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CLIMATOLOGICAL CONDITIONS FAVORING OCCURRENCE OF HIGH TEMPERATURES AT YUMA PROVING GROUND, ARIZONA

by

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FOREWORD

The hot desert has long been recognized as presenting extreme conditions for Army field operations. Different facets of such operating conditions occurring at the Yuma Proving Ground, Arizona, have been treated in previous reports of the Earth Sciences Division. This report highlights the environmental conditions favoring development of very high temperatures at the desert station, and thus provides a better understanding of the daily environment encountered during these spells of severe conditions in hot dry regions.

This study was performed under Project 1V025001A129, Environmental Research, Task 03, Methods for Predicting Environmental Conditions. Work in this area is directed toward the development of methods for making accurate and complete working estimates of natural environments, and the probable resulting stress on men and materiel, in any terrain or season throughout the world.

Thanks are due to Dr. Arnold Court of the Geography Department, San Fernando Valley State College, California, for his many helpful suggestions during the preparation of this report.

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ABSTRACT

Meteorological observations taken by the U. S. Army Meteorological Team at the Yuma Proving Ground, Arizona, provide some basic lower and upper limits to vertical solar and total sky radiation, ground-surface temperature, dewpoint temperature, wind speed, and wind direction during occurrence of high ambient air temperatures. However, even the more favorable combinations of these surface conditions do not provide an adequate explanation for occurrence of extreme temperatures at Yuma. The apparent key is the temperature of the air layer between 850 and 650 mbs. If this layer is warm, and a mechanism exists for bringing the air down to the surface, high ambient air temperatures exist. The mechanism may be the vertical exchange induced by the afternoon convection, or it may be the föhn effect brought about by the synoptic pressure pattern.

CLIMATOLOGICAL CONDITIONS FAVORING OCCURRENCE OF HIGH TEMPERATURES AT YUMA PROVING GROUND, ARIZONA

1. Introduction

Very high ambient air temperatures undoubtedly result, as Lamb[1] has proposed, from the cumulative effects of all compatible and favorable environmental conditions. The favorable factors he gives are, in brief, as follows: (a) high ground-surface temperatures induced by intense radiation, (b) long passage of air over the heated surface, (c) advection of previously heated air, (d) subsidence, and (e) the föhn effect. The first three factors are practically ubiquitous climatological characteristics of hot deserts in summer, as are high ambient air temperatures. Thus it is reasonable to assume that the compatible and favorable conditions for higher temperatures occur frequently at a desert station.

Because of frequent high temperatures and an unusually complete observation program, meteorological data taken at the Army desert test station near Yuma, Arizona, provide a basis for evaluating the comparative significance of the favorable factors listed above and may also provide some quantitative values for the elements involved. These values may not only be typical of hot desert regions but may also be indicative of necessary conditions for occurrence of high temperatures in any continental area.

The Yuma Proving Ground is located close to the junction of the Colorado and Gila Deserts and the Gran Desierto, which comprise the Sonoran Desert of southwestern United States and northwest Mexico. Topography in the area consists of the sandy plains, stony hills, desert pavement and broad washes characteristic of hot deserts. The Colorado River is west of the test area.

The weather observation program at the proving ground includes, in addition to the standard hourly data, a temperature profile (eleven levels from 25 cm depth to 400 cm above the ground) recorded on the same hourly base; vertical solar, total hemispheric, and net-exchange values of radiation integrated hourly on true solar time; and a probe of the upper air twice daily for temperature, humidity, and wind data. In general, this study is limited to presenting the analysis of data observed during days with "afternoon temperatures" (defined in the next section) of 105°F or higher. Ninety-seven such days occurring during the warmer months of 1961, 1962, and 1963 are used in this study.

2. General Conditions

Of primary interest is the range in radiation values associated with high temperatures and whether a noticeable difference exists in radiation received at progressively higher ambient temperature levels. However, since high temperatures occur under both high and low dewpoint regimes, it seems desirable to incorporate dewpoint temperatures into this general analysis of air temperature and radiation. Thus, the data are grouped in Figure 1 according to average afternoon temperature in ranges of 105 to 107°F, 108 to 110°F, and 111°F and over.

For this study "afternoon temperature" is defined as the average of the hourly shelter temperatures for a 5-hour span. With but few exceptions, these are the 1400 to 1800 hourly readings. This 5-hour span encompasses, essentially, all of the comparatively flat top of the diurnal temperature curve, a characteristic of these hot days. Similarly, "afternoon dewpoint" is the average of the corresponding five dewpoint temperatures. These are, generally, around the lowest for the day. Vertical Eppley and total hemispheric values are, again, averages, but of the three highest consecutive integrated readings, since the radiation curve at the Yuma Proving Ground remains near peak values for only two or three hours. The readings are predominately the 1200 to 1400 hourly integrated values although there is usually little difference between the 1100 and 1400 integrated hourly readings.

A time difference of slightly more than a half hour exists between the temperature and radiation readings. Coordinates for the Yuma Proving Ground are 32°50'N and 114°24'W and the time meridian is the 105th. Thus mean solar noon is about 38 minutes after 12:00 standard time, but in the summer actual noon is at 12:32 or 12:33. For the period studied, the sun is only 10 to 14 degrees from vertical at solar noon.

Figure 1 shows the vertical Eppley and total hemispheric radiation values, grouped according to afternoon temperature, plotted against afternoon dewpoint. The values given inside the graph and corresponding to the dewpoint temperatures are the respective relative humidity values. These were obtained from psychrometric tables for the average temperature of the group.

Radiation patterns shown in the three temperature groups of Figure 1 are essentially the same. In each group, vertical solar radiation decreases from 98 to 100 lys/hr* at the lower dewpoints to

*1 langley - 1 cal/cm^2

92 to 94 lys/hr at the higher dewpoints. Similarly, total hemispheric radiation decreases from 135 to 138 lys/hr at the lower dewpoints to below 130 lys/hr at the higher dewpoints. Evidently, afternoon surface dewpoints during these days of high temperature must be indicative of the water vapor content of a substantial thickness of air.

Figure 1 shows a more distinct upper limit existing between radiation and dewpoint than a lower limit. On checking the data for days with lower radiation intensities, it became apparent that once the meteorological pattern for developing higher temperatures is established, a temporary lapse in intensity of radiation received for a day does not necessarily cause a collapse to the continued development towards higher temperatures. Another item shown by these graphs is the relatively greater number of occurrences of higher temperatures during high dewpoint regimes than during periods with dryer air masses.

Radiation patterns shown in Figure 1 are not unique to days with high, average afternoon temperatures. Similar data were plotted for 35 days, of the same general period, with average afternoon temperatures of less than 100°F and for 14 of the days where the average was less than 95°F. The pattern of radiation values is similar to that of days with the higher afternoon temperatures. In this plot about two-thirds of the days had afternoon dewpoints in the 29 to 42°F range. This also was reflected among the 14 days with less than 95°F average afternoon temperature.

