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Temporal, spatial, and spectral variability at the Ivanpah Playa vicarious calibration site

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ABSTRACT

The Savannah River Technology Center (SRTC) conducted four reflectance vicarious calibrations at Ivanpah Playa, California since July 2000 in support of the MTI satellite. The multi-year study shows temporal, spatial and spectral variability at the playa. The temporal variability in the wavelength dependent reflectance and emissivity across the playa suggests a dependency witt precipitation during the winter and early spring seasons. Satellite imagery acquired on September and November 2000, May 2001 and March 2002 in conjunction with ground truth during the September, May and March campaigns and water precipitation records were used to demonstrate the correlation observed at the playa.

Key Words: MTI satellite, calibration, Ivanpah Playa

1. INTRODUCTION

The Multispectral Thermal Imager (MTI) is a research and development satellite sponsored by the Department of Energy (DOE) for accurate water surface temperature retrieval. The MTI mission[1] is to demonstrate the efficacy of highly accurate multispectral and thermal imaging for passive characterization of industrial facilities and related environmental impacts from space. The goal is to compare the information sensed by the satellite with information available directly at the cooperative sites.

The MTI satellite has 16 spectral bands in the visible (VIS), near (NIR), short-wave (SWIR), mid-wave (MWIR) and the long-wave (LWIR) infrared spectral regions. The spatial resolution of the spectral bands is divided into two subsets. Spectral bands A-D are 5-meter spatial resolution. Bands E through O are 20-meter spatial resolution bands. Top of the atmosphere (TOA) radiances from five thermal spectral bands in the MWIR and LWIR spectral regions (bands J [3.50-4.10μm], K [4.87-5.07μm], L [8.00-8.40μm], M [8.40-8.85μm], N [10.2-10.7μm]) are used to retrieve water surface temperatures. The validation and verification of ground truth targets for the temperature algorithms described by Garrett et al.[2] are primarily heated/unheated lakes. Power plant heated lakes provide a field laboratory to study an extensive range of water temperatures.

The thermal bands are vicariously calibrated with water targets instrumented with a variety of sensors during the satellite overpass. Vicarious calibration of the satellite in the visible and near-infrared spectral regions is conducted at playa sites (dry lakebed) with high reflectivity and uniformity of the terrain at a high elevation. Ivanpah Playa, California was selected as a site for the vicarious calibration of the MTI satellite. Although the prime importance for the playas in the satellite calibration is the visible and near-infrared spectral regions, knowledge of the spectral emissivity in the 4 - 12μm provides an opportunity for soil temperature retrieval and therefore the opportunity to test the MTI algorithms to extract soil surface temperature.

A baseline of the spectral properties of Ivanpah Playa is required in order to make a meaningful assessment of the site for vicarious thermal calibrations. Reflectance and spectral emissivity were measured at the playa during four calibration campaigns at the playa (July and September 2000, May 2001, and March 2002). MTI images were only available for the September, May and March campaigns. Additional images without ground truth were also investigated

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during the course of this study. The only available image during a winter season with a clear sky between March 2000 and September 2002 was in November 2000. Water precipitation records were acquired from Las Vegas and Kingsman meteorological stations. The May ground truth campaigns showed a distinct spectral emissivity not seen in the other ground truth campaigns. The remotely sensed imagery in conjunction with water precipitation records and the ground truth data from the campaigns was used to suggest an explanation for the missing quartz feature from the May spectral emissivity.

2. EXPERIMENTAL

A 280m x 80m calibration site with high reflectance properties was selected at Ivanpah Playa prior to the calibration campaign. The primary instrument for the surface-reflectance collection is the Analytical Spectral Devices FieldSpec FR that gives a 1.4-nm spectral resolution from 350 to 1000nm and 10-nm resolution for the 1000nm to 2500nm spectral range. Most reflectance work during the vicarious calibration campaign was conducted with at least two FieldSpec FR instruments. The instruments were warmed-up at least 1hour prior to data acquisition. The Surface reflectance measurements were conducted at the time of the sensor overpass. The surface reflectance from the calibration site at the playa was found by comparing radiometer measurements from the site surface to those from a diffusely reflecting panel of known calibrated reflectance.

The upwelling radiance across the spectral range between 350 and 2500nm was measured with the ASD spectroradiometer transported across the calibration site. A 25 degree field of view lens was attached to the fiber optic of the spectrometer. The fiber optic was held approximately 1 meter above the ground surface. The spectroradiometer collects a number of samples along a straight-line path within some fraction of the area representing an MTI pixel. Reflectance of the site was determined in each spectral channel by comparing measurements of the site to those of the calibrated panel and averaging all of the measurements.

Figure 1 shows preparations made with the mobile Fourier transform infrared spectrometer prior to data collection.

A Fourier transform infrared spectrometer (FTIR), manufactured by Midac Corporation (M2400 series, the illuminator), was used to measure wavelength dependent radiance of Ivanpah Playa soil surface. The spectrometer has a 3.8cm aperture diameter with a 40 milliradians field of view (FOV). The spectrometer was equipped with mercury cadmium telluride (MCT) detector cooled with liquid nitrogen to 77K. The housing of the FTIR spectrometer was maintained at 50C with the aid of an insulated jacket with heating blankets. Heating blankets were placed above and below the FTIR spectrometer. The heating blankets attached to the FTIR spectrometer were insulated from the ambient air with Styrofoam sheets and an aluminum shield. A thermocouple was attached to the FTIR spectrometer housing for temperature monitoring and control. The temperature controller maintained the FTIR spectrometer temperature within 0.2C of the selected temperature. A fan was placed inside of the spectrometer to circulate the air and to improve temperature equilibration. The instrument was warmed-up for 1½ hours prior to data acquisition.

