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Temperature and emissivity measurements with the Multispectral Thermal Imager satellite at Ivanpah Playa

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The Multispectral Thermal Imager (MTI) is a research and development satellite sponsored by the Department of Energy (DOE) for accurate water surface temperature retrieval. MTI uses five thermal spectral bands to retrieve ground temperatures. The application of MTI for land-based temperature and emissivity retrieval has been limited. Savannah River Technology Center conducted several ground truth campaigns at Ivanpah Playa to measure reflectance, temperature and emissivity. The results of MTI temperature and emissivity retrievals and material identification will be discussed in context with the ground truth data.

Key Words: MTI satellite, emissivity, Ivanpah Playa

1. INTRODUCTION

The Multispectral Thermal Imager (MTI) is a research and development satellite sponsored by the Department of Energy (DOE) for accurate surface temperature retrieval. The MTI mission described by Weber et al.[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 remotely sensed information from the satellite instrument to information available directly at the cooperative sites. MTI is a technology demonstration experiment, and is designed to observe a very limited number of selected sites per day, with modest spatial coverage and spatial resolution.

The MTI satellite has 16 spectral bands encompassing the visible (VIS), near (NIR), short-wave (SWIR), mid-wave (MWIR) and the long-wave (LWIR) infrared spectral regions. The visible and near-infrared spectral bands (11 bands) are used to characterize the surface reflectance and the atmosphere. The visible and near-infrared bands are calibrated in dry lakebed surfaces such as playas. The remaining five bands are 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]) used to retrieve ground temperatures. The validation and verification ground truth targets for the temperature algorithms described by Garrett et al.[2] are primarily heated/unheated lakes. The spatial resolution of the spectral bands is divided in two subsets (5-meter and 20-meter). Spectral bands A-D and E through O are 5-meter and 20-meter spatial resolution bands, respectively. Figure 1 shows an artist view of the MTI satellite in space.
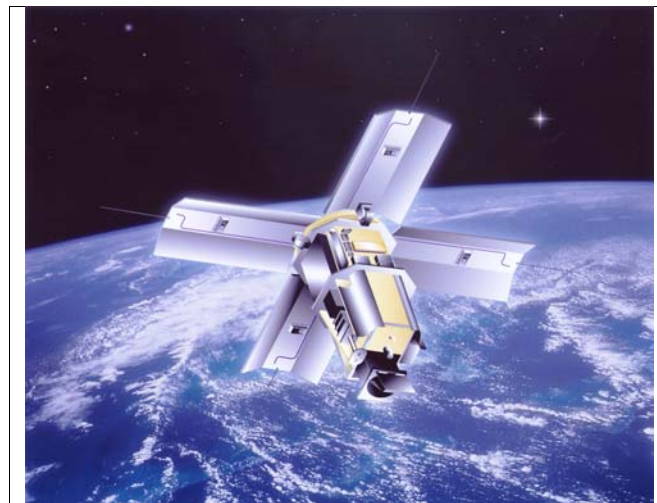

Figure 1 shows an artist view of the MTI satellite in space.

The visible and near infrared vicarious calibration of the MTI satellite is conducted at Ivanpah Playa, California. The primary advantages of the playas are the high reflectivity and uniformity of the terrain at a high elevation. Although the[1]

primary importance for the playas are the visible, near-infrared spectral regions, characterization of the wavelength-dependent emissivity in the 4 - 12µm provides an opportunity to compare space-based remote measurements with ground based calculated surface temperature and integrated band emissivities.

Remote determination of surface temperature relies on the spectral radiance reaching the satellite. The directional radiance measured at the satellite $(L_{satellite})$ is described by

$$L_{satellite}(\lambda,T) = [\varepsilon_\lambda L_{bb}(\lambda,T) + (1-\varepsilon_\lambda)L_{atm}(\lambda)\downarrow]\tau_{atm}(\lambda) + L_{atm}(\lambda)\uparrow \qquad (1)$$

$L_{atm}(\lambda)\downarrow$ is the downward atmospheric radiance on the ground surface, $L_{atm}(\lambda)\uparrow$ is the upward atmospheric radiance reaching the satellite and $\tau_{atm}(\lambda)$ is the spectral atmospheric transmissivity. Band J can only be used during nighttime measurements since solar reflection by the surface of a target is a large contributor to the radiance measured by the satellite. Radiance measurements with the FTIR spectrometer are described by equation (2), where transmissivity and upward atmospheric radiance are negligible.

$$L_{FTIR}(\lambda,T) = \varepsilon_\lambda L_{bb}(\lambda,T) + (1-\varepsilon_\lambda)L_{atm}(\lambda)\downarrow \qquad (2)$$

The MTI satellite use a combination set of spectral bands to retrieve the atmospheric transmissivity. The preferred set for water vapor retrieval is the combination of band F (water vapor, 0.91 – 0.97 µm) with bands E (water vapor reference, 0.86 – 0.90 µm) and G (water vapor reference, 0.99 – 1.04 µm). Alternatively, in the infrared spectral region, bands L (8.00 – 8.40 µm) and M (8.40 - 8.85 µm) can also extract the same atmospheric transmissivity. In contrast to the E, F, G band set that require sun light for atmosphere characterization, the bands L and M have the advantage of using the surface temperature for day or night for water vapor characterization.

