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HEADQUARTERS
QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND

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TECHNICAL REPORT

EP-9

AD No. 64 784
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HIGH HUMIDITIES AT HIGH TEMPERATURES



QUARTERMASTER RESEARCH & DEVELOPMENT CENTER
ENVIRONMENTAL PROTECTION DIVISION

MAY 1955

NATICK, MASSACHUSETTS

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HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND
Quartermaster Research & Development Center, US Army
Natick, Massachusetts

ENVIRONMENTAL PROTECTION DIVISION

Technical Report
EP-9

HIGH HUMIDITIES AT HIGH TEMPERATURES

Arthur V. Dodd
Meteorologist

ENVIRONMENTAL RESEARCH BRANCH

Project Reference:
7-83-03-008A

May 1955

Foreword

Since World War II the importance of extreme environmental conditions to which military equipment and personnel are likely to be subjected has prompted continued research. The Environmental Protection Division of the Quartermaster Research and Development Command has been delegated the responsibility for this research with the aim of determining reasonable environmental design limits. Past work, reflected by Environmental Protection Branch Report No. 146 "Climatic Extremes for Military Equipment" and Military Standard 210 of the same title, must be reevaluated as new evidence, which might dictate changes in recommended environmental limits, becomes available.

This report is a study of strategic subtropical desert areas characterized by extremely high humidities. In a previous report the relationship between dew point and sea surface temperature was investigated. From the conclusions of that report it was reasoned that the highest dew points are to be expected near the warmest seas. The Data Control Unit of the Air Weather Service was requested to furnish simultaneous dew point and temperature records for three stations on the coast of the warmest sea, the Persian Gulf, and for one station near the northern end of the warm Gulf of California. These data, which include some of the highest dew points recorded, are presented in a manner which makes it possible to determine the distribution of dew points at any temperature.

Austin Henschel, Ph.D.
Acting Chief
Environmental Protection Division

Approved:

A. Stuart Hunter, Ph.D.
Scientific Director
QM Research & Development Command

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Abstract

An analysis is made of summer humidities at three stations under the influence of the hot Persian Gulf, and one station in the southwest United States near the warm waters of the Gulf of California. At the Persian Gulf stations, Bahrein Island, Dhahran, and Abadan, the low dew points tend to be associated with high temperatures, and conversely, higher dew points tend to be associated with low temperatures. At El Centro, California, no clear relationship between temperature and dew point trends was found.

During June, July and August high wet-bulb temperatures (above 78°F) occurred two-thirds of the time at Bahrein, one-fifth of the time at Dhahran, and occasionally at Abadan and El Centro. Values above 85°F are encountered at all four stations; the highest (91°F) occurred at Dhahran.

Bivariate frequency distributions of temperature and dew point are presented for Bahrein Island and Dhahran, the two stations having dew points above 80°F an appreciable number of times. At Bahrein Island, which is subject to the maritime effect of the Persian Gulf at all times, the average summer temperature and dew point are 91.5° and 75.8°F , respectively. Mean dew points vary little with changes in temperature, except that at very high temperatures dew points are lower. At Dhahran, which is at times subject to the hot-dry environment of interior Arabia, the average summer temperature and dew point are 95.5° and 61.8°F , respectively. Average dew points decrease regularly with increasing temperature. The highest dew point noted during this study and one of the highest confirmed dew points recorded - between 88° and 89°F - was observed at Dhahran.

HIGH HUMIDITIES AT HIGH TEMPERATURES

1. Introduction

Humidity, a measure of the amount of water vapor present in the atmosphere, is an environmental factor of major military significance. It is difficult to conceive of any phase of Army operations which in some manner is not affected by humidity. Consequently, the Quartermaster Corps, charged with supplying troops with the most suitable clothing and equipment for the maintenance of comfort and efficiency, has directed particular attention to the investigation of possible measures to combat the detrimental effects of high and low humidities.

In this report an attempt is made to estimate the maximum likely atmospheric humidity at temperatures above 80°F. A previous report,⁴ in which the moisture content of the atmosphere was correlated with surface temperature of the nearest large body of water, is of importance to the present study.

2. Background

Relative humidity is defined as the ratio of moisture in a given volume of space to the amount which that volume would contain were it in a state of saturation. If in a given volume of air the relative humidity is 100 percent, the air is said to be saturated; if more moisture is added condensation will occur. The warmer the air the more water vapor it can hold. At high temperatures the air is rarely saturated. The amount is dependent on the temperature of the source of this moisture, usually the seas, and since the hottest sea, the Persian Gulf, seldom has surface temperatures higher than 90°F, this figure limits the possible quantity of water vapor in the atmosphere. Only in special local situations, such as thundershowers in the afternoon, over heated ground, could dew points, as defined below, much over 90°F occur and then for only a short time.

Since the atmosphere's capacity to hold moisture increases rapidly with increasing temperature, the relative humidity constantly changes as the temperature fluctuates. For this reason, relative humidity is an unsatisfactory measurement for use in this analysis. A measure with a small daily variation would be more suitable. The dew point, the temperature to which the air must be cooled in order to reach saturation (when fog forms), has been chosen for this study. It is an easy value to work with, and it has a direct relationship with the actual vapor pressure exerted by the water vapor in the atmosphere. Any dew point can be expressed in terms of vapor pressure, the humidity value often

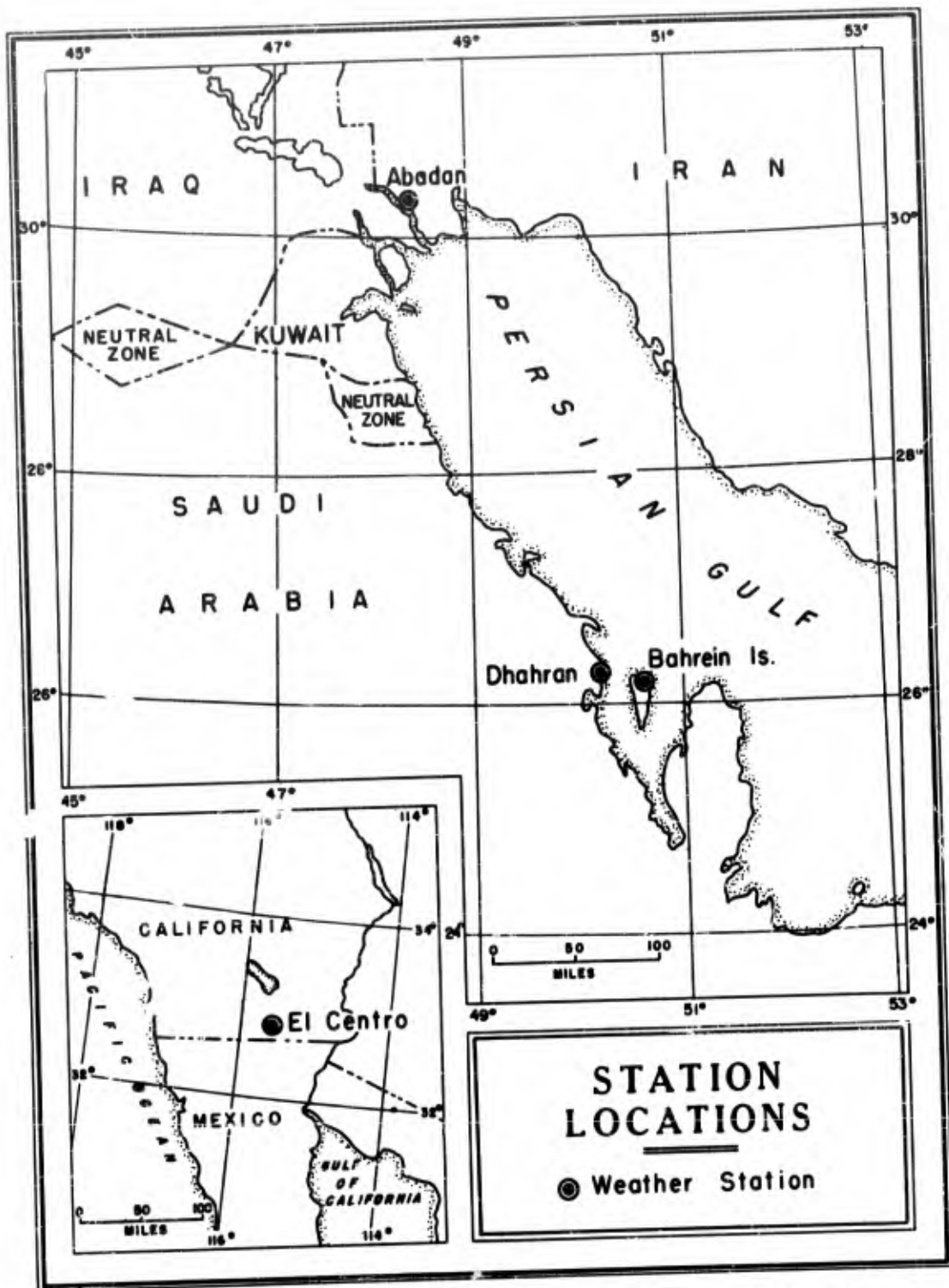


Figure 1: Location of Weather Stations in Persian Gulf Area and in Gulf of California Area

used by physiologists in studies of the thermal balance of the body.