The FTIR spectrometer was attached to a jack with bolts through a rubber-insulating mat for mechanical vibration reduction control. The jack with the FTIR spectrometer was attached to a garden cart as shown in figure 1. Besides the FTIR spectrometer, Figure 1 also shows the blackbodies, battery, power inverter and computer assembled in the cart. The cart grill dimensions are 0.61m x 1.22m. The cart grill is 0.30m from the ground (0.25m diameter inflated tires). The air-inflated cart tires were responsible for the reduction of vibrations during the calibration site walk-around. The FTIR spectrometer window entrance was 0.77m from the soil surface. A platform with a steering beam mirror made out of stainless steel rods was attached to the FTIR spectrometer front surface. The gold-coated mirror placed at 45 degrees for nadir measurements steered the soil radiance into the spectrometer.

Calibration of the FTIR spectrometer was accomplished through the use of two blackbodies held at two temperatures. The temperature of the hot blackbody was set at 58C with the aid of a temperature controller. The air temperature (30-40C during the course of the experiment) primarily determined the temperature of the cold blackbody. Two hundred fifty six spectra were co-added during the blackbody and sky background measurements. The sky background was measured with a diffuse infragold-coated plate manufactured by Labsphere. The temperature of the infragold-coated plate and the blackbodies were monitored with thermistor probe manufactured by Omega with 0.02C accuracy. The soil target radiance was measured by collecting spectra every 2 seconds in our calibration area. Approximately 20 minutes worth of data was acquired during the 15 passes at the calibration site measuring 80 x 280 m^2. Figure 3 shows the GPS track during the walk around through the calibration site area. The recorded data was acquired in the following manner: 1) measure radiance of cold blackbody, 2) measure radiance of hot blackbody, 3) measure radiance of gold-coated infragold plate 4) measure soil radiance and 5) measure hot and cold blackbody radiances.

3. Discussion

The Savannah River Technology Center conducted multi-year vicarious calibration campaigns at Ivanpah Playa in support of the multispectral thermal imager satellite (MTI). Reflectance and emissivity data were measured during the July and September 2000, May 2001, and March 2002 campaigns. The multi-year vicarious calibration campaigns were conducted at three locations in the playa. Figure 2 shows an overlay of the calibration sites at Ivanpah Playa in the September MTI image. The July and September 2000 campaigns were conducted at the same location (center location) and were a joint effort between the Remote Sensing Group (RSG) of the University of Arizona and SRTC. The MTI image for the July campaign was not available due to the shutdown of the satellite detector. The sites for the May 2001 and March 2002 campaigns were located 200 meter north and south of the July-September 2000 site location, respectively.

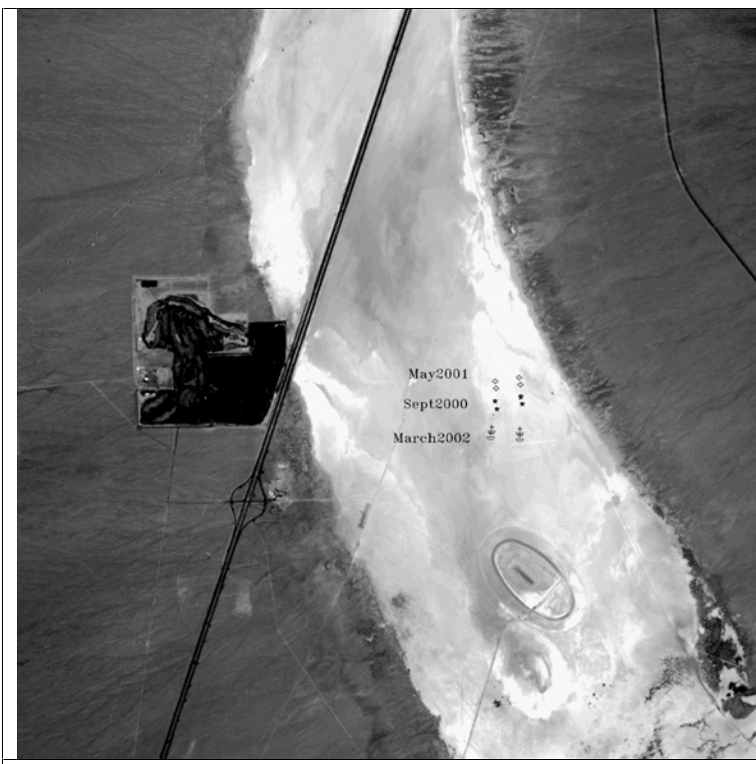

Figure 2 shows an overlay of the calibration sites at Ivanpah Playa in the September image.

The site of the May 2001 campaign was selected based on the higher reflectance of this location in the September 2000 image. The Remote Sensing Laboratory (Las Vegas) selected the March 2002 site. In order to avoid confusion between campaigns and sites, from here on, the sites will be referred as JS00 (July and September 2000), MY01 (May 2001), and MA02 (March 2002). The campaign and site differentiation is necessary in order to compare satellite-based computed reflectance at sites without ground truth reflectance. For example, ground truth reflectance data is only available at the JS00 site during the September 2000 while satellite-based computed reflectance data is available at all sites (JS00, MY01, and MA02). The same is true for the May 2001 campaign were ground truth reflectance data is available only at the MY01 site while satellite-based computed reflectance data is available at all the site and so on.

Figure 3 shows the acquisition of reflectance data with the ASD spectroradiometer. Reflectance data of the soil surface shows brightness variability at the different sites. Figure 4 shows a summary of the average reflectance spectra measured during the ground truth campaigns at Ivanpah Playa. The reflectance spectra, from higher to lower reflectance values, are May 2001, September 2000, July 2000 and March 2002 campaigns. The reflectance difference between the March and May campaigns ranged between 9.5 and 10 reflectance units in the 700 – 1200nm spectral region (49% and 39% reflectance). The July and September 2000 campaigns, conducted at the same location, showed a difference in reflectance of approximately 3 reflectance units (48%-44.8%). The May 2001 campaign showed a weaker reflectance (stronger absorption) in the blue-green region (350-500nm). The results are in agreement with the brown/reddish patches observed during our walk-around at the calibration site as shown in figure 3.

