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Land Surface Temperature Measurements from EOS MODIS Data

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Abstract

We applied the multi-method strategy of land-surface temperature (LST) and emissivity measurements in two field campaigns this year for validating the MODIS LST algorithm. The first field campaign was conducted in Death Valley, CA, on March 3rd and the second one in Railroad Valley, NV, on June 23-27. ER2 MODIS Airborne Simulator (MAS) data were acquired in morning and evening for these two field campaigns. TIR spectrometer, radiometer, and thermistor data were also collected in the field campaigns. The LST values retrieved from MAS data with the day/night LST algorithm agree with those obtained from ground-based measurements within 1 °C and show close correlations with topographic maps. The band emissivities retrieved from MAS data show close correlations with geological maps in the Death Valley field campaign. The comparison of measurement data in the latest Railroad Valley field campaign indicates that we are approaching the goals of the LST validation: LST uncertainty less than 0.5 °C, and emissivity uncertainty less than 0.005 in the 10-13 spectral range. Measurement data show that the spatial variation in LST is the major uncertainty in the LST validation. In order to reduce this uncertainty, a new component of the multi-method strategy has been identified.

1. Introduction

The field campaigns that we conducted in the past two years were mainly for the validation of the surface temperature parameter of the MODIS LST algorithm [Wan and Dozier, 1996]. We planned to conduct three field campaigns this year for validating both land-surface temperature and emissivity retrieved by the new day/night LST algorithm [Wan and Li, 1997]. Two field campaigns were conducted in the first half of this year, one in Death Valley, CA, on March 3, and another in Railroad Valley, NV, on June 23-27. In section 2, we will describe the multi-method strategy for LST validation activities. The results of the two field campaigns conducted in March and June will be given in sections 3 and 4. We will present the anticipated future actions and the new component of the multi-method strategy for LST validation in section 5.

2. Multi-Method Strategy for LST Validation

Our multi-method strategy for the LST validation consists of the following four components: 1) Laboratory measurements of small samples. 2) Field measurements of land-surface temperature and emissivity. 3) Airborne measurements for validations. 4) Intercomparison with other satellite measurements.

We use a TIR spectrometer/integrating-sphere system to measure the directional-hemispheric emissivity and the SIBRE (Spectral Infrared Bidirectional Reflectance and Emissivity) instrument to measure spectral BRDF of terrestrial materials in the 3.5-14.5μm spectral region in laboratory. Description of the SIBRE system and its applications in measurements of BRDF and emissivity is given in Snyder and Wan [1996] and Snyder et al. [1997(a)].

The UCSB SIBRE system can be used in the field for measurements of the angular distribution of LST. The sun/shadow LST method can be used to retrieve surface temperature and emissivity from TIR spectrometer data collected in the field. The sample size in the sun/shadow measurements ranges from 10cm to 50cm so that the effect of the surface structure in that scale can be investigated. We designed and fabricated a scanning mirror subsystem. Angular spectrometric data can be obtained by combining this subsystem with the portable TIR spectrometer. Broadband radiometers are used to measure the brightness temperature of land surfaces. Kinetic surface temperature can be calculated from the radiometer data and surface emissivity determined by other methods. Thermistors are used to measure the soil and playa temperature at the level a few millimeters below the surface. Surface temperature can be estimated by comparing the thermistor data with the broadband radiometer data at the same location.

We use MAS data for validating the land-surface emissivity and temperature algorithms and products. The description of the MAS instrument is given in King et al. [1996].

The LST retrieved from MODIS data will be compared with those retrieved from other satellite measurements, including ASTER, AVHRR and GOES Sounder data.

In order to validate LST at the 1 °K accuracy level, we have to calibrate the instruments carefully and make appropriate sampling in the spatial, temporal, spectral and angular domains. The capabilities of different instruments in measurements of land-surface temperature and emissivity are shown in Table I.

TABLE I. The capabilities of different instruments in measurements of land-surface temperature and emissivity.

instrument	spot size	spectral	spatial	temporal	angular
TIR spectrometer with integrating-sphere	2cm	3.5-14.5μm resolution $4cm^{-1}$	NA	NA	directional-hemispheric emissivity
SIBRE	10cm	3.5-14.5μm resolution $4cm^{-1}$	NA	8 spectra / s	BRDF
scanning TIR spectrometer	10-50cm	3.5-14.5μm resolution $4cm^{-1}$	NA	8 spectra / s	multiple angles in the scan plane
radiometer (Heimann)	40cm at 1m distance	10-13μm resolution $4cm^{-1}$	by multiple sets	every second - minutes	IFOV 20°
thermistor with data logger	a few mm	NA	by multiple sets	every second - minutes	NA
IR camera	vary with distance	8-14μm	320 by 240	every second - minutes	IFOV 1.3 mrad
MAS	50m / pixel	0.4-14.5μm 50 bands	2-D	4 scan lines per second	IFOV 2.5 mrad

3. Results of the field campaign in Death Valley, CA.

We conducted a field campaign in Death Valley, California on March 3rd, 1997. Dr. Bob Cechet, CSIRO Division of Atmospheric Research, Australia, participated in the field campaign. Death Valley is located at the southern edge of the Great Basin in the Basin and Range Province of California and Nevada. It is bounded on both east and west by north-trending, block-faulted ranges and contains a variety of rocks

[Hunt and Mabey, 1966]. Fig. 1 shows the topographic map (left), and the generalized geologic map (right) of the study area modified from Hunt and Mabey [1966]. The valley forms a closed hydrologic system, famous for its extensive salt pans and spectacular landscapes. The cottonball basin and badwater basin are below the sea level. Mountain ranges surrounding the valley top out at elevations greater than 3350m. Geologically, the Death Valley region is extremely diverse. Airborne Thermal Infrared Multispectral Scanner (TIMS) and Visible/Infrared Imaging Spectrometer (AVIRIS) data have been used for mapping alluvial fans and playa evaporite minerals in Death Valley, California [Gillespie et al., 1984; Crowley, 1993; Crowley and Hook, 1996]. Therefore, it is a very good test site for land-surface emissivity retrieval from MAS data. MAS data were collected with noon and evening flights at the same time when field measurements were made. Field measurements of surface temperature were made with two TIR broadband radiometers and nine thermistors at the flat alluvial fan called Devils Golf Course, which is approximately 2km wide in the east-west direction and much longer in the north-south direction. There were no TIR spectrometer data collected during this field campaign because the spectrometer had a problem of bad cable connection inside. Radiosonde data were collected around the day and evening MAS flight times to provide atmospheric temperature and water vapor profiles. The column water vapor calculated from the measured water vapor profile is 0.45cm. These profiles were used in radiative transfer simulations for establishment of the look-up tables of the atmospheric and solar terms used in the LST algorithm. The MAS was calibrated with the new spectral response functions and the new method [King et al., 1996]. The correspondence between MODIS and MAS bands is shown in Table II.

