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NOAA TM NWS WR84

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NOAA Technical Memorandum NWS WR84

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

Southwestern United States Summer Monsoon Source -- Gulf of Mexico or Pacific Ocean?

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Western Region

SALT LAKE CITY,
UTAH

March 1973

NOAA TECHNICAL MEMORANDA
National Weather Service, Western Region Subseries

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U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

NOAA Technical Memorandum NWSTM WR-84

SOUTHWESTERN UNITED STATES SUMMER MONSOON SOURCE - GULF OF MEXICO OR PACIFIC OCEAN?

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WESTERN REGION
TECHNICAL MEMORANDUM NO. 84

SALT LAKE CITY, UTAH
MARCH 1973

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I. INTRODUCTION

During summer the interior of the United States and northern Mexico west of the Continental Divide experience frequent intrusions of moist tropical air. In the months of July and August the greatest northward flux occurs. June and September are transition months from spring to summer and summer to fall, respectively. During these months, particularly June, there is a predominance of rather dry air-mass conditions.

In July and August the air mass is normally quite moist from northwestern Mexico southward. The frequency of moist air intrusions and their moisture content decrease northward from Mexico. Arizona normally is dominated by a deep, moist air mass from the middle of July through August. During the same period, western Nevada and Idaho have only infrequent periods of moderately moist air, while eastern Nevada and Utah have somewhat greater occurrences.

Over the years it has been widely accepted that moist air moves into western United States and Mexico on a broad band of southeast winds from the Gulf of Mexico (Bryson and Lowry (1955), Green and Sellers (1964) and Jurwitz (1953)). Every few years, primarily in late summer, dying tropical storms off the west coast of Mexico move northward and inland into northwestern Mexico and southwestern United States, bringing large amounts of moist tropical air with them from off the Pacific Ocean. These storms were generally believed to be of lesser importance as a moisture source for southwestern United States as compared with the Gulf of Mexico.

Hales (1972) presented a mechanism for the frequent transport of tropical moisture northward into southwestern United States and northwestern Mexico. The pressure gradient, which is directly related to the temperature gradient in the lower troposphere over the Gulf of California, was found to be the means by which this moisture surged northward up the Gulf of California. With more careful scrutiny of these surges in 1971, following the writing of the paper, fifteen distinct cases of moist, tropical Pacific air moving into southwestern United States were detected. This surprisingly large number of surges suggests that the role of the Gulf of Mexico as the primary air mass source region has been greatly overemphasized.

II. MEAN CIRCULATION PATTERNS

The mean circulation pattern over southwestern United States and northwestern Mexico during July and August can be separated into two distinct regimes under entirely different controls:

1. Upper-Level Circulation

During summer, at 700 mb and above, the flow pattern is controlled by the large high-pressure ridge normally located over southern United States and northwestern Mexico (Figure 1). According to present thinking, the trajectory of air around this ridge typically enters Mexico from the Gulf of Mexico, turns northwest and then north through southwestern United States and then recurves toward the east again at more northern latitudes.

It is this flow pattern that has been credited with the transportation of moisture into southwest United States from the Gulf of Mexico during the "summer monsoon". When using this model to move moisture into southwest United States, several problems arise. Reitan (1957) has shown that 50% of all precipitable water at Phoenix, Arizona, during the summer months is below the 800-mb level, while 86% is below the 600-mb level. It is difficult to ascribe the Gulf of Mexico as the source of this large percentage of precipitable water below the 800-mb level when air off the Gulf has to cross terrain over Mexico mostly above the 800-mb level before reaching Arizona.

Figure 2, taken from Reitan (1960), shows the 11-year average (1945-1956) of monthly precipitable water over the United States and Mexico from May through October. During July, August, and September there is a pronounced northward bulge of precipitable water isolines into Arizona. Values for Phoenix in July and August are 20% higher than at El Paso which is located at one of the lowest points along or near the Continental Divide.

Though the analysis was not complete for Mexico, data for several stations were compiled. Mazatlan, on the west coast of Mexico, has the greatest precipitable water of all stations analyzed from June through September. During each of the four months, the precipitable water at Mazatlan was more than 1 cm greater than at Brownsville, Texas.

2. Low-Level Circulation

The influence of the mean flow pattern above 700 mb was briefly discussed in the previous section. This section will deal with the mean circulation below 700 mb in the summertime, with primary emphasis on the layer from the surface to the 850-mb level.

As was pointed out by Hales (1972), the summer air mass at Mazatlan is very moist, particularly in the lower levels. Figure 3 shows the mean August 1969 sounding for both Mazatlan and Tucson. The Tucson sounding, which is typical of the air mass of southern Arizona, is moderately wet but considerably warmer below the 700-mb level than is Mazatlan. Above the 700-mb level, both stations exhibit similar air-mass characteristics.

Mean-sea-surface isotherms for August (Figure 4) over the Pacific Ocean, west of Mexico, are readily related to the overlying air-mass characteristics. From the southern portion of Baja California southward and then westward, there is a sharp gradient which separates the cool California current, associated with a very stable overlying maritime air mass, from the warm waters to the south and southeast. This area of warm water extends 300 km or more off the central Mexican coast and extends northward into the Gulf of California, providing a channel for the moist, tropical air mass to reach this Gulf. The air mass overlying this warm water is typified by the Mazatlan sounding in August (Figure 3).

The 850-mb circulation patterns on the east and west sides of Mexico are almost independent of those above the 850-mb level as will be shown later. Also the circulation patterns below the 850-mb level on either side of Baja California are most likely under separate dynamic controls. This is due to the fact that height of the ridge line along the northern two thirds of Baja California averages near the 850-mb level in the atmosphere. During summer the higher tropospheric flow over this area is quite light with very little baroclinicity. The dominant influence in the lower troposphere is the interaction of thermal patterns.

Along the United States and Baja California Pacific coast in summer, the dominant control is thermal. This is manifested by the inland intrusion of maritime air or the sea breeze. This same mechanism, but on a much larger scale, is at work during the summer through the Gulf of California and the desert south west, where there is large difference in air-mass temperature in the lower levels of the atmosphere with the largest gradient existing near the surface as in the sea-breeze situation. Note in Figure 3 that at 1000 mb the temperature difference between Mazatlan and the extrapolated Tucson sounding is 13°C and at 900 mb the difference is 10°C. As in the marine air mass, this difference decreases with elevation. In the polar Pacific marine air mass, this disappearance level is about 1 km, while in the tropical air mass it is near the 700-mb level or about 3 km.

As in the sea-breeze mechanism, the tropical air surges toward the region occupied by warmer, less dense air, in this case up the Gulf of California. Unlike the surging of the sea breeze, however, which is controlled by diurnal heating, surges up the Gulf of California are governed more by the large-scale movement of, or reformation of, a tropical air mass over the warm water corridor west of Mexico. As a new influx of tropical air takes place northward into the gulf, the temperature gradient along the gulf (which is also directly related to the surface pressure gradient) is increased, because this unmodified tropical air is cooler than the modified air to the north. The pressure gradient then forces a surge of tropical air northward up the Gulf of

California, providing the lower levels in northwestern Mexico and the desert southwest with a new supply of moisture.

The *Glossary of Meteorology* defines a monsoon as "a name for a seasonal wind". The wet season in the southwest has frequently been referred to as a monsoon by Bryson and Lowry (1955) and others. The series of mean 850-mb charts shown in Figures 5 - 8 lend support to the idea of a monsoon in the southwestern United States and northwestern Mexico. These mean charts were constructed from 10 years of data for the years 1962 - 1971, inclusive.

A problem in preparing the charts was that several stations were above the 850-mb level or were high enough so that morning surface-based inversions resulted in 850-mb temperatures unrepresentative of the free air. This problem was solved by finding on the sounding the 50-mb layer nearest to the surface that was representative of the free air, and extrapolating the mean temperature and mixing ratio of this layer to the surface using free air-lapse rates. Values thus obtained were compared to the nearest sounding below 850 mb which did not need adjustment. The 850-mb levels from both stations were then compared with some higher comparable level to check for consistency.

At the 850-mb level the colder months of the year have a strong temperature gradient up the Gulf of California with higher pressure to the north, inducing predominantly northerly winds. The mean 850-mb chart for June, Figure 5, is the transition month, with no significant temperature gradient along the gulf. The air mass is very dry over all of southwestern United States and northwestern Mexico, with moisture increasing to the south of Mazatlan (Station MZT). Adiabatic heating over the high plateau of Nevada and Utah induces lower pressure in this area, supporting a south to southwest flow.

East of the Continental Divide there is a very pronounced tongue of moist air moving northward, the moist tongue having its origin over the Gulf of Mexico. This air current is induced not only by the thermal pattern between the cool gulf and the warm land, but primarily by the lee-side troughing along the east slopes of the Rocky Mountains that still prevail during much of June. Note the strong south-to-southwest winds in the high plains. There is a very sharp decrease in this moisture westward into New Mexico, due to lack of any westward component in the flow pattern.

It is interesting to note that mixing ratios are slightly higher north of Arizona, i.e., over Utah and Nevada, indicating some north-Pacific moisture is still being carried inland by middle latitude storm systems.

The most significant feature of the June chart, as well as the other summer months, is the position of the warm core. In June this core is located over Sonora, Mexico.

The mean 1200-gmt 850-mb chart for July (Figure 6) is quite different from June. The two most important changes are:

a. The northwestward shift of the warm core from Sonora, Mexico, to extreme southern Nevada.

b. Large increases in moisture over northwestern Mexico and southwestern United States, particularly Arizona, western New Mexico, southern Utah and western Colorado.

The isotherm pattern through the Gulf of California indicates a very pronounced northward intrusion of cooler air from the tropical Pacific west of central Mexico. This should also be reflected in the low-level pressure gradient which will be shown later.

Though data is lacking both east and west of the Gulf of California, valid arguments can be made in support of this analysis. Over the mountains of western Mexico, the air mass at the 850-mb level should be warmer than on the coast since surface heating would have an effect to greater heights than over the nearby gulf. West of the Baja peninsula, 850-mb temperatures were analyzed higher since the underlying air mass had much different characteristics. Firstly, east of the peninsula the lower levels were exposed to northward transport of cooler air from the south. West of the peninsula below 850 mb, the Pacific Ocean is covered by a very cool marine air mass with warmer air to the south. This does not favor the northward transport of the tropical air mass. However, over the Pacific the marine layer is quite shallow (less than 1 kg), so that above the marine inversion a warmer, fairly dry air mass dominates. There is a point over the Pacific where the air mass reaches a maximum warmth at 850 mb and further to the south a gradual change to a cooler, more moist, tropical air mass occurs.