Then on a typical summer day, the vertical solar radiation may average from 92 to 100 lys/hr over a three-hour period during midday. This 78 to 84 percent of the value (2.00 lys/min) given to the solar constant, is indicative of the high transparency of the desert atmosphere. Although intense solar radiation is undoubtedly basic to the development of high, ambient air temperature, the radiation pattern at the Yuma Proving Ground on a typically clear day would show little essential difference between days with afternoon temperatures in the 90's and days with afternoon temperatures of over 110°F.

One direct effect of the radiation and terrain conditions in deserts is the high ground-surface temperatures. But, as is shown by Figure 2, afternoon air temperatures can be quite varied under similar ground temperature regimes. The latter are, again, an average of the five highest consecutive hourly readings of the day, either the 1100 to 1500 or the 1200 to 1600 hourly readings. The figure shows the possible scatter between ground surface and shelter temperatures. For days with average afternoon temperatures of 106°F, surface temperatures varied from 128 to 150°F whereas, at 108°F, the values were slightly lower, 127 to 128°F. But at 110°F, the values were slightly higher at 132 to 155°F.

While not conclusive, one could deduce that at these higher temperatures a minimum difference of about 20 F° exists between the shelter temperature and the ground surface temperature during the afternoon while the maximum difference would seldom be more than twice that amount. The figure does show the tendency of the ground surface temperature to top-off in the area of 150°F. This is not a feature of days with average, afternoon temperatures of less than 100°F. Here, a distinct increase occurred (130 to 141°F) for the upper values as the afternoon average air temperature increased from 86 to 99°F. However, ground surface temperature was, again, between 20 and 40 F° higher than the ambient.

In light of the rather regular vertical radiation pattern over the range of higher afternoon temperatures as shown in Figure 1 and the scatter between the paired ground surface and air temperatures as shown in Figure 2, one could conclude that no predictable relationship exists between the vertical Eppley and ground surface data. In fact, a plot of the paired data produced as much scatter as is shown in Figure 2.

A consistent feature during afternoons of higher temperatures is the predominance (80 percent of the afternoons) of west, west-southwest, and southwest winds. Average wind speed at the six-foot level for the 5-hour period of higher temperatures ranges from 5 to 18 mph. These show a concentration (about half) in the range of 8 to 11 mph, and about a quarter of the total were from 12 to 15 mph. There were five afternoons with average wind speeds from 16 to 18 mph and the rest (about 15 percent) ranged from 5 to 7 mph. This predominance in wind direction and range of wind speed is also applicable for days with average afternoon temperatures of less than 100°F.

A similar situation is reported at the Yuma city airport, about 25 miles southwest of the test station. During July almost 70 percent of the afternoon and early evening winds at the Weather Bureau station are from the southern quadrant. Average wind speed is close to 11 mph and the maximum reported speed was 27 mph.[3]

Thus, on a typical summer afternoon at the Yuma Proving Ground, the fetch of surface air is essentially from the Gran Desierto of northern Mexico, over the Colorado River lowlands, and through the river gap in the eastern rim of the valley. Although comparatively shallow (150 to 250 feet), the river gap must give the more westerly component to the wind direction at the Proving Ground. A slight adiabatic cooling (less than 1 F°) could be involved as the air flows from the river bottom (150 feet) up the steep slope to the test station (324 feet) on the rim.

In this presentation of general conditions during occurrence of high, ambient air temperatures at the Yuma Proving Ground, some basic lower and upper limits to vertical solar and total sky radiation, ground surface temperature, dewpoint temperature, wind speed, and wind direction have been established. However, values within these limits also occur during days of lower temperature. The fact is that, individually, these values occur with such frequency as to be regarded as ubiquitous climatic characteristics of the desert site. Although radiation must be considered the basic element, no one component appears as a dominant factor. Some degree of compensation in terms of compatibility among the meteorological elements is evident. Since a relationship exists between dewpoint temperature and radiation, a comparison of the daily cycle of the elements during a high dewpoint regime with those during a low dewpoint regime may show the direction in which the compensation takes place.

3. High Versus Low Dewpoint Regimes

To explore the contrast between high and low dewpoint regimes, the records were searched for two days with practically identical afternoon temperature regimes but differing markedly in their dewpoint temperatures. The two days chosen were 19 July 1961, a day of higher dewpoints, and 25 June 1962, a day with lower dewpoints. How well the two ambient air temperature regimes match is shown by Figure 3.

The regime of 25 June 1962 shows the influence of greater nighttime radiational cooling under the drier air mass by the dip in temperature at 0400 hours and in the more rapidly decreasing temperatures after 1900 hours. From sunrise to 1900 hours a slightly faster rate of heating occurs under the drier conditions; however, a slight prolongation of the high afternoon temperatures occurs under the more moist air mass. Nevertheless, the temperature regimes during these two days are considered sufficiently alike for the purposes of this study.

On the other hand, dewpoints on 19 July 1961 ranged from 65°F during the early morning to the low forties by early evening. Correspondingly, the relative humidity dropped rapidly from the low fifties at 0500 hours to 15 percent at 1400 hours and remained around this level to nearly the end of the day. In contrast, dewpoint temperatures of 25 June 1962 only ranged from the low thirties around 0600 hours to the mid-twenties by afternoon. The low point occurred at 2000 hours but after 2100 hours the dewpoint increased sharply to 50°F. Correspondingly, the relative humidity ranged from 17 percent at 0600 hours to 5 percent by noon and remained at this level until the influx of moister air. This influx was brought about by advection of air from the Gulf of California as a small, closed low developed over the Yuma area. This moist, advected air was less than 2500 feet deep, as indicated by the following morning upper air sounding.

Differences between the radiation regimes for the two days are shown by Figure 4. Under the drier air mass of 25 June 1962, vertical solar, total hemispheric and net-exchange radiation developed more rapidly than under the more moist air mass of 19 July 1961. Peak values are 140 lys/hr for total hemispheric radiation and 101 lys/hr (about 84 percent of possible) for vertical radiation in the drier air mass as compared to 125 lys/hr and 94 lys/hr (about 78 percent of possible), respectively, under the more moist conditions. However, peak value for net exchange radiation is greater in the more moist air, the values being 57 lys/hr during 19 July 1961, as compared to 48 lys/hr for 25 June 1962. By 1500 hours cumulative totals from midnight for vertical and total hemispheric radiation are about 15 percent greater on 25 June 1962 than on 19 July 1961. However, cumulative totals for net exchange radiation by 1500 hours are the same. After 1500 hours the three sets of curves are practically identical.

Rounding out the picture of surface conditions at the Yuma Proving Ground are ground surface temperatures, temperatures at 2.5 cm above the ground, and temperatures at the 400-cm level shown in Figure 5. Only the middle part of the latter curve is given because data for earlier and later hours are hardly distinguishable from temperatures at the other two levels. Early morning ground temperatures of 25 June 1962 reflect the greater nighttime cooling under low humidity conditions and slightly lower winds. These temperatures are 5 to 8 F° below those of 19 July 1961. Between 0700 and 0900 hours, ground temperatures increase rapidly and at the same rate for both days. Under low humidity the ground temperature continues the steep rise until noon and maintains a plateau for two hours, after which the two regimes again match. After 1400 hours ground temperatures decreased at the same rate until dark, when ground temperatures under the drier air mass again became the lower.

