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A Surge of Maritime Tropical Air--Gulf of California to the Southwestern United States.

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Western Region

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U. S. DEPARTMENT OF COMMERCE
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NATIONAL WEATHER SERVICE

NOAA Technical Memorandum NWSTM WR-88

A SURGE OF MARITIME TROPICAL AIR--GULF OF CALIFORNIA TO THE SOUTHWESTERN UNITED STATES

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WESTERN REGION
TECHNICAL MEMORANDUM NO. 88

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A SURGE OF MARITIME TROPICAL AIR--GULF OF CALIFORNIA TO THE SOUTHWESTERN UNITED STATES

ABSTRACT

This synoptic study, for the period 13 to 16 July 1972, involved the use of surface, radiosonde, and radar observations, as well as satellite pictures. Isentropic analyses indicated that the depth of the moisture with this surge of tropical air was of the order of 8,000 to 12,000 feet. A unique feature of this type of surge is its resemblance to a giant sea-breeze effect, where the main advective forces result from the low-level pressure gradient between the desert thermal low and the relatively higher pressures over the cooler Gulf of California. This effect is emphasized by the lack of upper-air support as shown in the mean vector winds from 10,000 to 20,000 feet for the period of concern. Satellite photographs and film loops give a dramatic picture of the movement of the cloud mass associated with the surge. They also suggest that one of the mechanisms that may be a factor in the development of the cloudy, showery area at the mouth of the Gulf of California is an easterly wave. These extensive and active cloud areas apparently establish the low-level conditions favorable for the northward push of the surge.

I. INTRODUCTION

Each year, a portion of the summer months in Arizona is devoted to a hot and humid weather regime popularly referred to as the Arizona Monsoon. This condition normally commences in early July and persists, with occasional breaks, until the middle part of September (Schmidli 1971 [1]). From a meteorological standpoint, the Arizona Monsoon is characterized by surges of maritime tropical air, which, combined with strong solar insolation, produce uncomfortable heat and humidity (Schmidli 1971 [1]). The number of thunderstorms which occur in the state during this portion of the year show a marked increase over those of the pre-monsoon months of May and June (Green [2]).

The onset of the monsoon is often quite dramatic due to the fact that dry continental air can be suddenly replaced by very moist tropical air. Periods of drying commonly occur during the course of the monsoon season, with surface dew points gradually dropping 10 to 20 degrees to the 40s and 50s. However, strong reinforcing surges of very moist air frequently bring these drying periods to an abrupt halt by raising dew points well into the 60s and 70s once again.

II. MOISTURE SOURCES

For a large number of years, theories have been formulated as to the possible location of the source of the bulk of the low-level tropical moisture for Arizona's thunderstorm season. Over the years, there have been two main schools of thought. The first, and also the longest standing, has been the transport of low-level moisture from the Gulf of Mexico into Arizona by means of the westward expansion of the Bermuda High (Jurwitz 1953 [3]). However, tropical air traveling in the lower levels on southeasterly winds from the Gulf of Mexico would have to be lifted over the 6,000 foot to 12,000 foot Sierra Madre Oriental and Sierra Madre Occidental Ranges on the east and west sides respectively of Mexico, as well as the Continental Divide in the United States. A very steep slope exists between these ranges and their respective coasts. Adiabatic effects during the low-level southeasterly flow in this mountainous terrain must reduce its moisture content by the time it reaches Arizona.

However, this does not totally rule out the possibility of an increase in low-level moisture in Arizona with a dominant easterly or southeasterly flow pattern. Vertical mixing many times may redistribute upper level moisture that enters Arizona with this type of flow pattern. The three primary mechanisms involved in this process would be as follows:

1. Vertical mixing induced by lee side troughing

2. Vertical mixing induced by PVA carried beyond the Continental Divide into Arizona

3. Saturation of the lower levels by precipitation.

With any or all of these mechanisms working at their maximum, a relatively dry sounding at Tucson (TUS), Winslow (INW) and/or Yuma (YUM) can suddenly become moderately wet inside of 12 hours. Quite often, this condition results in the forest-fire breeding high-level thunderstorms of the False Monsoon (Ingram 1972 [4]).

Recent attention has been focused on the second school of thought. As early as 1940, Willet suggested the Gulf of California as a source of low-level moisture (Willet 1940 [5]) and lately Hales (1972 [6]) (1973 [7]) has been instrumental in investigating the major role that this Gulf of California moisture plays on the summer weather regime in Arizona. Hales points out that the Gulf is a natural channel between the tropical Pacific and the southwestern United States (Figure 1). Reitan (1960 [8]) gave some idea of the available moisture in this area by portraying the average precipitable water vapor in centimeters for an eleven-year period for June, July, August and September. In all cases, the precipitable water at Mazatlan (MZT) is higher not only than any other area that surrounds the Gulf of Mexico, but also higher than anywhere in the United States.

Under normal conditions, a thermal balance between the tropical Pacific and the Gulf of California prevents a significant flux of tropical air northward through the Gulf. Close observation of this region, however, has revealed that the thermal equilibrium can be upset by the passage of a tropical disturbance or a large active tropical cloud mass across the lower portion of the Gulf (Hales 1972 [6]). Extensive precipitation associated with the cloud mass cools the air mass below it by means of evaporation. Differential heating within and without the cloud area aids in the constructing of a strong thermal gradient.

In effect, a dome of higher pressure is continuously building under the cloud mass. The result of these effects resembles a massive sea breeze. A surge of cooler and very moist air is generated northward into the deserts of Arizona and portions of southern California. Depending upon the depth of the tropical maritime air associated with the surge, the effects of the influx could be felt well into Arizona's central mountains.

This explains how the drastic change in Arizona's summer air mass can come about. The significance of this condition is far reaching. A complete change from a dry to a moist air mass over all of Arizona can take place in 24 hours or even less.

A dramatic increase in thundershower activity, which is greatly dependent on low-level moisture, can occur with this condition. Reitan (1957 [9]) showed that on an average summer (monsoon season) sounding for Phoenix, about 50 percent of the total precipitable water is below 800 mb, and roughly 86 percent is below 600 mb.

The remainder of this paper will be concerned with a case which exemplifies this Gulf Surge theory. Special emphasis will be placed on the establishment of the independence of the movement of the Gulf Surge with respect to the large-scale upper-level circulation. The surge of July 13th to 16th, 1972, was chosen as a representative example.

III. THE SURGE CATALYST

An important factor yet to be determined in connection with the surge theory as it stands is centered around the atmospheric process leading to the sudden development of the active tropical cloud mass in the vicinity of the mouth of the Gulf of California. Once the cloud mass and its associated precipitation develops, the thermally induced pressure differences drive the surge northward. Certainly, however, the mechanism for the development of this cloud mass must be considered as a very important aspect of the development of the Gulf Surge. Some agent (or agents) likely exist that serve as a catalyst in the surge process by developing the cloud mass.

Several possibilities exist that permit a hypothesis about the formation of the substantial cloud mass over the mouth of the Gulf of California. Tropical storm activity could certainly generate this type of cloudy area, despite the fact that the storm itself may remain some distance from the Gulf. In this particular study, however, no evidence of a tropical storm is apparent. The generation of vorticity in lee-side troughing by easterly winds over the Sierra Madre Occidentals could also be effective in producing this type of cloudy area.

This mechanism does not appear to be operative in this study as it is usually of a quasi-stationary nature. Migratory, cyclonic disturbances in the easterly flow, i.e., easterly waves, should be capable of producing substantial cloudy areas that are visualized in connection with the moisture surge. Riehl (1954 [10]) showed that convergence and positive vorticity advection exists to the east of an easterly wave. He also stated that the depth of the moist layer in this region attains a maximum where the convergence is most intense. It was also explained that wide zones of subsidence occur in this region between the associated areas of upward vertical motion in the individual cloud masses. As a result, in the region east of the westward moving trough line, there will be areas of concentrated convective activity associated with one or more areas of convergence within the larger convergence field. Cloudy, showery areas in these convergence zones can be as much as 300 to 450 miles east of the trough line itself. The most useful methods for discovering whether this type of mechanizm existed in this particular study would be to examine the mean vector flow (10,000 to 20,000 feet) as well as the satellite photographs for the area.

IV. FLOW PATTERN

Figures 2a-2d portray the mean vector flow (10,000 to 20,000 feet) at 1200Z each day for July 13 to July 16. These winds were computed graphically by resolving the vector at each level available into its U and V components. These components were averaged in the vertical and combined to give the average wind vector from 10,000 to 20,000 feet.

The anticyclonic flow pattern generally from the north, northeast or east over Arizona during this period is clearly evident. At 1200Z July 13 (Figure 2a), the mean vector flow suggested a weak cyclonic circulation in the easterlies--the axis of which extended roughly from 27N 107W to 26N 111W. By 1200Z July 14 (Figure 2b), this circulation became more northeast-southwest oriented and also intensified, as evidenced by the wind shifts and the increase in the wind speeds at Mazatlan (MZT) and Guaymas (GYM). The wind shifts at Guadeloupe Island (IGP), and GYM, and the more easterly wind at San Diego (SAN) at 1200Z July 15 (Figure 2c), suggests a west or west-northwestward elongation of the apparent circulation. This pattern is also supported by the slackening of the wind speed at MZT as well as the shifting of that wind to the west. Figure 2d for 1200Z July 16 portrayed a decrease and a shift in the winds at MZT and GYM, while neglible changes were reported at IGP. This indicates that the circulation in question was now likely stationary and deteriorating. In retrospect, the behavior and movement of this feature would suggest the apparent existence of an amorphous upper-air disturbance in the broad easterly flow over this region.

V. SATELLITE OBSERVATIONS

Surface data and satellite pictures on July 13th aroused suspicion that conditions were becoming favorable for a northward surge of moisture from the Gulf of California. The ESSA 8 picture for the morning of July 13 (Figure 3), showed a large cloudy area over the mouth of the Gulf of California. Surface observations indicated that this cloud mass contained substantial shower activity. The ESSA 9 picture on the afternoon of the 13th (Figure 4), indicated a northward drift of this cloudy, showery area.

Data from all sources for the following few days seemed to confirm that this cloud mass was effective in promoting a northward surge of deep tropical maritime moisture into the southwestern United States. During the course of this portion of the study, however, consideration was given to the possible mechanism or mechanisms that produce this initial large cloudy area. In order to pursue this idea further, satellite photographs from July 10 to July 12 were investigated.

On the 10th of July, extensive cumulonimbus activity was evident on the west coast of Mexico from 20N to 28N. The Gulf of California and Baja California were cloud-free. On July 11, the thunderstorm activity on the west coast of Mexico, which was so prominent the previous day, subsided. However, strong cumulonimbus activity was now taking place over the mountains of Baja from 25N to 27N. This activity intensified and expanded substantially, as viewed on the ESSA 9 picture for July 12, to cover Baja California from 25 1/2N to 28 1/2N. This shift of thunderstorm activity from the west coast of Mexico on the 10th, to the mountains of Baja California on the 11th and 12th, again hints at the action of an amorphous upper-air disturbance in the broad easterly flow over the region. Figure 4 for July 13 shows the existence of what appears to be a circulation, possibly associated with this upper-air disturbance centered near 27N 113W. The ATS-1 film loop for this day definitely showed a cyclonic spiraling of this cloud mass.

The ESSA 9 (Figure 5) photograph for July 14 showed a very distinct boundary separating relatively clear skies from the very heavy cloudiness to the south. This boundary extends from 25N 113W to 30N 105W and then gradually curves southeastward to 28N 98W. The fact that this boundary extends so far east is likely due to the interaction of the tropical moisture from the Gulf of California, and also moisture from the Gulf of Mexico*, with the drier continental flow illustrated previously on the mean flow chart for July 14 (Figure 2b). Although the quality of the picture is somewhat poor, the circulation feature noted the previous day can still be found near 27N and 111 to 114W. The ATS-1 film loop for this day again showed this feature to have the characteristics of a closed circulation. Up to this point, only a slight westward movement of this feature was observed visually. The ESSA 9 picture (Figure 5) also revealed areas of cumulus and altocumulus bounded roughly by 30N, 119W to 32N 110W, southeastward to 29N 107W and southwestward to 28N 111W. The significance of these clouds is that they suggest that low-level moisture values were fairly large beyond the visible cloud boundary. In addition, at this time of year, late morning is a rather unusual time of day for cumulus development over any of the lower areas of southern California, southern Arizona, or Baja California. This suggests that not only was the air moist, but that it was also rather unstable.

The ESSA 9 picture for July 15 (Figure 6) shows a cloudy area over the Gulf of California between 27N and 29N. This cloud area appears to have moved slowly northward, while the circulation feature has now accelerated to the west to be centered over the water near 26N to 27N and 115W. The cloudy area in the Gulf of California appears to have retained its sharp boundary to some degree in this picture. This cloud area appears to be associated with the upper-air circulation feature in the easterlies, whereas radar and surface observations indicate that the leading edge of the low-level moisture surge had already entered the southwestern United States well before this picture was photographed.

Further evidence of the early arrival of this moisture surge is given by a comparison of Figures 5 and 6. By the 15th (Figure 6), a significant increase in thundershower activity was indicated over south eastern Arizona and southwestern New Mexico (clearly west of the Continental Divide). Surface observations (Section IX) support the fact that the arc of thunderstorms located on Figure 6 from just south of Deming (DMN), New Mexico, to west of Show Low (E03), Arizona, was in actuality just behind the leading edge of this surge of tropical

*Hales (1973 [7]) pointed out that as moisture from the Gulf of California impinges on the western slopes of the Sierra Madre Occidental, it is heated rapidly and mixed. This lifting of the moist air increases the moisture values in the middle levels of the troposphere. This same process occurs on the east slopes of the Sierra Madre Oriental Range in eastern Mexico with regard to moisture from the Gulf of Mexico.

maritime air from the Gulf of California. Radar charts and surface observations also indicated that during the ten hours following the ESSA 9 pass in Figure 6, these rather strong thunderstorms gradually progressed towards the west-southwest. After the 0845Z July 16, 1972, Salt Lake City radar summary, the thunderstorms gradually diminished in coverage and intensity before dissipating in southeastern Arizona by the 1545Z July 16 radar summary.

South of 27N on Figure 6, the Gulf of California now appeared to be virtually cloud free. This was most likely a result of low-level cooling and large-scale stabilization of the air mass in that area. The west Mexico coastline from 22N to 27N was also cloud free at this time, indicating that convective activity had now assumed a more orographic and normal regime once again.

Cumulus clouds were very early to develop in south-central and southeastern Arizona on July 16. However, the lack of significant vertical development indicated that thunderstorm activity was being temporarily suppressed. By and large, this was due to the relative stability that resulted from the thunderstorm activity of the previous night and its associated low-level cooling in that area. This was sufficient to prevent renewed thunderstorm activity in this section until early that evening. The ESSA 9 pass (Figure 7) clearly points out, however, that a major change had occurred in southern Nevada and over the mountains of northern Arizona during the last 24 hours. Several quite large thunderstorms had developed in these areas. The orientation of these cells was that of an arc, stretching from east of Safford, northward to the north-central border of Arizona, to southwest Utah, and west to the Sierra Nevada mountains in California. The activity over the Sierra was greatly increased from the previous day in both intensity and coverage. Figure 8 is the radar summary for 2145Z July 16. This displays the same orientation that was discussed on the ESSA 9 pass. All efforts to locate any organized circulation feature on the ESSA 9 picture for the 16th and several other satellite photographs for the same day ended in failure. It must be assumed that the upper level support for this feature had weakened considerably.

The ESSA 9 photograph for July 17th (Figure 9), suggests that some destabilization of the atmosphere was occurring along western Mexico and Baja California south of 27N on July 17, as evidenced by the observed increase in cloudiness from the previous 24 hours. Again, no evidence of any organized circulation was visible. The substantial decrease in thunderstorm activity from the extensive activity of the previous afternoon in Arizona, southern Utah, southern Nevada, and the Sierra's in California, suggests that stabilization was now taking place in those areas. This picture definitely projects the image that equilibrium had once again been established between the southwestern United States and the Gulf of California.

