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U S ARMY

TECHNICAL REPORT

EP-120

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YUMA SUMMER MICROCLIMATE

QUARTERMASTER RESEARCH & ENGINEERING CENTER

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

NOVEMBER 1959 NATICK, MASSACHUSETTS

HEADQUARTERS
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Quartermaster Research & Engineering Center
Natick, Massachusetts

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

Technical Report
EP-120

YUMA SUMMER MICROCLIMATE

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FOREWORD

The United States Army needs to know more about the layer of the atmosphere in which military ground operations are conducted. It is well known that standard meteorological observations purposely avoid the complexities of the microclimate which exists closer to the ground than the height of standard humidity and temperature measurements in an instrument shelter (approximately 5 feet above the ground). Because the soldier and his equipment operate mostly in the lowest layer of the atmosphere, a great deal must be learned about this layer before full assessment can be made of the impact of environment on military activity.

The importance of the microclimate to military operations has been recognized ever since World War II. The Quartermaster Corps began studies of "The Climate of the Soldier" in 1947; by 1949 four reports had been published. These include a comprehensive bibliography and studies of the variation of wind and temperature in the microclimatic layer. Since 1949 the capability for analyzing the large amount of data involved in a microclimatic study has increased, and the desirability has become evident of making microclimatic investigations in the extreme environments of the world where the environmental stress on military operations is greatest. Plans for conducting such studies at arctic, desert, and tropical sites were made in 1954, and the observational program by the U. S. Army Signal Corps, Army Electronic Proving Ground, Fort Huachuca, Arizona, began in 1955. This report, covering a summer period (1956) at Yuma Test Station, Arizona, is the first dealing with the Signal Corps observations. Other microenvironmental studies already published or in preparation by the Quartermaster R&E Command are listed on the inside front cover of this report.

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ABSTRACT

Detailed and continuous temperature, wind, and radiation records for a 2-MO[redacted] summer period, under diverse terrain conditions at Yuma Test Station, Arizona, (were analyzed) ~~it was found~~ that the temperature regime near and at the earth's surface varies significantly from the regime as found by "standard" observations. Midday temperatures greater than 140F were frequent on both sand and desert pavement surfaces. Temperatures at levels 200 ~~centimeters~~ above these surfaces were seldom more than 110F.

The wind regimes at the relatively low sandy plains and desert pavement sites were quite similar, with strongest winds in the afternoon and very light winds at night. Winds measured at the crest of a hill averaged stronger day and night and had important effects on the temperature regime.

The total incoming radiation at ~~Yuma Test Station at~~ midday is extremely high, often exceeding 500 Btu/ft^2/hr. Outgoing radiation is also at a maximum at midday when it averages over 300 Btu/ft^2/hr. The net radiation is positive (incoming) for an average of 12 hours each day, and exceeds 150 Btu/ft^2/hr for an average of 6 hours each day. At night there is a small negative radiation balance.

YUMA SUMMER MICROCLIMATE

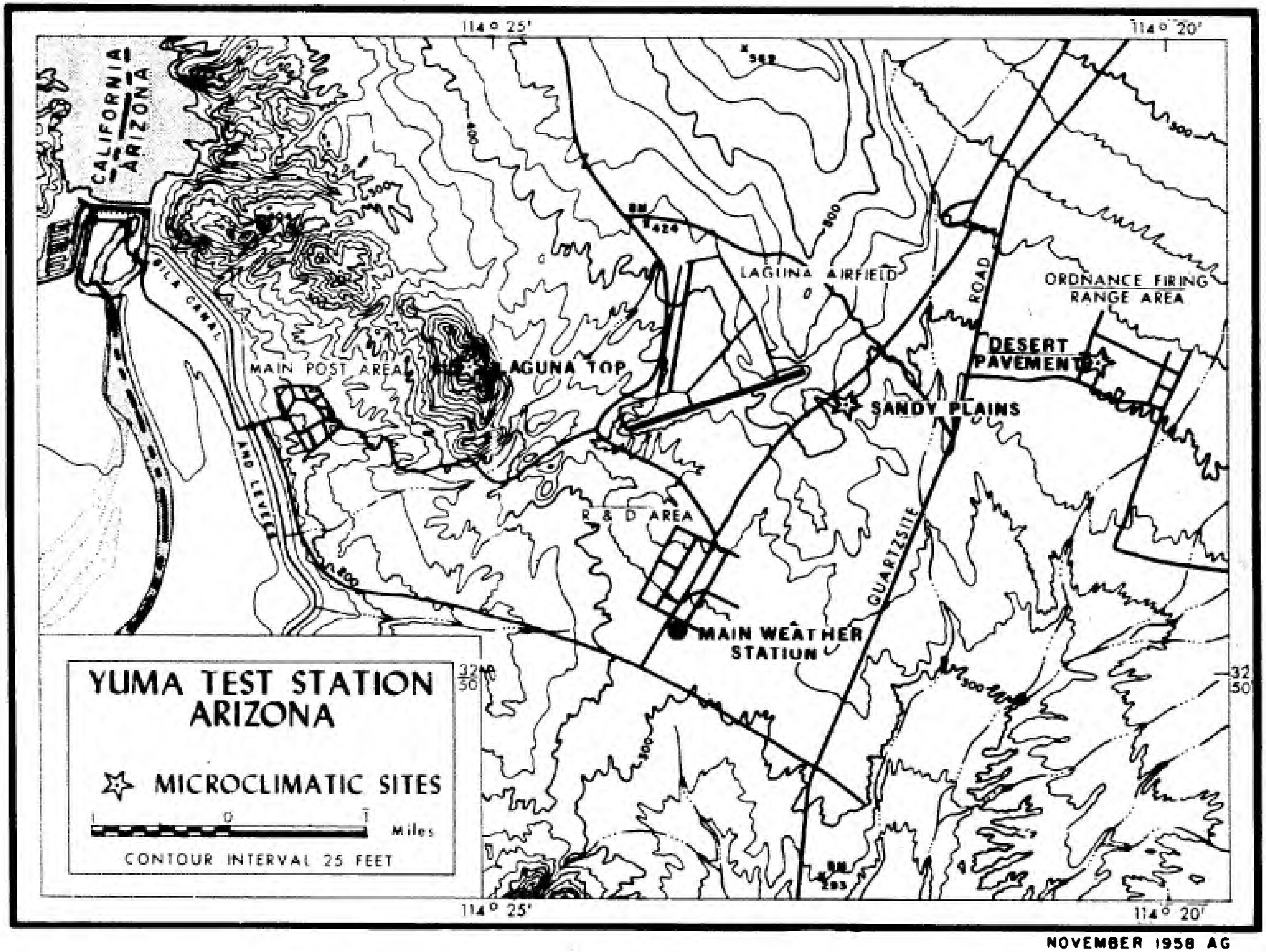
1. OBSERVATIONAL PROGRAM

AS PART OF A BROAD PROGRAM TO INVESTIGATE THE CLIMATE OF THE LOWEST LAYER OF THE ATMOSPHERE IN EXTREME ENVIRONMENTS, SIX MICROCLIMATIC STATIONS WERE INSTALLED AT YUMA TEST STATION, ARIZONA, AND OPERATED CONTINUOUSLY FOR A PERIOD OF 14 MONTHS. THE LONG OBSERVATION PERIOD MADE POSSIBLE THE DETERMINATION OF MONTHLY AND SEASONAL AVERAGES AS WELL AS EXTREME TEMPERATURE GRADIENTS NEAR THE GROUND. THE STATION SITES WERE CAREFULLY SELECTED AS REPRESENTATIVE OF CHARACTERISTIC TYPES OF DESERT SURFACE; THREE OF THE STATIONS ARE CONSIDERED PRIMARY BECAUSE OF THEIR FAIRLY COMPLETE INSTRUMENTATION, AND THREE ARE SECONDARY BECAUSE OF THEIR LESS COMPLETE INSTRUMENTATION. THE RESULTS OF AN ANALYSIS OF THE RECORDS FOR A SUMMER PERIOD AT THE THREE PRIMARY SITES ARE INCLUDED IN THIS REPORT; DISCUSSION OF THE LESS DETAILED RECORDS AT THE SECONDARY STATIONS WILL BE INCLUDED IN A SEPARATE REPORT.

THE MOST COMPLETELY INSTRUMENTED SITE WAS LOCATED ON A SANDY PLAIN EAST OF THE MAIN POST AREA OF YUMA TEST STATION AT AN ELEVATION OF 420 FEET. THE SECOND STATION WAS LOCATED ON A DARK BROWN DESERT PAVEMENT NEAR THE ORDNANCE FIRING RANGE AT ABOUT THE SAME ELEVATION. THE THIRD AND HIGHEST OBSERVATION POINT WAS ON A ROCKY PEAK OF THE NORTH LAGUNA MOUNTAINS AT AN ELEVATION OF 630 FEET, OR 210 FEET ABOVE THE PLAIN. FOR CONVENIENCE, IN THIS REPORT THE STATIONS ARE REFERRED TO AS SANDY PLAINS, DESERT PAVEMENT, AND LAGUNA TOP, RESPECTIVELY. FIGURE 1 IS A STATION LOCATION MAP, AND FIGURES 2, 3, AND 4 ARE PHOTOGRAPHS OF THESE PRIMARY STATIONS AND THEIR SURROUNDINGS.

AT EACH PRIMARY SITE, TEMPERATURES WERE MEASURED AT 10 POINTS BY 20-GAUGE THERMOCOUPLES PLACED AT: (A) ELEVATIONS OF 2.5, 7.5, 25, 50, 100, AND 200 CENTIMETERS ABOVE THE SURFACE, (B) DEPTHS OF 2.5, 7.5, AND 25 CENTIMETERS, AND (C) THE SURFACE, WHERE THE THERMOCOUPLE WAS KEPT LIGHTLY DUSTED. THE THERMOCOUPLES ABOVE THE SURFACE WERE SHIELDED, AS SHOWN IN FIGURES 2, 3, AND 4. AEROVANE ANEMOMETERS WERE INSTALLED 5 FEET ABOVE THE GROUND AT EACH SITE FOR WIND OBSERVATIONS, AND NET AND TOTAL RADIATION WERE OBSERVED AT THE SANDY PLAINS SITE. THE 10 TEMPERATURES AT EACH SITE WERE RECORDED IN SEQUENCE AT INTERVALS OF APPROXIMATELY 1 MINUTE SO THAT EACH COMPLETE CYCLE REQUIRED 10 MINUTES.

A STANDARD WEATHER STATION HAS BEEN MAINTAINED BY THE SIGNAL CORPS AT YUMA TEST STATION SINCE 1951. THE RECORD FROM THAT STATION GIVES AN ADEQUATE INDICATION OF THE "STANDARD" CLIMATE AND PROVIDES A BASE FROM WHICH MICROCLIMATIC VARIATIONS CAN BE DETERMINED. SOLAR RADIATION AND DEWPOINT MEASUREMENTS FROM THE STANDARD STATION WERE USED IN THIS REPORT.



YUMA TEST STATION
ARIZONA
MICROCLIMATIC SITES
Miles
CONTOUR INTERVAL 25 FEET
CALIFORNIA
ARIZONA
GILA CANAL
AND LEVEES
MAIN POST AREA
LAGUNA TOP
LAGUNA AIRFIELD
R & D AREA
MAIN WEATHER STATION
SANDY PLAINS
DESERT PAVEMENT
ORDNANCE FIRING RANGE AREA
QUARTZSITE
ROAD
114° 25'
114° 20'
32° 50'
NOVEMBER 1958 AG

FIGURE I

Figure 2

Sandy Plains

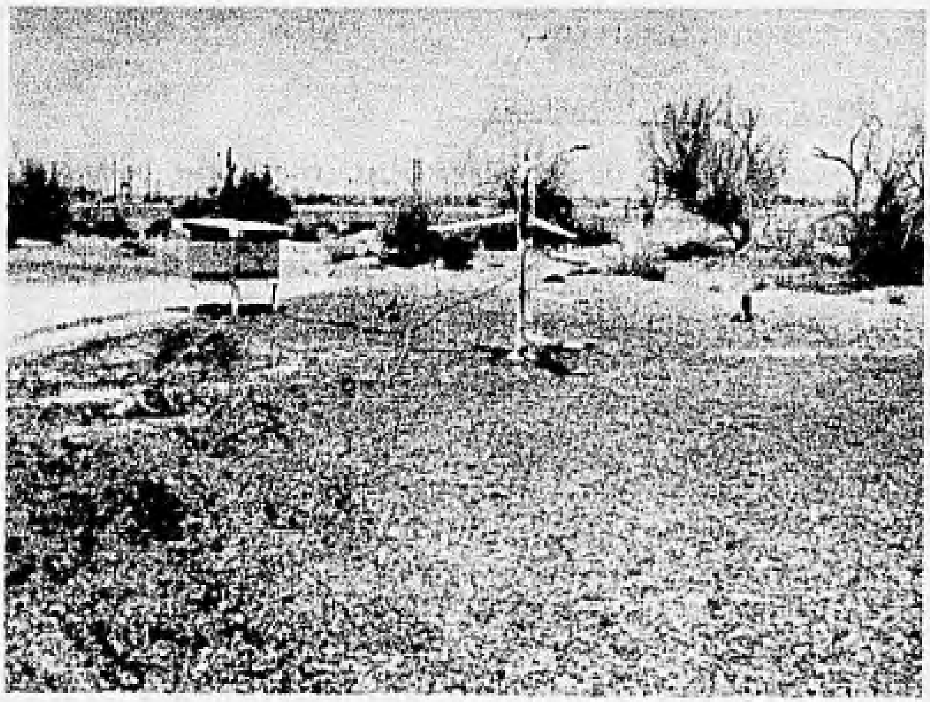


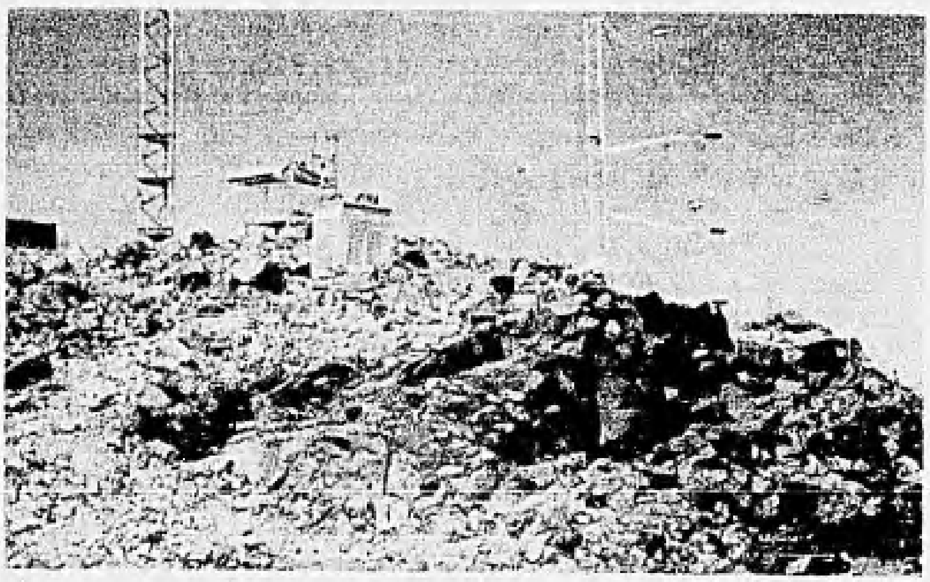
Figure 3

Desert

Pavement

Figure 4

Laguna Top



2. Analysis of Data

Because the most extreme microclimatic conditions in hot deserts occur in summer, the period of July and August 1956 was selected for analysis. Hourly temperatures at each of the 10 levels, hourly wind-speeds and direction for each site, solar radiation measurements at the standard weather station, and net and total radiation measurements at the Sandy Plains site were punched on cards. Four different machine methods were used to analyze the data. First, mean hourly temperatures and windspeeds for July and for August were determined as a basic step for comparisons between stations. Second, temperature distributions during the periods of net incoming and outgoing radiation were studied. Third, temperature distributions during extended periods of high and low absolute humidity were analyzed. Finally, the frequency distribution of temperatures at each station was determined.

a. Mean hourly temperatures and windspeeds

Figure 5 shows July and August mean temperature isotherms drawn against height and time for the Sandy Plains Station. (The data were originally plotted separately for July and August, but since little difference was noted in the temperature profiles during the two months, the observations were combined and are presented here for the two months.) The graph, based on mean hourly temperatures at each of the 10 observation levels, demonstrates well-known characteristics of the microclimatic layer, and makes possible quantitative statements as to temperature differences to be expected in and above the ground.

