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Analysis of the Southern California Santa Ana of January 15-17, 1966

BARRY B. ARONOVITCH

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U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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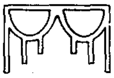
A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-42

ANALYSIS OF THE SOUTHERN CALIFORNIA SANTA ANA OF JANUARY 15 - 17, 1966

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ABSTRACT

A meteorological analysis of conditions during the severe Santa Ana of January 15 - 17, 1966 is given, with emphasis on the 500-mb flow.

The gradient-wind equation defines the maximum contour curvature which a parcel of air can follow dynamically for a given wind speed. If this maximum is exceeded, the parcel trajectory may become anti-cyclonic. This condition is related to the so-called "wet" Santa Ana.

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ANALYSIS OF THE SOUTHERN CALIFORNIA SANTA ANA OF JANUARY 15 - 17, 1966

I. INTRODUCTION

On January 15, 1966, a violent Santa Ana windstorm unleashed its force upon the harbor city of Avalon, Santa Catalina Island, California. Twenty boats ranging from 18-foot outboards to 65-foot pleasure cruisers were damaged by this storm. Of these, 16 were completely demolished. The four remaining vessels were beached and suffered minor, moderate, or major damage. Ten persons were rescued from various vessels. Ten others were admitted to the hospital for treatment. One person was drowned.

One hundred sixty feet of pier and twenty-six feet of 12-inch-thick seawall were washed away by the storm. Pieces of the seawall were found more than 150 feet from point of origin. Three buildings and many feet of brick walk sustained damage from this storm, along with much sea-water damage at the Catalina Art Gallery and Museum located at Casino Point. Total damage was estimated to exceed $300,000.

A meteorological analysis of this devastating storm showed that it differed considerably from the usual Santa Ana. Radar was particularly helpful in issuance of short-term warnings.

II. METEOROLOGY - LOW LEVEL FEATURES

The strong easterly winds which occurred in parts of southern California during January 15 - 17, 1966, were not the usual breed of Santa Ana winds which blow during fall and winter months. By 0400PST, January 14, a Los Angeles Forecast Center objective aid indicated a Santa Ana windstorm was imminent. This aid is based primarily on the presence of a rather strong west-to-east height gradient at the 500-mb level, coincident with a large surface pressure gradient between the Oregon coast and eastern Nevada. A third factor is a significant 500-mb temperature gradient between eastern Washington and eastern Nevada. Values of the above parameters on January 14 and January 15 are shown in Table 1 below. The possibility of a Santa Ana windstorm is listed as a percentage probability in the last column.

TABLE I

Hour/Day	500-mb ht diff. OAK-ELY (tens of GDM)	Sea-Level Press. diff. MFR-ELY (mb)	Temp diff. 500-mb GEG-ELY (°C)	Obj Sys. Santa Ana prob.(%)
04P 1/14	+7	+6.2	-9	18
16P	+10	+7.1	-6	20
04P 1/15	+16	+11.7	-2	50
16P	+21	+7.6	-9	70

A Santa Ana generally occurs after a 24-hour lag when large-scale features, as shown in the table, exist. However, the typical Santa Ana of sunny skies, low humidities, and strong northeast winds over particular mountain ridges did not develop. Primarily, the winds were accompanied by cloudiness and rainshowers. Secondly, the winds blew in unusual locations. Generally, they swoop down through the main passes of the coastal ranges, such as the Santa Clara Valley, the canyons of the Newhall and Saugus areas, and Cajon Pass (Figure 1). This time, however, the wind was not primarily guided by these usual terrain features, but by others. This wind behavior will be discussed in greater detail later in the paper. Thirdly, the usual high pressure characteristics of a Santa Ana were absent. This fact was partly responsible for extensive boat damage in Avalon Harbor. Many boat owners refused to believe the possibility of a Santa Ana occurrence during a period of low pressure, and thus chose to keep their boats in the harbor. A trace of the sea-level pressure at Santa Catalina is shown in Figure 2. Also on this graph is a line showing the normal sea-level pressure during January for the general area.

The situation that developed was one which southern California weathermen call a "wet" Santa Ana. The strong offshore winds of this type of Santa Ana were not caused solely by a high-pressure system inland, but rather by a combination of a low offshore and a high inland. The presence of the low offshore in the vicinity of southern California apparently resulted from anticyclogenesis upstream. This apparent paradox will be discussed later in the section dealing with dynamics, found in the Appendix. There is little doubt that large-scale features discussed in this section were a result of those dynamics.

The surface maps (Figures 3 through 7) show that instead of the usual strong high-pressure center over Idaho, Utah, and northern Nevada, the high remained far to the north near the Canadian border, while isobars over Nevada and southern California on January 15 and 16 gradually assumed a more east-west orientation. A measure of the surface pressure gradient vector is the difference in sea-level pressures between Los Angeles and San Francisco, and between Los Angeles and Tonopah. The former measures the gradient in a northwest-southeast direction, while the latter measures it in a northeast-southwest direction. Figure 8 shows that the former was stronger than the latter until noon, January 15, after which time there was a rapid rise in the Los Angeles-Tonopah gradient. This gradient remained strong until the afternoon of January 17, when it began to weaken rapidly. The high values of this latter gradient are typical of both the usual and the "wet" Santa Ana.

A measure of cold air advection is the change in the thickness of the 850-700mb layer. Thickness values for Las Vegas and San Diego are plotted on Figure 8. This figure shows that cold air advection took place at Las Vegas after 1600PST Friday and continued until early Sunday morning. At San Diego marked cooling did not begin until 1600PST Saturday, after which time there was rapid cooling until

Sunday afternoon. During the windy period, January 15 - 16, the air over southern Nevada remained significantly colder than that over southern California, indicating continued low-level advection of cold air toward the coast from the northeast. Progressive cooling of the air mass at San Diego is shown in Figure 9.

The unusually violent wind behavior at Santa Catalina Island has been previously mentioned. A graph of hourly windspeeds at Sandberg (SDB), Palmdale (PMD), and El Toro (NEJ) is shown in Figure 10. As usual, strong winds commenced earlier out on the desert than along the coast. Although Sandberg does not report gust velocities, with sustained wind speeds of 44 knots at 2100PST on Saturday, one may assume that gusts to at least 60 knots were present. Winds at El Toro were probably funneled through Trabuco Canyon in the mountains to the east of this station.

The anomalous behavior of the wind was probably due to instability of the air. The 1000PST San Diego sounding on Saturday the 15th showed a Showalter Index of +3 (1). At 1600PST the index was +4, while other soundings in the vicinity showed relatively low Showalter Indexes. Occurrence of thunderstorms further indicated air mass instability.

As in most cases, the most violent winds accompanied the initial arrival of cold air over southern California on January 15, even though the surface pressure gradient did not reach its highest value until a day or two later. At this later time, however, a weaker thermal gradient existed between the coast and inland, as shown by the smaller 850-700mb thickness difference between the Las Vegas and San Diego radiosonde observations (Figure 8).

The question arises whether or not the unusually strong winds which began late in the evening of the 15th were a result of a mesoscale front or squall line which formed at the leading edge of the cold air. To conclusively answer this question, an exhaustive study of all available observations, not just those used in this paper, would be necessary in order to detail storm mesoscale behavior. However, there is no strong evidence on the 3-hourly sectional charts (not shown) that such a mesoscale front or squall line existed. Furthermore, the radar at Santa Catalina Island showed no indication of such a feature which might be responsible for the violent winds. What was significant was the isobar packing between the southern California desert and the coast beginning 1600PST Saturday the 15th and continuing through 1000PST Sunday the 16th. This packing accompanied the strong cold-air advection during that period which was, in turn, a result of the dynamics discussed in the Appendix.

Another question arises as to whether or not the water trajectory was of sufficient length to permit any significant modification. A similar situation in a meteorological satellite study (2) shows the cumulus forming immediately off the eastern coast of North America in cold continental air as it moves offshore over warmer water. However, in the latter case the temperature contrast between the arctic air and Gulfstream is much greater than between the Santa Ana air and water off the southern California coast.

III. 500-MB DISCUSSION

The storm of January 15 through January 17 was the result of a classic example of 'Dynamic Digging". Following the time sequence of the 500-mb charts (Figures 11 through 15) one can readily see the rather rapid development of anticyclogenesis. At 1200Z January 14 (Figure 11), slight ridging exists off the northwest Pacific coast with a shortwave trough over southern Washington and eastern Oregon. By 1200Z January 15, the ridging increased and moved onto the mainland over British Columbia, while the shortwave trough "dug" south-southeastward, and cold air aloft began moving southward over western United States (as shown by Figure 12). At this time, direction of the jet stream shifted from northwest to north-northwest. The northward shift of the 546 contour was accompanied by the first indications of cross-contour flow (over Washington). Cross-contour flow is discussed in the Appendix.

In the next 24 hours a drastic change took place as cold air accompanying the shortwave trough plunged southward across southern Utah into southern Nevada. At 1200Z January 16 (Figure 13), the ridge was well over the mainland, and anticyclonic contour curvature over the Pacific Northwest was greatly increased. Winds generally increased and the jet over western U.S. shifted to north-northeasterly. At this point there were signs of a possible "closed low" formation over southern California. Within only 12 hours, the contour curvature increased further, and cold air had reached the California coast; by that afternoon, 0000Z January 17 (Figure 14), the 552 contour became closed and a "closed low" was formed over San Diego. Wind speeds again increased around the low and were now from the northeast over southern California. As part of the low was over relatively warm water, one would expect intensification; hence, some degree of low-level airmass modification was probably attained.

By 1200Z January 17 (Figure 15), the ridge curvature was still increasing and the "closed low" had moved north-northwestward to a position almost directly over Santa Catalina Island.

The dramatic atmospheric changes which took place during this period also are clearly shown by the 500-mb isotherm and jet stream patterns (see Figures 16 to 20). One can readily follow the veering of the jet from a northwest to a northeast orientation from Friday afternoon (Figure 16) to Sunday morning (Figure 19) as cold air plunged southward.

A strong absolute vorticity maximum of 18×10^{-5} per second was centered close to Los Angeles by early morning Sunday, January 16 (Figure 21), and the associated positive vorticity advection implied marked upward vertical motion. Also, the vorticity value was exceptionally high for southern California; thus it was not surprising that the upper-air low was associated not only with strong winds but with clouds and showers as well.

Not shown in the sequence is the rather rapid dissipation of the storm as the "closed low" moved inland on January 18. Within 24 hours the upper low center was located over northern Arizona. Associated with this northeastward movement was a general weakening of the contour gradient and the establishment of another ridge in the northwest Pacific; 500-mb winds then generally backed to north-northwest and finally to northwest over northern California.

IV. RADAR SCOPE DISCUSSION

To the author's knowledge, this is the first and only analysis of a Santa Ana windstorm in which radar was employed as an operational observation tool. Radar permitted a continuous watch of the storm's activities for the entire period, from the time it left the mainland to its farthest reach and eventual dissipation at sea.

The WSR-57 (10 cm.) radar will pick up a "sea return" target from any disturbed area of sea surface. Research is presently being done (3,4) to correlate strength and size of such targets with disturbing factors such as the wind.

Figure 22 (1916PST--radar clock is one hour fast) shows the normal ground and sea-clutter pattern on the 250-mile range as observed during normal periods of quiet sea. Circles are 50-mile range markers. In Figure 23 (1938PST) one can clearly see (arrow near center) the advancing Santa Ana as reflected by the sea-return pattern south of the Long Beach area.

In Figure 24 (1948PST) the radar range was switched from 250 miles to 50 miles, and the circles are 10-mile range markers. Also, Sensitivity Time Control (STC) was employed. STC is used to ensure that all video presented on the scope is of the same intensity. It operates as a quasi-logarithmic function, i.e., decreasing effect with increasing range. For purposes of a study of sea return, it would have been better not to employ STC since this circuit eliminates close-in targets to prevent "blooming" on the scope. Thus the leading edge of the sea return may not be where shown in Figure 24, but is probably less than ten miles from Santa Catalina Island. Had STC not been employed, the speed of the advancing edge of heavy seas could have been calculated from successive positions of the leading edge. In this manner it would have been possible to obtain a correlation between wind speed and advance of sea return. It would also have been possible to determine the lag, if any, between arrival of winds and heavy sea. However, it is standard operating procedure to employ STC during periods of precipitation to determine the intensity of such precipitation.

Figure 25 (1959PST) clearly shows that the region of disturbed sea includes the entire channel between the mainland and Santa Catalina Island, and also beyond the island. Figure 26 (2015PST) illustrates the orographic effect of the island on the wind. It appears that the strong winds were lifted by the island and touched down again at sea level about eight miles south of the island. This indicates that if all owners had heeded the warning issued by the Harbor Master to move their boats to the lee side of the island, the boats would most likely have been saved. Also, injuries and loss of life would probably have been avoided.

Beginning with Figure 24, a sea-surface disturbance also appears to exist about the Pt. Dume region (40 miles north-northwest of Catalina--see Figure 1). An isotach analysis (not shown) revealed a secondary boundary layer jet over this general area. Thus this Santa Ana's configuration was that of a crescent with the main jet over the Long Beach-Santa Ana region and the other arm in the Pt. Dume region. However, the secondary jet seemed to dissipate rapidly over the open water and never extended beyond ten miles off the coast.

V. ISSUANCE OF WARNINGS

Based largely on radar scope pictures, small-craft warnings were issued at 1530PST, January 15, by the U. S. Weather Bureau Airport Station on this island to the Harbor Master, Sheriff's department, and all other offices that are normally notified of Santa Ana conditions. The Harbor Master immediately warned boat owners to move their boats to the lee side of the island. He was met in several instances with rebuffs such as, "A Santa Ana cannot occur on such a beautiful day", and, "The barometer is too low for a Santa Ana to occur."