VI. SURFACE SYNOPTIC PATTERNS

General low pressure covered the southwestern two-thirds of Arizona on July 13 (Figure 10a) as far south as GYM. The isallobaric analysis for the 24-hour period ending at 2100Z July 13 (Figure 10b) indicated that the center of the pressure falls was located in an area bounded roughly by Needles (EED), Blythe (BLH), Thermal (TRM), Daggett (DAG), China Lake Naval Air Facility (NID), and Las Vegas (LAS). By July 14 (Figures 11a and 11b), this low-pressure area had expanded and pressures had fallen over southeastern California, southern Nevada, all of Arizona, and into western New Mexico. However, pressures generally south of Hermosillo (HMO) showed some increase from values of 24 hours previous. By 1800Z July 15 (Figure 12a), a change in the pressure pattern was definitely taking place. High pressure to the south was building northward into southern and western Arizona. Figure 12b shows that the area of greatest 24-hour pressure falls now was located in an area bounded by Tonopah (TPH), Yucca Flat (UCC), NIC, Bakersfield (BFL) and Bishop (BIH). A second area was located in northeastern Arizona and southern Utah*. Figure 12b also shows that the southern and western portions of Arizona were definitely coming under the influence of a new pressure regime, while that regime had not as yet reached into the northern and central mountains of the state. The 1010-mb isobars that are present in the state on Figure 12a are due solely to poor pressure reduction over the higher terrain of Arizona. Figure 13a for 1800Z on July 16 indicates clearly that a dome of high pressure had engulfed most of Arizona. Equilibrium was now returning to the lower Gulf of California region where the surge had long since passed. The isallobaric analysis for the 24-hour period ending 2100Z July 16 (Figure 13b) shows that pressures were rising over nearly all of Arizona. The area of greatest pressure falls was now mostly in central Nevada and roughly extended from TPH to just west of Cedar City (CDC), Utah. Another area of pressure falls was also located in northwestern New Mexico. This analysis also shows that the influences from the surge had reached as far west as Fresno (FAT), California, and at least as far east as Deming (DMN), New Mexico. Surge effects in extreme northern and northeastern Arizona were evident, but generally weak at this time.

VII. TEMPERATURE AND MOISTURE DISTRIBUTIONS

Figures 14 to 20 are vertical cross sections from MZT to GYM to TUS and to INW at 12-hour intervals for the period 1200Z July 13 to 1200Z July 16. A steady progression of the moist layer was evident and was depicted as a region of higher mixing ratio and lower dry bulb potential temperature.

*The continued deepening of the thermal low can be attributed to the fact that these areas were still in the dry continental flow and were continuing to warm at the surface (Ingram 1972 [4]).

Figure 21 shows the moisture distribution at INW throughout the period from a different viewpoint. A moisture increase occurred at INW between 0000Z July 15 and 0000Z July 16. However, the lack of any strong low-level concentration of moisture, coupled with the fact that the moisture increase that did occur was fairly uniform at both low and higher levels, rules out the possibility of this increase being associated with a Gulf Surge. However, the packing of high values of mixing ratio shown between 0000Z July 16 and 0000Z July 17 in the lower levels suggest that this concentration of low-level moisture is connected with the Gulf Surge. This argument is supported by the low-level winds from the west and southwest to near the top of the concentrated moisture. It is also significant that the winds above this level were predominantly north of west.

Figure 22 shows the thermal gradients that existed from 0000Z July 13 to 0000Z July 16 between MZT, GYM, TUS and INW. The progression of the surge can also be followed on this graph, by noting the changes in the 800-mb temperatures at each of the stations. The most obvious indications of the surge passage at a station are falling 800-mb temperatures during the last 24 hours at that station, while a station downstream from it was showing an increase in 800-mb temperatures.

Figures 23 and 24 are maps of initial and final values of wet bulb potential temperatures at 850 mb for the period 0000Z July 13 to 0000Z July 17. Maps of wet bulb potential temperature were drawn at 12-hour intervals (not shown) in order to establish continuity. In each case, a steady expansion towards the north and northwest of higher values of wet bulb potential temperature was noted. This can easily be seen by noting the appearance of the 23 degree C wet bulb potential temperature line by 0000Z July 17. It is interesting to note, also, the remnants of a previous surge on Figure 23. This is evidenced by rather high values of wet bulb potential temperature (21 degrees C) over large portions of Arizona and Nevada. However, by this time, most of this moist air was rather shallow in depth.

VIII. SURFACE OBSERVATIONS - SURGE CHARACTERISTICS

The most useful means for detecting the passage of the Gulf Surge is to examine the surface observations in the area concerned. In order to utilize the surface observations properly as an aid to locating the change in air mass, an awareness of the various characteristics of the surge is necessary. Hales (1972 [6]) pointed out that in most cases, the invading cool tropical air mass can be detected at the surface fairly easily by keeping in mind the following characteristics:

1. The intensity of the surge is strongest just above the surface and gradually decreases with height.

2. Cooling always accompanies the surge into Arizona, but decreases in magnitude and sharpness of change as the surge spreads through the state.

3. Common changes in surface weather at lower elevations with the passage of the surge are:

   a. Drop in temperatures

   b. Rise in dew point

   c. Windshift to some southerly component

   d. Increase in wind speed

   e. Rise in sea-level pressure

   f. Lowering visibilities (due to hazy nature of tropical maritime air and blowing dust and sand)

   g. Increasing middle and/or low clouds.

4. Usually the only way to detect surge-associated changes in surface weather in the higher elevations of northern Arizona is by 24-hour comparisons of temperature, dew point and pressure.

5. Relative humidity substantially increases at the surface, especially in the deserts.

6. A deep surge (8,000 to 12,000 feet) will likely sharply increase thunderstorms over all the state, with possible heavy activity.

7. Within 24 hours after the onset of the surge into Arizona, the desert heat low will fill, as thermal equilibrium once again becomes established between the southwestern United States and the Gulf of California.

IX. SURFACE OBSERVATIONS - YUMA, ARIZONA

A detailed inspection of hourly reports and 24-hour changes in these hourly reports was used in order to determine approximate times of the surge passage at various stations in the Gulf of California and southwestern United States regions. Experience has shown that Yuma (YUM) is a key station in detecting surges entering Arizona from the Gulf of California. Since these surges are often easily detected by examining the surface observations at YUM, this station is discussed in detail as a representative example. Similar careful analyses were made for all regularly reporting stations in the above mentioned area. The results of these analyses are shown in Figure 27.

Yuma is the first regularly reporting station in Arizona where the arid continental air mass is suddenly replaced by a tropical maritime air mass. A jump in surface dew point in excess of 10 degrees C in less than a half an hour at YUM is not uncommon with a surge passage. The particular surge examined in this paper was not accompanied by as sharp a rise in dew point, since fairly moist but very shallow low-level air was already present over the area. Except in particularly strong surges, sharp boundaries at the leading edge of the surge are gradually diminished after the surge passes YUM. Friction, topography and air-mass modification within the surge all tend to reduce the inherent organized structure of a surge. The forward thrust of the system is also diminished since the original mass of the surge must be spread over a progressively larger area once the surge passes YUM (Hales 1972 [6]). A classic characteristic with respect to the movement of a Gulf Surge is that it will try to follow the path of least resistance as it travels (Hales 1972 [6]). This allows the Gulf Surge to move the fastest and remain intact the longest as it moves up the Colorado River Valley along the western border of Arizona.

Temporary changes in temperature, dew point, cloud conditions, wind, visibility and sea-level pressure similar to those which accompany a Gulf Surge, are not uncommon several hours ahead of the actual passage of the surge. These transient changes in the above parameters are often misleading with respect to the actual arrival of the main surge at a station. The transient nature of these effects suggest that they are related to critical temperature and/or pressure values which are achieved sometime before the main surge arrives. These critical temperatures and/or pressures in the deserts probably induce a significant, but temporary, onshore flow from the Gulf of California. While this frequently heralds the approach of the main surge its temporary effects on dew point, wind, etc., can be easily mistaken for the main surge.

The surface observations for YUM on July 15 (Figure 25), portray one such influx between 0800Z and 0900Z. The arrival of the influx was highlighted by a very dramatic blast of wind, dust and sand from the southeast. The curious slackening of the surface wind, as noted on the 1100Z and 1200Z observations was the reflection of the atmosphere adjusting to the critical values referred to above. However, the basic structure of the overall atmosphere in the area was still in a general state of imbalance. This imbalance would eventually cease with the passage of the main surge.

The passage of the main surge at YUM between 1400Z and 1500Z on July 15 was again rather dramatic (Figure 25). The special observation taken at 1429Z reflects the force with which the new air mass can strike. The arrival of the Gulf Surge was signaled by a blast of wind from the southeast, along with reduced visibilities in blowing dust and sand. The development of the lower clouds was a result of the strong area of lift at the leading edge of the onrushing tropical maritime air mass. The sea-level pressure rose 1.3 mb between 1400Z and 1500Z at YUM, while Blythe to the north only rose .7 of a mb during the same period.

A most useful method of illustrating the effects of the surge at YUM again would be to examine 24-hour comparisons of the hourly observations (Figures 25 and 26). Sea-level pressure at Yuma for each hour inclusive between 0000Z and 0700Z July 15th were lower than the corresponding values 24 hours previous. Due to the effects of the influx between 0800Z and 0900Z, the sea-level pressures were higher for the hours 0800Z to 1300Z on July 15th than the values at the same hours the previous day.

Pressures normally rise at this time of year between 1200Z and 1400Z in Arizona. During this period Yuma's sea-level pressure was in the process of recovering from the pressure increase associated with the earlier influx. As a result, the sea-level pressure at Yuma only increased 1.2 of a mb between 1200Z and 1400Z on July 15, while on the 14th, an increase of 2.3 mb was noted during the same period. After 1400Z, under average conditions in Arizona at this time of year, pressure begins to level off and then fall during the remainder of the afternoon due to diurnal effects. It is interesting to note that this was the order of events on July 14. However, the passage of the main surge at YUM on the 15th caused a pressure jump of 1.3 mb between 1400Z and 1500Z, while on the previous day, no change was noted for the same period. The sea-level pressure at YUM on the 15th did not even begin to exhibit the normal diurnal tendency until 2000Z, whereas on the 14th, the diurnal falls began at 1800Z. Also, the sea-level pressure of 1006.1 at 1400Z on the 15th (a half hour before surge passage), was exactly the same value as 24 hours previous. However, with the passage of the Gulf Surge, sea-level pressures for the remainder of the 15th as well as all of the 16th, never fell below the corresponding values of 24 hours previous. Values of sea-level pressure for the remainder of the 15th were roughly 2 to 3 mb higher than values at the same hour on the 14th. In general, sea-level pressures on the 16th were 3 to 3.5 mb higher than at the same hours on the 15th with a peak difference of 4.3 mb being recorded.

As a final illustration, Figure 27 portrays the progress of the Gulf Surge at three-hour intervals. Points of particular interest and importance on this figure are as follows. The surge accelerated once it passed GYM. The surge traveled faster over the Gulf of California than the adjacent coasts as well as faster along the Colorado River Valley on the western border of Arizona than the adjacent land areas. This is in support of the concept that the surge will follow the path of least resistance. The indicated winds on the map are the observed surface winds at the time the surge passed the station. As would be expected, the majority of the wind directions were towards the direction of movement of the surge. Note, also, the stalling effects that mountains have on the surge movement. This is particularly noticeable in and near the area of the San Bernardino Mountains of California and the Mogollon Rim of Arizona. This effect was also noted as the surge impinged upon the higher terrain of southern Nevada and northern Arizona. Another point that is most interesting is the fact that once the surge was out of the guiding effects of the mountains of Baja and western Mexico, it tended to spread out considerably.

X. CONCLUSION

Intrusions of tropical maritime moisture from the Gulf of California do enter Arizona during the summer monsoon months. The northward movement of this moisture has been found not to be necessarily related to the large-scale upper-level circulation over the area. In this particular study, the mean flow (10,000 to 20,000 feet) over the area concerned was predominately from the north, northeast and east. However, a strong surge of tropical maritime moisture did in fact move into Arizona from the south during this period. This occurrence is possible due to the fact that the low-level circulation (below 10,000 feet) throughout the Gulf of California region, as well as Arizona is primarily controlled by thermal influences during the summer monsoon season. Hence, the pressure gradient, which is directly related to the temperature gradient, in the lower troposphere is the dominant mechanism by which the tropical maritime moisture surges northward into Arizona. The Gulf Surge is, therefore, generally independent of the large-scale upper-level circulation, except insofar as impulses in the upper-air circulation are the causitive factors in creating the cloud masses over the mouth of the Gulf of California which initiates the pressure imbalance between the mouth of the Gulf and the hot interior desert areas of southwest United States and northwest Mexico.

Additional detailed studies of these Gulf of California surges of tropical maritime moisture, as well as the obscure mechanism that apparently serves as the catalyst agent leading to these surges, are greatly needed in order to develop reliable forecasting rules and techniques concerning these major moisture influxes.

XI. ACKNOWLEDGMENTS

Special thanks are in order for Mr. Nick Ropar, Principal Assistant/Forecaster, Phoenix, Arizona, and Mr. Woodrow Dickey, Scientific Services Division, Western Region Headquarters, for offering their useful comments and criticisms during the preparation of this paper and to Mrs. Norma Milinski, Secretary, for her most conscientious typing contribution.

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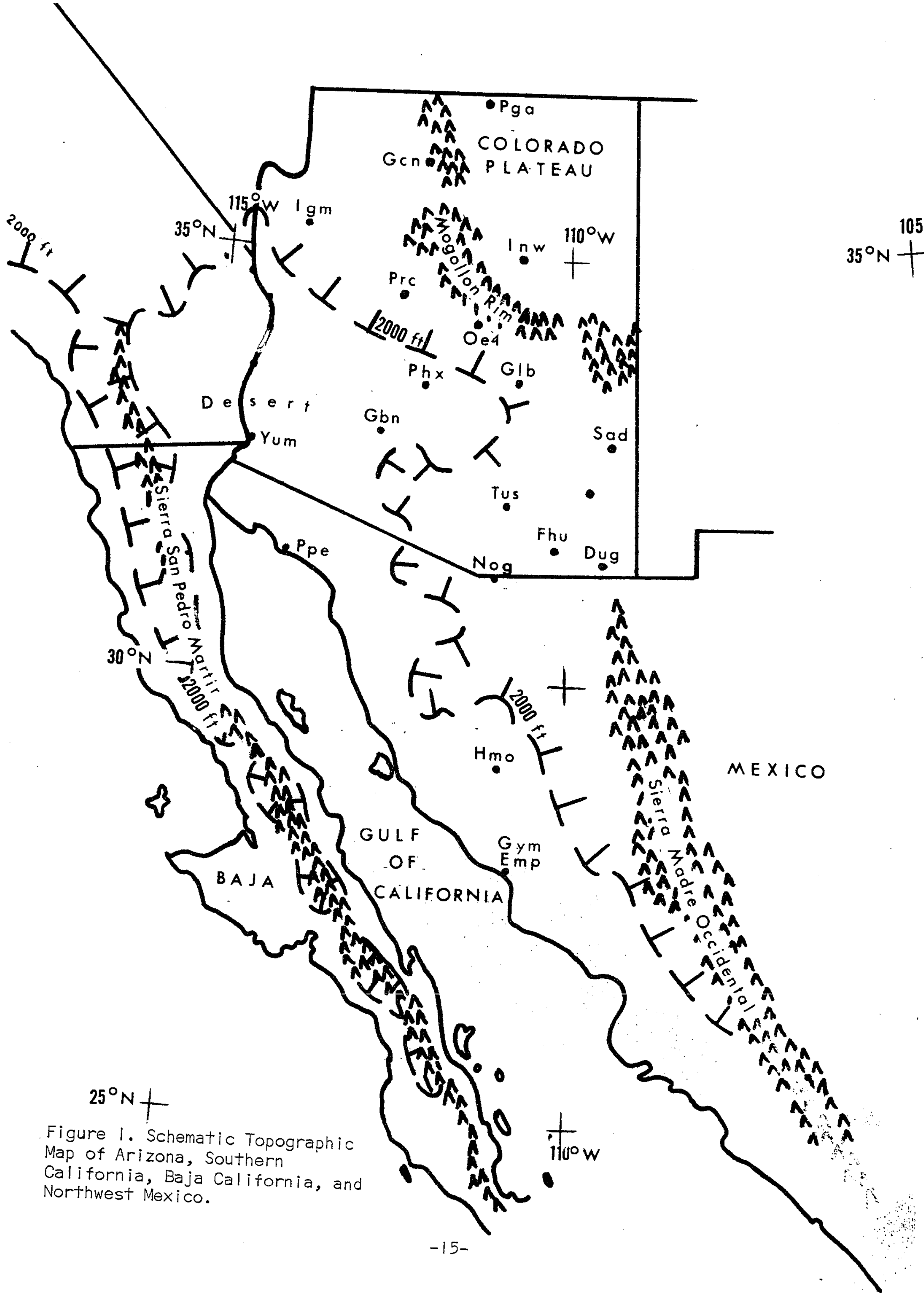

Figure 1. Schematic Topographic Map of Arizona, Southern California, Baja California, and Northwest Mexico.