The daily temperature range was greatest at the ground surface, mainly because of the extremely high temperatures at the surface during the day. The range of temperature narrowed much more rapidly with depth below than with height above the surface. The temperature extremes in the soil lagged behind the extremes at the surface so much that the lowest mean hourly temperature at the 25-centimeter depth occurred at 1230 MST; the highest was at 2230 MST. The highest mean hourly temperature observed, 138F, occurred at the ground surface at 1430. The absolute maximum at this level was 148F. The lowest mean hourly temperature, 76F, did not occur at the surface as would be expected, but at 7.5 centimeters above it at 0430 MST. The absolute minimum temperature observed at Sandy Plains during the two-month period was 62F. It occurred at the surface, and at the 2.5 and 7.5 centimeter levels.

In Figures 6, 7, 8, and 9 the differences which occurred between the Sandy Plains regime, shown in Figure 5, and the regimes at the other sites are depicted.

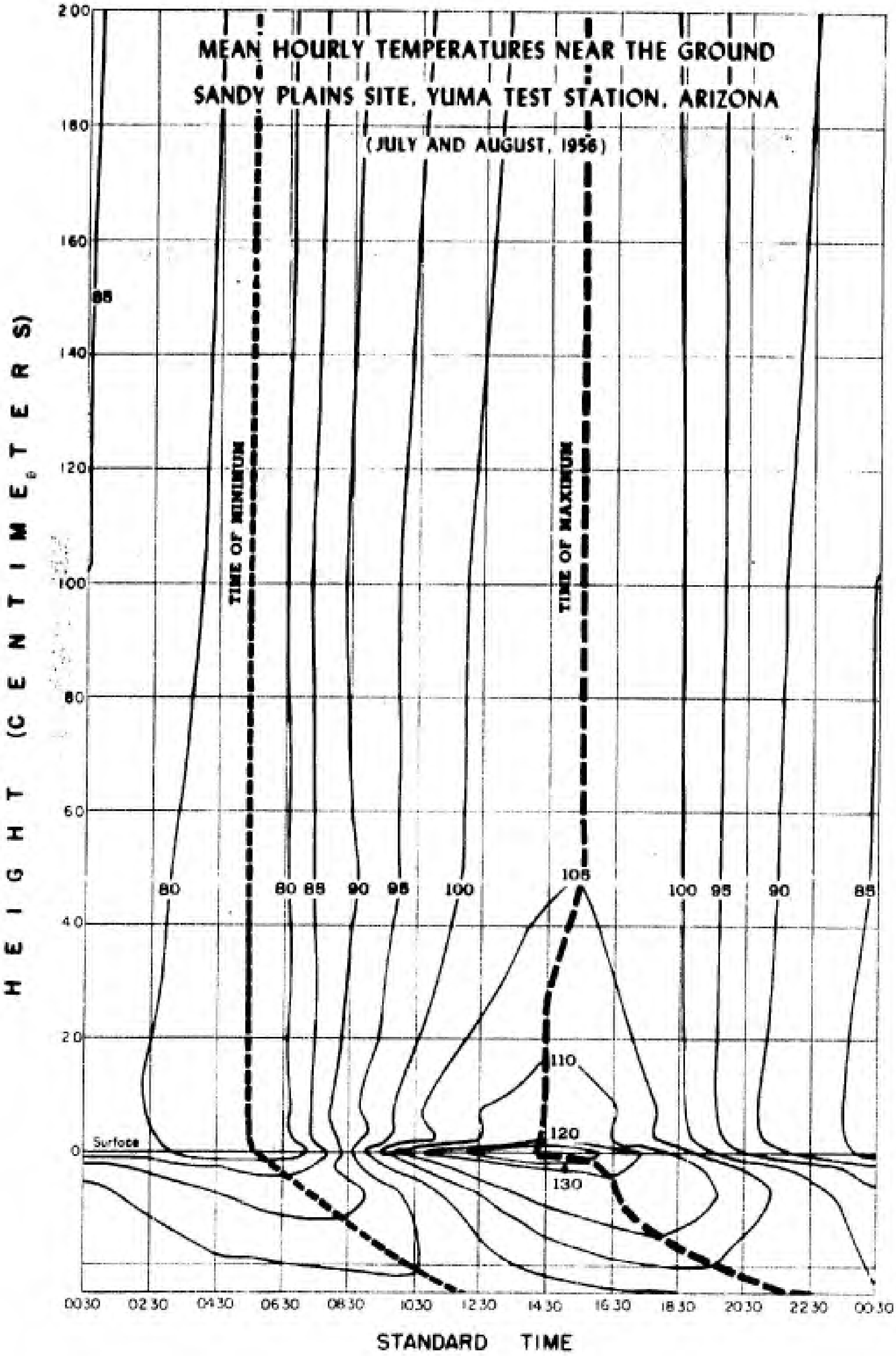

MEAN HOURLY TEMPERATURES NEAR THE GROUND
SANDY PLAINS SITE, YUMA TEST STATION, ARIZONA
(JULY AND AUGUST, 1956)
HEIGHT (CENTIMETERS)
STANDARD TIME
TIME OF MINIMUM
TIME OF MAXIMUM
Surface
200
180
160
140
120
100
80
60
40
20
0
0030
0230
0430
0630
0830
1030
1230
1430
1630
1830
2030
2230
0030
85
80
80
85
90
95
100
105
110
120
130
100
95
90
85

FIGURE 5

DIFFERENCE IN MEAN MONTHLY TEMPERATURE BETWEEN DESERT PAVEMENT AND SANDY PLAINS,
YUMA TEST STATION, ARIZONA

HOURLY MEASUREMENTS (°F) AT NINE LEVELS, JULY 1956

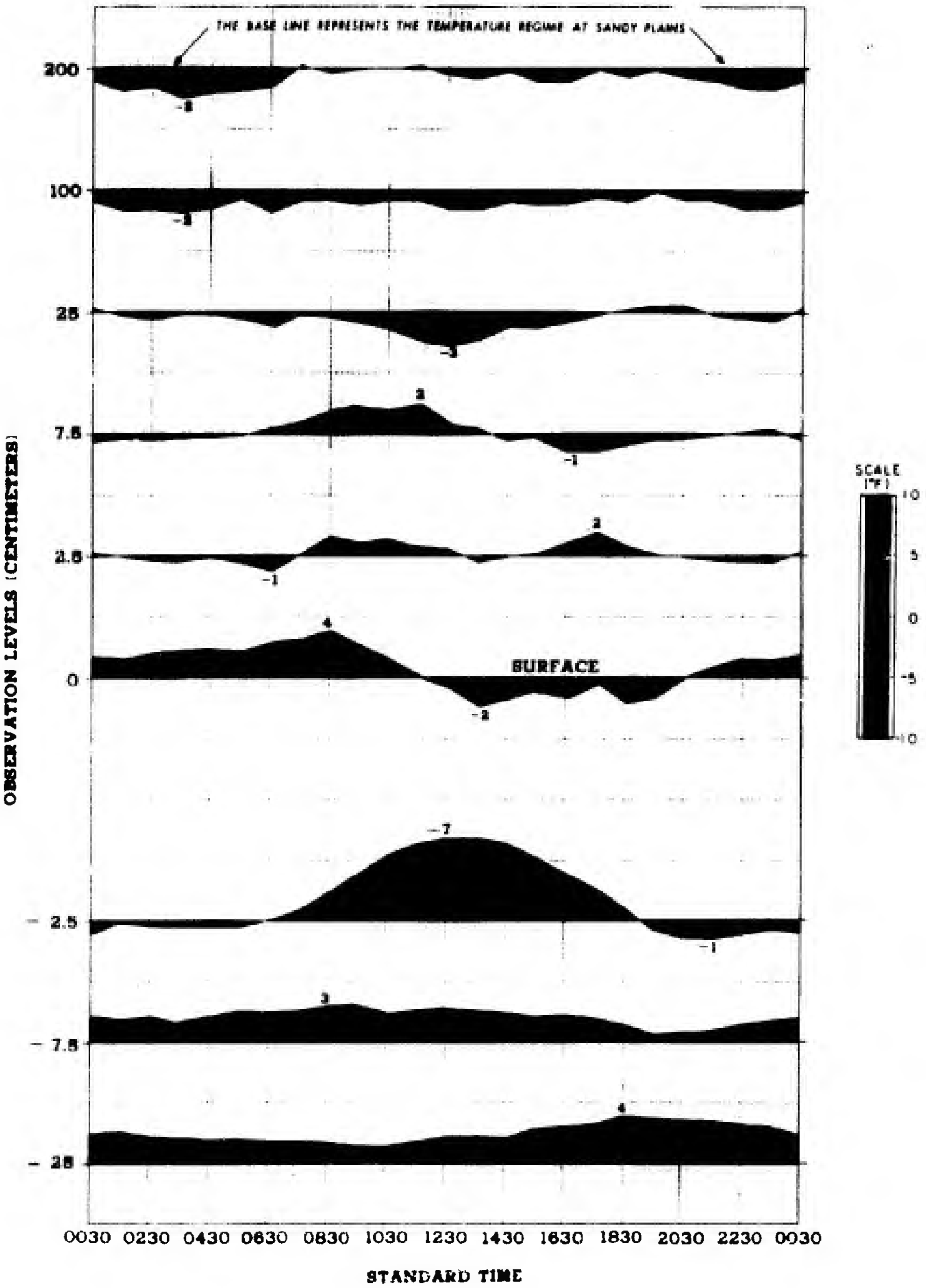


FIGURE 6

DIFFERENCE IN MEAN MONTHLY TEMPERATURE BETWEEN DESERT PAVEMENT AND SANDY PLAINS
YUMA TEST STATION, ARIZONA
HOURLY MEASUREMENTS (°F) AT NINE LEVELS, AUGUST 1956

