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Land Surface Temperature Measurements from EOS MODIS Data

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The PGE codes for daily, 8-day, and monthly land-surface temperature/emissivity (LST) products at 0.05° climate model grids (CMG) were delivered to the MODIS team in January 2003. In June the MODAPS started the generation of the CMG LST products from Terra MODIS data. The Terra MODIS CMG LST products were released to the public in June 2003. The MODIS LST web page and Users' Guide were updated in June.

A major field campaign was conducted in Railroad Valley, NV, in late June. Ground-based measurements were made in the clear-sky days from June 26 to 30. Sky radiance and surface-leaving TIR radiance under sunshine and shadow conditions were measured with a Bomem TIR spectroradiometer (Model MR100). Diurnal surface temperatures were measured with four TIR radiometers. Six radio sounding balloons were launched in the period of clear-sky days to measure the atmospheric temperature and water vapor profiles. MODIS Airborne Simulator (MAS) data were acquired in a daytime flight and a nighttime flight on June 27. The excellent match between the measured spectral sky radiance and the radiance calculated with the atmospheric radiative transfer code MODTRAN4.0 based on the measured atmospheric profiles provides a solid evidence of the good quality of both the Bomem TIR spectroradiometer and the radiative transfer code. The measured surface-leaving TIR radiance under sunshine and shadow conditions were used to retrieve playa surface spectral emissivity by a sun-shadow method. The band-averaged emissivities calculated from the retrieved spectral emissivity agree within 0.005 with those used in the MODIS split-window LST algorithm for the site. Terra and Aqua MODIS 1km LST products were validated with the conventional temperature-based method using the LSTs measured by the TIR radiometers at nights. This method is limited by the spatial variation in LSTs, which is obviously shown in the day and night MAS images. We also used a radiance-based method that is based on the MODTRAN code, measured surface emissivity and atmospheric profiles. The Terra and Aqua MODIS LST products were validated with the radiance-based method successfully both in day and night conditions. The LST accuracies are better than 1K in all seven Aqua cases where viewing zenith angle ranges are up to 56°, and in four of six Terra cases. The LST accuracy is better than 1.5K in the remaining two Terra cases with viewing zenith angle at 54° and 60°. The accuracy of nighttime LSTs at viewing zenith angles within 47° is better than 0.5K in all six cases (including two Terra cases and four Aqua cases).

Recent Papers

Z. Wan, P. Wang, and X. Li, Using MODIS land-surface temperature and normalized difference vegetation index products for monitoring drought in the Southern Great Plains, USA, *Int. J. Remote Sens.*, in press 2003.

Z. Wan, Y. Zhang, Q. Zhang, and Z.-L. Li, Quality assessment and validation of the MODIS global land-surface temperature, *Int. J. Remote Sens.*, in press 2003.

Z.-L. Li, L. Jia, Z. Wan, and R. Zhang, A new approach for retrieving precipitable water from ATSR-2 split-window channel data over land area, *Int. J. Remote Sens.*, in press 2003.

1. LAND-SURFACE TEMPERATURE PRODUCTS AT CLIMATE MODEL GRIDS

There is a strong requirement within the land research community for MODIS global land products at a climate model grids (CMG) of equal angles in the conventional latitude and longitude projection, that is widely used in the climate model studies. Based on recommendations in the Science Working group for the AM Platform (SWAMP) meetings before launch (December 1999), the grid size was set to 0.25° or 0.5°. In the last a few years, land modelers made a request for the 0.05° resolution. The MODIS Land group decided that the 0.05° resolution would be a base for the MODLAND CMG products. Therefore, this CMG size has been used for the MODIS CMG land-surface temperature (LST) products. The exact areal size of the equal angle grids varies with latitude, and it is 5.6km by 5.6km at the Equator.

The temperature and emissivity values in the daily CMG LST product (MOD11C1) are derived by reprojection and average of the values in the daily MODIS LST product (MOD11B1) at 5km equal area grids in the sinusoidal projection. Before making reprojection in the production of MOD11C1, cloud-contaminated daytime and nighttime LSTs are removed by the double-screen scheme, which is described in the LST validation paper (Wan et al., 2002). In the first step, the temperature difference distributions between the LSTs at 5km grids retrieved by the day/night LST algorithm and the LST values aggregated to 5km grids from those retrieved by the generalized split-window algorithm are calculated for all grids in northern or southern hemisphere, for daytime and nighttime LSTs, respectively. The LSTs which correspond to the 1% of the difference distributions by the upper and lower ends are removed. In the second step, the histogram of difference between daytime and nighttime LSTs is used to remove the grids contaminated with cloud effects after the first screen described above: screen off 0.5% of the daytime and nighttime LST pairs by the upper and lower ends of the LST difference distribution. The retrieved emissivity values corresponding to these removed LSTs are also removed. After cloud-contaminated daytime and nighttime LSTs are removed, the LST values aggregated to 5km grids from those retrieved by the generalized split-window algorithm are used to supplement the LSTs retrieved by the day/night LST algorithm at grids where there is no valid pair of day and night observations (usually in high-latitude regions). Due to this LST supplement, the spatial coverages of LSTs are larger than the spatial coverage of retrieved emissivities in the MOD11C products. There are 15 science data sets (SDSs) in the MOD11C1 product. They are LST_Day_CMG, QC_Day, Day_view_time, Day_view_angle, LST_Night_CMG, QC_Night, Night_view_time, Night_view_angle, emissivity values in bands 20, 22-23, 29, and 31-32, and QC_Emis, which gives the indexes of day and night view angle sub-ranges (each in 4 bits) used in the day/night algorithm.

The 8-day CMG LST product (MOD11C2) provides 8-day composited and averaged temperature and emissivity values at the 0.05 degree CMGs, as well as the averaged observation times and viewing zenith angles for daytime and nighttime LSTs. The temperature and emissivity values in the MOD11C1 product over a period of 8 days are simply composited and averaged. The days and nights in clear-sky conditions and with validated LSTs are flagged in each bit of two 8-bit unsigned integers (one for daytime LSTs and another for nighttime LSTs).

The monthly CMG LST product (MOD11C3) provides monthly composited and averaged temperature and emissivity values at 0.05 degree CMGs, as well as the averaged observation times and viewing zenith angles for daytime and nighttime LSTs. The temperature and emissivity values in the MOD11C1 product in a calendar month are simply composited and averaged. The days and nights in clear-sky conditions and with validated LSTs are flagged in each bit of two 32-bit unsigned integers (one for daytime LSTs and another for nighttime LSTs).

The PGE codes for daily, 8-day, and monthly land-surface temperature/emissivity (LST) products at 0.05° climate model grids (CMG) were delivered to the MODIS team in January 2003. In June the MODAPS started the generation of the CMG LST products from Terra MODIS data. Early V4 Terra MODIS CMG LST products since June 1, 2000 were generated at the MODIS LST Science Computing Facility (SCF) at UCSB. The Terra MODIS CMG LST products were released to the public from the Land Processes Distributed Active Archive Center at the EDC in June 2003. They can be ordered through the EOS Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/). Users can also download the MOD11C products from the MODIS LST ftp site.