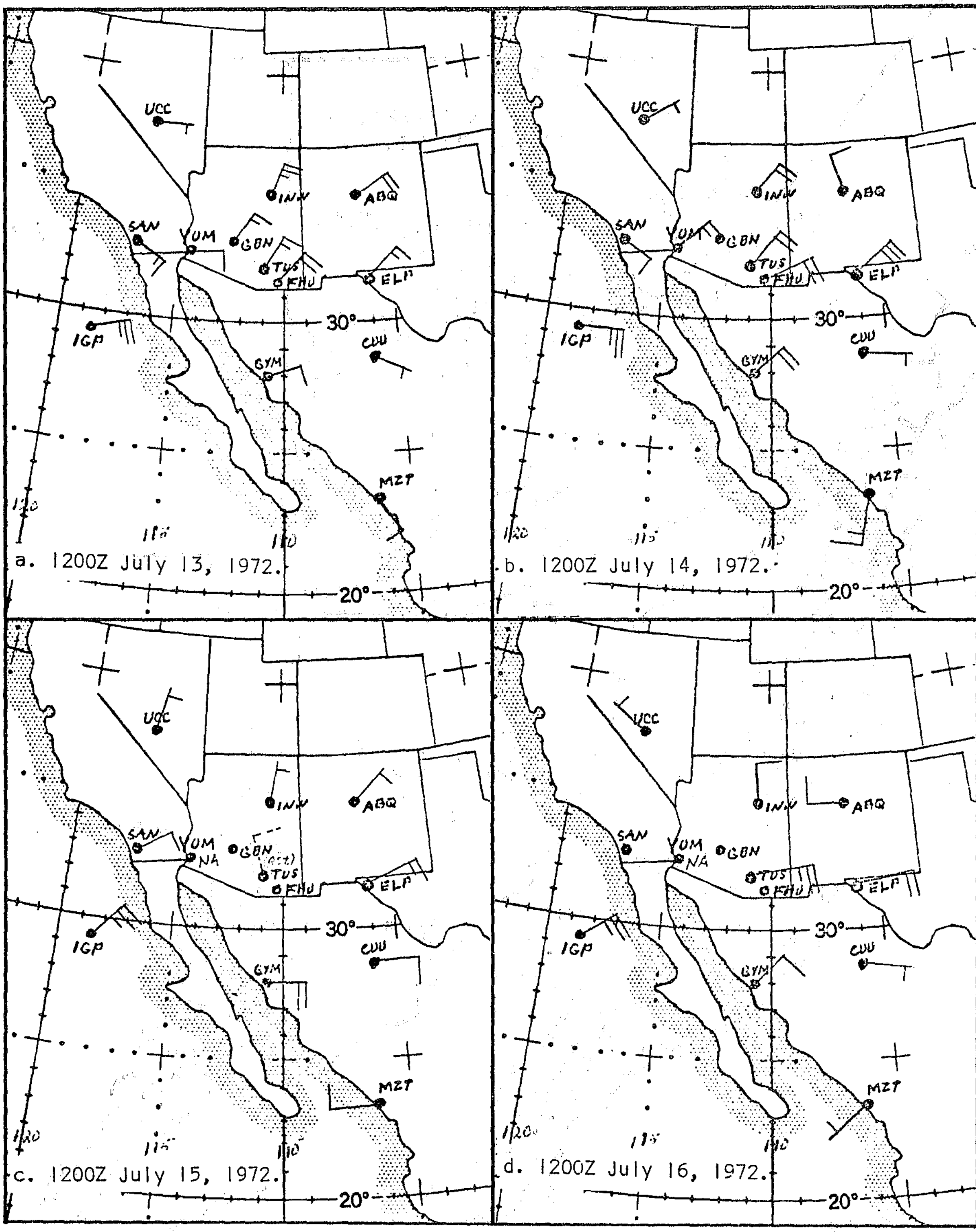

Figure 2. Mean Vector Winds 10,000 to 20,000 Feet.

Figure 3. ESSA 8 Satellite Picture for July 13, 1972, Approximately 1800 GMT (0900 MST).

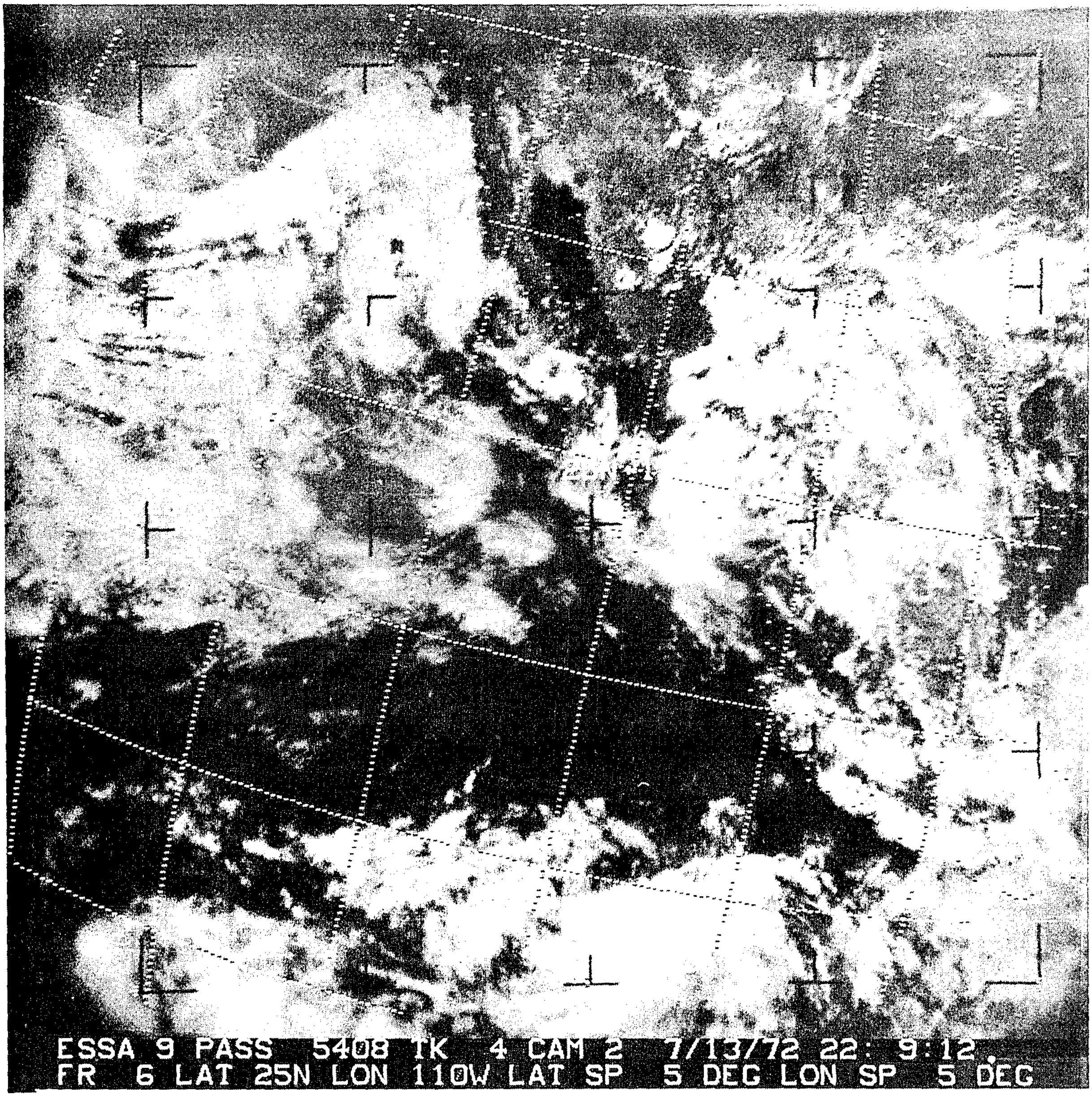

Figure 4. ESSA 9 Satellite Picture, July 13, 1972, 2209 GMT (1509 MST).

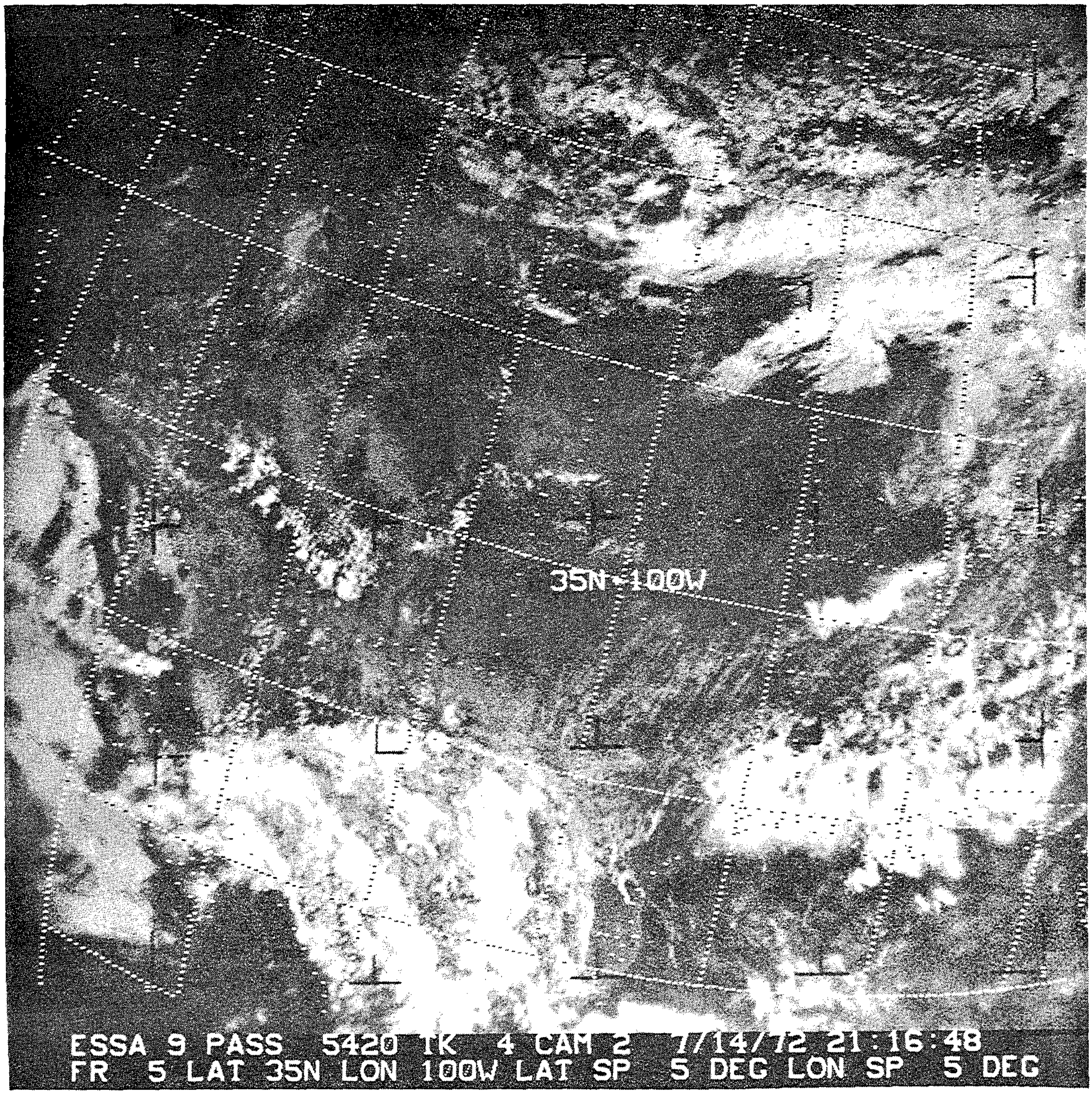

Figure 5. ESSA 9 Satellite Picture for July 14, 1972, 2117 GMT (1417 MST).

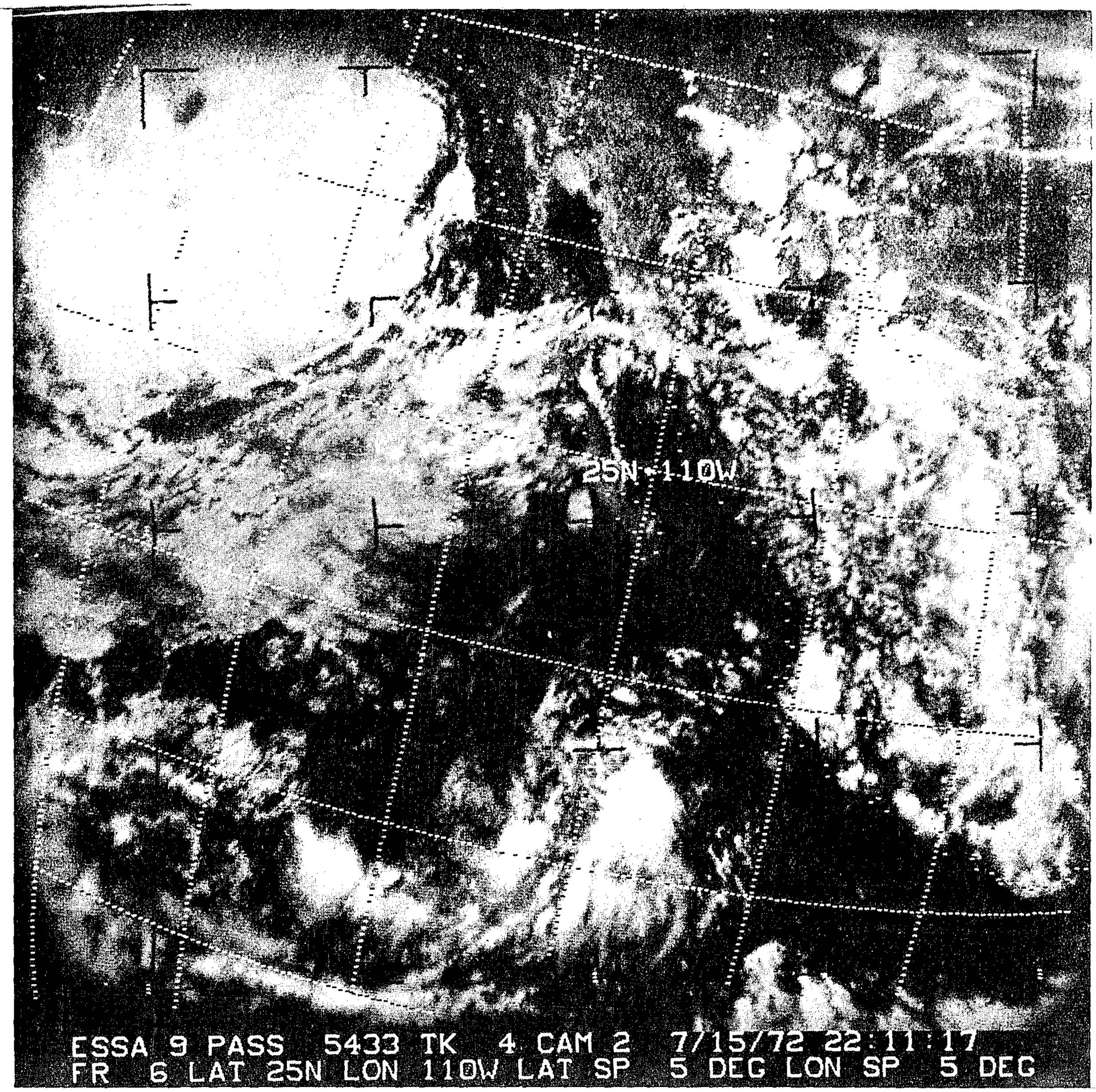

Figure 6. ESSA 9 Satellite Picture for July 15, 1972, 2211 GMT (1511 MST).