Observations of dew point temperatures above 90° F are rare. A dew point of 99° F was reported twice in eight years at Kamaran Island in the Red Sea. A study of maximum dew points in India indicates that the maximum likely dew point there is 90° F.² In the Persian Gulf area maximum dew points of nearly 90 F have been reported, and will be discussed in this report.^{2, 3}

Another measure of the moisture content of the atmosphere is the wet-bulb temperature, the lowest temperature to which air can be cooled by evaporating water into it. The wet-bulb temperature may be used to indicate the amount of cooling possible through evaporation of the moisture on the body surface; thus it can be considered an element related to human comfort.¹ Wet-bulb temperatures between 78° and 85° F are regarded by many as too debilitating for continuous labor; sustained values above 85° F represent conditions near the limit of physical endurance for people foreign to humid subtropical areas.^{2, 6}

3. Data

Frequency distributions of hourly temperatures and dew points during June, July and August were obtained for four stations, three of which (Abadan, Iran; Bahrein Island; and Dhahran, Saudi Arabia) are to varying degrees under the tropical maritime influence of the hot Persian Gulf. The fourth station, El Centro, California, is located near the Mexican border in the same depression occupied by the Gulf of California, 75 miles to the south (Fig. 1). It is likely that El Centro is at times under the influence of the warm waters of the Gulf.

A three-year record was available at El Centro and Dhahran, and a two-year record at Bahrein Island and Abadan. Observations were divided as follows into four daily periods, local standard time: 1) 0030-0630, 2) 0630-1130, 3) 1230-1730 and 4) 1830-2330. Temperature-dew point observations at each station are summarized in monthly tables. Temperatures are given to the nearest degree Fahrenheit, and dew points are tabulated in classes of two Fahrenheit degrees. Table I shows the number of hourly observations taken during each month for each time group and the maximum possible number of hourly observations.

TABLE I: NUMBER OF HOURLY OBSERVATIONS (N) AND POSSIBLE NUMBER OF HOURLY OBSERVATIONS (P) AT FOUR STATIONS DURING YEARS INDICATED

Month	Time Group	Abadan		Bahrein Island		Dhahran		El Centre	
		<u>1944, 1945</u>		<u>1944, 1945</u>		<u>1946, 47, 48</u>		<u>1945, 47, 48</u>	
		<u>N</u>	<u>P</u>	<u>N</u>	<u>P</u>	<u>N</u>	<u>P</u>	<u>N</u>	<u>P</u>
June	I	359	360	359	360	199	540	537	540
	II	360	360	356	360	450	540	538	540
	III	360	360	360	360	509	540	538	540
	IV	360	360	359	360	420	540	539	540
July	I	371	372	369	372	365	558	549	558
	II	372	372	372	372	462	558	553	558
	III	371	372	371	372	526	558	551	558
	IV	372	372	372	372	495	558	552	558
August	I	372	372	372	372	371	558	551	558
	II	*	372	372	372	468	558	555	558
	III	372	372	372	372	527	558	538	558
	IV	372	372	271	372	494	558	549	558
Total		4,041	4,416	4,405	4,416	5,286	6,624	6,570	6,624

*Data unavailable.

4. Analysis

a. Mean temperatures and dew points. Mean temperatures and dew points are presented for each station by time groups for June, July, and August (Fig. 2). The graphic analysis indicates the following diurnal effects in mean temperatures and dew points at the four stations:

(1) The influence of an island location dominates at Bahrein. Mean afternoon (time period III) temperatures are considerably lower, and mean early morning (time period I) temperatures average somewhat higher than at the other stations. Dew point temperatures at Bahrein Island are high and the diurnal range is small. The mean summer (June, July, August) temperature at Bahrein is 91.5°F; the mean dew point temperature is 75.8°F.

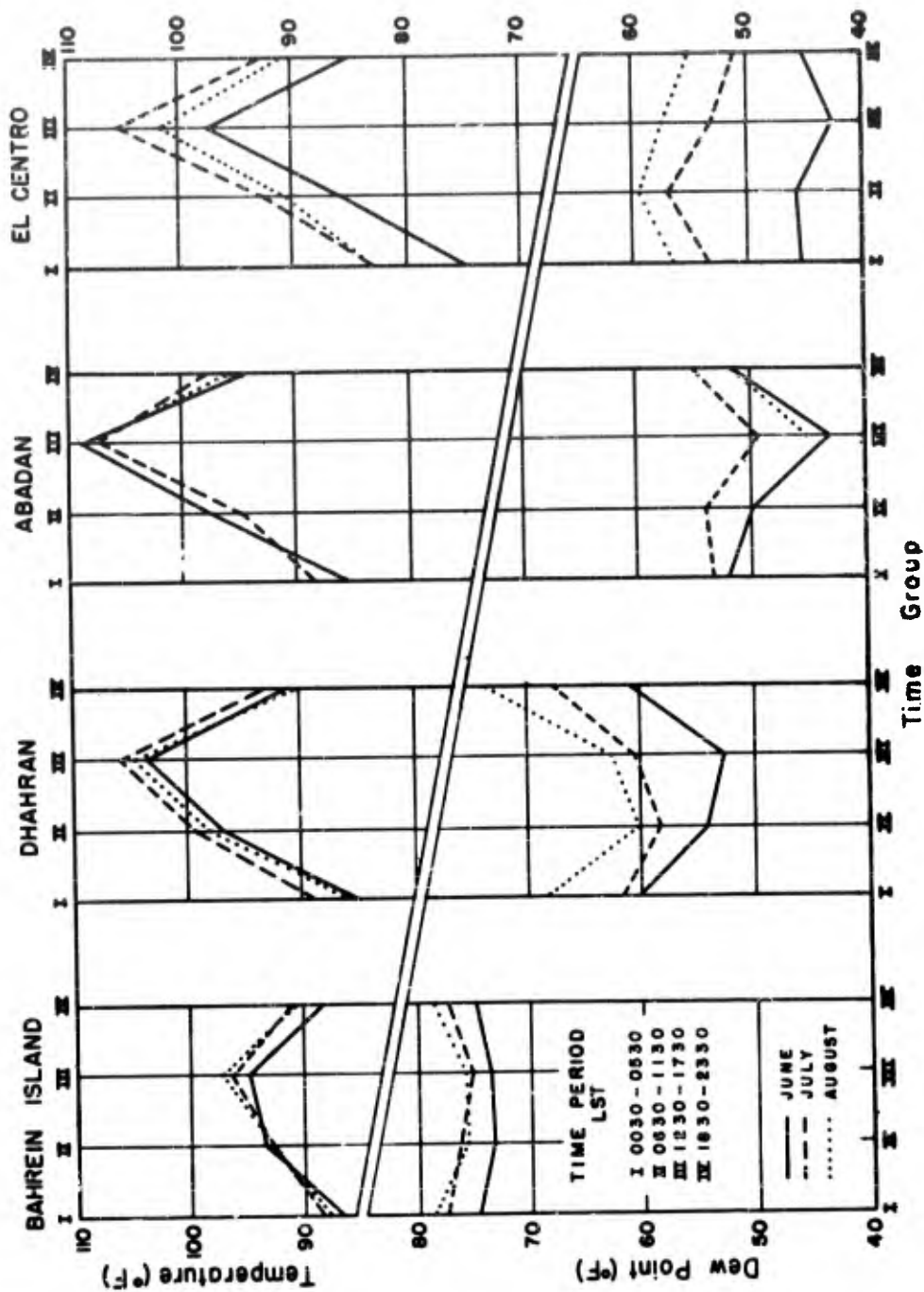


Figure 2 : Mean Temperatures and Dew Points during Four Daily Time Periods - June, July, and August

(2) The effects of maritime exposure are less marked at Dhahran on the west coast of the Persian Gulf, and are scarcely noticeable at Abadan which is located a short distance inland from the north coast (Fig. 1). This condition is primarily a result of prevailing northwesterly summer winds at these stations. Wind data for Bahrein Island indicate that winds in the Gulf are from the Northwest 40 percent of the time and from the West-through-North 80 percent of the time. Although this wind pattern is interrupted along the coast by the land-sea breeze effect, the dominating wind, nevertheless, is oriented coastwise at Dhahran, and is offshore from the dry interior at Abadan. The mean summer temperature at Dhahran is 95.5°F; the mean dew point is 61.8°F. At El Centro these values are 91.0°F and 52.0°F respectively. Because of missing data during one time period these averages were not computed for Abadan.