On the ground, radiosonde profiles in conjunction with a sun photometer are used to measure solar radiation and atmospheric parameters. The sun photometer measures atmospheric optical depth while the radiosonde profiles provide altitude dependent relative humidity, temperature, and barometric pressure. The satellite transmissivity measurements of the atmosphere are compared with the ground truth for data validation. Once the atmospheric transmissivity has been determined, the ground surface radiance measured by the satellite can be converted into surface temperature for a known emissivity surface. The software entitled "The Environment for Visualization Images", (ENVI), can be used to calculate a surface map temperature given an atmospheric profile of the site and ground emissivity for a given spectral band. The emissivities at other bands can be calculated for a known temperature and top of the atmosphere radiance. MTI satellite has shown surface temperature retrievals of water and land targets at better than ±2C.

A calibrated Fourier transform infrared spectrometer was used to measure ground surface spectral emissivity and average temperature. The soil surface radiance measured with the FTIR spectrometer for the satellite calibration was obtained from a rectangular calibration site with 80m x 280m dimensions. Three phenomena affect the radiance-temperature measurements by the FTIR spectrometer; the wind induced cooling effect on the soil surface, the inhomogeneous morphology of the ground surface and the ratio of the mud-cracked tile-like surface area versus crack area. The experimental results show that the wind can effect the observed temperature by more than a degree with transients as high as two degrees. The experimental results with an infrared camera also show a different temperature-emissivity composition between the cracks and the tile-like surfaces (the crack area corresponds to approximately 14% of the total surface area). Aerial thermal imagery shows inhomogeneous temperature maps of the surface at Ivanpah Playa. Besides errors in the calibration of the FTIR spectrometer (blackbody temperatures), each distinct effect contributes to the total emissivity and surface temperature standard deviation.

2. EXPERIMENTAL

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. 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. 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 2. Besides the FTIR spectrometer, figure 2 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 reflected the soil radiance into the spectrometer. The mobile FTIR spectrometer was moved over the

Figure 2 shows preparations made with the mobile Fourier transform infrared spectrometer prior to data collection.

calibration site to sample hundreds of points within ± 10 minutes of the satellite flight time over Ivanpah Playa in order to average out soil radiance measurements.

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 80m x 280m. Figure 3 shows the GPS track during the walk around through the calibration site area. The FTIR 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.
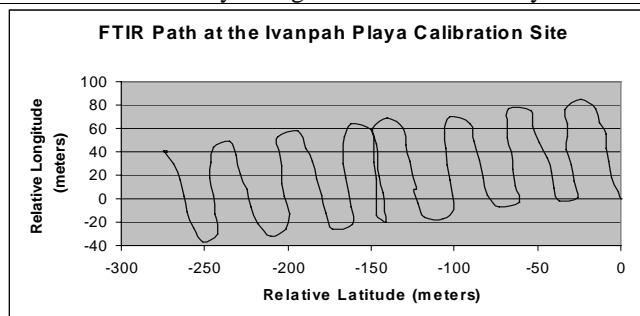

Figure 3 shows the path taken over the calibration site with dimensions of 280m x 80m.

3. RESULTS AND DISCUSSION

3.1 FTIR Measurements

Soil targets like Ivanpah Playa are complicated by the heterogeneous nature of the soil surface. Besides the spectral and spatial variability, the wind speed over the playa also affects the surface temperature. Single point measurements at the playa can be biased due to the above mentioned problems. The accuracy of our land temperatures was estimated within $\pm1.1C$.

Prior to the soil-sampling step, the FTIR spectrometer was calibrated by calculating the instrument response function (IRF) with the aid of two blackbodies. The IRF was calculated as

$$IRF = \frac{BB_{Hot} - BB_{Cold}}{L_{Hot} - L_{Cold}} .$$

3)

where BB_{hot} and BB_{cold} are the raw machine units for the hot and cold blackbodies and L_{hot} and L_{cold} are the Planck distribution functions for the temperatures of the blackbodies. Once the IRF was calculated, the target radiance was calculated from

$$L_{Soil} = L_{Hot} - \frac{(BB_{Hot} - BB_{Soil})}{IRF}$$

4)