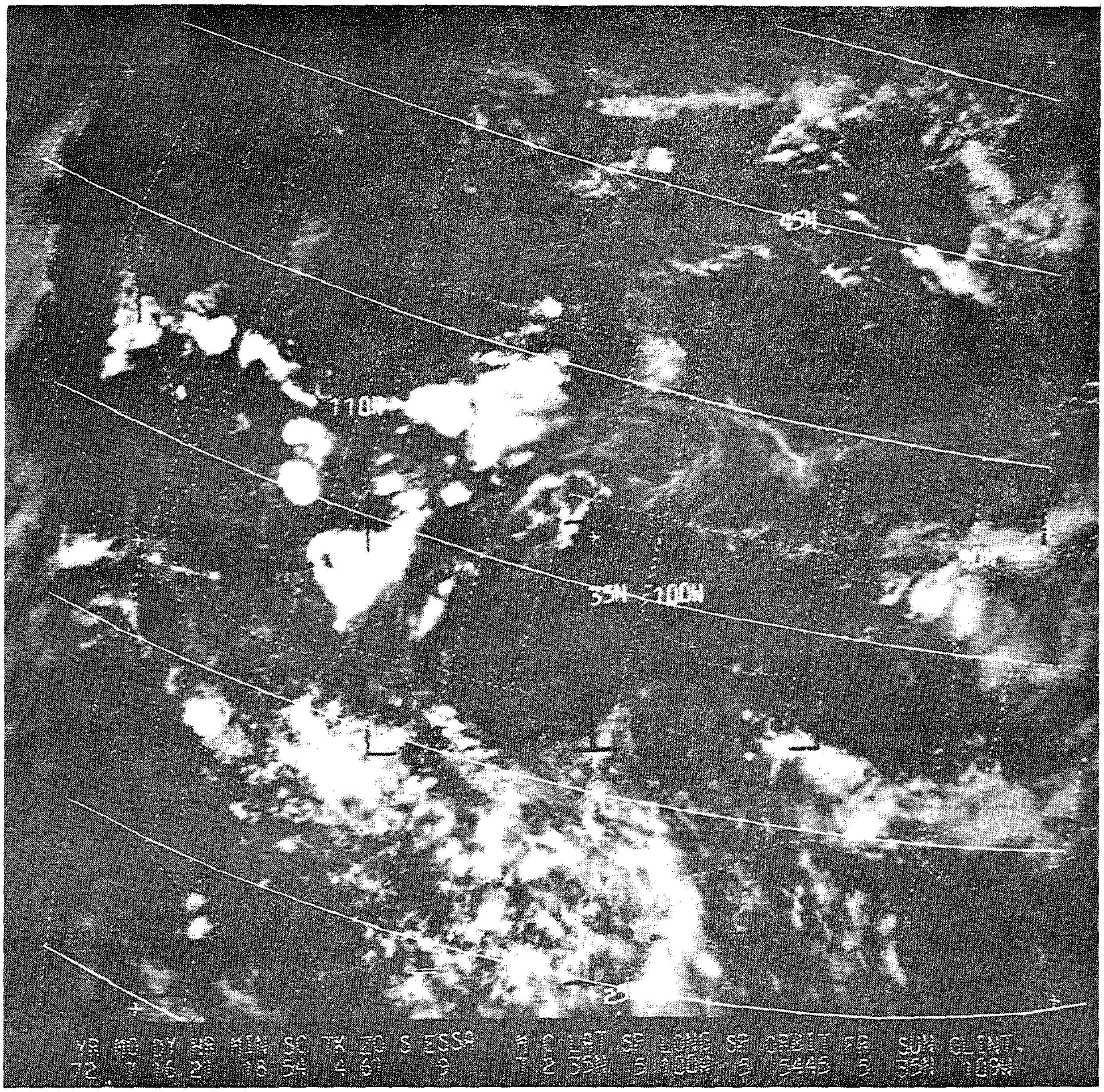

Figure 7. ESSA 9 Satellite Picture for July 16, 1972, 2119 GMT (1419 MST).

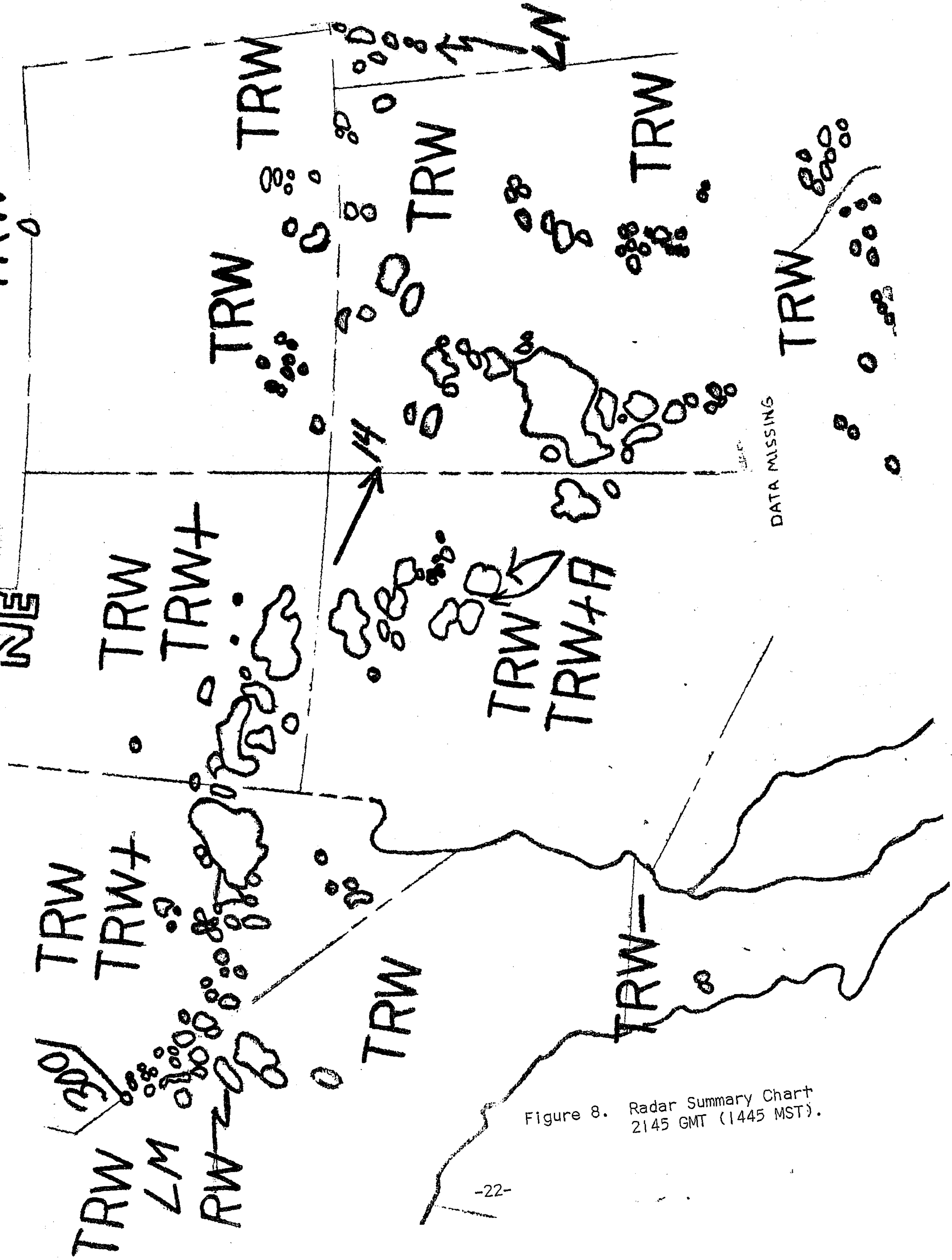

Figure 8. Radar Summary Chart
2145 GMT (1445 MST).

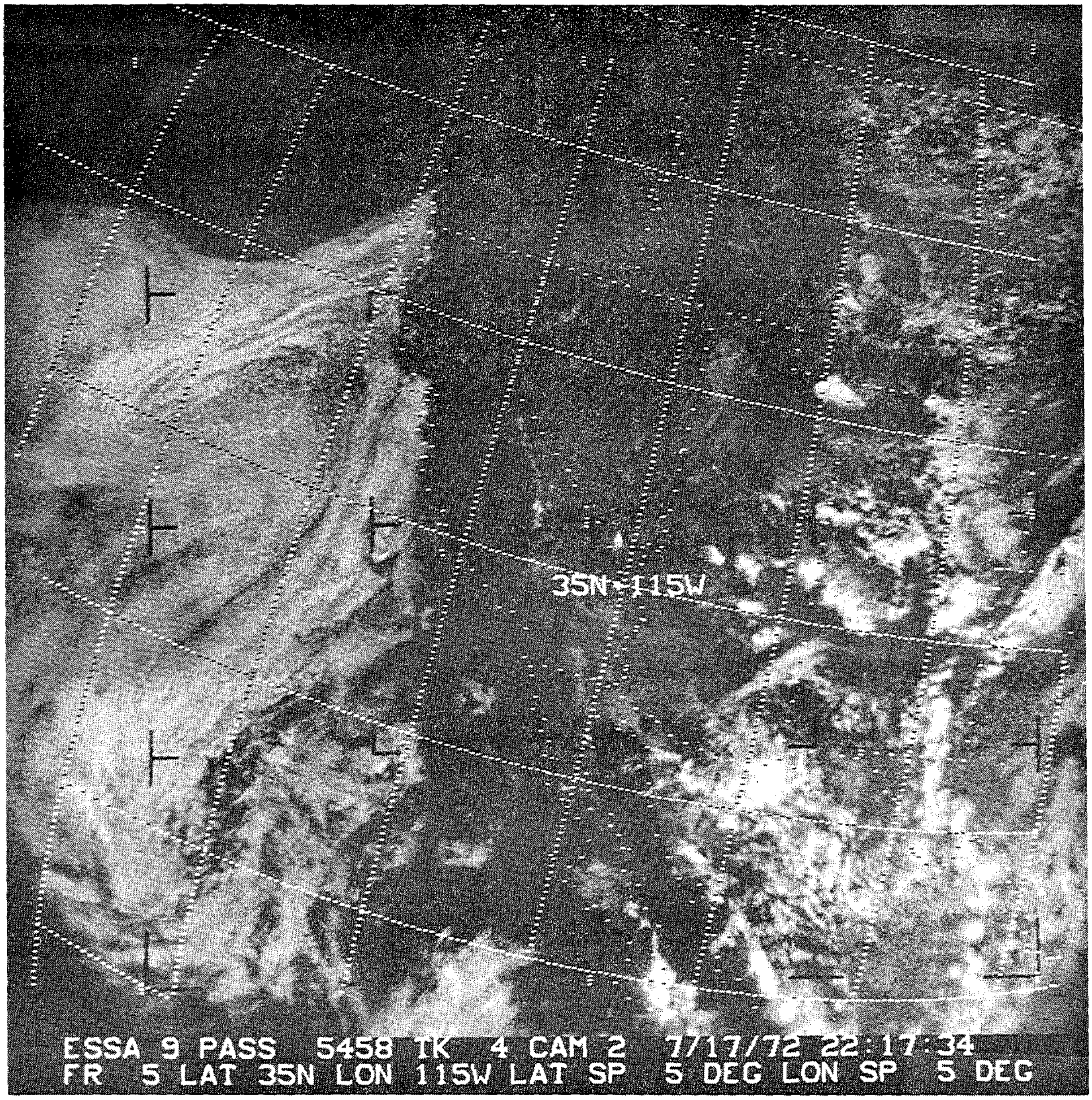

Figure 9. ESSA 9 Satellite Picture for July 17, 1972, 2217 GMT (1517 MST).

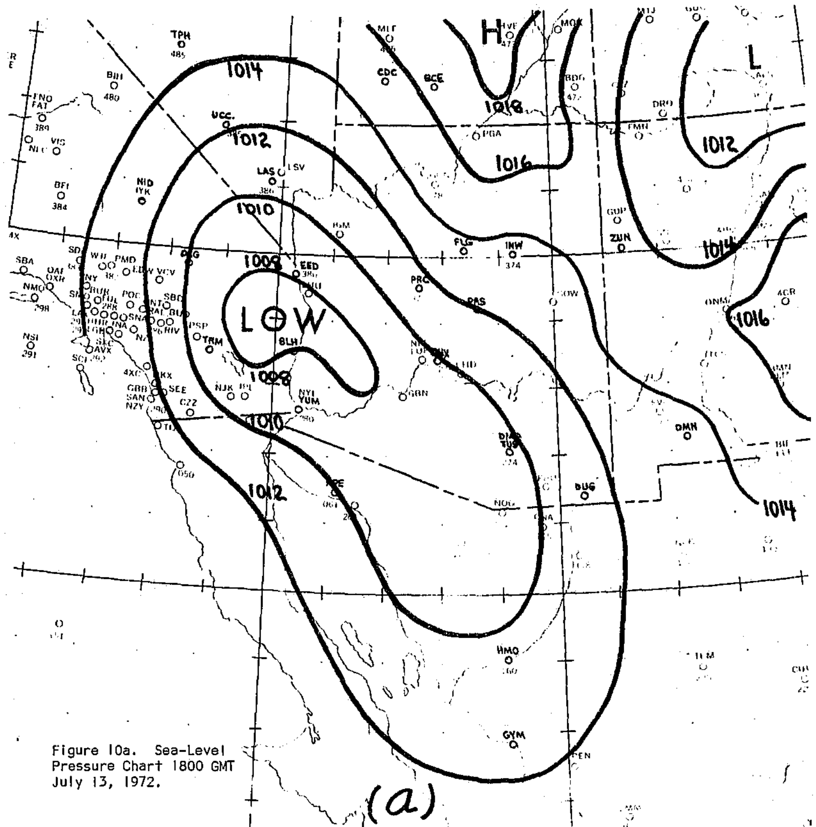

Figure 10a. Sea-Level Pressure Chart 1800 GMT July 13, 1972.

(a)

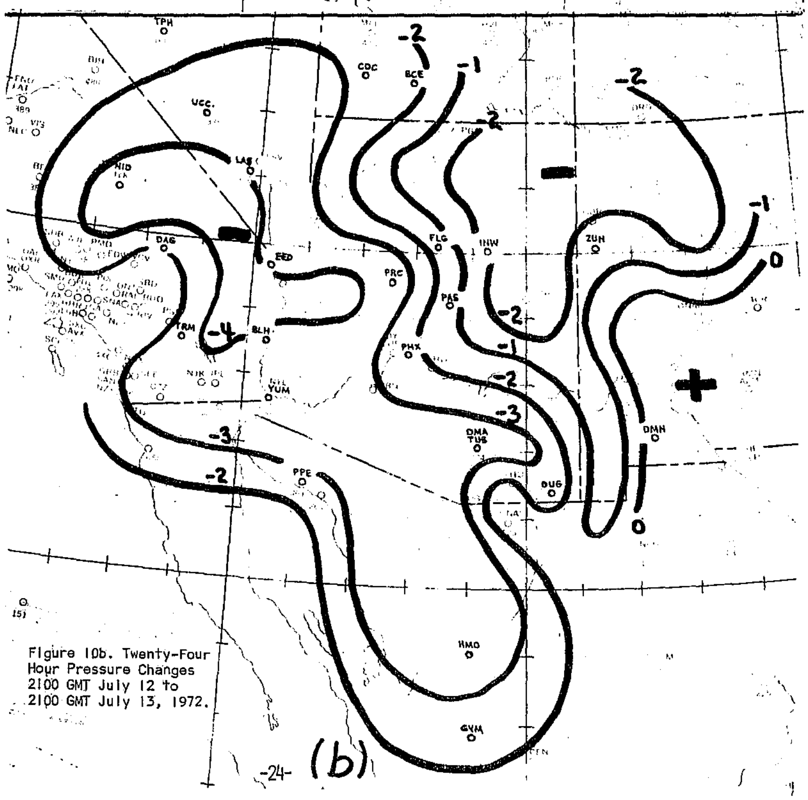

Figure 10b. Twenty-Four Hour Pressure Changes 2100 GMT July 12 to 2100 GMT July 13, 1972.