The mean 850-mb temperature at Mazatlan cools almost 1°C from June to July and Empalme (GYM) shows no change, while stations in the southwest United States and the remainder of northern Mexico have significant warming of 2 to 4°C. This alone strongly supports the change of air mass that takes place through the Gulf of California. Note that there is a temperature gradient of 5°C through the Gulf of California in July whereas in June the gradient is nearly zero.

Corresponding with the intrusion of tropical air into the Gulf of California, values of mean mixing ratio show a large increase from

June to July. Empalme jumps from about 6 gm/kg in June to 11 gm/kg in July. A large increase also takes place over Arizona; Tucson has 5 gm/kg in June and 9.5 gm/kg in July; however, the increase is less north of Tucson. In northern Nevada there is a decrease, Winnemucca has 6.3 gm/kg in June and 5.2 gm/kg in July. Note that the greatest mixing ratio value on the July chart is located at Mazatlan (11.7 gm/kg) on the west coast of Mexico, not along the Gulf of Mexico.

The wind field, though weak, indicates a gradual flow of air up the Gulf of California and then a turning northeastward through southwestern United States.

East of the Continental Divide, very little change takes place between the two months. Moisture spreads farther north, with the temperature and wind pattern remaining nearly the same.

From the discussion of June and July patterns, it is readily apparent that a shift in low-level circulation takes place that manifests itself at the surface as the common thermal or heat low in the summertime over the desert southwest. Since terrain over central Mexico and along the Continental Divide in the United States is mostly above 850 mb, the circulation patterns on each side of the divide are mostly independent of each other.

The mean 850-mb chart for August (Figure 7) is very similar to July, except that average moisture values are even higher in Sonora and southwestern United States. Note that the greatest mixing ratio on the chart (11.6 gm/kg) is now located at Empalme.

The wind flow pattern remains light but still supports movement of air up the Gulf of California into Arizona and then northeastward, as implied by the pressure pattern.

During September (Figure 8) a reversal takes place in the mean isotherm and mixing ratio pattern. Both the warm core as well as the mixing ratio maximum in Sonora have shifted southward from August to September. Over most of the Gulf of California, a sufficient pressure gradient exists up the Gulf for the continued northward transport of tropical air. This is reflected by the high mixing ratio at Empalme, though the mixing ratio is down about 2 gm/kg from August.

In September the warm core retreats southward to a position near the upper end of the Gulf of California, at about the same latitude as in June. This would reflect the lag in the water losing heat in September and gaining heat in June.

Mean 1000-mb charts were developed for June through September, using 850-mb heights and temperatures and assuming dry adiabatic lapse rates from 1000 to 850 mb. Thus, a mean temperature and thickness was obtained, and from this, an estimated height of the 1000-mb surface.

The mean 1000-mb chart for June (Figure 9) has the low along the lower Colorado River Valley in western Arizona with a trough extending southeastward to east of the Continental Divide in Mexico. This clearly follows the 850-mb isotherm analysis for June (Figure 5) except that the 850-mb warm core is not located over southern Arizona but rather over the higher terrain in northern Mexico.

In July both the 1000-mb mean low center (Figure 10) and the 850-mb mean warm core (Figure 6) shift northward into extreme southern Nevada with a strong height gradient northward and thermal gradient southward through the Gulf of California. Note also that a trough at 1000 mbs still exists along the east slopes of the Sierra Madre in Mexico.

Very little change is indicated on both charts for August with the 1000-mb low (Figure 11) and 850-mb warm core (Figure 7) both remaining in southern Nevada.

In September the pattern is again very similar on both charts. The 1000-mb chart (Figure 12) shows the low center shifting southward down the lower Colorado River Valley in western Arizona, with the 850-mb warm core (Figure 8) just south of the Arizona border.

A comparison was made between the 850-mb temperature at Empalme and the 850-mb relative humidity at Tucson for the period June 1 - September 9, 1972. If the cooler and more moist tropical air mass does in fact move northward up the Gulf of California, there should be a relationship between cooling at Empalme and increasing humidity at Tucson. The temperature at Empalme was used since the low-level air mass along the Gulf of California during the summer is nearly always very moist; thus, the change in temperature would better reflect the arrival of tropical air, which is cooler than the air over the Sonoran Desert. Relative humidity was used at Tucson to reflect the influx of moisture and/or the lowering of temperature. Temperature was not used at Tucson since moisture change is more sensitive to the arrival of tropical air.

The plot of the 5-day running means (Figure 13) of the Empalme 850-mb temperature and the Tucson 850-mb relative humidity for the period clearly shows the close relationship between the change in air mass at Empalme followed by a change in the moisture at Tucson. Throughout the entire summer it can be noted that cooling at Empalme is followed by an increase in moisture at Tucson.

Linear correlation coefficients of temperature and relative humidity were computed for zero time lag between the two stations and then 24- and 48-hour lags. The results were:

	Correlation Coefficient
zero lag	-.712
24-hour lag	-.762
48-hour lag	-.690.

Even with the smoothing by using 5-day running means, the distance of 400 km from Empalme to Tucson supports the best correlation coefficient in the 24-hour lag period of -.762.

The regression equation for the 24-hour lag is:

$$Y = 85.09 - 2.57X \qquad (1)$$

with standard error of estimate of 5.3%.

Where Y = Tucson 850 mb relative humidity

X = Empalme 850 mb temperature.

Twenty-four hour changes in the 5-day mean values were computed. Zero, 24-, and 48-hour lag correlations between these changes were computed with the following results:

		Correlation Coefficient
Zero Lag	(Past 24-hour change in Empalme 850-mb temperature vs past 24-hour change in Tucson 850-mb relative humidity)	-.491
24-Hour Lag	(Past 24-hour change in Empalme 850-mb temperature vs future 24-hour change in Tucson 850-mb relative humidity)	-.681
48-Hour Lag	(Past 24-hour change in Empalme 850-mb temperature vs change in Tucson 850-mb relative humidity 24-48 hours later).	-.519

The linear regression equation for the 24-hour lag between Empalme 850-mb temperature and Tucson 850-mb relative humidity is:

$$\Delta \text{RH } 850 = .1328 - 2.46 \, \Delta T_{850} \qquad (2)$$

Where Δ RH 850 = future 24-hour change in Tucson 850-mb relative humidity

ΔT_{850} = past 24-hour change in Empalme 850-mb temperature,

The standard error of estimate of Δ RH 850 from this equation is 2.23%.

Estimates of Δ RH850 were computed from equation (2). These estimated changes were added to the "current" RH values to obtain an estimate of the "future" values 24-hours later. These estimated "future" values were compared with the "observed" RH values 24 hours later, with a correlation coefficient of .963 and a standard error of 2.21%

Though both are transition months, there is a very important difference between June and September. Over the Gulf of California, pressure gradients (which are directly related to the thermal gradients) favor a northward flux of tropical air to latitudes of about 25 or 30°N in September (Figure 8) whereas in June (Figure 5) the tropical air is confined to below 20°N. This makes available a ready source of moisture for the fall months when the westerlies dip well south in the form of a deep trough or cut-off low. In spring the region between 20 and 30°N is very dry, thus a westerly disturbance or cut-off low is usually much drier.

East of the Continental Divide, there is very little decrease in moisture below 30°N from June to September, as the increasing frequency of lee-side troughing continues to draw moisture north from the Gulf of Mexico as the westerly winds aloft increase.

As the tropical air mass moves from its source region in the Pacific up the Gulf of California into the interior of the western United States, it undergoes considerable change. Since the Gulf of California provides a path with very little surface friction and little convective mixing due to lack of surface heating, the tropical air mass moves rapidly northward with little modification. Hales (1972) has shown that shallow surges can move up the gulf at 30 kt even though the mid-tropospheric flow pattern is quite light and variable.

As moist air moving up the Gulf impinges on the western slopes of the Sierra Madre in Mexico, and to a lesser extent on the east slopes of the mountains of Baja California, it is rapidly heated and mixed. This lifting along the west slopes in Mexico quickly increases moisture values in the middle levels of the troposphere and results in a large increase of July-August rainfall inland from the coast in western Mexico (Figure 14). This moisture would then be carried on the south to southeast winds into the western United States, along with the moisture from the Gulf of Mexico that was lifted on the east slopes of the Sierra Madre.

The depth of the tropical air mass during the push up the gulf is usually between 2 and 3 km. Strong heating progressively mixes the air to higher levels as it moves over the Arizona and southern California deserts. Due to topography, the trajectory into southeast Arizona lifts the moisture some 1-1/2 to 2 km, while over western Arizona little topographical lifting takes place. The Sierra Madre determines the eastward extent of the moisture and though elevation of the terrain lowers considerably north of 30°N, the effect of this mountain barrier results in southeastern Arizona being wetter than southwestern New Mexico, on the average.

Upon impinging on Arizona's Mogollon Rim, the northward moving moist air is forced to even higher levels. Under favorable synoptic conditions, and with a sufficiently deep surge, low-level moisture spreads northward up the Colorado valley to southern Nevada, where it is orographically lifted by the higher terrain in Nevada and Utah.

Above about 700 mb, the moist air is above the control of the low level pressure gradient and its trajectory is then determined by the larger scale circulation pattern, i.e., by the upper-level high-pressure systems.

III. SUMMER RAINFALL DISTRIBUTION

The mean rainfall chart (Figure 14) for July and August shows the axis of greatest rainfall is located along the western foothills of the Sierra Madre with decreasing amounts eastward over the Sierra Madre into valleys on the east side. The difference between rainfall amounts on the west and east sides of the mountains decreases from south to north. The relationship of the precipitation pattern at stations east of Mazatlan to the terrain and the Pacific Ocean is quite striking. There is a very rapid increase of rainfall inland from the Pacific to the foothills of the Sierra Madre. With a further increase in elevation to the east, rainfall amounts decrease. Mazatlan (23°N) has 409 mm while inland about 120 km in the foothills at an elevation of 600 m, Panuco receives 644 mm. To the east, another 150 km, El Salto at an elevation of 2500 m on a high plateau but still west of the Continental Divide receives only 216 mm. Precipitation amounts continue to decrease east of the Continental Divide. This reflects the decreasing available precipitable water and quite obviously illustrates the influence of the Pacific Ocean as a moisture source.