TABLE II. MODIS and MAS bands used in the day/night LST algorithm.

algorithm band no.	1	2	3	4	5	6	7
MODIS band no.	20	22	23	29	31	32	33
MAS band no.	30	31	32	42	45	46	48

The color composite MAS images of bands 30, 42 and 45 are shown in Fig. 2 for both day and evening. The cottonball basin, badwater basin, and the ranges on the east and west sides are clearly revealed in the

MAS images. The quality of the MAS data is very good. There is no strip line and bad pixel. Because there is no geolocation information of individual pixels in the MAS data, we made co-registration of the daytime and evening MAS images with ground points in the MAS images. It is relatively easy to make co-registration by using a few ground points on the images because the ER2 flew along the same flight line in the north-south direction at the same altitude and speed in both daytime and evening missions. We retrieved LST and band emissivity values from the co-registered MAS data with the day/night LST algorithm. The retrieved LST and band emissivity images are shown in Fig. 3a as color composite, and in Fig. 3b as black-white image. There are 256 grey levels in both LST and emissivity images. The temperature ranges from -5 to 58.75 °C in steps of 0.25°C. The emissivity ranges from 0.49 to 1.0 in steps of 0.002. The topographic features are clearly shown in the LST images, but not in the emissivity images. However, there is a close correlation between the generalized geologic map and the emissivity images. As shown in Table III, LST values retrieved from MAS data using the day/night LST algorithm agree with field measurement LST values within 1 °K. The values in parentheses are the standard deviation of measured LST values. The band-averaged emissivities retrieved from MAS data agree with those measured from samples in the UCSB MODIS LST laboratory within 0.015 for MAS bands 42, 45, 46 and 48, within 0.05 for bands 30 and 31, and within 0.075 for band 32. The accuracies of measured LST and LSE values are mainly limited by the uncertainty due to its spatial variation.

TABLE III. LST values measured at a site in Death Valley, CA, at 12:39 and 18:50 PDT on March 3rd, 1997.

sensor	daytime LST at 12:39PDT (°C)	evening LST at 18:50PDT (°C)	spot size
MAS	41.3 (1.5)	18.6 (1.6)	1km × 1km
Heimann	41.8	18.4	≈ ø 30cm
Everest	42.1	18.9	≈ ø 30cm
9 thermistors	40.6 (1.5)	18.5 (0.6)	≈ ø 4mm

4. Results of the field campaign in Railroad Valley, NV.

We conducted a joint field campaign with other EOS groups in Railroad Valley, Nevada, during June 23-27, 1997. Railroad Valley is located in the semi-arid climate zone of Nevada. We selected a silt playa in the Railroad Valley as our test site. The playa is at an elevation of 1500m and has a uniform region more than 15km by 15mk of light tan silt with 2-5cm hexagonal stress cracks. Our test site is in the middle of playa, surrounding the point of latitude 38° 31.46' N, longitude 115° 42.74' W. Because of its size and uniformity in thermal and optical properties, the playa site provides a unusual opportunity for validating LST and other radiometric remote sensing products [Snyder et al., 1997(b)].

MAS data were acquired on four ER2 flight lines, each in the north-south direction, in the morning of June 23rd and in the evening of June 24th, 1997. The MAS data covered the Lunar Lake in the first flight line, the Railroad Valley playa in the first and second flight lines, and the White River Valley in the last two flight lines, giving a total coverage of approximately 80km by 80km. We just completed the data processing of the MAS data collected on the second flight line which was centered at the playa test site. The ER2 passed over the site at 11:12 PDT on June 23rd and at 19:59 PDT on June 24th. ER2 flew in the same north-south directions and its altitude was kept at 20km within 300m. It is easy to make co-registration by shifting a few pixels in the scanning direction and moving one image over another in the flight direction to get the best match of the images. Fig. 4 shows the day and evening color composite MAS images on the background of a reduced copy of the topographic map of the Railroad Valley region. Because the playa is not at sea level, the pixel size in the east-west direction is smaller than the size in the north-south flight direction. The daytime MAS color composite image consists of one near infrared band (band 7) in red, TIR band 30 in green, and TIR band 45 in blue. The pixels in red show the places by the edge of the playa and on the mountain ranges, where vegetation coverage is relatively high. The evening MAS color composite image is made of three TIR bands, band 30 (centered at 3.75 μm) in red, band 42 (centered at 8.54 μm) in green, and band 45 (centered at 11.01 μm) in blue.

Total of ten thermistors were deployed at the site, all placed 1-2mm under the surface except one (#10) at 5mm depth. Two thermistors were placed at the center of the test site (one at 2mm depth, the other at 5mm depth). Other two (referred as the northern and southern thermistors hereafter) were placed one meter to the north and south of the central thermistors. Thermistors 3, 5, 8, and 9 were placed at a distance of approximately 50m from the center. Thermistor 4 was 50m west of thermistor 3, and thermistor 7 was 50m east of thermistor 8. Along with the northern thermistor, a Heimann IR thermometer was deployed, approximately 2m above the surface. A second thermometer (Tasco) and a MIDAC TIR spectrometer were deployed between the northern thermistor and thermistor 9. Fig. 5 shows the locations of these ground-based instruments. All the instruments were calibrated with a temperature-controlled blackbody at three different temperatures before and after the MAS flights. The TIR spectrometer was also calibrated with two custom-built blackbodies, one at ambient temperature, another at temperature higher than the first by 10-15 °C. Because these two blackbodies are much smaller and lighter than the sophisticated commercial blackbody, they can be placed in front of the spectrometer so that the calibration with these two blackbodies is included in the cycle of automatic scanning routine for measurements at multiple viewing angles. The angular dependence in LST measured by the TIR spectrometer is shown in Fig. 6. We also collected radiosonde data, wind speed, surface air temperature and relative humidity data at the site. The column water vapor calculated from the water vapor profiles measured on June 23rd and 24th 1997 ranges from 0.51 to 0.72cm.

