gile *et al*., 1981).

The Jornada is the largest and most arid North American desert grassland. The principal grasses include black grama (*Bouteloua eriopoda* (Torr.) Torr.), mesa

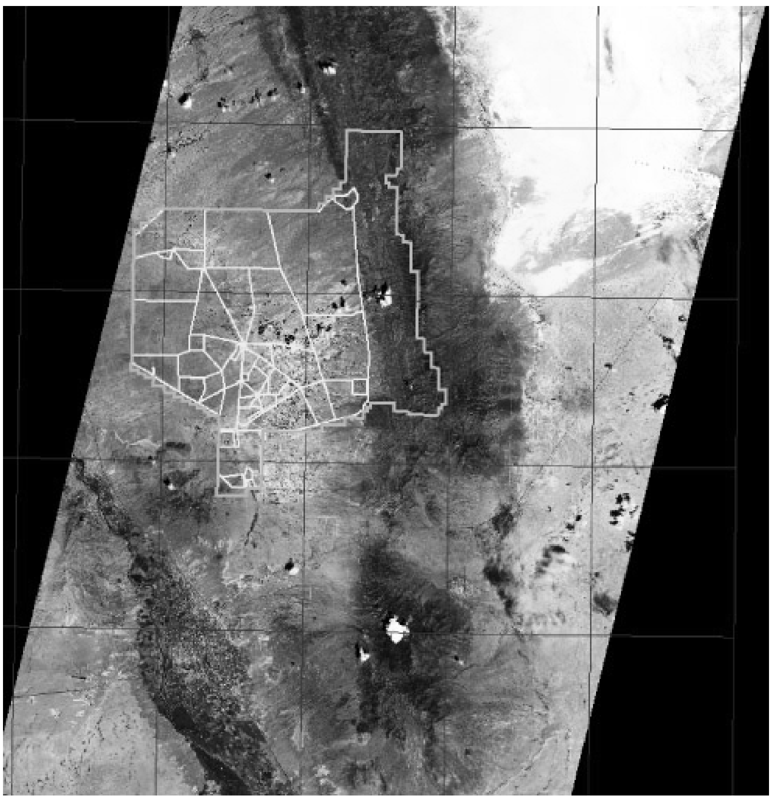

Fig. 1 VNIR ASTER image of the Jornada Experimental Range (outlined) and surrounding area collected on 12 May 2001. White Sands, NM is located in the upper right corner.

dropseed (*Sporobolus flexuosus* (Thurb. Ex Vasey) Rydb.), and three awn (*Aristida purpurea* Nutt. and *Aristida pansa* Wooton & Standl.). Shrubs and suffrutescents include honey mesquite (*Prosopis glandulosa* Torr.), creosote (*Larrea tridentata* (DC.) Coville), tarbush (*Flourensia cernua* DC), fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.), broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britton & Rusby), and soaptree yucca (*Yucca elata* Engelm.). Seasonal rains trigger flushes of both annual and perennial forbs. More than 490 plant species have been identified on the Jornada (Havstad *et al*., 2000).

Grass communities, which once dominated the landscape, have been susceptible to replacement by shrubs during the last century. Vegetation surveys made in 1858, 1915, 1928, 1963, and 1998 show that total area dominated by grasses has decreased from 90% in 1858 to approximately 1% in 1998 (Gibbens *et al*., 2005). Conversion from grass dominated to shrub-dominated vegetation on these loamy soils has resulted in the formation of coppice dunes with honey mesquite shrubs growing on top of them (Buffington & Herbel, 1965; Gile, 1966). These changes have significant effects on ground cover and the surface albedo from these desert ecosystems with resulting potential effects on global climates (Schlesinger *et al*., 1990).

Three sites at the Jornada were chosen for these studies. The sites were selected to represent grass, grass-shrub ecotone (transition), and shrub (mesquite) communities. The grass site is dominated by black grama grass and is typical of the grass ecosystems that once dominated the area. The transition site has vegetation components of both the grass and shrub communities. Coppice dunes are developing at the transition site but are usually less than 0.5 m in height. Honey mesquite on top of 1–3 m tall coppice dunes dominates the shrub site (Giles, 1966). Bare soil with almost no vegetation dominates the areas between these coppice dunes at the shrub site. These sites will be referred to as grass, transition, and shrub (mesquite) in this paper.

METHODS AND MATERIALS

Reflectance data used in this study were collected on 12 May 2001, 6 October 2002, and 2 May 2003 from ground (ASD), aircraft (MASTER), and satellite (ASTER) platforms from the three vegetation communities. ASD measurements were made on a 30 × 30 m grid at each of the sites.