The abrupt change at noon on 25 June 1962 is due to advection of slightly moister air. This is deduced from the change in dewpoint curve between 1200 and 1400 hours in conjunction with the shifting of the wind from northwest to west, to southwest, and then west and southwest again in the hours of 1000 to 1400. Source of this air would be the Colorado River bottom lands or possibly nearby irrigated areas. The local circulation that brings in the air has not developed sufficiently to totally destroy the stratification under the morning inversion.

Curves for the 2.5-cm height duplicate much of the ground surface temperature conditions except for the reversal of conditions between 1000 and 1400 hours. During these hours temperatures on the moist day (19 July 1961) at this level are higher. This reflects the net exchange radiation patterns (see Figure 4). By 1000 hours net exchange on 19 July 1961 became greater than on 25 June 1962, but by 1400 hours radiation values and ground surface temperatures are becoming more nearly equal and they have begun to drop. This association is presented with reservations because these differences at the 2.5-cm level disappear at the 7.5-cm level (not shown in the Figure). Temperatures at the 400-cm level reflect those of the instrument shelter. As mentioned, changes brought about by the developing local circulation could account for the slight dip in the temperature curve at 1100 hours that occurred on 25 June 1962.

Figures 3, 4, and 5 serve principally to show two quite different sets of meteorological conditions producing practically the same cumulative results in afternoon temperatures. It is becoming evident that the common denominator for the high temperatures is not to be found among the surface elements. This is further confirmed by considering the synoptic patterns. The normal pattern during the summer months is a thermal low over the desert and plateau regions of northern Mexico and southwestern United States. This low is sandwiched between the well-developed Pacific high to the west and the Bermuda high to the east. Slight variations occur but a distinct variation could not be associated with days of high temperatures. In the two cases, surface pressures were slightly lower on 25 June 1962 and the pressure gradient to the west slightly tighter. However, in both cases, the 500-mb pattern showed a closed, warm high over southwestern United States.

4. Air Mass Characteristics

Since the critical component for the higher temperatures is reflected neither in the general surface conditions nor in the circulation pattern, there remains the characteristics of the air masses to be looked into. Air masses of 25 June 1962 and of 19 July 1961 will be considered first.

Meteorological conditions at very high levels are not critical to the development of high surface temperatures. Upper air soundings for the two days show winds in the levels between 450 and 125 mbs (approximately 21,000 to 50,000 feet) as moderate (5 to 20 mph) and northeasterly during days of the more moist regime, whereas a strong (20 to 45 mph) westerly flow occurred at these levels during the dry regime of 25 June 1962 and the days immediately preceding. Below 21,000 feet both air masses had characteristics of subsidence, light winds, and gradually decreasing humidities. Temperature, humidity, and wind profiles from the surface to the 400-mb level (approximately 23,500 feet) are shown in Figures 6a and 6b for the two morning and afternoon conditions.

In both regimes, subsidence is a factor in causing warming of the air below 850 mbs. Clearly shown is the greater nighttime inversion developed in the drier air mass. Wind was generally light during both regimes, but its direction was more consistent in the drier air mass. In the latter case, wind was mainly southwesterly whereas during the moist regime the wind had made the general shift from northeast to southeast and to south as the air mass modified. Humidity was low in both the upper and lower levels in the drier air mass, but a moister layer of air existed between 700 and 550 mbs. However, by the afternoon of the 25th the sounding shows a consistent 10 percent humidity from the surface to 400 mbs. The moist air mass also underwent a gradual drying process. This, at first, was more rapid in the upper levels. But, by the 19th, lower humidities were reported at all levels. However, the feature of most concern to this study is the development of practically identical temperature-height curves during both afternoons.

The two morning curves (see Fig. 6a) differ principally in the degree to which the inversions have developed and in the layer between 850 and 650 mbs where the temperature of the drier air mass is 2 to 4 F° below that of the more moist regime. Above 600 mbs the two curves are essentially alike up to the 450-mb level.

In the surface inversions winds are light and variable. In the stable layer above the inversion in the moist air mass, winds are westerly but as the lapse rate approaches the dry adiabatic rate, winds back to south and remain southerly up to the stable layer at 500 mbs. In contrast, in the layer above the inversion in the drier air mass where the lapse rate is practically at the dry adiabatic rate, winds are west-southwesterly and then back to southerly in the more stable layer between 700 and 600 mbs. Winds again become southwesterly in the less stable layer between 600 and 500 mbs, and in the stable air above, the winds begin to reflect the strong westerly flow of the upper levels.

The striking feature of the two afternoon soundings is, of course, the identical nature of the temperature-height curves (see Fig. 6b). Meteorological and environmental conditions have combined to create a very unstable layer of air from the surface to the 550-mb level. This replaces the very stable conditions under the morning inversions. From 950 mbs to 600 mbs the afternoon lapse rates are only slightly less than the dry-adiabatic. In the drier air the lapse rate is practically constant, whereas in the moister air the lapse rate is in two segments, the air between 800 to 600 mbs being slightly more stable than that between 950 and 800 mbs. This is similar to the morning condition found in the drier air mass.

In the more moist regime winds are generally 16 to 20 mph below 700 mbs. They veer from southwest at the surface to west-northwest at the 750-mb level, and then back to west-southwest at 9 mph at the 700-mb level. The winds then remain light and southerly to the 450-mb level. Winds in the drier air mass are not as strong (14 to 18 mph), but their direction remains southwesterly from the surface to 850 mbs. The wind veers to west-southwest between 850 and 750 mbs and then backs to southwesterly from 750 mbs to 500 mbs. Above this level begins the strong west-northwesterly flow of the higher levels. The uniformly consistent, southwesterly winds practically to the 500-mb level, the nearly dry adiabatic lapse rate from 950 to 600 mbs, and the greater degree of warming between 850 and 650 mbs suggests that the vertical exchange of air had been greater in the drier air mass than in the more moist air.

The apparent key to the high temperatures recorded on these two days is the temperature of the layer of air between 850 and 650 mbs. At the dry adiabatic rate (lines of constant potential temperature), the temperature of this layer at the ground would compare favorably with the maximum temperature of 113°F, the maximum hourly temperature of 112°F, and the average of the five highest consecutive readings of 111°F obtained on both of these days. Then it is reasonable to assume that a warm layer of air between 850 and 650 favors the development of high ambient air temperatures in desert areas.

A necessary condition for very high temperatures is that a mechanism exist for effecting the exchange of air between the 850- to 650-mb levels and the surface. On the two days studied, the high ground surface temperature and the practically dry adiabatic lapse rate between the surface and the 650-mb level were conducive to effecting this exchange. Considering the ubiquitous characteristic of favorable surface conditions during a typical summer afternoon, the problem becomes primarily one of the frequency of favorable lapse rates in the lower layers of the air mass.