We retrieved LST and band emissivity values from the co-registered MAS data collected on June 23rd and 24th with the day/night LST algorithm. The retrieved LST and band emissivity images are shown in Fig. 7. The topographic effect on the LST is clearly shown in both daytime and evening LST images. As expected, the LST is higher on the east-facing slopes in the mountain ranges in morning, and is higher on the west-facing slopes in evening. We can see that the pixels of small ponds, wetland, and vegetated lands had lower LST values and higher emissivity values compared to their neighboring pixels. We can also see the spatial variation in daytime LST in the middle of the playa, the temperature in the north part is lower than in the south part. The retrieved emissivities in bands 30 and 42 reveal the similar pattern, showing lower values in the north part. These spatial variations in daytime LST and surface emissivities indicate the variation in moisture content of the playa surface. We felt that the playa surface was softer during this field campaign than in the last one conducted on June 4th, 1996. The temperatures measured by the thermistors and the IR thermometers are shown in Fig. 8. Note that the temperature range of the data logger is from -37 to +46 °C for thermistors 7 to 9, and from -39 to +122 °C for others. Around noon, the temperature values recorded for thermistors 7-9 were affected even before being saturated at 46 °C. Therefore, thermistors 7-9 will not be used to get the averaged value at the MAS overpass time 11:12PDT on June 3rd for comparison. We made emissivity correction for the temperature values from IR thermometer by using the emissivity values retrieved from MAS data. The averaged emissivity for the four bands in the 8-14 μm range is 0.967, and the sensitivity of the Planck function in this spectral range is approximately 0.64 °C for one percent change in the averaged radiance. Therefore, the emissivity correction for playa surface temperature is 2.1 °C. Table IV shows the comparison of LST values retrieved from MAS data and measured by IR spectrometer, IR thermometer, and thermistors. The numbers in the parentheses are the standard deviation of the thermistor data. The LST values retrieved from MAS data agree with the LST values measured by the ground-based instruments within 0.6 °C. The emissivity value retrieved from MAS data collected in this field campaign is 0.970 and 0.986, for MAS bands 45 and 46, respectively. Their average value, 0.978, is 0.006 higher than the value measured from silt samples in the field campaign on June 4th, 1996. This is consistent to our observation in the field that the playa surface was softer in this field campaign than in the last field campaign on June 4th, 1996. These numbers indicate that we are approaching the goals of the LST validation: LST uncertainty less than 0.5 °C, and emissivity uncertainty less than 0.005 in the 10-13 spectral range.

TABLE IV. LST values measured at the Railroad Valley playa, NV, at 11:12 PDT on June 23rd, and 19:59 PDT on June 24th, 1997.

sensor	daytime LST 11:12PDT, 6/23 (°C)	evening LST 19:59PDT, 6/24 (°C)	comments
MAS	46.5	22.5	retrieved from a pair of 2 by 2 pixels
MIDAC	46.0	22.8	at viewing angle 0 °
Heimann	47.1	22.3	after emissivity correction of 2.1 °C
thermistor	46.5 (0.8)	23.1 (0.5)	averaged from 7 thermistors (w/o #7-9)
surface air T	32.9	25.5	for reference only

5. Anticipated Future Actions

In the next several months, we will complete the data processing and analysis of the data collected in the first two field campaigns this year, including the LST and emissivity retrieval from MAS data for all four flight lines in the Railroad Valley, Nevada. We will measure surface emissivities in several locations in Death Valley, California, in October and November, 1997, for validating the emissivity image retrieved from MAS data.

As shown in the Death Valley field campaign, the accuracies of measured LST and LSE values are mainly limited by the uncertainty due to its spatial variation. We expect that the spatial variation is larger in vegetated areas. In order to reduce this uncertainty, we need a relatively inexpensive IR instrument to provide continuous 2-dimensional LST images. After comparing IR cameras from three manufacturers, we selected a microbolometer-based IR camera from AGEMA because of its advantages in functions, easy to use, size, weight, and price. We will make the following custom improvements to the AGEMA IR camera: adding two small blackbodies in the front for its real-time calibration, placing the IR camera on a motor drive system so that a wider field of view can be achieved. We plan to deploy this IR camera on existing towers and a low-level aircraft or balloon for field campaigns at test sites in crop fields, shrub and forest areas in the future. This will be a new component in our multi-method strategy for LST validation.

Version 2 of the MODIS LST code will be delivered in the next quarter.

Acknowledgments

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REFERENCES

Crowley, J. K. and S. J. Hook, "Mapping playa evaporite minerals and associate sediments in Death Valley, California, with multispectral thermal infrared images," *J. Geophys. Res.*, vol. 101, no. B1, pp. 643-660, 1996.

Crowley, J. K., "Mapping playa evaporite minerals with AVIRIS data: a first report from Death Valley, California," *Remote Sens. Environ.*, vol. 44, pp. 337-356, 1993.

Gillespie, A. R., A. B. Kahle, and F. D. Palluconi, "Mapping alluvial fans in Death Valley, California, using Multispectral thermal infrared data," *Geophys. Res. Letters*, vol. 11, no. 11, pp. 1153-1156, 1984.

Hunt, C. B. and D. R. Mabey, "Stratigraphy and structure, Death Valley, California," *U.S. Geol. Surv. Prof. Paper*, vol. 494-A, 162 pp., 1966.

King, M. D., W. P. Menzel, P. S. Grant, J. S. Myers, G. T. Arnold, S. E. Platnick, L. E. Gumley, S. C. Tsay, C. C. Moeller, M. Fitzgerald, K. S. Brown, and F. G. Osterwisch, "Airborne scanning spectrometer for remote sensing of cloud, aerosol, water vapor and surface properties ," *J. Atmos. Ocean. Technol.*, vol. 13, pp. 777-794, 1996.

Snyder, W. and Z. Wan, ''Surface temperature correction for active infrared reflectance measurements of natural materials,'' *Appl. Optics*, vol. 35, no. 13, pp. 2216-2220, 1996.

Snyder, W., Z. Wan, Y. Zhang, and Y.-Z. Feng, ''Requirements for satellite land surface temperature validation using a silt playa,'' *Remote Sens. Environ.*, vol. 61, pp. 279-289, 1997(a).

Snyder, W., Z. Wan, Y. Zhang, and Y.-Z. Feng, ''Thermal infrared (3-14 μm) bidirectional reflectance measurements of sands and soils,'' *Remote Sens. Environ.*, vol. 60, pp. 101-109, 1997(b).

Wan, Z. and J. Dozier, ''A generalized split-window algorithm for retrieving land-surface temperature from space,'' *IEEE Trans. Geosci. Remote Sens.*, vol. 34, no. 4, pp. 892-905, 1996.

Wan, Z. and Z.-L. Li, ''A physics-based algorithm for retrieving land-surface emissivity and temperature from EOS/MODIS data,'' *IEEE Trans. Geosci. Remote Sens.*, vol. 35, no. 4, pp. 980-996, 1997.

