The Investigations of the Temperature and Spectral Emissivity Characteristics of Cloud Tops and of the Earth's Surface

Second Semi-Annual Report
By

William E. Marlatt

Contract NASr-147 Between the National Aeronautics and Space Administration and Colorado State University

Technical Paper No. 72
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado
December 1965

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SUMMARY

Since May of 1963, the Department of Atmospheric Science of Colorado State University has been conducting an investigation of certain aspects of radiation transfer through the earth's atmosphere under NASA contract NASr-147. The overall objectives of this investigation were discussed in detail in the project report dated February 1964 and will not be repeated here. In brief, these objectives are as follows:

1) To study the relationship between actual surface temperatures and cloud-top temperatures, and the temperatures of these surfaces as measured by radiometers from aircraft, balloon and meteorological satellites.

2) To continue the investigation of the relationship between cloud type and thickness, effective radiation temperatures of the optical surface of the cloud, and air temperatures outside the cloud at cloud height.

3) To study the attenuation of radiation intensity to the lowest atmosphere between the surface and 25,000 feet m.s.l. under various synoptic conditions.

4) To study the spectral characteristics of (1) various cloud types, and (2) the surface of the earth in desert, grassland and forested areas.

5) To provide ground and aircraft support for field studies conducted by, or under, the direction of the National Aeronautics and Space Administration.

This report will discauss progress during the period February 1964 through September 1964 for objectives 1 , 4 , and 5.

During the period of this report, measurements of surface temperatures over the Pawnee National Grassland were continued using thermistors, ground-based and air-borne radiometers. Measurements of albedo and of clouds, ocean surfaces and various earth surfaces were obtained using the TIROS radiometer (channel 3 and channel 5) and the sol-a-meters. Measurements of desert and ground radiation and temperatures were obtained near Edwards Air Force Base, California, in conjunction with flights conducted by the CARDE Project and the University of Michigan. Measurements of ocean and grassland-surface temperatures were obtained for several orbits immediately following the launching of NIMBUS I . A few measurements of cloud-top radiation temperatures were obtained for comparison with air temperatures; however, this objective has been limited by lack of aircraft altitude capabilities. A Piper Twin Comanche was placed on the contract June of 1964 replacing the Cessna 180. The planned modification of the aircraft will allow flights to altitudes of 30,000 feet and higher. A report on cloud-top temperatures will be issued at a later date. An emissivity box, designed after one built by the Department of Atmospheric Science of the University of Washington, was built and tested. Further design improvements will be needed before field emissivity measurements are considered accurate and reliable.

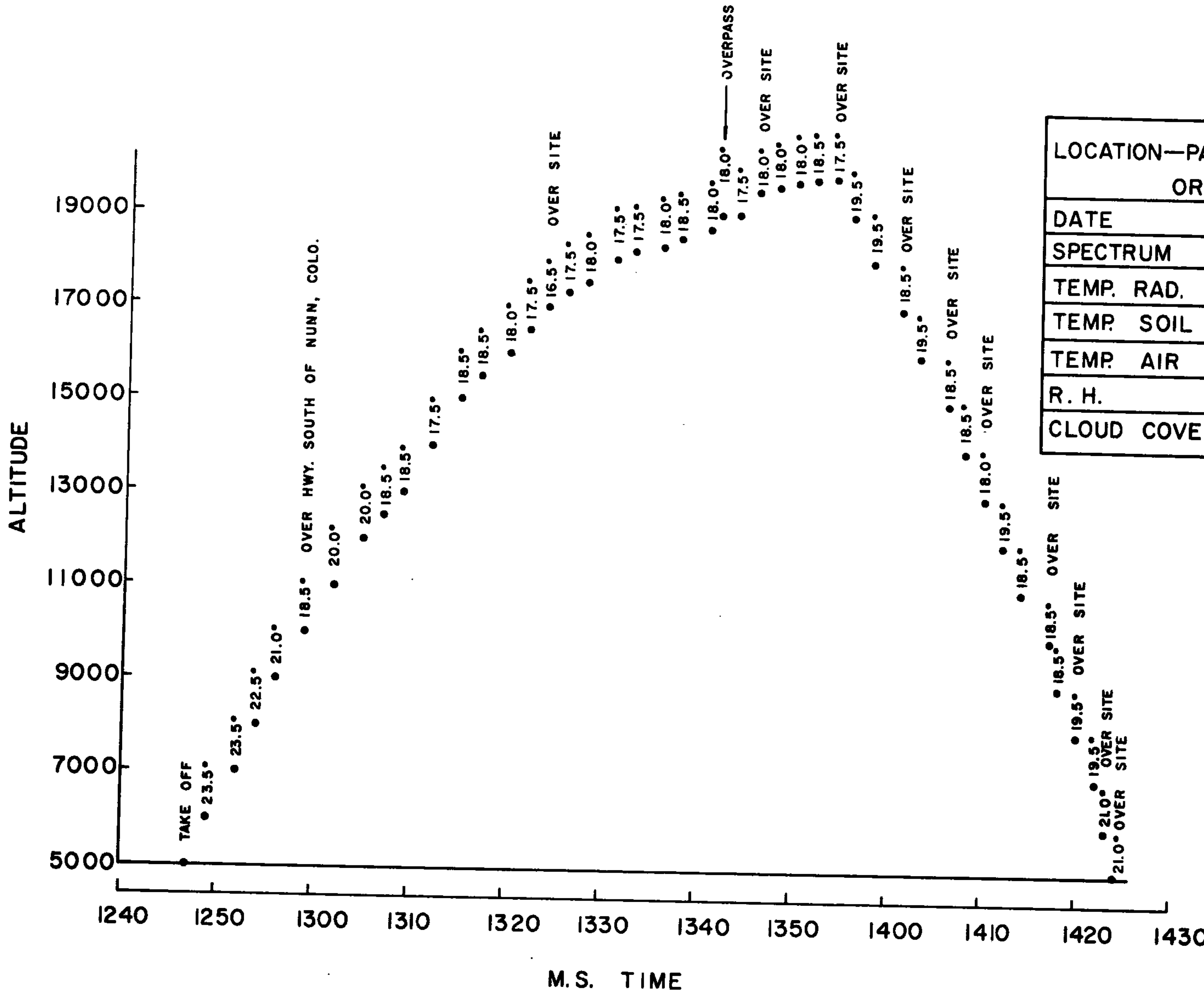
OBJECTIVE 1

Measurements of surface temperature and terrestrial radiation in the 8 - 13 μ waveband over Pawnee National Grassland in conjunction with T 7 overpasses were continued. Eleven sets of measurements were obtained between March 1964 and September 1964 (Figures 1 through 11). Details of the method of measurements were presented in the progress report of February 1964 and will not be repeated here. A final report of this objective should be available in 1966.

OBJECTIVE 4

Albedo Measurements Using TIROS Channel 3 and Channel 5:

A series of measurements over various types of terrain and clouds were made during June and July of 1964 over the western United States and adjacent ocean areas using the visible channels of the TIROS radiometer mounted on the underside of the Piper Twin Comanche. For the July flights, measurements of total



LOCATION—PAWNEE GRASSLAND ORBIT# 4072	
DATE	3-20-64
SPECTRUM	8–13μ
TEMP. RAD.	18.0° C
TEMP. SOIL	20.7° C
TEMP. AIR	7.8° C
R. H.	53 %
CLOUD COVER	CLEAR

Figure 1 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.