This precipitation-terrain relationship is similar as far north as 28°N. To the north of 28°N, the Sierra Madre are located further inland from the coast as well as being lower. This, in conjunction with increased distance from the tropical Pacific, results in a sharp decrease in precipitation northward into Arizona. However, the axis of maximum precipitation remains well west of the Continental Divide as far north as Arizona.

Another argument against the Gulf of Mexico being the principal moisture source is the distribution of rainfall in Arizona during the July-August period. Precipitation in the southeast portion of the state is more than double that in the northeastern part, even though elevations are comparable. Precipitation in the southeast averages a little over 75 mm in both July and August, while in the northeast about 35 mm falls in each month (Green 1964). The logical explanation for this difference is that there is a loss of moisture as the air mass moves northward across the Mogollon Rim in central Arizona. However, it would be difficult to accept this theory if the moisture came from the Gulf of Mexico. For this air mass to get into Arizona from the Gulf of Mexico, it would have to cross two mountain ranges comparable in height to the Mogollon Rim. After crossing these ranges, there would have to be enough precipitable water remaining to result in as much as 250 mm of rain in the July-August period in the Nogales area along the Mexico-Arizona border; yet this same air mass would have to dry out so rapidly on crossing the Mogollon Rim that it could produce only 75 mm at Winslow some 300 m higher than Nogales.

One of the wettest stations in Arizona in summer is Arivaca, at an elevation of 1200 m, located west of the higher mountains of southeast Arizona, with no mountains in the immediate vicinity above 2500 m. To the south of Arivaca, the terrain slopes steadily downward to the Gulf of California. This station is in a favorable location for upslope lifting with low-level southerly winds, which would enhance convective processes. On the other hand, if the moist flow into Arivaca was from the east or southeast, off the Gulf of Mexico, it would be coming downslope and this source therefore could not account for Arivaca being so wet.

As is evident from the preceding discussion, there is serious doubt as to the importance of the Gulf of Mexico as a moisture source for the western United States and Mexico west of the Continental Divide.

IV. CONCLUSIONS

The tropical north-Pacific Ocean west of central Mexico has long been overlooked as an important source of summer moisture for western United States. This same ocean area is the second most active tropical storm breeding zone in the world, being secondary only to the western north-Pacific and much more active than the north-Atlantic.

The discussion and figures on the distribution of precipitable water, mixing ratios, and rainfall in Mexico and southwestern United States clearly shows that the importance of the Gulf of Mexico as a moisture source for the area west of the Continental Divide is minimal.

Very little work heretofore has been done on synoptic controls of the lower troposphere in the summer in this section of the North American continent, mostly due to scarcity of data, and much more needs to be done as additional data becomes available.

V. ACKNOWLEDGMENT

The author expresses thanks to the Western Region Scientific Services Division of the National Weather Service, particularly to Mr. Woodrow W. Dickey who provided invaluable assistance. Also thanks to Mr. Nicholas Ropar and Mr. Paul Kangieser for their professional guidance.

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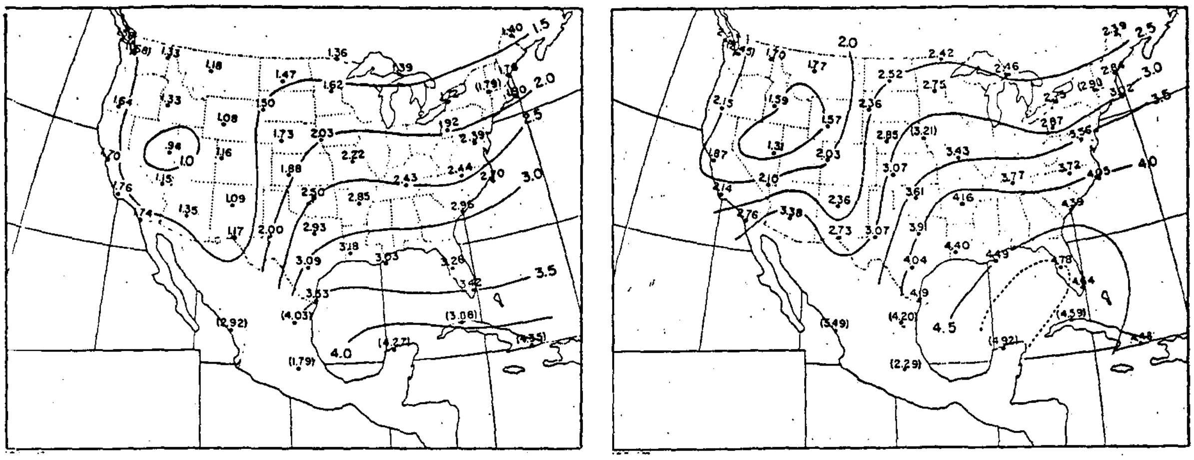
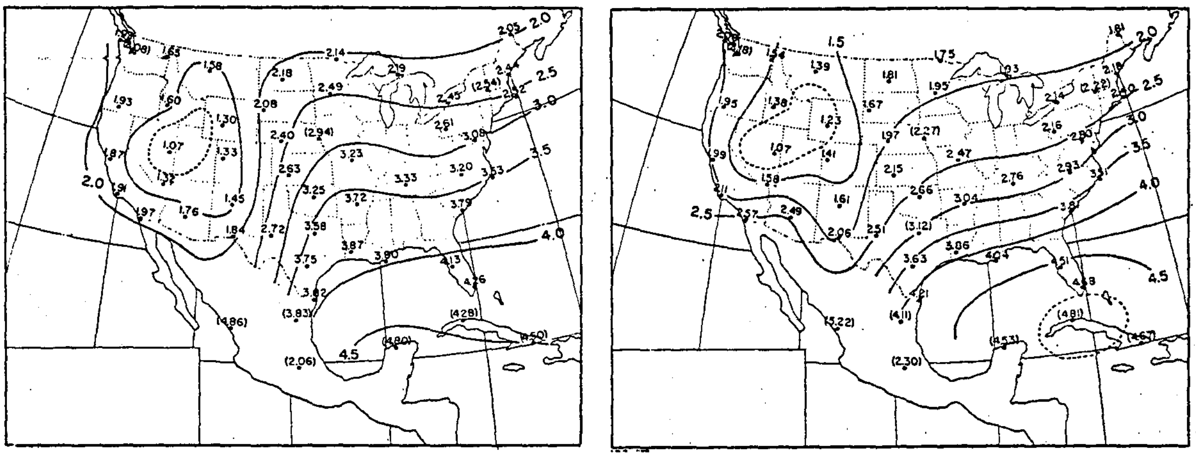


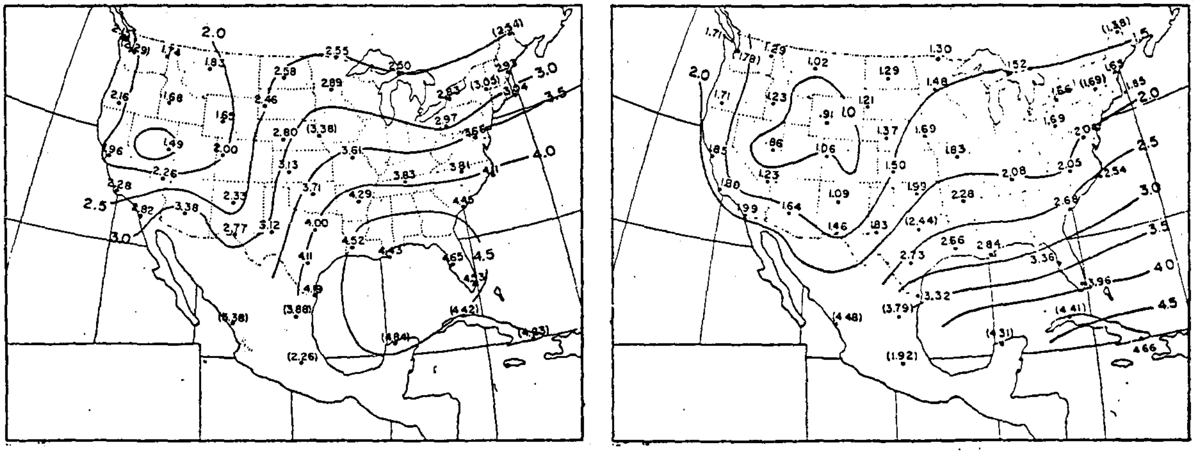
May average precipitable water vapor, in centimeters, for the eleven-year period.

August average precipitable water vapor, in centimeters, for the eleven-year period.



June average precipitable water vapor, in centimeters, for the eleven-year period.

September average precipitable water vapor, in centimeters, for the eleven-year period.



July average precipitable water vapor, in centimeters, for the eleven-year period.

October average precipitable water vapor, in centimeters, for the eleven-year period.

Figure 2. Average Precipitable Water Vapor, in Centimeters, for the Eleven-Year Period (1946-1956); May through October.