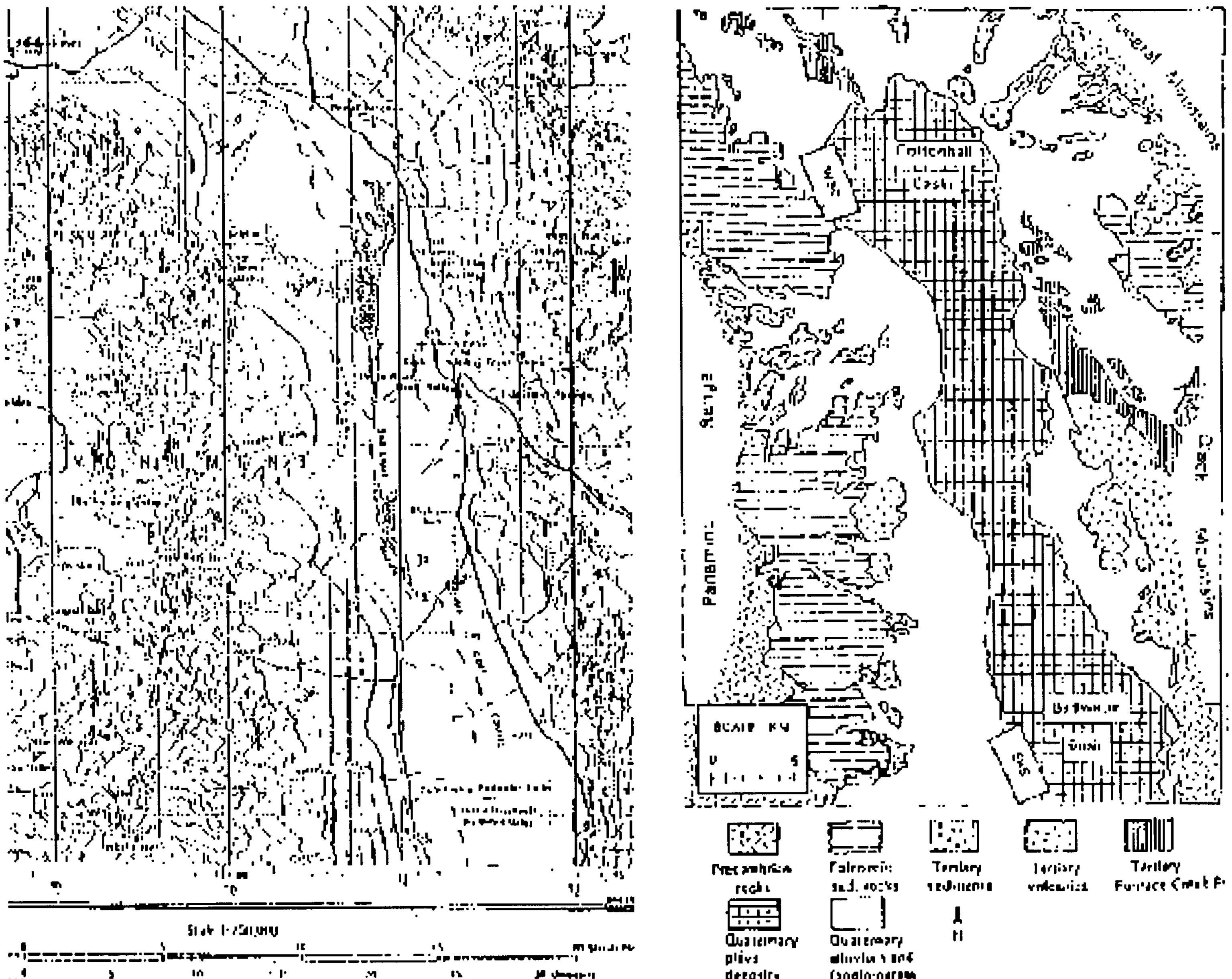
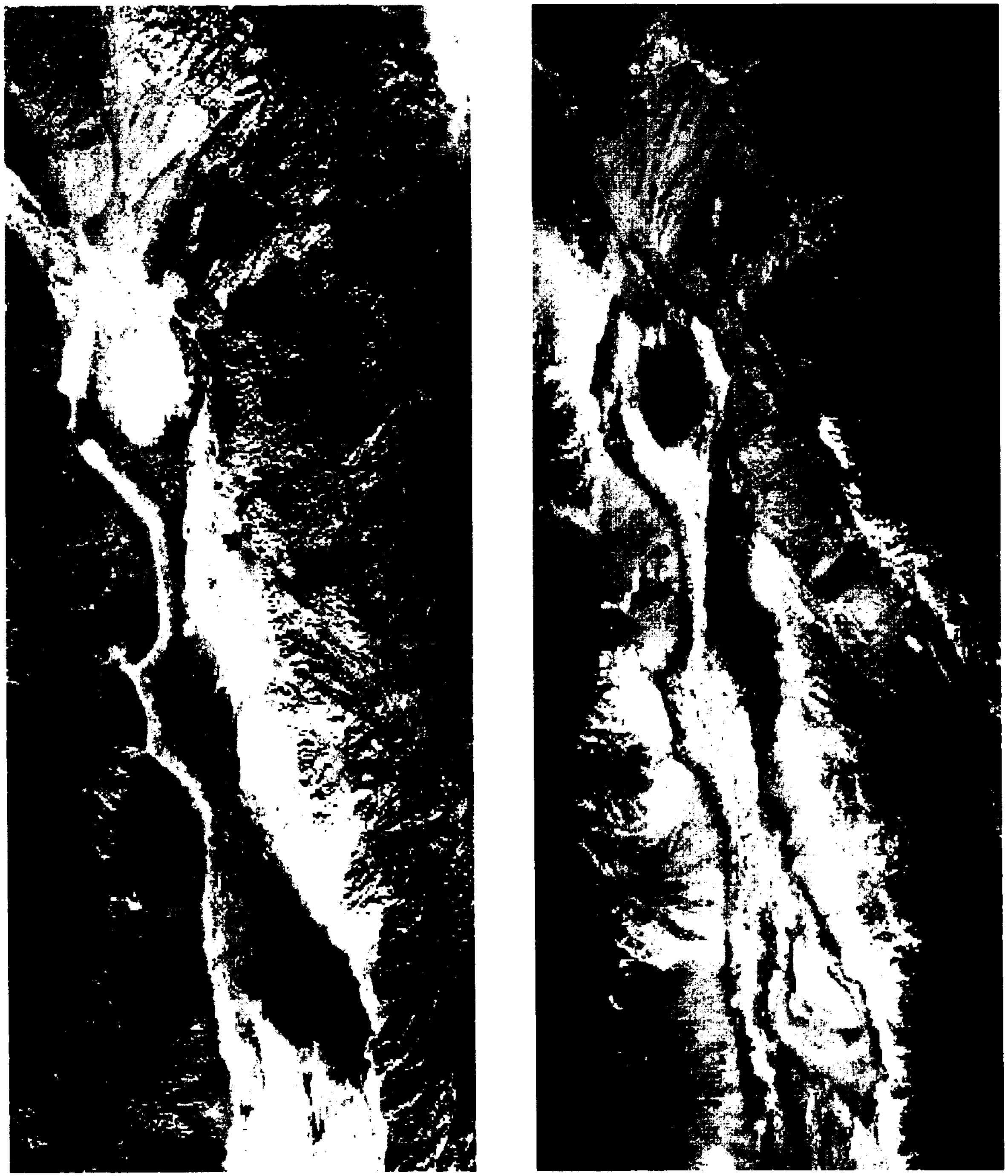


Fig. 1, Topographic map (left) and generalized geological map (right) of Death Valley, California.