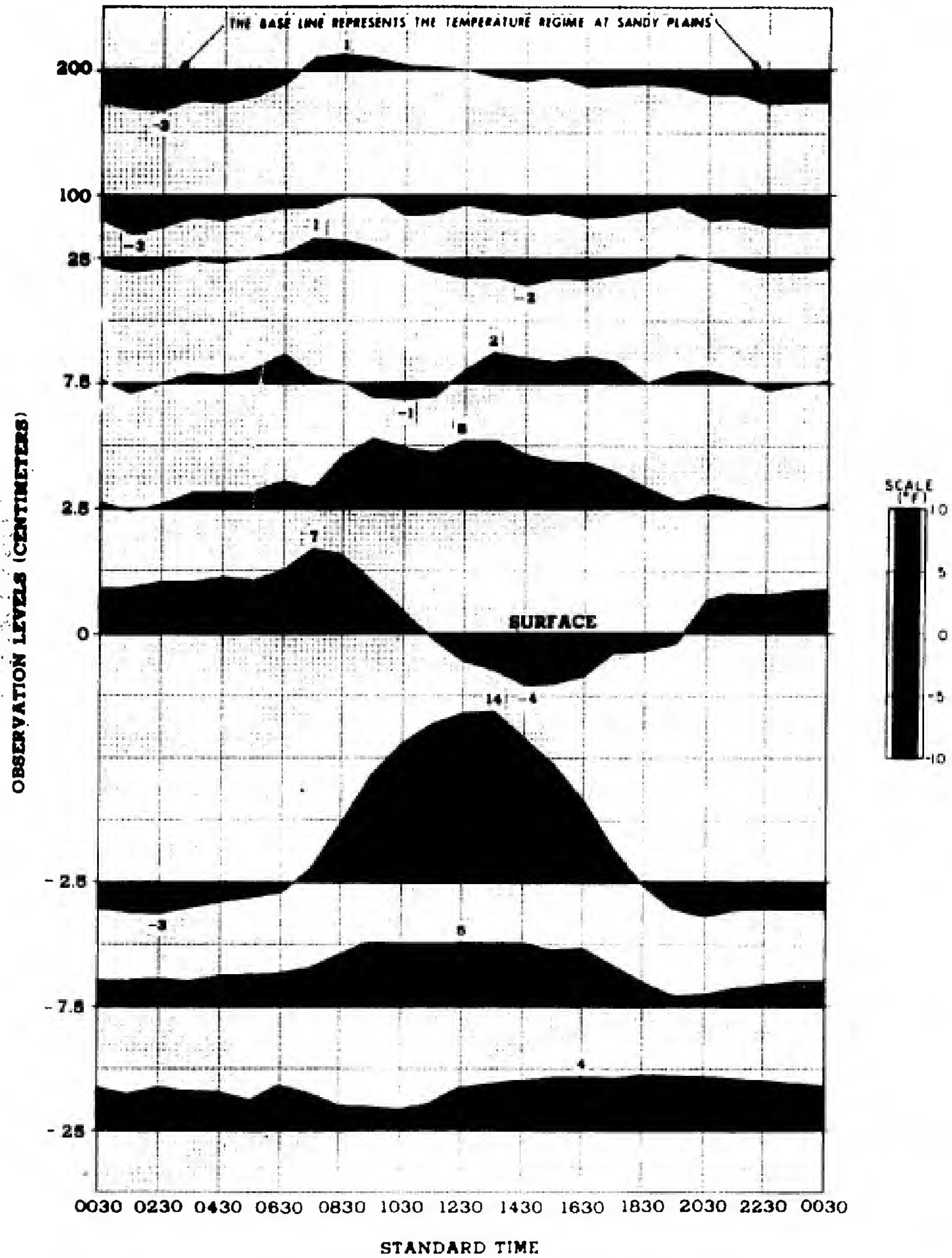


FIGURE 7

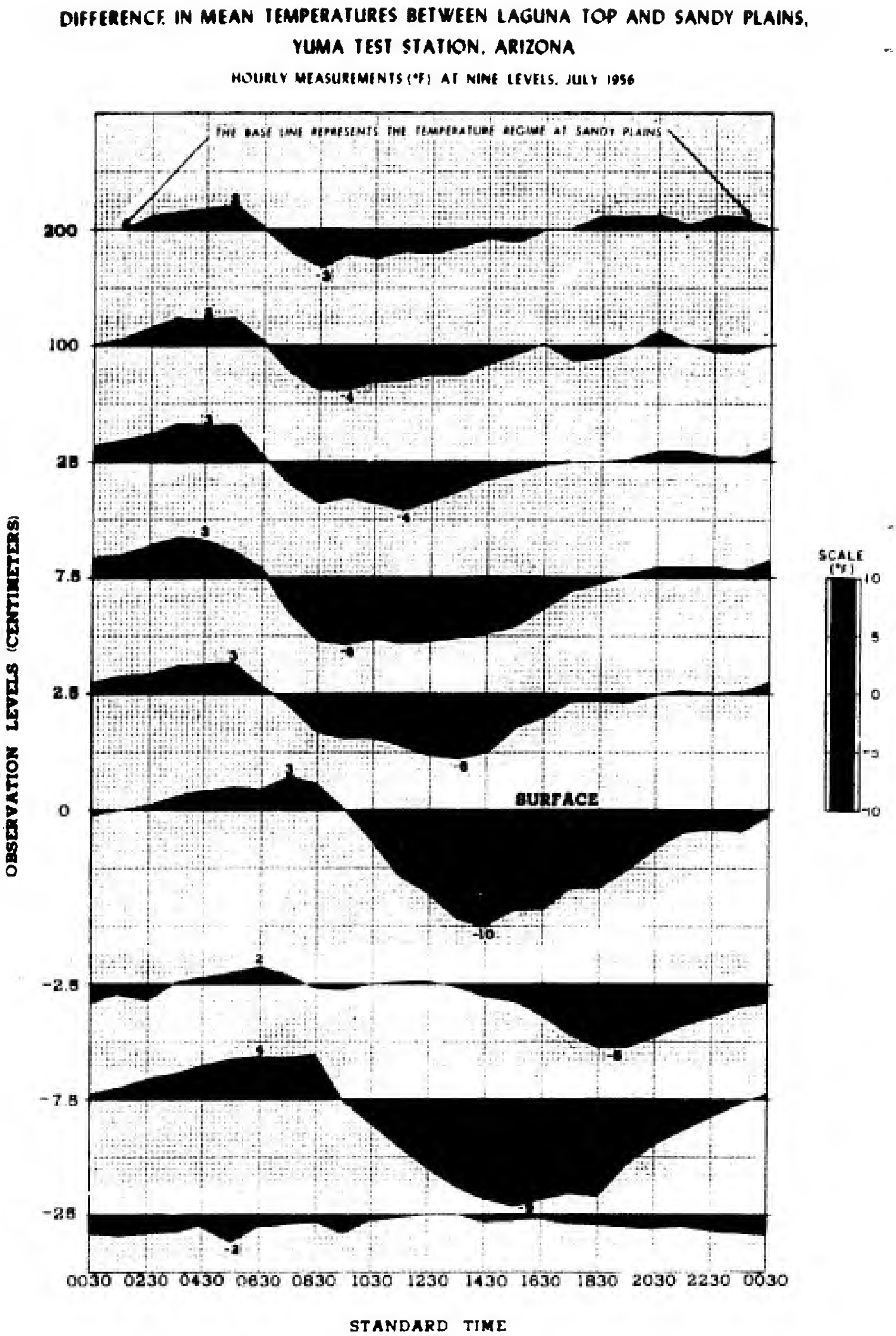

DIFFERENCE IN MEAN TEMPERATURES BETWEEN LAGUNA TOP AND SANDY PLAINS, YUMA TEST STATION, ARIZONA
HOURLY MEASUREMENTS (°F) AT NINE LEVELS, JULY 1956
THE BASE LINE REPRESENTS THE TEMPERATURE REGIME AT SANDY PLAINS
OBSERVATION LEVELS (CENTIMETERS)
200
100
25
7.5
2.5
0
-2.5
-7.5
-25
SURFACE
-10
SCALE (°F)
10
5
0
-5
-10
0030 0230 0430 0630 0830 1030 1230 1430 1630 1830 2030 2230 0030
STANDARD TIME

Figure 8

DIFFERENCE IN MEAN TEMPERATURES BETWEEN LAGUNA TOP AND SANDY PLAINS, YUMA TEST STATION, ARIZONA

HOURLY MEASUREMENTS (°F) AT NINE LEVELS, AUGUST 1956

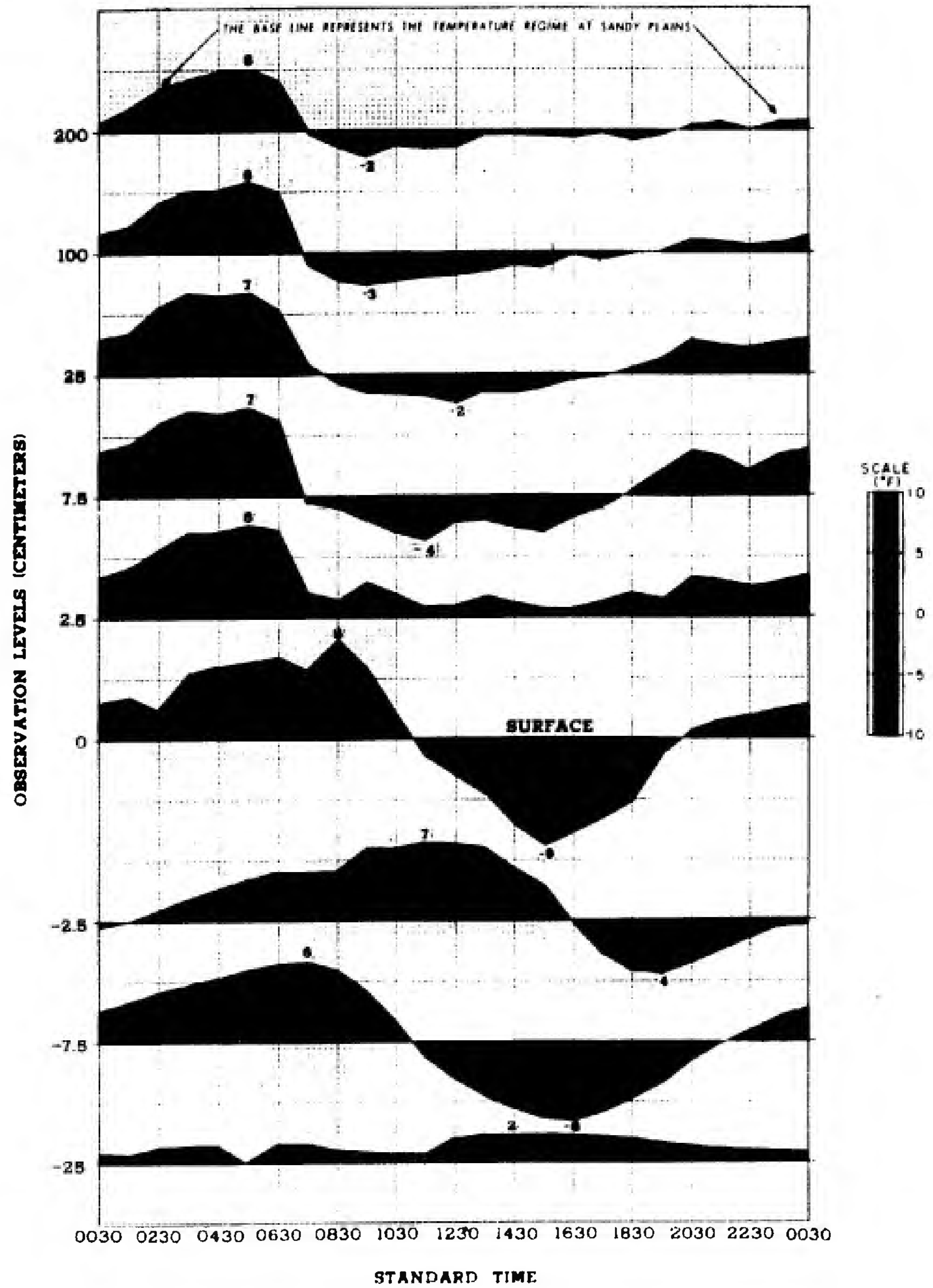


FIGURE 9

(1) COMPARISON OF DESERT PAVEMENT AND SANDY PLAINS TEMPERATURES

DIFFERENCES IN MEAN HOURLY TEMPERATURES BETWEEN SANDY PLAINS AND DESERT PAVEMENT ARE SHOWN IN FIGURE 6 (JULY) AND FIGURE 7 (AUGUST). THE MOST NOTABLE DIFFERENCES BETWEEN THESE STATIONS WERE AT THE 2.5 CENTIMETER DEPTH, WHERE MIDDAY TEMPERATURE VALUES AT THE DESERT PAVEMENT SITE AVERAGED 7F HIGHER THAN THOSE AT SANDY PLAINS IN JULY AND 14F HIGHER IN AUGUST. AT GREATER DEPTHS, THE DESERT PAVEMENT SITE WAS ALSO CONSISTENTLY WARMER.

THE DIFFERENCES IN SUBSURFACE TEMPERATURES CAN BE EXPLAINED BY DIFFERENCES IN HEAT ABSORPTION AT THE SURFACE AND HEAT TRANSMISSION INTO THE GROUND AT THE TWO SITES. MEASUREMENTS TAKEN NEAR THESE SITES* SHOW THAT ABOUT 65 PERCENT OF THE SOLAR RADIATION AT MIDDAY IS ABSORBED OVER THE SANDY PLAINS AREAS, AND ABOUT 85 PERCENT IS ABSORBED OVER THE DESERT PAVEMENT AREAS; THAT IS, THERE IS MORE HEAT AVAILABLE FOR TRANSMISSION INTO THE GROUND AT DESERT PAVEMENT. THE AMOUNT OF HEAT ACTUALLY TRANSMITTED INTO THE GROUND IS DEPENDENT UPON THE THERMAL DIFFUSIVITY OF THE SOIL; THERMAL DIFFUSIVITY IS A TERM DENOTING JOINT CONSIDERATION OF CONDUCTIVITY, DENSITY, AND SPECIFIC HEAT. DRY SAND IS NOTED FOR ITS LOW THERMAL DIFFUSIVITY (GEIGER, 1957); THUS LESS HEAT IS TRANSMITTED INTO THE GROUND AT SANDY PLAINS.

THE DAILY RANGE OF SURFACE TEMPERATURES AT DESERT PAVEMENT IS GENERALLY LESS THAN AT SANDY PLAINS. DURING AUGUST, AFTERNOON SURFACE TEMPERATURES WERE AS MUCH AS 4F LOWER AT DESERT PAVEMENT; MORNING TEMPERATURES WERE AS MUCH AS 7F HIGHER. HOWEVER, THE HIGHEST TEMPERATURE RECORDED FOR THIS STUDY, 150F, OCCURRED AT THE DESERT PAVEMENT SURFACE IN JULY.

THE REASON FOR SOMEWHAT HIGHER DAYTIME TEMPERATURES AT 2.5 CENTIMETERS ABOVE THE GROUND AT DESERT PAVEMENT IS NOT APPARENT. SURFACE ROUGHNESS AND THE THERMAL CAPACITY OF THE SURFACE MATERIAL ARE TWO FACTORS INVOLVED IN THE TEMPERATURE REGIME JUST ABOVE THE SURFACE. ALSO, THE POSSIBILITY OF SLIGHT ERROR IN THE LOCATION OF THE THERMOCOUPLES CANNOT BE ENTIRELY DISCOUNTED, ALTHOUGH THESE POSITIONS WERE CHECKED PERIODICALLY.

(2) COMPARISON OF LAGUNA TOP AND SANDY PLAINS TEMPERATURES

FIGURES 8 AND 9 SHOW THAT LAGUNA TOP HAS A SMALLER DAILY RANGE OF AIR TEMPERATURES THAN SANDY PLAINS, WITH APPRECIABLY HIGHER TEMPERATURES AT NIGHT AND LOWER TEMPERATURES DURING THE DAY. THE

*THE MEASUREMENTS TAKEN BY MR. RICHARD PRATT OF THE BIOPHYSICS BRANCH, ENVIRONMENTAL PROTECTION RESEARCH DIVISION, WITH AN EPPLEY PYRHELIOMETER ATTACHED TO THE UNDERSIDE OF A HELICOPTER, WERE COMPARED WITH THE INCOMING RADIATION MEASUREMENTS AT THE STANDARD WEATHER STATION.

decrease in temperature range is particularly distinct in August; nighttime hourly temperatures were as much as 8F warmer and daytime temperatures were as much as 4F cooler. Because of the greater thermal diffusivity of the rocky surface at Laguna Top, incoming radiant energy is stored for gradual release at night. The reason for lower daytime temperatures at Laguna Top is partly ascribed to the stronger winds at that site. (See following section.) The range of temperatures at the surface is also greatly reduced at Laguna Top, with maximum daytime values averaging 9F lower and minimum nighttime values averaging 8F higher. The highest surface temperature at Laguna Top was 148F, the same as the Sandy Plains site.

An interesting feature shown in Figures 8 and 9 is that in August the temperatures at Laguna Top are relatively higher than in July. The instruments at Laguna Top were on a slight, south-facing slope. Because of this orientation, the sun shines more directly on the Laguna Top surface in August when the angle of incidence of the sun is lower than in July; at the Sandy Plains site, where the ground surface is essentially flat, the reverse is true. It is reasonable to assume that the comparatively higher August temperatures at Laguna Top are caused by the slope differences of the two sites.

(3) <u>Significance of temperature comparisons</u>

In order to determine whether the temperature differences shown in Figures 6, 7, 8, and 9 were real or possibly due to chance, the August data (too many days were missing in July) were analyzed. In any one sequence (e.g., the complete 24-hour comparison between Desert Pavement and Sandy Plains at a particular height is shown in Fig. 7), if there were no real difference in the mean temperature at each one of the 24 hours, there would be a 50-50 chance that the temperature of one point would exceed the temperature of the comparable point at the other site. The temperature differences were translated into a series of signs (plus or minus), which formed sequence patterns. Of the 18 sequence patterns in the analysis, only one could reasonably have been expected by chance.

Where the sequences were shown to be nonrandom, it was reasonable to calculate a confidence interval within which the true difference between the two points would be expected to fall 95% of the time. The confidence intervals, assuming a normal distribution of differences, are presented in Tables I and II for selected times and heights.

As these tables show, there were only three cases in the sample selected where the differences could have arisen by chance.

TABLE I

TABLE OF 95% CONFIDENCE LIMITS FOR TEMPERATURE DIFFERENCES BETWEEN DESERT PAVEMENT AND SANDY PLAINS (AUGUST)

OBSERVATION LEVEL (CM)	TIME	DIFF. IN MEAN TEMP.*	95% CONFIDENCE LIMITS (°F) LOWER	UPPER
200	0230	-3.1	-3.5	-2.6
	0830	1.0	0.7	1.3
	2230	-2.6	-3.0	-2.2
100	0130	-3.0	-3.3	-2.7
	1630	-1.7	-1.9	-1.5
	2330	-2.5	-2.9	-2.1
25	0730	1.3	1.1	1.5
	1230	-1.6	-1.9	-1.3
	2230	-1.0	-1.2	-0.8
2.5	0630	1.9	1.6	2.2
	0930	5.3	4.5	6.1
	2330	-0.2 N.D.	-0.5	0.1
SURFACE	0730	6.6	6.3	6.9
	1430	-4.1	-4.6	-3.6
	2330	3.3	3.1	3.5
-2.5	0230	-2.5	-2.8	-2.2
	1330	13.8	13.0	14.6
	2030	-2.6	-2.9	-2.3
-7.5	0230	2.2	2.1	2.3
	0930	5.0	4.9	5.1
	2230	1.6	1.4	1.8
-25	0230	2.3	2.1	2.5
	0730	2.1	1.8	2.4
	1730	4.3	4.1	4.5

*MINUS SIGNS INDICATE LOWER TEMPERATURES AT DESERT PAVEMENT THAN AT SANDY PLAINS; OTHERWISE DESERT PAVEMENT TEMPERATURES ARE HIGHER.