The advancing wind, as evidenced by the sea-return radar pattern, was first noted on the U. S. Weather Bureau's radarscope at 1920PST by the operator on duty. He subsequently advised the Harbor Master that the storm would hit within one hour. The advancing sea return was tracked and a final warning was issued minutes before the storm's arrival. By 2000PST all those willing to leave their boats were taken ashore, and all others were given a final warning of the impending northeast winds.

VI. STORM DAMAGE

The first boat to break its moorings due to the storm was a 45-foot motor-sailer valued at $45,000. Within minutes it crashed against the seawall and was destroyed. Following almost immediately was a 35-foot sailboat with three persons aboard. These people might easily been lost had it not been for the cushioning effect of the first boat against the seawall. Spray was up to 30 feet as waves crashed over the seawall. Wind at this time was estimated at 50 knots from the northeast. The sea had nine-foot breakers.

By 2300PST a 65-foot converted pleasure boat broke its moorings and fouled its screw in the dock float mooring. Throughout the night boat after boat broke its moorings and disintegrated against the seawall. Many acts of bravery by the Fire Department, Sheriff's office, and private individuals prevented the loss of several lives as boats with people aboard hurtled toward the seawall.

By 0200PST, January 16, sea breakers rose to twenty feet. At 0300PST a 24-foot cabin cruiser with a family of three aboard went adrift and headed for the seawall. The son jumped into the raging sea and managed to swim close enough to a pier to be rope-hauled to safety. The wife, tangled in a boat rope after narrowly escaping death, was finally hauled ashore seriously injured. The husband was washed overboard and drowned.

At 0400PST, with sustained winds of 50 knots, waves crashed over the city pier. One breaker rolled onto the pier, smashing windows of the pier-level floor of the Harbor Master's building. The same breaker moved an airline office building 2 - 3 inches. Spray now foamed well over the top of the Harbor Master's office, 30 feet above sea level. The pier was then secured and abandoned by its personnel--telephone lines had been knocked out. By 0500PST ten other boats had broken their moorings and were severely damaged.

VII. CONCLUSIONS

1. Most of the property damage, loss of life, and injuries sustained during this Santa Ana could possibly have been avoided if skippers of small craft in and about Avalon Harbor had heeded the Harbor Master's warning. Without a doubt the radar observations from Santa Catalina Weather Bureau Airport Station were the key to issuing wind warnings on January 15. Without the warning, Avalon Harbor would have sustained much greater loss of life and property than actually took place.

2. The WSR-57 radar is a valuable research tool in the study of sea return.

VIII. ACKNOWLEDGMENTS

The author wishes to thank Mr. George W. Kalstrom, Meteorologist in Charge of the Los Angeles Weather Bureau Forecast Office, whose help made it possible for me to write this paper; and to Dr. Seymour Hess, Professor of Meteorology, Florida State University, who permitted the use of some of his lecture material. Thanks must also go to my former coworkers at Santa Catalina Island WBAS, and to staff members of the Weather Bureau Forecast Office, Los Angeles, who read the paper and offered many suggestions which improved its form.

Most of all I owe thanks to Leo A. Sergius, Fire-Weather Forecast Supervisor, Los Angeles Weather Bureau Forecast Office, for discussions which led to appreciation of problems involved in forecasting the advent of a Santa Ana. Finally, I must express my thanks to Mr. George Ellis, Forecaster, Los Angeles Weather Bureau Forecast Office, who analyzed synoptic features of the storm.

IX. REFERENCES

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X. APPENDIX

Dynamics

In order for the wind speed to be a real number, the following condition must obtain, using the gradient wind equation (5).

$$r \geq \frac{4}{\rho f^2}\left|\frac{\partial p}{\partial r}\right|$$

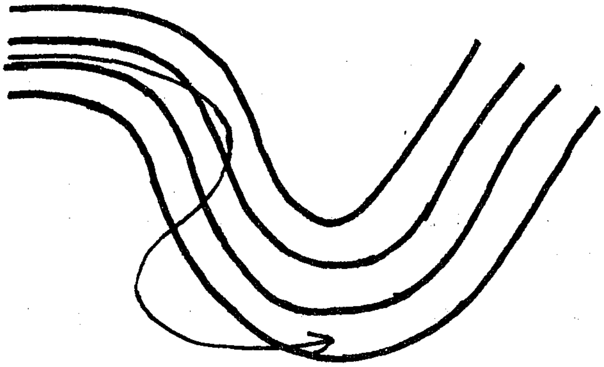
where r = radius of isobar curvature
ρ = density
p = pressure
f = Coriolis Parameter
g = gravity
Z = contour height

which may be rewritten as:

$$r \geq \frac{4}{f^2}\, g\left(\frac{\partial z}{\partial r}\right)_p$$

here, r is the radius of contour curvature, and subscript p denotes differentiation on a constant pressure surface. Thus, for a given height gradient, the radius of curvature of flow theoretically must not fall below the value given in the equation.

The acceleration of flow which occurs if this criterion is not met results in cross-contour flow. There is a sharp increase of anticyclonic curvature in the upstream ridge with a pronounced cyclonic flow downstream,(6) as seen in Figures 11 - 13. Thus, a "cutoff low" is formed south of the building ridge as seen in Figures 13 - 15.



From Hess: Trajectory of air through a sharply curved ridge of high pressure when gradient balance cannot be maintained

As a point of interest, one calculation (not shown) was made on Figure 13 to determine the least possible radius of contour curvature which an air parcel could follow dynamically. It was found to be approximately 3.6° of latitude. Four of the five contours constituting the ridge and associated trough had a smaller radius of curvature.

If a correlation could be found between wind speeds in the ridge and speeds attained in the associated trough, this would imply a significant forecast tool. However, it has previously been shown (7) that large ageostrophic behavior exists in regions of anticyclogenesis. Thus the problems of forecasting wind speeds for such regions are tremendously difficult if not, indeed, impossible.

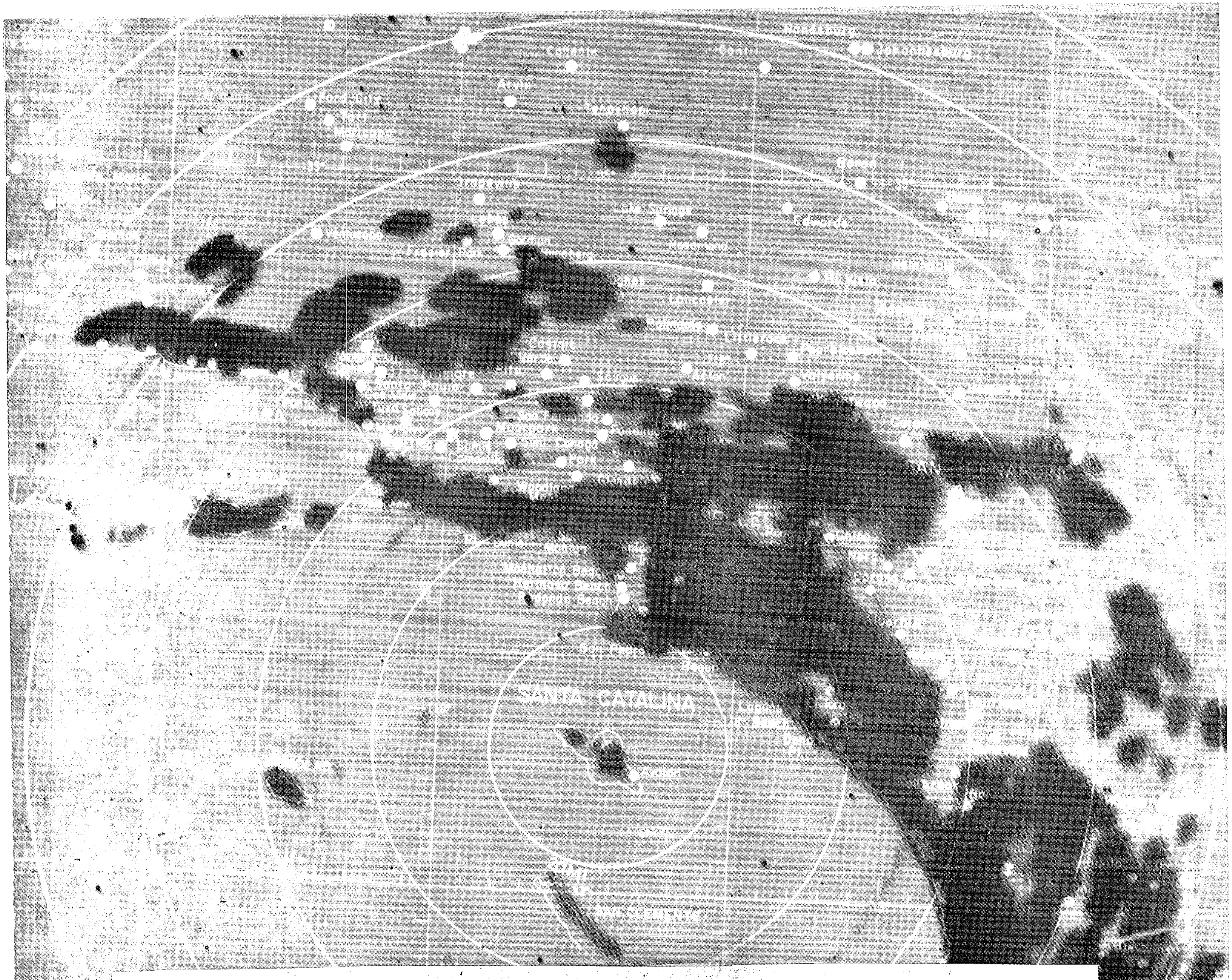


FIGURE 1. MAP OF SOUTHERN CALIFORNIA SHOWING NORMAL CATALINA RADAR GROUND CLUTTER PATTERN.