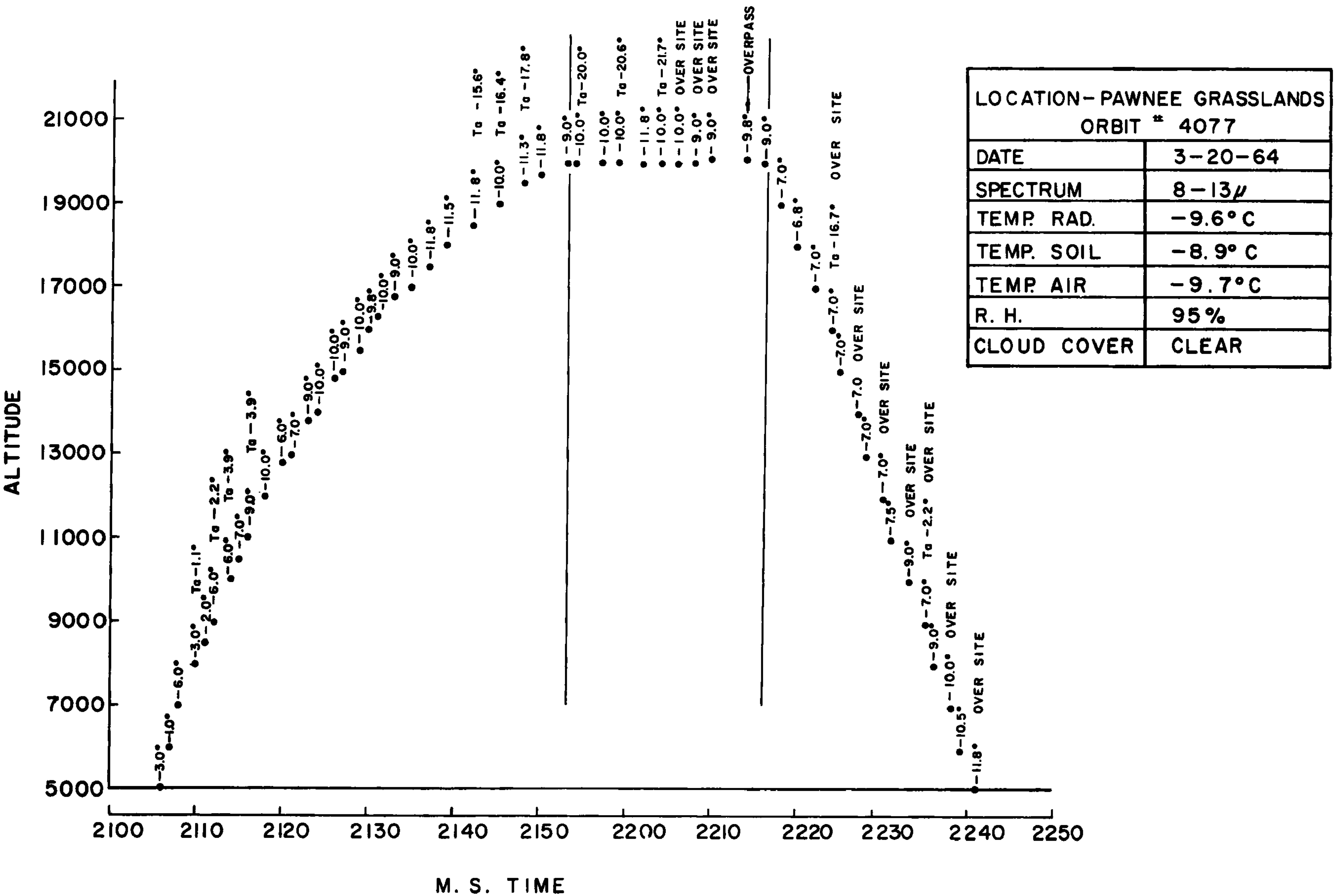


Figure 2 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.

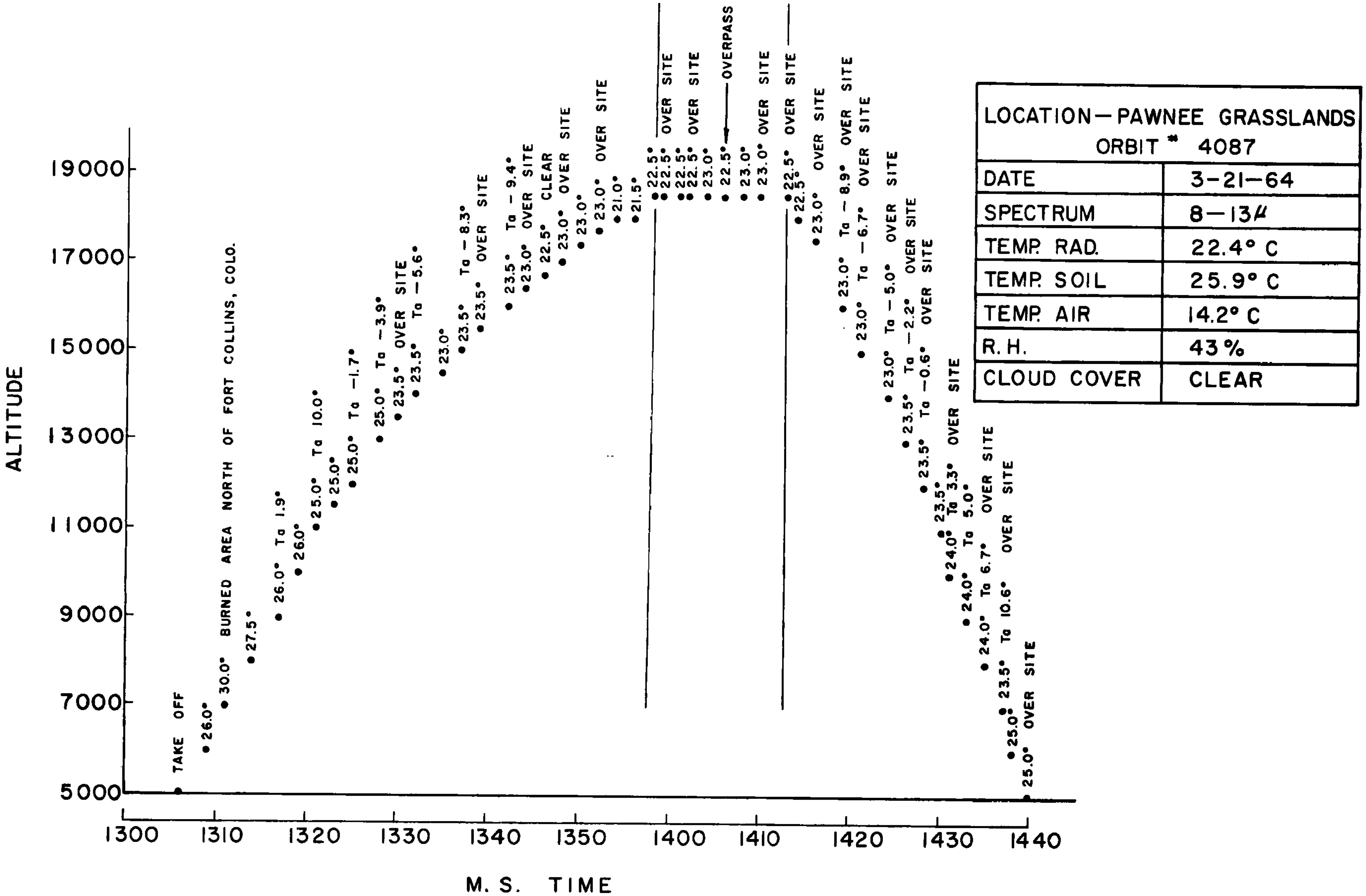


Figure 3 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.

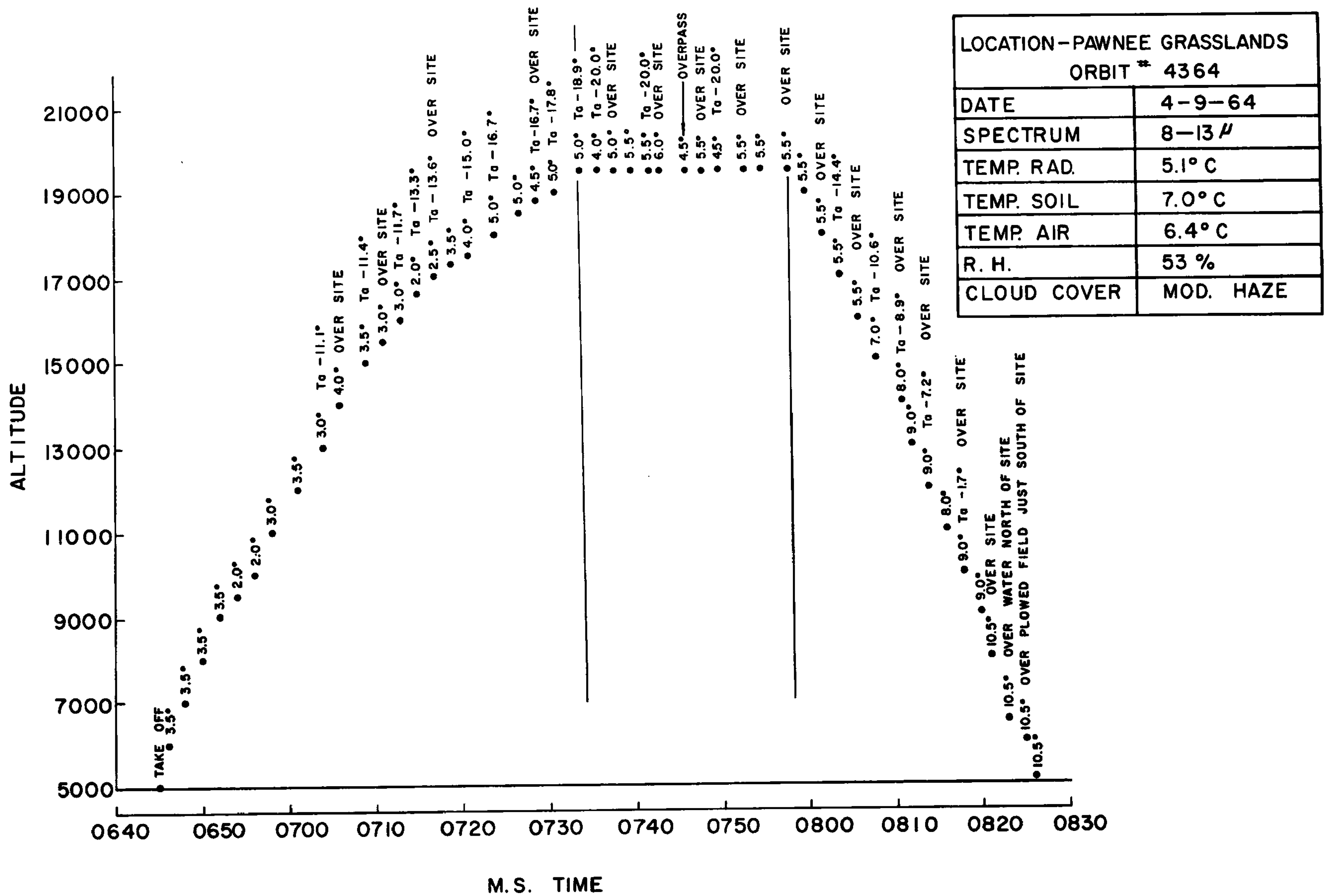


Figure 4 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.