Satellite-based reflectance analysis can be conducted using the top-of-the-atmosphere (TOA) measured radiance, ground truth at a given location, and software such as ENVI (The Environment for Visualization of Images). The reflectance spectra at the three calibration sites (JS00, MY01, MA02) were computed using the MTI September 2000 image and the ground truth data collected at the JS00 site (September campaign) and ENVI 3.2. Ground reflectance can be calculated from either three methods (flat field, IAR reflectance and empirical line) available in the utilities/utilities calibration in the toolbar menu. Since ground reflectance at a given site was measured during the satellite overpass, the selection (empirical line/compute the factors and calibrate) was used to estimate ground reflectance at the playa from the wavelength dependent (spectral bands) TOA radiance values.

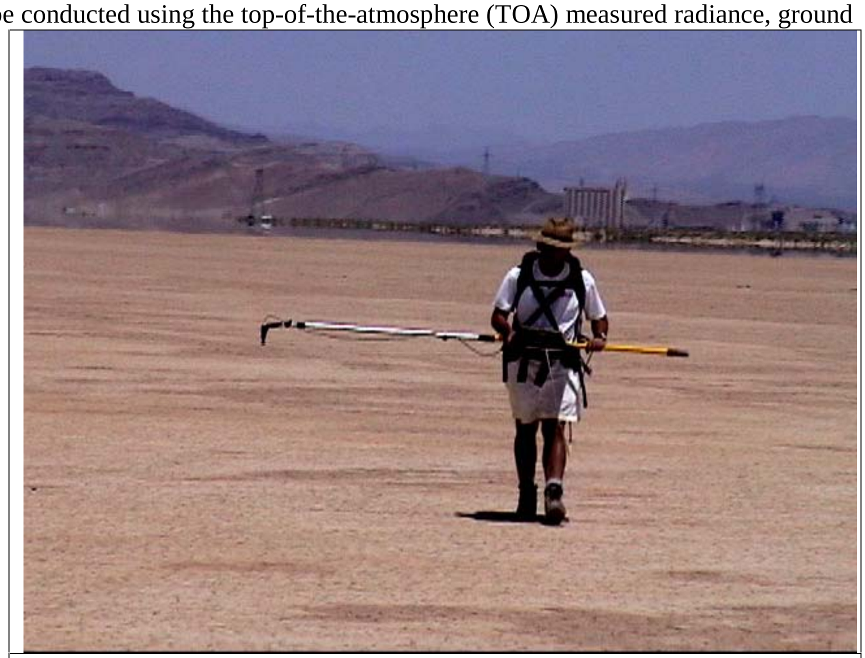

Figure 3 shows reflectance measurements at Ivanpah Playa with an Analytical Spectral Devices spectroradiometer.

Figures 5a and 5b show the computed reflectance spectra at the JS00, MY01 and MA02 sites in the September image in conjunction with the average experimental reflectance spectrum measured at the JS00 site. Figure 5b is an expansion of the reflectance axis in the reflectance spectra shown in Figure 5a. The computed reflectances of the calibration sites measured from the September image follow a similar trend of the multi-year reflectance measurements shown in Figure 4. The computed reflectance difference between the MY01 and MA02 sites in the 700 – 1200nm spectral region was 3 reflectance units in contrast to the ~10 reflectance units observed between the May and March ground truth campaigns. The reflectance difference was probably due to the changing nature of the playa. Overall, the reflectance spectra obtained in the different ground truth campaigns have a similar shape.

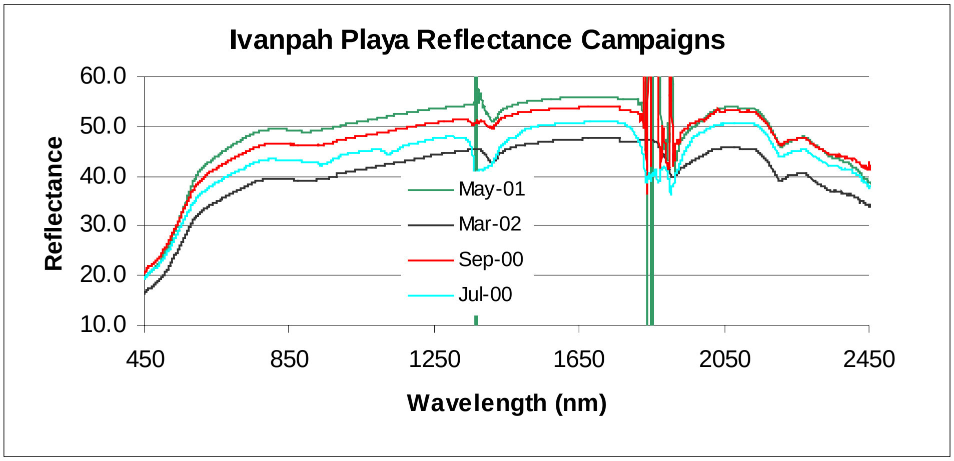

Figure 4 shows reflectance campaigns at Ivanpah Playa.