In order to extract reflectance values at the three vegetation sites from MASTER and ASTER data, these airborne and spaceborne data were geo-referenced. For ASTER data, ground control points were selected based on USGS 1:24 000 topographic maps. ASTER data were rectified to UTM projection with WGS84 datum by a first order polynomial. It is more difficult to geo-reference airborne (MASTER) data since aircraft platforms are less stable than satellite. The MASTER data around the three study sites were subset from the entire MASTER flight line. These subsets were then rectified to a geo-referenced 1-m resolution image collected by the IKONOS commercial Earth observation satellite. Data for the MASTER and ASTER instruments were extracted from the geo-referenced data based on the GPS coordinates of the 30 × 30 m grids used for the ASD measurements.

ASD (Analytical Spectral Devices) Spectroradiometer

Landscape surface radiance measurements were made using an Analytical Spectral Devices (ASD) (trade names are included for the benefit of the reader and do not imply an endorsement of or a preference for the product listed by the US Department of Agriculture) full range (0.35–2.5 µm) spectroradiometer at 5-m intervals on 30 × 30 m grids (49 measurements) at the grass, transition, and shrub sites. A standard Spectralon® Reference Panel was measured before and after the 49 measurements at each grid. Measurements were made at 1-m above the ground surface and were recorded as an average of 10 measurements at each grid point. Measurements at a grid site (49 measurement) took less than 5 minutes and were made within 2 hours of the solar noon (and also MASTER and ASTER overpasses). The field-of-view (fov) for the bare fibre ASD was 28°, providing a land surface footprint of approximately 0.5 m. The ASD provided estimates of radiance at 0.001-µm (1 nanometer) intervals across its full range. Reflectance for each 0.001-µm wavelength was calculated as the ratio of measurements of the land surface divided by the average of the two measurements of the Spectralon® Reference Panel. For comparison with the ASTER and MASTER data, the ASD reflectance measurements for the 49 grid points from each 30 × 30 m grid were averaged to provide a single average reflectance value for the 30 × 30 m grid. These average reflectance values were then integrated to provide bandwidth reflectance values comparable to the first 21 MASTER and first nine ASTER VNIR and SWIR bandwidths using spectral response functions of the MASTER and ASTER instruments' bandwidths.

MASTER (MODIS/ASTER Airborne Simulator)

The MASTER instrument was developed to provide airborne support for studies with the ASTER and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments. The MASTER spectroradiometer collects data in the visible and near infrared (VNIR), shortwave infrared (SWIR), and thermal infrared (TIR) wavelengths (Hook *et al*., 2001). In this study only the first 21 VNIR and SWIR wavebands (0.4574–2.3939 µm) were used. The MASTER instrument was flown on the US Department of Energy (DOE), King Air Beechcraft B200 at 1000 and 4000 m above ground level over the three study sites at the Jornada giving a pixel size of approximately 6 and 16 m, respectively. The MASTER data for the three dates were atmospherically corrected using MODTRAN (Beck *et al*., 1998) and georeferenced using a georeferenced IKONOS image.

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)

The ASTER instrument has three channels in the visible near infrared (VNIR) with 15 m pixel resolution, six channels in the shortwave infrared (SWIR) with 30 m pixel resolution, and five channels in thermal infrared (TIR) with 90 m pixel resolution (Jacob *et al*., 2004). In this study only the nine VNIR and SWIR bandwidths were used. The ASTER On-Demand L2 Surface Reflectance VNIR and SWIR data products were used for this study.

RESULTS AND DISCUSSION

After the ASD data were integrated to provide similar bandwidth data to the 21 MASTER and the nine ASTER VNIR and SWIR bandwidths, a comparison of reflectance data from the three instruments showed a strong significant linear relationship (Table 1; Fig. 2) between the data for the three instruments. The intercepts were all within one standard deviation of zero. Slopes were slightly greater than 1.0 but were not significantly different from each other.

These analyses indicate that the three instruments were measuring similar absolute values of reflectance of the landscape surface. While there were differences due to date of collection and vegetation cover, all the data were explained by the same linear relationship. Considering that the measurements were from three different instruments, three different vegetation covers, three different dates, and three different pixel sizes, the strong linear relationship was a good indication that the three instruments were measuring similar land surface properties.

Table 1 Coefficients for the linear relationship between ASD, MASTER, and ASTER reflectance data.