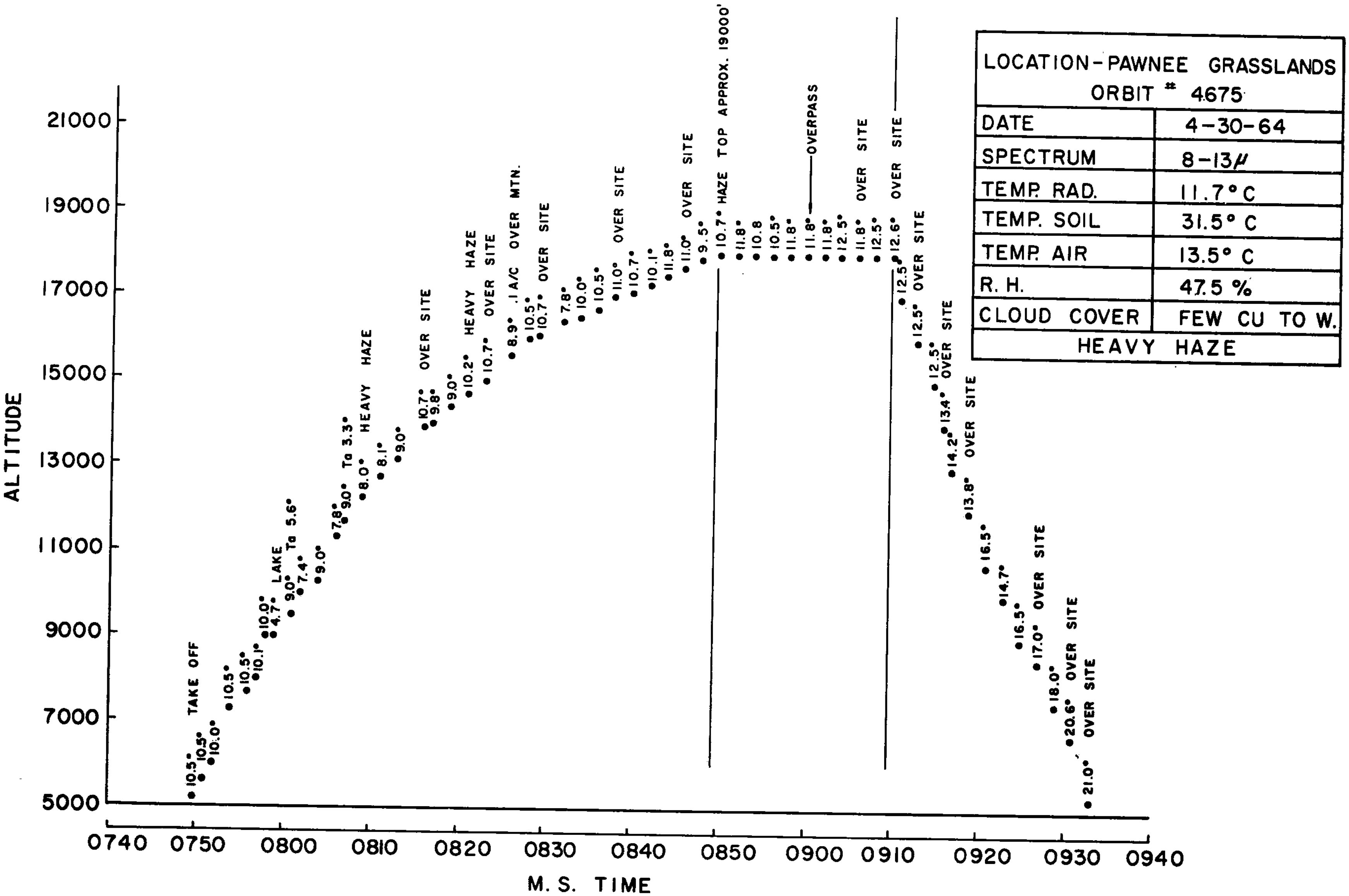


Figure 5 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.

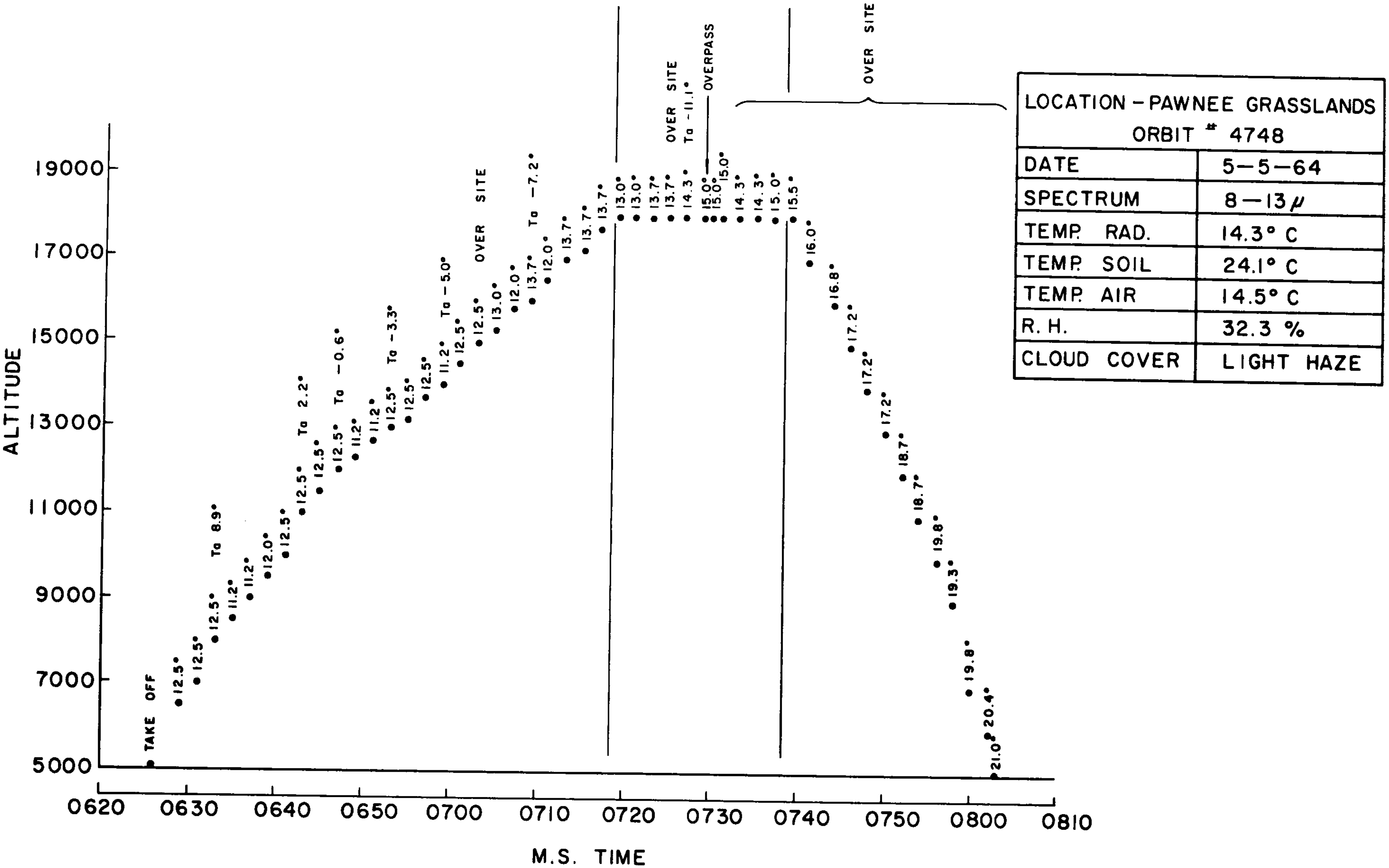


Figure 6 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.