To explore this, the potential temperature of the highest hourly shelter temperature of the day was compared with the potential temperatures, at 50-mb intervals, of the afternoon sounding from 950 to 650 mbs for the months of July 1961 and June 1962. The assumption is made that the difference in potential temperature between the surface and the sounding indicates the stability of the air mass between the two levels. Since the potential temperature at the shelter height was invariably the larger, the level at which the difference changed from negative to positive should indicate the potential for effecting the change of air between the two levels. Besides the few cases of practically neutral stability in the lower layer, in about 10 percent of the afternoons the change in stability occurred by the 900-mb level or around 2,800 feet; in another 10 percent it occurred by 850 mbs or about 4,400 feet; and in 70 percent of the afternoons the change in stability occurred from 800 to 700 mbs. In the remaining 10 percent it occurred above the 700-mb level and in one case the change was not effected until the 600-mb level (about 13,400 feet). Thus the mechanism is present in the high radiant-energy exchange at the ground surface, and the high temperatures of that surface, to create instability in the lower layers of the air in about 80 percent of the summer days.

However, active subsidence inhibits the development of steep lapse rates in the lower layers of air. The afternoon of 10 July 1961 is an example of this. The morning temperature-height curve for that day is practically identical to that of 19 July 1961, except that it is about 1 F° warmer at all levels. The vertical Eppley and total hemispheric radiation curves for the two days are also practically identical. So is the ground surface temperature, except for the five hours from 1400 through 1800 when the regime for the 10th ran 5 F° higher than on the 19th of the month. The afternoon ambient air temperatures were also higher on the 10th than on the 19th; the afternoon average was 112°F and both the maximum hourly and maximum for the day were 113°F. However, this increase in shelter temperatures does not totally reflect the general 5 F° increase in afternoon temperature of the air mass at all levels. Furthermore, the air mass on the 10th did not develop the very unstable layer of air from the surface to the 950 level that was present on 19 July 1961.

The significant difference between the two air masses is the amount of subsidence taking place. The general increase of temperature throughout the air mass is one indication of this. Another indication is the wind field. On the morning of the 10th the surface wind was light and northeasterly, while at 950 and 900 mbs winds were southwesterly at 14 to 18 mph. The direction veered to west-northwest at 16 mph for both the 850- and 800- mb levels. But at 750 mbs the wind shifted to north-northeast at 5 mph in a more stable layer of air more than 50 mbs thick. Above this stable layer the winds became more easterly and stronger with height. By afternoon the surface wind had become the typical southwest breeze, having reached 12 mph. The 950- and 900-mb winds were still southwesterly but had dropped to 7 to 9 mph. The wind then shifted at the 850-mb level to north-northwest at 5 mph and continued the shift to north-northeast at 7 mph at the 800-mb level. This corresponds to the 800- to 750-mb wind shift recorded when the morning sounding entered the more stable layer of air. Above the stable layer, winds were again more easterly but speeds had dropped to 13 to 18 mph. In the 12-hour, daytime period between the two soundings, the stable layer had a general displacement downward of about 50 mbs. This subsidence is typical of the entire air mass.

In one sense, this marked subsidence had no effect on the afternoon temperatures; the morning sounding showed an air mass slightly warmer than that of the 19th and the resultant ambient, afternoon air temperatures were also slightly warmer than those of the 19th of the month. On the other hand, if the unstable layer from the surface to the 950 level had developed, afternoon temperatures would have been about 2 F° higher; if an effective vertical exchange had developed to the 750-mb level, the afternoon temperatures may well have been 4 to 5 F° higher than those reported for the day.

5. Discussion

This dissection of the environmental conditions favoring development of high ambient air temperatures at the Yuma Proving Ground has shown that there is nothing particularly obvious about these conditions. Even the patently direct one, as put by Lamb,[3] "Strong heating of the surface, most effective on dry sand or bare rock, when the sun is high and when the atmosphere is especially clear," has its limitations. Judging from Figures 1 and 2, the probability of reaching high surface air temperatures is greater under something less than this "ideal" situation. What must be avoided is the implied sequence from intensity of radiation to high ground surface temperatures to higher air temperatures. The situation is somewhat analogous to a pot of boiling water. The more intense the heat applied, the quicker the water is brought to boil; once reaching that point, the water boils more vigorously but at no increase in temperature. In fact, I would chance the opinion that a radiation and kinetic energy balance exists so that even the ideal conditions of intense radiation and high ground surface temperatures of desert areas would not, in unconfined free air, generate shelter temperatures in excess of 110°F.

Under this postulate, a long fetch of air over the hot desert surface also has limited capabilities towards development of high ambient air temperatures. There exists the radiant transfer of energy to the upper layers of the air mass. The effectiveness of this mechanism throughout the non-daylight hours is shown by the greater development of the early morning inversion under the drier air conditions. It is also an effective mechanism during the afternoon hours. Convection is also an important mechanism for transferring heat from the ground surface upward into the free air. But even when convection was controlled, as under the strongly subsiding air mass of 10 July 1961, the shelter temperatures did not reflect a significant increase, reaching only to 113°F, although this temperature was maintained for a three-hour period. One must conclude that there exists an upper limit to what the combination of radiation and ground surface temperature can do in developing high ambient air temperatures.

The meteorological conditions of 10 July 1961 show the role of subsidence in developing high ambient air temperatures. The inhibition of vertical convection or circulation in conjunction with advection of air from Africa was proposed by Lamb[4] as leading to the record high temperatures at Malta. Subsidence is also an effective mechanism for bringing warm air aloft down to within the vertical convection cycle developed over the desert during the typical summer afternoon. If a suitable lapse rate develops in the lower layers in conjunction with the rate of subsidence, then a situation exists for developing very high ambient air temperatures. The other possibility would be a synoptic pressure pattern such as might develop the föhn effect. Although this effect was not noticed in the present study, it is Lamb's principal mechanism for explaining record high air temperatures.[5] Otherwise, high temperatures may result, as occurred on 10 July 1961, but the potential for developing very high surface air temperatures will not be reached without the vertical exchange of air.

6. Conclusions

The environmental factors favoring the development of high ambient air temperatures have been shown to be practically ubiquitous climatic characteristics of desert areas during the summer season. In this sense they are obvious enough to need no justification. Beyond this, only one condition is obvious and that is that the potential temperature of the air at shelter height cannot be maintained for many hours at a higher potential temperature than that of the lower troposphere. Thus, if there exists one key to the higher temperatures at a station, it must be the temperature of the air mass between the 850- and 650-mb levels. If this air is warm and a mechanism exists for bringing the air down to the surface, very high ambient air temperatures result. Such a mechanism may be the vertical exchange induced by afternoon convection, or it may be a föhn effect brought about by the synoptic pressure pattern.