N.D. - WHEN THE SIGNIFICANCE LIMITS INCLUDE 0, THE TEMPERATURE DIFFERENCE IS NOT SIGNIFICANT AT THE 95% LEVEL; ALL OTHER TEMPERATURE DIFFERENCES IN THIS SAMPLE ARE SIGNIFICANT.

TABLE II

TABLE OF 95% CONFIDENCE LIMITS FOR TEMPERATURE DIFFERENCES BETWEEN LAGUNA TOP AND SANDY PLAINS (AUGUST)

Observation Level (cm)	Time	Diff. in Mean Temp.*	95% Confidence Limits (°F) Lower	Upper
200	0530	4.9	4.3	5.5
	0930	-1.8	-2.1	-1.5
	2130	0.6 N.D.	-0.2	1.4
100	0530	5.7	5.1	6.3
	0930	-2.7	-3.1	-2.3
	2130	0.9	0.2	1.6
25	0530	6.9	6.3	7.5
	1230	-2.2	-2.6	-1.8
	2030	3.0	2.2	3.8
7.5	0530	7.3	6.7	7.9
	1130	-3.3	-4.1	-2.5
	2030	3.8	3.0	4.6
2.5	0530	7.6	6.9	8.3
	1330	1.7	1.2	2.2
	2030	3.3	2.5	4.1
Surface	0830	7.7	7.1	8.3
	1530	-8.6	-9.2	-8.0
	2330	2.5	2.0	3.0
-2.5	0730	4.0	3.6	4.4
	1130	6.3	5.5	7.1
	1930	-4.3	-4.7	-3.9
-7.5	0730	6.8	6.4	7.2
	1630	-6.4	-6.7	-6.1
	2330	2.1	1.8	2.5
-25	0330	0.2 N.D.	0.0	0.4
	0730	0.8	0.5	1.1
	1530	2.3	2.1	2.5

*Minus signs indicate lower temperatures at Laguna Top than Sandy Plains; otherwise Laguna Top temperatures are higher.

N.D. - When the significance limits include 0, the temperature difference is not significant at the 95% level; in only two cases in this sample are mean temperature differences too small to be considered significant.

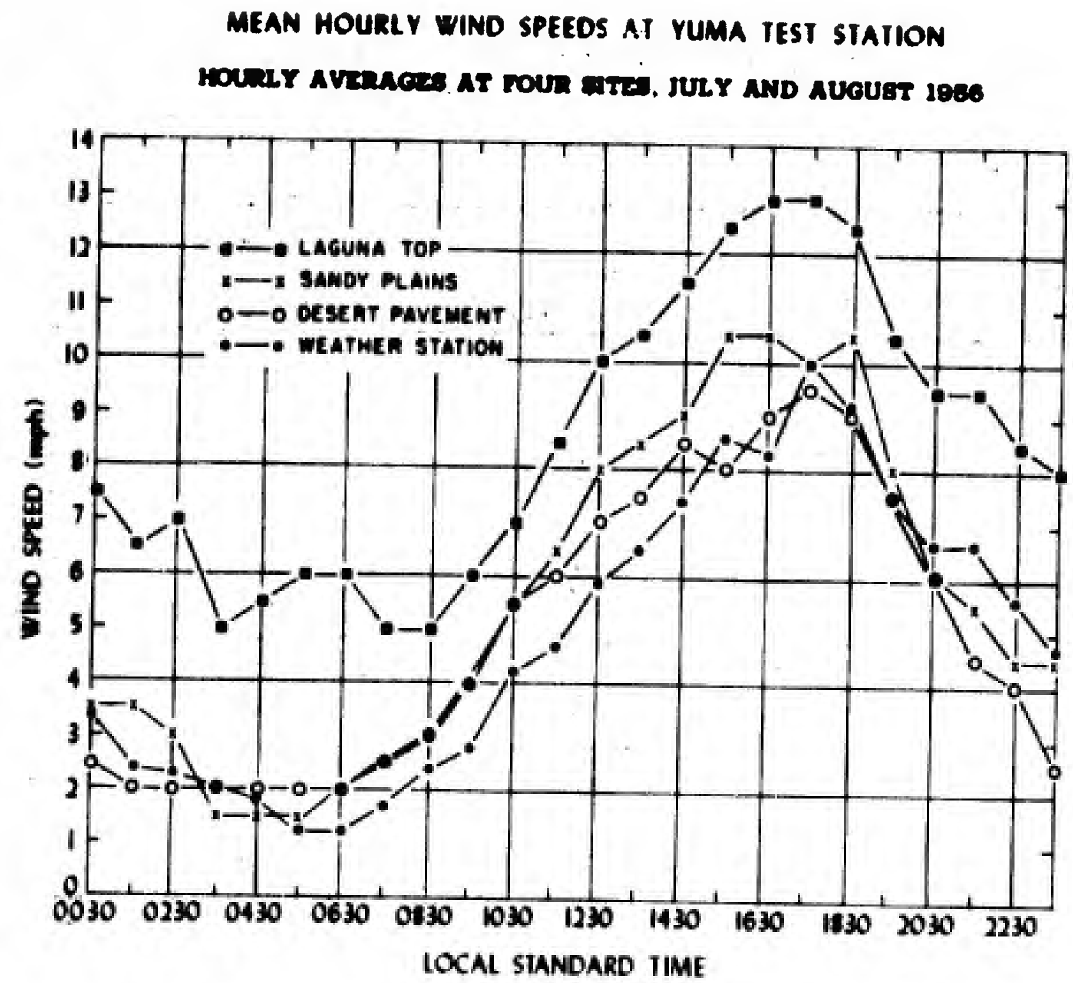


FIG. 10

(4) MEAN HOURLY WINDSPEEDS

THE DAILY WINDSPEED PATTERNS AT THE THREE MICROCLIMATIC SITES AND AT THE STANDARD STATION ARE GRAPHED IN FIGURE 10. THE OUTSTANDING FEATURE OF THE LOW STATIONS IS THE DIURNAL VARIATION IN WINDS FROM MEAN SPEEDS OF LESS THAN 2 MPH IN THE EARLY MORNING TO MORE THAN 10 MPH IN THE AFTERNOON. ANOTHER FEATURE IS THE CONSISTENTLY STRONGER WINDS AT LAGUNA TOP. THIS IS PARTICULARLY IMPORTANT AT NIGHT WHEN NEAR-CALM CONDITIONS PREVAIL FAR MORE OFTEN AT THE LOWER STATIONS AND ALLOW THE DEVELOPMENT OF INVERSIONS. NO IMPORTANT DIFFERENCES BETWEEN THE WIND REGIMES OF THE LOWER STATIONS ARE APPARENT.

B. TEMPERATURE GRADIENTS

THE GREATEST VERTICAL TEMPERATURE DIFFERENCES IN THE LOWEST LAYER OF THE ATMOSPHERE OCCUR DURING THE PERIOD OF MAXIMUM INCOMING solar radiation when high temperatures occur at and near the ground surface. The reverse situation occurs in the early morning when outgoing radiation dominates and results in a cooling trend near the surface.

(1) Outgoing radiation type

The outgoing radiation type of temperature distribution was best developed between 0130 and 0530 MST. To study this temperature distribution, all cards in which the 7.5-centimeter temperature was lower than the 2-meter temperature during this time period were sorted out and analyzed. The 7.5-centimeter height was selected as the base of the inversion because it was the height with the lowest mean early morning temperatures at Sandy Plains, the station with the most inversions. Such an occurrence of minimum temperatures at some point above the surface has been noted in other desert regions (Sinclair, 1922, Ramdas, 1951, and Raschke, 1957), and has been observed repeatedly at the University of Washington above several types of surface on clear nights (Fleagle and Badgley, 1952).

The development of an inversion near the surface depends upon the amount of cooling at the surface and the amount of mixing of air in the low levels. Because the amount of mixing is partially a function of windspeed, the observations in which inversions were found were subdivided into windspeed classes of 3 mph (Table III).

Inversions were most common at Sandy Plains, where they occurred on 281 of 305 early morning hours, or 92 percent of the time from 0130 to 0530. At Laguna Top, inversions occurred during 66 percent of the early morning hours and at Desert Pavement they occurred only 35 percent of the time.

Although nighttime cloud cover observations were not available for this study, it is reasonable to assume that the effect of cloud cover on outgoing radiation was of the same order at the three stations. The difference in the number of inversions at the three sites, therefore, was caused by other factors such as air movement, surface configuration, or surface materials.

At each station, average windspeeds were lower during periods of inversion. However, Desert Pavement, the station with the lightest winds, had the fewest inversions, an indication that factors other than wind also are involved in the formation of inversions. It is likely that at Desert Pavement, higher nighttime surface temperatures (Figs. 6 and 7) prevented a more frequent occurrence of inversions.

TABLE III

NUMBER OF OBSERVATIONS WITH AND WITHOUT INVERSIONS AT THREE SITES AT YUMA TEST STATION, BY WINDSPEED CLASSES. (BASED ON HOURLY OBSERVATIONS FROM 0130 TO 0530 MST DURING JULY AND AUGUST, 1956)

Wind Class (mph)	Sandy Plains Inversion Yes*	Sandy Plains Inversion No**	Desert Pavement Inversion Yes*	Desert Pavement Inversion No**	Laguna Top Inversion Yes*	Laguna Top Inversion No**
Calm	131	5	64	72	29	3
1-3	87	2	30	60	30	23
4-6	45	9	13	46	67	21
7-9	16	5	1	17	41	21
10-12	2	3		1	11	14
13-15				1		7
16-18					3	2
19-21						2
Total Hours	281	24	108	197	181	93
% of Hours	92	8	35	65	66	34
Mean Speed	1.8	4.9	1.1	2.4	4.6	6.9

*Temperature at 200 centimeters higher than at 7.5 centimeters.

**Temperature at 200 centimeters equal to or less than at 7.5 centimeters.

TABLE IV

INVERSION FREQUENCIES DURING JULY AND AUGUST 1956 AT YUMA TEST STATION
(Based on hourly observations from 0130 to 0530 MST at three stations)

Wind Class (mph)	Number of hours with indicated inversion (°F)* <1	1	2	3	4	5	6	7	8	9	10	>10	Total	%
0-3	74	79	77	57	31	22	10	8	4	4	1	4	371	65
4-9	79	68	22	7	5	2							183	32
10-15	7	6											13	2
15+		2	1										3	<1
Total	160	155	100	64	36	24	10	8	4	4	1	4	570	
%	28	27	18	11	6	4	2	1	<1	<1	<1	<1		

*Temperature at 200 centimeters higher than at 7.5 centimeters by the indicated amount

In Table IV the amount of nighttime inversion between the 7.5- and 200-centimeter heights is indicated for the three stations by windspeed class. In no case was an inversion of more than 5F associated with a wind of more than 3 mph. The best-developed inversion, 14F, occurred at the Sandy Plains site during a period of low humidity in early July.

Wind roses, for the period of outgoing and incoming radiation, are shown in Figure 11. The random directions of the light morning winds is quite apparent at the Sandy Plains and Desert Pavement stations. Calms prevailed at these two sites nearly half the time between 0130 and 0530 MST. At Laguna Top, nighttime winds averaged over 5 mph, and prevailed from the west-southwest. Calm conditions occurred only 11 percent of the time.

WIND ROSES DURING PERIODS OF INCOMING AND OUTGOING RADIATION AT YUMA TEST STATION, ARIZONA

(JULY AND AUGUST, 1956)