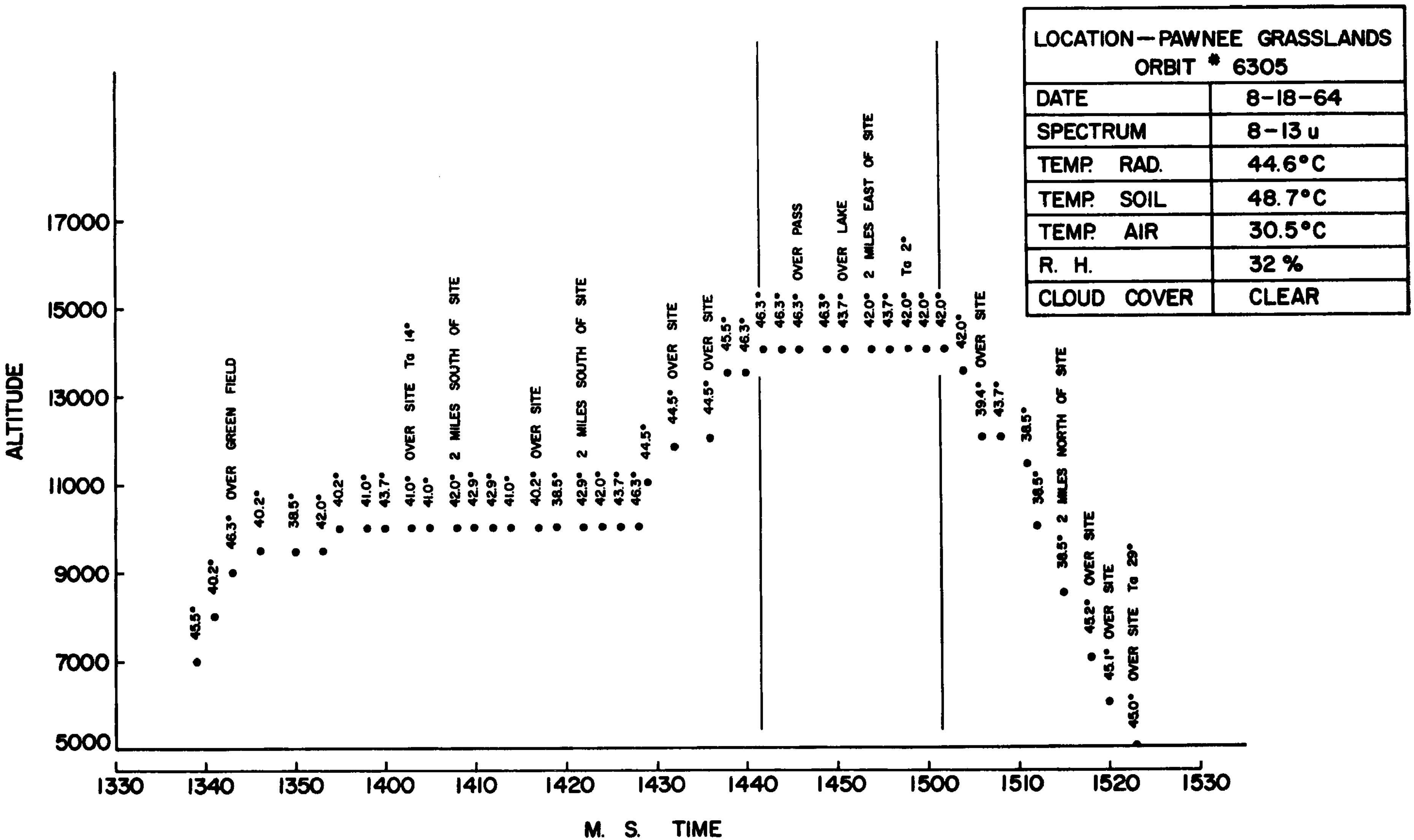
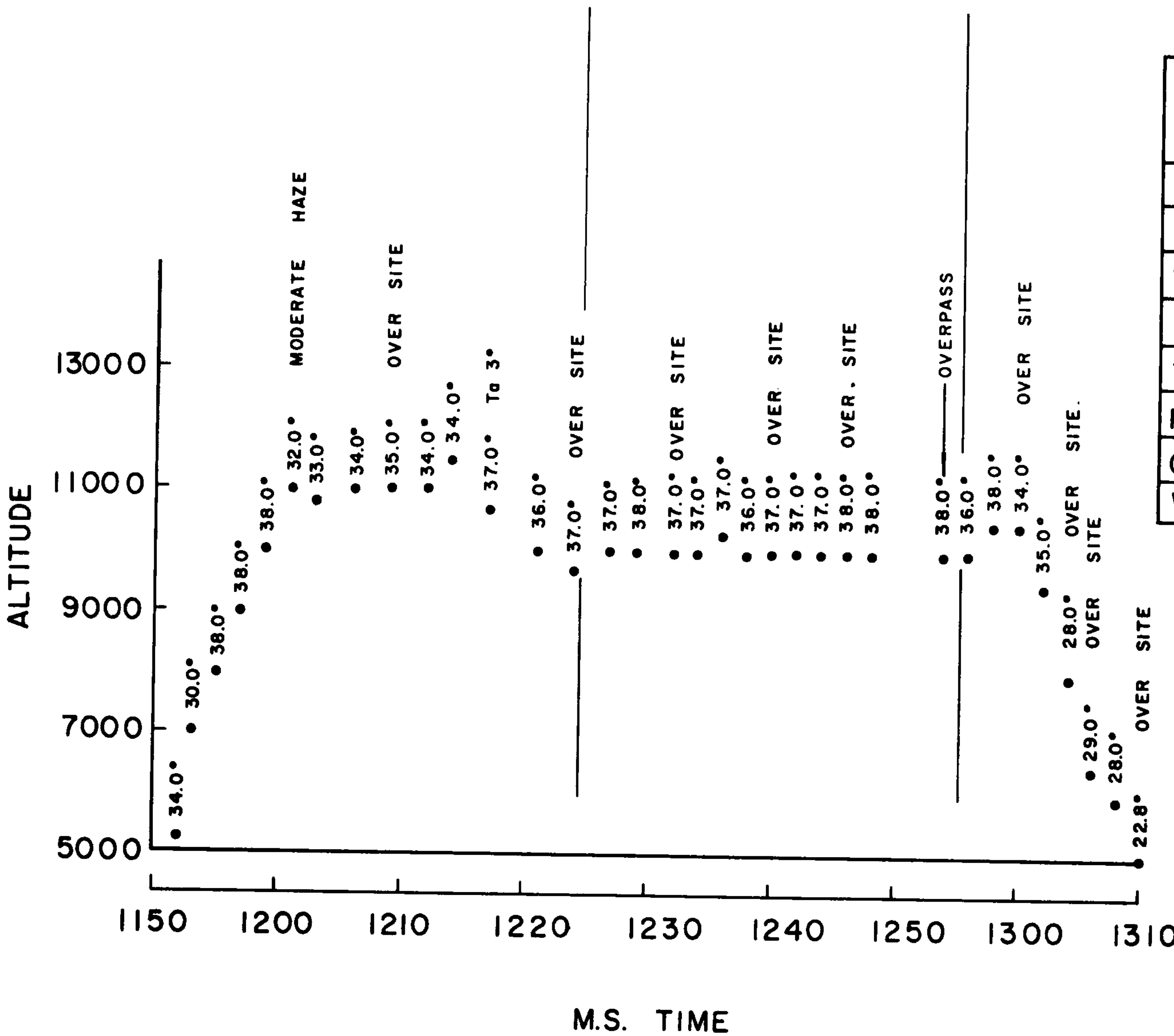
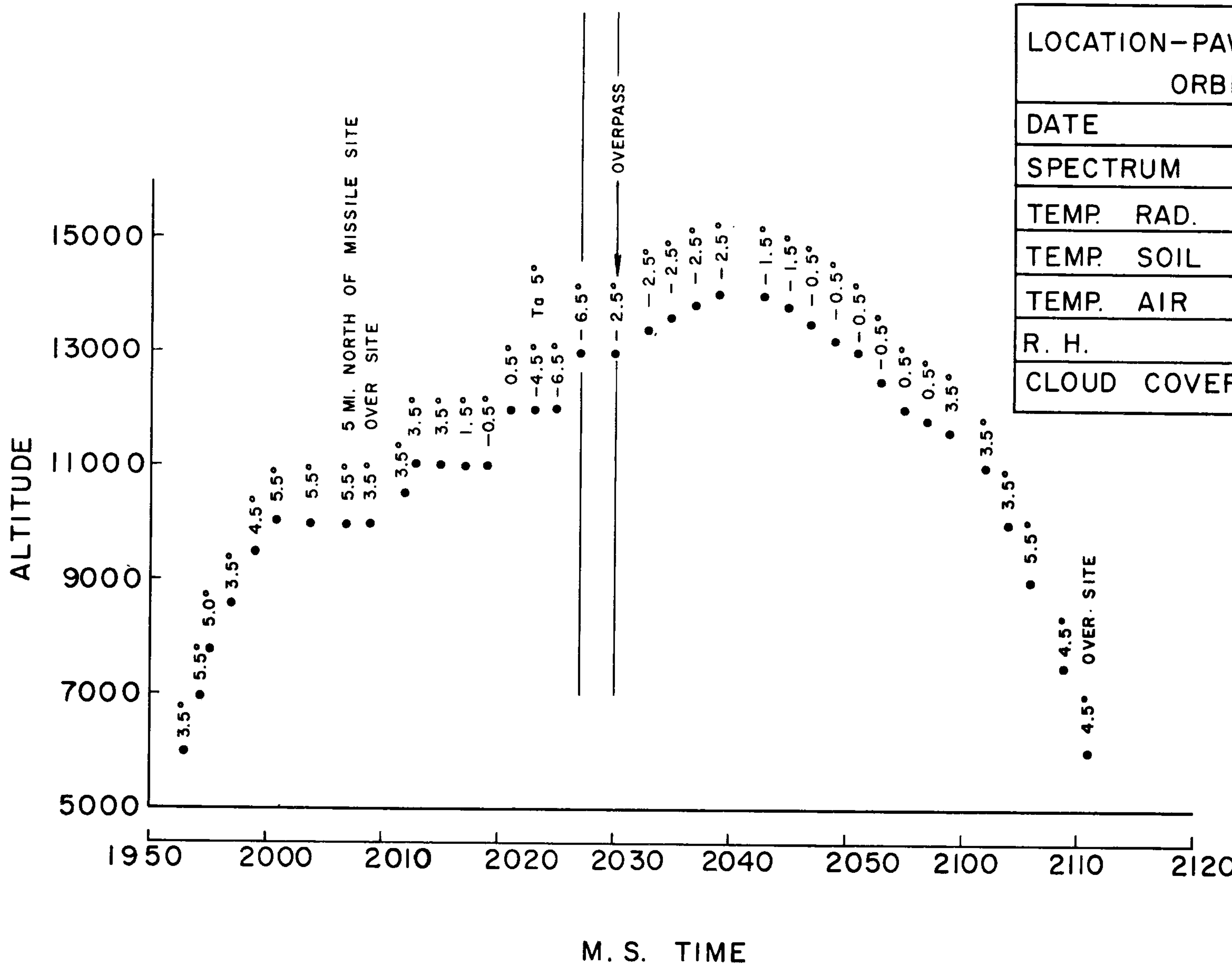