(3) In most parts of the world the dew point, affected by evapotranspiration, rises slightly with increasing temperature. At all three Persian Gulf stations, however, daily trends of temperature and dew point are reversed; as temperatures rise, dew points fall, and conversely, as temperatures fall, dew points rise. This tendency is broken only in July and August at Dhahran where mean temperature and dew point both rise between time periods II and III. This is probably a consequence of the influx of moist air associated with sea breezes which usually develop during the day. At El Centro there is no clear relationship between temperature and dew point variations. Here, the diurnal trend of the dew point is unique in that the lowest mean dew points occur in the evening (time period IV) and the highest in the late morning (time period II).

(4) At all four stations, mean dew points are lowest in June (during the summer period) and at three stations (Bahrein Island, Dhahran, and El Centro) they are highest in August. This may be a reflection of the lower sea surface temperatures of nearby bodies of water in early summer, shown in Table II. Dew points at El Centro may be affected by irrigation or by brief wetting of heated ground by thunderstorms, since values above 80°F, higher than the surface temperature of nearby large bodies of water, have been recorded.

TABLE II: SEA SURFACE TEMPERATURES
(°F)

Month	Northwest Persian Gulf	North Gulf of California	Pacific Ocean South California Coast
June	80	70	60
July	85	70	65
August	90	80	65

b. Wet-bulb temperatures. From temperature and dew point values it is possible to determine wet-bulb temperatures. As previously stated, wet-bulb temperatures above 78°F are considered by many too oppressive for continuous labor; when they rise above 85°F they may be dangerous for people not accustomed to the subtropical climates. Table III shows the occurrence of wet-bulb temperatures above these values, expressed in numbers and in percent of the total observations. The high percentage of wet-bulb temperatures above 78°F indicates continuously uncomfortable conditions at Bahrein Island, a fact substantiated by people who have lived there.

TABLE III: NUMBER OF OBSERVATIONS (N) WITH WET-BULB TEMPERATURES ABOVE INDICATED VALUES AND PERCENT (P) OF TOTAL OBSERVATIONS (JUNE, JULY, AUGUST)

Station	Total Observations	Above 78°F		Above 85°F	
		N	P	N	P
Bahrein Island	4,405	2,939	67.0	66	1.5
Dhahran	5,286	957	18.0	52	1.0
Abadan	4,041	102	2.5	4	-
El Centro	6,570	172	2.6	3	-

Although the number of observations of wet-bulb temperatures above 85°F are few, such extremes occur with appreciable frequency at Dhahran, and at Bahrein Island. Highest wet-bulb temperatures were reported at Dhahran, where values of 91°F occurred twice on afternoons in August. Values in Table III should be considered to be low since dew points are given in 2°F class intervals and, in order not to exaggerate when computing wet-bulb temperatures, the lower value of each class was used. This is particularly important at Bahrein Island where a significant number of wet-bulb temperatures are near 85°F, but cannot definitely be ascertained to be above 85°F.

c. Temperature-dew point distribution. High humidities did not occur often enough at Abadan and El Centro to warrant further consideration in this report.* Temperature-dew point distribution graphs are

* Of the 4,041 observations at Abadan only 34 dew points above 80°F were recorded. The highest was in the 86° to 87°F class. El Centro had only six dew points above 80°F out of 6,570 observations, and the highest was in the 82° to 83°F class.

presented for Bahrein Island and Dhahran. Data for each station are arranged on one graph so that for any temperature the distribution of dew points can readily be determined. The changes from month to month are small compared to diurnal changes, and records for the three months are consolidated into a single 3-month record, which is presented by time periods only. Values for the four time periods are also combined, giving one record for the entire period under consideration. At each degree of temperature above 80°F the distribution of dew points is divided, making it possible to determine the highest 25 percent, the middle 50 percent, and the lowest 25 percent of the dew points occurring at any temperature. The mean dew point and the 2°F class in which the median dew point falls are also computed.

The breakdown of the original data is shown in Figures 3 to 12, in the Appendix. Figure 3 shows the temperature-dew point distribution at Dhahran for the four time groups combined. At the top of the Figure a graph showing the number of observations in each 2-degree dew point class, and at the right a graph showing the number of observations at each temperature are included. The next four figures show the distribution at Dhahran for each time group. Figures 8 to 12 similarly show the temperature-dew point distributions at Bahrein Island for the four time groups combined and for each time group. Wet-bulb temperature lines are included on Figures 3 and 8 for use when wet-bulb measurements are more meaningful than dew points. The following is an example in the use of the graphs:

In Figure 5, temperature-dew point distributions are shown for Dhahran for the second time period. Of the 74 observations at 100°F in this time period (0630 to 1130) the middle half (37) will fall between dew points of 49° and 66°F. The mean dew point is 57°F and the median dew point occurs in the 60° to 61°F class. The lowest dew point is in the 34° to 35°F class and the highest is in the 80° to 81°F class (shown on the graph as 34.5° and 80.5°F).

These graphs present the original data from the Air Weather Service in a more usable form. It is intended that they answer specific and varied questions, many of which cannot be anticipated at this time. A few pertinent facts are presented below:

(1) Maximum dew points

(a) At Dhahran dew points above 80°F occurred at all air temperatures between 81° and 112°F, whereas at Bahrein maximum dew points exceeded 80°F at temperatures between 83° and 103°F. The highest dew point (88° to 89°F) in this study was recorded at Dhahran during an afternoon in July at an air temperature of 99°F.

(b) At very high temperatures (above 103° at Bahrein and above 112° F at Dhahran) dew points were significantly lower.

(c) There is little correlation between time of day and occurrence of maximum dew points, for high dew point values occurred in all time periods.

(2) Minimum dew points

Minimum dew points are considerably lower at Dhahran than at Bahrein Island, as evidenced by the lowest values at both stations. At Dhahran this value was in the 26° to 27° F class and at Bahrein Island in the 48° to 49° F class. At both stations lower minimum dew points were recorded during the day than at night.

(3) Dew point range

(a) The average of the ranges of dew points for all temperatures is about 45° F at Dhahran and 25° F at Bahrein Island. The larger range at Dhahran can be attributed to the periodic influx of dry air from interior Arabia. By the time this air reaches Bahrein it has gained considerable moisture from the Persian Gulf.

(b) The middle half of the dew point observations at any one temperature falls approximately within a 10° to 15° F range at Dhahran, and within 5° to 7° F range at Bahrein Island.

(4) Mean dew points

(a) At Dhahran mean dew points decrease regularly with increasing temperature. A high percentage of the drier and warmer air originates over interior Arabia.

(b) At Bahrein Island dew points change very little with increasing temperature up to 100° F; above 100° F, dew points usually decrease with increasing temperatures. The uniformity of moisture content is a reflection of the influence of the Persian Gulf at this island station.

(c) Mean dew points at a given temperature are higher at Bahrein Island than at Dhahran; the difference becomes greater with increasing temperatures. It is as small as 4° F (at 82° F) and as high as 61° F (at 99° F). The few observations at very high temperatures indicate no systematic difference in dew points between the stations.

d. High temperature and dew point expectancy. Dr. Douglas H.K. Lee included the following data obtained from Air Weather Service in a report on human climatology in the Persian Gulf area, prepared for the former Environmental Protection Branch.