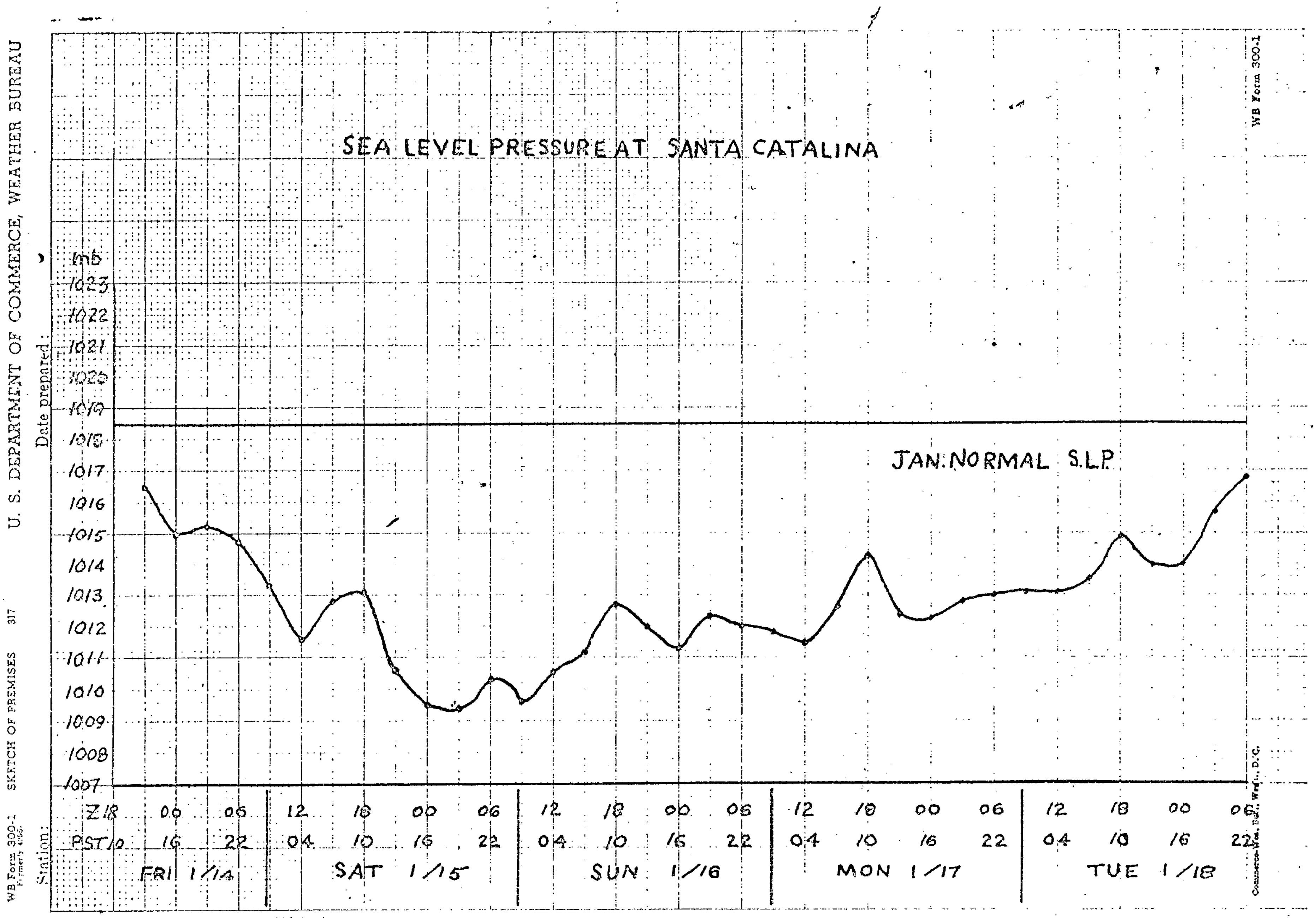


FIGURE 2 - GRAPH OF SEA-LEVEL PRESSURE AT SANTA CATALINA, JANUARY 14-18, 1966

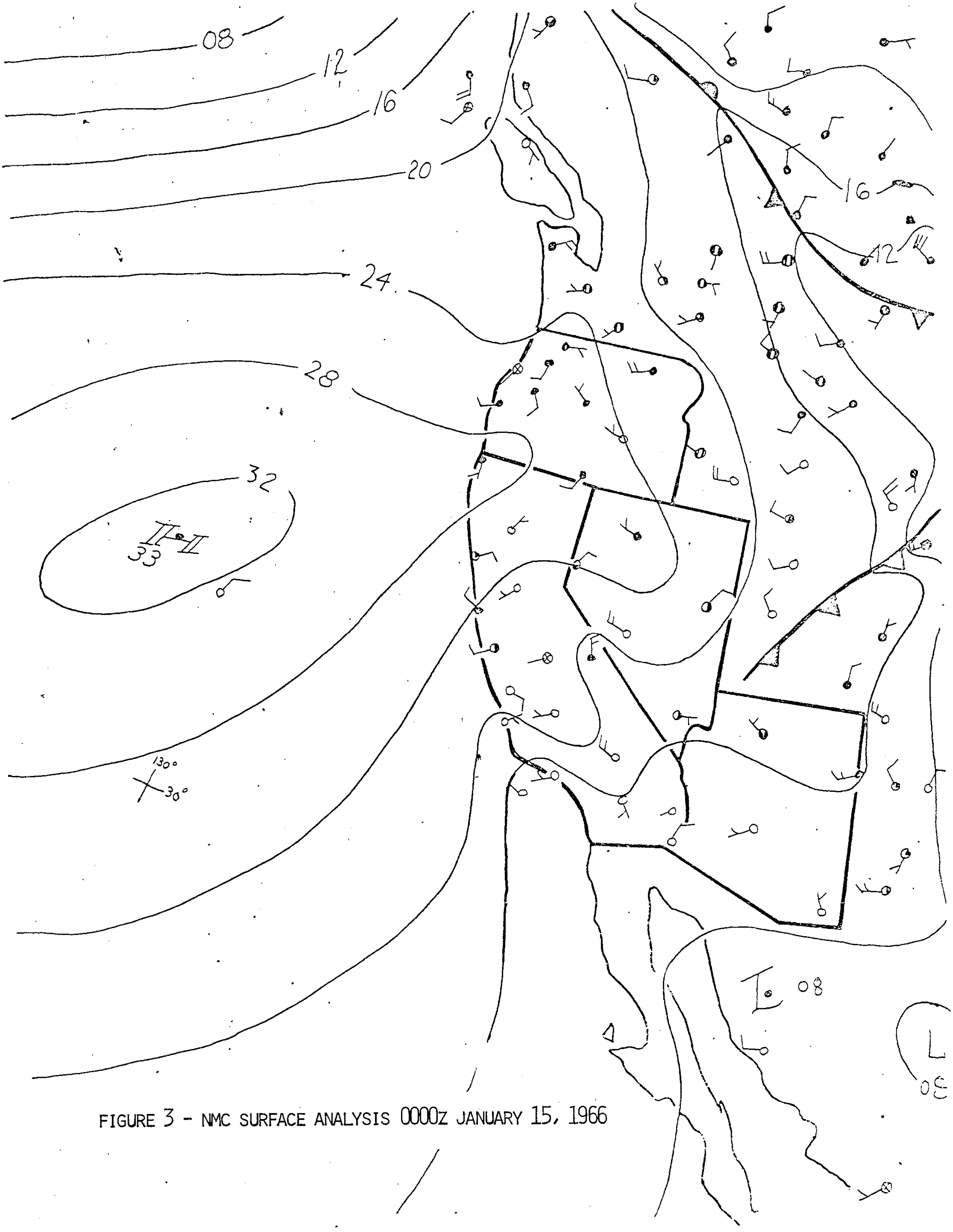


FIGURE 3 - NMC SURFACE ANALYSIS 0000Z JANUARY 15, 1966

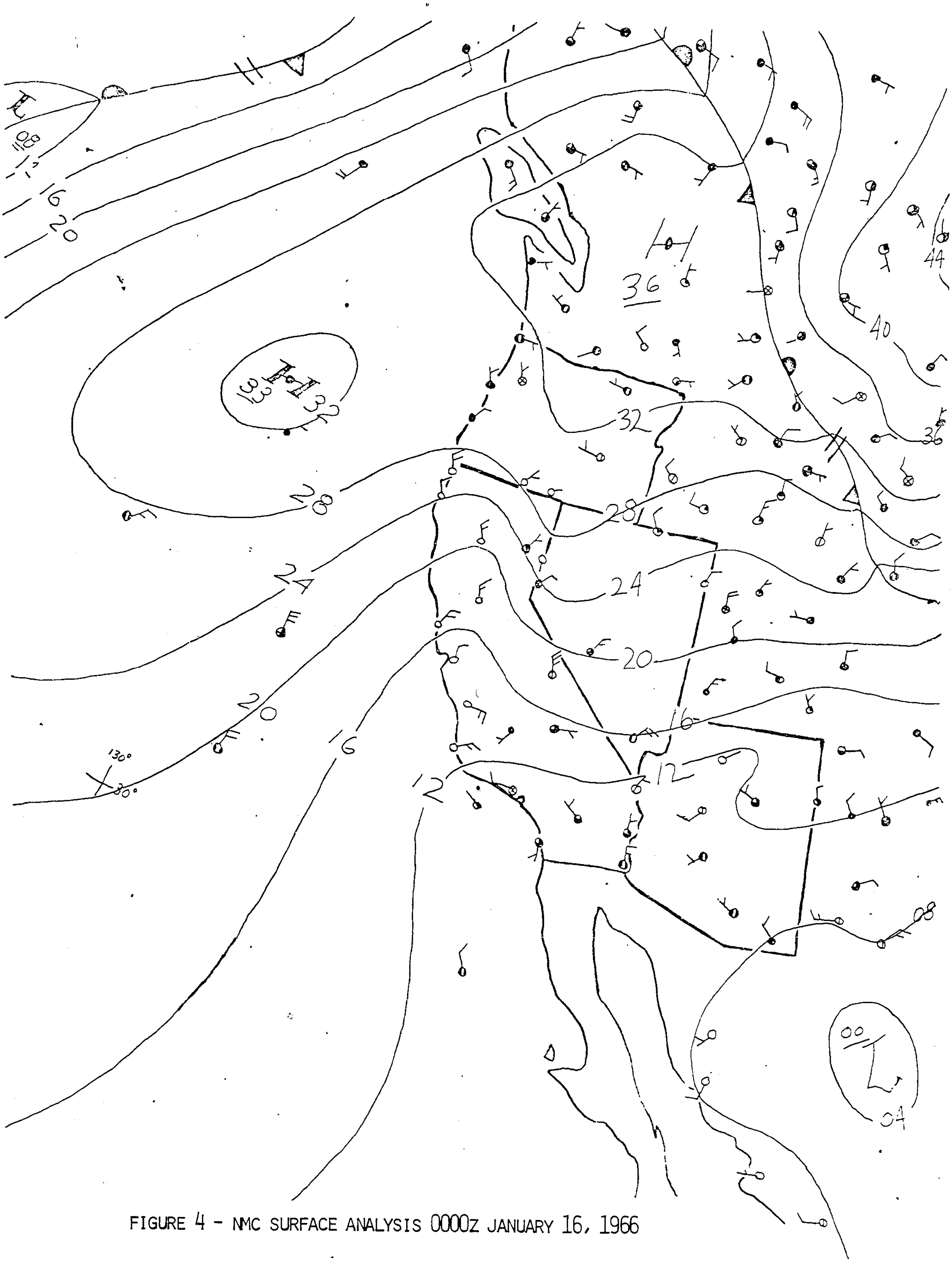


FIGURE 4 - NMC SURFACE ANALYSIS 0000Z JANUARY 16, 1966

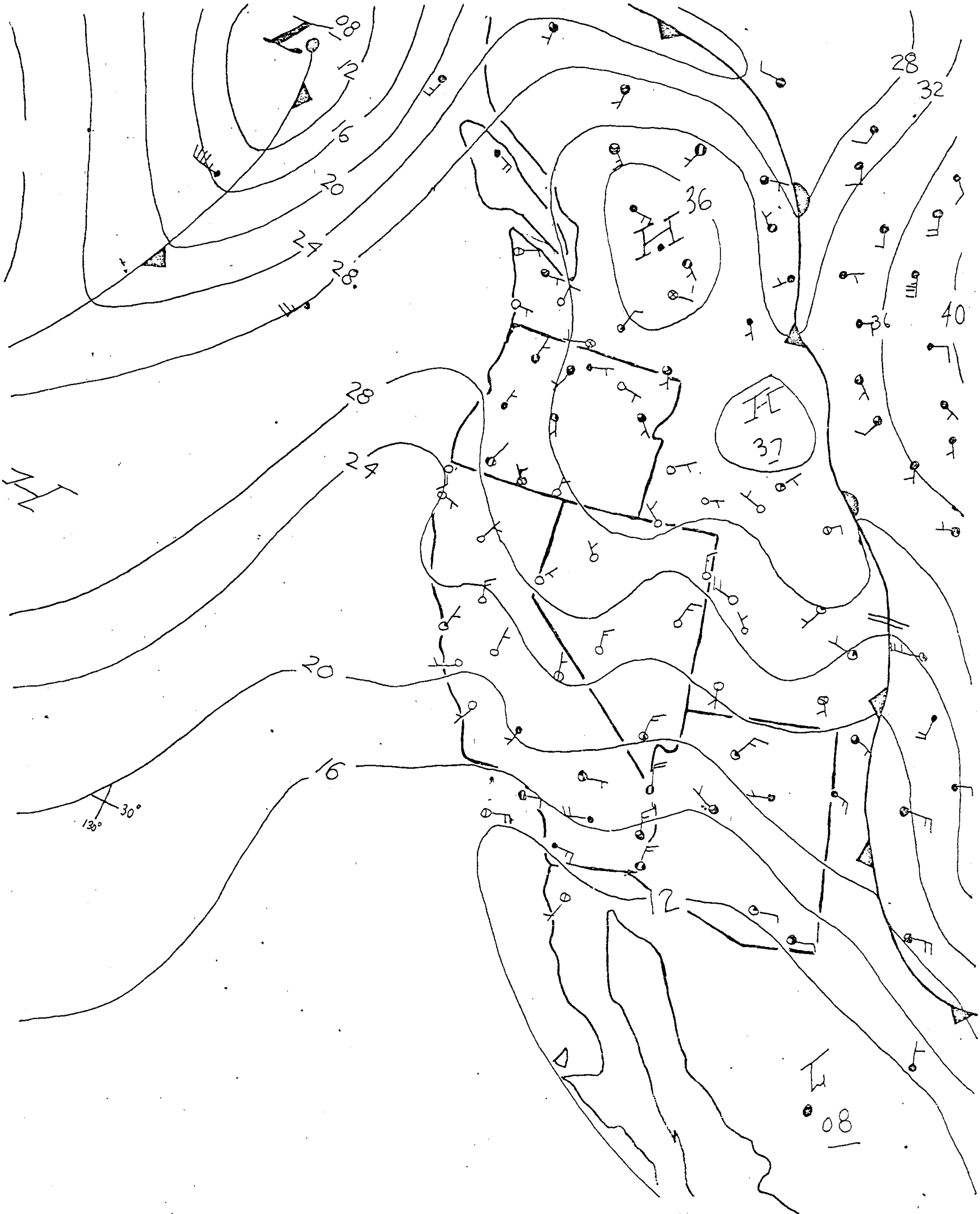


FIGURE 5 - NMC SURFACE ANALYSIS 1800Z JANUARY 16, 1966

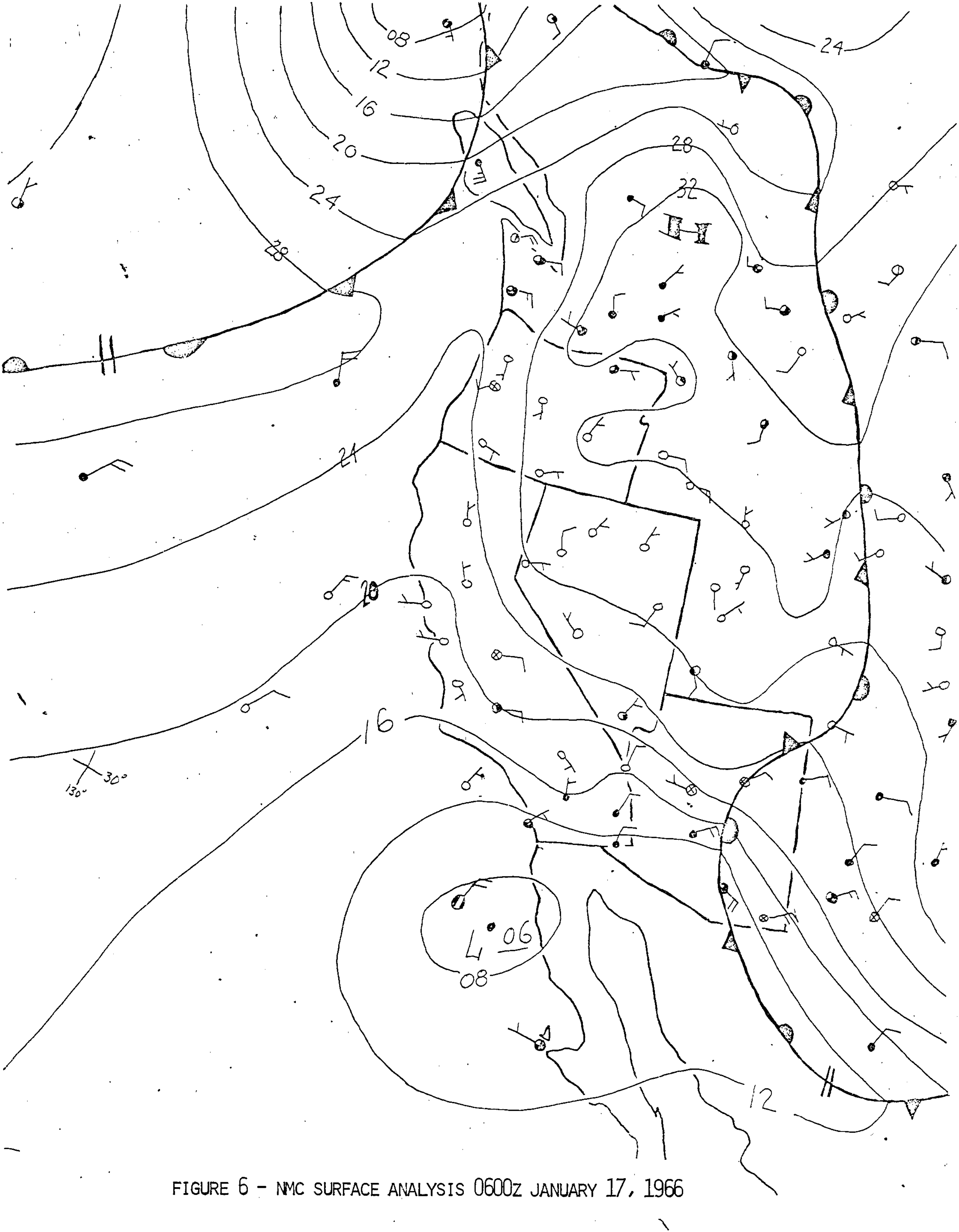


FIGURE 6 - NMC SURFACE ANALYSIS 0600Z JANUARY 17, 1966