Figure 7 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.



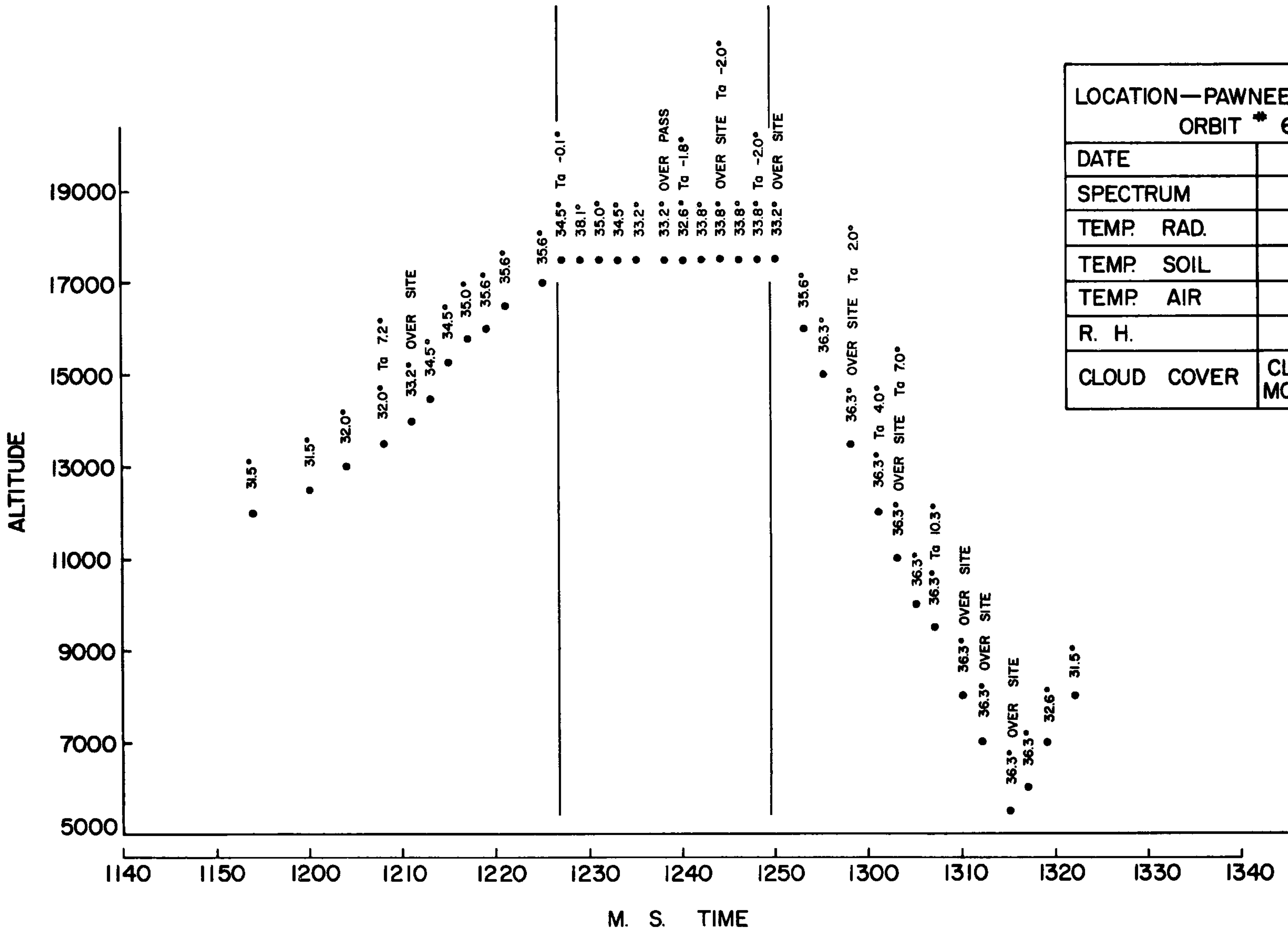
LOCATION — PAWNEE GRASSLANDS ORBIT # 6363	
DATE	8 — 22 — 64
SPECTRUM	8 — 13 μ
TEMP. RAD.	37.1° C
TEMP. SOIL	42.6° C
TEMP. AIR	41.7° C
R. H.	MISSING
CLOUD COVER	MOD. — HAZE
WIND	35 MPH

Figure 8 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.