TABLE IV: MEAN NUMBER OF DAYS PER YEAR WITH MAXIMUM TEMPERATURES AND DEW POINTS WITHIN SPECIFIED RANGES ($^{\circ}$ F) AT SPECIFIED HOURS

Period of Record: Bahrein Island - Feb 1944 to Dec 1945
 Dhahran - Mar 1946 to Dec 1948

Time	Station	Temperature		Dew Point		
		90 to 99	100 & over	70 to 79	80 to 89	90 to 99
0700	Bahrein	38.0	0	142.2	31.0	0
	Dhahran	39.5	0	36.7	4.6	0
1300	Bahrein	117.7	22.5	129.1	11.5	0
	Dhahran	58.1	128.6	19.0	1.6	0
1900	Bahrein	103.9	2.0	136.2	26.6	0
	Dhahran	100.1	25.6	65.5	9.2	0

This information, though in a different form and on an annual basis, tends to substantiate the discussion above. Dr. Lee points out, from these figures and from personal experience, that in the Persian Gulf region steep gradients in the moisture content of the atmosphere occur. The logistical implications in this strategically significant area are apparent.

5. Summary

The summer temperature and dew point records indicate that dew points as high as 90° F may occur. Variations in the dew point are a reflection of the influence of the Persian Gulf. The following variations are apparent at three Persian Gulf stations during June, July, and August:

a. Bahrein Island with on-shore winds has a mean temperature of 91.5° F and a mean dew point of 75.8° F. The daily ranges of temperature and dew point are small. At Bahrein dew points above 80° F occur about 20 percent of the time.

b. Dhahran with prevailing along-shore winds has a mean temperature of 95.5° F, and a mean dew point of 61.8° F. The daily ranges of temperatures and dew points are larger than at Bahrein. Dew points above 80° F occur only about five percent of the time; nevertheless, the highest dew point noted in this study (88° or 89° F) occurred at Dhahran.

c. Abadan with prevailing off-shore winds has the highest mean temperature and the lowest mean dew point. Daily fluctuations in these values are great.

d. At all three stations mean dew points are higher at night than during the day, but high dew points can occur any time.

6. Recommendation

That further investigations of the moisture content of the atmosphere should be made with special emphasis on the moisture gradients that exist in the lowest level of the atmosphere near warm bodies of water. Such a study should be helpful in establishing the criteria to be used in estimating humidity conditions in areas where records of observations are not available.

7. References

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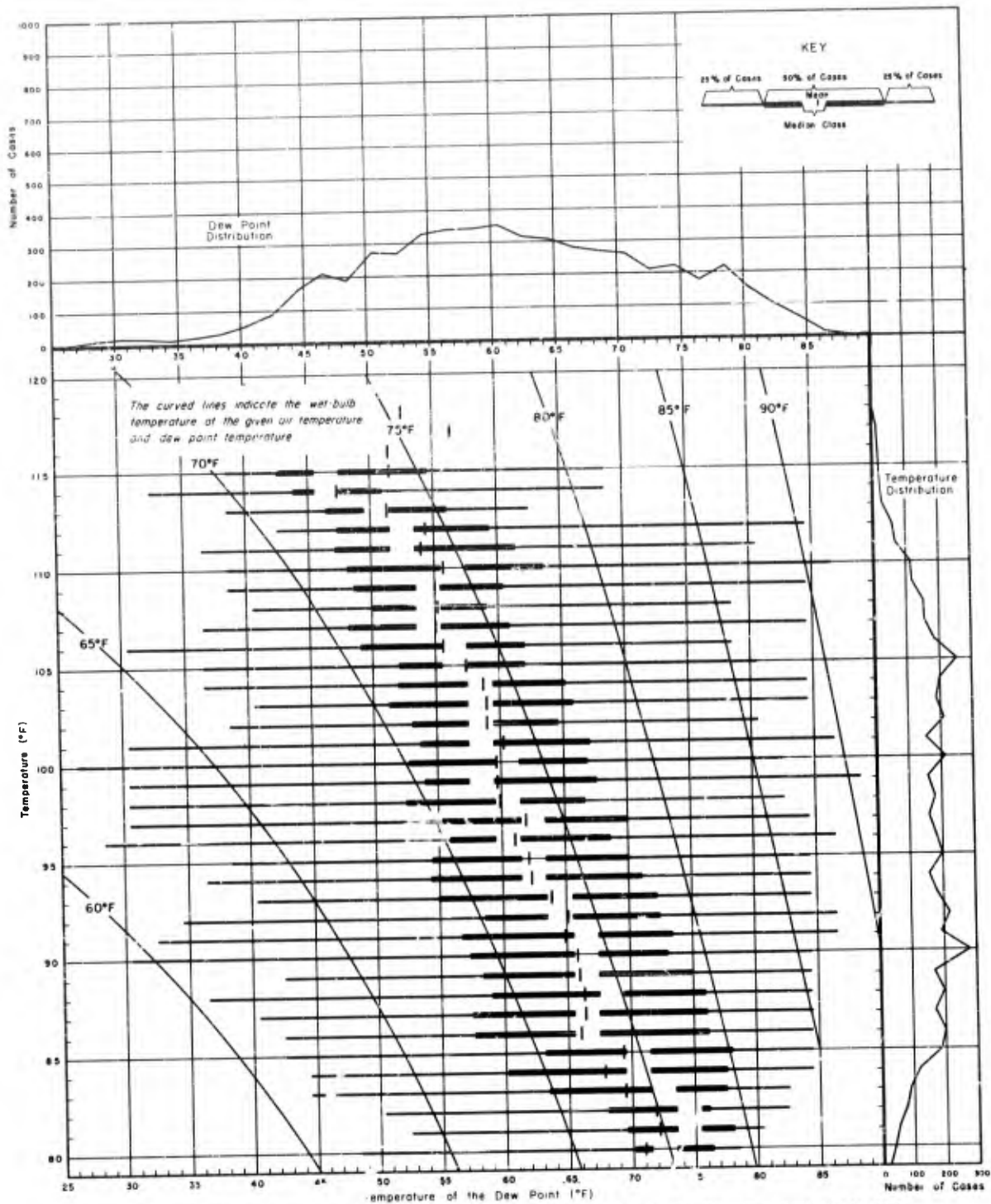


Figure 3: Temperatures versus Dew Point Temperatures at Dhanra: June through August, 1946-1948, For All Four Time Groups