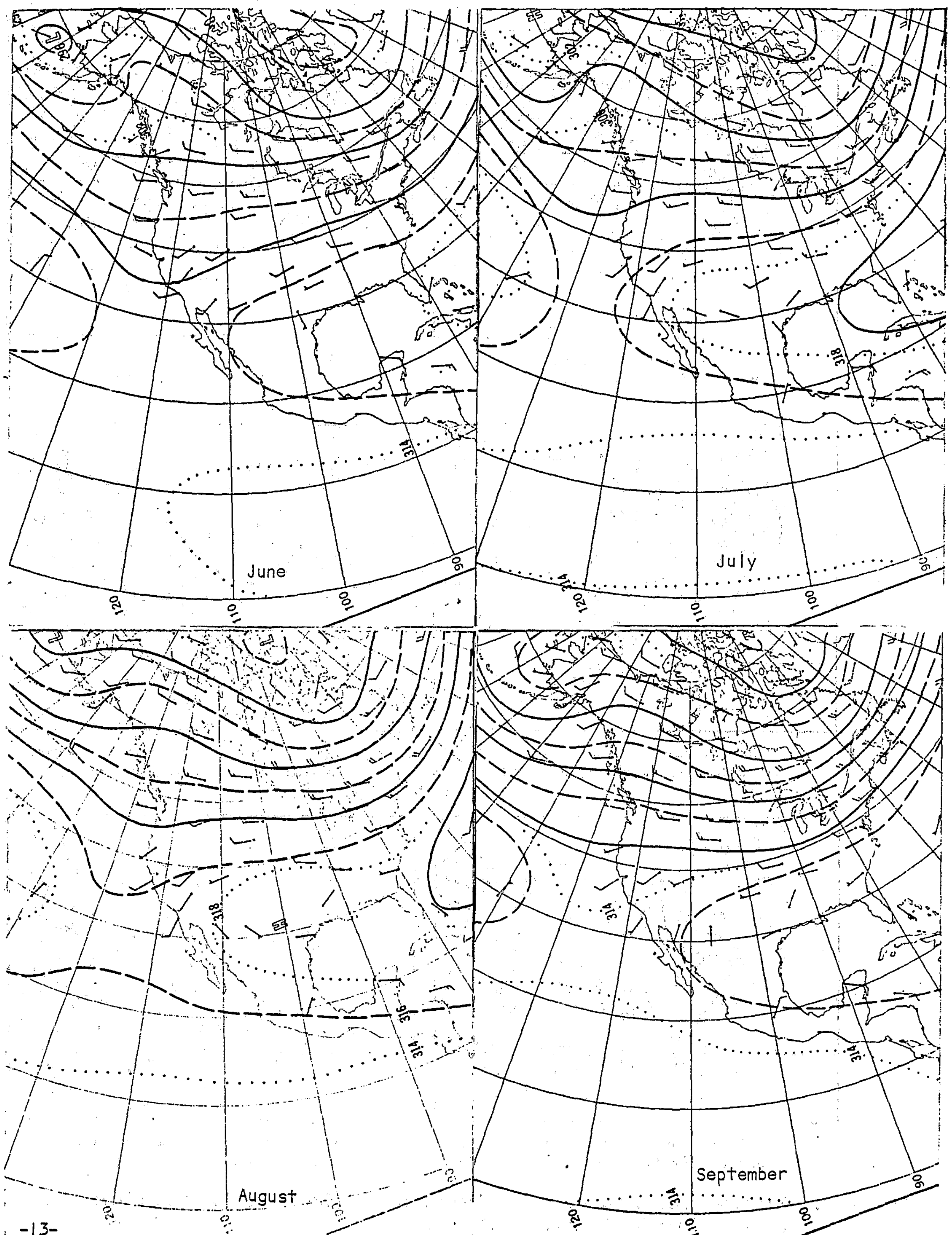


Figure 1. Mean 700-mb Contours--June, July, August, and September.

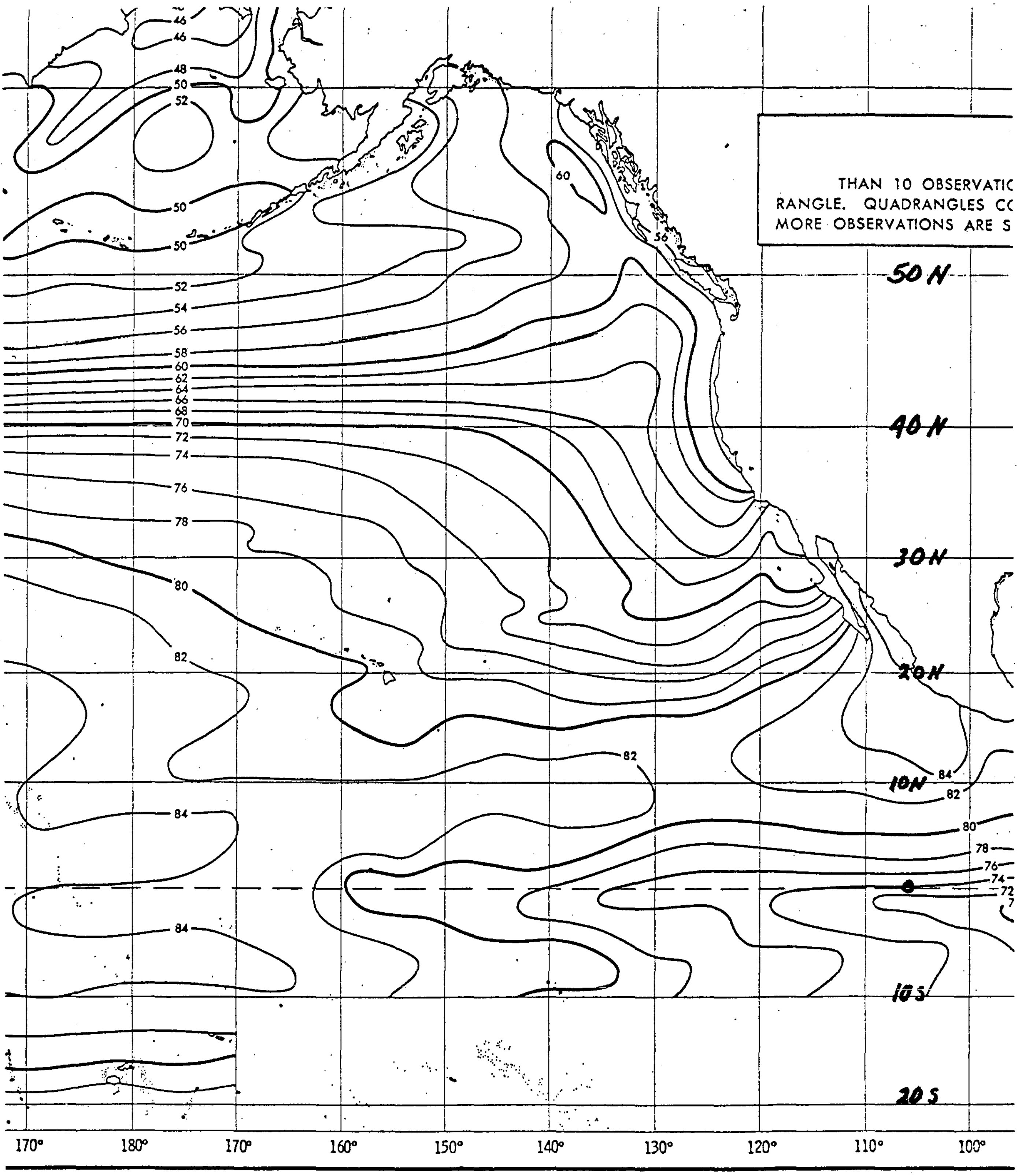


Figure 4. Mean Sea-Surface Temperature (°F.), August.