The MODIS LST web page and Users' Guide were updated in June.

Fig. 1 shows the spatial distributions of the temporal changes in the global daytime monthly CMG LSTs in January-June, 2003. The MODIS CMG LST products generated at the MODIS LST SCF have been used in test studies by scientists at the NASA/GSFC Data Assimilation Office (DAO) even before their official release. Many other users also download the MOD11C products from the MODIS LST ftp site.

2. CALIBRATION AND VALIDATION FIELD CAMPAIGNS

We conducted a successful vicarious calibration field campaign in Walker Lake, NV, in January 2003. The results were reported in the last semi-annual report (for July - December, 2002). The conclusions were that the calibration bias in the Aqua MODIS data is within 0.2K in bands 22, 23, 29, and 31-32, and that the averaged calibration bias of Terra MODIS agrees with the calibration bias of Aqua MODIS within 0.2K in bands 20, 22, 23, 29, and 31-33.

We conducted another field campaign in Walker Lake, NV, in March 2003 in order to have more clear-sky cases to confirm the above conclusions. Unfortunately, there was no single real clear-sky day in the period of two weeks and the weather forecast for the following week in early April was also not good. We have to wait for the next dry season starting in November to make another vicarious calibration field campaign.

In order to validate the Terra and Aqua MODIS LST products, we conducted a major field campaign in Railroad Valley, NV, in late June. Ground-based measurements were made in the clear-sky days from June 26 to 30. Because the Land Management Office did not allow us to drive off the road, we deployed four TIR radiometers by the road in the central portion of the Railroad Valley playa, two in the east side and two in the west side. The distance between two is about 500m. The TIR radiometers were placed at approximately 3.5m above ground and their field-of-view is about 1.5m in diameter. The TIR radiometers are the same used in our early field campaigns (Wan et al., 2002). The accuracy of these TIR radiometers is better than 0.2K. A Bomem TIR spectroradiometer (Model MR100) was deployed by the center of the rectangular consisting of the four radiometers on the ground. The position of the spectroradiometer was at latitude 38.48168 °N and longitude 115.69053 °W. This TIR spectroradiometer is the new version of the Atmospheric Emitted Radiance Interferometer (AERI) that is used to measure downwelling infrared radiation from 3-25μm (Feltz et al., 1998) and to measure the surface-leaving radiance for the validation of sea surface temperature measurements (Smith et al., 1996). This TIR spectroradiometer is equipped with two accurate blackbody sources for calibration at an accuracy better than 0.1K. MODIS Airborne Simulator (MAS) data were acquired in two ER-2 flights on June 27, one for the daytime Terra overpass, and another for the nighttime Terra overpass. As shown in Table I, six sounding balloons that carry Vaisala radiosonde RS90-A were launched in the period of clear-sky days to measure the atmospheric temperature and water vapor profiles.

TABLE I. Atmospheric temperature and water vapor profiles measured with radio sonde Vaisala RS90-A in Railroad Valley (at 38.48166 °N, 115.69051 °W), NV, under clear-sky conditions during June 26-29, 2003.

case no.	date m/d/y	start time PDT (hh:mm)	duration (minutes)	height reached (km)	cwv (cm)	T_{s-air} (K)
A	6/26/03	10:22	112	16.1	0.71	298.2
B	6/27/03	10:14	103	19.1	0.78	299.7
C	6/27/03	22:56	102	23.2	1.00	291.8
D	6/28/03	02:13	120	23.3	0.90	284.2
E	6/29/03	10:29	120	24.4	0.84	305.2
F	6/29/03	22:05	120	24.4	0.67	291.6

3. RESULTS OF THE JUNE 2003 FIELD CAMPAIGN

3.1 Temporal and Spatial Variations in LSTs Shown in the MAS Images

We made ground-based measurements of surface temperatures in the site of Railroad Valley playa at least three times, in June-July of 1997, 2001, and 2003. We learned that there may be significant temporal and spatial variations in LSTs, especially during the daytime. The variations are smaller at night. It may be possible to validate the nighttime MODIS LSTs with ground-based measurements if multiple TIR radiometers are deployed in an area of a few km^2 with relatively homogeneous LSTs.

Figure 2 is the color composite with the 6/27/03 daytime MAS images in bands at 11μm, 8.66μm, and 3.97μm as RGB components. Figure 3 is the color composite of the nighttime MAS images in the same bands on the same day. We can see that the location (38.48168 °N, 115.69053 °W), where our TIR instruments were deployed, is in the lower right side of the + symbol at 38.5 °N, 115.7 °W at a small distance. This location is just by the boundary of the central portion of the playa, where surface temperatures are relatively homogeneous and warmer than the surroundings, in both the daytime and nighttime MAS images of June 27, 2003. As shown in Figure 4, the color composite with the daytime MAS images in similar bands acquired on June 23, 1997, the location we selected to make ground-based measurements is within the central portion of the playa, where surface temperatures are relatively homogeneous.

We observed that the surface in the central portion of the playa was covered with loose soils this year. The surface conditions in its surrounding areas, especially in the west and south, were smoother and harder, and with obvious polygon structures, similar to the conditions observed in 1997 and 2001. On strong windy days such as June 23, 2003, we observed heavy dusts above the ground in the central portion, but not in the western and southern surrounding areas. Based on the experience from our laboratory emissivity measurements of the surface samples taken from the field in the previous years, we expect that the surface emissivity in the central portion of the playa to be higher this year. The measurements of samples taken from the field support this expectation. However, these samples are too loose to keep their same conditions in the field.

3.2 Comparison between Measured and Calculated Sky Radiances

As shown in Figure 5, the TIR spectroradiometer MR100 was used to measure the downwelling radiance at the 4 wavenumber resolution at 10:30 PDT on June 29, 2003. The atmospheric temperature and water vapor profiles were measured during 10:29-12:29 PDT on the same day. The measured atmospheric profiles are shown in Figure 6. We used this set of profiles, time 10:29 PDT and the location as inputs to the atmospheric radiative transfer simulation with the MODTRAN4.0 code (Berk et al., 1999) to calculate the downwelling radiance at the same spectral resolution. The brightness temperatures of calculated downwelling radiance and the measured radiance are compared in atmospheric windows 3.3-5μm and 8-

14μm, as shown in Figure 7. They are in excellent agreements except near 4μm and in the 4.2-4.5μm region, where the downwelling radiance is sensitive to the atmospheric temperature in the lower boundary. The small difference of a few degree K may reflect the temporal and spatial variations in the atmospheric temperature.

The significances of this comparison includes: (1) The Bomem TIR spectroradiometer performs well in a wide temperature range; (2) The spectral data confirm that it was a clear-sky day without invisible cirrus clouds; (3) The Bomem TIR spectroradiometer can be used to evaluate our blackbody sources which calibrate our TIR radiometers; (4) The MODTRAN4.0 code works well in these two spectral windows, especially at the wavelengths of the seven MODIS bands used in the MODIS LST algorithms; (5) The excellent agreements provide a solid evidence of the good quality of the instrument and the radiative transfer code; (6) It increased our confidence in the MODTRAN4.0 code in the development of coefficients and look-up tables for the MODIS LST algorithms.