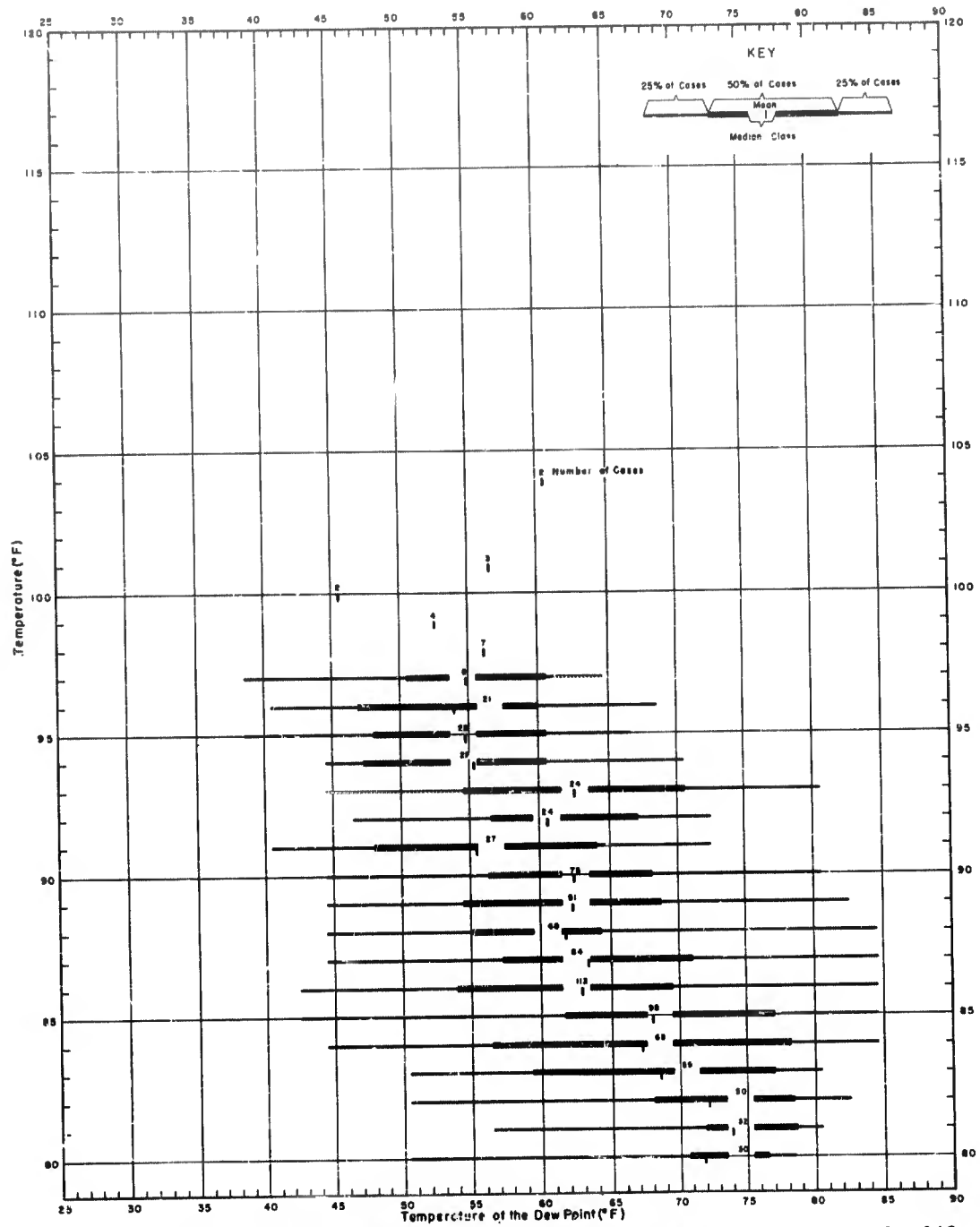


Figure 4: Temperatures versus Dew Point Temperatures at Dhahran, June through August, 1946 - 1948 for Time Group I (0030-0530, LST)

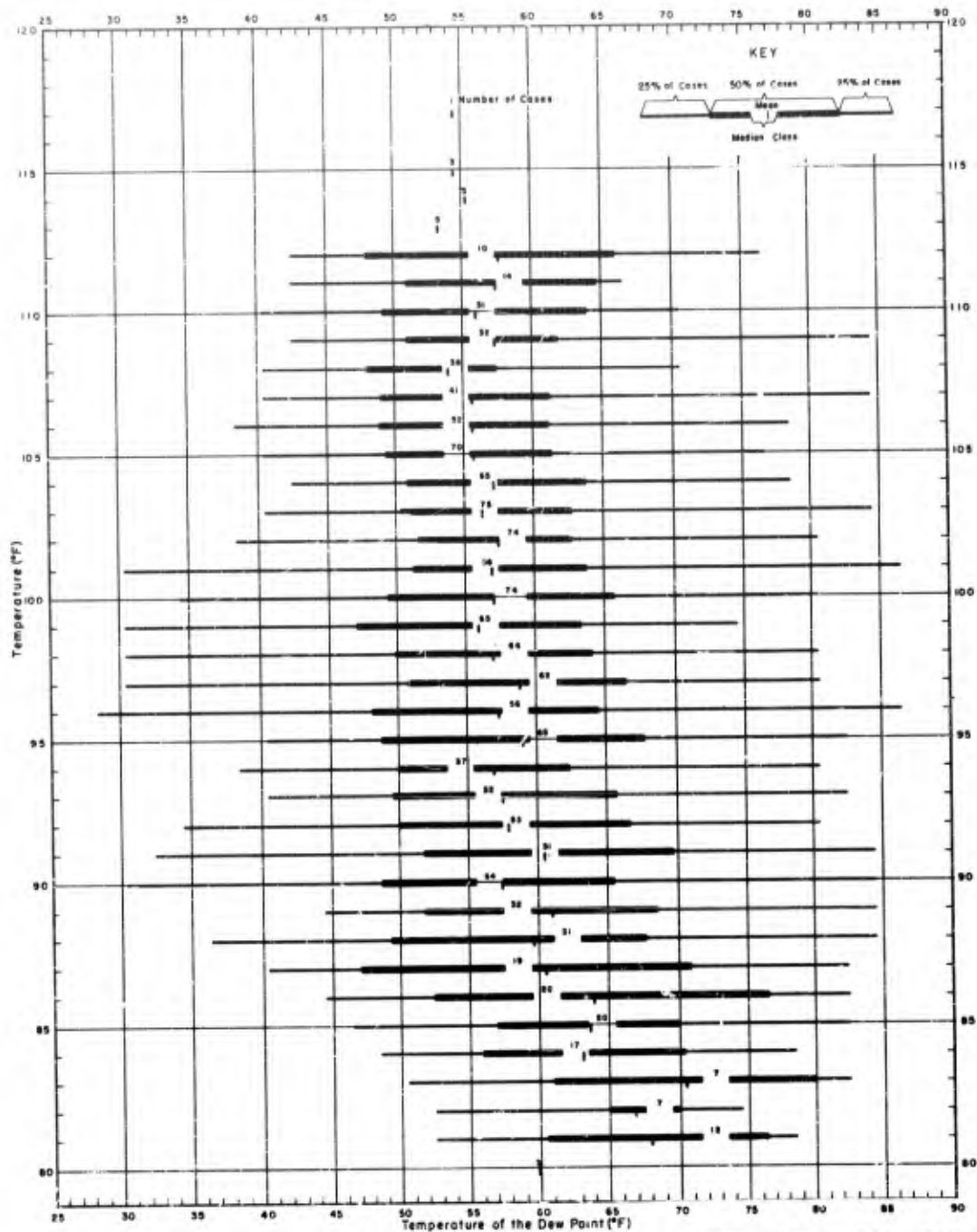


Figure 5: Temperatures versus Dew Point Temperatures at Dhahran, June through August, 1946 - 1948 for Time Group II (0630-1130, LST).