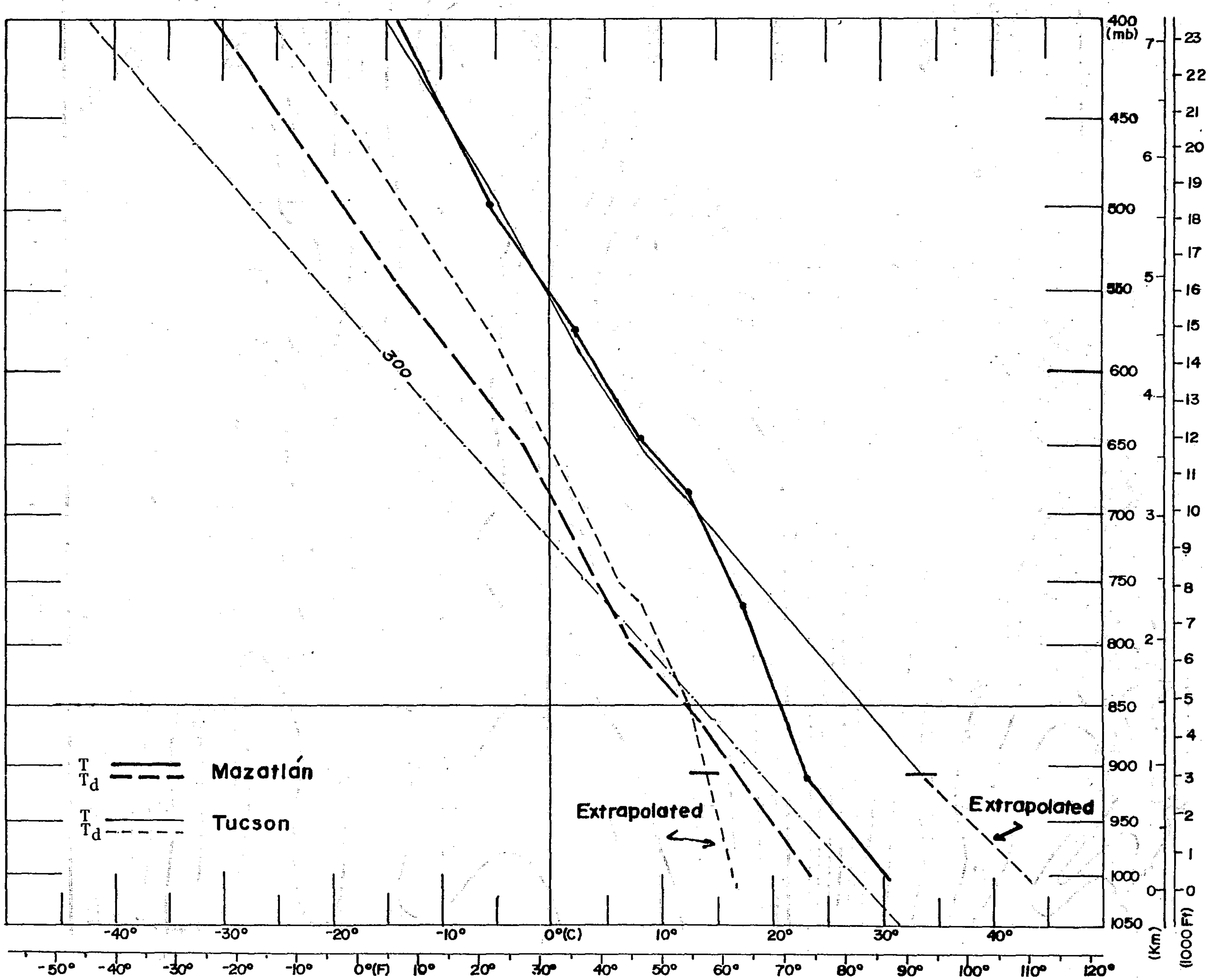


FIGURE 3. AVERAGE AUGUST 1969 DEW POINT AND TEMPERATURE SOUNDINGS FOR MAZATLAN, MEXICO, AND TUCSON, ARIZONA

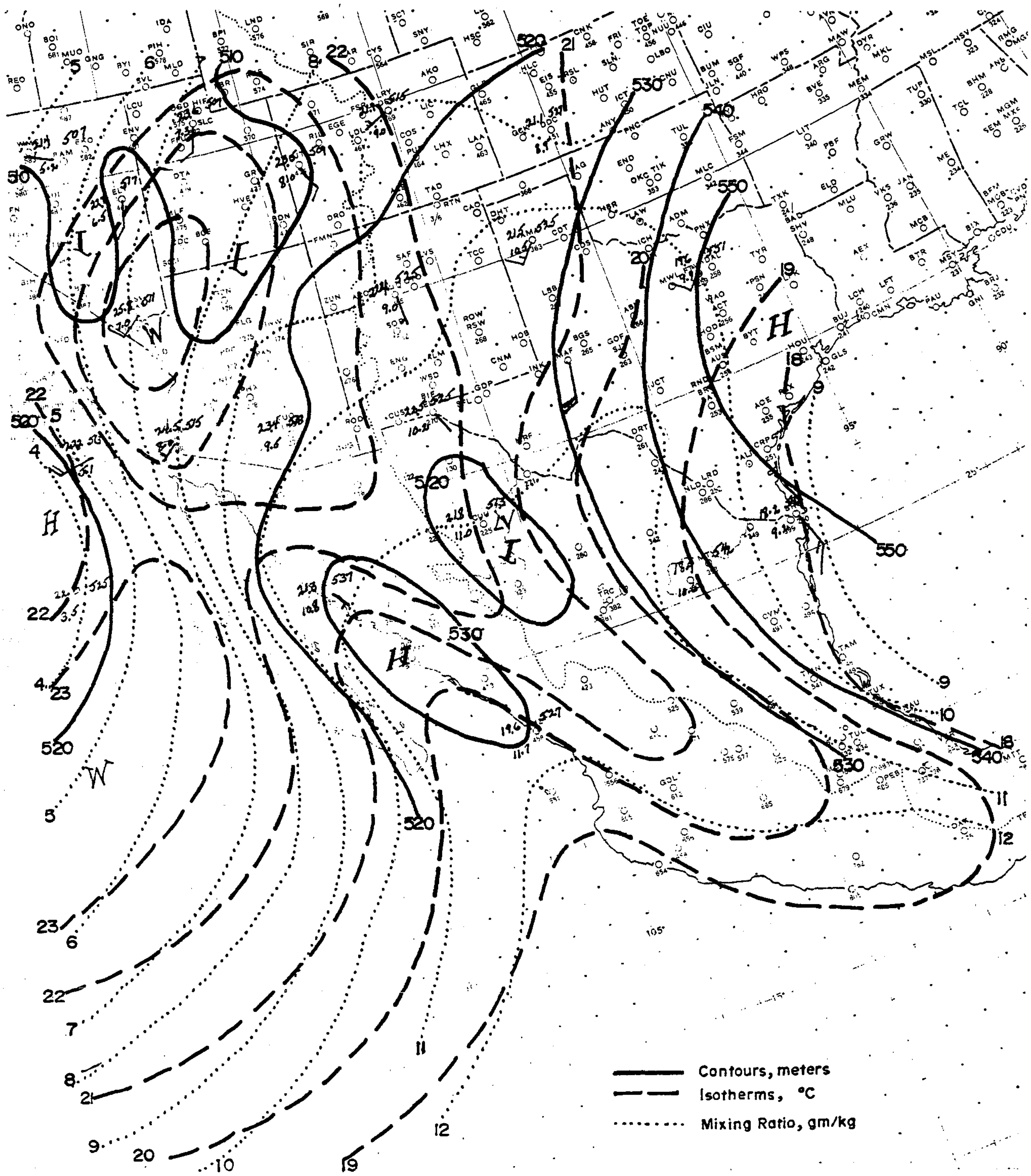


FIGURE 6. MEAN 850-MB CHART OF TEMPERATURE (°C), MIXING RATIO (GM/KG), WIND (MPH), AND HEIGHT (METERS) FOR TEN-YEAR PERIOD (1962-1971), JULY. FULL WIND BARB EQUALS 10 MPH.

W.B. 1

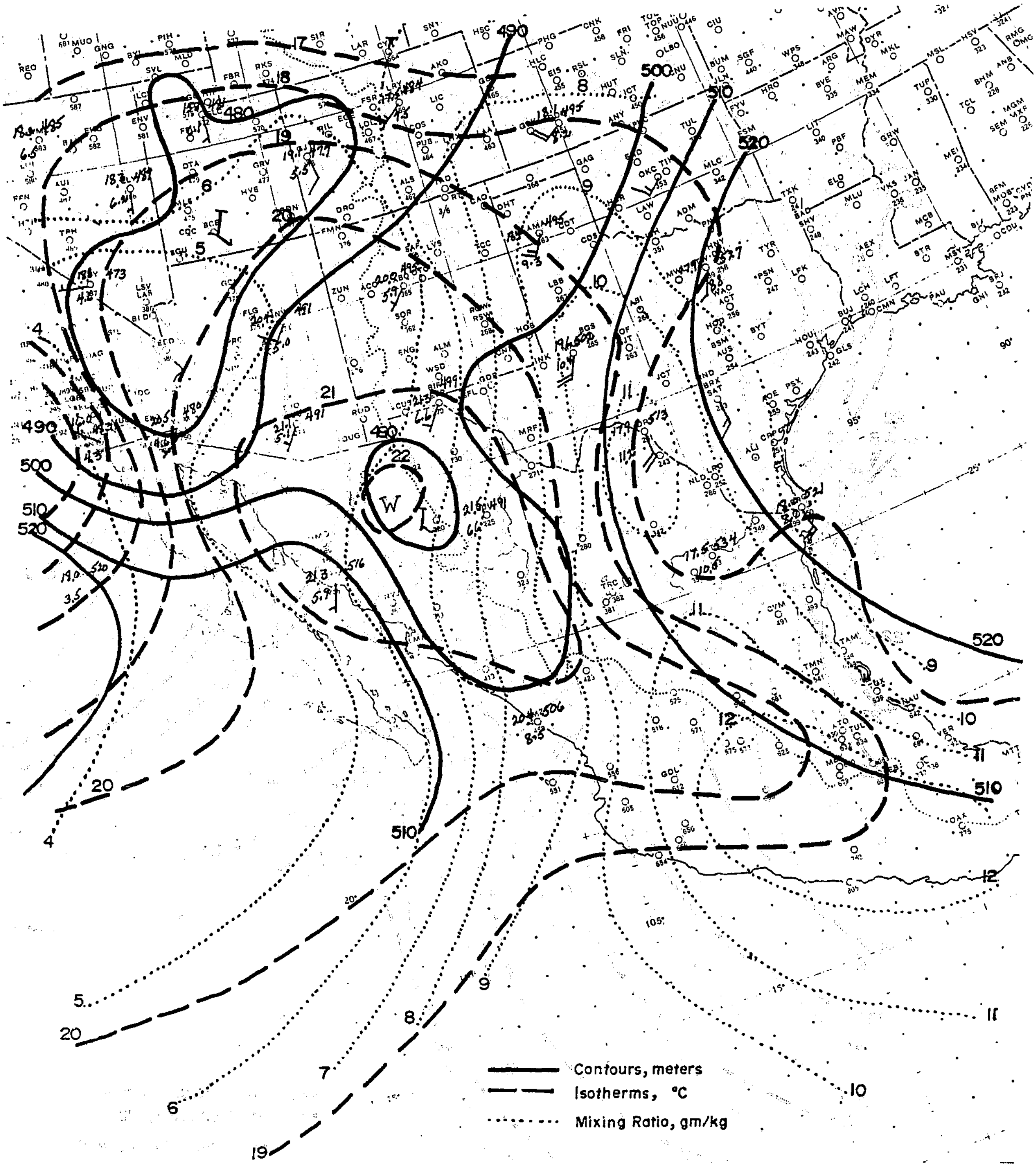


FIGURE 5. MEAN 850-MB CHART OF TEMPERATURE (°C), MIXING RATIO (GM/KG), WIND (MPH), AND HEIGHT (METERS) FOR TEN-YEAR PERIOD (1962-1971), JUNE. FULL WIND BARB EQUALS 10 MPH.