7. References

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2. Green, C. R., and W. D. Sellers, Editors, Arizona Climate (Tucson: The University of Arizona Press, 1964), Table 3f, p. 44.

3. Lamb, *op. cit.*, p. 39.

4. Lamb, *op. cit.*, pp. 42-43.

5. Lamb, *op. cit.*, pp. 40-43.

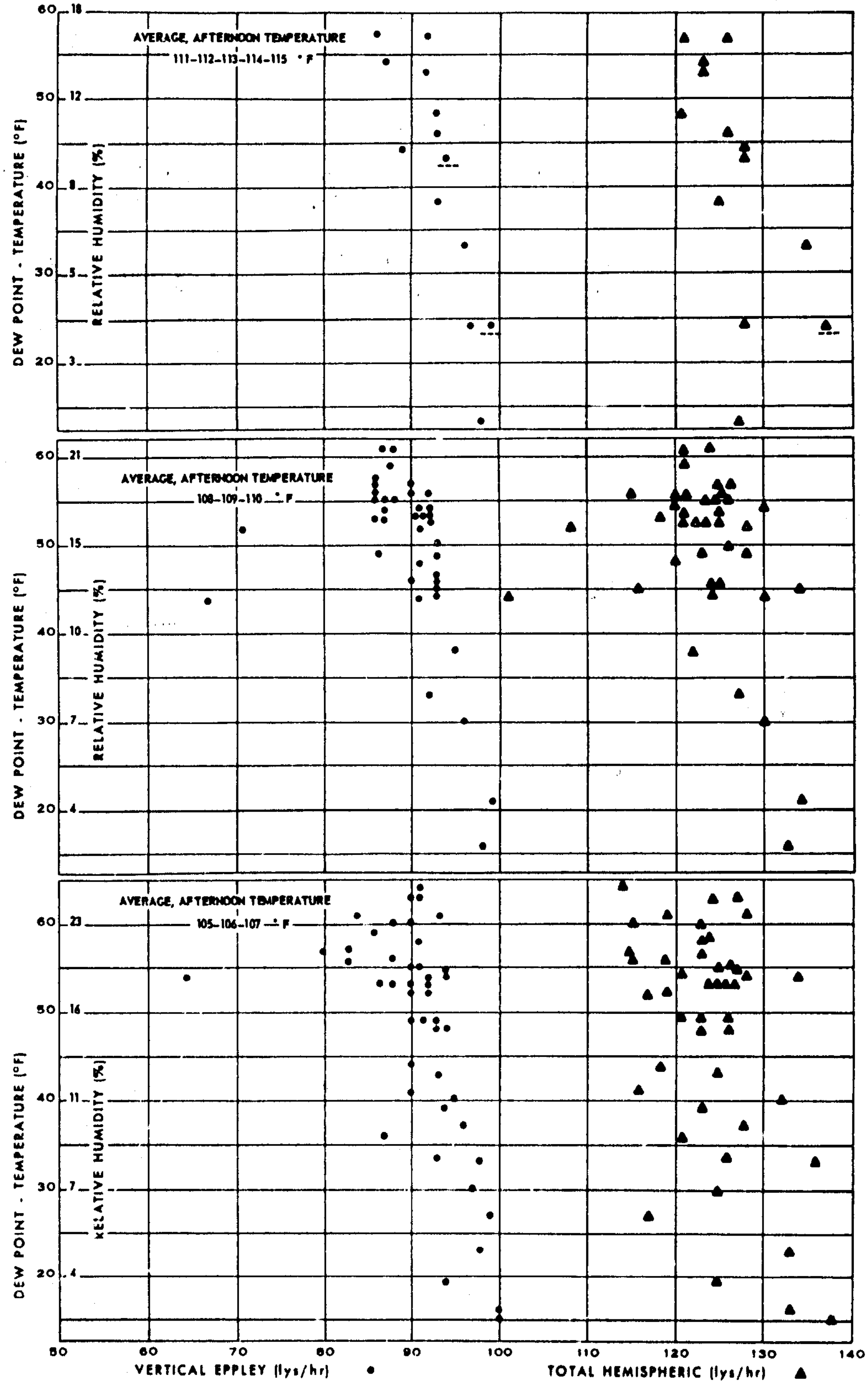


Figure 1. Dependence of vertical solar and total hemispheric radiation on dewpoint temperatures during afternoons with average temperatures of 105°F and higher at Yuma Proving Ground, Arizona.