3.3 Spectral Emissivity of Playa Measured with the Sun-shadow Method

We measured the surface-leaving TIR radiance at viewing zenith angles of 0°, 15°, 30° and 45° under sunshine and shadow conditions with the spectroradiometer MR100 on June 29. The field-of-view of the spectroradiometer is approximately 15cm when it is placed at the ladder supporting structure about 2.5m above the ground. The surface-reflected solar, atmospheric emission, and environmental radiances under sunshine and shadow conditions were measured the same spectroradiometer when an aluminum plate was placed just above the surface target locations. The aluminum plate was blasted with sands to make its surface rough so that it is close to a Lambertian surface. The reflectance of the aluminum plate is around 0.7 in the 3-14μm spectral region. The surface temperature of the aluminum plate was measured by a thermistor continuously and the temperature data were recorded in a data logger. Each set of the measured spectra of the surface and the aluminum plate under sunshine and shadow conditions are used to retrieve the surface emissivity in a sun-shadow method. In the first step, the radiance values in MODIS bands 20, 22-23, 29, and 31-33 were calculated from the measured spectra. Then a simplified version of the same algorithm used in the day/night LST method (Wan and Li, 1997) was used to retrieve the playa surface temperatures under sunshine and shadow conditions, and its emissivity values in the seven bands. Once the playa surface temperature is determined, the measured spectral data can be used to calculate the spectral emissivity of the playa surface. The spectral emissivity shown in Figure 8 is for the playa surface at the nadir direction. The band-averaged emissivities calculated from this retrieved spectral emissivity are slightly larger and agree within 0.005 with those in bands 31 and 32 used in the MODIS split-window LST algorithm for the site. The spectral emissivities at viewing zenith angles of 15°, 30° and 45° were also retrieved. The changes in band-averaged emissivities in bands 31 and 32 calculated from these spectral emissivities are less than 0.005, and these changes are the combined effects of spatial and angular variations in the surface emissivity values. In order to separate the effects of spatial and angular variations, we have to move the heavy spectroradiometer MR100 (approximately 150lb) and its supporting structure in the field. We will try to do so in the future.

3.4 Two Methods for the Validation of Space-measured LSTs

There are two method to validate the LSTs retrieved from airborne or satellite data.

The first method is based on in-situ surface temperature measurements with TIR radiometers. We also call this method as the conventional method. In order to correct the effects of surface emissivity and reflected atmospheric radiation, we need to have surface spectral emissivity and typical atmospheric temperature and water vapor profiles as inputs to atmospheric radiative transfer simulations for the ground-based measurements. The sensor position is set at the height of the TIR radiometers used in field measurements. It is 3.5m above surface in our cases. The radiance measured by the TIR radiometer can be calculated from the simulated spectral radiance at the TIR radiometer level and the spectral response function of the radiometer. The difference between the given surface temperature and the brightness temperature of the radiance measured by the TIR radiometer is the correction for the effects of surface emissivity and reflected atmospheric radiation. Based on the measured spectral emissivity of playa surface shown in Figure 8 and the atmospheric profiles measured on Jun 29 , the correction is 1.9K.

The second method is a radiance-based method. The LST value in the MODIS 1km LST product at the field location, and measured spectral emissivity and atmospheric temperature/humidity profiles are used as inputs to the atmospheric radiative transfer simulations with the MODTRAN4.0 code. The sensor (MODIS in our cases) is set at the top of the atmosphere and at the real MODIS viewing angle. The spectral response functions of MODIS bands 29, 31, and 32 are used to calculate the brightness temperatures in these three bands from the simulated spectral radiance of the MODIS. Then comparison between the calculated and actual brightness temperatures in MODIS band 31 shows the accuracy of the MODIS LST value that is retrieved from the MODIS data in bands 31 and 32 by the split-window method. The sensitivity of the calculated band 31 brightness temperature to the surface LST is the atmospheric transmission in band 31. The difference between the calculated and actual brightness temperatures in MODIS band 29 indicates how well the measured atmospheric temperature and water vapor profiles agree with the real conditions in the MODIS observation.

The atmospheric radiative transfer code MODTRAN4.0 is the same theoretical basis for these two method. The surface spectral emissivity is required in both methods. The advantage of the temperature-based method is that the real-time atmospheric temperature and humidity profiles are not required because the surface-reflected atmospheric radiation is only a small value compared to the effect of the surface emissivity in the correction term. The disadvantage of the method is that the spatial variation in the in-situ measured LSTs is the primary limiting factor, i.e., the LST in a MODIS 1km pixel may not be measured by a limited number of TIR radiometers on the ground. The advantage of the radiance-based method is that the spatial variation in LSTs is not an issue because the MODIS LST value and the brightness temperatures of the MODIS data are always on the same scale of MODIS pixels. However, the atmospheric temperature and humidity profiles are the primary inputs in this method. The atmospheric profiles measured by the radio sonde may be different from the atmospheric profiles in the path of the MODIS observation. Therefore, this method is more effective in dry and relatively dry atmospheric conditions where the effects of the temporal and spatial variations in the atmospheric profiles are smaller.

3.5 Validation of the Terra and Aqua MODIS LSTs with the Temperature-based Method

There are large differences in the LST values measured by the four TIR radiometers. The maximum difference may be several degrees K at the time of daytime MODIS overpasses. The maximum difference is a few degrees K during night. Therefore, we only used the temperature-based method to validate the nighttime MODIS LSTs in two Terra cases and two Aqua cases with the in-situ measured LSTs, as shown in Table II. We have a low confidence for these validation results in the Railroad Valley site this year because of the large spatial variation in LSTs.

TABLE II. Temperature-based validation of the MODIS LSTs using in-situ measured LSTs in the June 2003 Railroad Valley field campaign.

case no.	platform	granule ID	date & time (m/d/y hh:mm)	viewing zenith angle (°)	atmos. cwv (cm)	in-situ T_s from radiometers (δT_s) (K)	MODIS T_s (δT_s) (K)	MODIS - in-situ T_s (K)
1	Terra	A2003179.0545	6/27/03 22:49 PDT	4.6	1.00	289.11 (0.9)	288.43 (0.6)	-0.7
2	Terra	A2003181.0535	6/29/03 22:37 PDT	18.4	0.67	290.15 (0.5)	289.86 (0.6)	-0.3
3	Aqua	A2003179.0955	6/28/03 02:59 PDT	31.9	0.90	282.33 (0.7)	281.09 (0.3)	-1.2
4	Aqua	A2003181.0945	6/30/03 02:47 PDT	11.4	0.67	283.54 (0.4)	282.34 (0.6)	-1.2

3.6 Validation of the Terra and Aqua MODIS LSTs with the Radiance-based Method

We used the radiance-based method to validate the Terra and Aqua MODIS LSTs using the measured atmospheric profiles shown in Table I. We considered all clear-sky cases for both Terra and Aqua MODIS daytime and nighttime granules during the period of June 26-30, 2003. There are six clear-sky cases for Terra MODIS and seven clear-sky cases for Aqua MODIS. The detailed validation results are given in Tables III and IV, respectively. The match score (MS) at a scale from 1-10 is given in the parentheses after the atmospheric profile case number. As shown in Table III, the minimum value of the atmospheric transmission in band 31 is 0.84 for case 4, where the MODIS viewing zenith angle is 60.2°. The difference between the calculated and real brightness temperature values given in the last column is -0.95K in this case. Dividing this value by the atmospheric transmission (0.84) gives -1.13K, an estimate of the error in the MODIS LST in this large zenith angle case. Similarly, the estimate of error in case 1 is -1.25K.