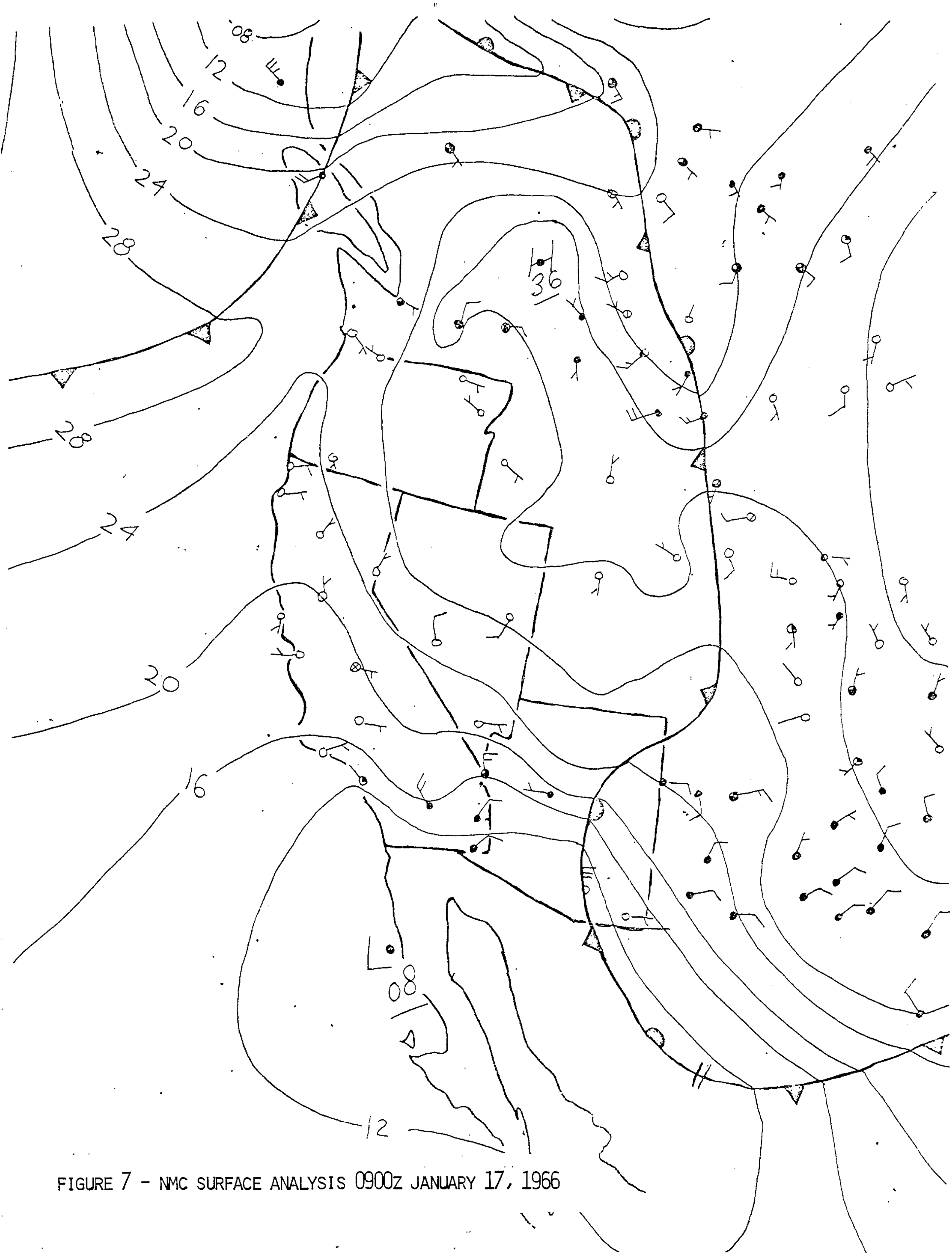


FIGURE 7 - NMC SURFACE ANALYSIS 0900Z JANUARY 17, 1966

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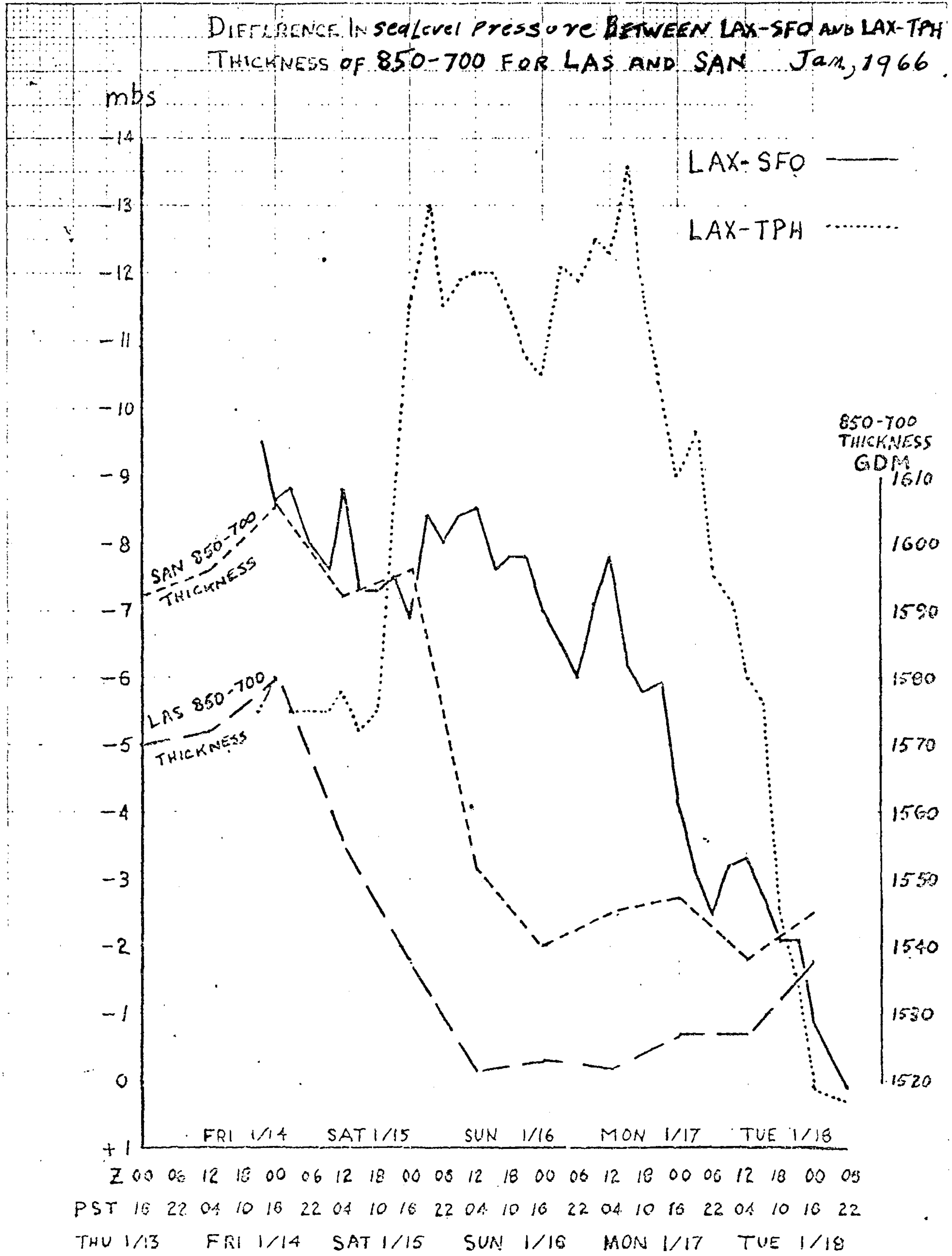

FIGURE 8 - DIFFERENCE IN SEA-LEVEL PRESSURE LAX - SFO AND LAX - TPH, 850- 700-MB THICKNESS FOR LAS AND SAN, JANUARY 13 - 18, 1966

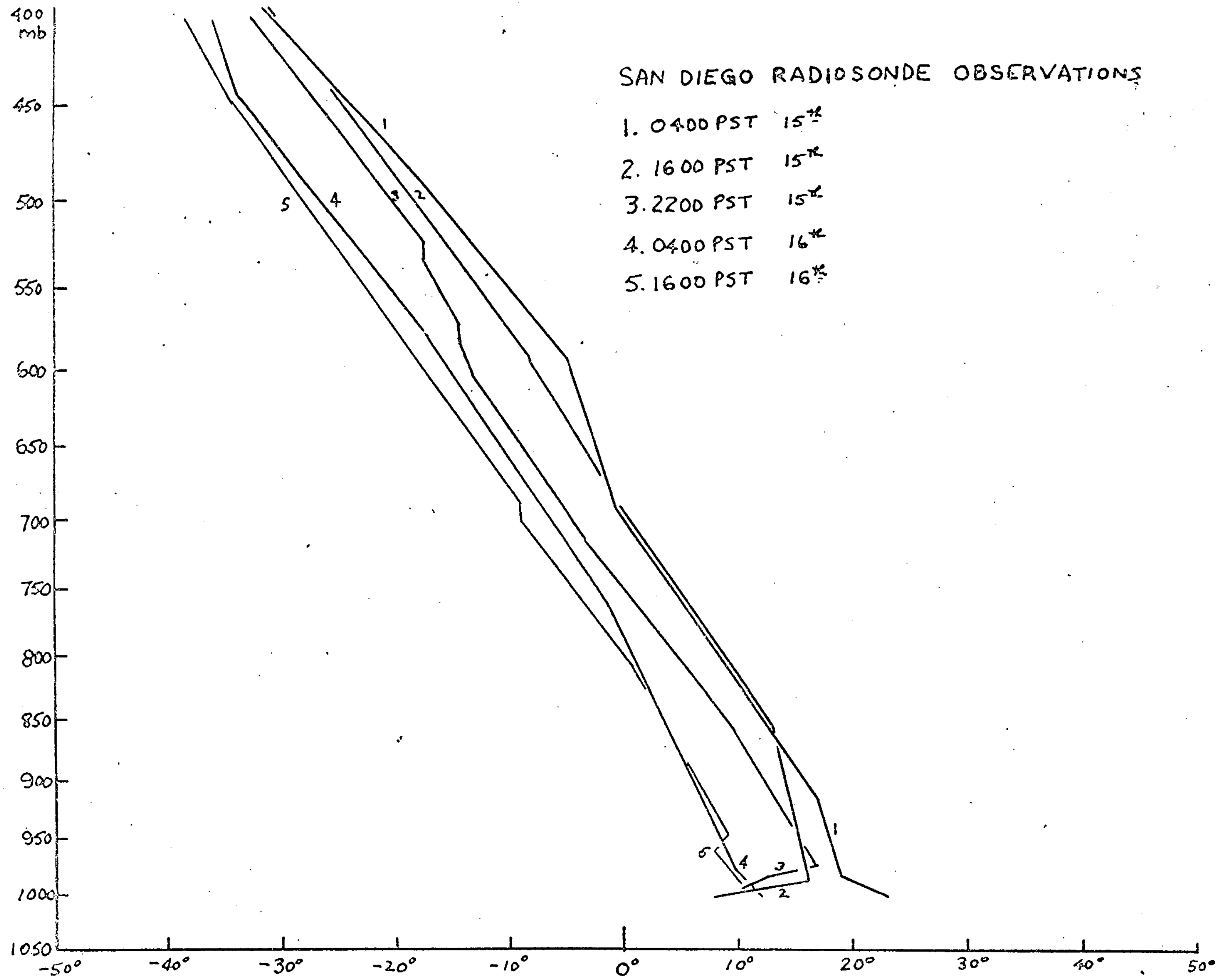

FIGURE 9 - SAN DIEGO RADIOSONDE OBSERVATIONS, JANUARY 15 - 16, 1966

WB Form 300-1 (Formerly 4-566) SKETCH OF PREMISES 317 U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU

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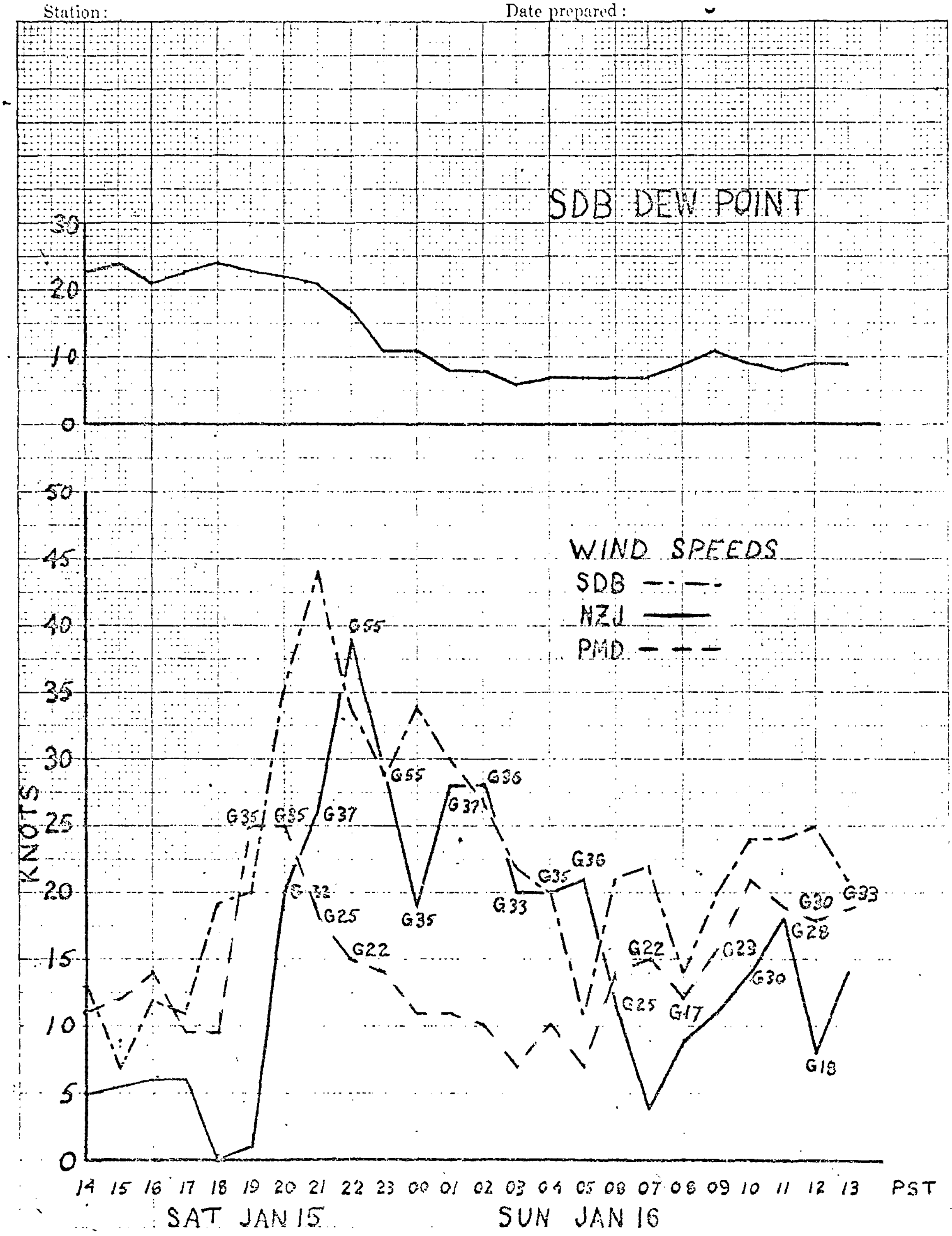