Fig. 2, MAS Images of Death Valley, CA., March 3rd, 1997

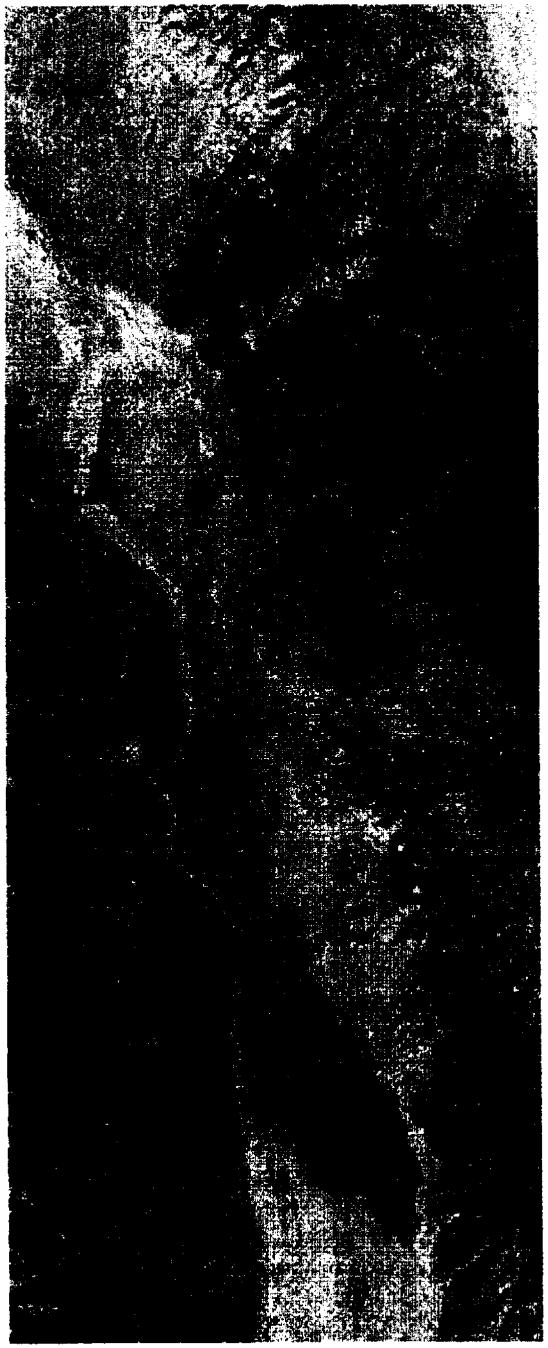


R: band 30 (3745nm)

G: band 42 (8537nm)

B: band 45 (11012nm)

Fig. 3a, Land-surface temperatures & emissivities retrieved from day/night MAS data, Death Valley, CA, 3/3/97