TABLE III. Radiance-based validation of the LSTs in the V4 level-2 Terra MODIS LST product (MOD11_L2) in the June 2003 Railroad Valley field campaign. ΔT_b is the difference between the brightness temperature calculated by MODTRAN4.0 based on the MODIS LST value and the measured atmospheric profile and the brightness temperature of the MODIS radiance in band 29 or 31. The match score (MS) is given after the atmospheric profile number.

case no.	granule ID	date & time PDT (m/d hh:mm)	viewing zenith (°)	MOD07 cwv, T_{s-air} (cm, K)	atmos. profile no. (MS)	MOD11 LST (K)	ΔT_b in b29 (K)	trans. in b31	ΔT_b in b31 (K)
1	A2003177.1800	6/26 11:02	53.7	0.67, 299.3	A (9)	320.18	-0.85	0.88	-1.10
2	A2003178.1840	6/27 11:45	11.5	1.90, 305.2	B (9)	326.78	-0.18	0.92	-0.59
3	A2003179.0545	6/27 22:49	4.6	1.30, 291.8	C (9)	288.43	+0.14	0.91	-0.21
4	A2003180.0630	6/28 23:32	60.2	1.30, 293.4	C (6)	287.82	-0.84	0.84	-0.95
5	A2003180.1830	6/29 10:33	12.0	0.96, 301.4	E (9)	327.62	-0.58	0.92	-0.81
6	A2003181.0535	6/29 22:37	18.4	0.67, 291.6	F (9)	289.86	+0.44	0.93	+0.01

For Aqua case 3 in Table IV, the atmospheric profile (B) measured in the morning of June 27 was used for the early afternoon Aqua case on the same day. If we increase the atmospheric temperatures at levels up to 4km by 3K, the comparison results are shown as case 3'. Similarly, for cases 5 and 6. The maximum effect of the change in atmospheric temperatures is 0.15K, dividing it by the minimum transmission value (0.87) giving 0.17K, an uncertainty on the LST error estimate due to atmospheric temperature changes. We also considered the effect of uncertainties in the measured atmospheric water vapor profiles for case 6, the case at viewing zenith angle 55.7°, by multiplying a factor of 0.9 on the water vapor profile. The results are given as case 6", showing that the effect of the uncertainties in water vapor profiles on the LST error estimate is 0.32K in this large zenith angle case. The effect of the uncertainty of 0.005 in the surface emissivity on the LST error estimate is about 0.3K.

TABLE IV. Radiance-based validation of the LSTs in the V3 level-2 Aqua MODIS LST product (MYD11_L2) in the June 2003 Railroad Valley field campaign. ΔT_b is the difference between the brightness temperature calculated by MODTRAN4.0 based on the MODIS LST value and the measured atmospheric profile and the brightness temperature of the MODIS radiance in band 29 or 31. The match score (MS) is given after the atmospheric profile number.

case no.	granule ID	date & time PDT (m/d hh:mm)	viewing zenith (°)	MYD07 cwv, T_{s-air} (cm, K)	atmos. profile no. (MS)	MYD11 LST (K)	ΔT_b in b29 (K)	trans. in b31	ΔT_b in b31 (K)
1	A2003177.1010	6/26 03:11	46.9	0.64, 287.6	A (7)	280.55	+0.09	0.90	-0.23
2	A2003178.0915	6/27 02:16	40.9	0.61, 288.9	D (6)	280.56	-0.22	0.90	-0.26
3	A2003178.2020	6/27 13:20	44.4	0.56, 298.5	B (8)	331.12	-0.51	0.90	-0.65
3’	A2003178.2020	6/27 13:20	44.4	0.56, 298.5	B* (8)	331.12	-0.29	0.90	-0.50
4	A2003179.0955	6/28 02:59	31.9	1.01, 289.6	D (9)	281.09	-0.03	0.91	-0.28
5	A2003179.2100	6/28 14:03	26.9	1.29, 290.6	E (6)	331.31	-0.53	0.92	-0.62
5’	A2003179.2100	6/28 14:03	26.9	1.29, 290.6	E* (7)	331.31	-0.34	0.92	-0.48
6	A2003180.2005	6/29 13:08	55.7	0.80, 302.6	E (8)	326.51	-0.37	0.87	-0.72
6’	A2003180.2005	6/29 13:08	55.7	0.80, 302.6	E* (9)	326.51	-0.11	0.87	-0.58
6’’	A2003180.2005	6/29 13:08	55.7	0.80, 302.6	E*-(8)	326.51	+0.30	0.87	-0.30
7	A2003181.0945	6/30 02:47	11.4	0.50, 289.9	F (8)	282.34	+0.17	0.87	-0.06

Note *: the atmospheric temperatures at levels up to 4km are increased by 3K.

Note *-: add 3K to atmospheric temperatures at levels up to 4km and multiply 0.9 on the water vapor profile.

The results in Tables III and IV indicate that the MODIS LST accuracies are better than 1K in all seven Aqua cases where viewing zenith angle ranges are up to 56°, and in four of six Terra cases. The LST accuracy is better than 1.5K in the remaining two Terra cases with viewing zenith angle at 54° and 60°. The accuracy of nighttime LSTs at viewing zenith angles within 47° is better than 0.5K in all six cases (including two Terra cases and four Aqua cases).

4. CONCLUSION

The PGE codes for daily, 8-day, and monthly land-surface temperature/emissivity (LST) products at 0.05° CMGs were delivered to the MODIS team in January 2003. In June the MODAPS started the generation of the CMG LST products from Terra MODIS data. The Terra MODIS CMG LST products were released to the public in June 2003. The MODIS LST web page and Users' Guide were updated in June.

We conducted a successful field campaign in Railroad Valley, NV, in late June. The excellent match between the measured and calculated spectral sky radiances provides a solid evidence of the good quality of the Bomem TIR spectroradiometer and the atmospheric radiative transfer code MODTRAN4.0. The surface-leaving TIR radiance under sunshine and shadow conditions measured by the TIR spectroradiometer were used to retrieve playa surface spectral emissivity by a sun-shadow method. The band-averaged emissivities calculated from the retrieved spectral emissivity agree within 0.005 with those used in the MODIS split-window LST algorithm for the site. We used a radiance-based method, that is based on the MODTRAN code, measured surface emissivity and atmospheric profiles, to validate Terra and Aqua MODIS 1km LST products. The LST accuracies are better than 1K in all seven Aqua cases and in four of six Terra cases. The LST accuracy is better than 1.5K in the remaining two Terra cases with viewing zenith angle at 54 ° and 60 °. The accuracy of nighttime LSTs at viewing zenith angles within 47 ° is better than 0.5K in all six cases (including two Terra cases and four Aqua cases).