The sky background was measured with a diffuse infragold-coated plate. The infragold-coated plate is not a perfect reflector (emissivity=0.04) and therefore has a small thermal contribution. The plate temperature was used to calculate the small radiance contribution and therefore the correction to the sky measurements. The sky radiance was calculated from

$$L_{sky} \downarrow = L_{Hot} - \frac{(BB_{Hot} - BB_{sky})}{IRF} - L(T)_{Gold\_Plate} .$$

5)

and the spectral emissivity calculated from equation 6.

$$\varepsilon = \frac{(L_{Soil} - L_{Sky})}{(L_{Soil\_BB} - L_{Sky})} .$$

6)

The L_{Soil_BB} is the blackbody radiance calculated from the best Planckian fit over the measured soil radiance. The best Planckian fit is accomplished by changing the temperature that produces the best fit to the experimental results. The calculated temperature was compared with the temperature measured with a mobile heated cone radiometer (MHCR). The MHCR is a cart with an 8-14 μm broadband radiometer attached to a heated cone. The cone is heated approximately to the ground apparent surface temperature creating a radiance background similar to the surface radiance. This condition eliminates the surface emissivity from the radiance equation and therefore producing a quasi blackbody. Moving the cart on the playa's surface eliminates the cooling effect created by the shadow of the cone. Temperatures calculated with the FTIR spectrometer and the mobile heated cone radiometer cart were within 0.5C.

Spectral emissivity was measured at the playa during the four calibration campaigns (July and September 2000, May 2001 and March 2002). MTI images were only available for the September, May and March campaigns. Cloud coverage precluded a comparison of temperature measurements between satellite and the FTIR spectrometer during the March campaign. Therefore, the September 2000 and May 2001 were the only campaigns used to test temperature retrievals by the MTI satellite. Figure 4 shows a visible image (band C, 0.62-0.68μm) of Ivanpah Playa

during the September 2000 campaign. The location of the calibration sites during the different campaings is illustrated in the September image. The surface reflectance and spectral emissivity of Ivanpah Playa has been shown to change

With precipitation during the winter-spring seasons. The many faces of Ivanpah Playa were described by Villa-Aleman[3] et al. in a study from July 2000 through March 2002.

Figure 5 shows the emissivities measured at Ivanpah Playa during the July and September 2000, May 2001 and March 2002 campaigns. The spectral emissivities measured during July and September 2000 are very similar to the emissivity measured in the March 2002 campaign. In contrast, the May 2001 spectral profile was very different below 9.5μm. The emissivity spectrum measured in the May 2001 campaign resembles very closely the desert varnish emissivity spectrum. Salisbury and D'Aria[4] 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

Figure 4 shows an overlay of the calibration sites at Ivanpah Playa in the September image.

stretching vibration band of the clay. Further analysis of the emissivity measured in the July, September, and March campaigns suggest the contribution of two material components to the shape of 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 6 shows the emissivity spectra in the July and May campaigns, the difference spectrum, and the location of the three thermal spectral bands (L, M, and N) of the MTI satellite. The shapes of the MTI thermal bands in Figure 6 were selected to point out the spectral region of the emissivity measured with the Fourier transform infrared spectrometer. Figure 7 shows the match between the difference 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.

The MTI thermal bands appropriate for the surface emissivity analysis at the playa are bands L, M, and N. The spectral coverage of bands L, M and N is [8.00-8.40μm], [8.40-8.85μm], [10.2-10.7μm], respectively. Satellite-based temperature and emissivity measurements require a known emissivity at a given wavelength or spectral region. The behavior of the spectral emissivity shown in figure 5 near band N region suggests that it remains quite constant through the years. The intensity of bands L and M are indicative of the quartz content over the playa surface.

Large spectral emissivity variability is observed between the May 2001 campaign and the other campaigns. Variability in emissivity intensity is common for each calibration site campaign. For example, 600 emissivity spectra were recorded on the May 2001 calibration site campaign and found to have the same spectral features but with large swings in

intensity values. The spectrum intensity values were correlated with soil spatial variability. Although the emissivity in the 14 – 15 μm spectral range is unchanged in value, a two-degree temperature difference was calculated for soilsurfaces with maximum and minimum emissivity values of 0.87 and 0.75 at 9.6 μm. The average temperatures for the calibration sites within the 20-minute walk-around period for the September 2000 and May 2001 campaigns were 325.3± 1.1K (52.2 ± 1.1C) and 324.5 ± 1.1K (51.4 ± 1.1C), respectively.

The average soil temperature was calculated from the curve fit to the spectral exitance curve in the long wave infrared, >12μm spectral range. The long-wave region was selected in temperature calculations due to the small difference in values between the background radiance to soil radiance (the closer the background radiance to the target radiance the smaller the uncertainty in temperature calculation due to emissivity). The average temperatures included the radiance from tile-like surface and crack areas, time dependent wind surface cooling and inhomogeneous patches of surface reflectance/emissivity effects. It is worthwhile to point out that the single Planckian curve fit used to determine the temperature is a best fit to experimental surface data with variable temperature and emissivity.