Relationship	Intercept	Slope	R^2
ASD *vs* MASTER	–0.03	1.28	88.8
ASD *vs* ASTER	0.03	1.10	91.9
ASTER *vs* MASTER	–0.02	1.06	84.7

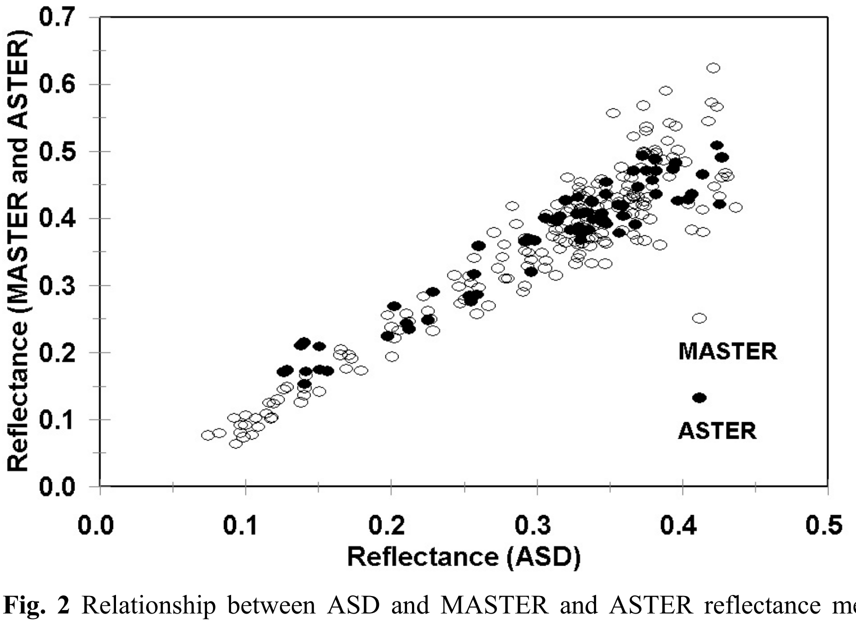

Fig. 2 Relationship between ASD and MASTER and ASTER reflectance measurements.

Differences in reflectance were related to cover type and wavelength (Fig. 3). Since the reflectance measurements from ASTER, MASTER, and the ASD instruments were highly correlated they all showed patterns similar to that for the ASD measurements shown in Fig. 3. In general reflectance was highest from the shrub (mesquite) community and lowest from the grass community with the transition site intermediate between the grass and shrub communities. These differences are probably related to amount of ground cover at each site. The grass site usually had the highest leaf area index (LAI) as measured by the LAI-2000 and the shrub site had the lowest LAI indicating a greater bare soil surface visible to reflect the solar radiation at the shrub site. There was an exception to this pattern on 6 October 2002 when the transition site had the highest reflectance. It also had the lowest LAI and thus the greater reflectance. In general reflectance was highest when LAI was lowest and lowest when LAI highest. This pattern is consistent with highest reflectance when bare soil was exposed for the sensor to measure.

Differences in reflectance from the different vegetation covers also varied with wavelength (Fig. 3). In the visible wavelengths little absolute or significant differences in reflectance were noted. In the near infrared wavelengths the absolute differences between vegetation communities were significant with the pattern of reflectance in shrub communities greater than transition, which was greater than grass regardless of instrument. In the SWIR wavelengths differences in reflectance were measured but they varied with wavelength and vegetation. No consistent pattern was found in the SWIR wavelengths between vegetation communities. There were differences in reflectance with the different dates (Figs 4 and 5). In general these differences were related to the LAI measured. At the grass site (Fig. 5) and also the shrub site (not shown), the patterns of reflectance were similar for the three dates. At the transition site (Fig. 4) the 6 October 2002 date had the highest reflectance related the very low cover (LAI) measured on that date.

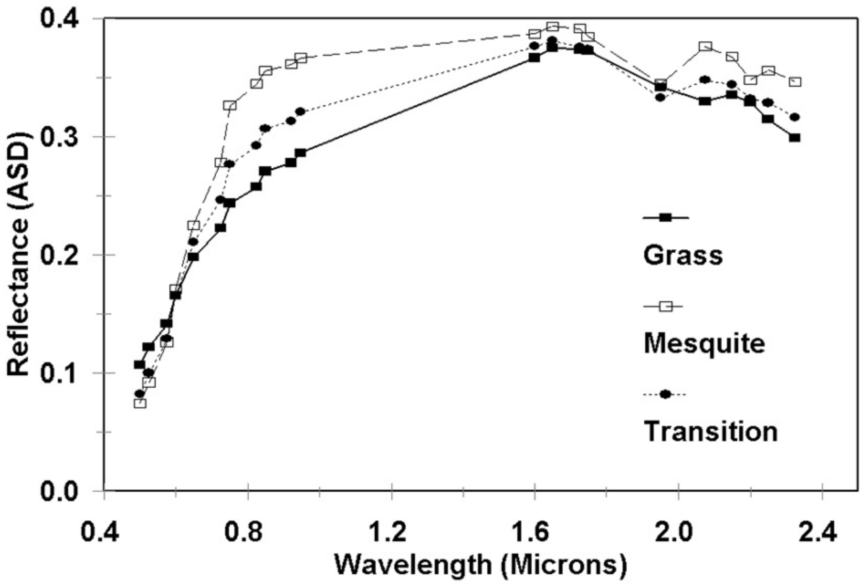

Fig. 3 ASD reflectance measured from the three different vegetation types (12 May 2001).