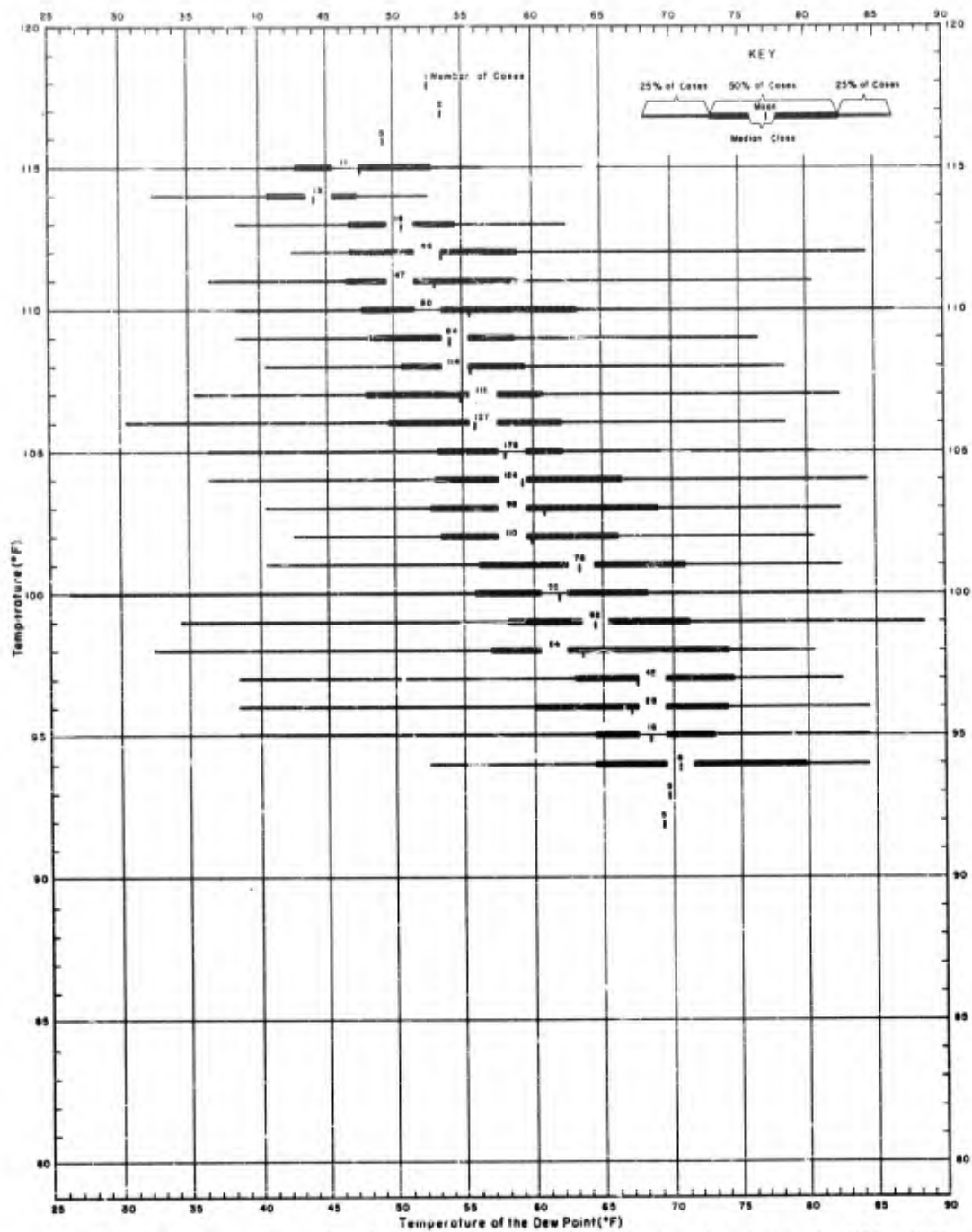


Figure 6: Temperatures versus Dew Point Temperatures of Dhahran, June through August, 1946 - 1948 for Time Group III (1230-1730, LST).

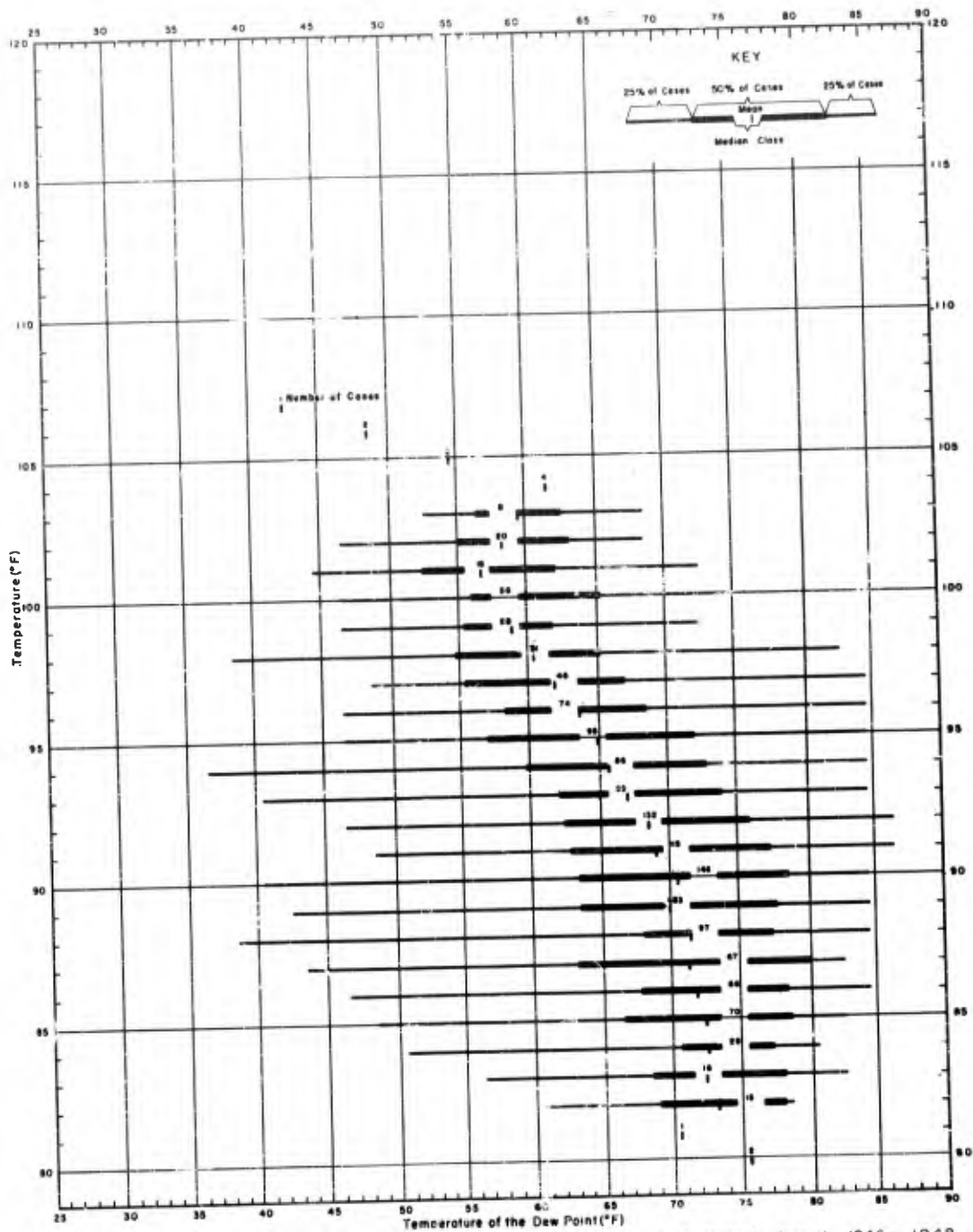


Figure 7 : Temperatures versus Dew Point Temperatures at Dhahran, June through August, 1946 - 1948 for Time Group IV (1830-2330, LST).