Figure 8 and 9 show the measured spectral exitances and temperatures calculated from the best Planckian fit to the soil radiance measured at the September and May calibration sites for 12-16μm and 4-8μm. The short-wave spectral region was also used in the temperature calculation during the September campaign. The temperature difference between the regions is only 0.5C.
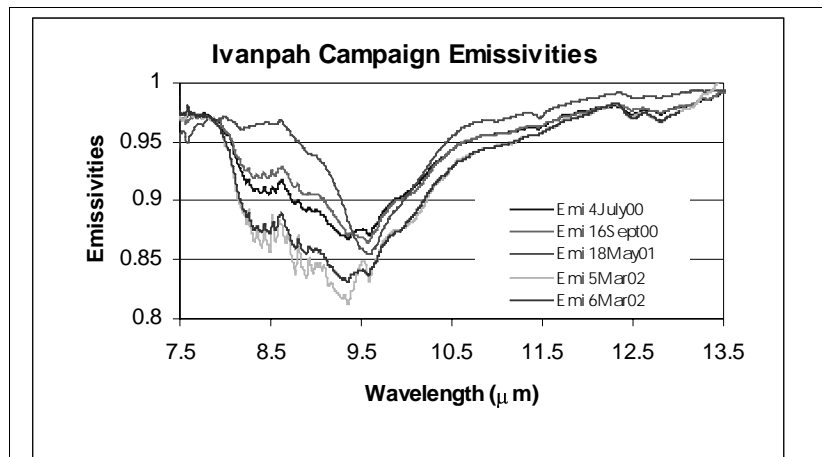

Figure 5 shows the emissivity spectra measured during the different playa campaigns.
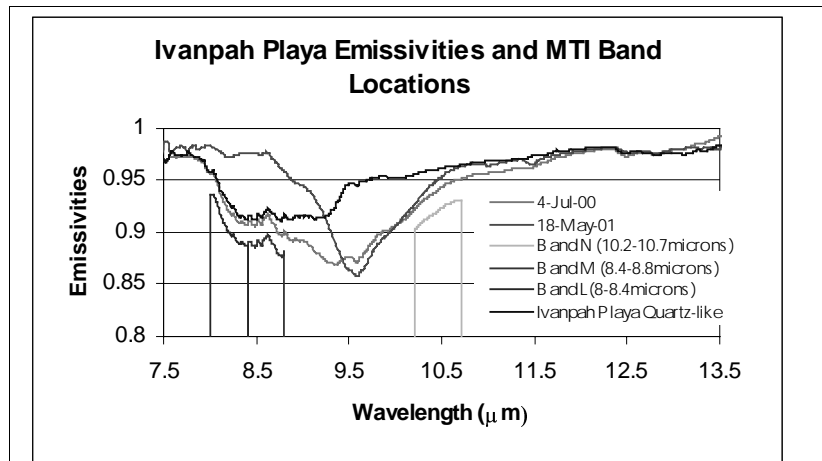

Figure 6 shows the July and May campaigns and the difference spectrum in conjunction with three of the MTI satellite bands (L, M, and N).
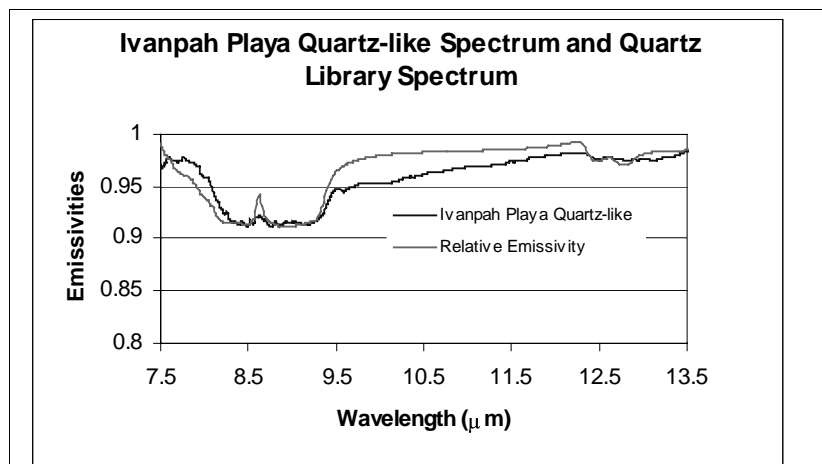

Figure 7 shows the match between the resultant spectrum and mineral library spectrum.