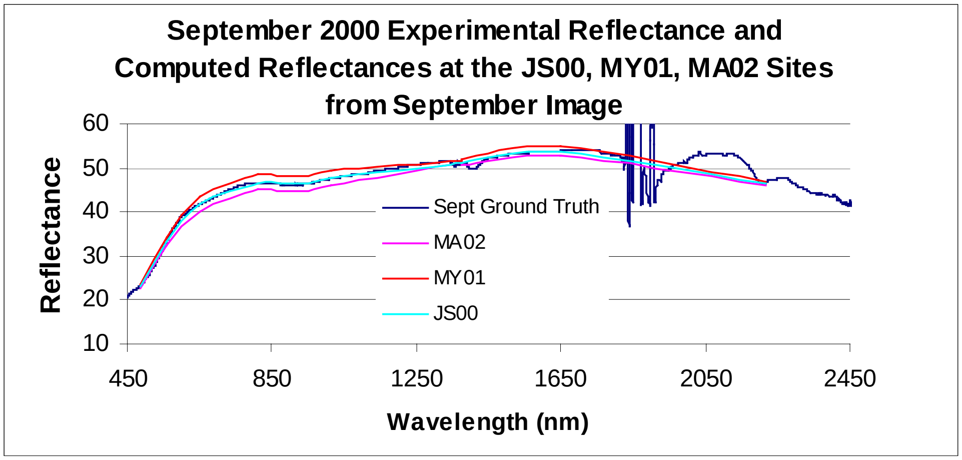

Figure 5a shows the reflectance spectra derived from ENVI software and the ground truth spectrum measured at the September calibration site.

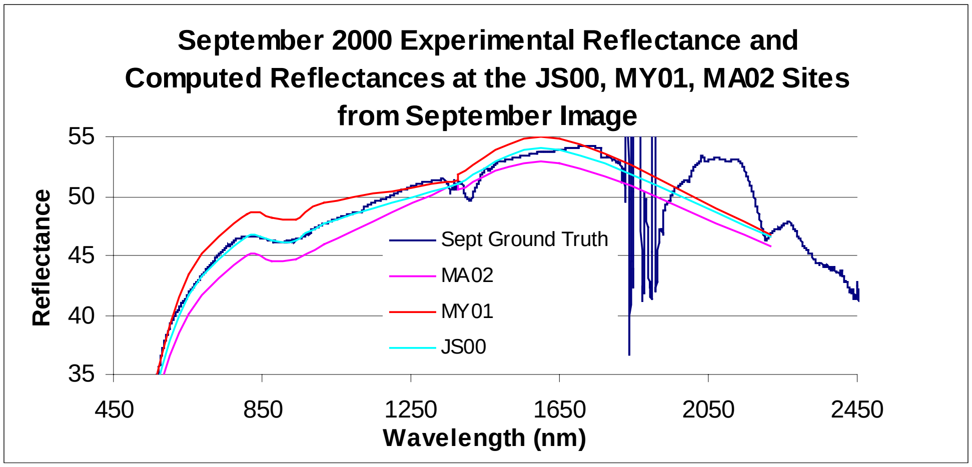

Figure 5b shows an amplification of figure 5a.

Figure 6 shows the emissivity spectra measured during the different playa campaigns. The emissivity measured in the May 2001 campaign was drastically different from the emissivity measured in the July, September and March campaigns. The emissivity spectrum measured at the MY01 calibration site resembles very closely the desert varnish emissivity spectrum. Salisbury and D'Aria[3] studied the emissivity/reflectance of terrestrial materials and the masking effect of desert varnish to rock spectrum measurements. Desert varnish is composed of manganese and ferric oxides intimately mixed with montmorillonitic clay. The only spectral feature displayed by desert varnish in the 8-12 µm spectral region is the Si-O stretching vibration band of the clay. Further analysis of the emissivity measured in the July, September, and March campaigns suggest the contribution of two materials to the emissivity spectrum. One of the components seems to be missing from the May campaign emissivity data. In order to determine the missing component in the May emissivity campaign, the May emissivity spectrum was subtracted from the July emissivity spectrum and the resultant spectrum was analyzed using a commercially available spectral library. Figure 7 shows the emissivity spectra in the July and May campaigns, the computed quartz spectrum, and the spectral position of three of the MTI satellite thermal spectral bands (L, M, and N). Figure 8 shows the match between the computed quartz emissivity spectrum and mineral library spectrum. The missing component was identified as quartz. The reflectance and emissivity data suggest a correlation between higher absorption of light in the blue-green spectral region and the missing quartz component in the emissivity spectrum.

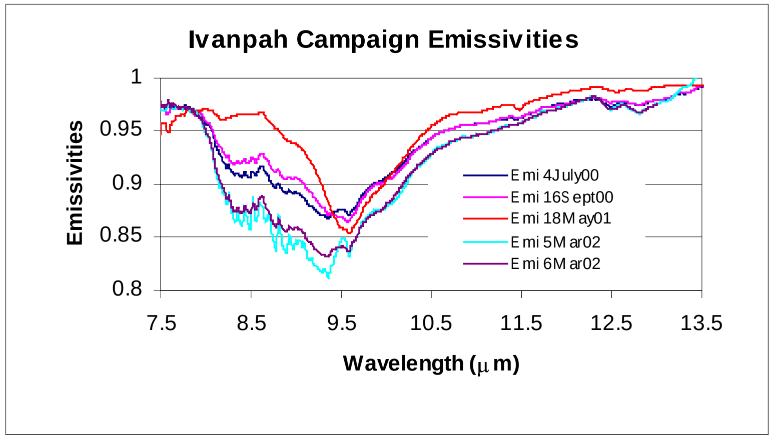

Figure 6 shows the emissivity spectra measured during the different playa campaigns.