(b)

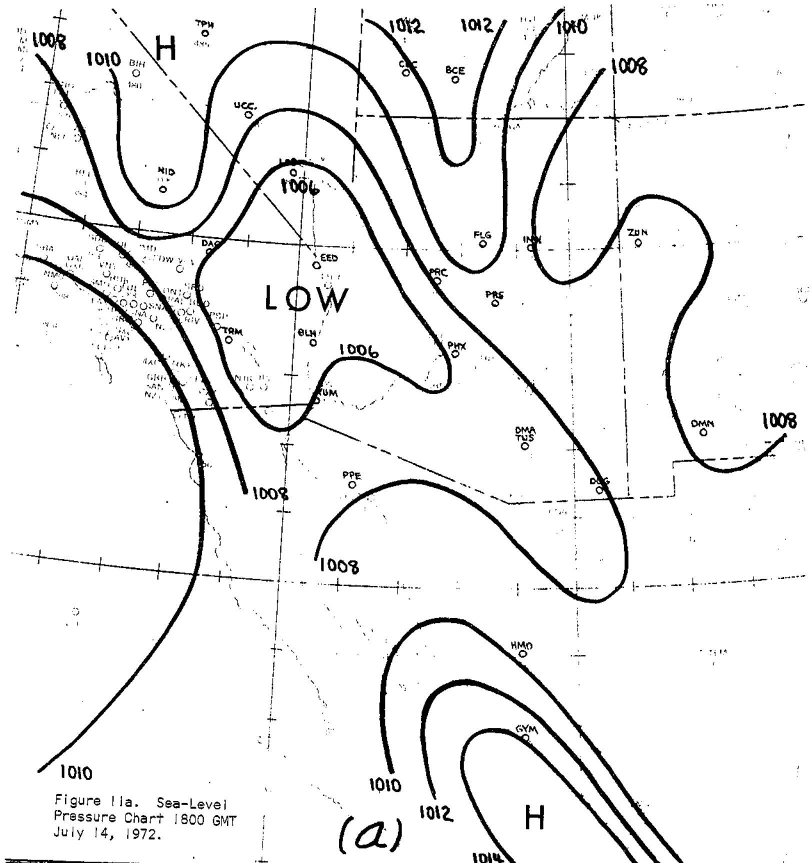

Figure 11a. Sea-Level Pressure Chart 1800 GMT July 14, 1972.

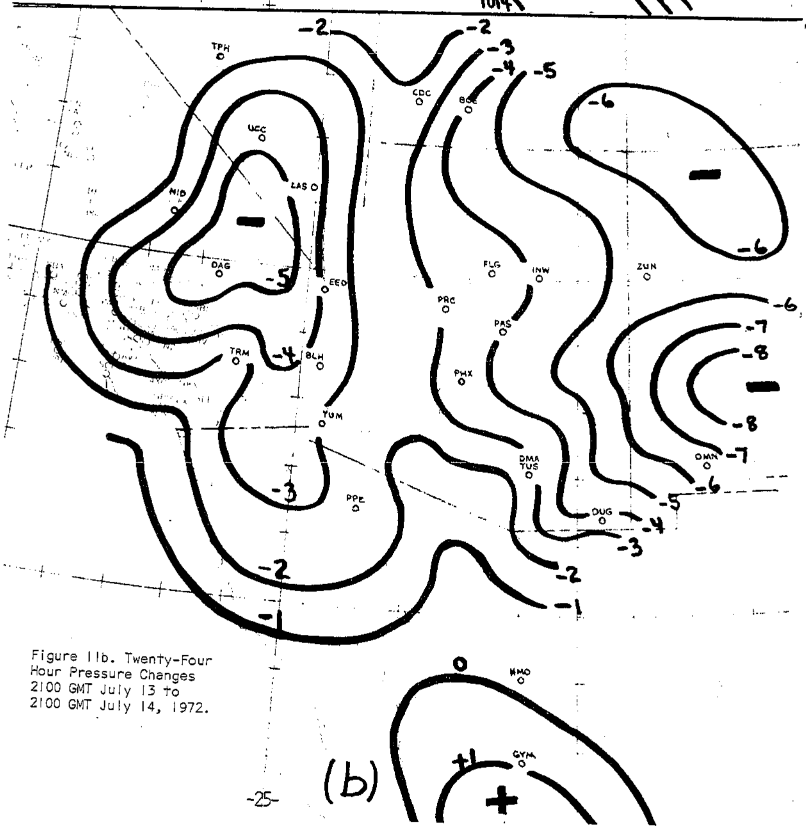

Figure 11b. Twenty-Four Hour Pressure Changes 2100 GMT July 13 to 2100 GMT July 14, 1972.

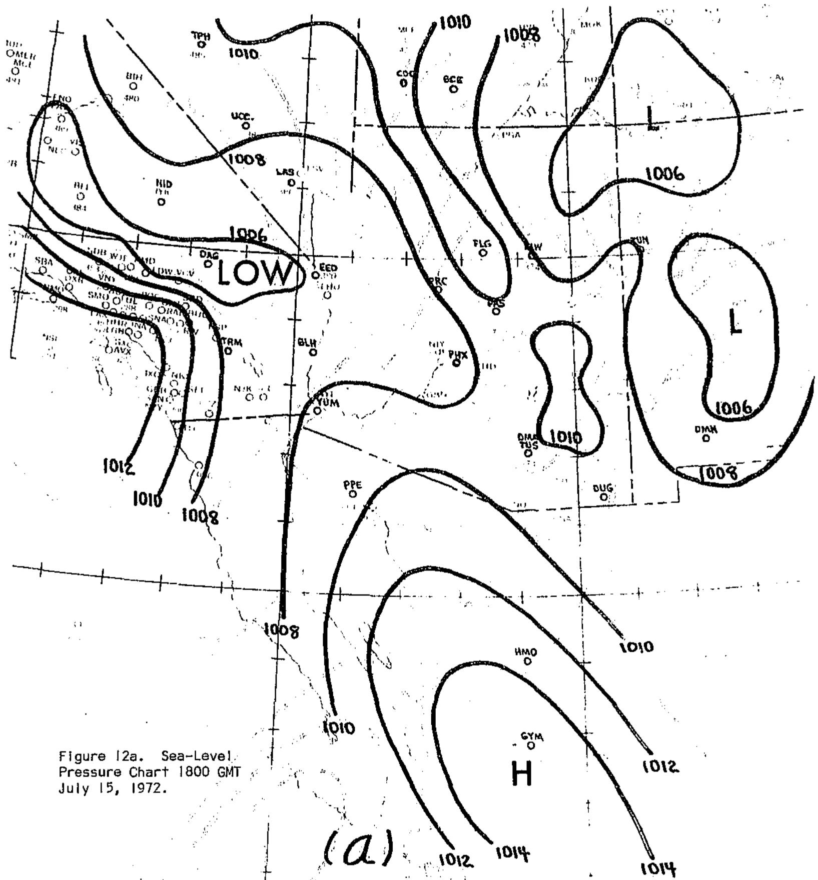

Figure 12a. Sea-Level Pressure Chart 1800 GMT July 15, 1972.

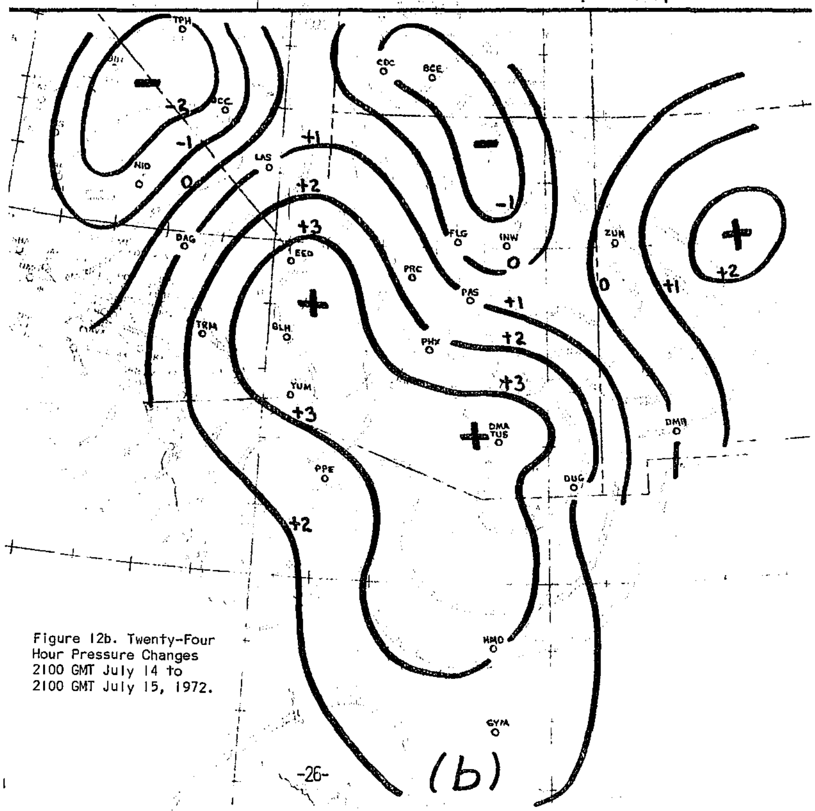

Figure 12b. Twenty-Four Hour Pressure Changes 2100 GMT July 14 to 2100 GMT July 15, 1972.

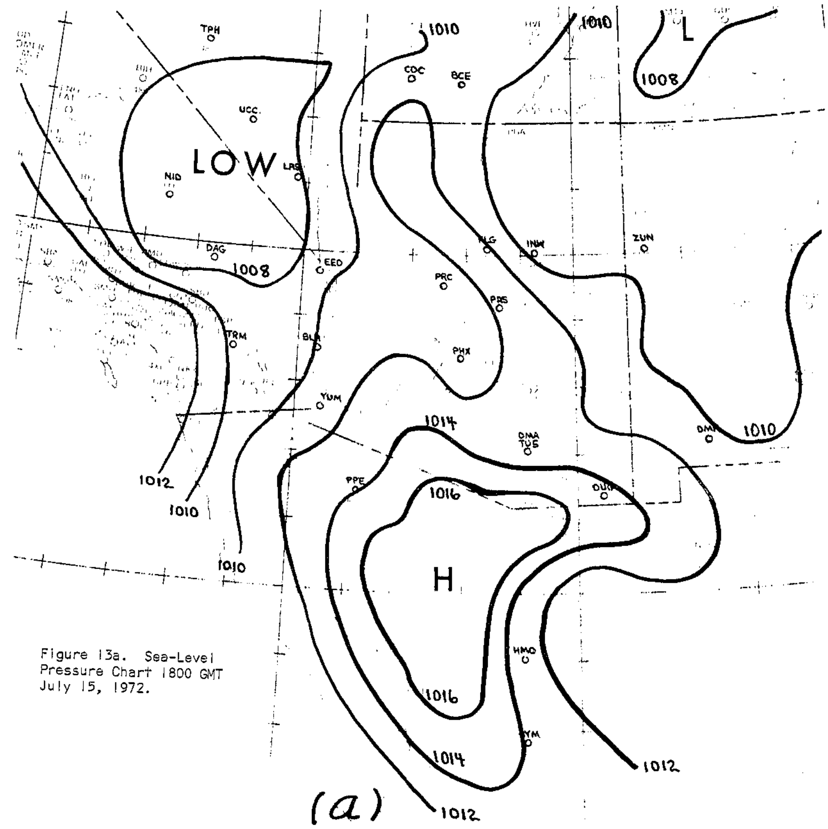

Figure 13a. Sea-Level Pressure Chart 1800 GMT July 15, 1972.

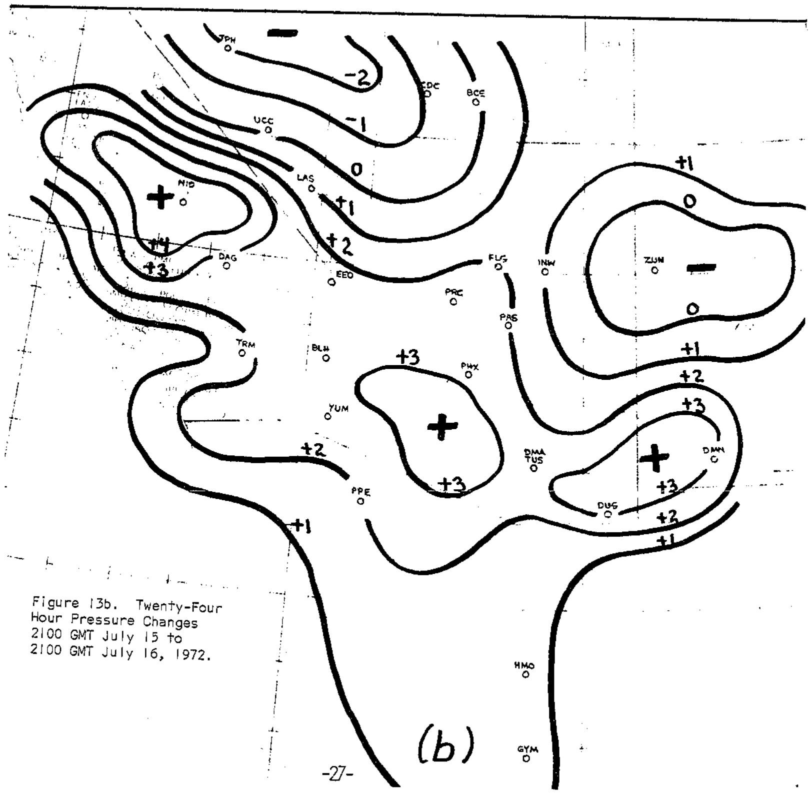

Figure 13b. Twenty-Four Hour Pressure Changes 2100 GMT July 15 to 2100 GMT July 16, 1972.

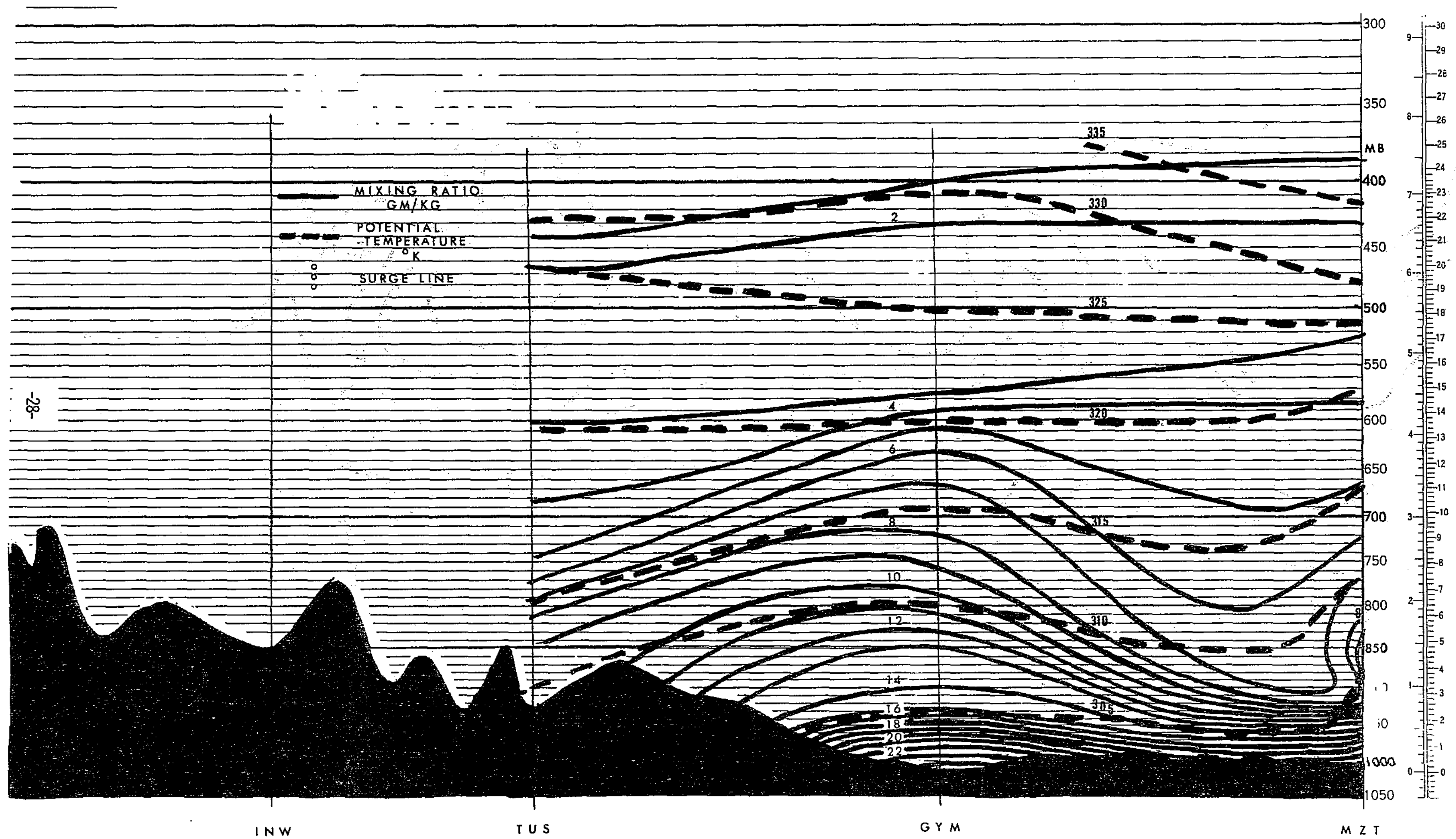

FIGURE 14. NORTH-SOUTH CROSS SECTION SURFACE TO 400 MB, WINSLOW (INW), ARIZONA, TO MAZATLAN (MZT), MEXICO, FOR 1200 GMT JULY 13, 1972.