3.2 Temperature and emissivity analysis from MTI imagery

The temperature retrieval and band emissivities of land targets from space-based sensors requires knowledge of emissivity at a given wavelength or band. Although the MTI has five thermal bands (J, K, L, M, and N), the primary emphasis was given to the L, M and N spectral bands since these bands lies near the desert varnish and quartz absorption features. Figure 6 shows the locations of the MTI satellite spectral band superimposed on the ground measured emissivity curves. The ground truth emissivity measurements at the calibration sites suggest that variability in the emissivity of band N across the playa is minimal. In contrast to band N, the emissivity of bands M and L was found to vary dramatically from the May campaign to the July, September, and March campaigns. Reflectance and thermal radiance images (L, M and N) of the playa surface were analyzed in conjunction with 2-d scatter plots. An inverse relationship between the reflectance and the thermal radiance is expected for a band with low variability across the playa. The inverse relationship will not hold if the band emissivity is not uniform across the playa.

Figures 10a, 10b, and 10c show bands C, M and N images of Ivanpah Playa during the September 2000 campaign, respectively. The visible image from band C and the thermal image band N are clearly inversely proportional, that is, the higher the reflectance, cooler the surface and vice versa. The
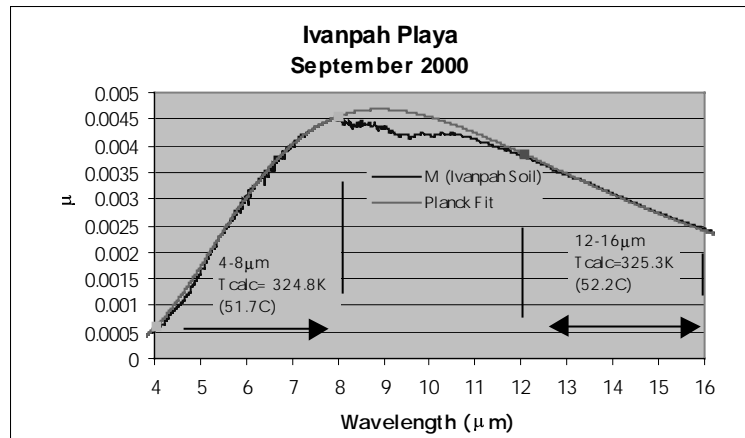

Figure 8 shows the soil surface temperature calculated from the spectral exitance measured at Ivanpah Playa during the September 2000 campaign.
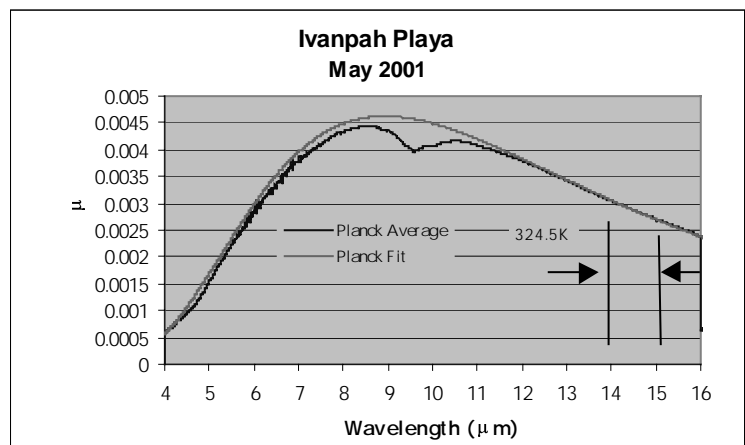

Figure 9 shows the soil surface temperature calculated from the spectral exitance measured at Ivanpah Playa during the May 2001 campaign.

correlation suggests minimum variability in the band N emissivity across the playa. In contrast, the thermal bands M and N images are very different indicating variability of surface material in band M emissivity across the playa. Scatter plots of band C versus band N and M were produced from a 1.7km x 1.9km at the playa. Figures 11a and 11b show the calculated 2-d scatter plots for bands C and N and bands C and L. The linearity of the 2-d scatter plot from band C and N is evident suggesting once again a minimum variability in the selected area. In contrast, the shape of the 2-d scatter plot from bands C and L suggest different materials or concentrations across the playa.

Since the spatial variability of band N across the playa is minimal as well as the temporal emissivity variability measured with the FTIR spectrometer, band N can be used as an emissivity reference for space-based temperature and wavelength dependent emissivity measurements. The emissivity calculated with the FTIR spectrometer from all the campaigns show an integrated emissivity in the band N region of 0.93±0.01. Temperature images of the playa were calculated using band N as a reference with an emissivity of 0.93, atmospheric profile and ENVI software.