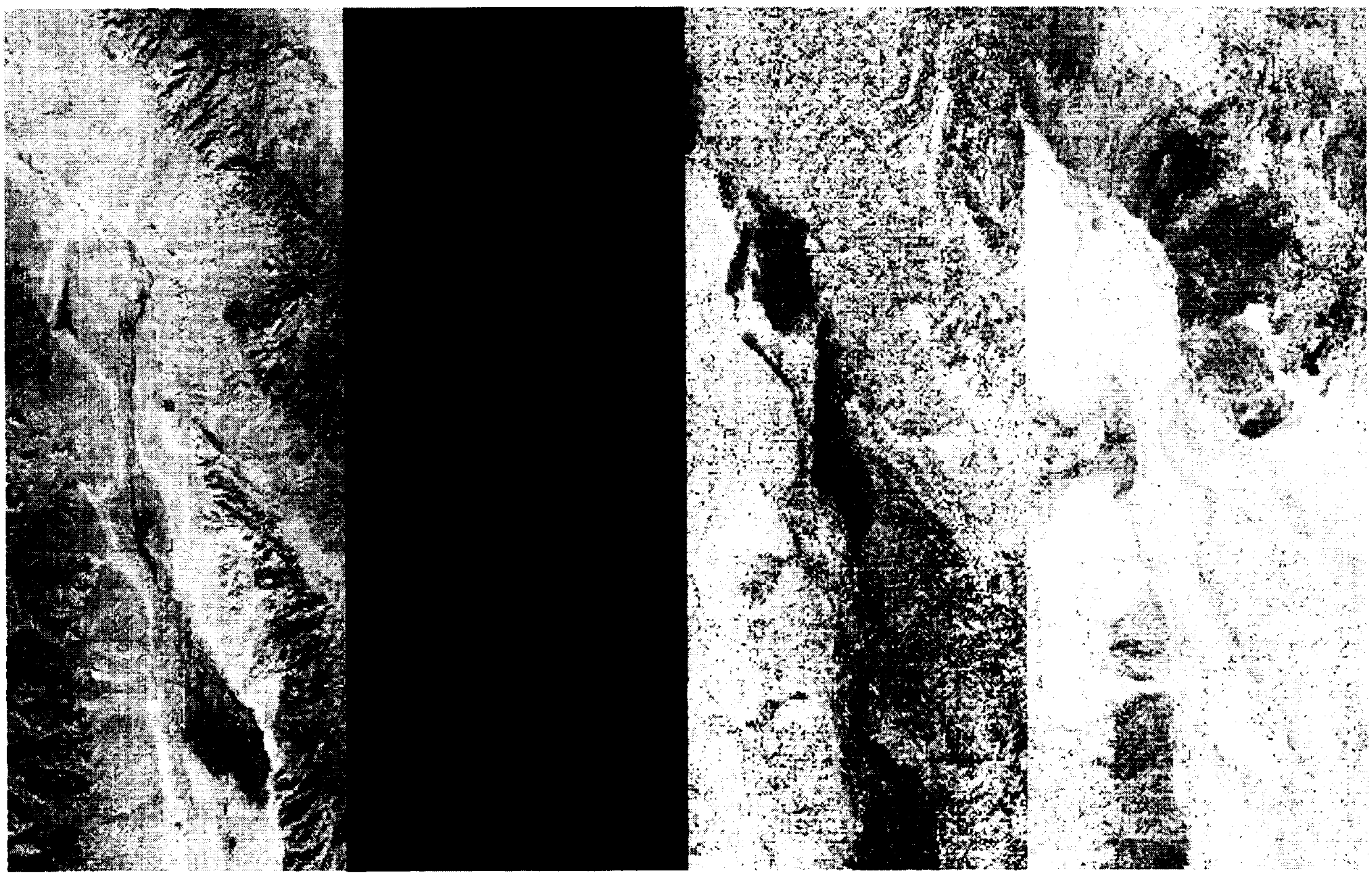


R: emis in band 42
G: daytime T_srf
B: nighttime T_srf

emis in band 42
emis in band 30
emis in band 45

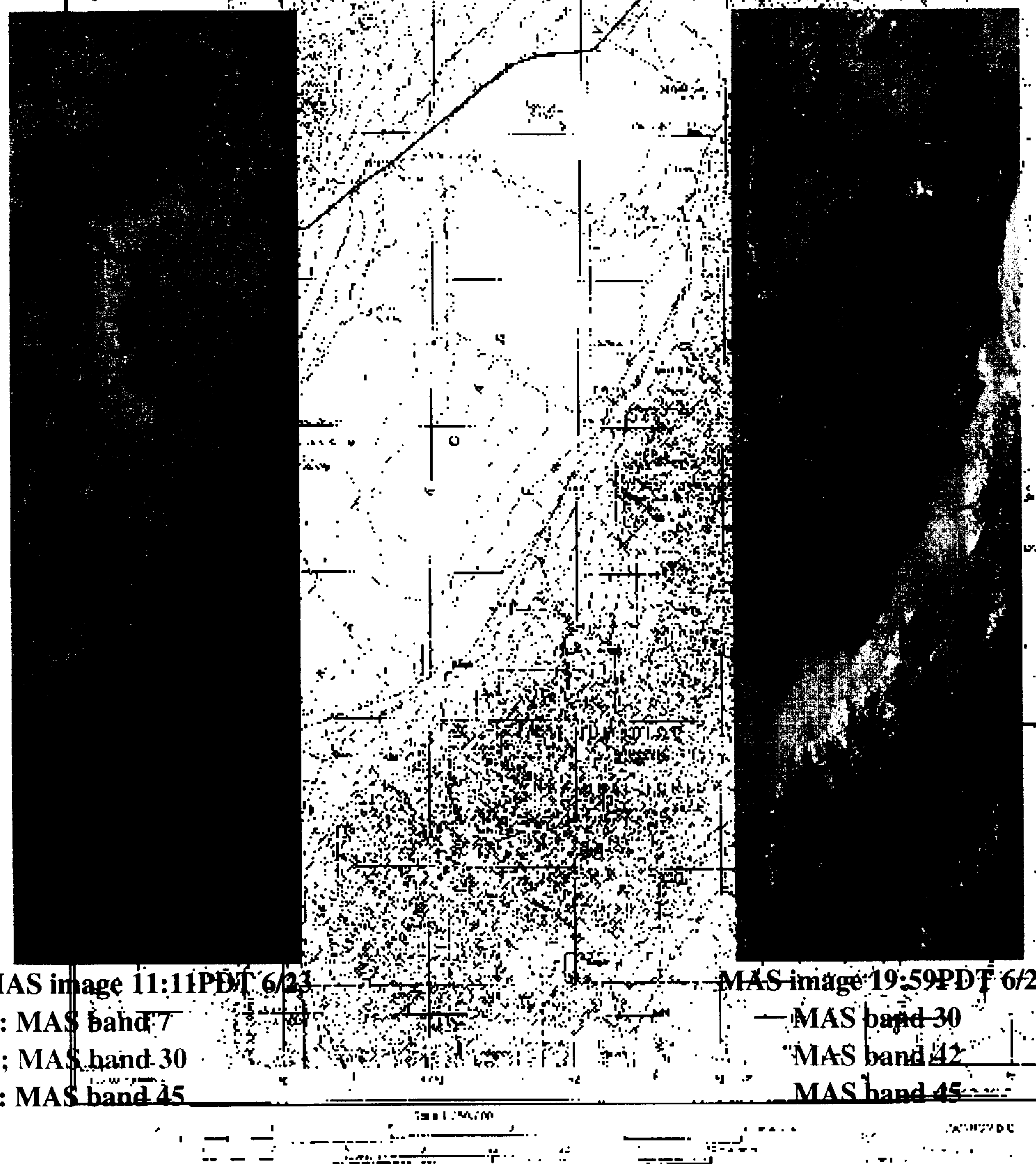
emis in band 42
emis in band 31
emis in band 32

Fig. 3b, Land-surface temperatures and emissivities retrieved from MAS data at Death Valley, CA, on 3/3/97



LST 12:39PDT 3/3/97 LST 18:50PDT 3/3/97 em(band 30, 3.75mu) em(band 42, 8.55mu) em(band 45, 11.02mu)