Acknowledgment

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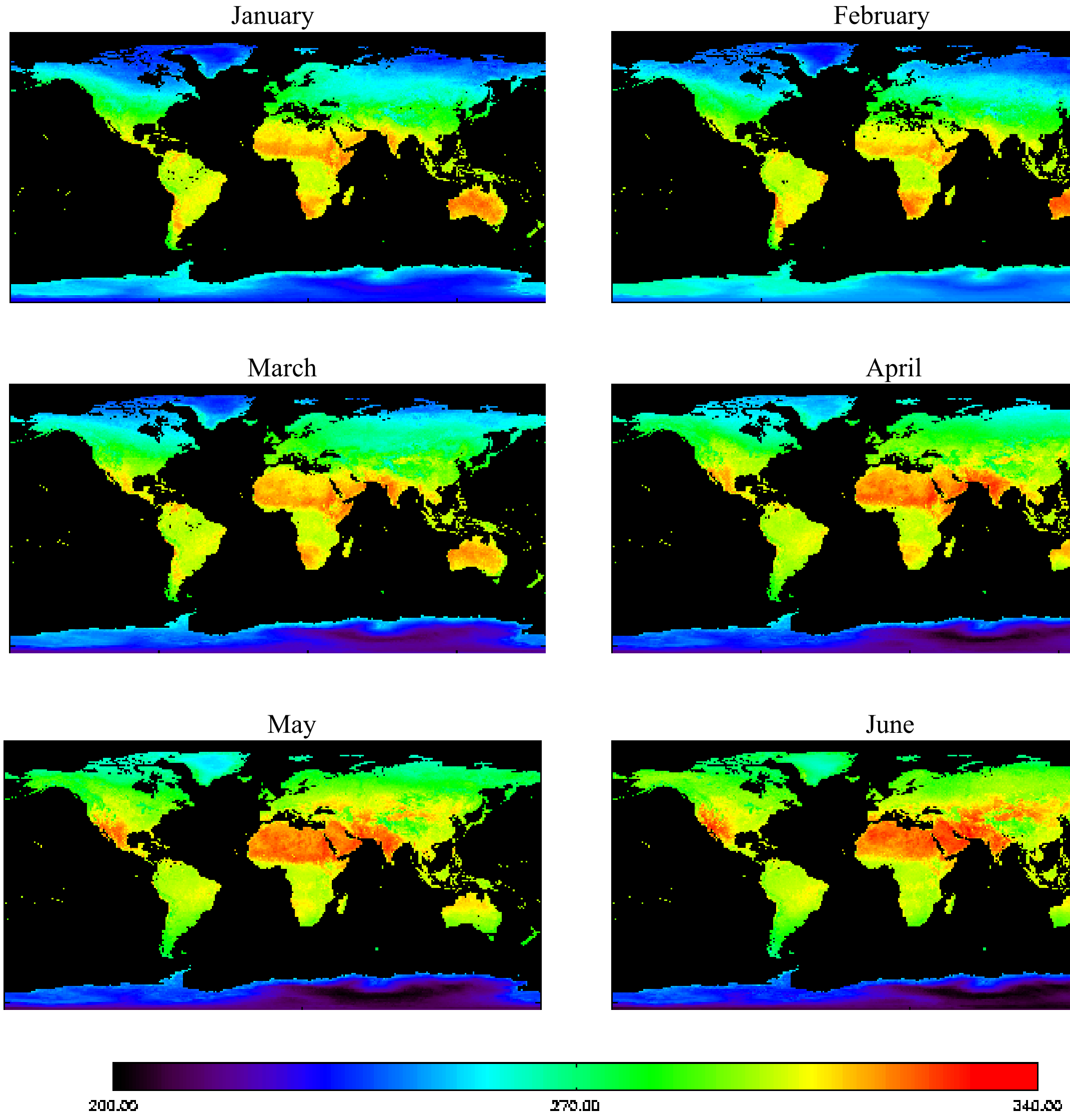
Fig. 1, Monthly averaged daytime CMG LSTs from Terra MODIS data in 2003.



January

February

March

April

May

June

Fig. 2, Color composite with MAS bands at 11µm, 8.66µm and 3.97µm as RGB components.