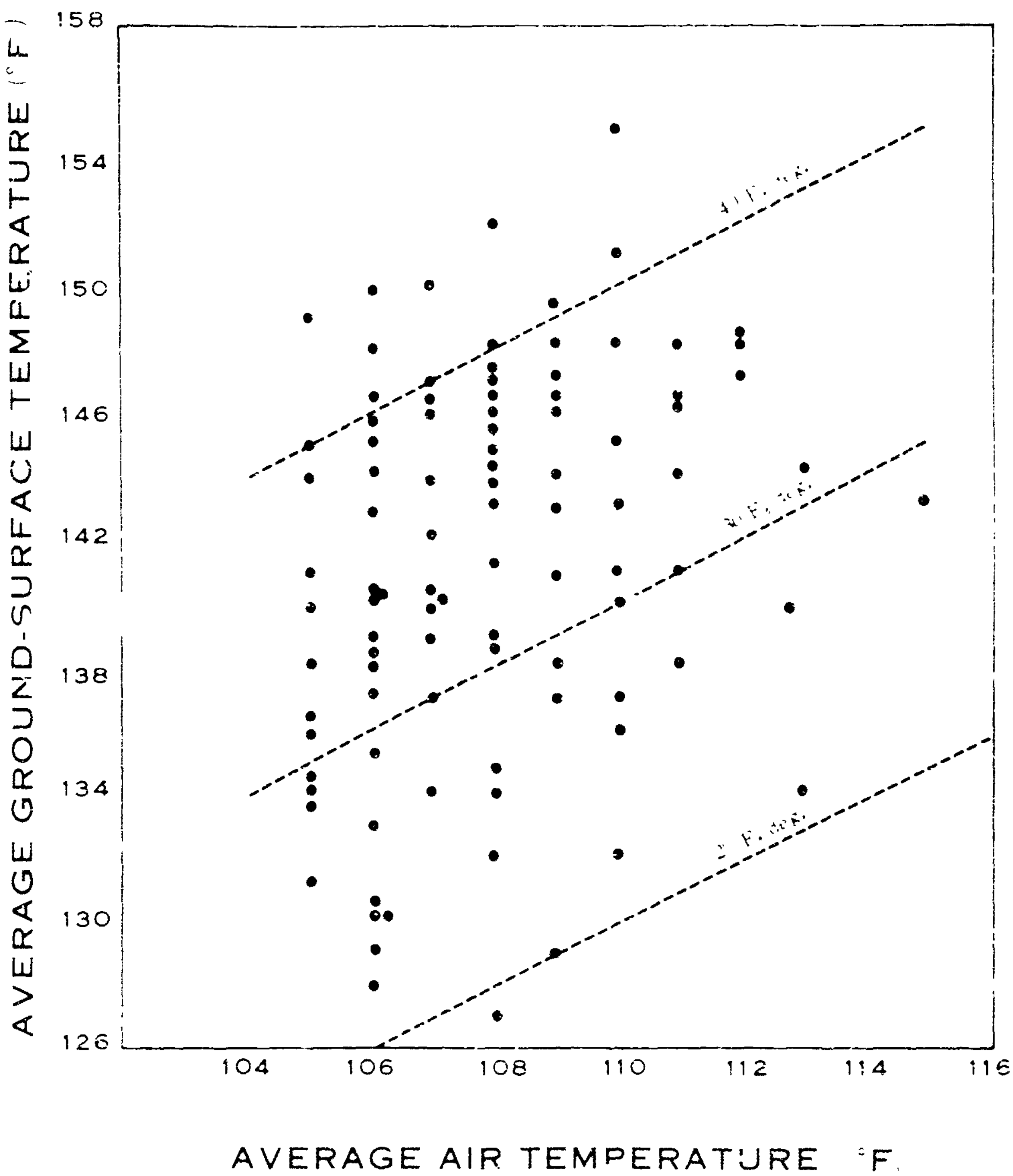


Figure 2. Afternoon average ground surface temperature plotted against afternoon average air temperature at Yuma Proving Ground, Arizona.

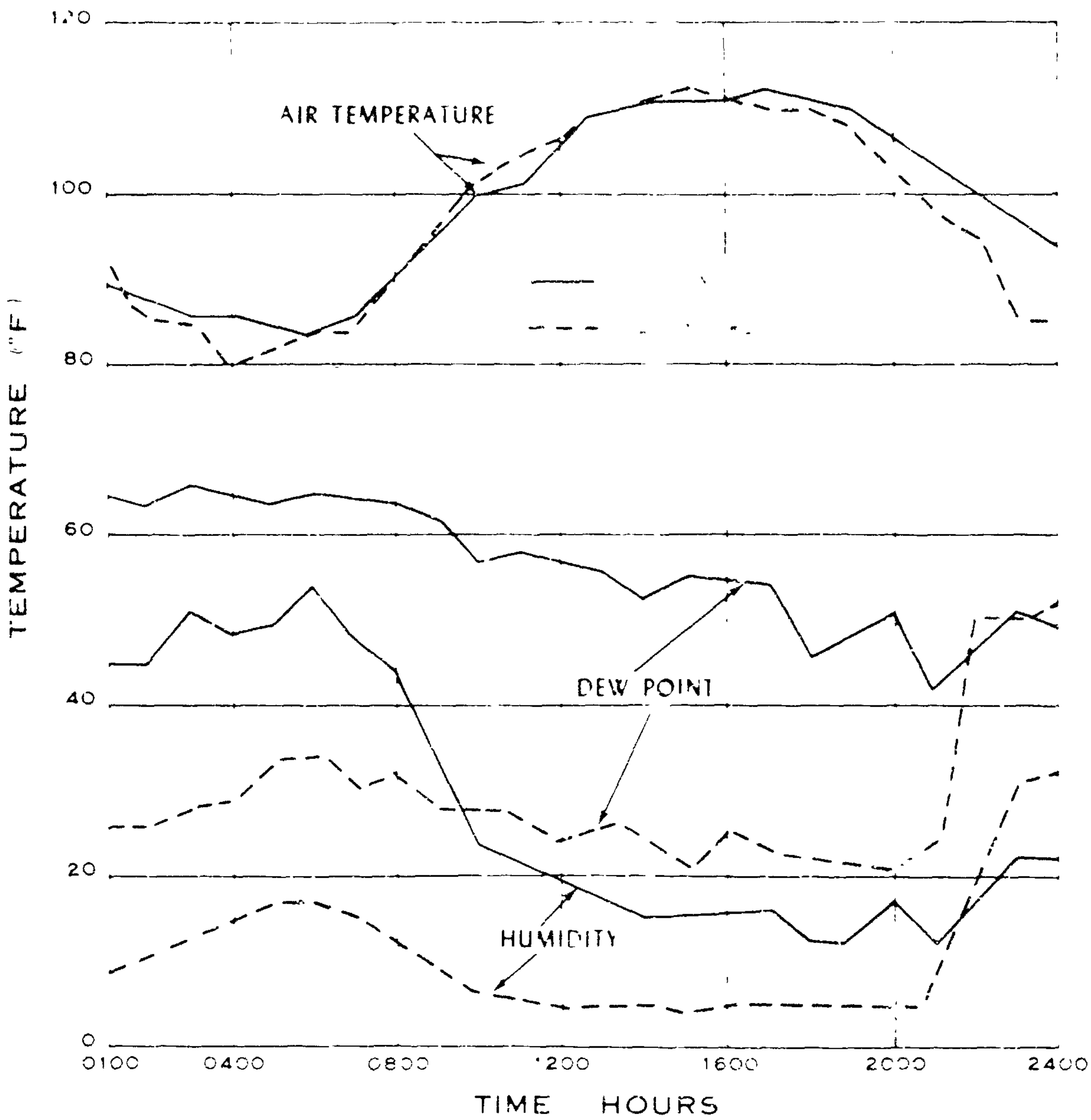


Figure 3. Air temperature, dewpoint, and relative humidity regimes for 19 July 1961 and 25 June 1962 at Yuma Proving Ground, Arizona.