Fig. 4, **MAS Day and Night Images at Railroad Valley, NV, on June 23-24, 1997**



MAS image 11:11PDT 6/23
R: MAS band 7
G; MAS band 30
B: MAS band 45

MAS image 19:59PDT 6/24
MAS band 30
MAS band 42
MAS band 45

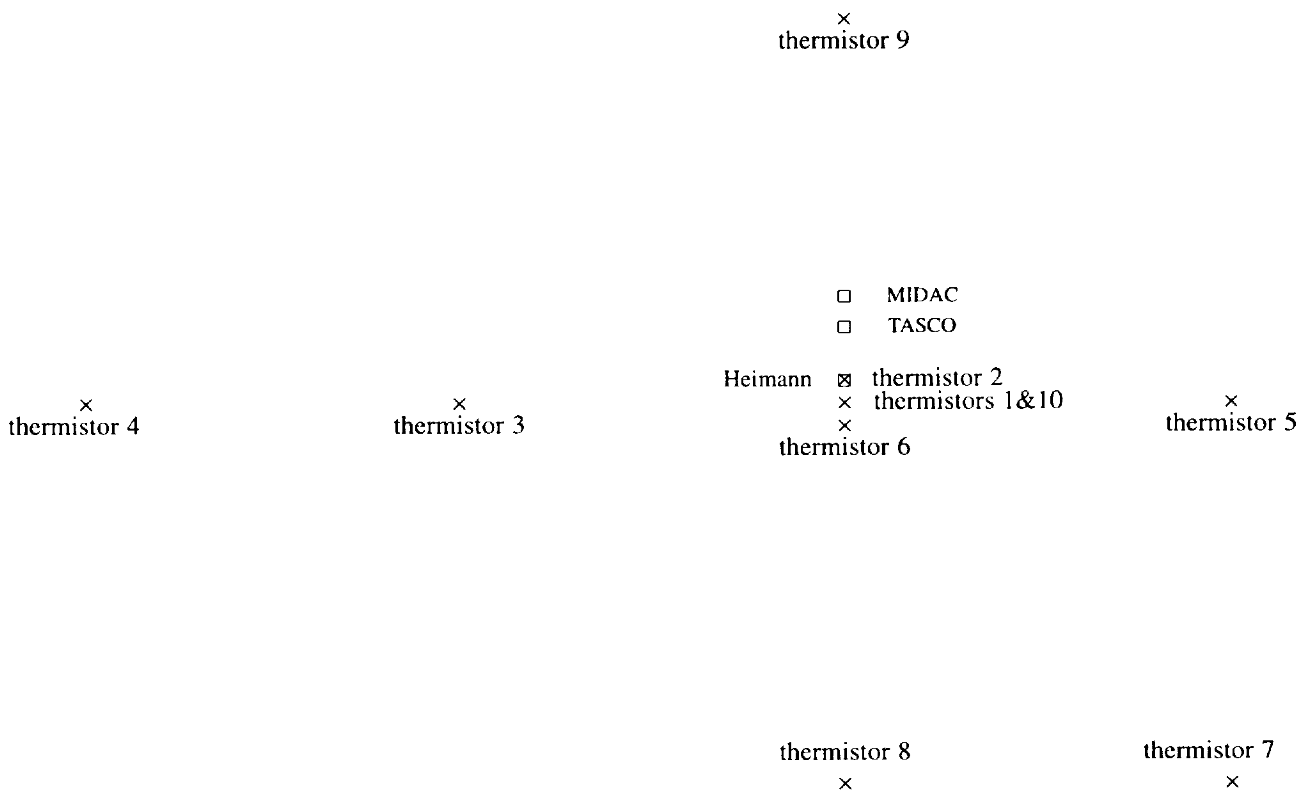


Fig. 5, locations of the ground-based instruments deployed in the Railroad Valley campaign in June 1997.

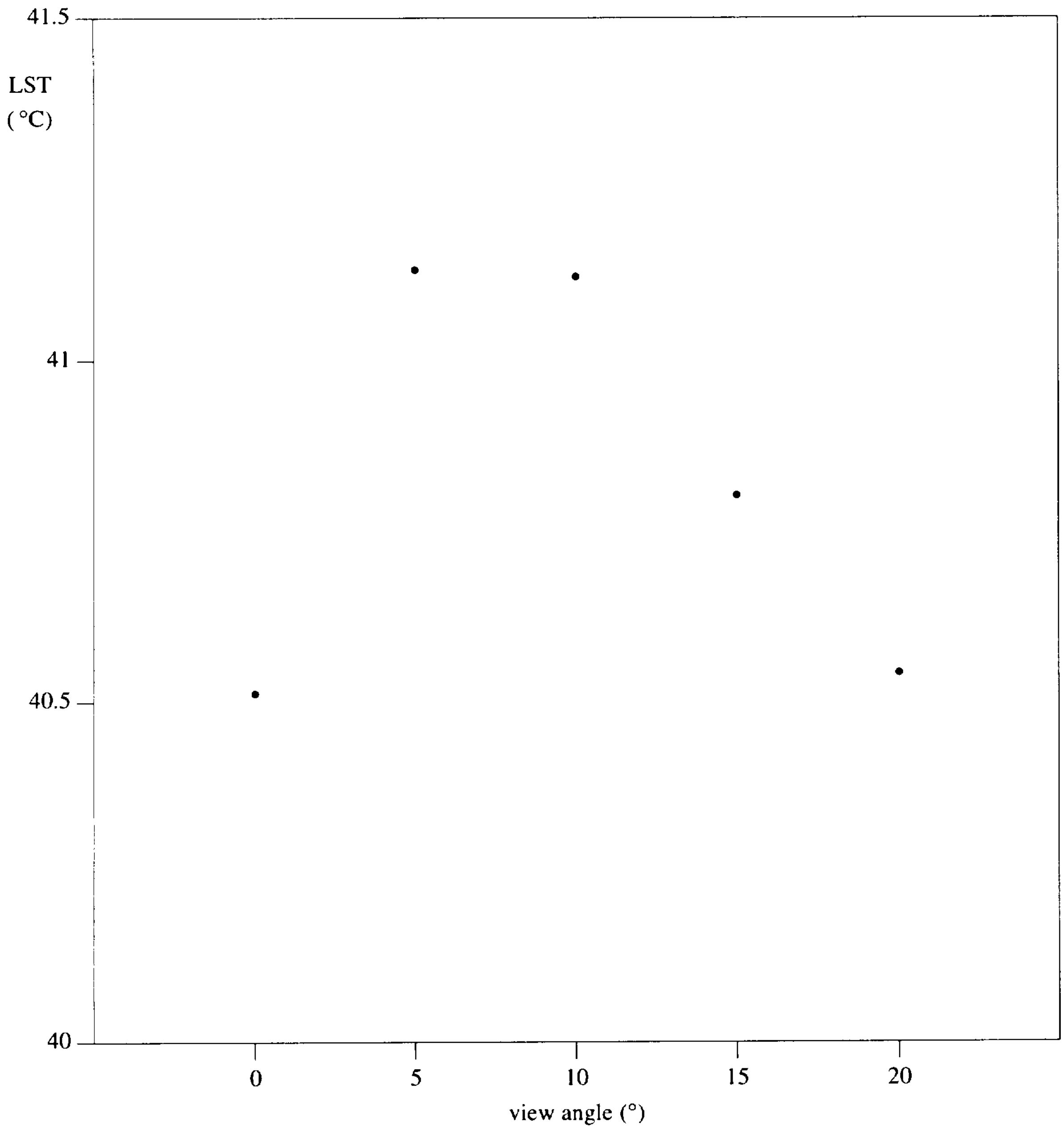
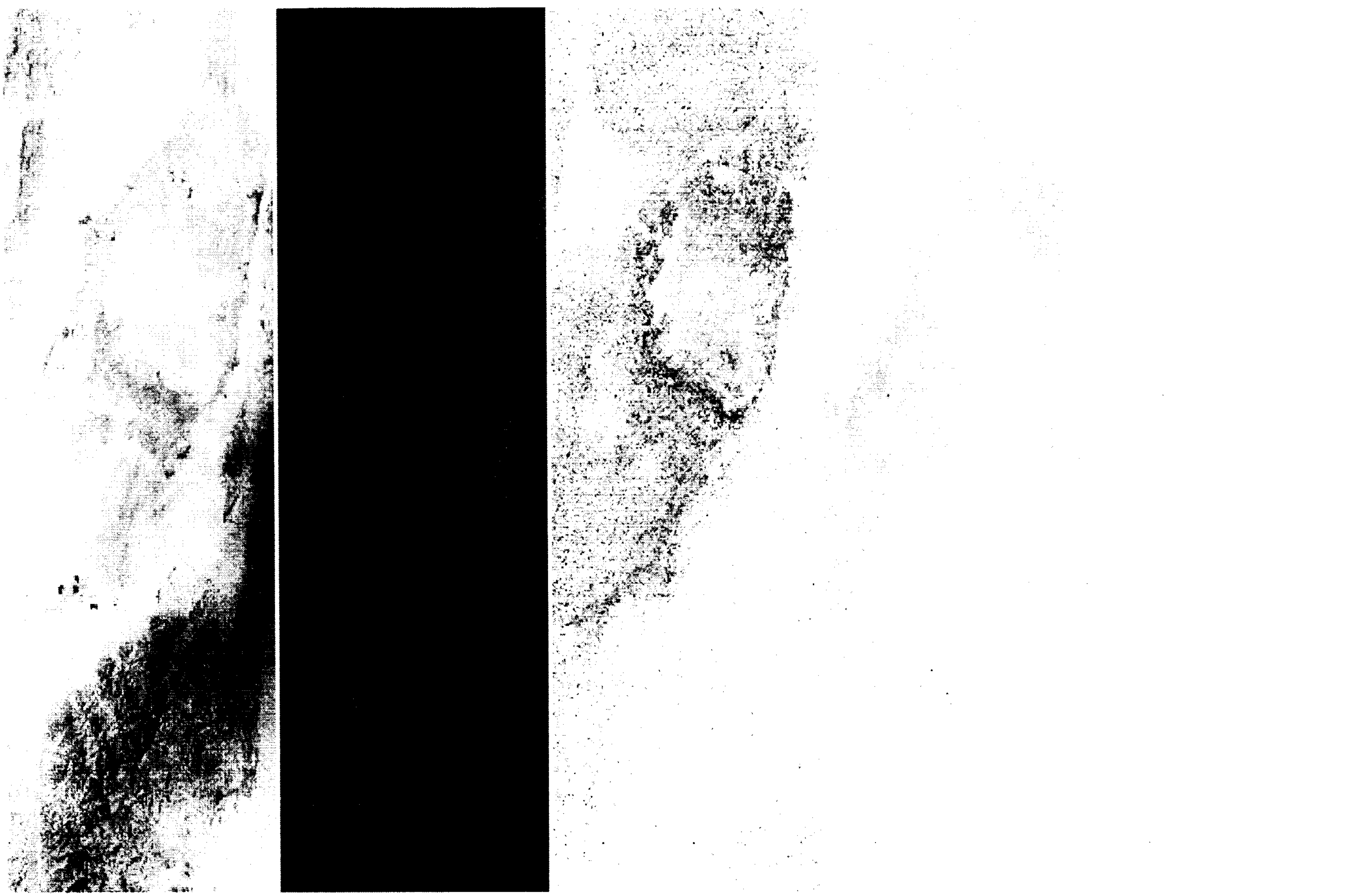