FIGURE 10 - SANDBERG DEWPOINT, SANDBERG, EL TORO, AND PALMDALE WIND SPEEDS, JANUARY 15 -16, 1966

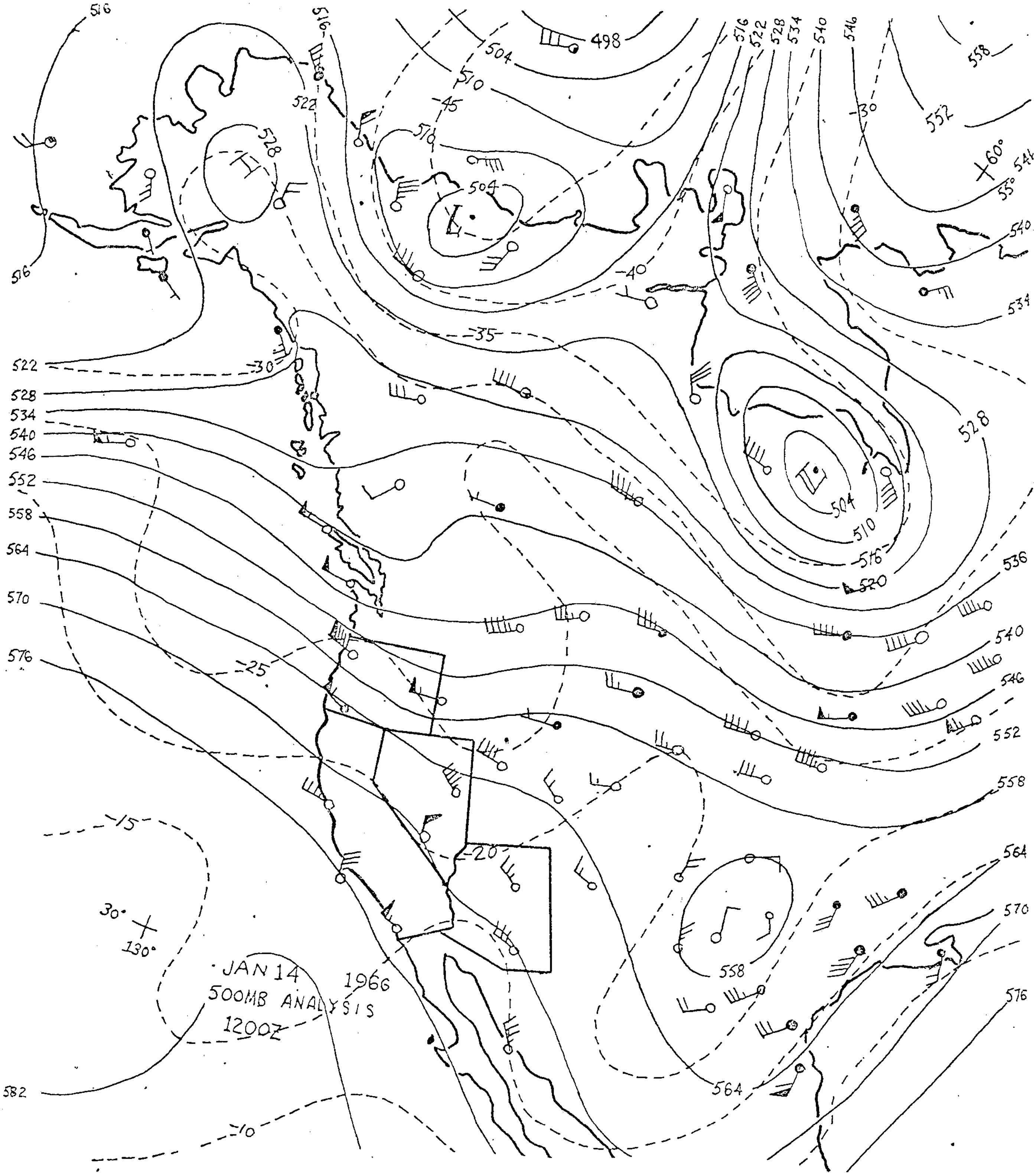

FIGURE 11 - 500-MB ANALYSIS - 1200Z JANUARY 14, 1966

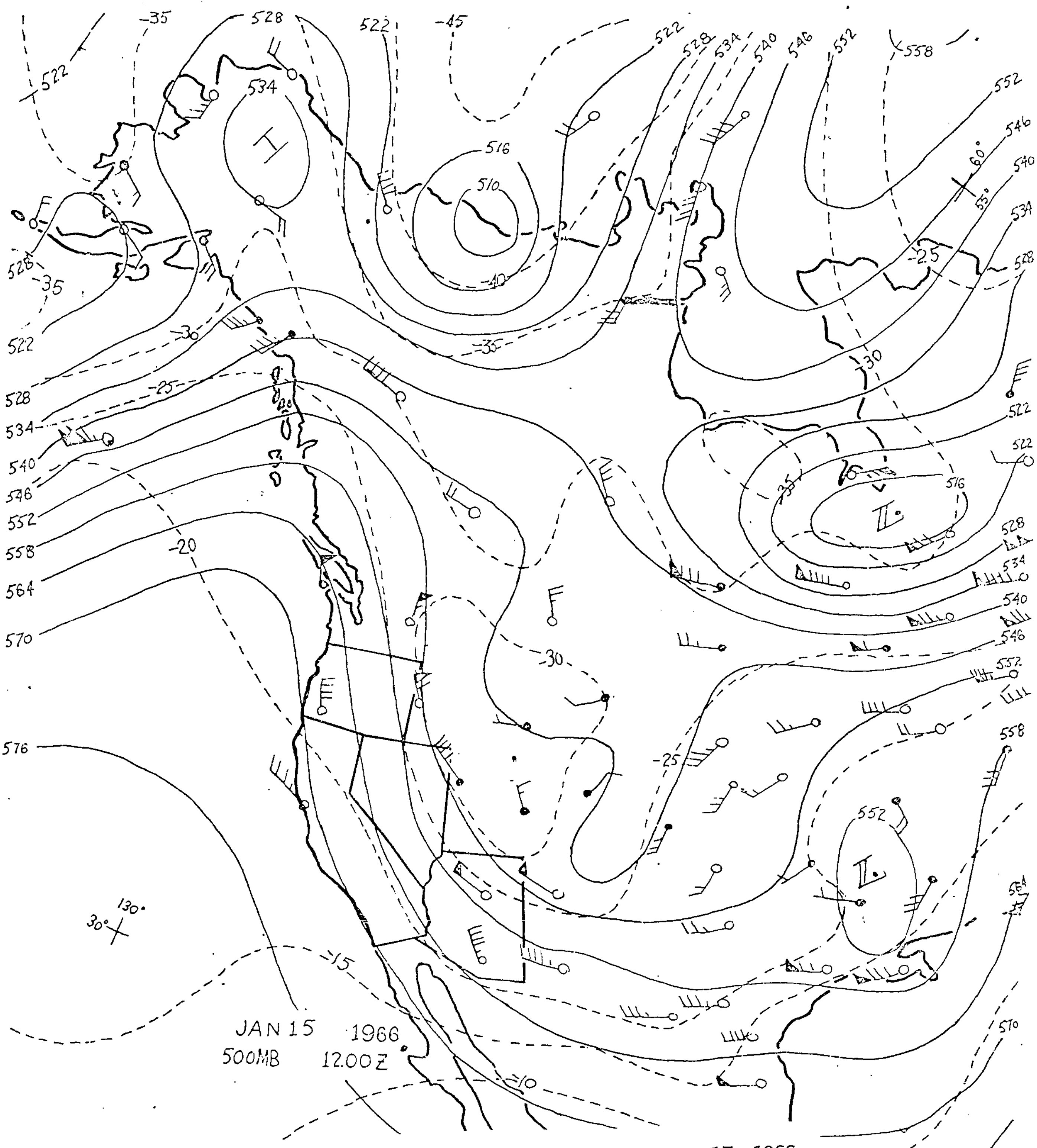

FIGURE 12 - 500-MB ANALYSIS - 1200Z JANUARY 15, 1966

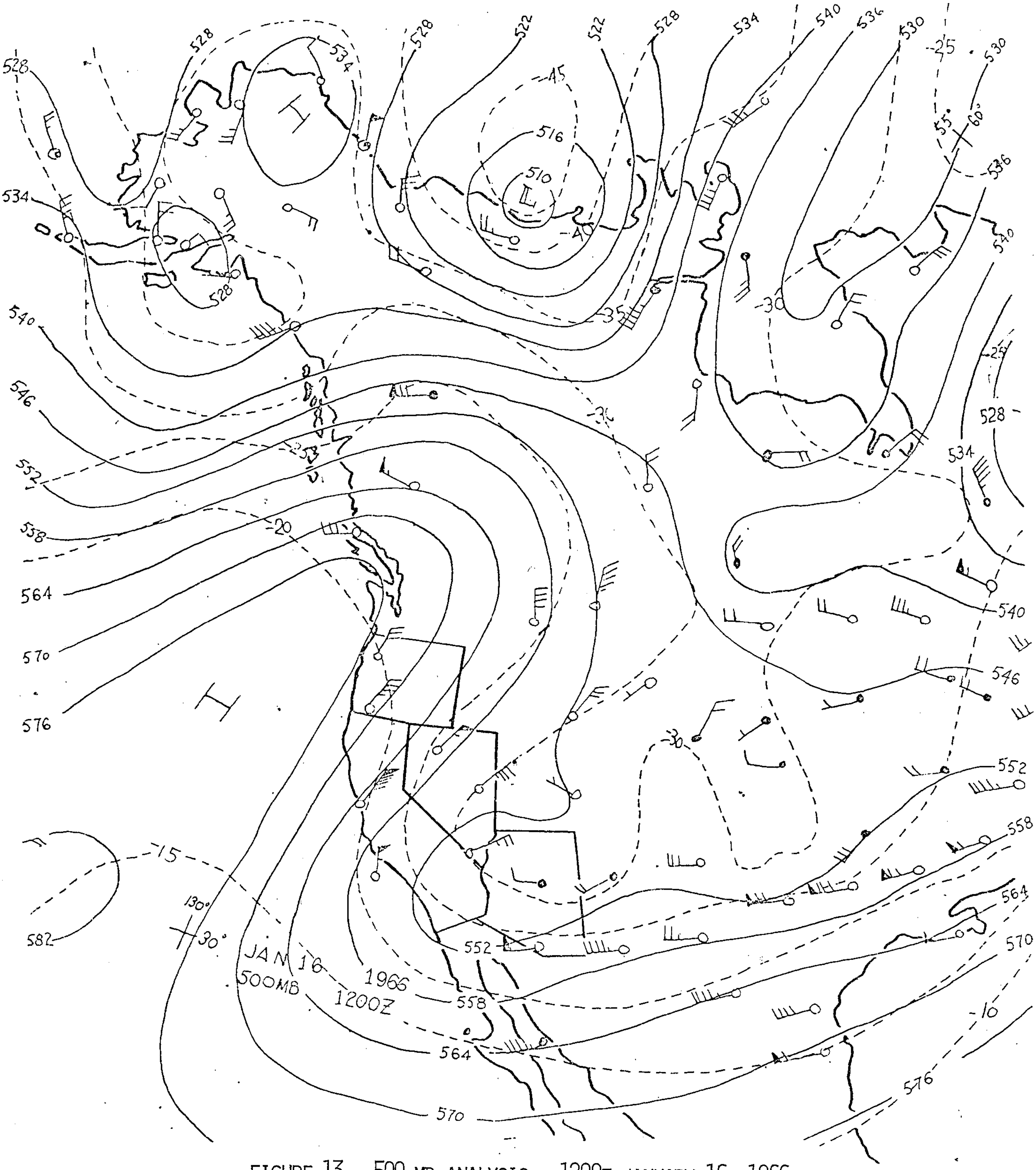

FIGURE 13 - 500-MB ANALYSIS - 1200Z JANUARY 16, 1966

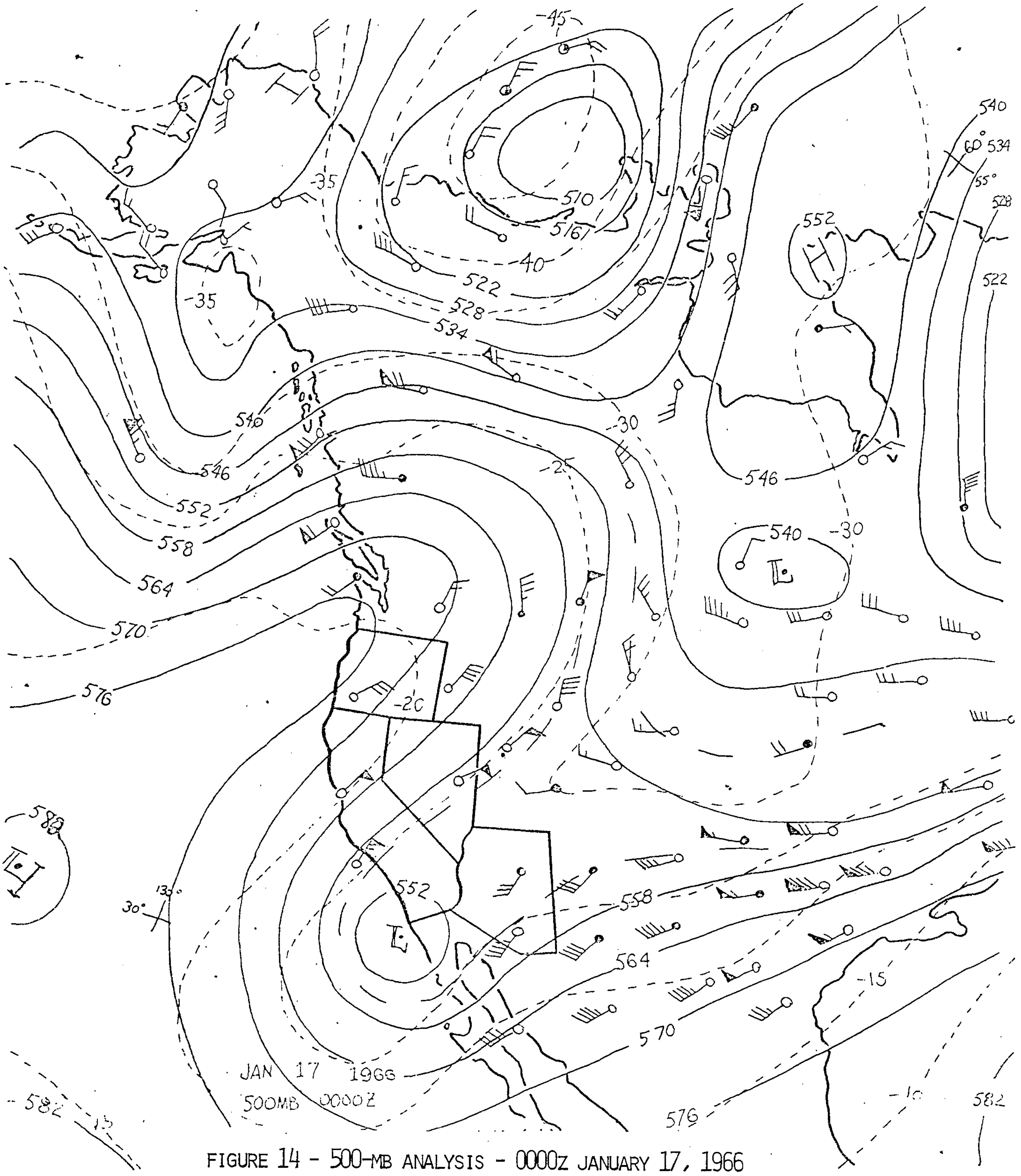

FIGURE 14 - 500-MB ANALYSIS - 0000Z JANUARY 17, 1966