2003/06/27 18:32:10 UTC

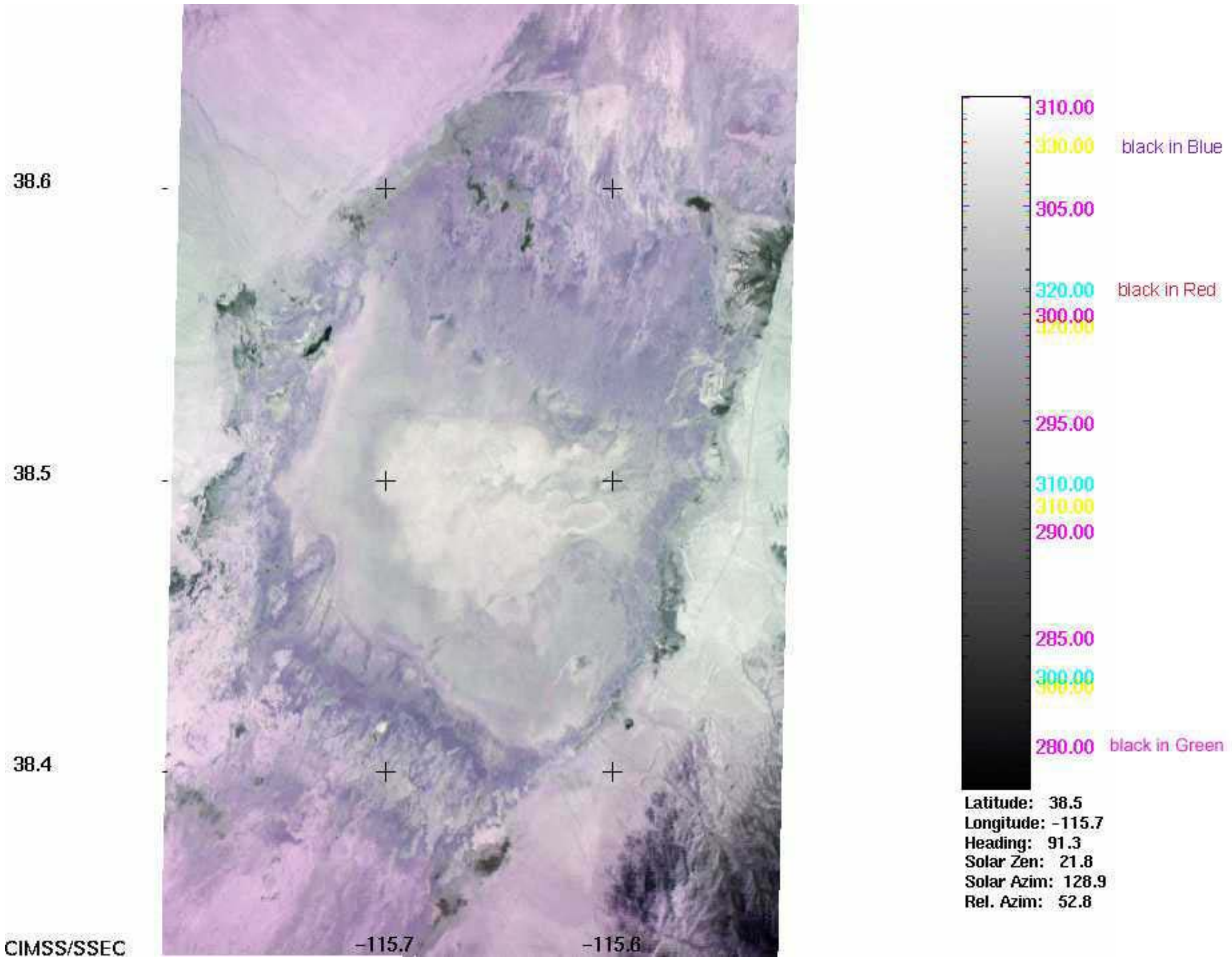


Fig. 3, Color composite with MAS bands at 11µm, 8.66µm and 3.97µm as RGB components.

2003/06/28 05:38:09 UTC

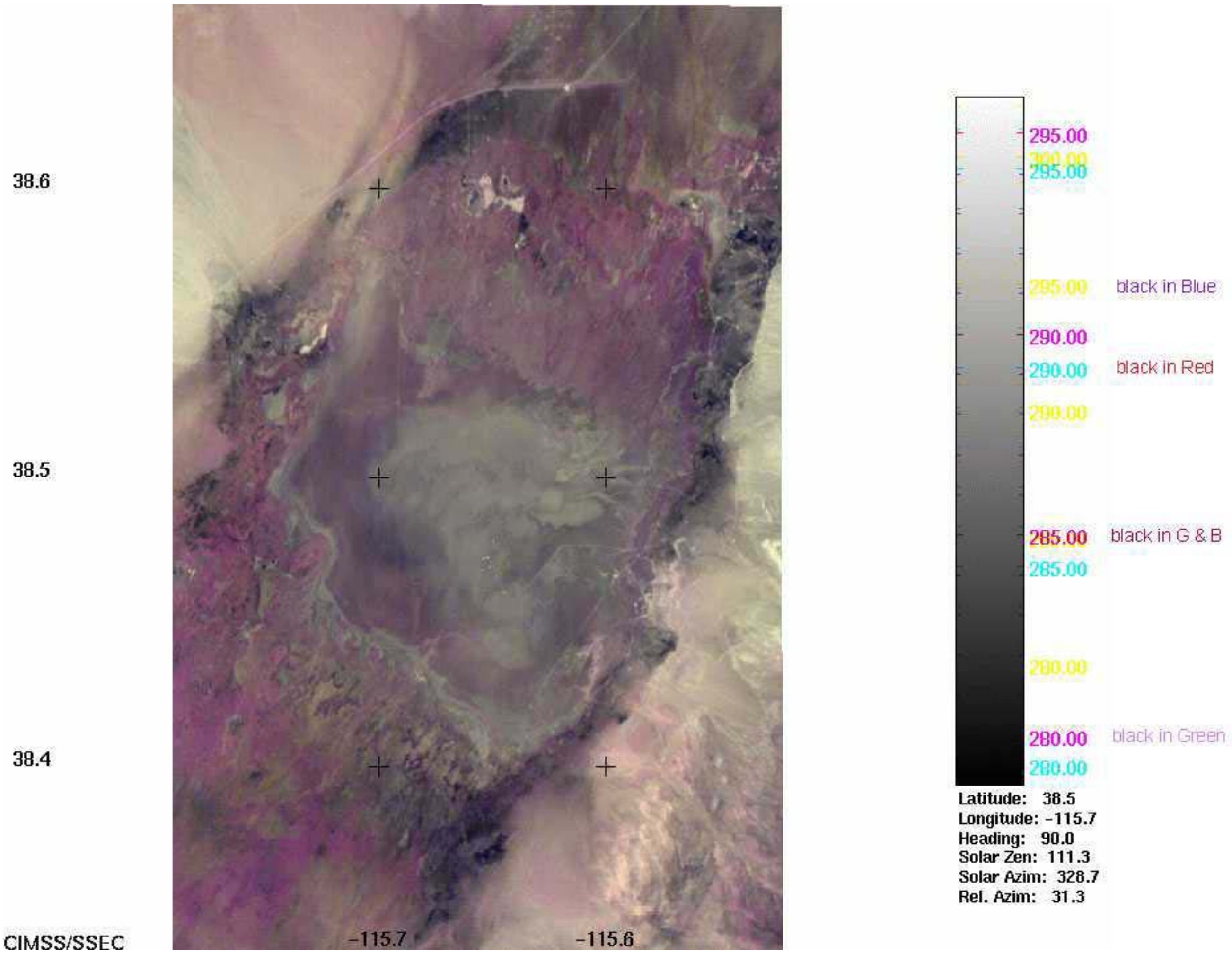


Fig. 4, Color composite with MAS bands at 11μm, 8.66μm and 3.97μm as RGB components.