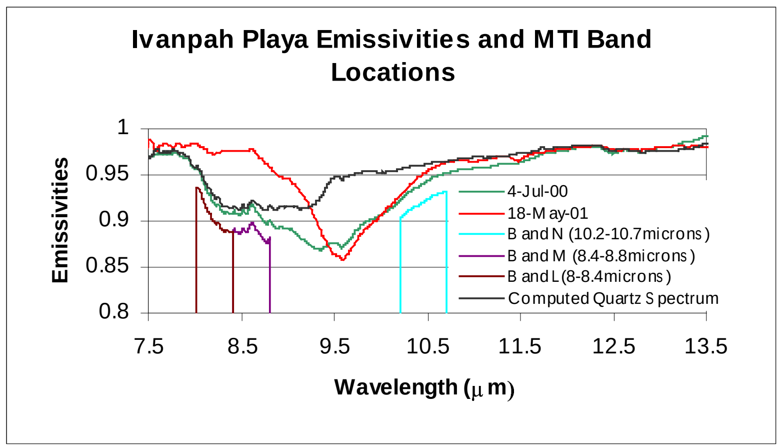

Figure 7 shows the July and May campaigns and the difference spectrum in conjunction with three of the MTI satellite bands (L, M, and N).

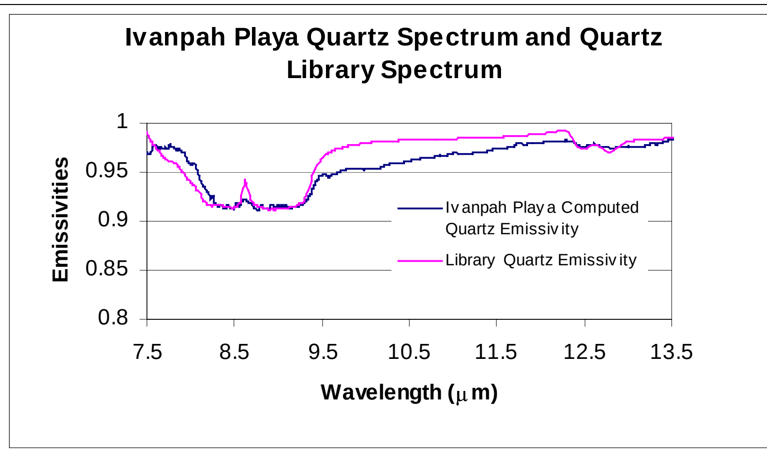

Figure 8 shows the match between the resultant spectrum and mineral library spectrum.

The MTI images of Ivanpah Playa collected during our ground truth calibration campaigns showed dramatic temporal/spatial variability across the playa. Figures 9a through 9d shows the MTI images of Ivanpah Playa (band C) recorded on September 2000, November 2000, May 2001 and March 2002. Reflectance and spectral emissivity ground truth was available for the September, May and March campaigns. The MTI image for the July campaign was not recorded due to satellite problems. The images show large spatial reflectance changes from the September 2000 campaign to the May 2001 campaign. The spatial reflectance changes were minimal from the May 2001campaign to the March 2002 campaign. Spatial reflectance changes seem to follow the rainfall during the winter-spring seasons prior to the ground truth campaign. The images suggest heavy rains and overfilled playa during the 2000-2001 season and a dryer 2001-2002 season.

In order to investigate the precipitation hypothesis, rainfall records in the nearby areas were analyzed from October 1999 through March 2002. The two closest locations to Ivanpah Playa with meteorological capabilities were located west to Las Vegas and west to Kingsman. Ivanpah Playa is located 50 miles south of Las Vegas and 80 miles from Kingsman. Both locations had similar temporal rainfall results, although the Kingsman location shows larger quantities. The primary rainfall discrepancy between Las Vegas and the Kingsman stations occurred between May 2001 and March 2002. The rainfall at the Kingsman location in this period was about five times the rainfall measured at the Las Vegas location. The spatial similarities between the May 2001 and March 2002 Ivanpah Playa images do not support heavy rainfall in the May 2001 and March 2002 period (very small spatial changes in the visible images). Therefore, the satellite images at the different campaigns in conjunction with the shorter distance between Las Vegas meteorological site to Ivanpah Playa and the temporal precipitation distribution measured at Las Vegas station suggest that Las Vegas meteorological location is a better measure for rainfall at the playa calibration site. Figure 10 shows the monthly precipitation and the satellite overpass time. The plot bars with a value of 100 indicate the campaign month of the MTI satellite snap shot. The precipitation records show that in the period between September 2000 and November 2000, the area received an estimated 22.8mm/month of water. Large spatial and reflectance changes were observed between the September 2000 and the November 2000 MTI images. In the period between November 2000 and May 2001, the playa received 17.2mm/month (total of 86mm of water in 5 months). Another drastic spatial/reflectance change was observed between the November 2000 and May 2001 MTI images. Ivanpah Playa received an estimated rainfall of 1.6mm/month (14.5 mm of water in 9 months) between May 2001 and March 2002 period. The spatial/reflectance MTI images of March 2002 and May 2001 show very small changes.

Figure 9a shows September 2000 band C image.

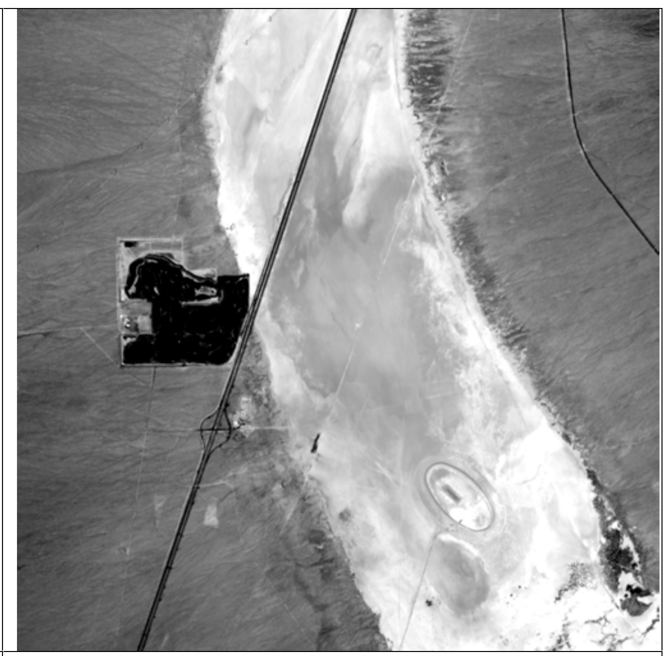

Figure 9b shows November 2000 band C image.