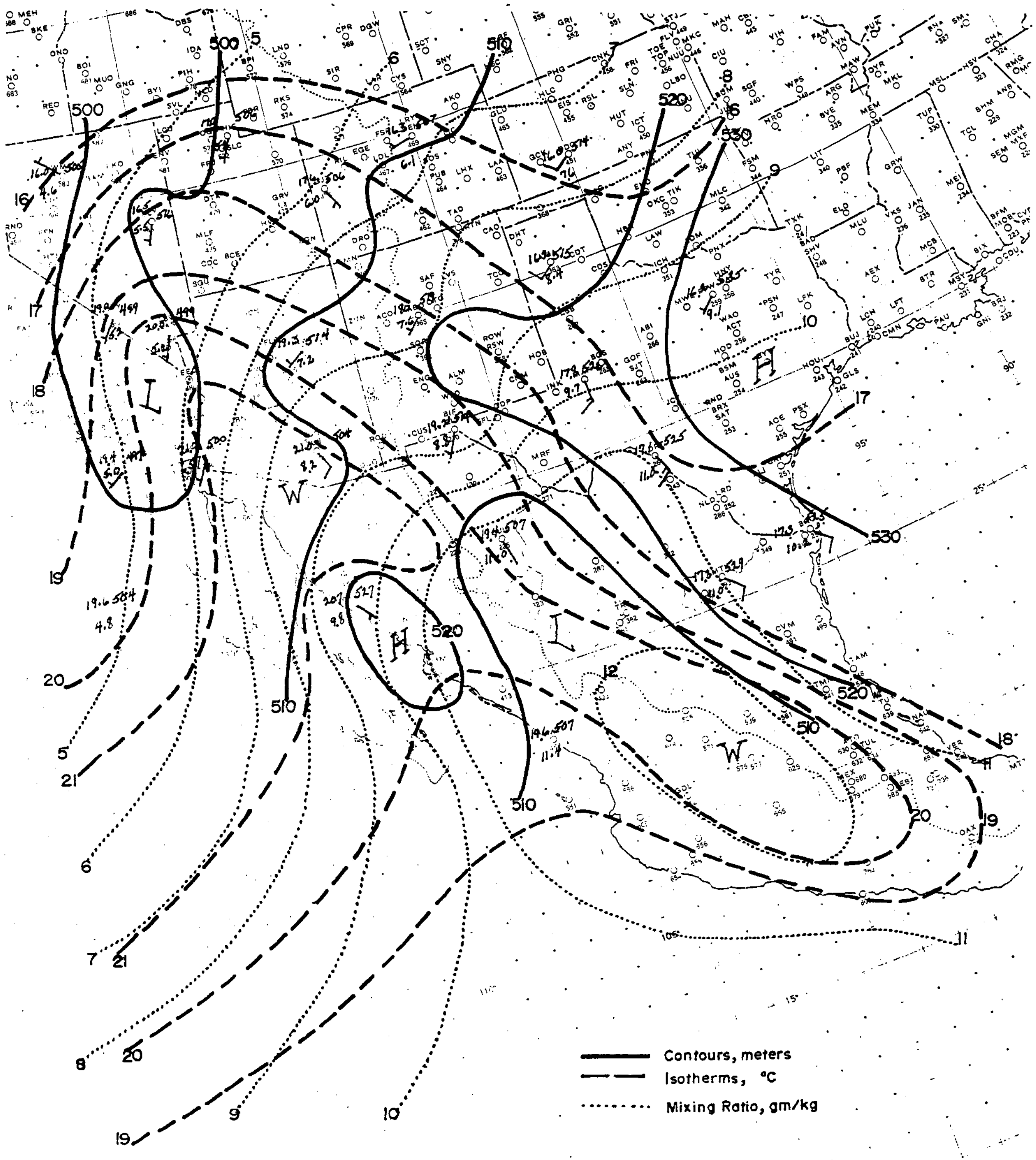


FIGURE 8. MEAN 850-MB CHART OF TEMPERATURE (°C), MIXING RATIO (GM/KG), WIND (MPH), AND HEIGHT (METERS) FOR TEN-YEAR PERIOD (1962-1971), SEPTEMBER. FULL WIND BARB EQUALS 10 MPH.

W.B.

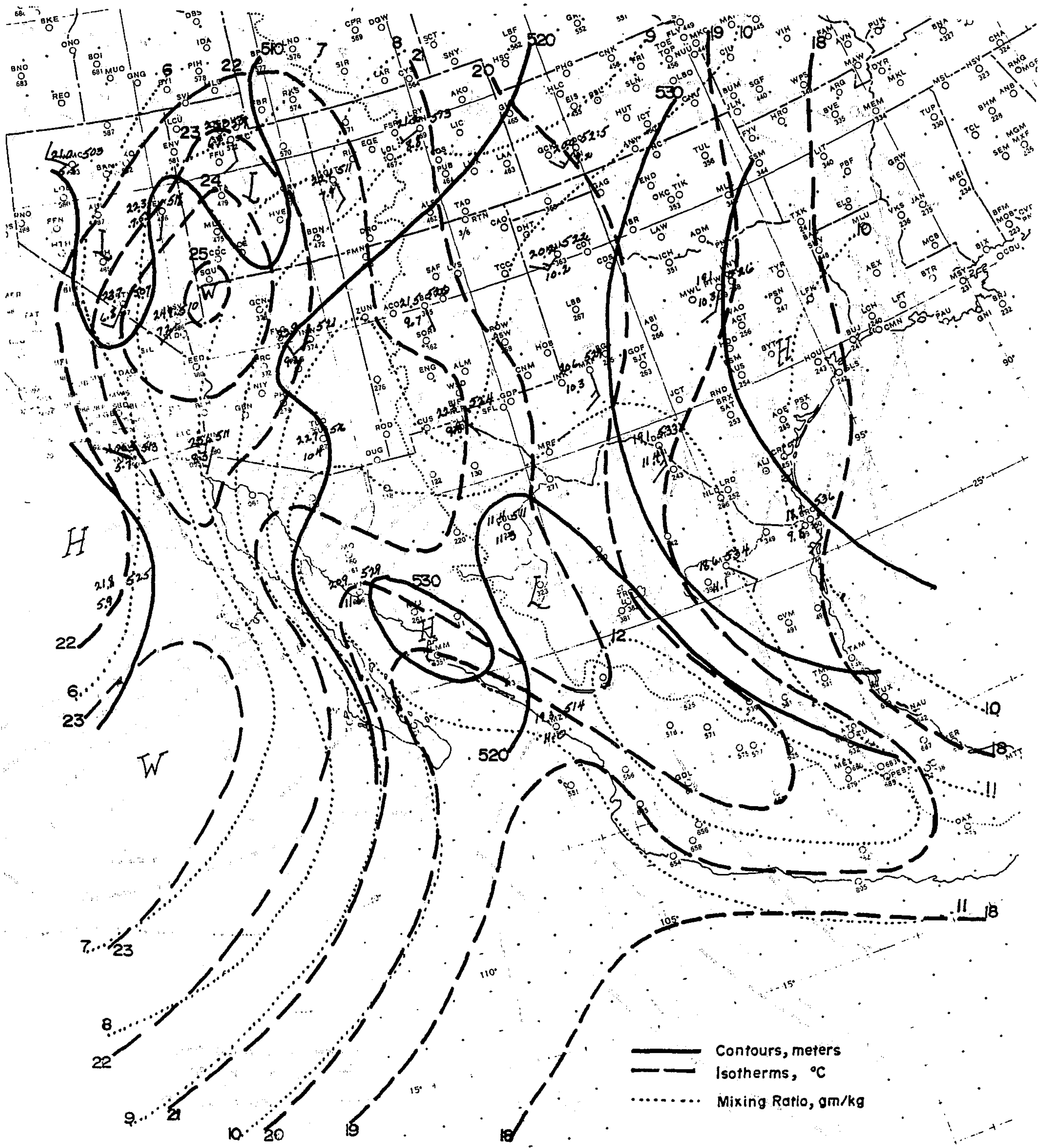


FIGURE 7. MEAN 850-MB CHART OF TEMPERATURE (°C), MIXING RATIO (GM/KG), WIND (MPH), AND HEIGHT (METERS) FOR TEN-YEAR PERIOD (1962-1971), AUGUST. FULL WIND BARB EQUALS 10 MPH.

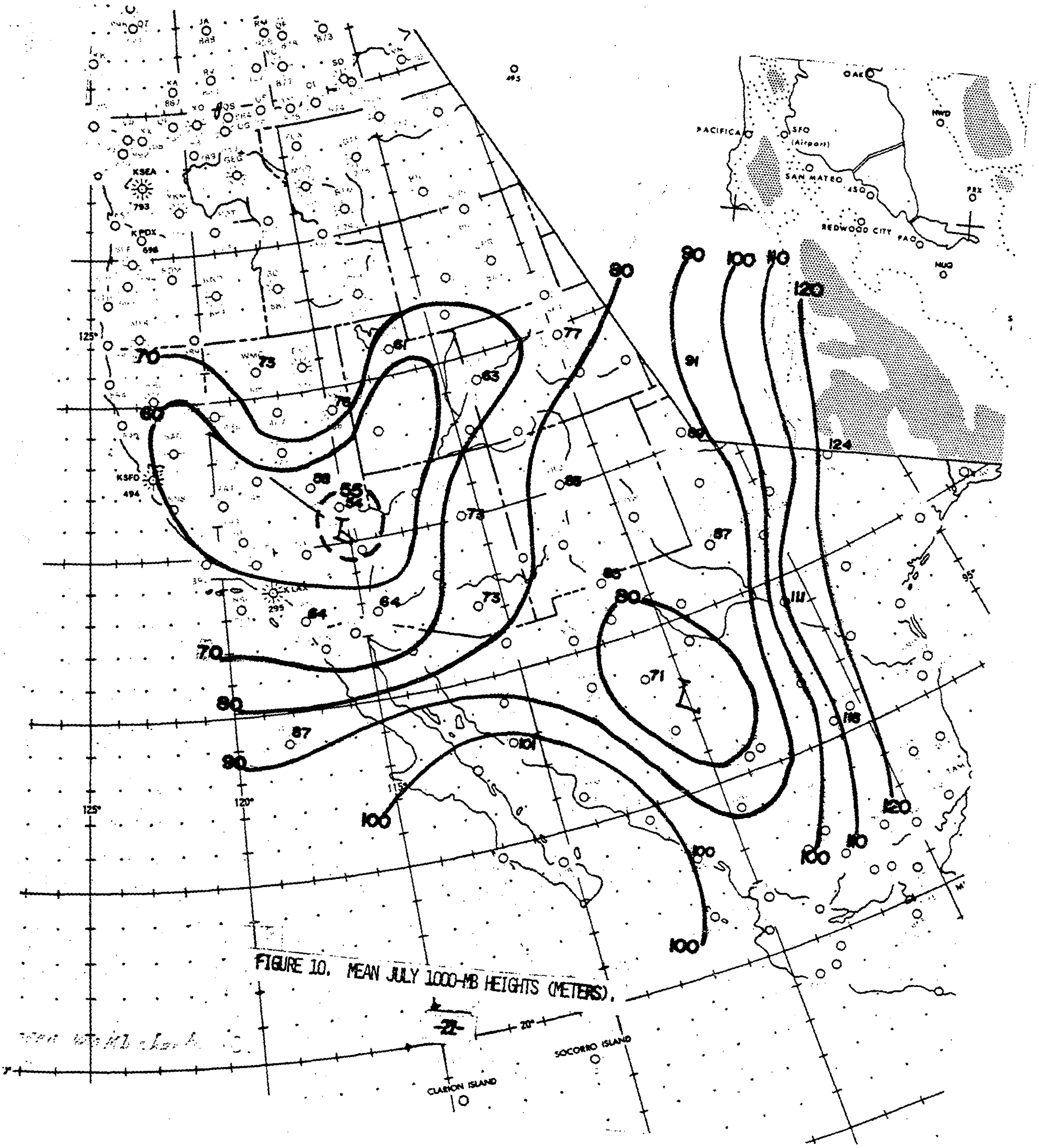


FIGURE 10. MEAN JULY 1000-MB HEIGHTS (METERS).