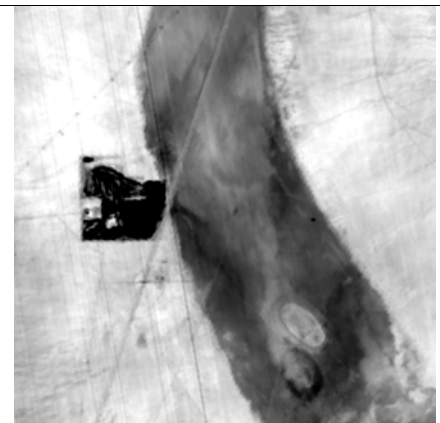| Figure 10a shows band C in the September image.	Figure 10b shows band M in the September image.	Figure 10c shows band N in the September image.

3.2.1 September 2000 Campaign

During the September campaign, the atmospheric conditions (humidity, air temperature, and pressure) were measured by releasing a balloon with a radiosonde. The atmosphere transmission was calculated using radiative code (MODTRAN 3.3). The TOA band N radiance was corrected to ground level radiance using the atmosphere transmission from MODTRAN (transmission=0.96). The atmosphere corrected band N radiance image was used with ENVI 3.2 software and a band N emissivity of 0.93 to calculate the temperatures across the playa and to produce emissivities at the other MTI thermal bands. Figure 12 shows the temperature image calculated with the MTI satellite in the calibration site area. Once again, the calibration site area for the temperature measurement is 280m x 80m. The temperature retrieved with the MTI satellite using band N for the September calibration site was 326.08±0.12K. The temperature measured with the FTIR at the calibration site was 325.3±1.1K. The agreement between the satellite retrieved temperature and the FTIR retrieved temperature is comparable to the 1K accuracy obtained by the MTI satellite for water targets.

Figures 13a, 13b, and 13c show the emissivity images for the bands K, L, and M, respectively. The emissivity of band N was set to a constant value in order to calculate the image temperature and the emissivities at other bands. Large variability in the emissivities from bands L and M were observed across the playa. Band M image shows a low emissivity region surrounding most of the playa suggesting the presence of material with high SiO_2 (quartz) concentration. Band L also provides similar information and complements band M to a lesser extent. The same periphery is also distinguished in band K as a region of high emissivity.

Figures 14a through 14c show the images of the K, L, and M bands at the calibration site with the corners represented by stars. Variations in emissivity for all bands at the calibration site were less
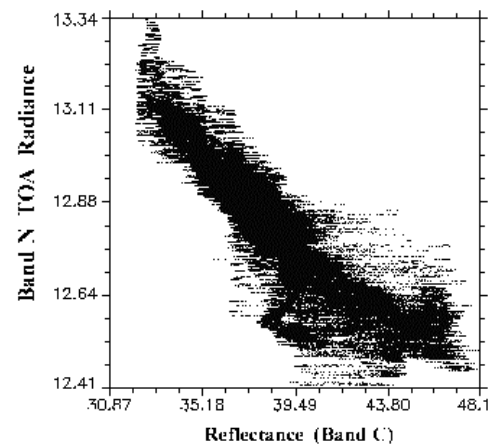

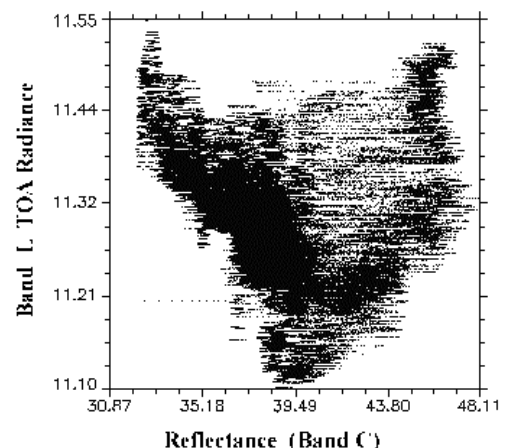Figure 11a shows a 2-d scatter plot of band C and band N for a 1.7km x 1.9km area.

Figure 11b shows a 2-d scatter plot of band C and band L for the area of Figure 11a.

than 0.005. Once again, the L and M bands emissivity variations were much larger than the corresponding emissivity in the K band.