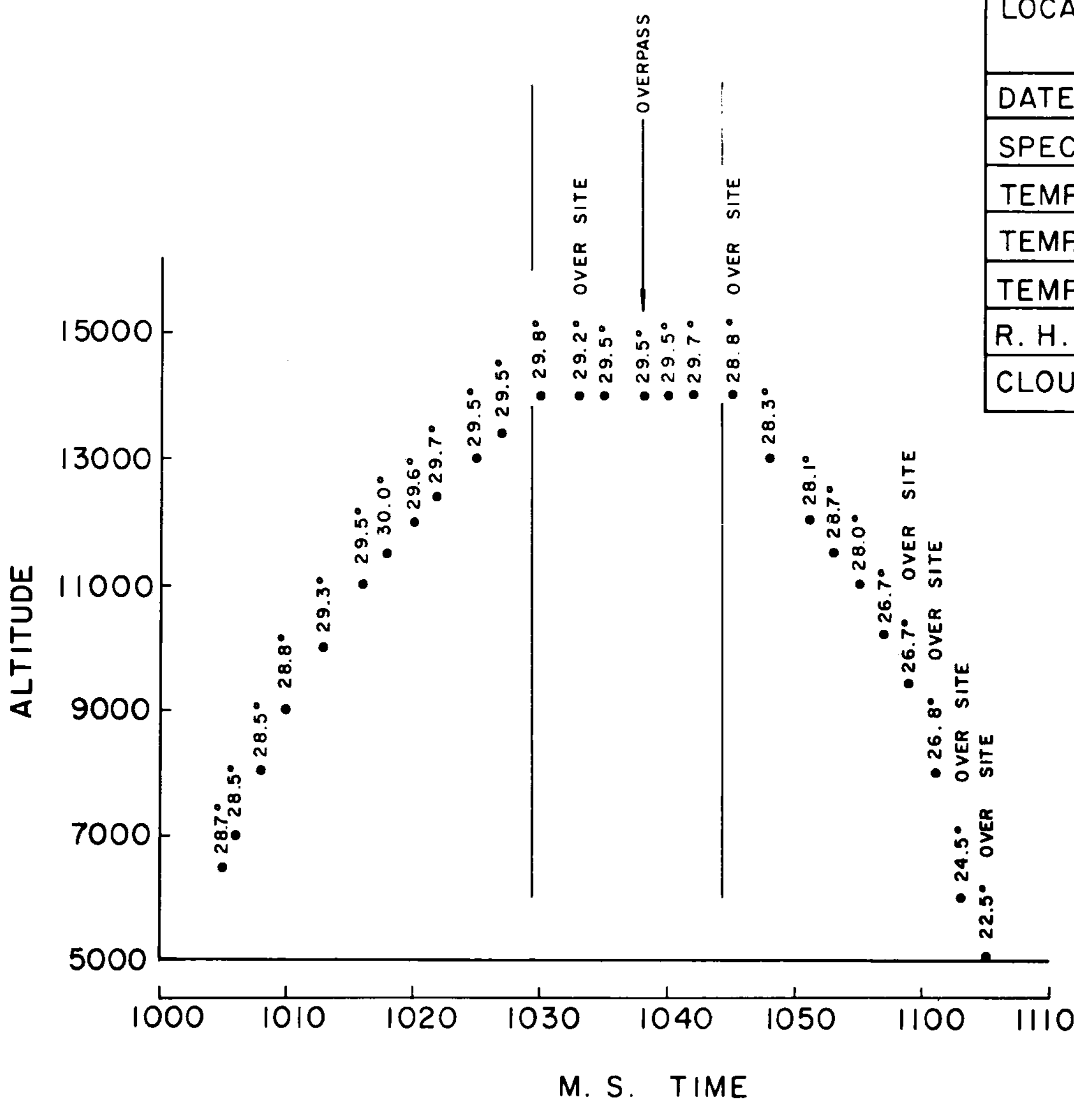
LOCATION–PAWNEE GRASSLANDS ORBIT # 6397	
DATE	8–24–64
SPECTRUM	8–13 μ
TEMP. RAD.	–4.2° C
TEMP. SOIL	11.4° C
TEMP. AIR	10.9° C
R. H.	71 %
CLOUD COVER	LIGHT HAZE

Figure 9 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.



LOCATION—PAWNEE GRASSLANDS ORBIT # 6747	
DATE	9-17-64
SPECTRUM	8-13 u
TEMP. RAD.	31.4°C
TEMP. SOIL	42.7°C
TEMP. AIR	27.2°C
R. H.	36 %
CLOUD COVER	CLEAR WITH MODERATE HAZE

Figure 10 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.



LOCATION-PAWNEE GRASSLANDS ORBIT # 6864	
DATE	9-25-64
SPECTRUM	8-13 μ
TEMP. RAD.	29.1° C
TEMP. SOIL	49.1° C
TEMP. AIR	26.6° C
R. H.	21.6 %
CLOUD COVER	10 % CIRRUS

Figure 11 Minute averages of black body radiation temperatures measured over grassland from air-borne radiometers.

incoming and reflected visible spectrum radiation were also obtained using sol-a-meters (Yellot Solar Energy Laboratory, Phoenix, Arizona), mounted on the top and underside of the aircraft. By using the sol-a-meter measurements as a reference in the manner discussed below, it was possible to compute the albedo for various surfaces in the 0.2 - 6.0 μ (channel 5) and the 0.55 - 0.75 (channel 3) regions of the spectrum.

Sol-a-meter on the top side of the aircraft measured the total incoming visible radiation received on the horizontal surface at the aircraft altitude. The sol-a-meter on the underside of the aircraft measured the total reflected visible radiation over a 180° view. The view of the TIROS radiometer was 5°, pointed vertically down from the aircraft.

Albedos from channel 3 and channel 5 measurements were calculated by:

$$A = \overline{w'}/\overline{w} \times 100$$

where A = albedo (%)

$\overline{w'}$ = measured effective radiant emitance

$\overline{w}$ = effective solar constant at aircraft level

Since the "solar constant" $\overline{w}_{3,5}$ for the TIROS radiometer was originally determined for a space environment, it was necessary to adjust for the reduction of solar radiation in these wavebands between the top of the atmosphere and the aircraft flight altitude. This adjustment was made in the following manner:

$$\frac{\overline{w_s}}{\text{solar constant}} = \frac{\overline{w_3}}{\overline{w^*}} = \frac{\overline{w_5}}{\overline{w^*}}$$

where $\overline{w_s}$ is the total energy received on the sol-a-meter on top of the aircraft, $\overline{w^*_3}$ and $\overline{w^*_5}$ are the "space" solar constants of the channel 3 and 5 filters, respectively.

Albedo measurements were made over stratus clouds, open ocean, forest, snow and desert surfaces. Table 1 gives the albedo values measured by the sol-a-meter and TIROS channel 3 and channel 5.

The sol-a-meters were calibrated against four Eppley pyrheliometers owned by Colorado State University and two Eppley pyrheliometers borrowed from the National Bureau of Standards' Radio Propagation Laboratory at Boulder, Colorado. Readings from the sol-a-meter were found to be within the range of values recorded by the six Eppley pyrheliometers. Measurements from the sol-a-meter mounted on top of the airplane were compared with an Eppley pyrheliometer at the Seattle Weather Bureau and were found to be approximately 16% higher than the Seattle measurements. This difference is probably due primarily to the effect of local city haze on the Seattle readings.

From Table 1, it is seen that the albedo values determined from channels 3 and 5 are usually much lower than those from the sol-a-meters. This is to be expected since the view angle of the

Table 1 Comparison of Albedo Values Measured by TIROS Channel 3 and 5 with those from Sol-A-Meter.

Mo. /Day	Time	Sun Angle	Sol-A-Meter	Ch. 3	Ch. 5	Surface
7/10	0621	16°	49.2%	6.1%	27.7%	Stratus Clouds
7/10	0639	18	40.4	5.6	20.2	Clouds
7/11	0917	46	24.3	3.3	9.9	Coniferous Forest
7/11	1042	59	3.4	1.8	7.1	Open Ocean
7/11	1120	64	3.5	1.6	7.4	Open Ocean
7/11	1132	61	9.8	2.7	8.7	Wet Sand
7/11	1132	61	19.8	7.3	8.7	Dry Sand
7/11	1132	61	3.5	2.0	8.7	River Water
7/11	1458	46	85.0	34.0	52.1	Snow
7/13	0837	40	22.4	7.4	14.7	Desert Shrub
7/13	0851	47	20.9	5.0	24.2	Dry Lake
7/13	1001	50	33.3	15.7	17.2	Death Valley
7/13	1012	53	27.0	9.8	14.6	Death Valley
7/13	1032	55	26.5	14.0	15.3	Death Valley

TIROS radiometer is only 5°, whereas the sol-a-meter "sees" the total 180°. The spectral influence of albedo is apparent in the channel 5 measured reflectance which is considerably higher than channel 3. In the case of open ocean measurements, channel 5 albedo values were even greater than those from the sol-a-meter. Data from channel 5 on the TIROS radiometer contained a considerable amount of microphonic instrument noise, however, resulting in a slightly lower confidence in the albedo values determined.

The influences of sun angle and instrument angle are of utmost importance in the determination of albedo values. All of the above measurements were obtained with the instruments oriented in the vertical. Effect of sun angle on the reflectance from a smooth sea surface is given in Table 2. Measurements over the open ocean at sun angles of 59° and 64° indicate that sol-a-meter values compare quite favorably with data from this table, while channel 3 reflectances are somewhat low and channel 5 quite high.

It is planned that the view angle of the sol-a-meter will be modified to correspond to that of the satellite instrument.

OBJECTIVE 5

Measurements over Rosamond Dry Lake and Vicinity:

During February 1964, a series of flights and ground-based infrared measurements were obtained over Rosamond Dry Lake and the

Table 2 Albedo of a Smooth Sea Surface

Solar Elevation (Degree)	Albedo (%) *
5	40
10	25
20	12
30	6
40	4
50 - 90	3

*Instrument pointed vertically downward

Sierra mountains and desert areas between Edwards Air Force Base and Mt. Whitney. Measurements using the NIMBUS HRIR and MRIR were conducted by the University of Michigan.

Four periods of measurements were obtained. During the first period, 1825 through 1900 hours - February 20, surface temperatures were obtained over Rosamond Dry Lake using thermistors and a hand-held radiometer. A profile of infrared radiation was obtained by the C. S. U plane from the surface to an altitude of 8, 000 feet m. s. l. At the same time, measurements were obtained using medium- and high-resolution infrared radiometers over the same area from the jet aircraft at an altitude of approximately 40, 000 feet m. s. l. A radiation—radiosonde balloon ascent was conducted by the University of Wisconsin simultaneously with the aircraft measurements.