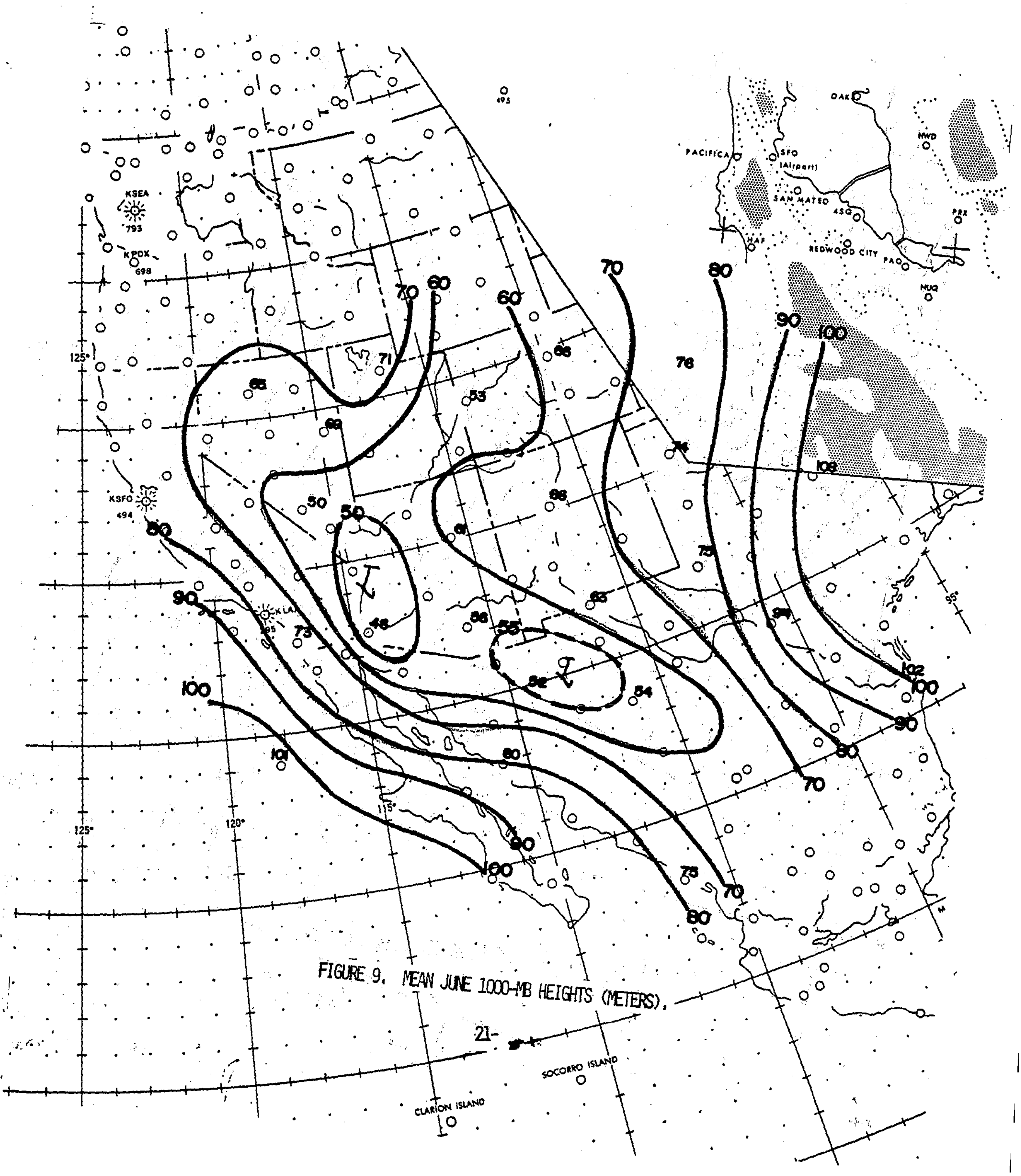


FIGURE 9. MEAN JUNE 1000-MB HEIGHTS (METERS).

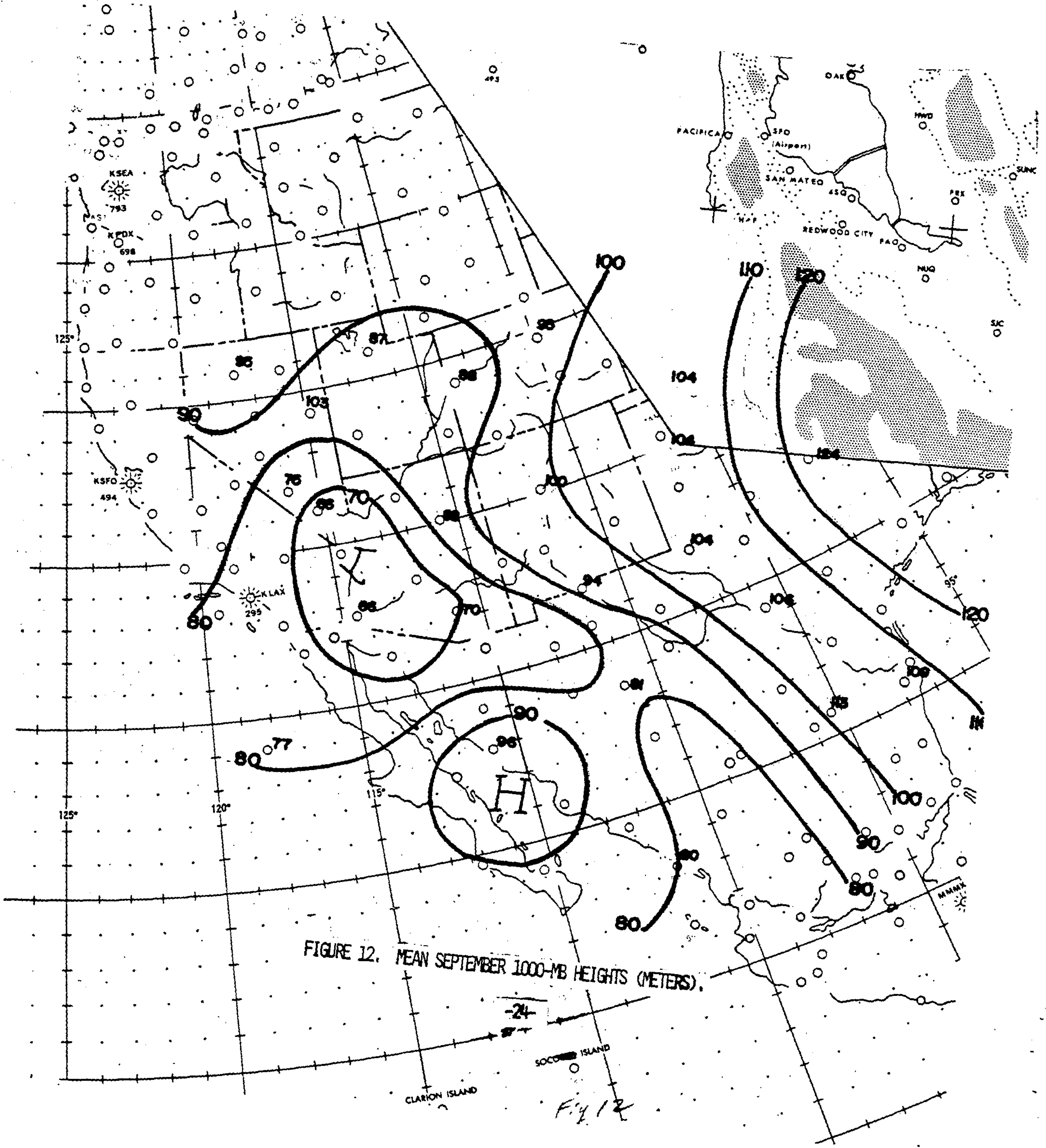


FIGURE 12. MEAN SEPTEMBER 1000-MB HEIGHTS (METERS).