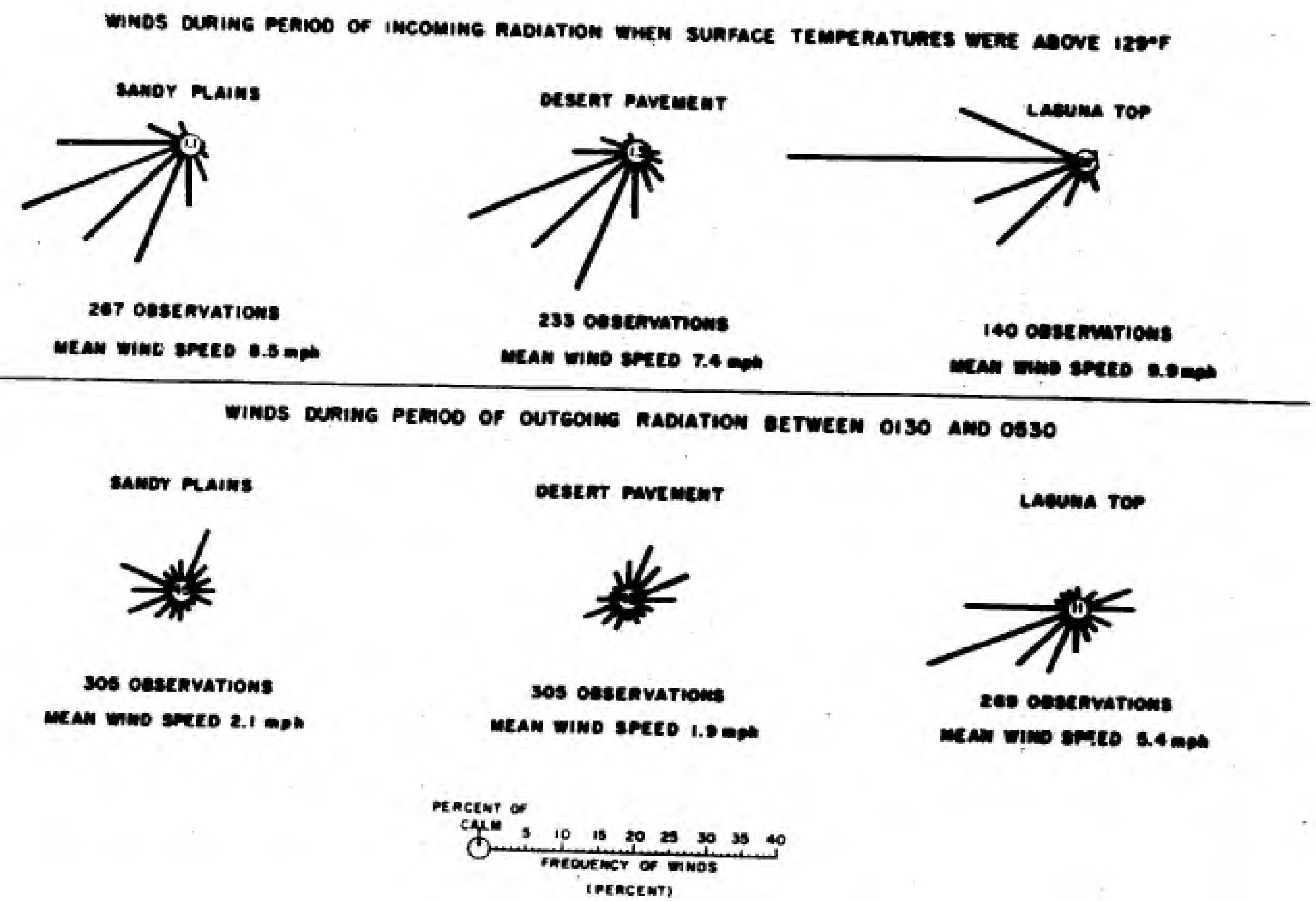


FIGURE 11

TEMPERATURE GRADIENTS DURING PERIOD OF STRONG INCOMING RADIATION AT YUMA TEST STATION

AVERAGES AT THREE SITES WHEN SURFACE TEMPERATURE WAS GREATER THAN 129°F, JULY AND AUGUST 1956

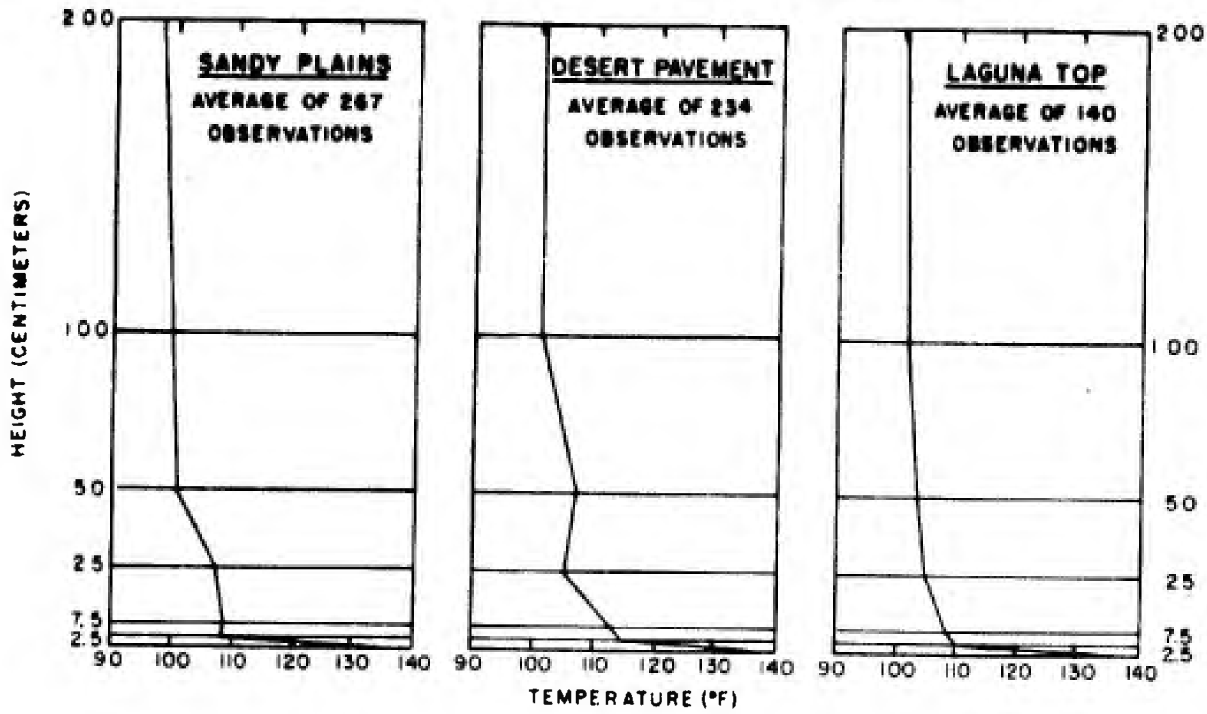


FIGURE 12

(2) INCOMING RADIATION TYPE

THE TYPE OF TEMPERATURE GRADIENT ASSOCIATED WITH STRONG INCOMING RADIATION IS LIMITED FOR PURPOSES OF THIS STUDY TO TIMES WHEN SURFACE TEMPERATURES WERE ABOVE 129F. THIS INDIRECT METHOD OF DELIMITATION, USED BECAUSE THE RADIATION DATA WERE NOT COMPLETE, IS SATISFACTORY BECAUSE A HIGH NET INCOMING RADIATION IS REQUIRED TO RAISE THE GROUND SURFACE TEMPERATURE ABOVE 129F. AT SANDY PLAINS, SURFACE TEMPERATURES WERE ABOVE 129F FOR 267 HOURS DURING THE 2-MONTH PERIOD, AN AVERAGE OF OVER 4 HOURS A DAY, OR ABOUT 18 PERCENT OF THE TIME. AT DESERT PAVEMENT, SURFACE TEMPERATURES WERE ABOVE 129F ABOUT 15 PERCENT OF THE TIME, WHILE AT LAGUNA TOP, ABOUT 10 PERCENT OF THE OBSERVATIONS WERE THIS HIGH. THE AVERAGE TEMPERATURE GRADIENTS AT THE THREE SITES DURING THESE PERIODS ARE PRESENTED IN FIGURE 12.

AT LAGUNA TOP, MEAN TEMPERATURES DURING THE PERIOD OF STRONG INCOMING RADIATION DECREASED WITH ELEVATION IN A REGULAR MANNER, THE GREATEST DECREASE OCCURRING IN THE LOWEST 2.5 CENTIMETERS. AT DESERT PAVEMENT AND SANDY PLAINS THE GREATEST DECREASE ALSO OCCURRED IN THE LOWEST 2.5 CENTIMETERS; HOWEVER, SLIGHT INCREASES IN TEMPERATURE WITH HEIGHT CAN BE NOTED AT THE HIGHER LEVELS. THE EXISTENCE OF THESE INVERSIONS DURING THE DAY WAS UNEXPECTED, ALTHOUGH THEY HAVE BEEN RECORDED BEFORE BY SINCLAIR (1922) AND ARE DISCUSSED BY GEIGER (1957). SUCH daytime inversions may be a function of eddy diffusion or turbulent mixing near the surface. Table V shows the heights and amounts of afternoon inversions at Sandy Plains and Desert Pavement between the hours of 1230 and 1730 MST.

At Sandy Plains, the primary layer of daytime inversion is between 2.5 and 7.5 centimeters. Inversions between these levels often were greater than 1F and on two occasions were greater than 5F. An inversion also existed between 50 and 100 centimeters on 87 of the possible 372 hours during the two months. This inversion, however, was seldom greater than 1F.

At Desert Pavement, inversions occurred more frequently than at Sandy Plains and the temperature gradient pattern was different. Occasionally (71 out of 372 observations), inversions were found between 2.5 and 7.5 centimeters. In three cases these inversions were greater than 3F. Inversions existed between 25 and 50 centimeters more than two-thirds of the afternoon hours (265 of 372 observations); the greatest was more than 5F. The inversions at Sandy Plains and Desert Pavement occurred despite the afternoon air movement (Fi[illegible]).

The daytime inversions discussed above were based mainly on afternoon observations. However, at both Sandy Plains and Desert Pavement, daytime inversions were often more pronounced in the morning.

Total incoming radiation and net radiation were measured during the day at the Sandy Plains site. Solar and sky radiation were measured with an Eppley pyrheliometer at the nearby weather station. The Eppley is not sensitive to longwave radiation beyond approximately 2.5 microns (.00025-centimeter wavelength) because the infrared is not transmitted through the glass bulb of the instrument. The total hemispheric radiometer theoretically is sensitive to the total radiation impinging upon it and thus will indicate higher values than the Eppley, the difference being mainly longwave radiation. The net radiometer is similar to the total hemispheric radiometer except that it is sensitive to the difference in radiation from the ground and the sky (Gier and Dunkle, 1951).

In Figure 13 the daily march of incoming radiation, net radiation, solar radiation, and the outgoing radiation (obtained by subtracting the net radiation from the incoming radiation) are presented for the period 0530 through 2030. Radiation totals are hourly averages for the 2-month period. The total incoming radiation exceeds the solar radiation during the daylight period by 110 to 160 Btu/ft^2/hr, the greatest difference occurring at the time of maximum solar radiation. The outgoing radiation is also greatest near the time of maximum solar radiation.

TABLE V

AFTERNOON INVERSIONS AT TWO STATIONS AT YUMA TEST STATION
(OBSERVATIONS FROM 1230 TO 1730 MST DURING JULY AND AUGUST 1956)

HEIGHT (CM)	SANDY PLAINS		DESERT PAVEMENT	
	INVERSION	NO INVERSION	INVERSION	NO INVERSION
2.5 TO 7.5	0 1* 2 3 4 5 6 66 58 42 16 6 2 TOTAL 190	182	0 1 2 3 4 52 16 2 1 TOTAL 71	301
7.5 TO 25	NONE	372	NONE	372
25 TO 50	3 INVERSIONS DURING RAIN	369	0 1 2 3 4 5 6 68 85 70 32 9 1 TOTAL 265	107
50 TO 100	0 1 2 3 58 27 2 TOTAL 87	285	TWO 0.5F INVERSIONS	370

*66 OBSERVATIONS WITH INVERSIONS OF FROM 0 TO 1F, ETC.

MEAN HOURLY RADIATION TOTALS DURING DAYLIGHT HOURS AT YUMA TEST STATION, ARIZONA (JULY AND AUGUST 1956)

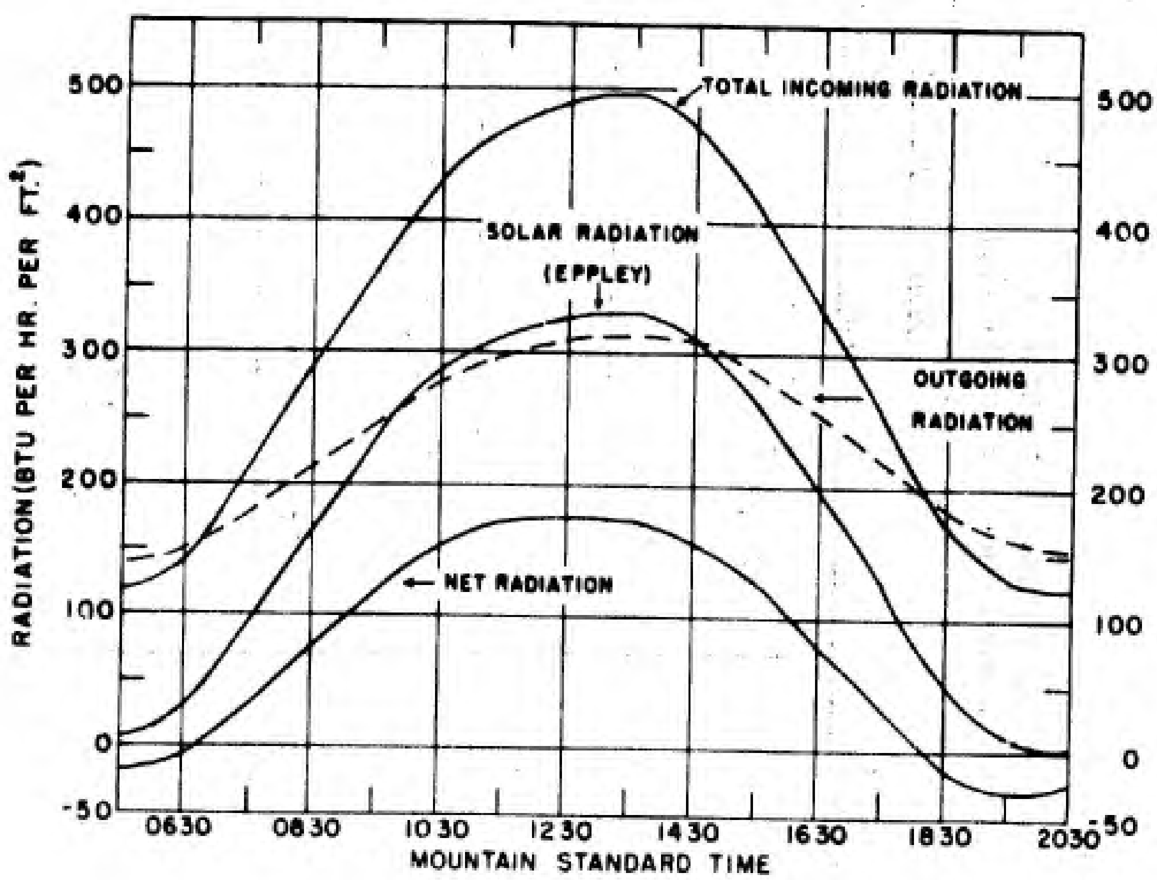


FIGURE 13

c. <u>HUMIDITY EFFECTS</u>

IN FIGURES 14 THROUGH 21, MEAN TEMPERATURE GRADIENTS ABOVE THE GROUND DURING PERIODS OF HIGH AND LOW DEWPOINTS ARE PRESENTED IN DETAIL FOR THE SANDY PLAINS AND DESERT PAVEMENT SITES. AT YUMA TEST STATION, THE FIRST WEEK OF JULY 1956 WAS CHARACTERIZED BY LOW DEWPOINTS. THE PERIOD 2 THROUGH 5 JULY WAS SELECTED AS REPRESENTATIVE OF THIS LOW HUMIDITY PERIOD. DEWPOINTS WERE CONSISTENTLY HIGH AT THE END OF JULY, AND THE PERIOD FROM 27 THROUGH 31 JULY WAS SELECTED TO REPRESENT THIS HIGH HUMIDITY PERIOD.* AT BOTH THE SANDY PLAINS AND DESERT PAVEMENT SITES THE TEMPERATURE GRADIENTS WERE GROUPED ACCORDING TO DAILY PERIODS OF RISING AND FALLING TEMPERATURES TO FACILITATE READING THE GRAPHS. MEAN HOURLY DEWPOINTS AND WINDSPEEDS DURING THE RESPECTIVE HUMIDITY PERIODS ARE INCLUDED AS INSERTS IN THE EIGHT BASIC GRAPHS.

*CHANGE IN AIR MASS WITH RESULTANT CHANGE IN HUMIDITY IS A REGULAR FEATURE OF THE YUMA SUMMER ENVIRONMENT (BRYSON AND LOWRY, 1955.)