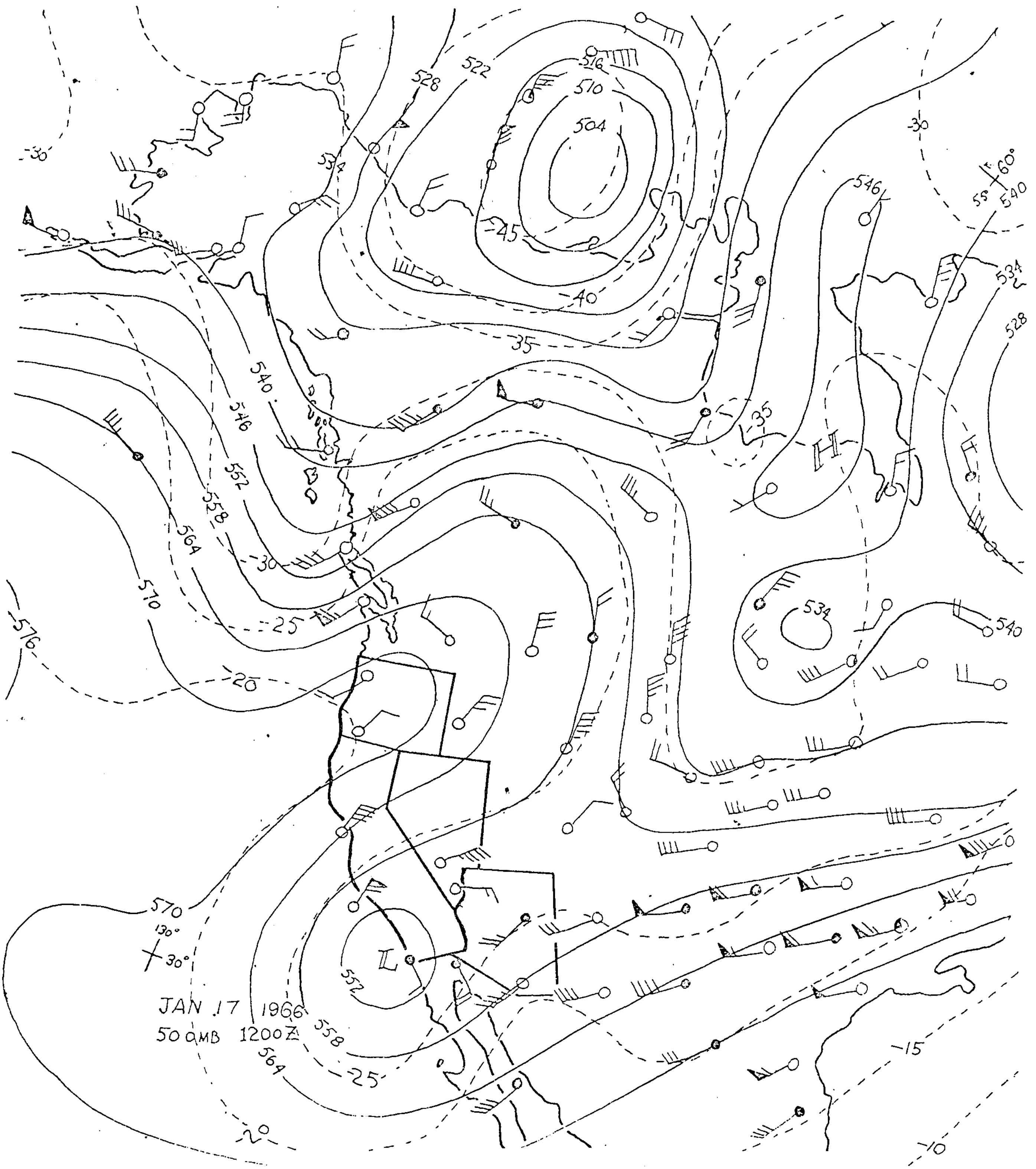

FIGURE 15 - 500-MB ANALYSIS - 1200Z JANUARY 17, 1966

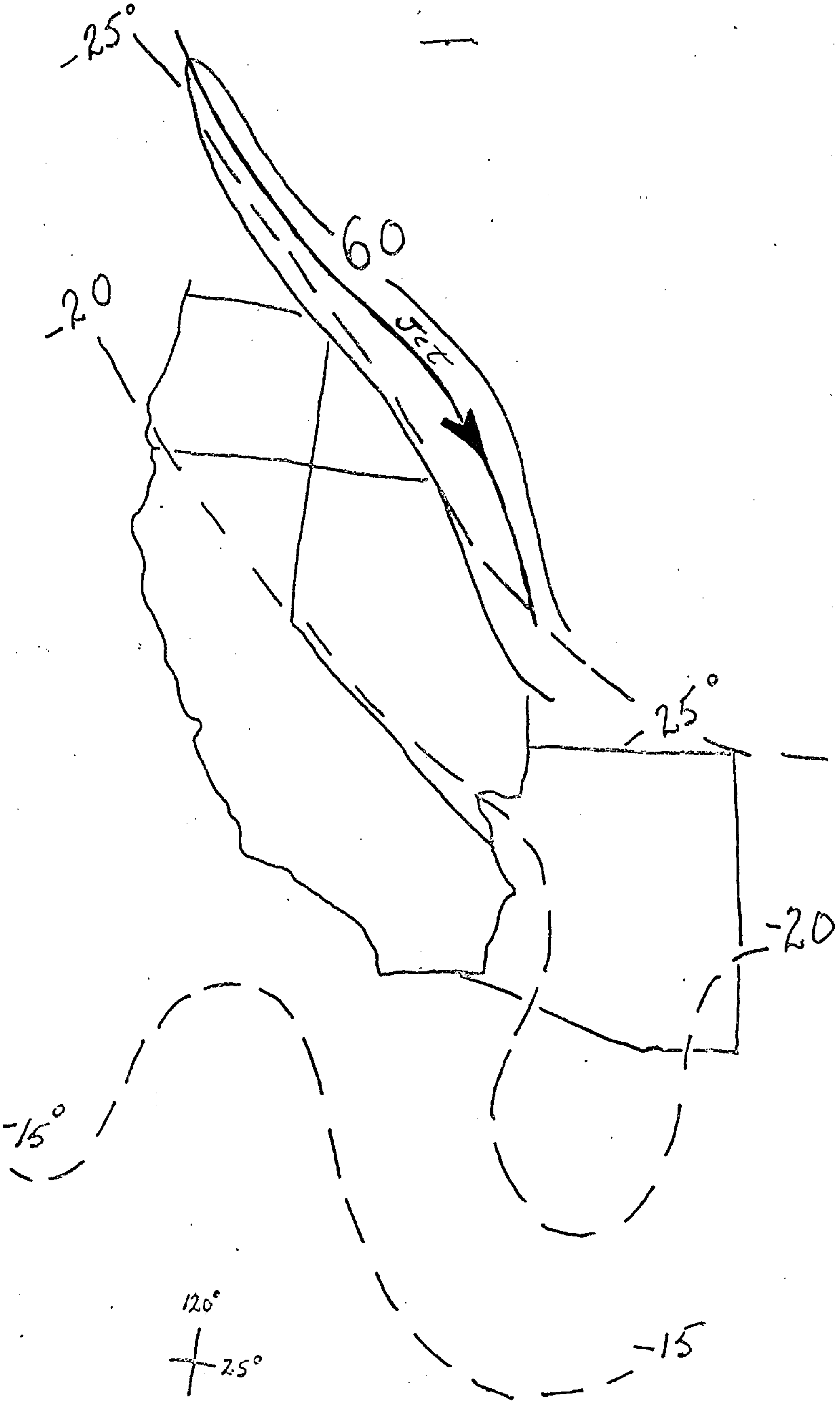

FIGURE 16 - 500-MB ISOTHERMS AND JET STREAM - 0000Z JANUARY 15, 1966

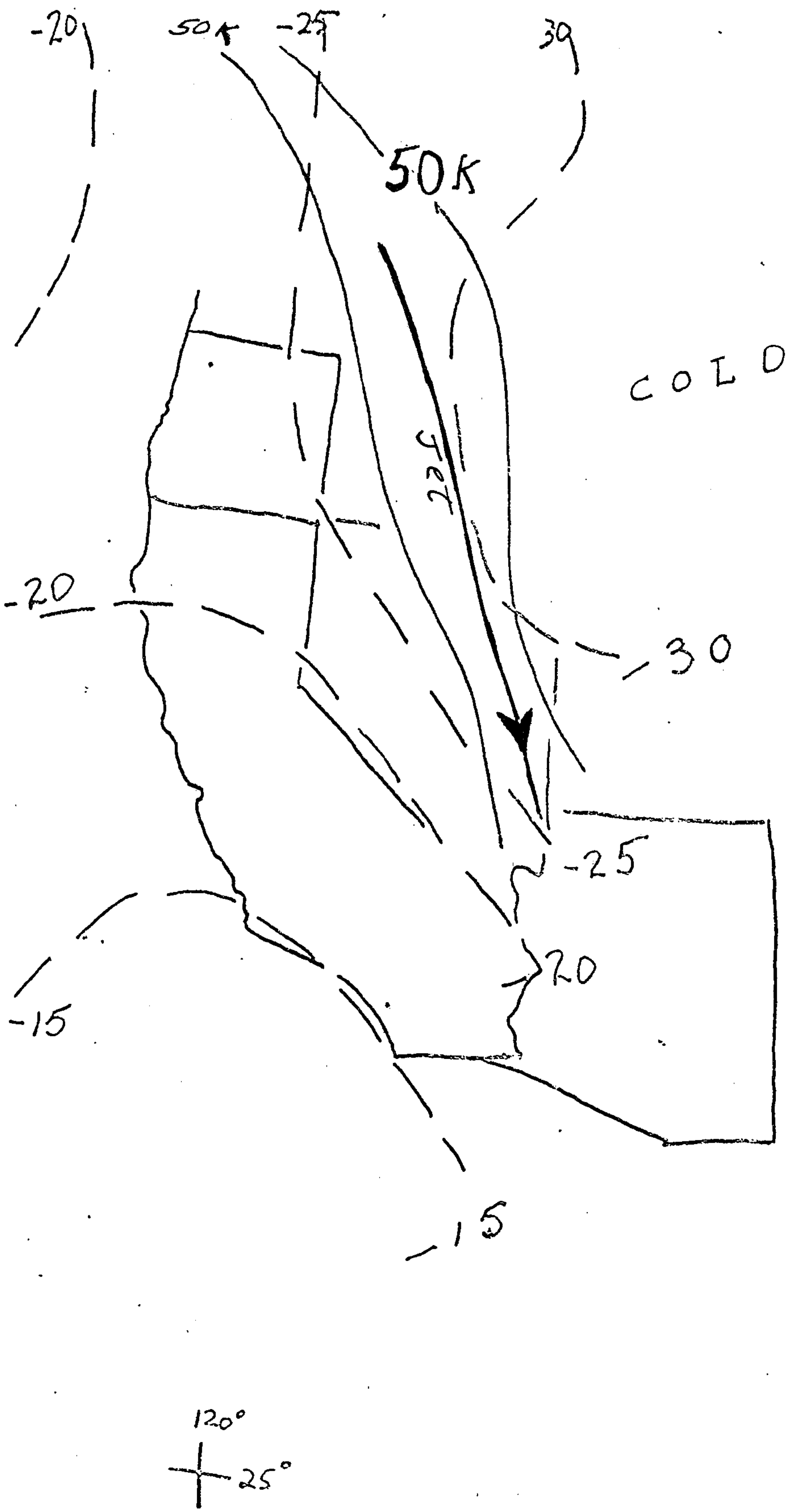

FIGURE 17 - ISOTHERMS AND JET STREAM - 1200Z JANUARY 15, 1966

1

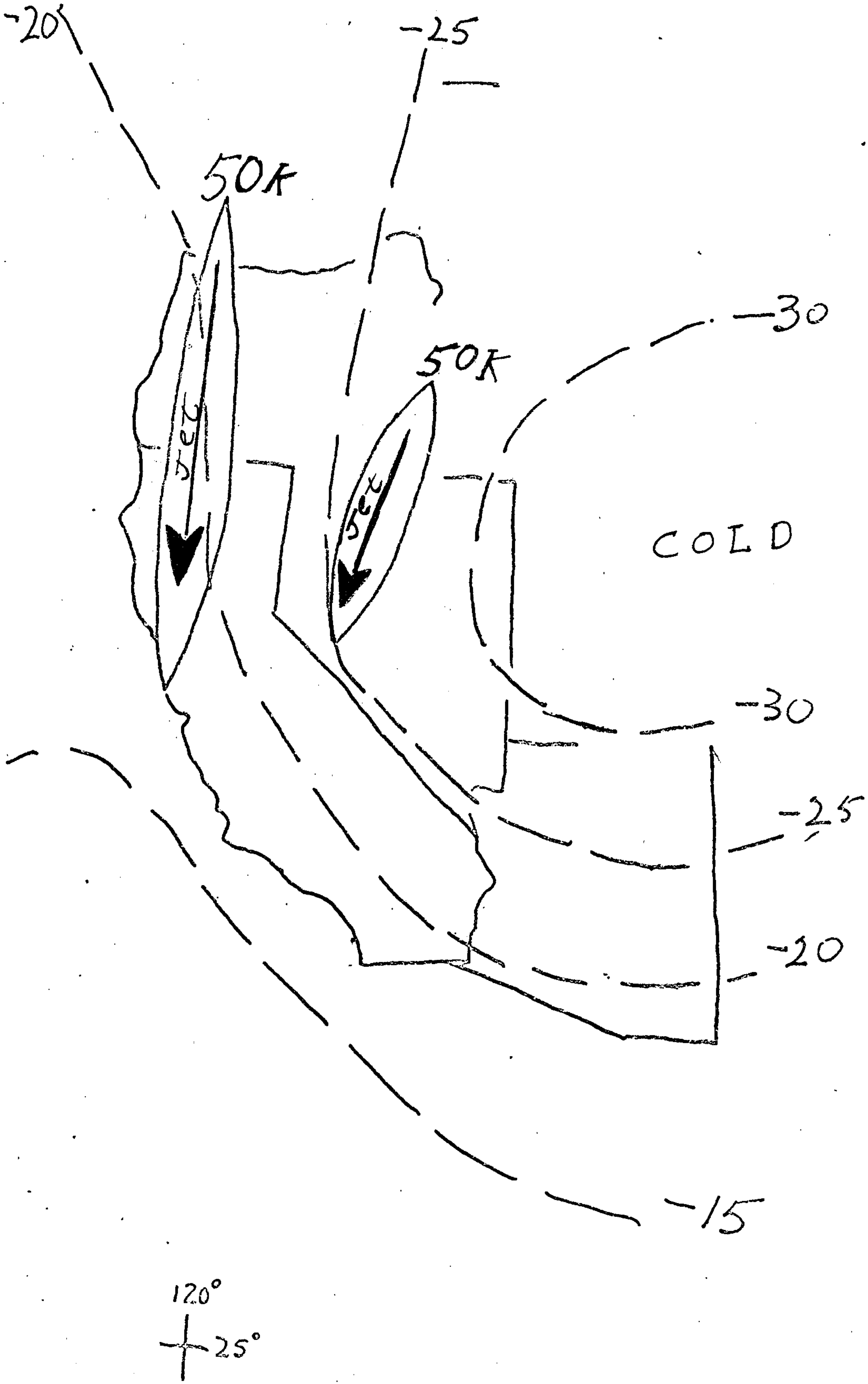

FIGURE 18 - 500-MB ISOTHERMS AND JET STREAM - 0000Z JANUARY 16, 1966

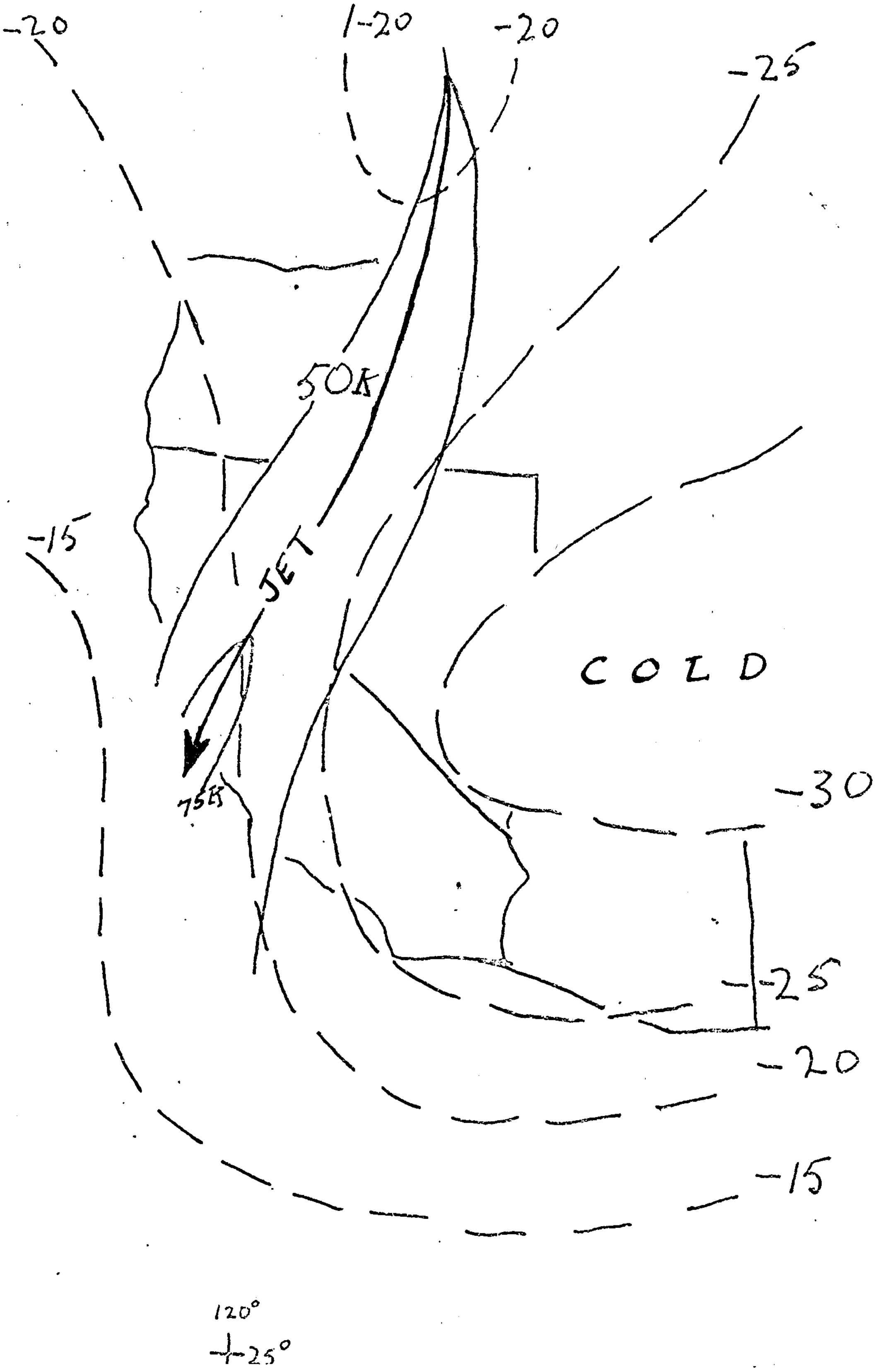