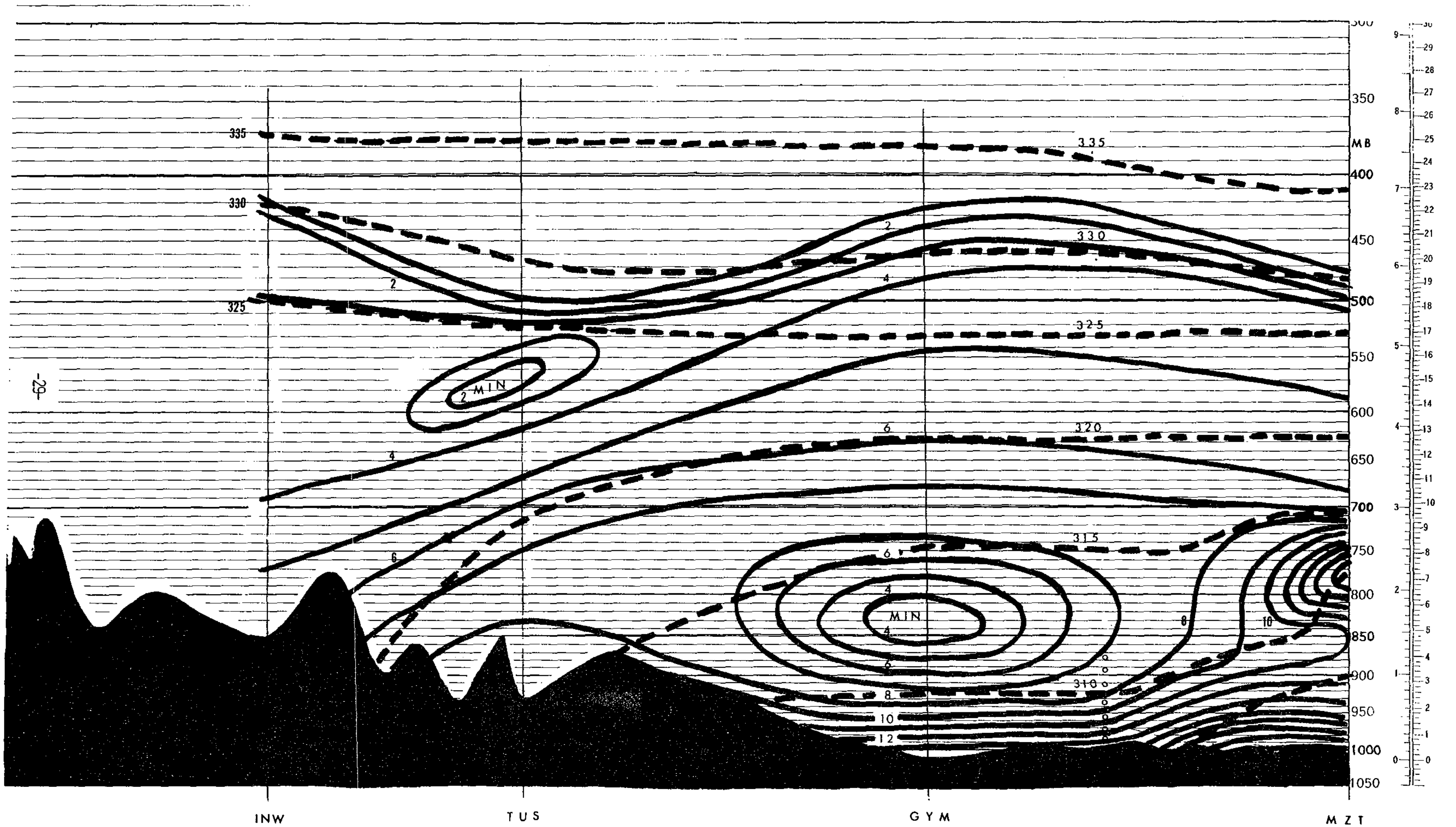

FIGURE 15. NORTH-SOUTH CROSS SECTION SURFACE TO 400 MB, WINSLOW (INW), ARIZONA, TO MAZATLAN (MZT), MEXICO, FOR 0000 GMT JULY 14, 1972.

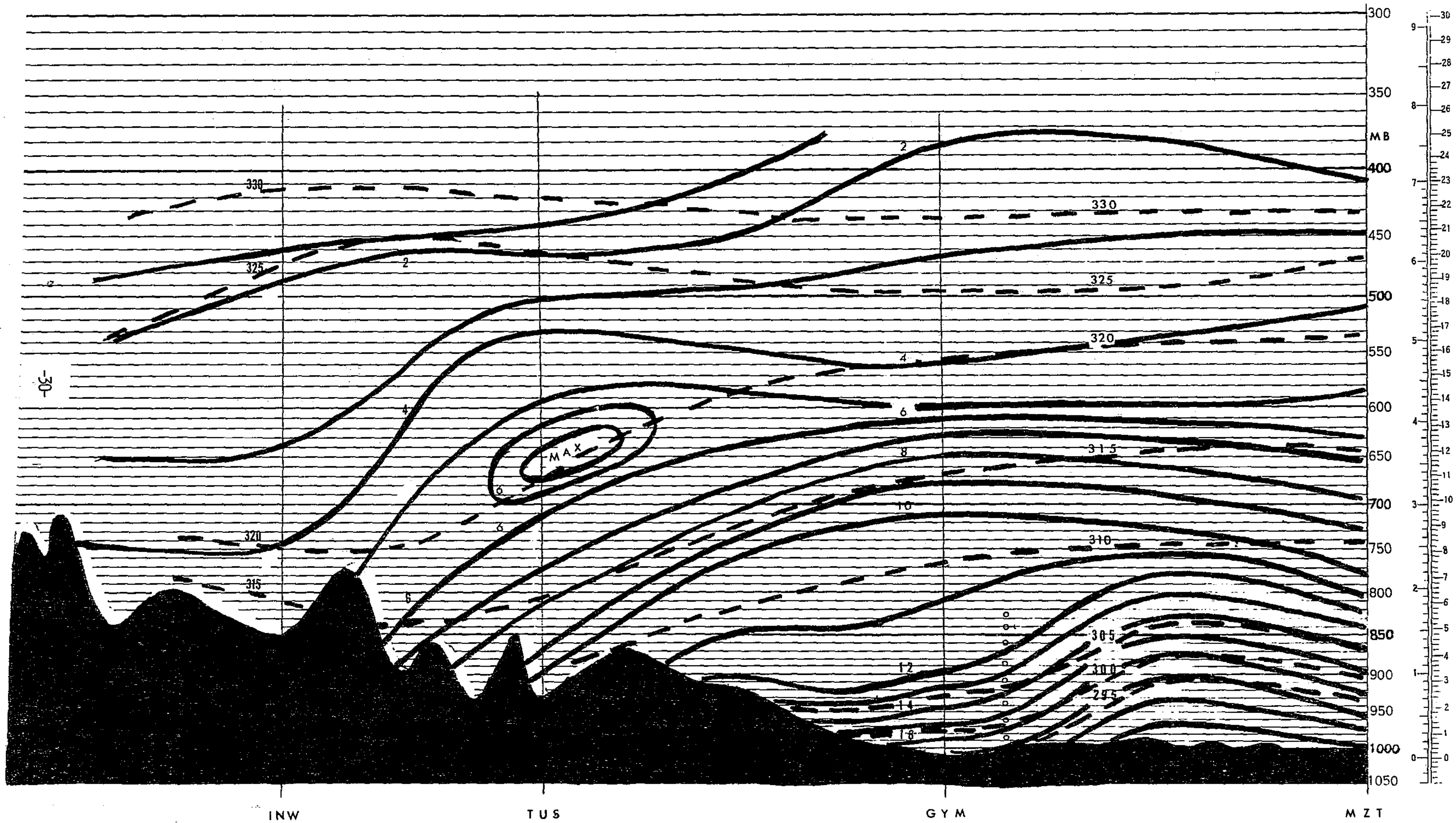

FIGURE 16. NORTH-SOUTH CROSS SECTION SURFACE TO 400 MB, WINSLOW (INW), ARIZONA, TO MAZATLAN (MZT), MEXICO, FOR 1200 GMT JULY 14, 1972.

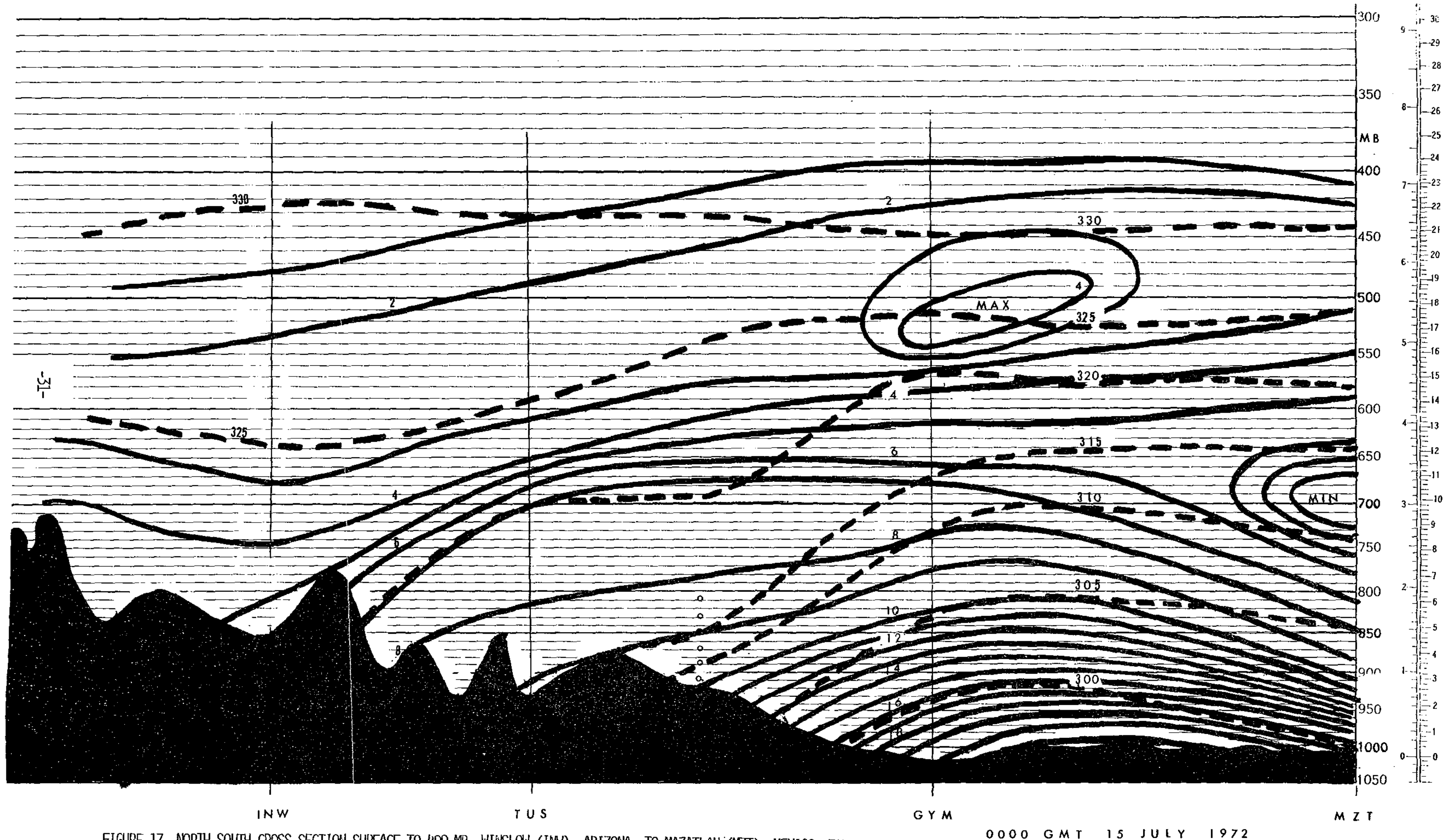

FIGURE 17. NORTH-SOUTH CROSS SECTION SURFACE TO 400 MB, WINSLOW (INW), ARIZONA, TO MAZATLAN (MZT), MEXICO, FOR 0000 GMT JULY 15, 1972.

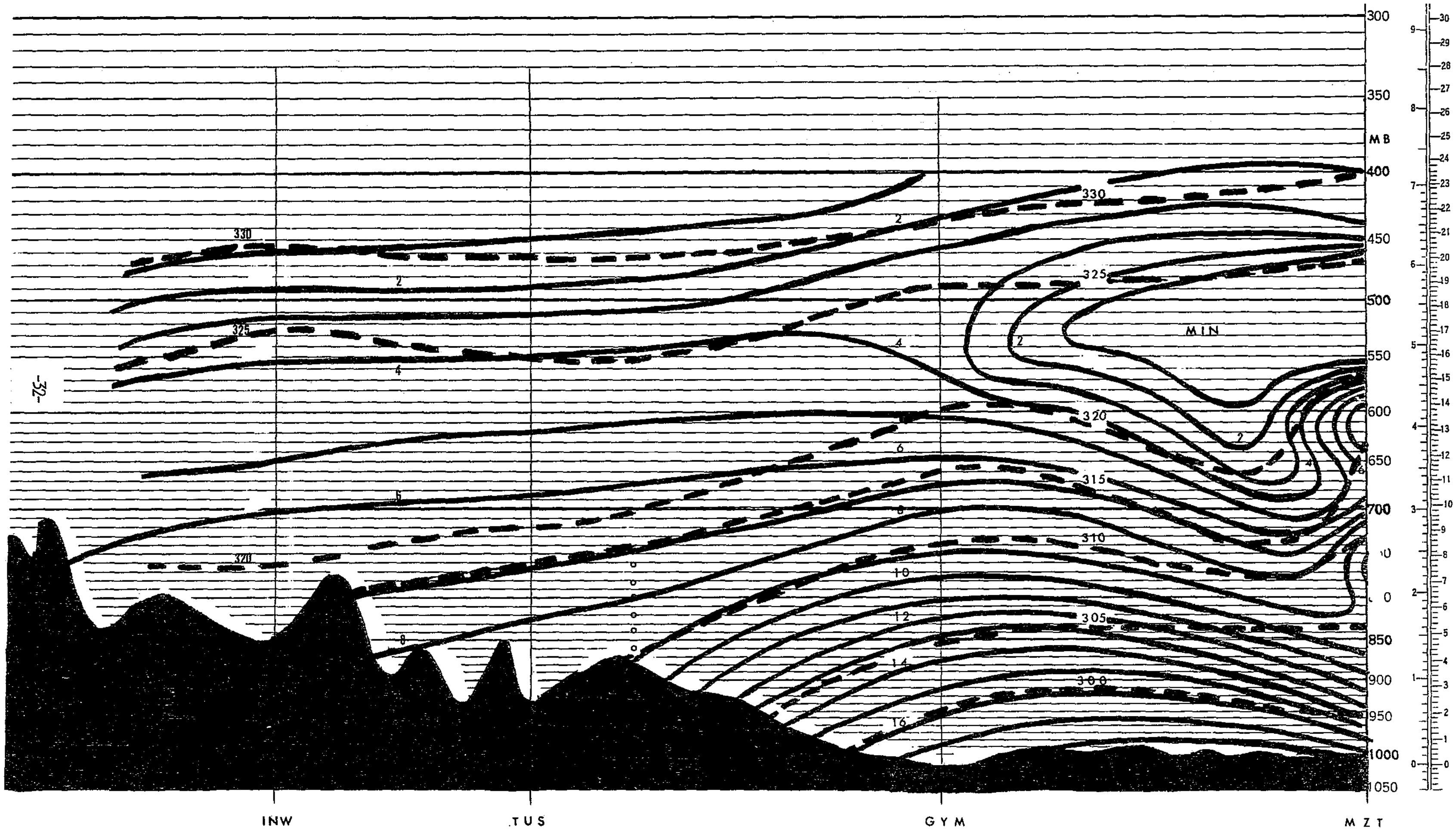

FIGURE 18. NORTH-SOUTH CROSS SECTION SURFACE TO 400 MB, WINSLOW (INW), ARIZONA, TO MAZATLAN (MZT), MEXICO, FOR 1200 GMT JULY 15, 1972.