3.2.2 May 2001 Campaign

Figures 15a through 15c shows the K, L, and M bands for the May campaign. In contrast to the September campaign, small variability is seen among the band images. It is believed that a wet winter-spring seasons[3] washed away most of the quart-like component of the emissivity. The calculated emissivities of bands M and L during the May campaign are larger than the emissivities calculated during September campaign. Large changes were also observed in the visible bands between the September 2000 and May 2001 campaigns. Figures 16a through 16c show the calibration site of the May campaign. The spatial emissivity distribution around the calibration site for the K, L, and M bands was nearly constant.
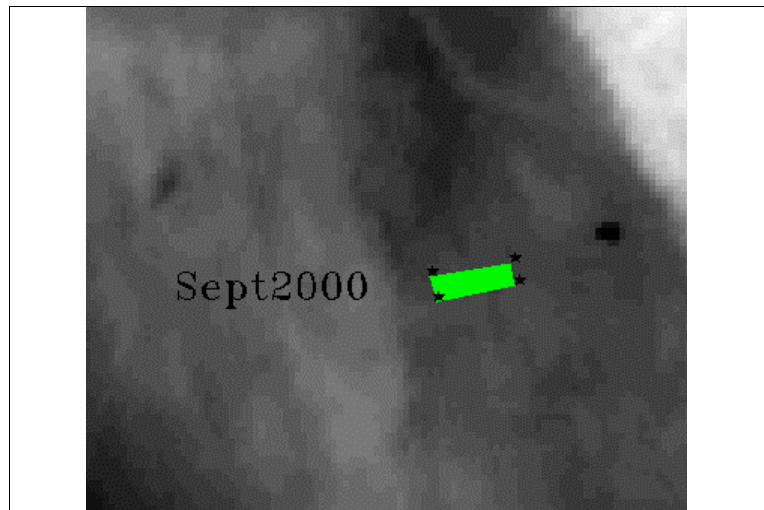

Figure 12 shows the location of the calibration site during the September 2000 campaign. The image is a temperature image calculated using band N with an emissivity of 0.93.

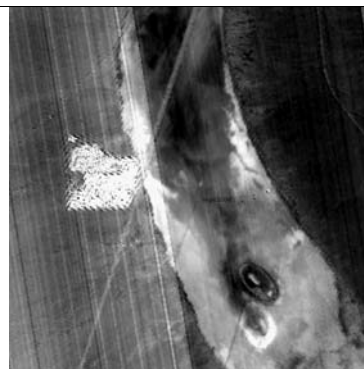Figure 13a shows band K emissivity image for the September 2000 campaign.

Figure 13b shows band L emissivity image for the September 2000 campaign.

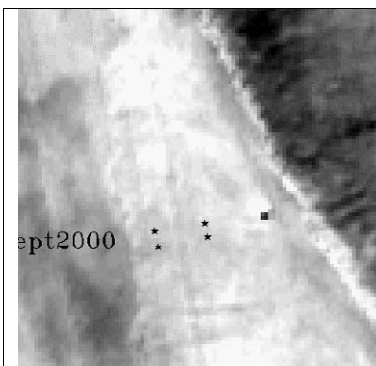Figure 13c shows band M emissivity image for the September 2000 campaign.

Figure 14a shows the band K emissivity image of the calibration site for the September 2000 campaign.
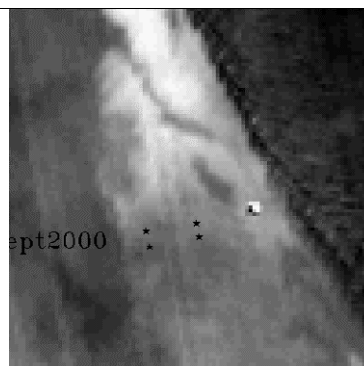

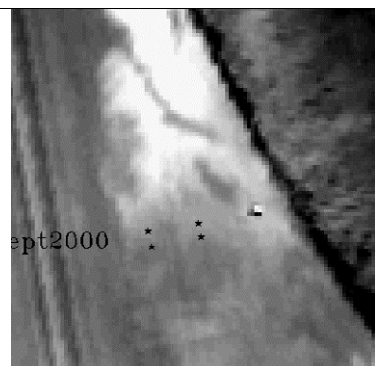Figure 14b shows the band L emissivity image of the calibration site for the September 2000 campaign.

Figure 14c shows the band M emissivity image of the calibration site for the September 2000 campaign.
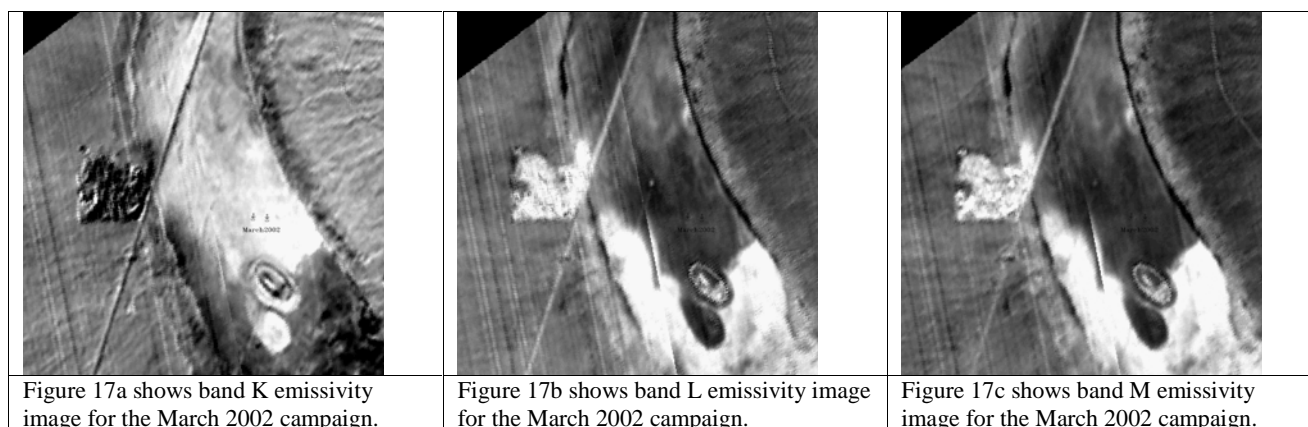
Figure 15a shows band K emissivity image for the May 2001 campaign.	Figure 15b shows band L emissivity image for the May 2001 campaign.	Figure 15c shows band M emissivity image for the May 2001 campaign.