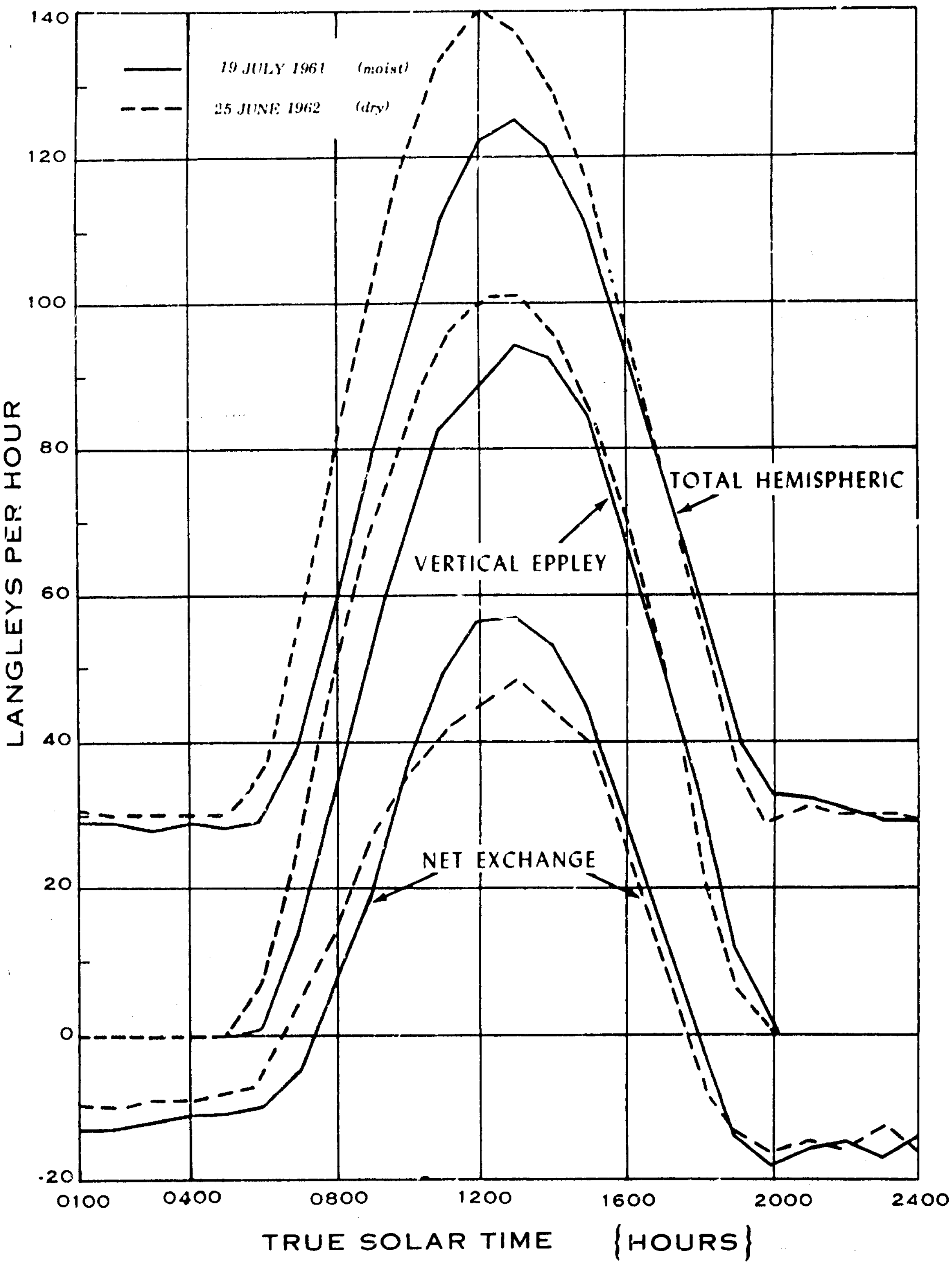


Figure 4. Vertical solar, total hemispheric, and net exchange radiation regimes for 19 July 1961 and 25 June 1962 at Yuma Proving Ground, Arizona.