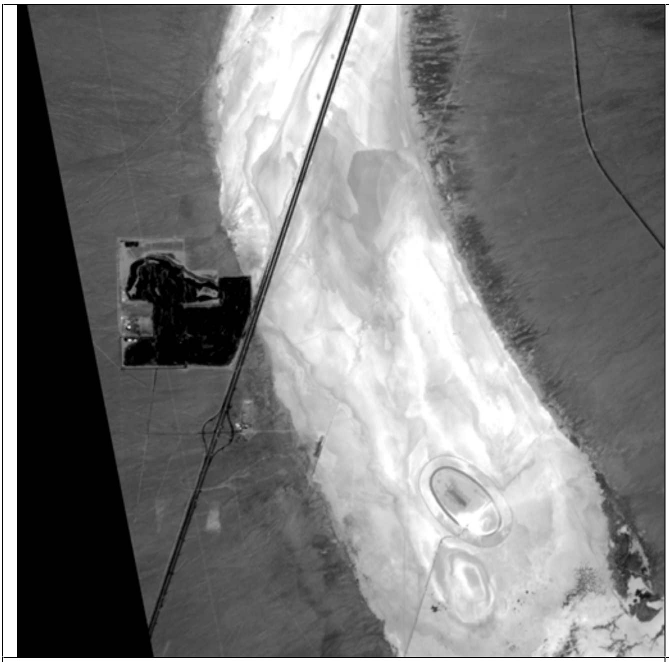

Figure 9c shows May 2001 band C image.

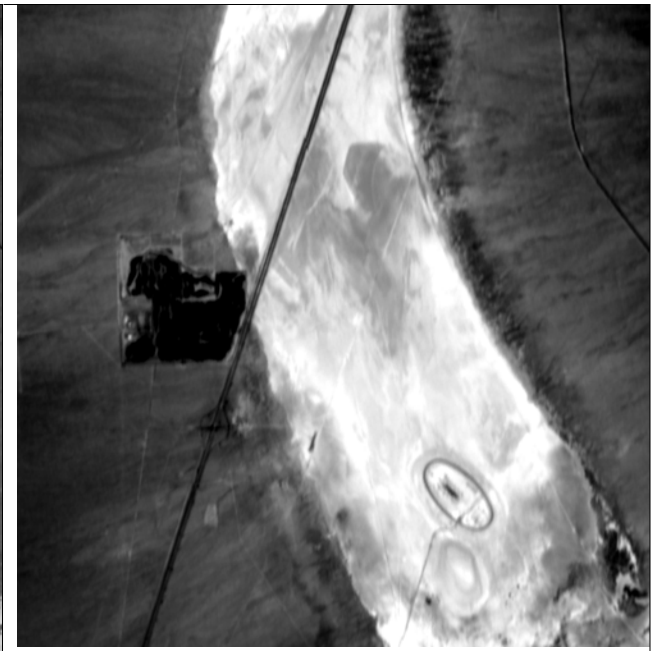

Figure 9d shows March 2002 band C image.

One of the most noticeable spectral differences among the campaigns was the temporal variations in emissivity at the playa as shown in Figure 6 and the absence of quartz absorption feature in the May campaign as shown in Figure 7. Figures 11a, 11b, 11c, and 11d show the top-of-the-atmosphere radiance for bands C, L, M, and N, respectively for the September campaign. Band C (red, 0.62-0.68μm) was chosen as representative band of the visible bands. Figure 7 shows the spectral location of bands L, M, and N in conjunction with the spectral emissivities measured in the July and May campaigns and the July/May difference emissivity spectrum (quartz). The position of the bands L and M are ideal to monitor the quartz content at the playa. Band N is located on the right shoulder of the desert varnish spectral feature as shown in Figure 7.

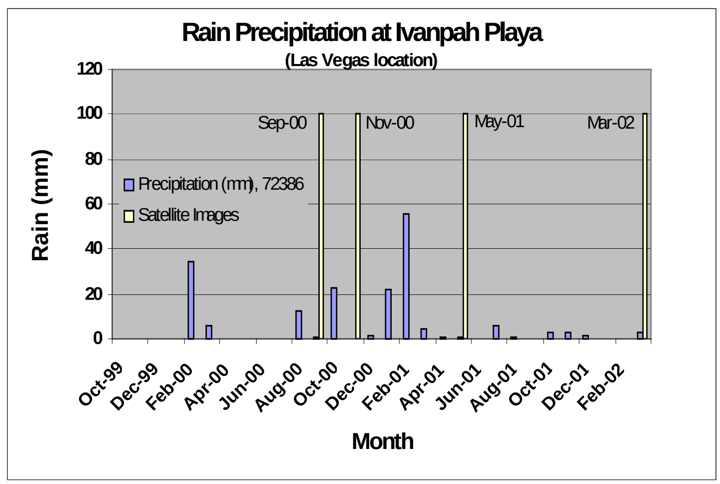

Figure 10 shows the rainfall measured at a meteorological station west of Las Vegas and 50 miles north of Ivanpah Playa.