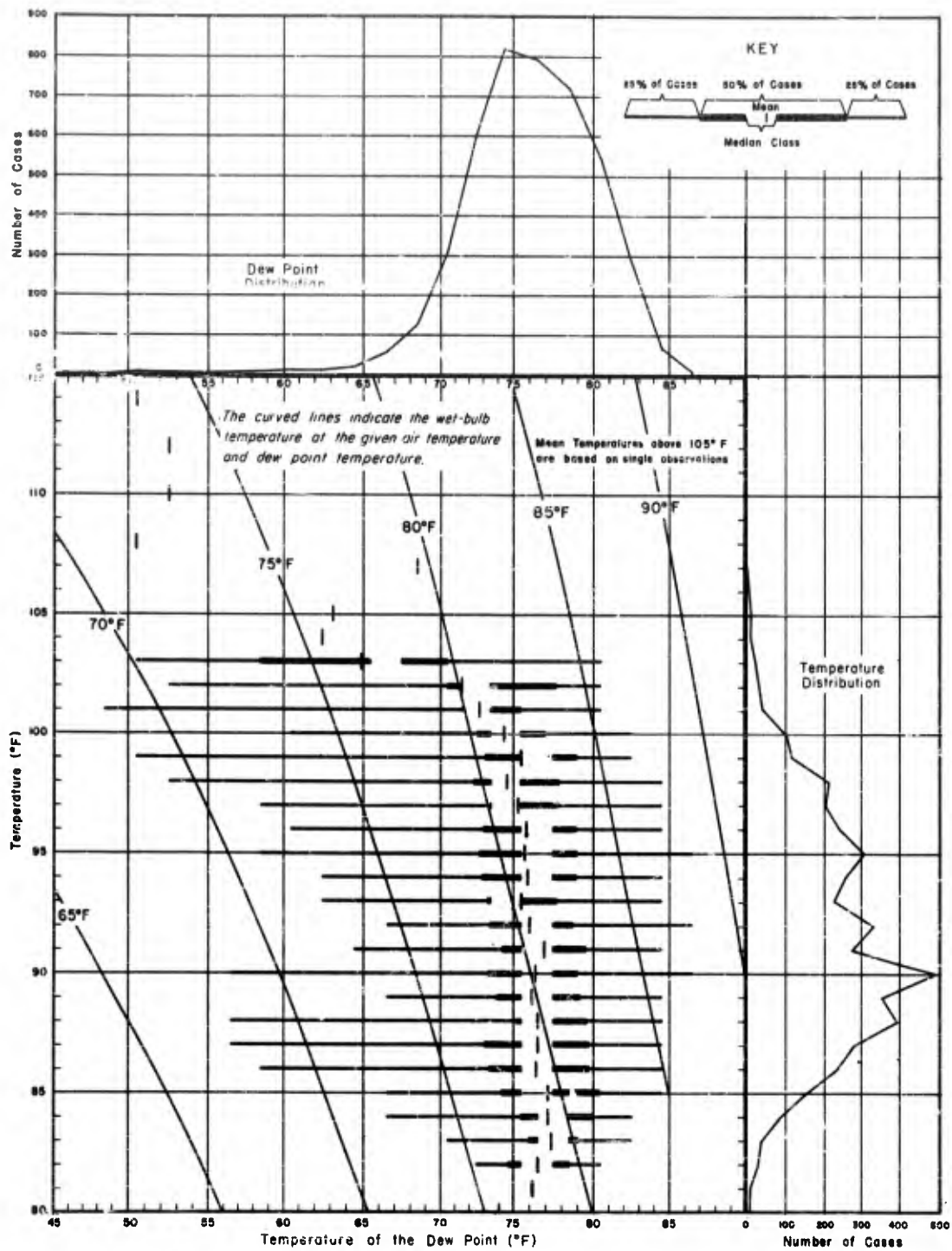


Figure 8: Temperatures versus Dew Point Temperatures at Bahrein Island
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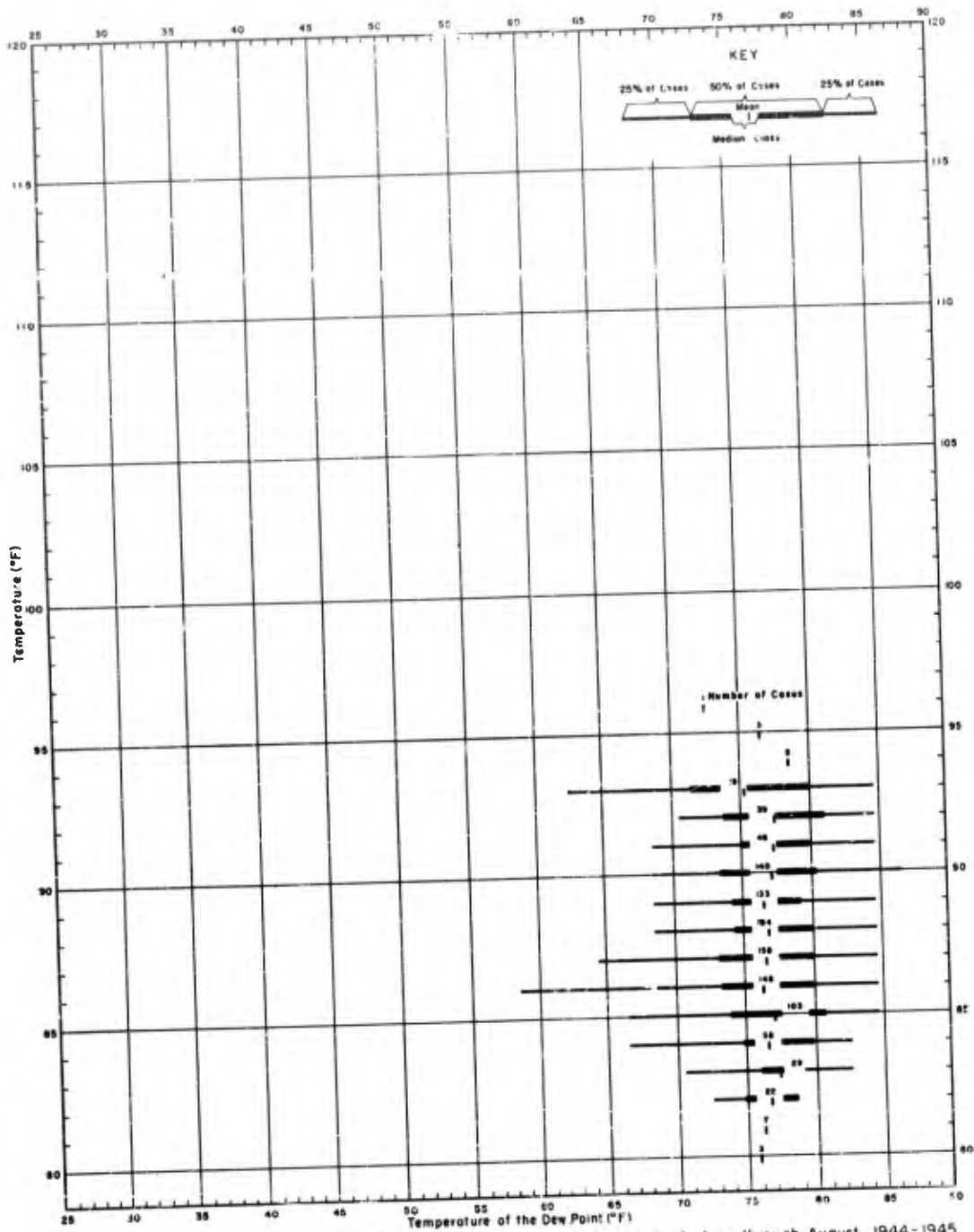


Figure 9: Temperatures versus Dew Point Temperatures at Bahrein Island, June through August, 1944-1945 for Time Group I (0030-0530, LST).

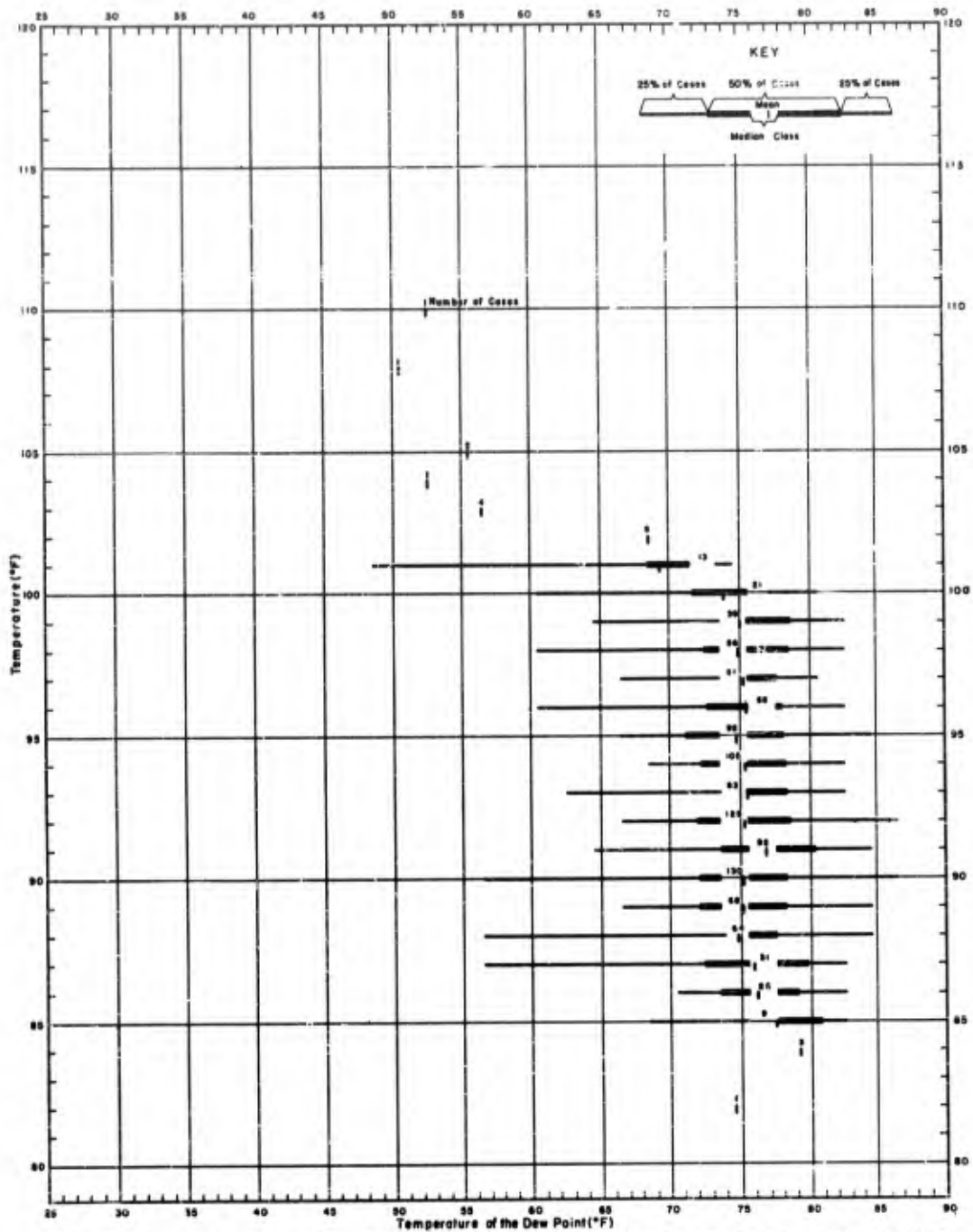


Figure 10: Temperatures versus Dew Point Temperatures at Bahrein Island, June through August, 1944-1945 for Time Group II (0630-1130, LST).