Figure 12 shows the C. S U. aircraft measurements of temperature over and around Rosamond Dry Lake. Table 3 shows the true surface temperature near the center of the dry lake bed at the time of the first flight.

The second flight is shown in Fig. 13. This was a nighttime flight from Edwards Air Force Base to Owen's Lake, near Lone Pine, California. No ground measurements were made during this period.

The third flight in mid-afternoon of February 21 covered the crest of the mountain range and adjacent desert from Rosamond

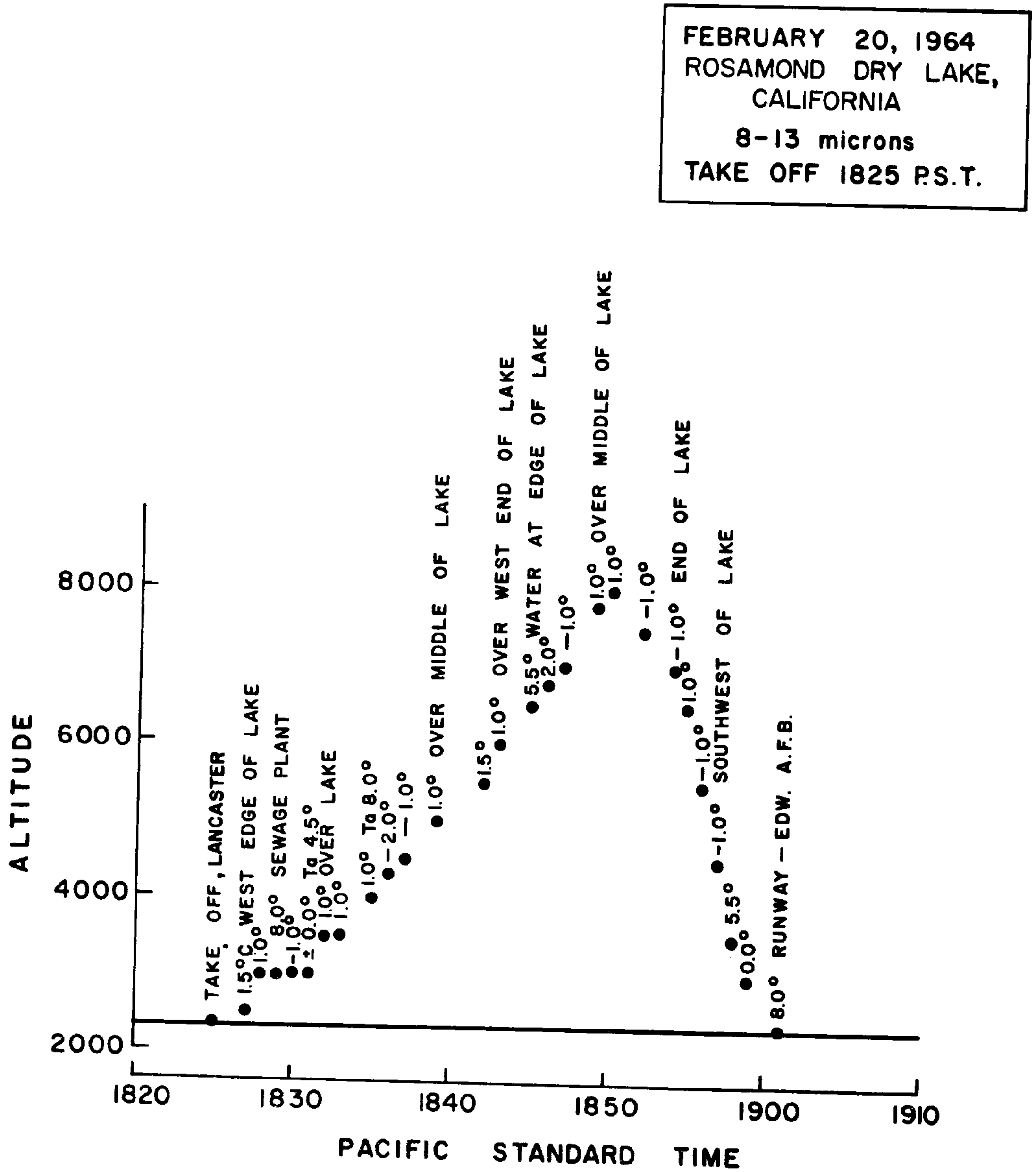


Figure 12 Minute averages of black body radiation temperatures measured over Rosamond Dry Lake, California.

Table 3 Surface Temperature near Center of Rosamond Dry Lake

Date	Time	Sfc. Temp.	St. Dev.
2/20/64	1658 - 1708	10.7°C	± 1.32°C
"	1719 - 1729	8.6	1.43
"	1736 - 1746	3.6	1.51
"	1800 - 1810	3.8	.88
"	1822 - 1832	2.7	.90

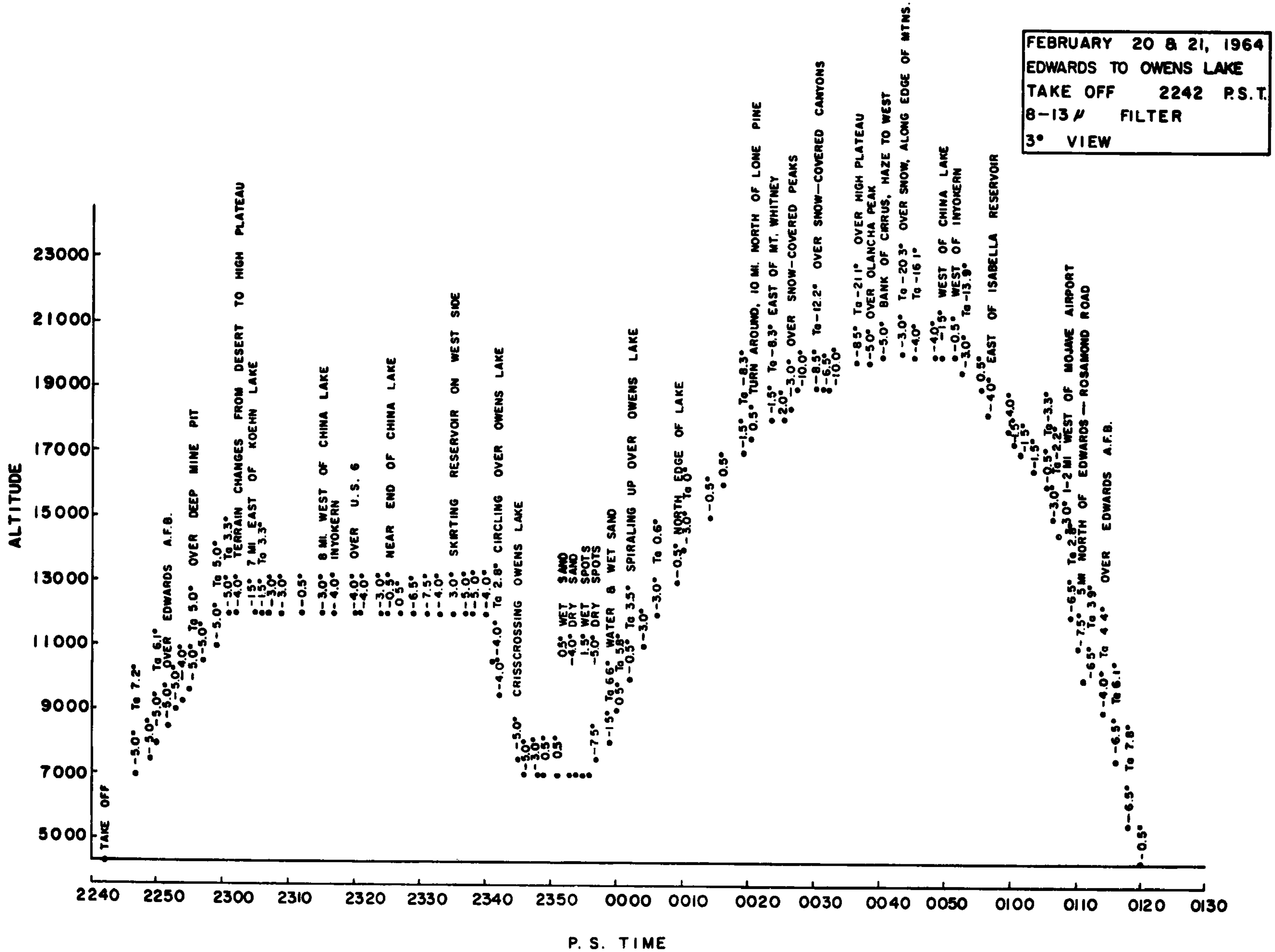


Figure 13 Minute averages of black body radiation temperatures on nighttime flight over desert, lake and mountain terrain.

to Mt. Whitney (Figure 14). Measurements of dry lakes, forests, desert, lava flow, snow, etc., were obtained on this flight. Surface temperature measurements of Rosamond Lake during this period are given in Table 3.