The thermal images are dependent on the surface temperature and emissivity. At constant emissivity, the radiance emitted in the thermal bands is proportional to the solar radiation absorption. Therefore, it is expected that surface areas with high reflectance would be cooler in the thermal band image and vice versa. The inversely dependence relationship between the band C and band N images is shown very well in Figures 11a and 11d (band N is almost the negative exposure of band C). The straight-line correlation (Figure 11e) between the visible band and the thermal band is indicative of low variability in the spectral emissivity. In contrast to band N, bands L and M present a different image of the playa. A different image is representative of the emissivity variability across the playa and suggest the presence of at least two materials with different concentration at different sites of the playa. Since bands L and M are located in the quartz region, the images suggest a representation of different quartz concentration. Although emissivity intensity measured with the mobile Fourier transform infrared spectrometer was also variable across the calibration site, variability between the L and M band regions versus the band N region was not detected. The emissivity spectrum presented in Figure 7 is the average of the calibration site (280m x 80m).

A 2d-scatter plot study was conducted to establish a relationship between the playa reflectance (band C) and thermal bands L, M, and N. The 2-d scatter plot of band C reflectance and band N TOA radiance in figure 11e shows a straight line. The width in the ordinate axis is indicative of the variability of the thermal radiation emitted versus solar radiation reflected (or absorbed). The reflectance in band C is proportional to the reflectance at the other bands. As an approximation, the TOA radiance measured in band N is a function of the reflectance and emissivity. Therefore, the width of TOA radiance values for a given reflectance is indicative of low emissivity variability in the band N region. In the limit where the emissivity variability becomes high, the linear relationship in Figure 11e disappears. The 2-d scatter plot of band C and L (or M) shows two components in agreement with our conclusions or variable quartz concentration across the playa. The width of the 2-d scatter plot between band C (any visible band) and band N expanded in the high reflectance region (39.5-48.1). The broader width is indicative of higher emissivity variability in geographical areas with high reflectance values and possibly another component in these areas. The area studied at the playa for the 2-d scatter plot encompassed a region of 1.7km x 1.9km and no attempts were made to characterize smaller regions.

Figure 11a shows band C in the September image.

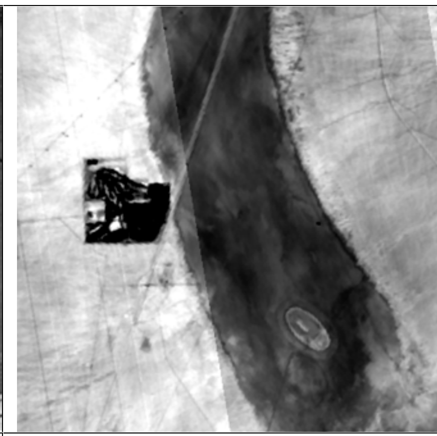

Figure 11b shows band L in the September image.

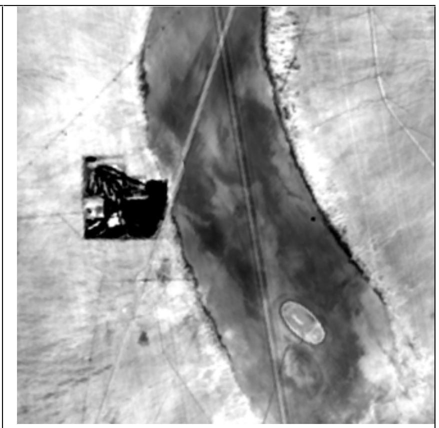

Figure 11c shows band M in the September image.

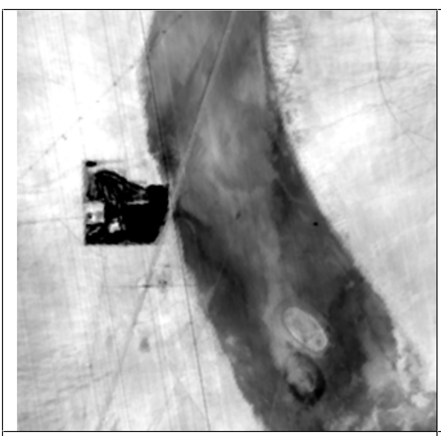

Figure 11d shows band N in the September image.

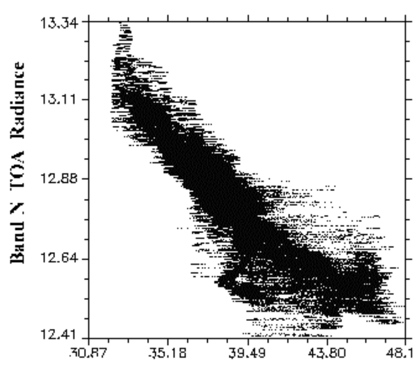

Figure 11e shows a 2-d scatter plot of band N versus band C.

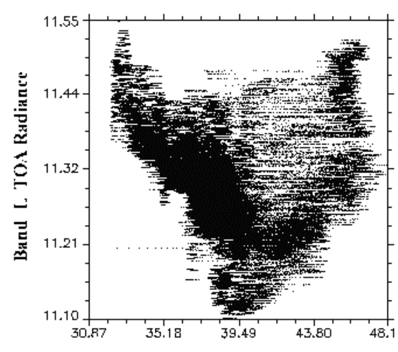

Figure 11f shows a 2-d scatter plot of band L versus band C.

Figures 12a, 12b, 12c, and 12d show the images of band C, band L, band M, and, band N of Ivanpah Playa during the May 2001campaign. In contrast to the September campaign, there are no major distinctions among the thermal bands. Once again, there is a very good negative correlation between the reflectance band C and the thermal band N (figures

12a and 12d). The 2-d scatter plot of band C and N in Figure 12e shows once again the linear behavior. A 2-d scatter plot of band C versus bands L and M (Figure 12f) is much wider although still elongated in the same direction of the band C and N 2-d scatter plot (Figure 12e). The bifurcated 2-d scatter plot in Figure 11f was indicative of quartz concentration variation across the playa. In contrast, the 2-d scatter plot in Figure 12f does not support the bifurcation signature suggesting that there are no large changes in the quartz concentration across the playa during the May campaign. The spectral emissivity measured with the FTIR spectrometer during the May campaign and shown in figures 6 and 7 indicate very little quartz at the playa.