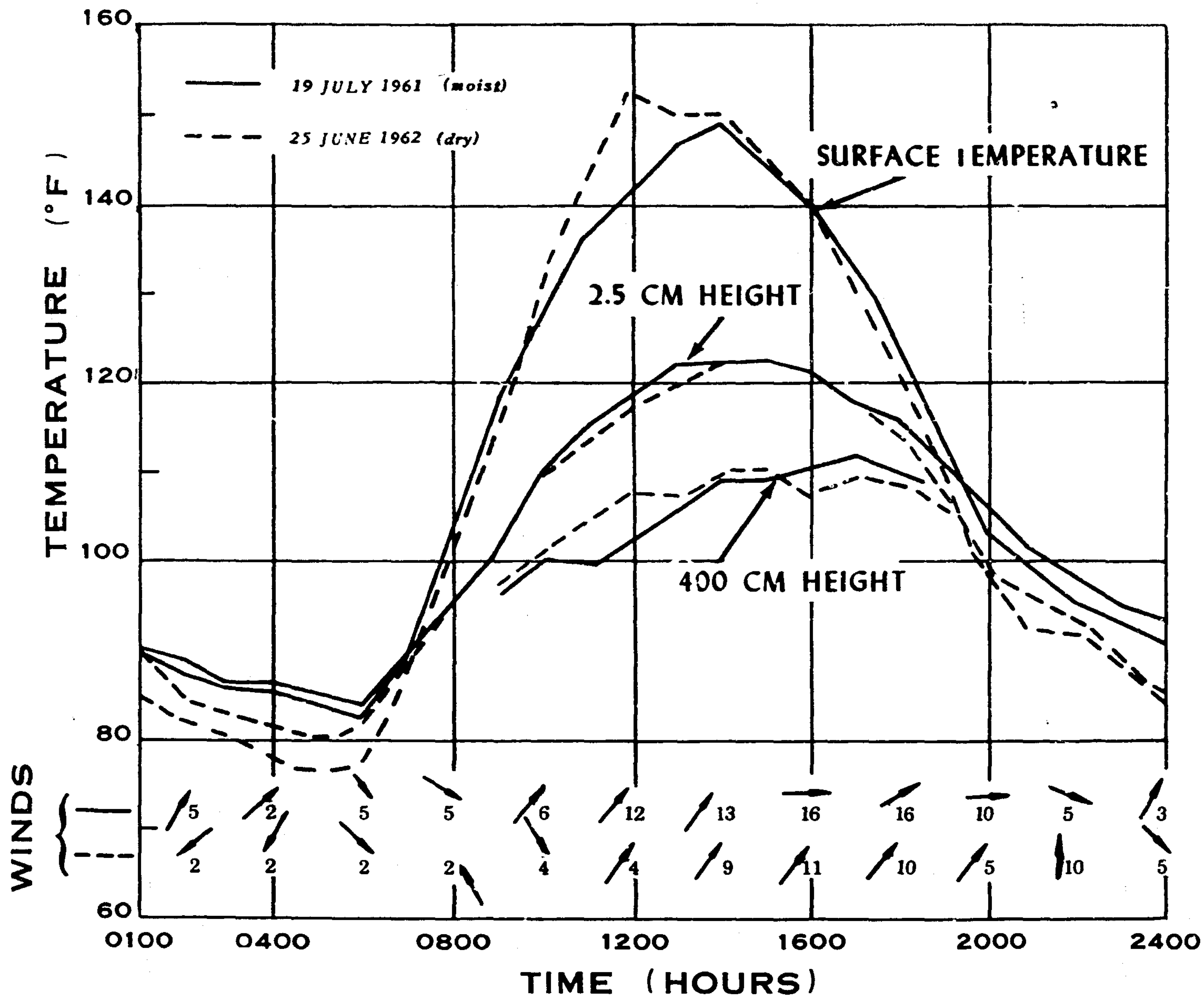
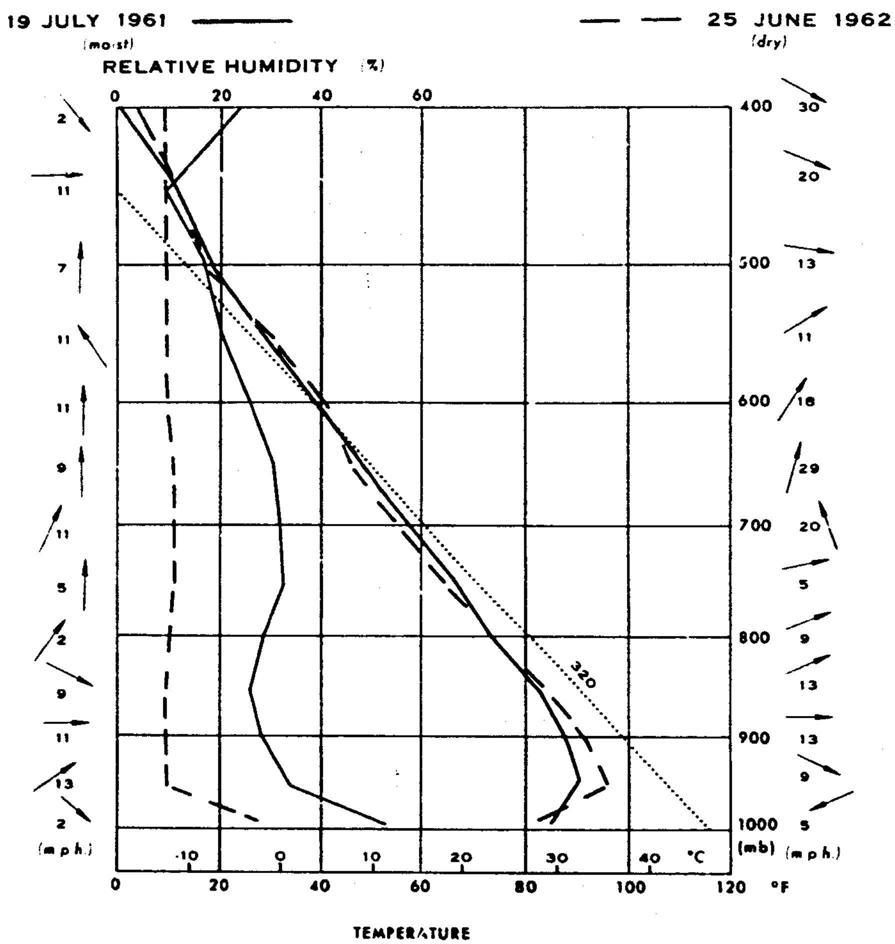
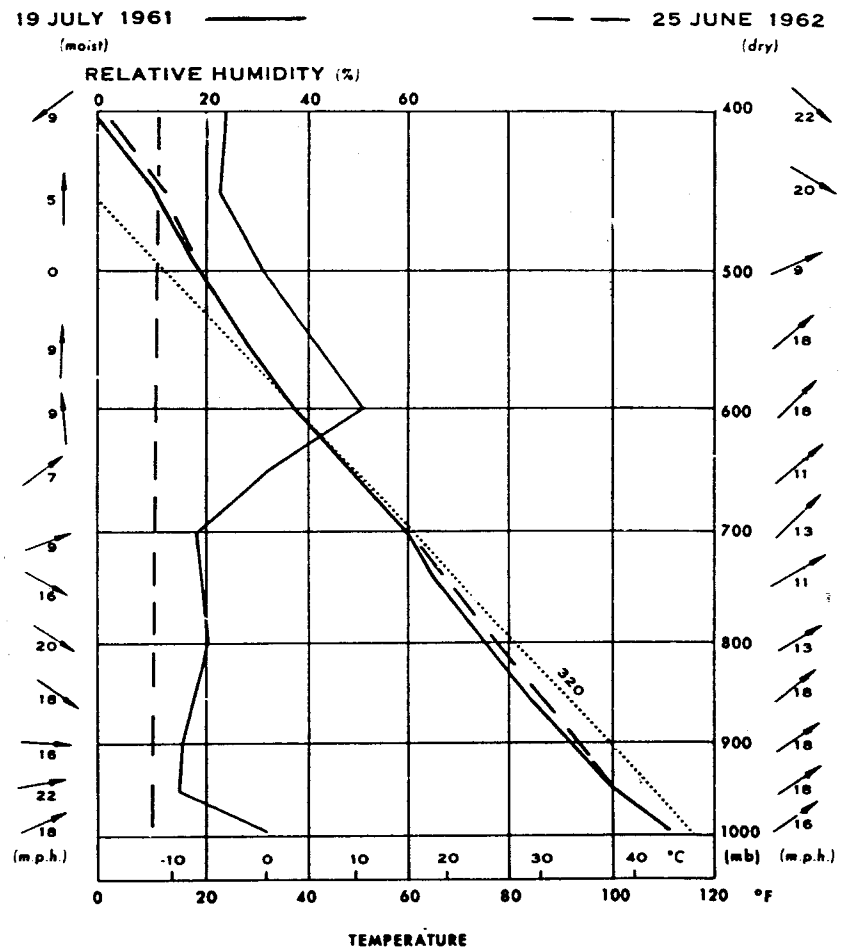


Figure 5. Ground surface, 2.5 cm and 500 cm height temperatures, and wind regimes for 19 July 1961 and 25 June 1962 at Yuma Proving Ground, Arizona.



a. Morning (0500 hours local time) temperature and relative humidity relationship with height for 19 July 1961 and 25 June 1962 at the Yuma Proving Ground, Arizona. The dotted line indicates a dry adiabatic lapse rate.



b. Afternoon (1700 hours local time) temperature and relative humidity relationship with height for 19 July 1961 and 25 June 1962 at the Yuma Proving Ground, Arizona. The dotted line indicates a dry adiabatic lapse rate.

Figure 6

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3 REPORT TITLE CLIMATOLOGICAL CONDITIONS FAVORING OCCURRENCE OF HIGH TEMPERATURES AT YUMA PROVING GROUND, ARIZONA	
4 DESCRIPTIVE NOTES (Type of report and inclusive dates)	
5 AUTHOR(S) (Last name, first name, initial) Williams, Llewelyn	
6 REPORT DATE January 1967	7a TOTAL NO OF PAGES 19 — 7b NO OF REFS 5
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10 AVAILABILITY LIMITATION NOTICES Distribution of this document is unlimited. Release to CFSTI is authorized	
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13 ABSTRACT

Meteorological observations taken by the U. S. Army Meteorological Team at the Yuma Proving Ground, Arizona, provide some basic lower and upper limits to vertical solar and total sky radiation, ground-surface temperature, dewpoint temperature, wind speed, and wind direction during occurrence of high ambient air temperatures. However, even the more favorable combinations of these surface conditions do not provide an adequate explanation for occurrence of extreme temperatures at Yuma. The apparent key is the temperature of the air layer between 850 and 650 mbs. If this layer is warm, and a mechanism exists for bringing the air down to the surface, high ambient air temperatures exist. The mechanism may be the vertical exchange induced by the afternoon convection, or it may be the föhn effect brought about by the synoptic pressure pattern.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Meteorological parameters	8					
Solar radiation	6					
Dew point	6					
Wind	6					
Temperature	6,7					
Ground-surface	6					
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Air	7					
Yuma Proving Ground	9					
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