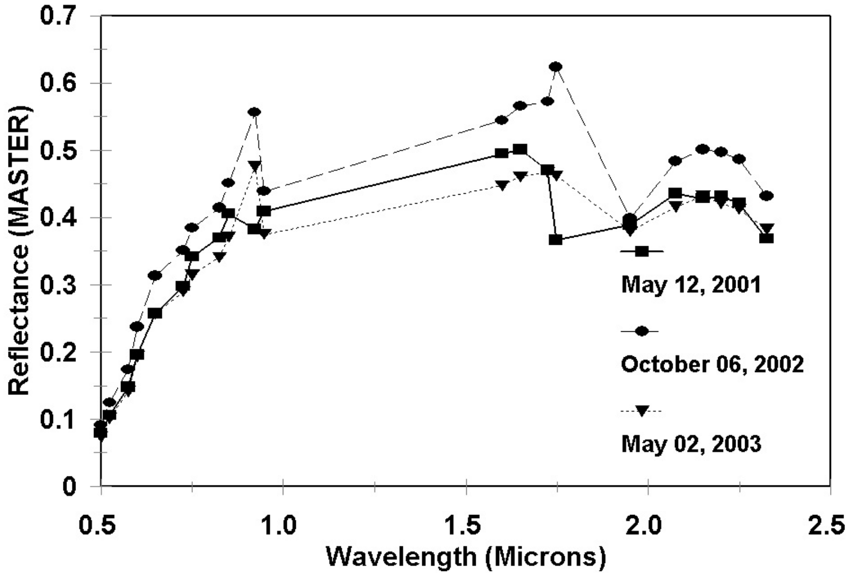

Fig. 4 Reflectance at the transition site measured on the different dates by the MASTER instrument.

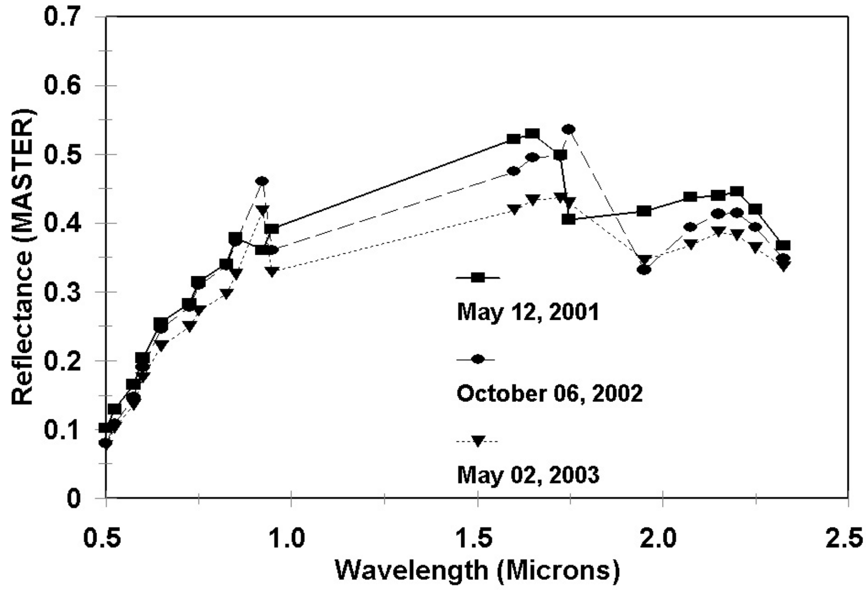

Fig. 5 Reflectance at the grass site measured on the different dates by the MASTER instrument.

CONCLUSIONS

A comparison of reflectance measured in the visible, near infrared, and shortwave infrared wavelengths by the ASTER instrument, MASTER instrument, and ground-based ASD instrument for three different vegetation communities (grass, transition, and shrub) and three different dates (May 2001, October 2002, and May 2003) in a semi-arid rangeland of southern New Mexico found a strong positive relationship between the reflectance measurements of three sensors. This indicates that the three sensors were measuring similar reflectance values for three different dates and three different vegetation communities. Reflectance was highest from the communities with low LAI (shrub and shrub-grass transition) communities and lowest from the grass communities with the higher LAI indicating a strong relationship with the amount of ground (vegetation) cover present. This has implications for the energy and water budgets in this region of the Chihuahuan desert where shrub communities with lower ground cover are invading and replacing grass communities.

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