Figure 16a shows the band K emissivity image of the calibration site for the May 2001 campaign.	Figure 16b shows the band L emissivity image of the calibration site for the May 2001 campaign.	Figure 16c shows the band M emissivity image of the calibration site for the May 2001 campaign.

The average temperature of the calibration site retrieved with the FTIR was 324.5±1.1K. The average temperature of the calibration site measured by the MTI satellite with band N (emissivity 0.93) and with an atmospheric transmission of 0.96 was 323.4K, in excellent agreement with the FTIR spectrometer results.

3.2.3 March 2002 Campaign

The ground truth campaign was conducted during the period of March 4-7, 2002. In this period, March 4 was used primarily for reflectance measurements. Unfortunately, March 4 was the only clear day in this period. Emissivity measurements and temperatures were conducted during March 5-6. Variable cloud coverage made it difficult to truly assess temperature retrievals at the calibration site with MTI imagery. On March 4, the temperature retrieved with band N, and with an emissivity of 0.93 was 297.3K. The temperature measured on the ground on March 6 under variable cloud coverage was 292.5K.

The band N calculated average emissivity at the ground level with the FTIR on March 6 was 0.922. The March emissivity value for band N is very close to the emissivity values measured on the other campaigns with the FTIR spectrometer. The spectral emissivity measured at the March site is also very similar to the emissivities measured during the July and September 2000 campaigns (combination of desert varnish and quartz). Figures 17a through 17c show the emissivity images for bands K, L, and M, respectively. Once again, the similarity of band L and M emissivities is evident from the images and dramatically different from band K emissivity.

Figure 17a shows band K emissivity image for the March 2002 campaign.	Figure 17b shows band L emissivity image for the March 2002 campaign.	Figure 17c shows band M emissivity image for the March 2002 campaign.

Summary

Four campaigns were conducted at Ivanpah Playa. The campaigns combined the visible, near-infrared and infrared regions of the electromagnetic spectrum. The Fourier transform infrared spectrometer was the primary instrument for the measurement of temperature and emissivity at the calibration sites. The mobile heated cone radiometer was used to confirm the soil surface temperature calculated with the FTIR spectrometer. Spatial and temporal analysis of soil surface temperature was characterized with a variety of instruments that included infrared imaging radiometers, and point radiometers. The surface emissivity of the playa was identified as a combination of desert varnish and quartz-like material. The ratio of these two components was approximately the same for the July and September 2000 and March 2002. The quart emissivity component was missing from the emissivity measured during the May 2001 campaign. The data suggest that the quartz component was washed away and mixed with the clay during the winter/spring rains prior to the May 2001 campaign. The emissivity in the spectral region of band N was almost constant during the multi-year campaigns (=0.93±0.01) and was used for temperature calculations from space.

Satellite imagery of Ivanpah Playa was reviewed and compared with ground truth temperatures and emissivity. Satellite data was available during the September 2000, May 2001 and March 2002 campaigns. Scatter plots were calculated from different reflectance bands and thermal bands. In contrast to bands L and M, visible and TOA band N radiance show an inverse relationship. The bands L and M were shown to have two components in the playa. Band N with an average emissivity of 0.93 was used to calculate ground temperatures. The temperatures calculated from satellite imagery and with the FTIR agreed within 1K for the September 2000 and May 2001 campaigns. Ground truth temperature measurements were not conducted on the only clear day of the March campaign, therefore, temperature comparison between the satellite and ground truth was not available.

Emissivity images for the different thermal bands were conducted for the different campaigns. The emissivities across the playa follow many of the changes observed in the visible images. A large change in the visible and infrared images was observed during the September 2000 and May 2001 campaigns. A small change was observed during the transition between May 2001 and March 2002 campaigns.

ACKNOWLEDGMENTS

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