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF HIGH HUMIDITY
AT SANDY PLAINS, YUMA TEST STATION, ARIZONA

27 THRU 31 JULY, 1956

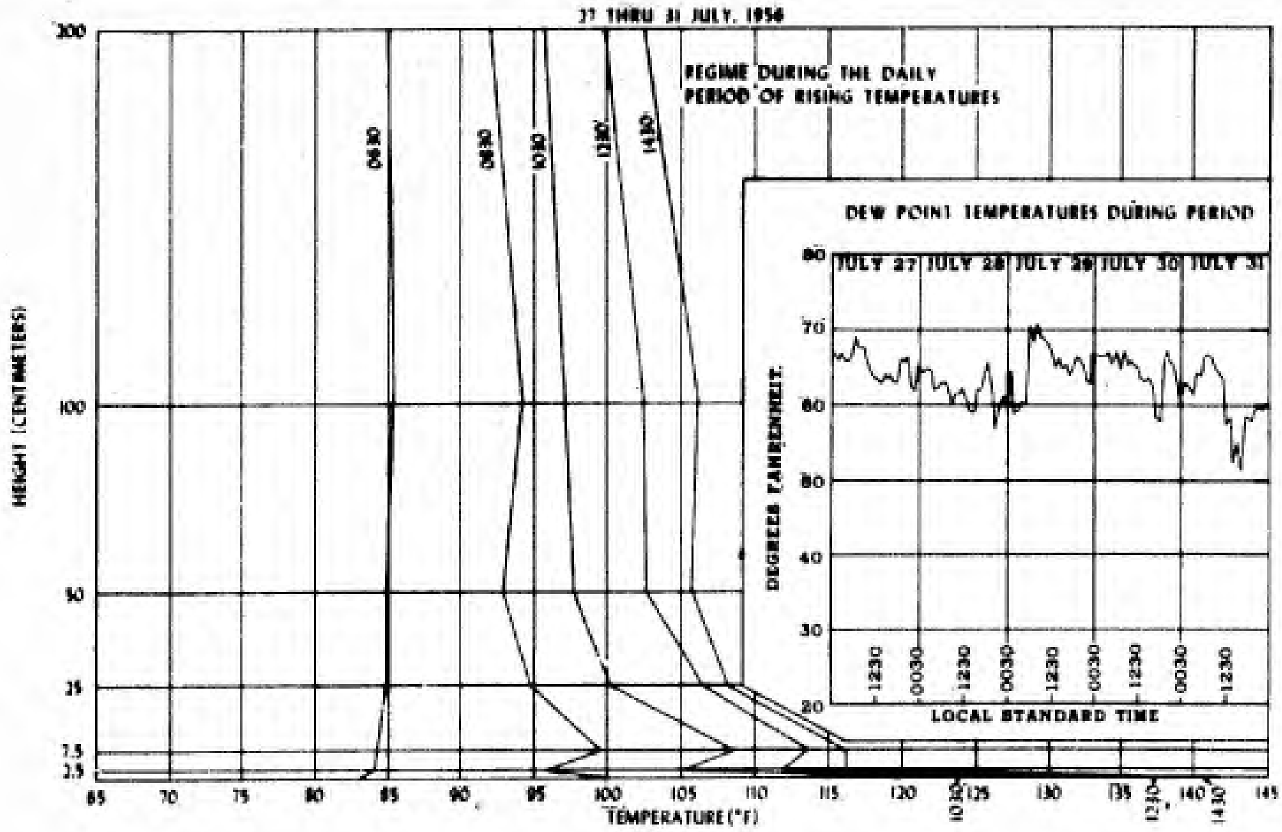


FIGURE 14

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF HIGH HUMIDITY
AT SANDY PLAINS, YUMA TEST STATION, ARIZONA

27 THRU 31 JULY, 1956

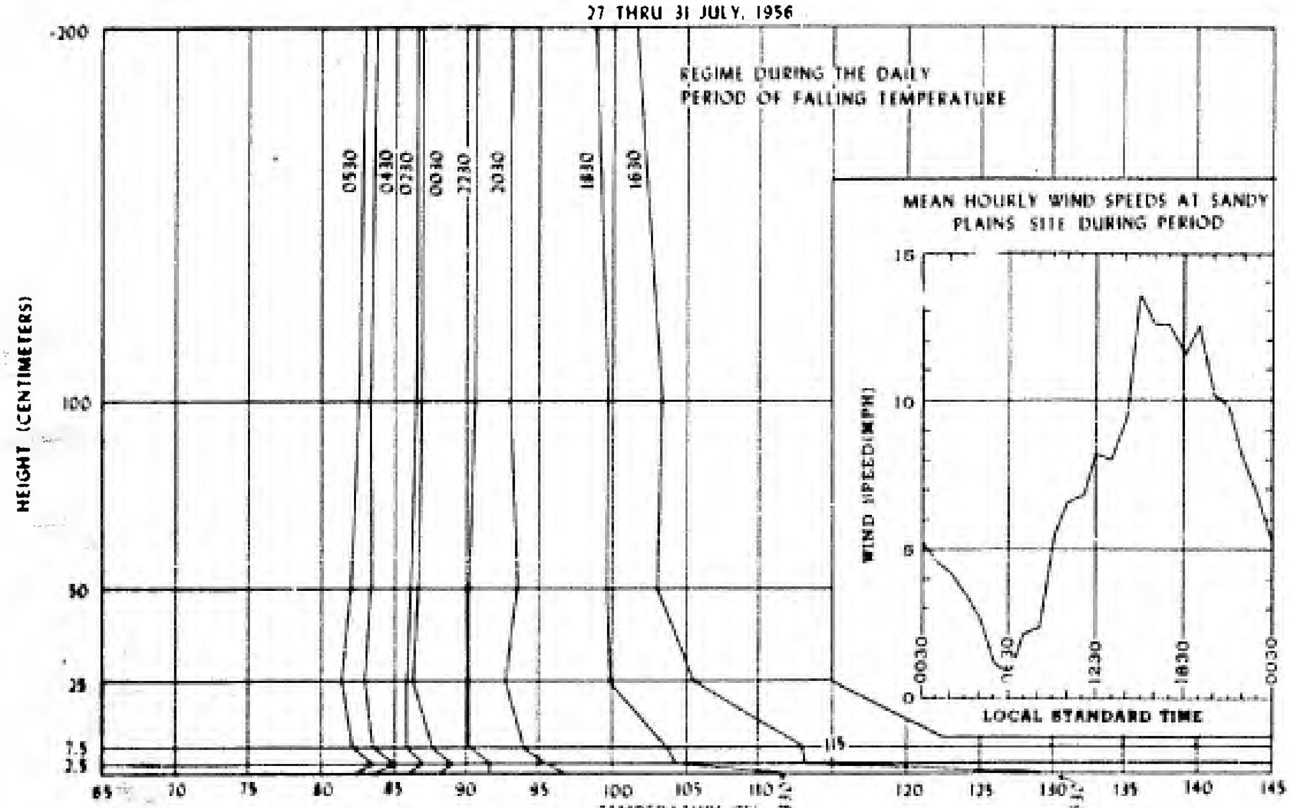


FIGURE 15

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF LOW HUMIDITY
AT SANDY PLAINS, YUMA TEST STATION, ARIZONA
3 THRU 5 JULY, 1956

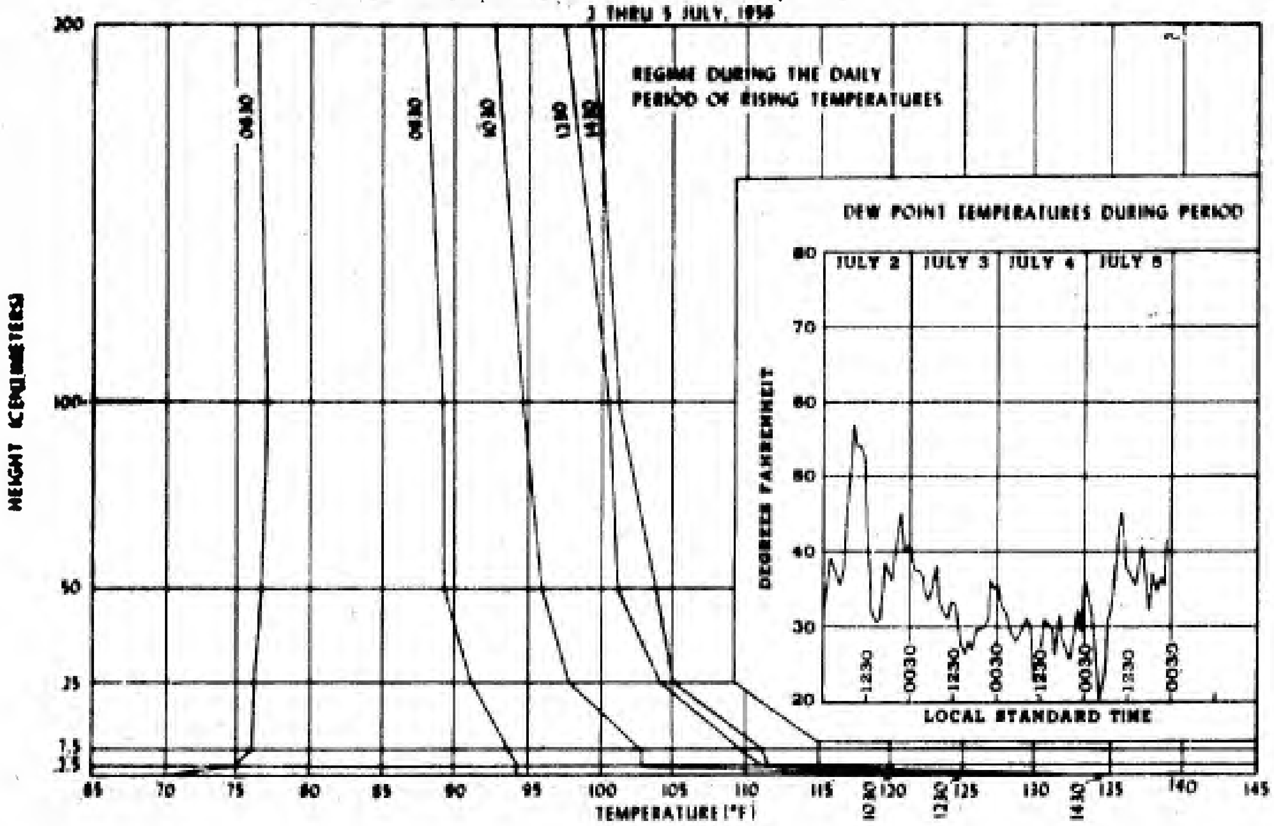


FIGURE 16

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF LOW HUMIDITY
AT SANDY PLAINS, YUMA TEST STATION, ARIZONA.
3 THRU 5 JULY, 1956

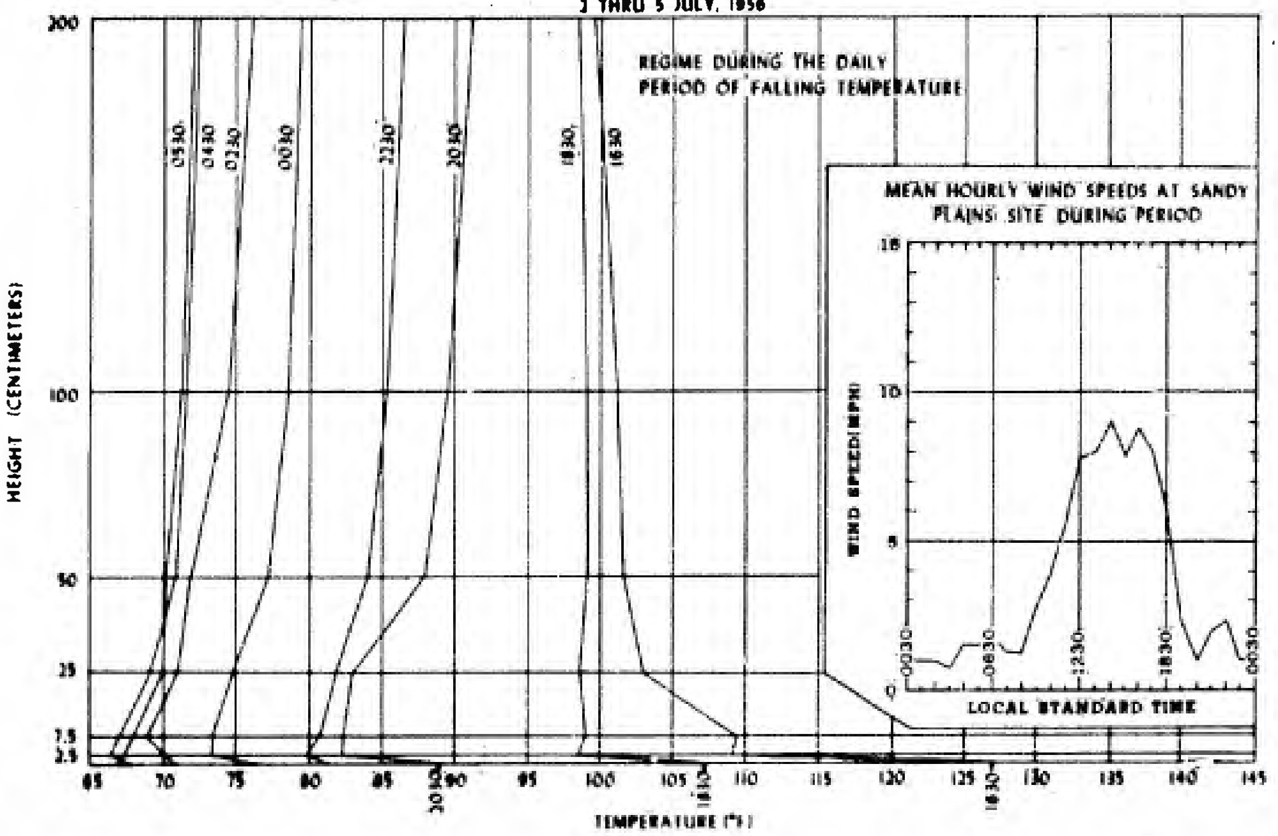


FIGURE 17

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF HIGH HUMIDITY
AT DESERT PAVEMENT, YUMA TEST STATION, ARIZONA
27 THRU 31 JULY, 1956

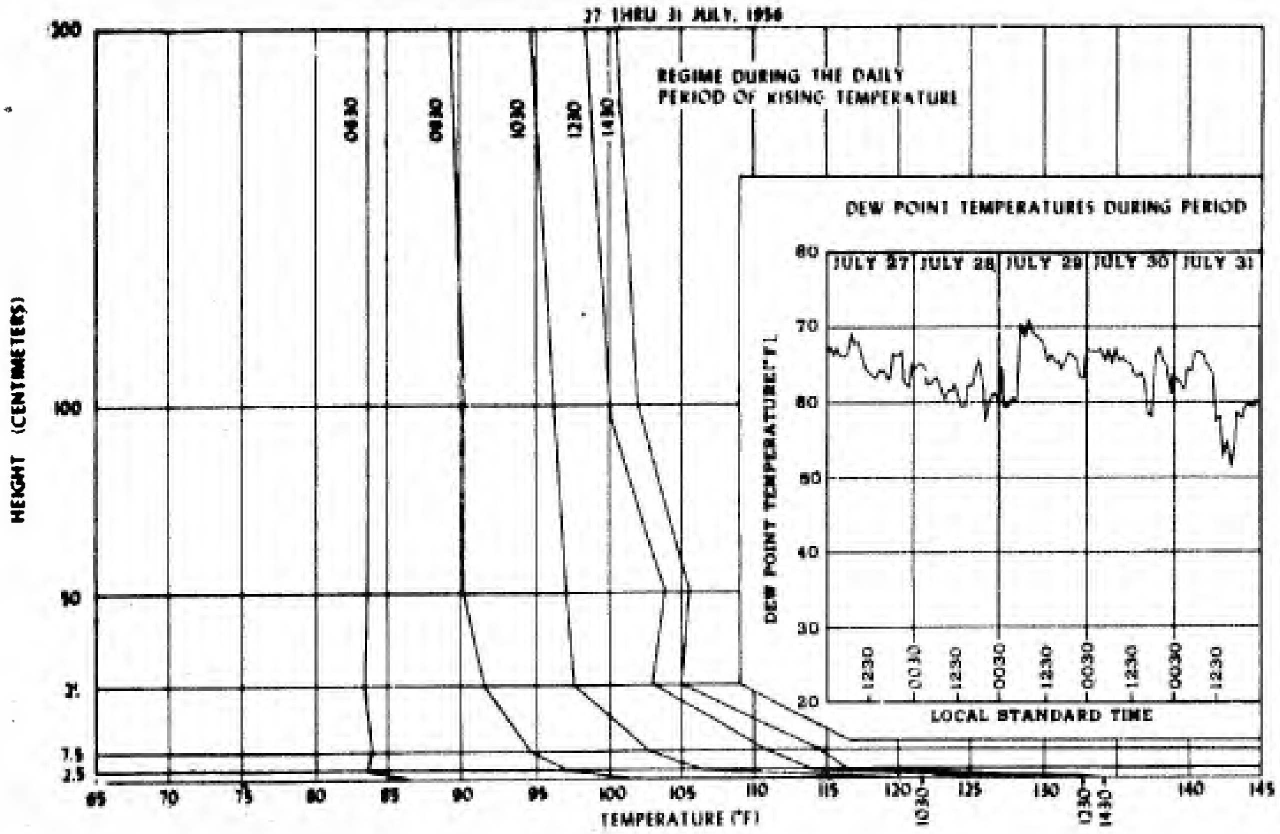


FIGURE 18

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF HIGH HUMIDITY
AT DESERT PAVEMENT SITE, YUMA TEST STATION, ARIZONA
27 THRU 31 JULY, 1956