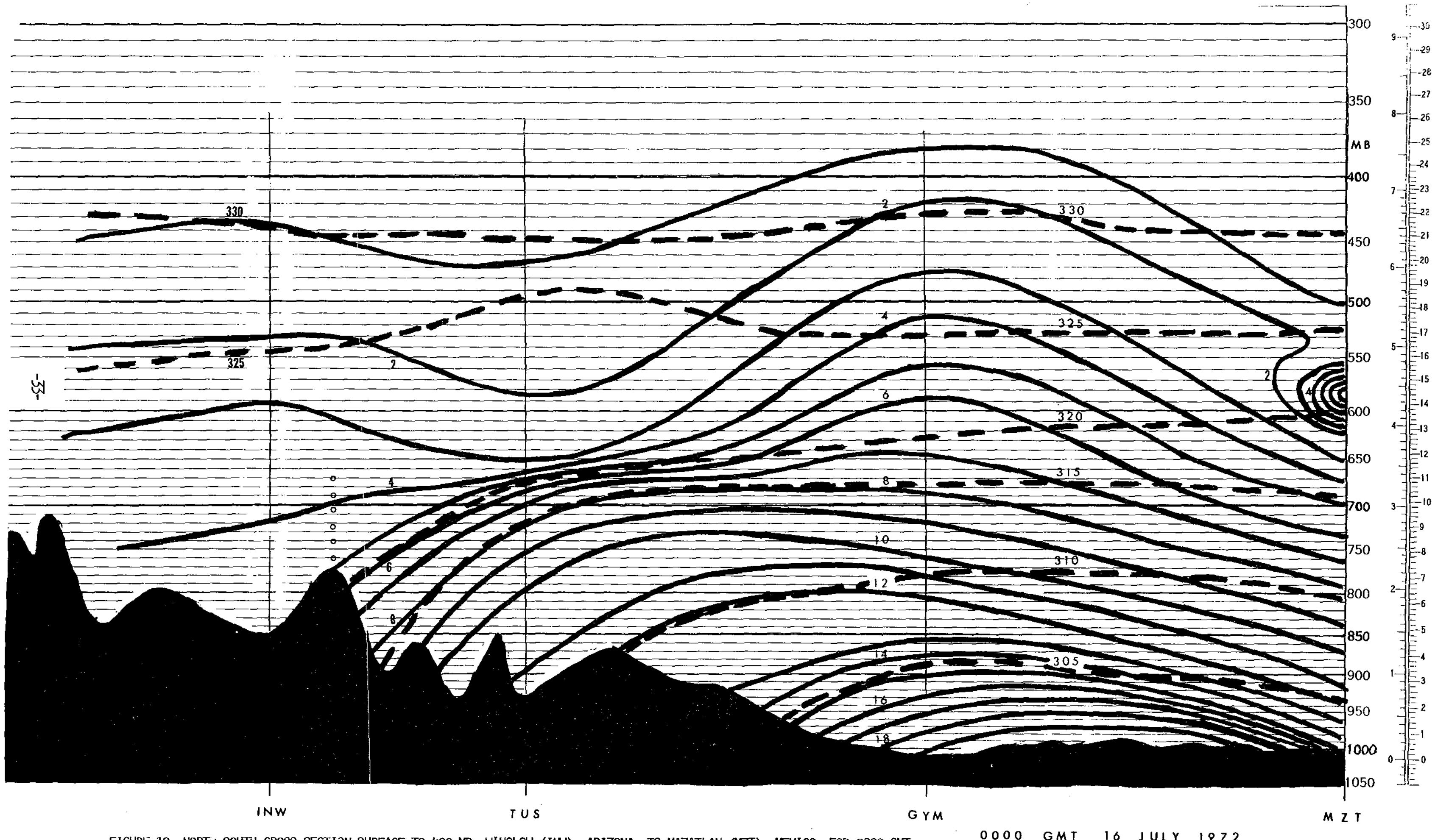

FIGURE 19. NORTH-SOUTH CROSS SECTION SURFACE TO 400 MB, WINSLOW (INW), ARIZONA, TO MAZATLAN (MZT), MEXICO, FOR 0000 GMT JULY 16, 1972.

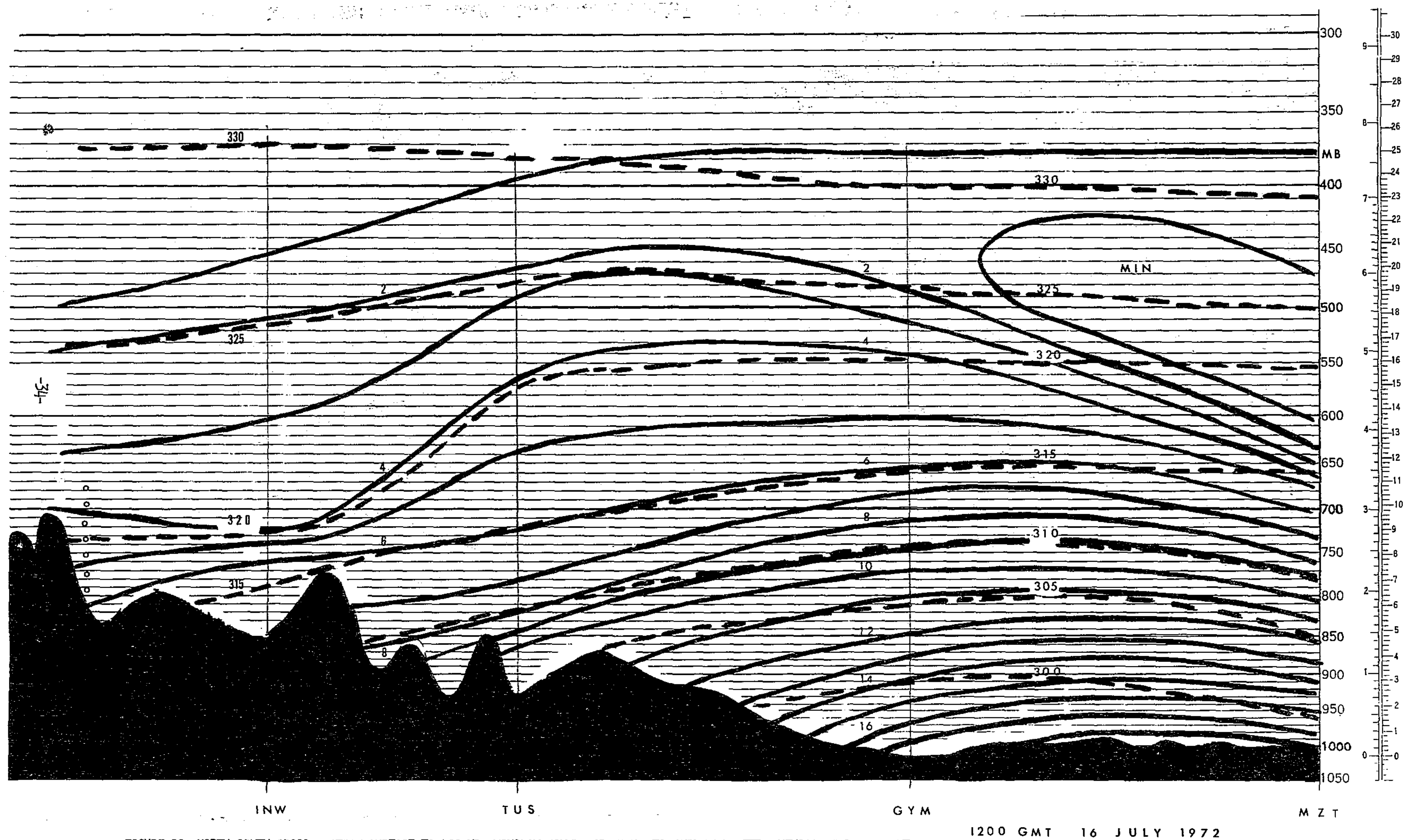

FIGURE 20. NORTH-SOUTH CROSS SECTION SURFACE TO 400 MB, WINSLOW (INW), ARIZONA, TO MAZATLAN (MZT), MEXICO, FOR 1200 GMT JULY 16, 1972.

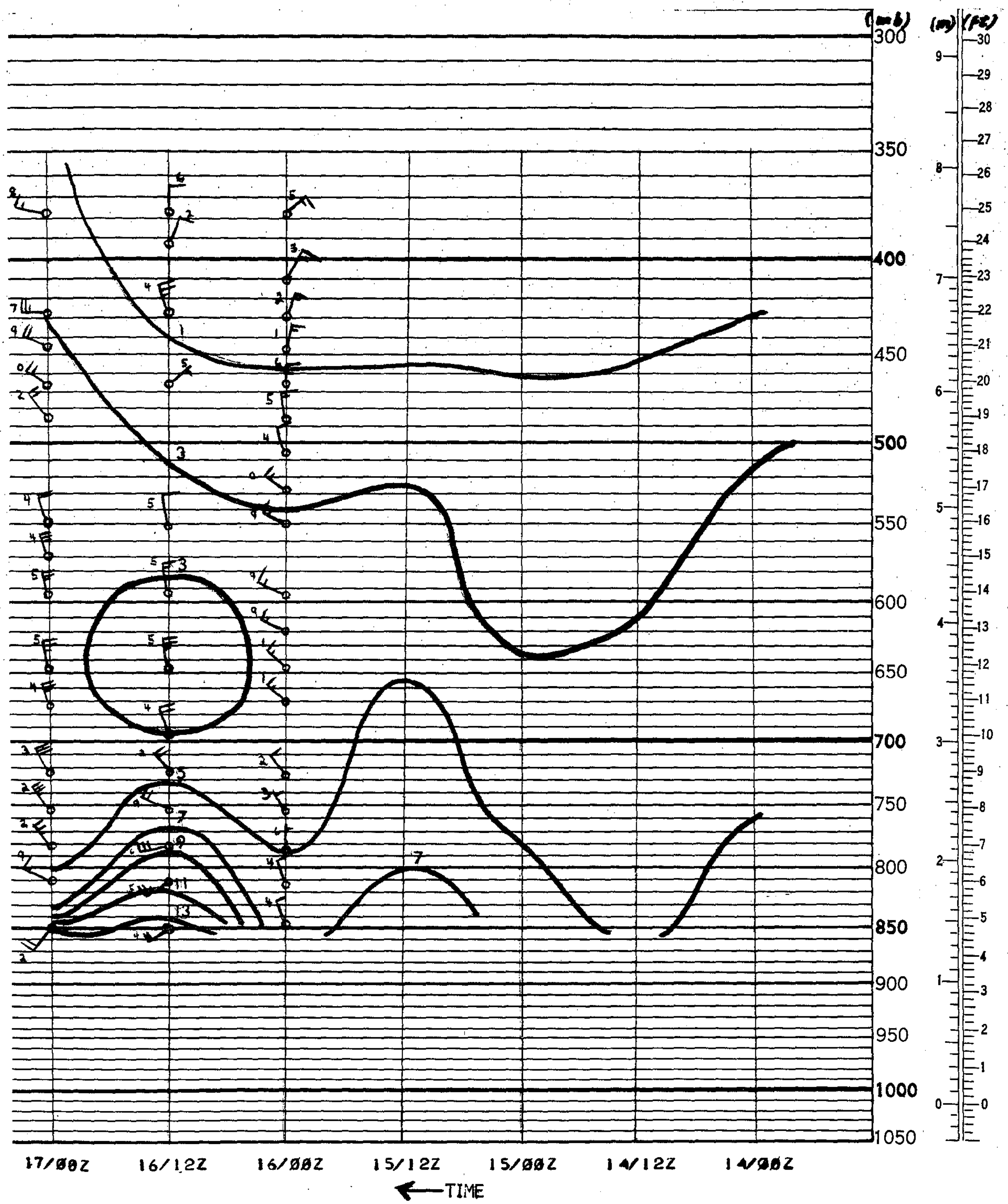

Figure 21. Time-Section 850-1400 mb of Mixing Ratio and Winds from 0000 GMT, July 14 to 0000 GMT, July 17, 1972 at Winslow, Ariozna. Units of Mixing Ratio gm/kg.

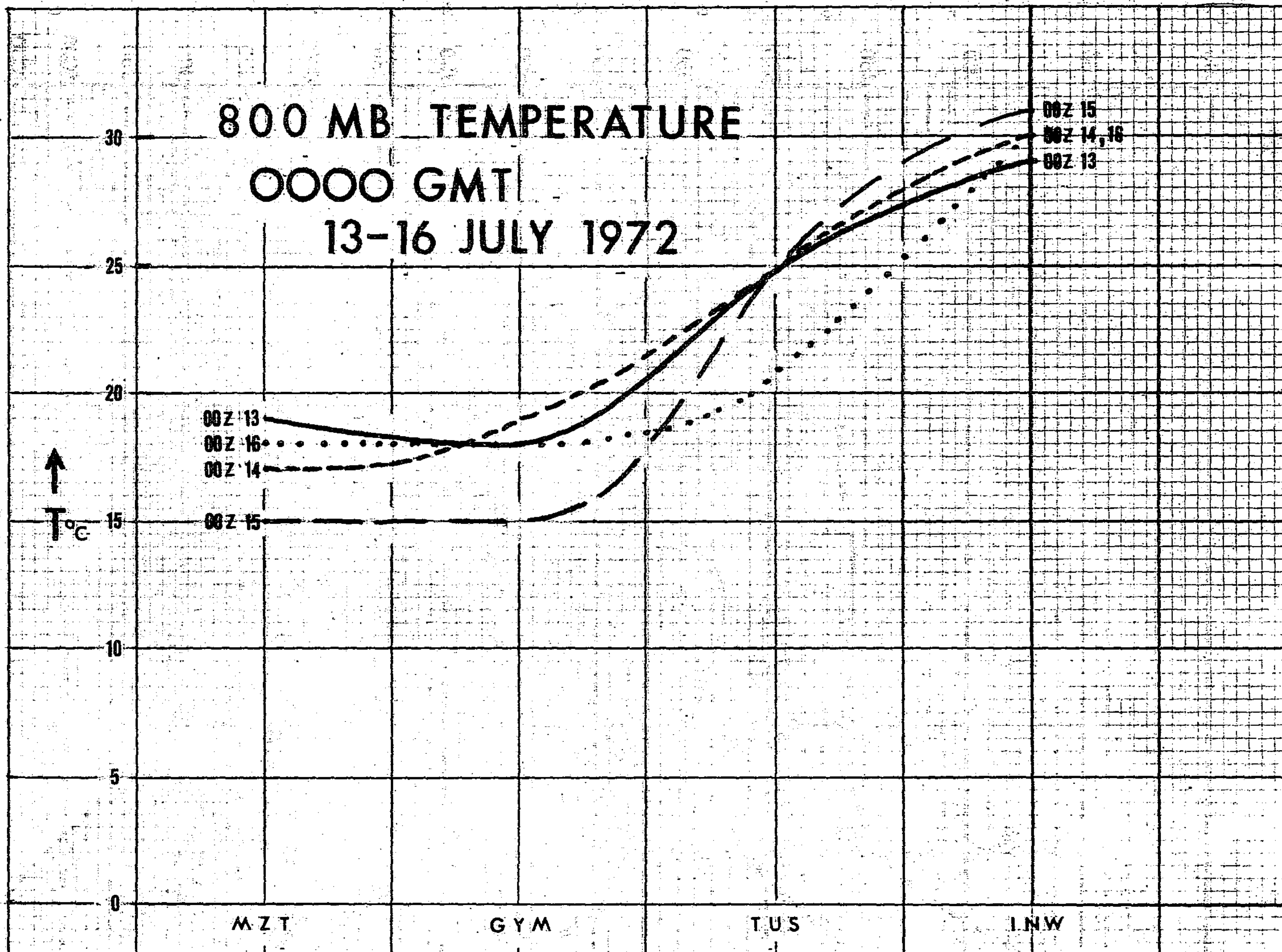

Figure 22. North-South Distribution of 0000 GMT 800-mb Temperatures, July 13 to July 16, 1972.