A possible explanation for the temporal variability of the spectral emissivity and the disappearance of the quartz component during the May campaign is heavy precipitation and possible standing water preceding the ground truth campaign. It is proposed that during a wet winter-spring season, the quartz particles across the playa's surface are mixed with the clay. Once the playa is dried during the late spring/early summer wind erosion on the playa's surface uncovers the quartz particles. The extent of this process is determined by the amount of precipitation on the playa. Ground truth campaigns conducted after a relatively dry spring-winter season are characterized by a playa image that resembles the previous year image (March 2002 and May 2001) and the presence of quartz features in the spectral emissivity. This rationale suggests that if the ground truth campaign would have been conducted during the September 2001 instead of May 2001, the emissivity would have been characteristic of the quart and desert varnish combination.

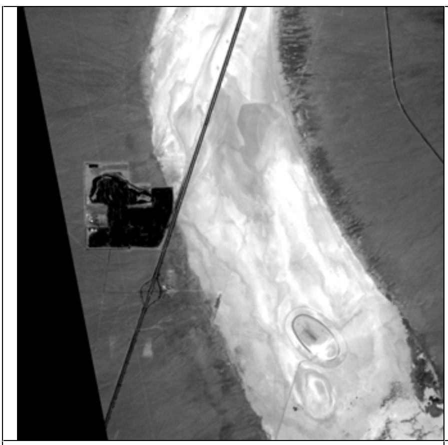
Figure 12a shows band C in the May image.

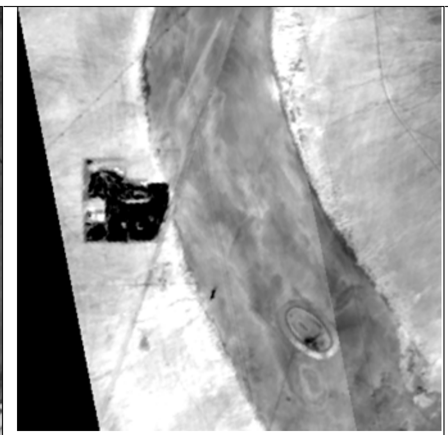
Figure 12b shows band L in the May image.

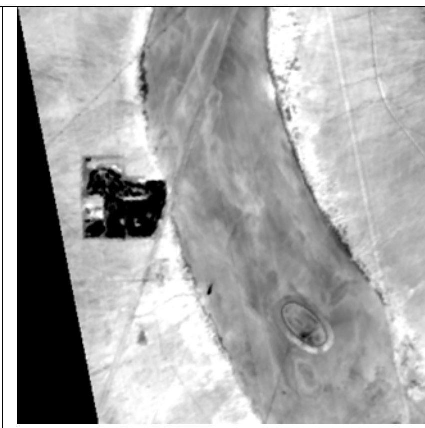
Figure 12c shows band M in the May image.

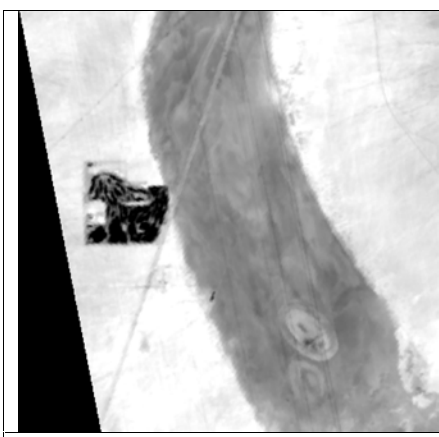
Figure 12d shows band N in the May image.

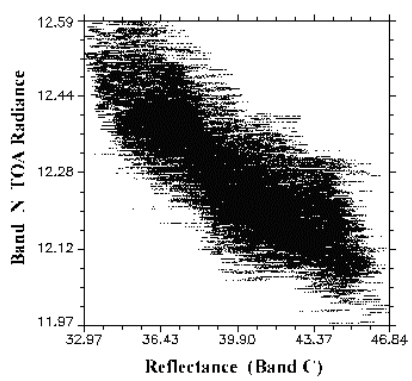

Figure 12e shows a 2-d scatter plot of band N versus band C.

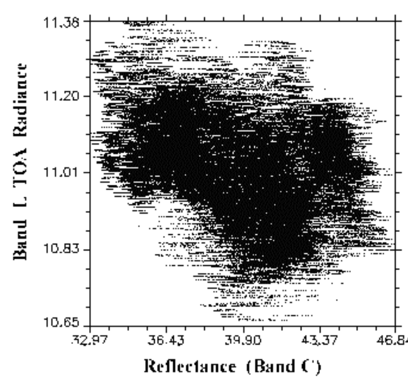

Figure 12f shows a 2-d scatter plot of band L versus band C.

SUMMARY

Reflectance and emissivity measurements were conducted in July and September 2000, May 2001, and March 2002. The campaigns were conducted at three different locations separated by approximately 200 meters. Visible and thermal images of Ivanpah Playa with the MTI satellite were taken on September and November 2000, May 2001 and March 2002. Reflectance images and spectra of Ivanpah Playa were computed with TOA radiance measured by the MTI satellite, ground truth reflectance at the calibration site and ENVI software. The correlation between visible and thermal images was studied using 2-d scatter plots. The limited image set of Ivanpah Playa show marked spatial changes following a wet winter/spring season. In contrast, the small change between the May 2001 and March 2002 is indicative of light precipitation in the area during the 10-month intervening period. The disappearance of the quartz spectral feature in the May 2001 campaign suggested heavy rainfall in the preceding months, which was confirmed by the precipitation records. The results from all these sources show the importance of precipitation in the temporal, spatial, and spectral behavior of the playa.

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