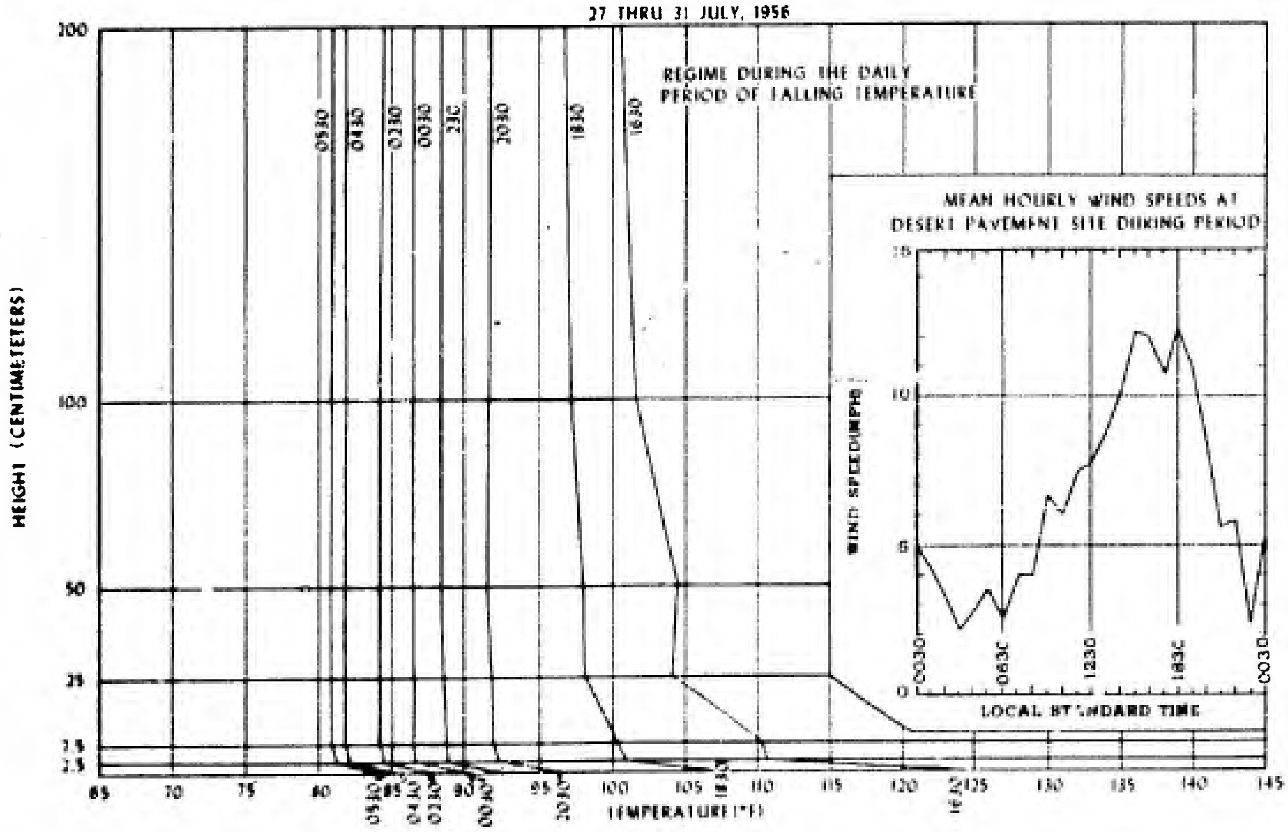


FIGURE 19

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF LOW HUMIDITY AT DESERT PAVEMENT, YUMA TEST STATION, ARIZONA

2 THRU 5 JULY, 1956

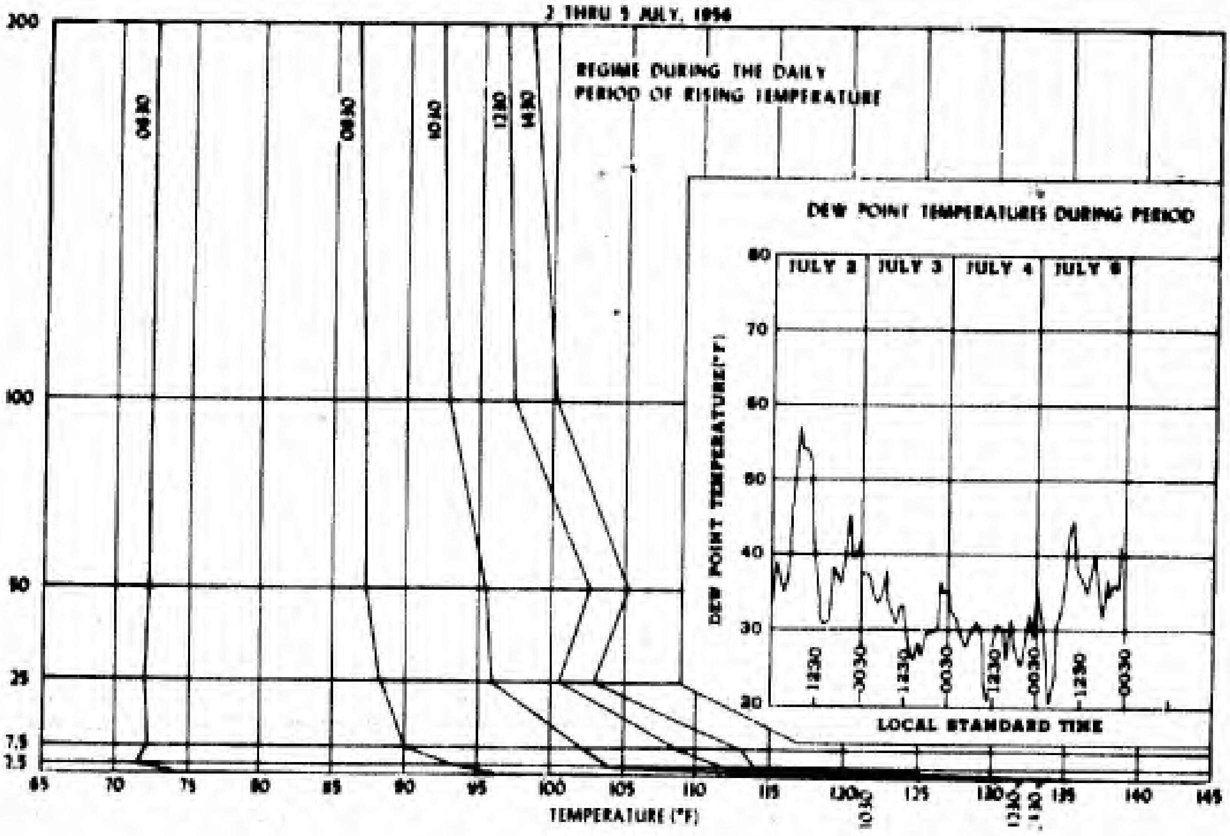


FIGURE 20

MEAN TEMPERATURES NEAR THE GROUND DURING A PERIOD OF LOW HUMIDITY AT DESERT PAVEMENT SITE, YUMA TEST STATION, ARIZONA

2 THRU 5 JULY, 1956

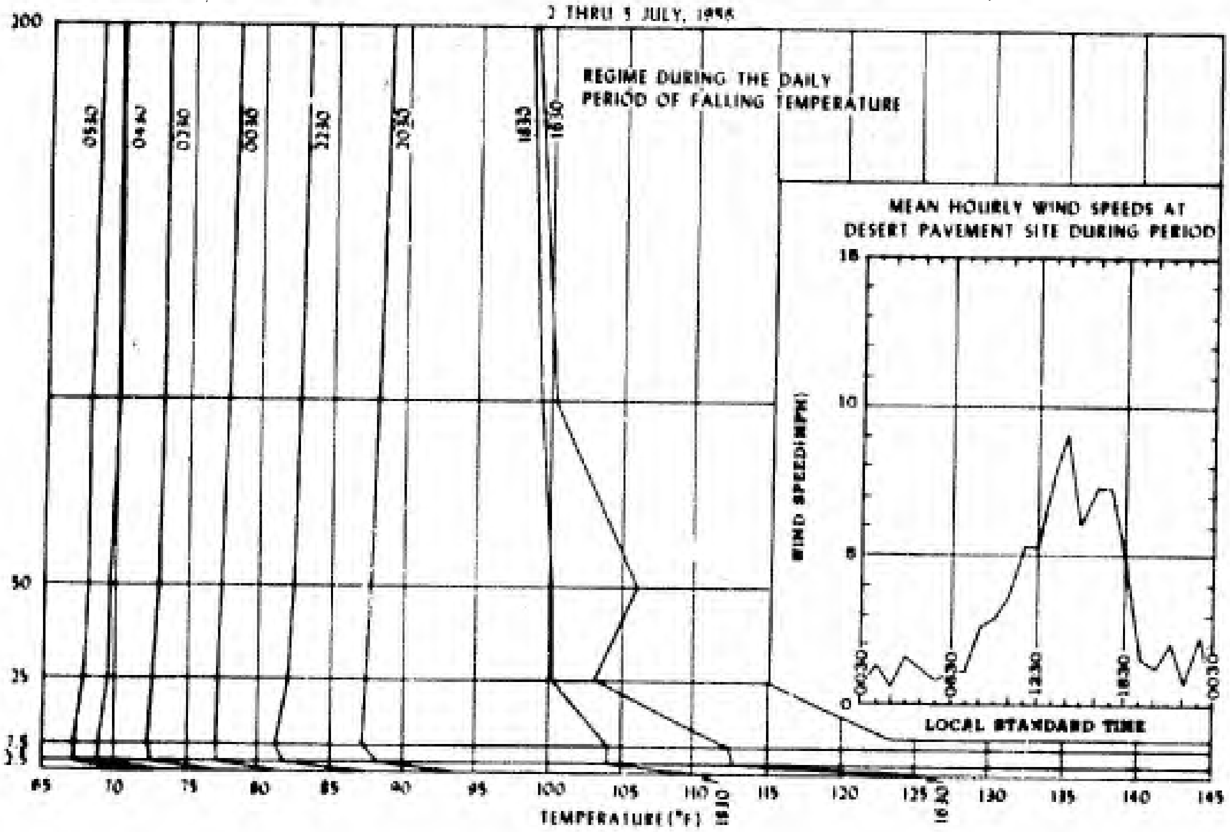


FIGURE 21

At Sandy Plains during the high humidity period of rising temperature (Fig 14), inversions between 2.5 and 7.5 centimeters were well developed in the morning. A slight increase in temperature with height is also found between 50 and 100 centimeters at 0630, 0830, and 1430. During the high humidity period of falling temperatures, an early morning inversion is noted between the ground and 2.5 centimeters, but at both these levels temperatures were higher than at 25 centimeters (Fig 15).

During the period of low humidity at Sandy Plains (Figs 16 and 17), minimum temperatures were considerably lower and the effect of cooling from the surface at night was more apparent. No daytime inversions similar to those found during the period of high humidity occurred during the period of low humidity.

At Desert Pavement during the high humidity period (Figs 18 and 19), an inversion occurred between 25 and 50 centimeters during the afternoon. During the low humidity period (Figs 20 and 21), the inversion at this level was more distinct, averaging more than 2F between 1230 and 1630 MST. There was no inversion between 2.5 and 7.5 centimeters as at Sandy Plains. Daytime surface temperatures were generally higher at Sandy Plains than Desert Pavement, especially during the high humidity period.

During the low humidity period, at Desert Pavement, early morning (0030-0630) temperatures at the surface were higher than early morning temperatures at Sandy Plains (e.g., at 0530 the surface temperature at Desert Pavement averaged 71F, compared to the average of 67F at Sandy Plains). The warmer surface temperatures at Desert Pavement during the early morning hours have already been shown in Figures 6 and 7. They are associated with the higher thermal capacity of the pavement surface.

D. Temperature frequencies

For military planning purposes it is often useful to know the occurrence frequency of temperatures. Cumulative temperature frequency curves for four levels at each station are plotted in Figures 22 through 24. At all stations, the highest temperatures were at the surface, where temperatures were above 100F more than 40 percent of the time. At Desert Pavement and Sandy Plains, surface temperatures were above 130F more than 15 percent of the time, and at Sandy Plains temperatures were above 140F about 4 percent of the time. The highest surface temperature observed was 150F at the Desert Pavement site. High surface temperatures were not as frequent at Laguna Top, probably because of the stronger winds. A few centimeters above the surface, temperatures were much lower, rarely above 120F. At the 200 centimeter level, occurrences of temperatures above 110F were extremely rare at the three stations.