Fig. 6, LST versus viewing angle at 10:30PDT on June 23rd, 1997.

Fig. 7, Land-surface temperatures and emissivities retrieved from MAS data at Railroad Valley, NV, on 6/23-24/97



LST 11:11PDT 6/23/97 LST 19:59PDT 6/24/97 em(band 30, 3.75mu) em(band 42, 8.55mu) em(band 45, 11.02mu)

Fig. 8a, Temperatures measured by thermistors on June 23, 1997.

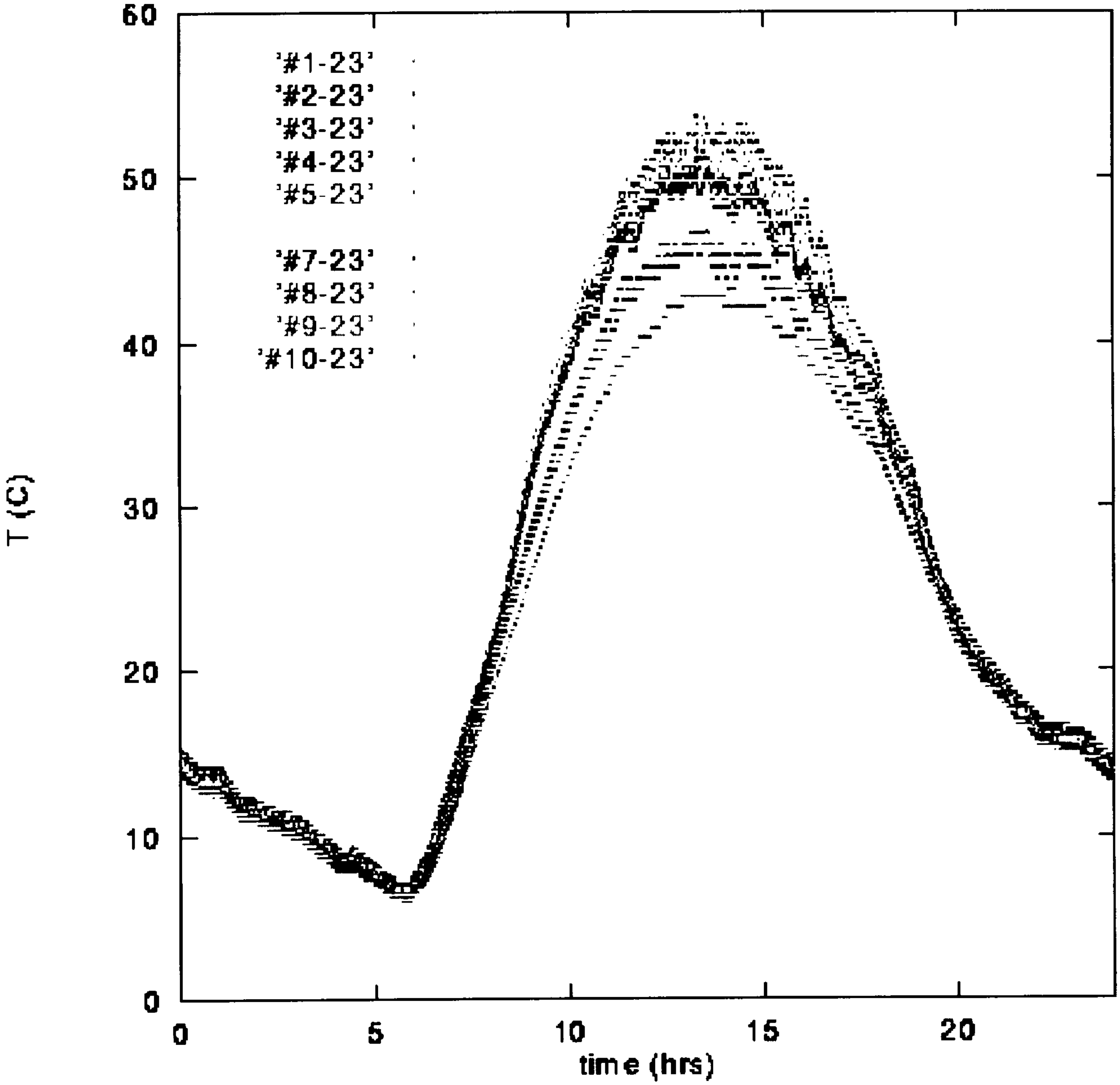


Fig. 8b, Temperatures measured by thermistors on June 24, 1997.