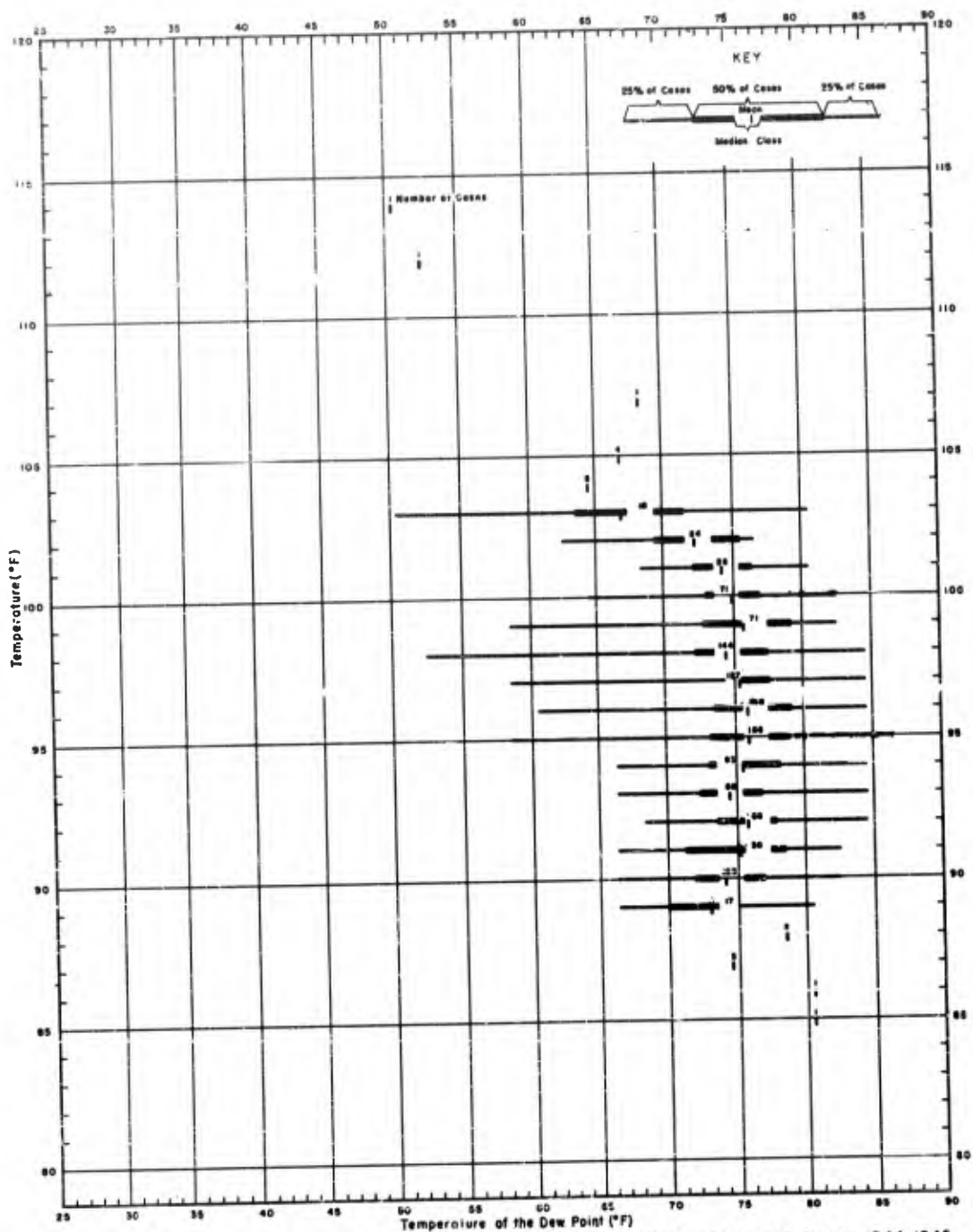


Figure II : Temperatures versus Dew Point Temperatures at Bahrain Island, June through August, 1944-1945 for Time Group III (1230-1730, LST).

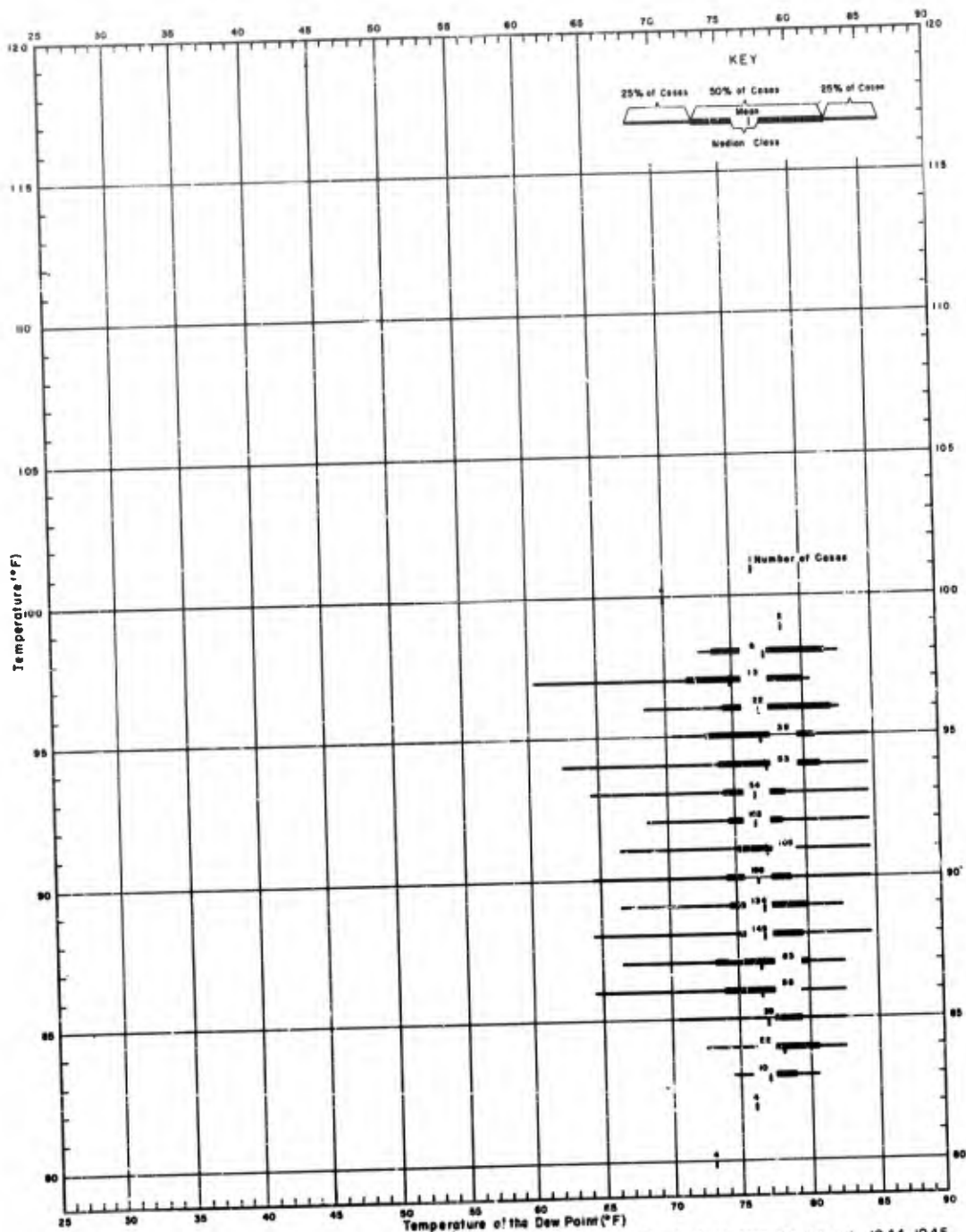


Figure 12: Temperatures versus Dew Point Temperatures of Bahrain Island, June through August, 1944-1945 for Time Group IV (1630-2330, LST).

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