The final set of measurements was obtained on an evening flight from Edwards Air Force Base to a dry lake southwest of Bakersfield, California. The Bakersfield area had been covered by a dense haze layer throughout the day; however, the haze appeared to dissipate over the area during the duration of the flight. Data from Figure 15 indicates that the difference in radiation measurements over Buena Vista Dry Lake, southwest of Bakersfield, amounted to only about 2°C due to the attenuation by the haze layer. This was a much smaller effect than had been observed on several earlier haze flights over the Pawnee National Grassland in Colorado.

No official comparisons have been made by this project of the measurements made by the two aircraft. Copies of the measurements made by the NIMBUS radiometers aboard the CF 100 aircraft are available from Goddard Space Flight Center, Greenbelt, Maryland.

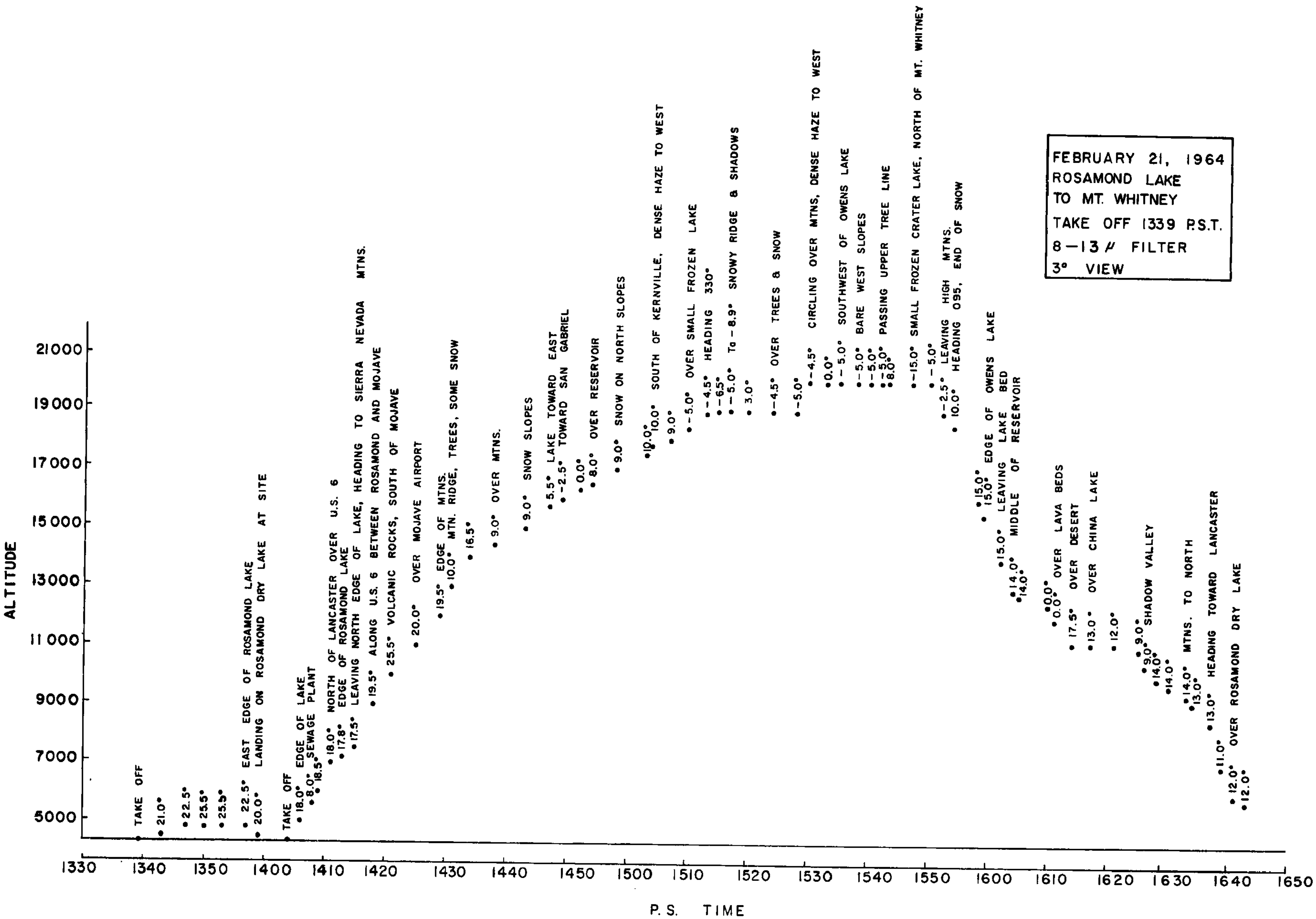


Figure 14 Minute averages of black body radiation temperatures on daytime flight over desert, lake and mountain terrain.

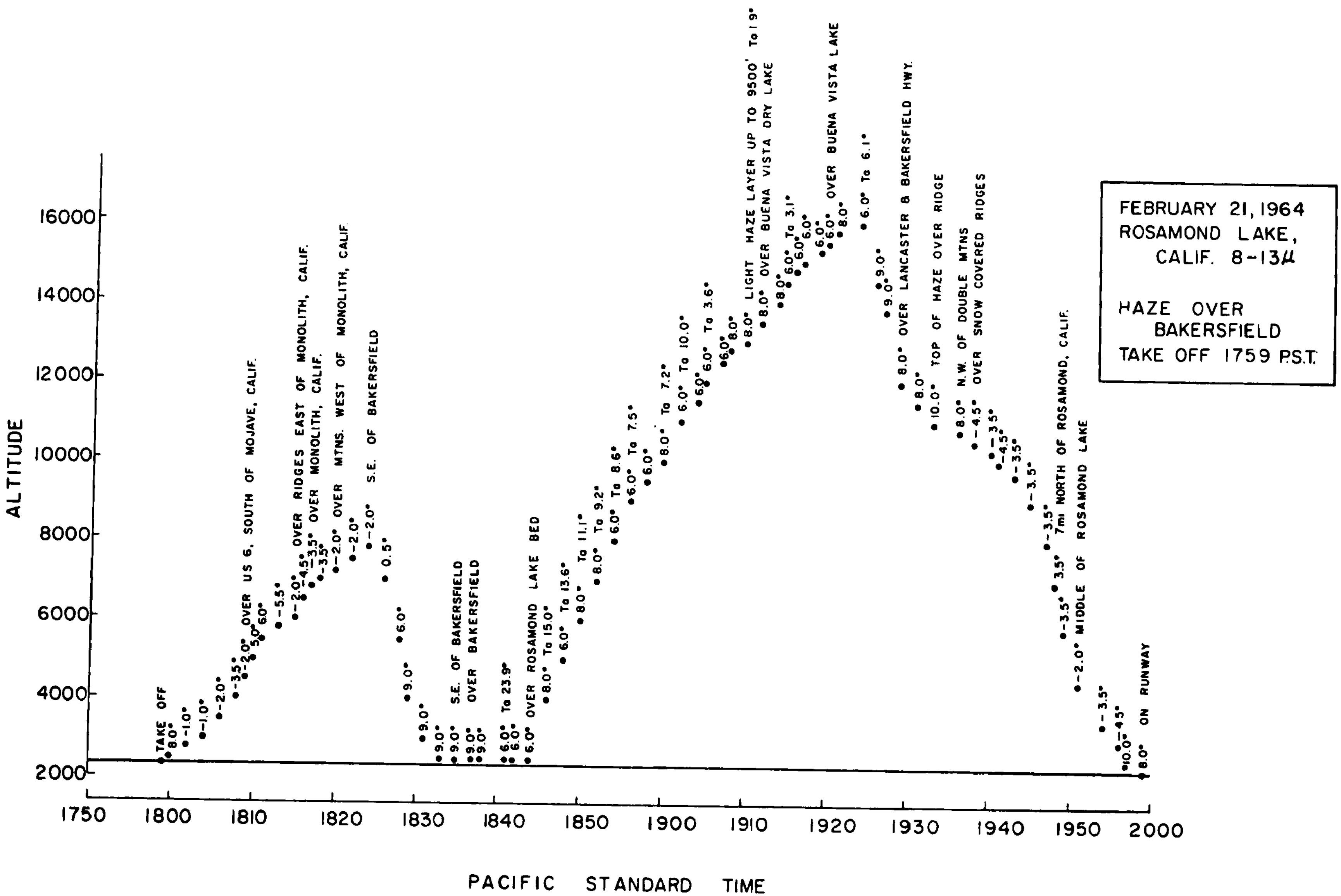


Figure 15 Radiation temperatures measured through haze over Buena Vista Dry Lake - Bakersfield, California.