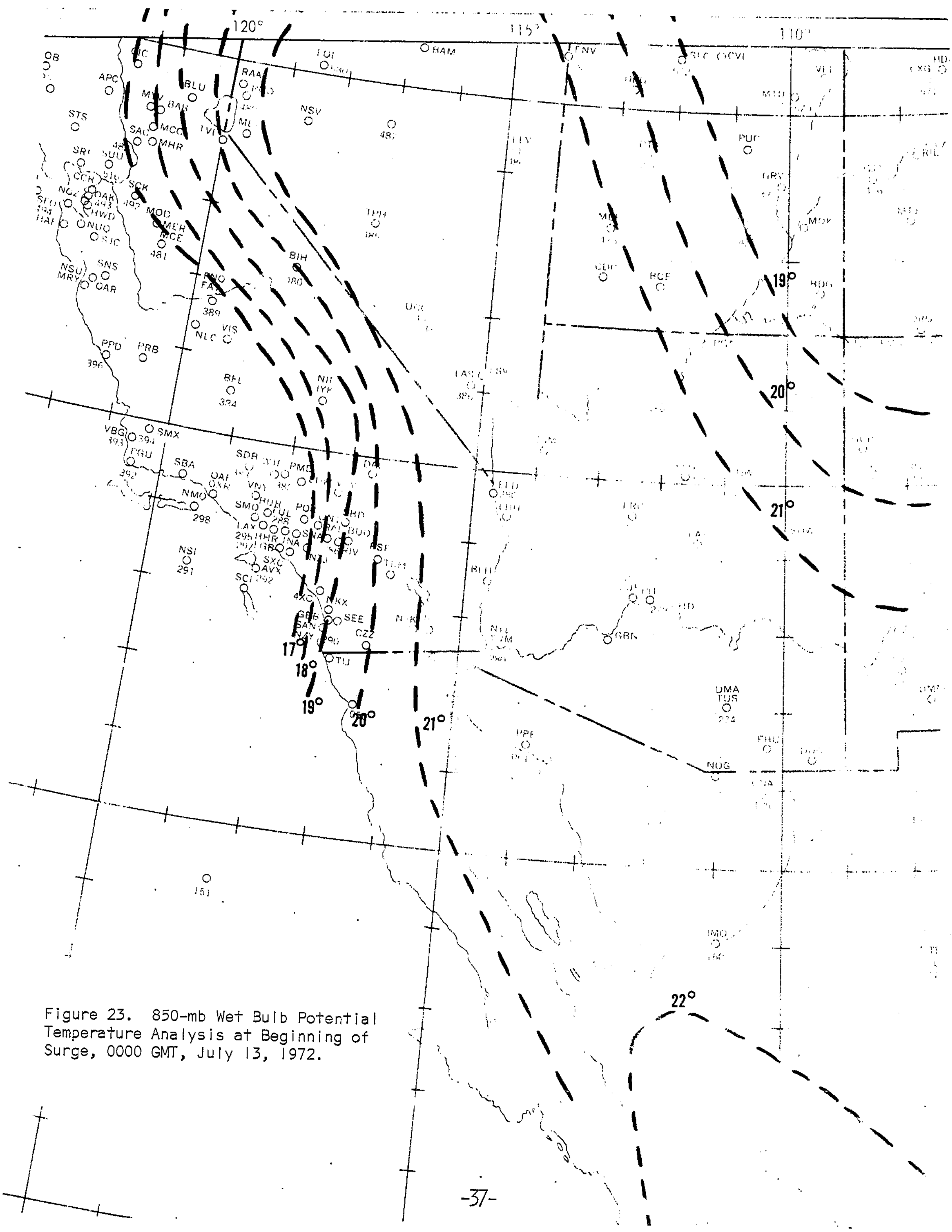

Figure 23. 850-mb Wet Bulb Potential Temperature Analysis at Beginning of Surge, 0000 GMT, July 13, 1972.

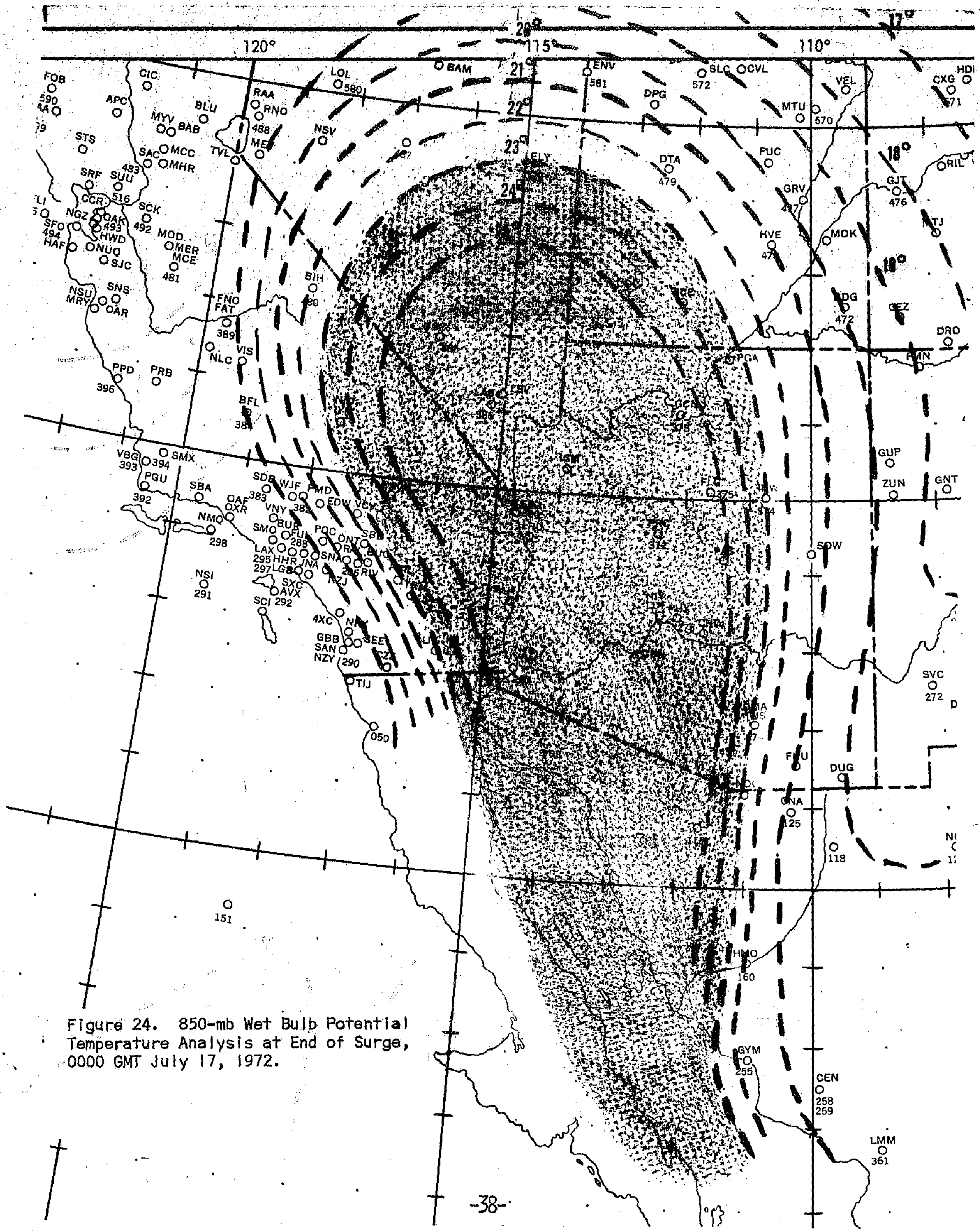

Figure 24. 850-mb Wet Bulb Potential Temperature Analysis at End of Surge, 0000 GMT July 17, 1972.

YUM

DAY	TIME Z	SKY CONDITION	VSB	WX	PRES/T/TD/WIND	
15	0000	1600	40		019/105/59/1813	
15	0100	1600	40		016/102/61/1613	
15	0200	E1600	40		019/100/62/1515	
15	0300	1600	40		023/96 /62/1613	
15	0400	E1600	20+		028/93 /62/1612	
15	0500	1600	20+		030/90 /67/1615G20	
15	0600	E1600	20+		030/37 /63/1617	
15	0700	E1600	20+		037/36 /70/1613	
15	0800	E1600	10		044/37 /70/1523	DUSTY
15	SP 0833	-X	3	BDBN	/1524G32	
15	0900	-X	3	BDBN	047/36 /70/1523	
15	1000	-XE2000	5	BDBN	047/35 /73/1618	
15	1100	200-0	10		050/34 /72/1708	D ALQDS
15	1200	16002000	10		049/33 /71/1206	
15	1300	16002000	15		054/33 /72/1314	
15	1400	2000	10		061/33 /74/1317	DUSTY
15	SP 1429	-X8002000	3	BDBN	/1320G23	D2 VSB N TO E 21/2
15	1500	2000	10		074/36 /73/1318G24	FEW CUFRA 40
15	1600	400	10		080/39 /74/1316G23	D ALQDS
15	1700	0	10		080/92 /63/1616	CU NW TO NE TO E
15	1800	400	15		081/94 /71/1718	
15	1900	0	15		081/96 /69/1521	
15	2000	0	15		074/37 /63/1719	
15	2100	0	15		071/99 /67/1617	
15	2200	1600	15		064/99 /66/1514	
15	2300	0	15		057/100/65/1614	

Figure 25. Hourly and Special Weather Observation at Yuma, Arizona, July 15, 1972.

YUM

DAY	TIME Z	SKY CONDITION	VSB	WX	PRES/T/TD/WIND
14	0000	0	40		040/109/59/2408
14	0100	0	40		033/108/59/2608
14	0200	0	40		027/105/61/2406
14	0300	0	40		030/101/64/1809
14	0400	0	20		037/96 /66/1812
14	0500	0	20+		040/95 /66/1809
14	0600	0	20+		037/93 /64/1614
14	0700	2000	20+		038/91 /67/1411
14	0800	200-0	20+		038/90 /66/1713
14	0900	200-0	20+		037/38 /67/1706
14	1000	0	20+		037/88 /66/1707
14	1100	0	20+		037/38 /67/1612
14	1200	0	10		038/88 /69/1417
14	1300	1800	20		047/86 /70/1415
14	1400	1800	15		061/88 /74/1415
14	1500	1800	15		061/88 /74/1415
14	1600	1800	15		064/90 /73/1313
14	1700	1800	15		064/93 /71/1415
14	1800	1800	20		061/96 /67/1715
14	1900	1800	20		056/101/67/1813
14	2000	1600	30		050/101/65/1611
14	2100	1600	25		042/103/66/1513
14	2200	1600	30		035/104/66/1714
14	2300	1600	30		027/104/61/1714

Figure 26. Hourly Weather Observations at Yuma, Arizona, July 14, 1972.

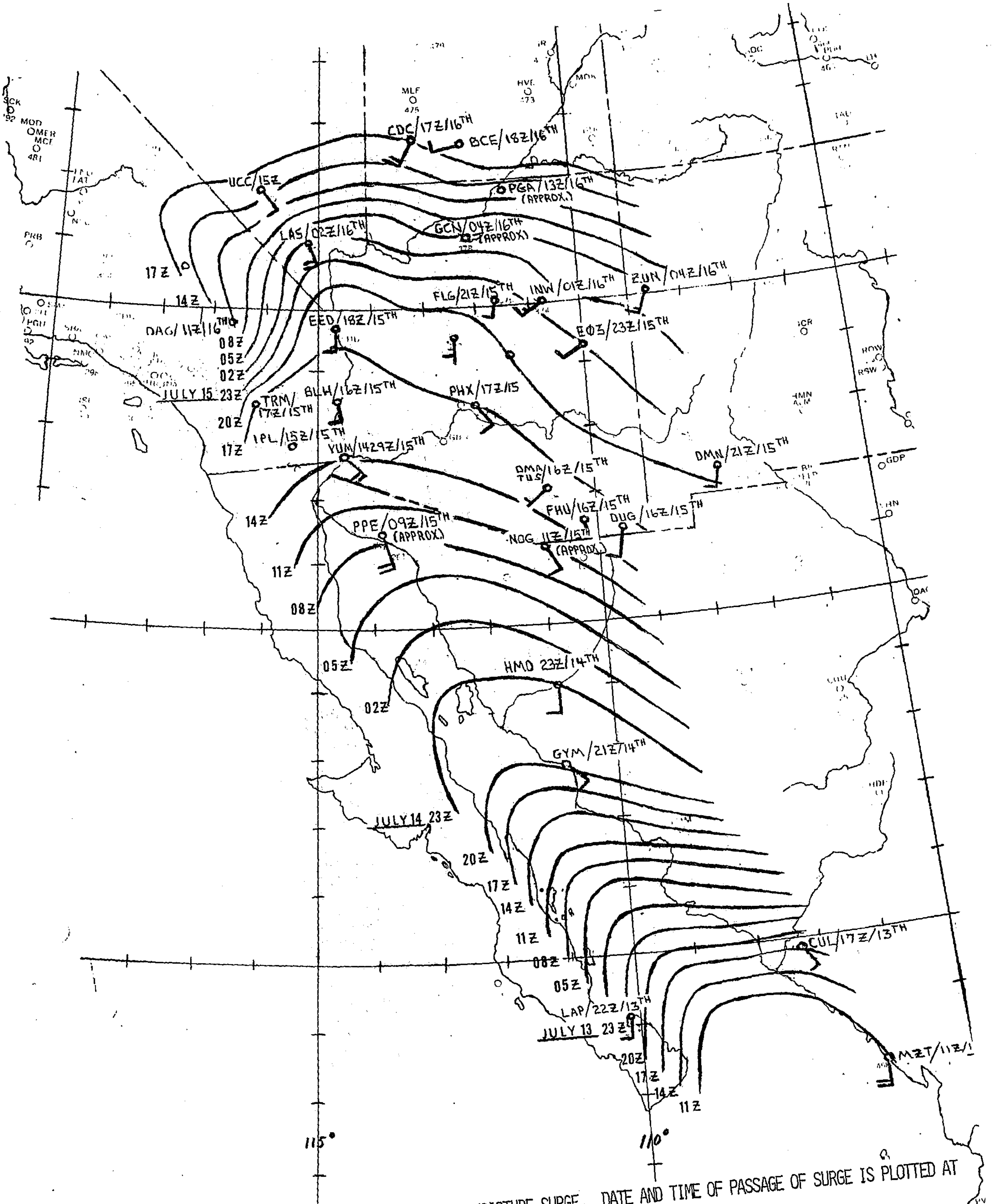

FIGURE 27. ISOCHRONES OF PASSAGE OF LEADING EDGE OF MOISTURE SURGE. DATE AND TIME OF PASSAGE OF SURGE IS PLOTTED AT EACH STATION. PLOTTED WINDS ARE AT TIME SURGE PASSED THE STATION.

No. 45/2 Precipitation Probabilities in the Western Region Associated with Spring 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189434)
No. 45/3 Precipitation Probabilities in the Western Region Associated with Summer 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189414)
No. 45/4 Precipitation Probabilities in the Western Region Associated with Fall 500-mb Map Types. Richard P. Augulis. January 1970. (PB-189435)
No. 46 Applications of the Net Radiometer to Short-Range Fog and Stratus Forecasting at Eugene, Oregon. L. Yee and E. Bates. December 1969. (PB-190476)
No. 47 Statistical Analysis as a Flood Routing Tool. Robert J. C. Burnash . December 1969. (PB-188744)
No. 48 Tsunami. Richard A. Augulis. February 1970. (PB-190157)
No. 49 Predicting Precipitation Type. Robert J. C. Burnash and Floyd E. Hug. March 1970. (PB-190962)
No. 50 Statistical Report of Aeroallergens (Pollens and Molds) Fort Huachuca, Arizona 1969. Wayne S. Johnson. April 1970. (PB-191743)
No. 51 Western Region Sea State and Surf Forecaster's Manual. Gordon C. Shields and Gerald B. Burdwell. July 1970. (PB-193102)
No. 52 Sacramento Weather Radar Climatology. R. G. Pappas and C. M. Veliquette. July 1970. (PB-193347)
No. 53 Experimental Air Quality Forecasts in the Sacramento Valley. Norman S. Benes. August 1970. (PB-194128)
No. 54 A Refinement of the Vorticity Field to Delineate Areas of Significant Precipitation. Barry B. Aronovitch. August 1970.
No. 55 Application of the SSARR Model to a Basin Without Discharge Record. Vail Schermerhorn and Donald W. Kuehl. August 1970. (PB-194394).
No. 56 Areal Coverage of Precipitation in Northwestern Utah. Philip Williams, Jr., and Werner J. Heck. September 1970. (PB-194389)
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