Fig 12

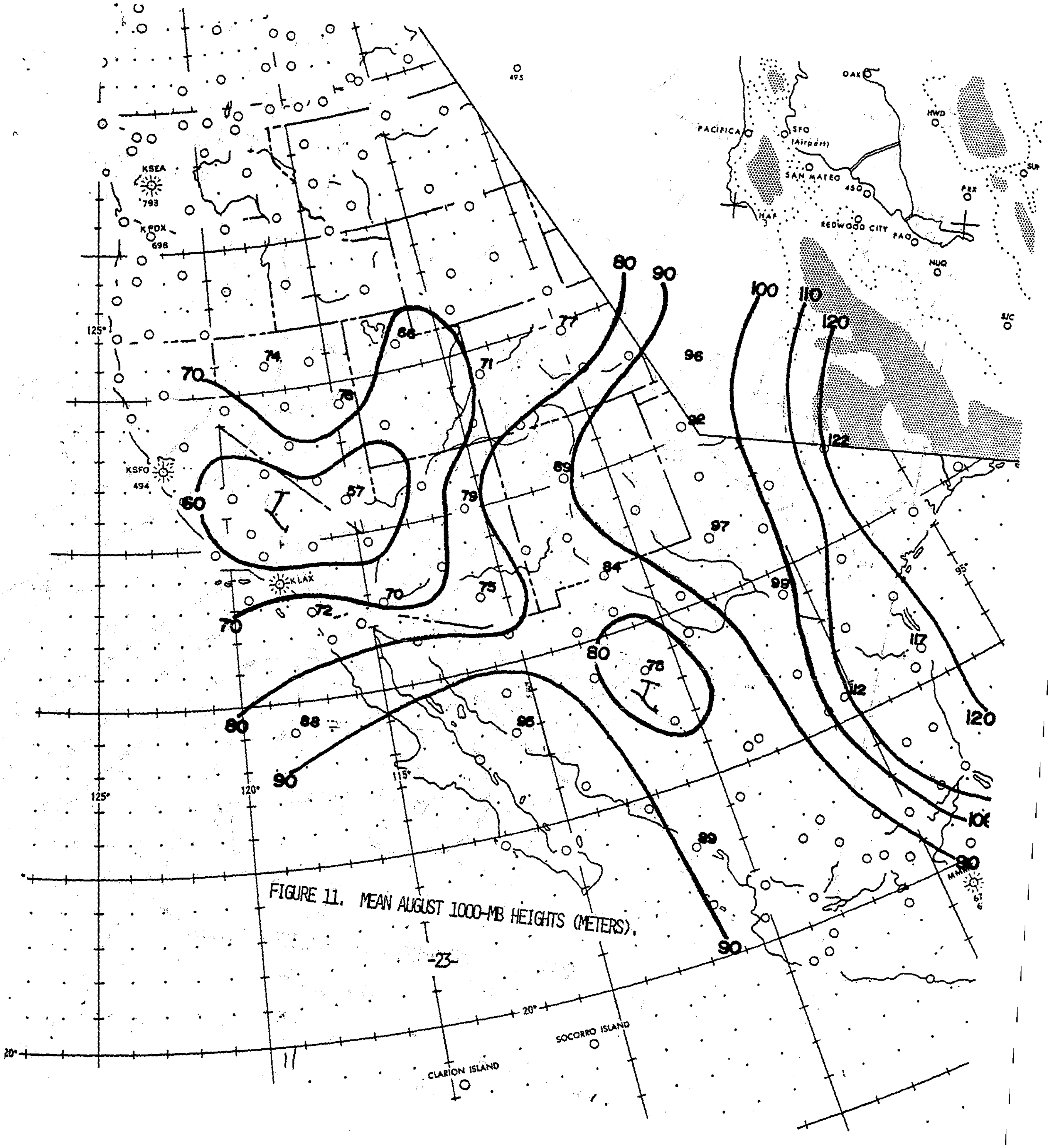


FIGURE 11. MEAN AUGUST 1000-MB HEIGHTS (METERS).

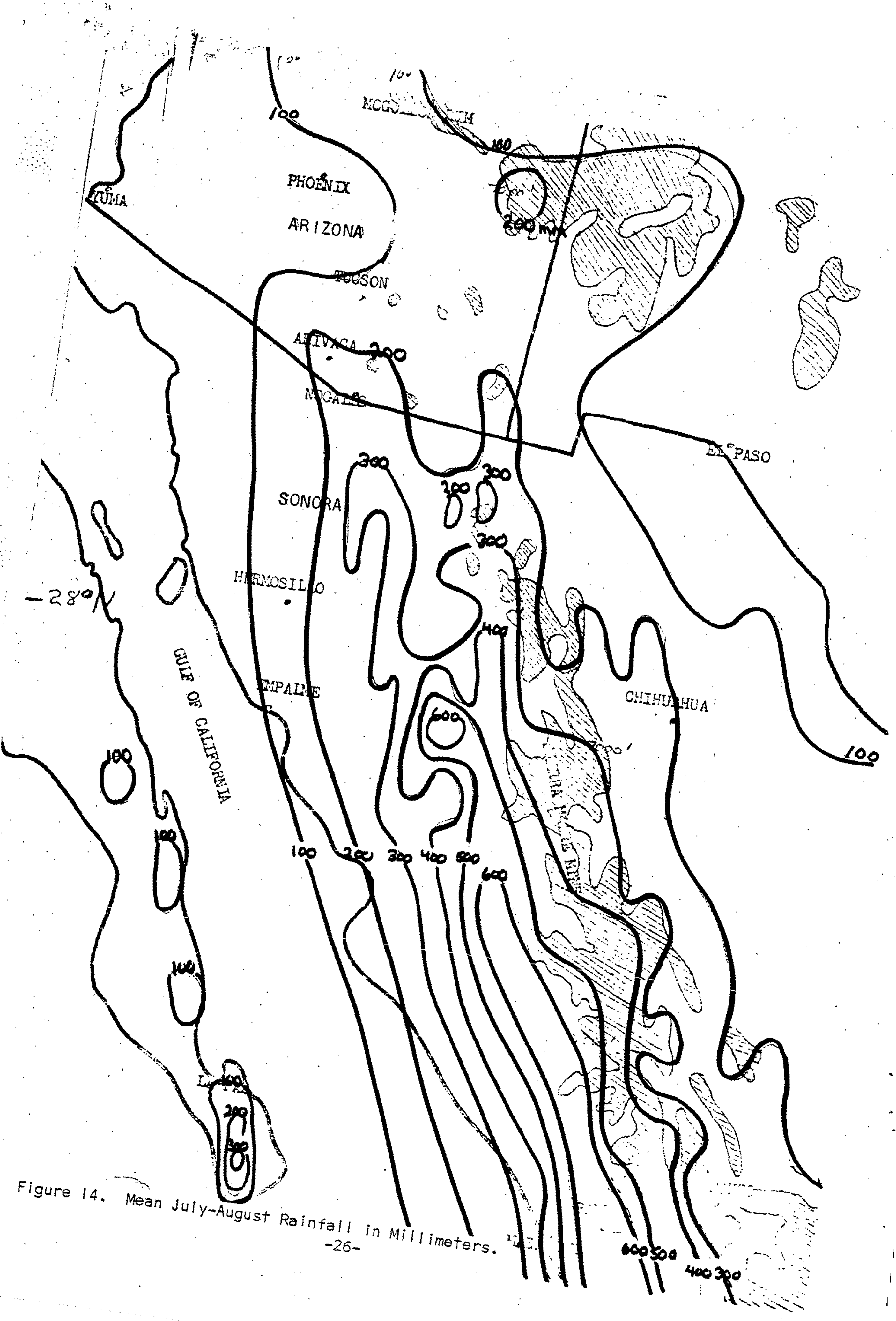


Figure 14. Mean July-August Rainfall in Millimeters.

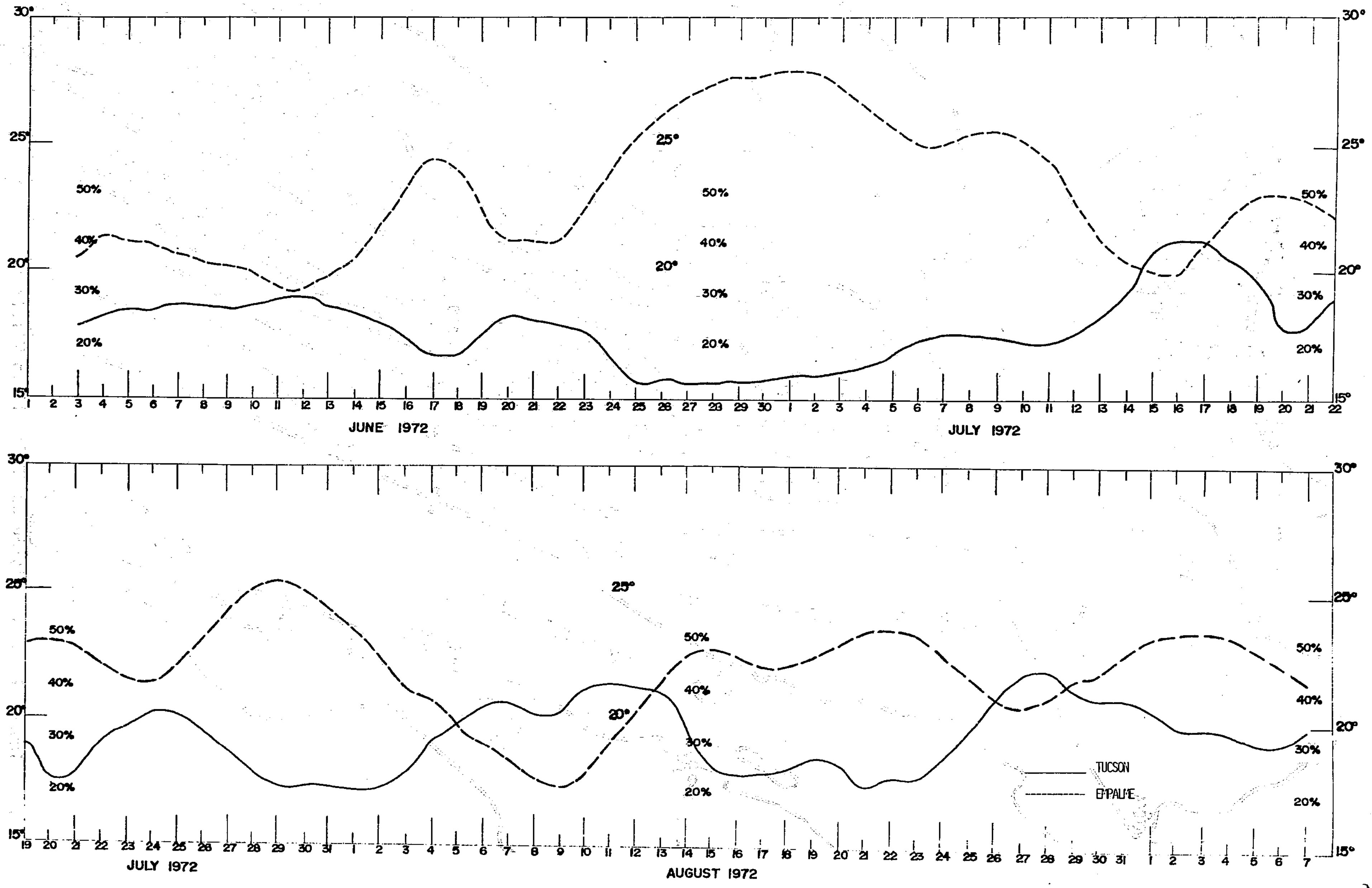


FIGURE 13. FIVE-DAY RUNNING MEANS OF 850-MB RELATIVE HUMIDITY AT TUCSON AND 350-MB TEMPERATURE (°C) AT EMPALME, SEPT. 1972.

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