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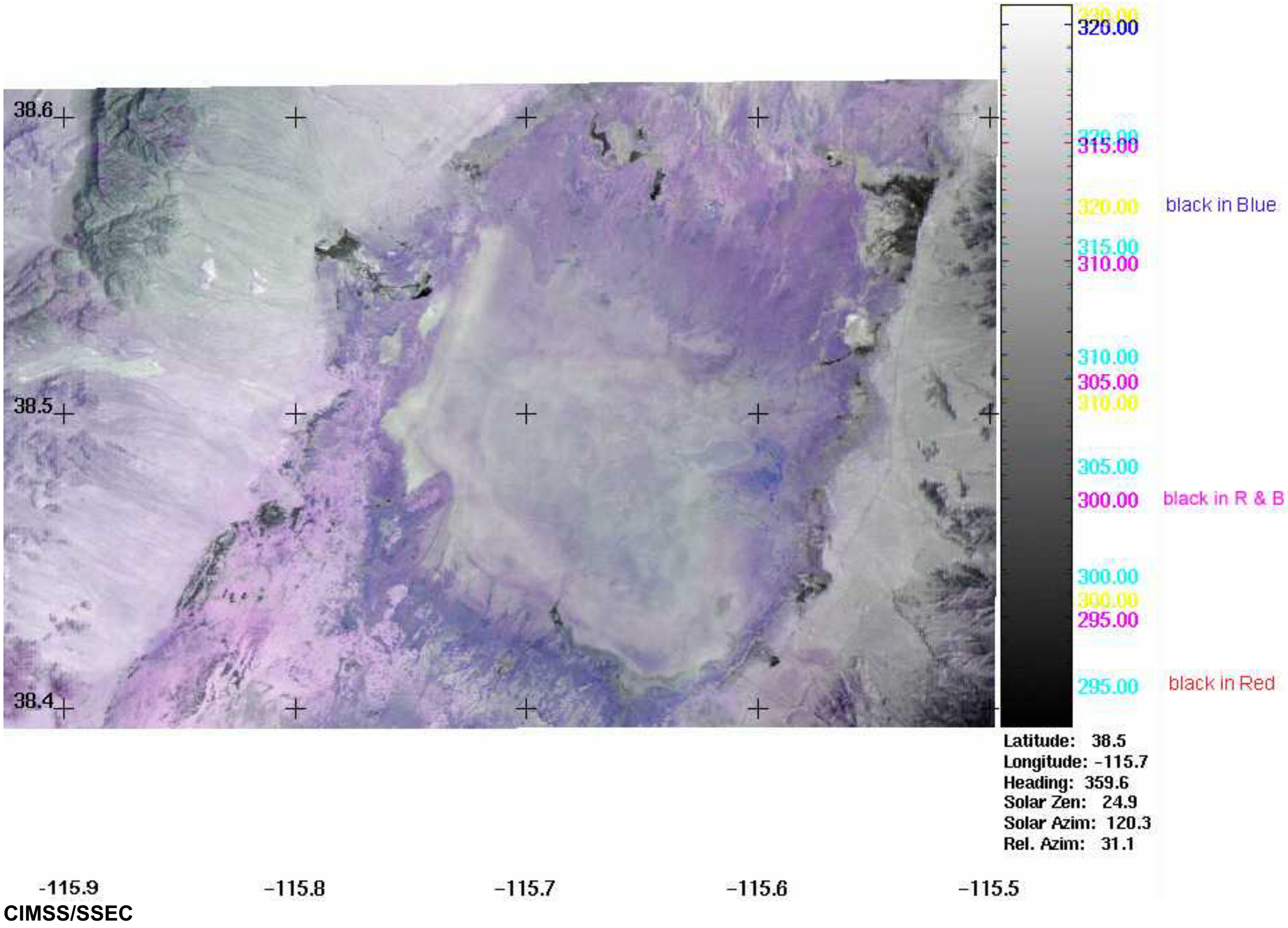

Fig. 5, Bomem spectroradiometer MR100 deployed in Railroad Valley, NV, in late June 2003.

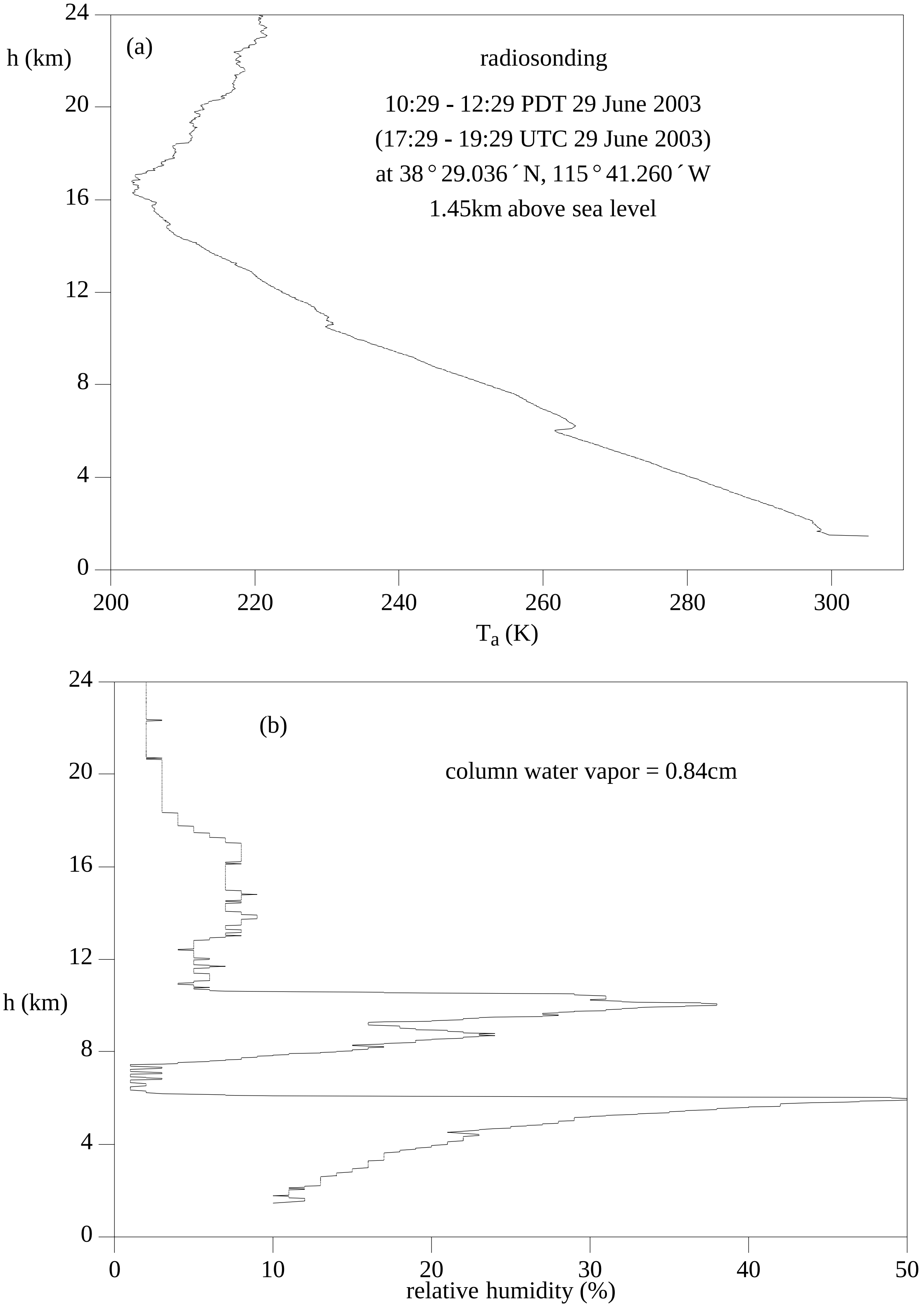

Fig. 6, Atmospheric temperature (a) and relative humidity (b) profiles measured by radiosonding over Railroad Valley, NV on 29 June 2003.