CUMULATIVE TEMPERATURE FREQUENCIES AT SANDY PLAINS
YUMA TEST STATION, ARIZONA
JULY AND AUGUST, 1966

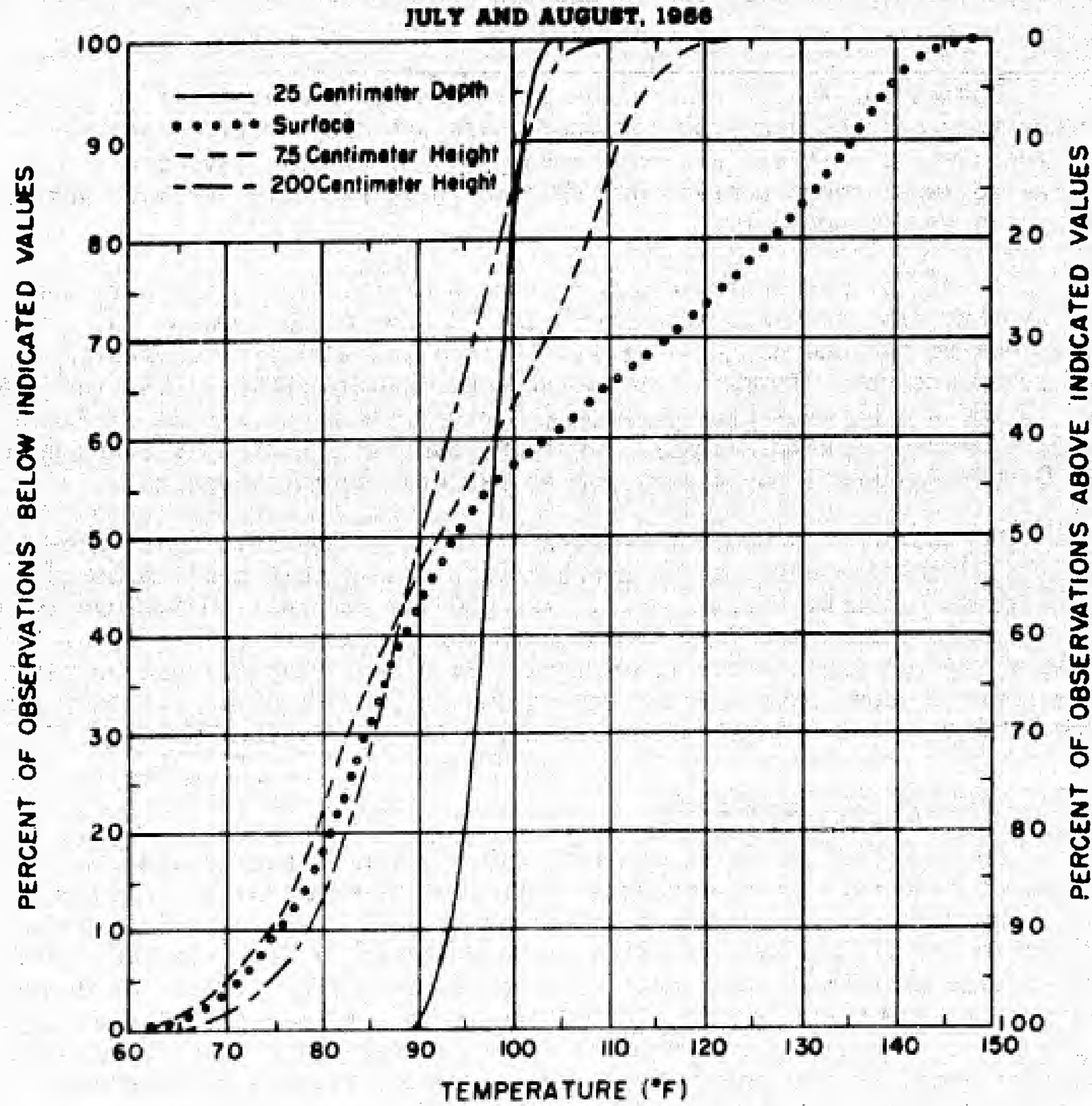


FIGURE 22

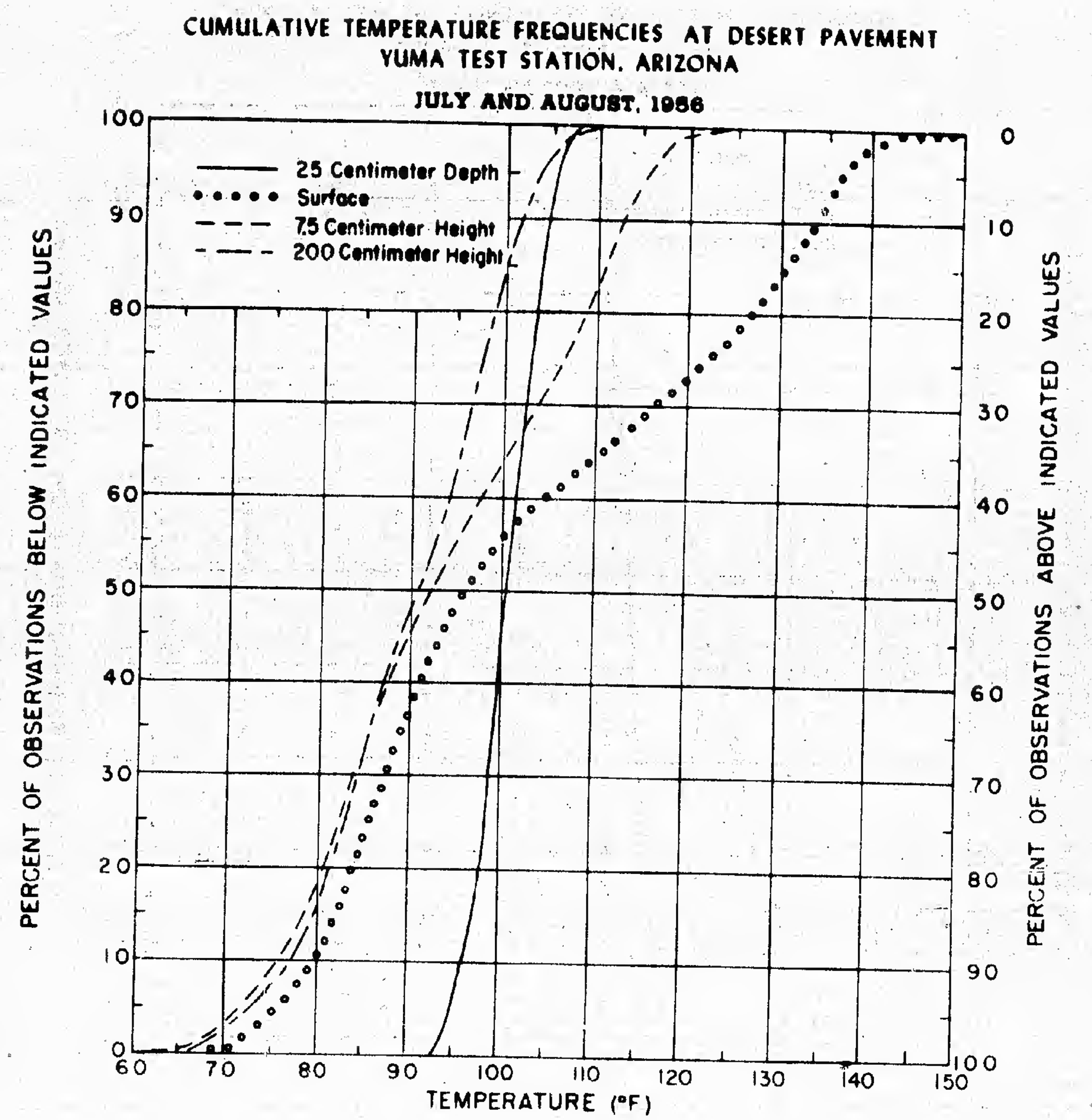

CUMULATIVE TEMPERATURE FREQUENCIES AT DESERT PAVEMENT
YUMA TEST STATION, ARIZONA
JULY AND AUGUST, 1956
25 Centimeter Depth
Surface
7.5 Centimeter Height
200 Centimeter Height
PERCENT OF OBSERVATIONS BELOW INDICATED VALUES
PERCENT OF OBSERVATIONS ABOVE INDICATED VALUES
TEMPERATURE (°F)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

FIGURE 23

CUMULATIVE TEMPERATURE FREQUENCIES AT LAGUNA TOP, YUMA TEST STATION, ARIZONA

JULY AND AUGUST, 1956

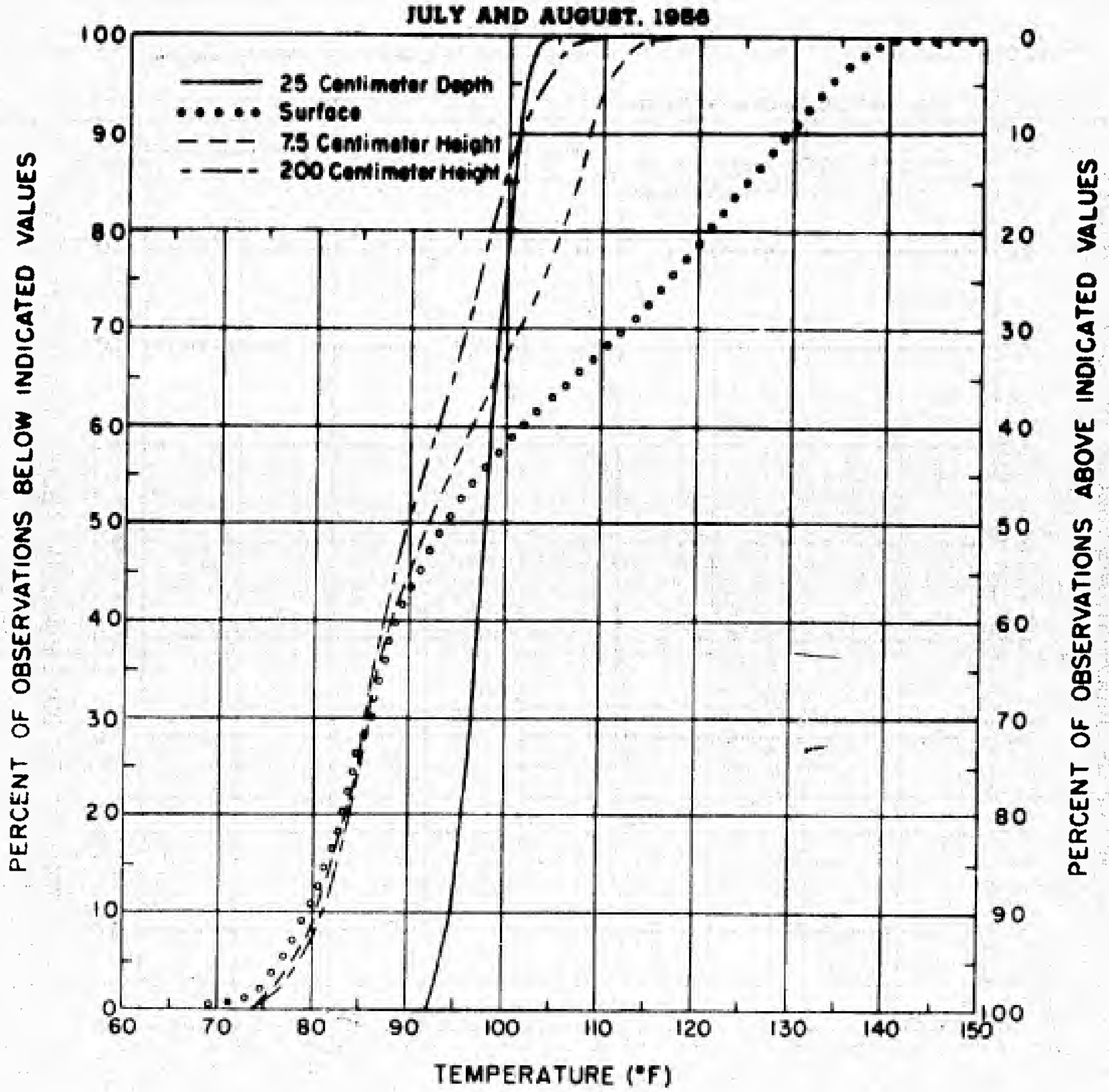


FIGURE 24

The standard temperature averages at Yuma Test Station for July and August 1956 of 92.7F and 92.0F, respectively, compare with the 5-year averages of 92.7F and 91.9F. The cumulative temperature frequencies for 1956 are likely to be fairly representative of the long-term frequency curves, except that higher and lower extremes expected in a longer record would cause extension of the ends of the curves.

3. Conclusions

a. General

The temperature regime at the height of "standard observations," approximately 200 centimeters, differs markedly from the regime close to the ground. Differences in temperature regimes at the standard level above three ground surface types were also noted. The variation from the "standard" climate at each site and between sites is great enough to warrant consideration when tests are planned at Yuma Test Station, or in other hot desert areas, particularly when the tests involve contact with the ground surface.

b. Specific

The following specific conclusions can be drawn from the 1956 study of the summer climate near the ground at three sites, Sandy Plains, Desert Pavement, and Laguna Top (a hilltop) at Yuma Test Station.

(1) The temperature regime at the surface differs markedly from the regime well above the surface. For example, the July-August 1430 MST mean temperature at the surface at Sandy Plains was 138F, or 37F higher than at the 200-centimeter height (representative of the "standard" measurement). Most of the decrease in temperature with height occurred very close to the surface, and the differences in mean temperature between the 50-centimeter level and the 200-centimeter level were less than 3F during day and night (Fig 5).

(2) The daily temperature range decreases more rapidly below than above the surface; below the surface, temperature lags behind the air temperature so greatly that the highest temperatures at a 25-centimeter depth occur near midnight and the lowest near noon (Fig 5).

(3) Differences in the temperature regimes at Sandy Plains, Desert Pavement, and Laguna Top are due to differences in exposure and the nature of the ground surface (Figs 6, 7, 8, and 9).

(a) The sand surface is warmest during the day and coolest at night because of the low thermal diffusivity of dry sand.

(b) Just beneath the surface, at 2.5-centimeters depth, midday temperatures at Desert Pavement averaged 7F warmer in July and 14F warmer in August than at Sandy Plains. The temperature differential is caused by the difference in thermal diffusivity and albedo of the two sites.

(c) At Laguna Top, temperatures at all levels above the ground are higher at night and lower during the day than at Sandy Plains. The decreased temperature range is attributed partly to the increased winds at Laguna Top.

(d) At the 200-centimeter height, hourly daytime temperature averages at the three sites were within 2F of one another. At night, Laguna Top was warmest and Desert Pavement coolest, the difference averaging as much as 8F at 0430.

(4) There is a marked diurnal variation in windspeeds at Yuma Test Station; average windspeeds were strongest in the late afternoon. Calm conditions often occurred in the early morning at Sandy Plains and Desert Pavement. Winds were strongest at all hours at Laguna Top (Fig 8).

(5) The prevailing directions of wind between 0130 and 0530 at Desert Pavement and Sandy Plains are difficult to discern. Calm prevailed 45 percent of the time. During this early morning period, winds prevailed from the west or west-southwest at Laguna Top and calms occurred only 11 percent of the time (Fig 9).

(6) Winds prevailed from the southwest at Sandy Plains and Desert Pavement and from the west at Laguna Top during the period of intense solar radiation. During this incoming radiation period, calm conditions were rare, and mean windspeeds ranged from 7 to 10 miles per hour at the three sites (Fig 9).

(7) During the period of intense solar radiation, strong temperature gradients are present above the ground. Only at Laguna Top, however, is the average decrease in temperature upward from the hot surface not interrupted by a temperature inversion at some level. There was an average decrease in temperature of approximately 20F in the first 2.5 centimeters above the surface (Fig 10).

(8) The daytime inversions noted above occur most frequently between 2.5 and 7.5 centimeters at Sandy Plains and between 25 and 50 centimeters at Desert Pavement. At times these inversions were as great as 5F, but were generally less than 3F. (Table V).

(9) The hourly average total incoming radiation measured at Sandy Plains exceeds the solar radiation by 110 to 160 Btu/ft^2/hr during

THE DAYLIGHT HOURS, THE GREATEST DIFFERENCE OCCURRING AT MIDDAY. THIS EXCESS IS MAINLY LONG-WAVE RADIATION. THE OUTGOING RADIATION FROM THE EARTH IS ALSO AT A MAXIMUM DURING THE DAY WHEN IT EXCEEDS 300 BTU/FT^2/HR, NEARLY AS INTENSE AS THE INCOMING SOLAR RADIATION. THE RESULTANT OF INCOMING AND OUTGOING RADIATION, THE NET RADIATION, EXCEEDS 175 BTU/FT^2/HR FROM 1030 TO 1430. AN OUTGOING RADIATION BALANCE PREVAILS FROM 1830 TO 0630 (FIG 11).

(10) TWO GENERALIZATIONS CAN BE MADE FROM ANALYSIS OF TEMPERATURE PROFILES DURING PERIODS OF HIGH AND LOW HUMIDITIES. NIGHTTIME COOLING IS GREATER DURING PERIODS OF LOW HUMIDITY, AND THE EFFECT OF HUMIDITY ON TEMPERATURE PROFILES IS DEPENDENT TO SOME EXTENT ON CHARACTERISTICS OF THE SITE. DIFFERENCES IN AVERAGE TEMPERATURE PROFILES AT SANDY PLAINS AND DESERT PAVEMENT ARE APPARENT DURING PERIODS OF HIGH AND LOW HUMIDITIES (FIGS 14 THROUGH 21).

(11) HIGH TEMPERATURES OCCUR MOST FREQUENTLY AT THE GROUND SURFACE AT ALL THREE SITES. THE MOST NOTICEABLE TEMPERATURE FREQUENCY DIFFERENCE BETWEEN SITES AT THE LEVELS WELL ABOVE THE SURFACE IS THE OCCURRENCE OF HIGHER MINIMUM TEMPERATURES AT LAGUNA TOP. BELOW THE SURFACE, HIGHER TEMPERATURES OCCUR AT DESERT PAVEMENT DUE TO THE GREATER THERMAL DIFFUSIVITY AT THAT SITE (FIGS 22 THROUGH 24).

4. ACKNOWLEDGMENTS

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