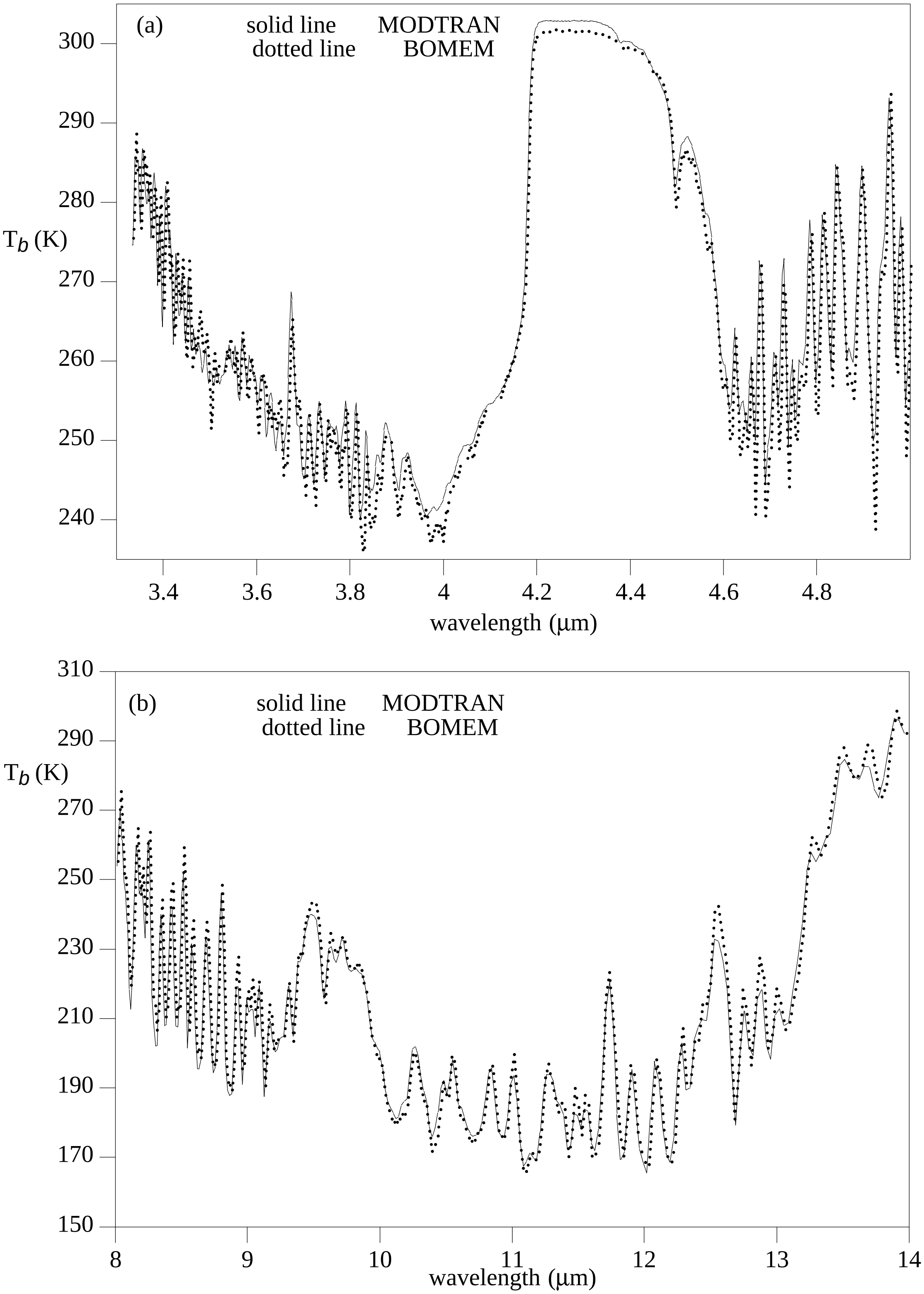

Fig. 7, The brightness temperature T_b of downwelling radiance at nadir measured by Bomem TIR spectroradiomter MR100 at 10:30 PDT 6/29/03 in Railroad Valley, NV, and the T_b calculated by MODTRAN4.0 based on measured atmospheric profiles.

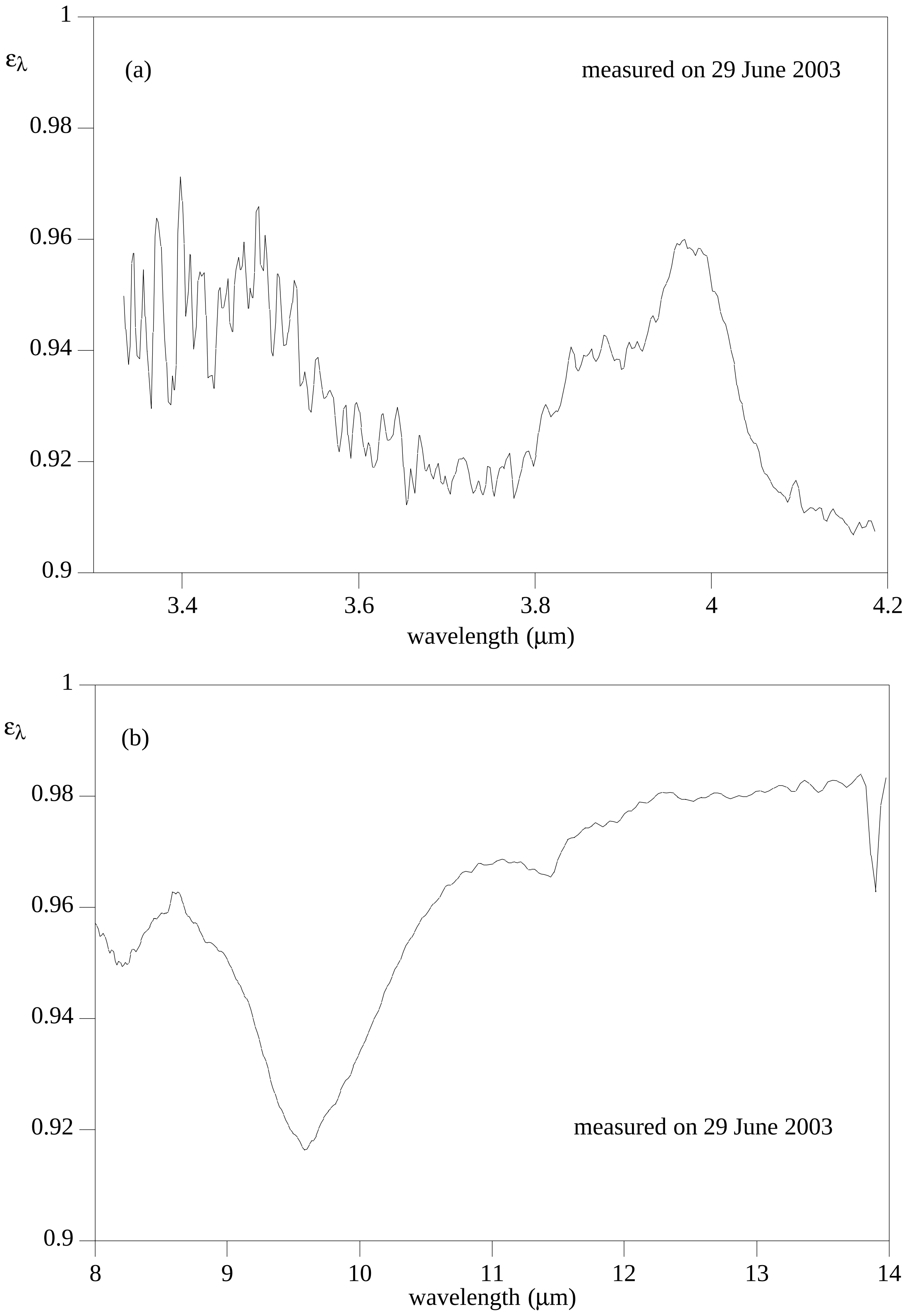

Fig. 8, Spectral emissivity of playa measured by the sun-shadow method in Railroad Valley.