FIGURE 19 - 500-MB ISOTHERMS AND JET STREAM - 1200Z JANUARY 16, 1966

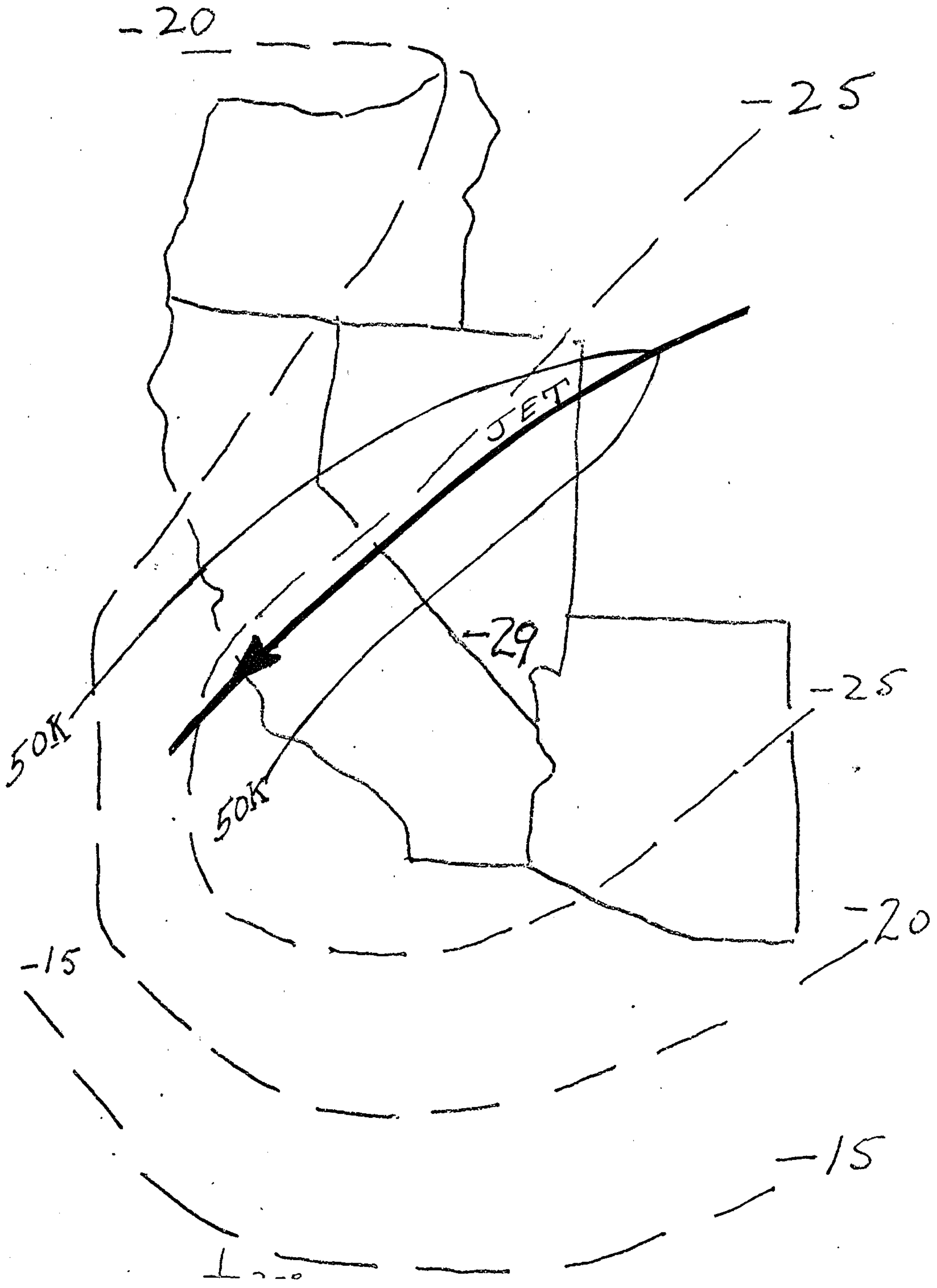

FIGURE 20 - 500-MB ISOTHERMS AND JET STREAM 0000Z JANUARY 17, 1966

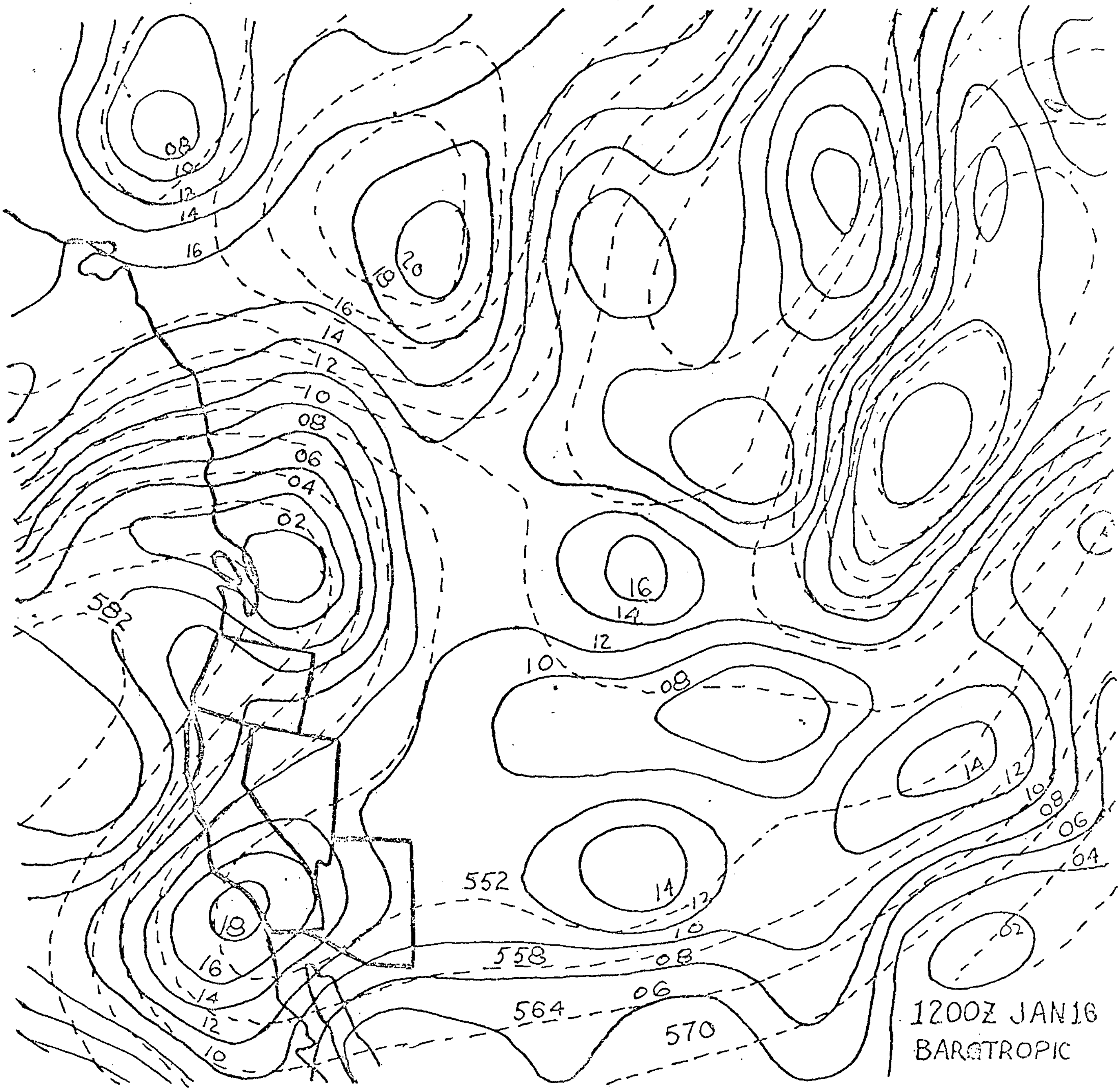

FIGURE 21 - 500-MB BAROTROPIC VORTICITY 1200Z JANUARY 16, 1966

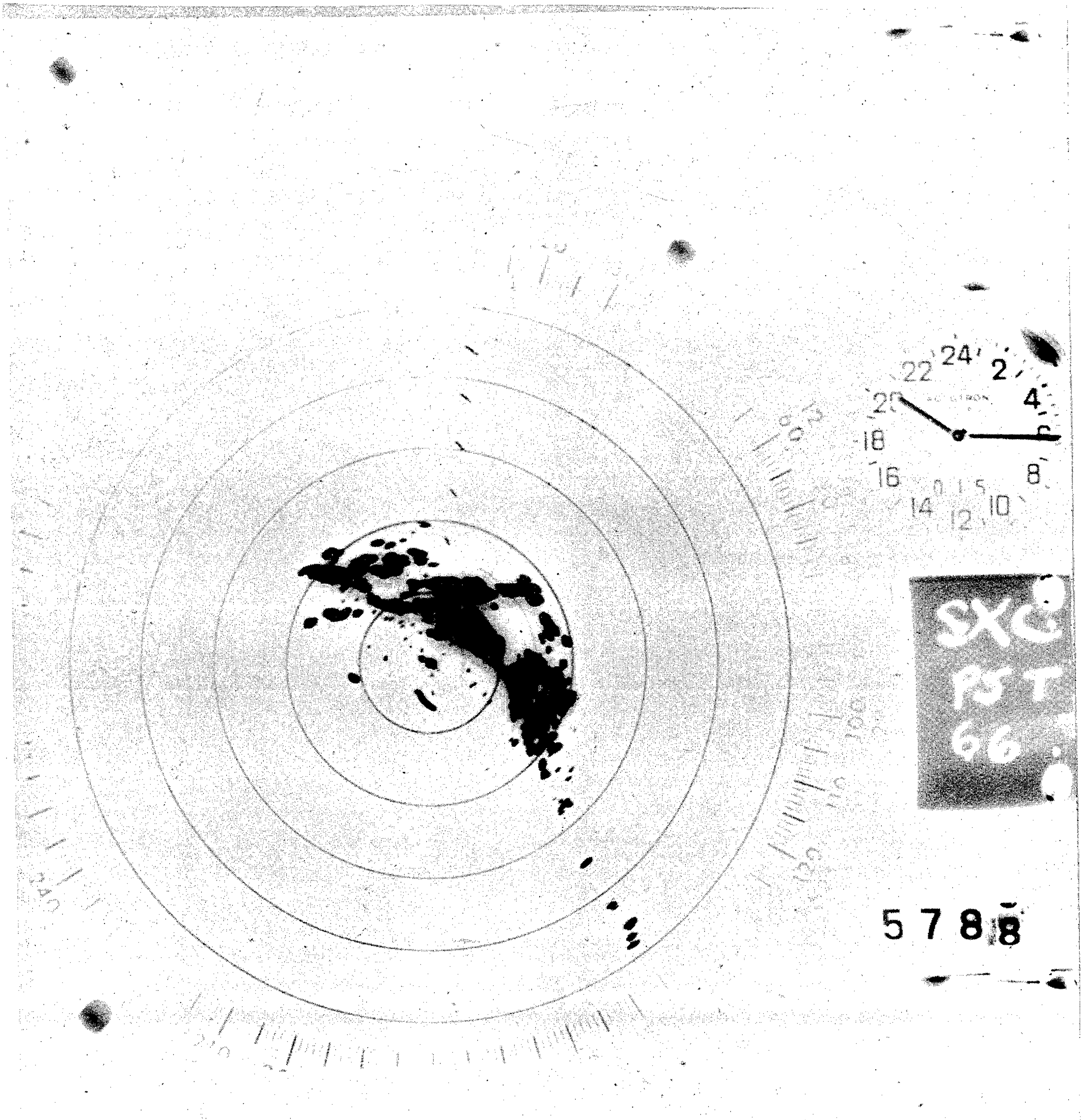

FIGURE 22 - CATALINA RADAR, 1916 PST, JANUARY 16, 1966

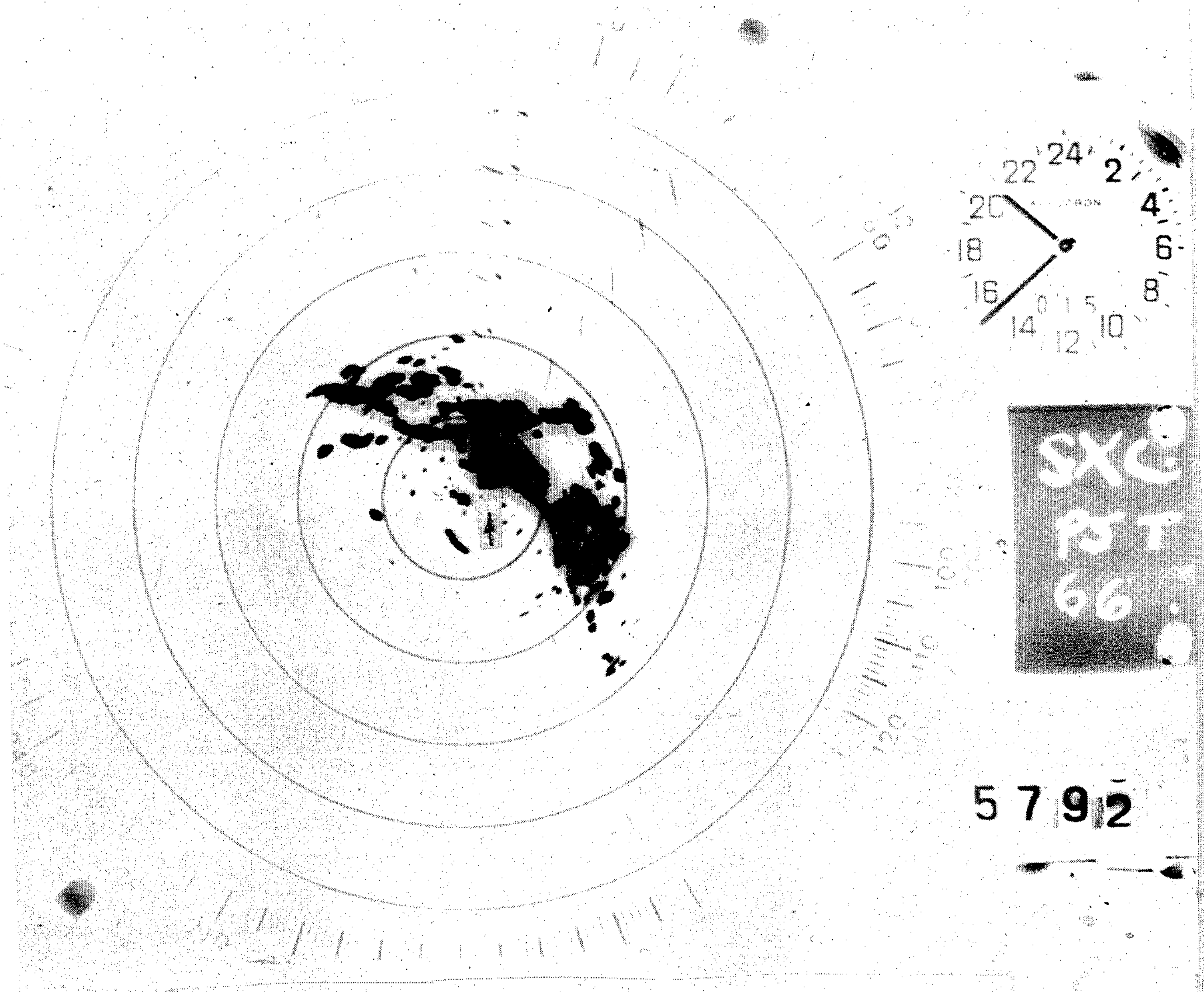

FIGURE 23 - CATALINA RADAR, 1938 PST, JANUARY 16, 1966

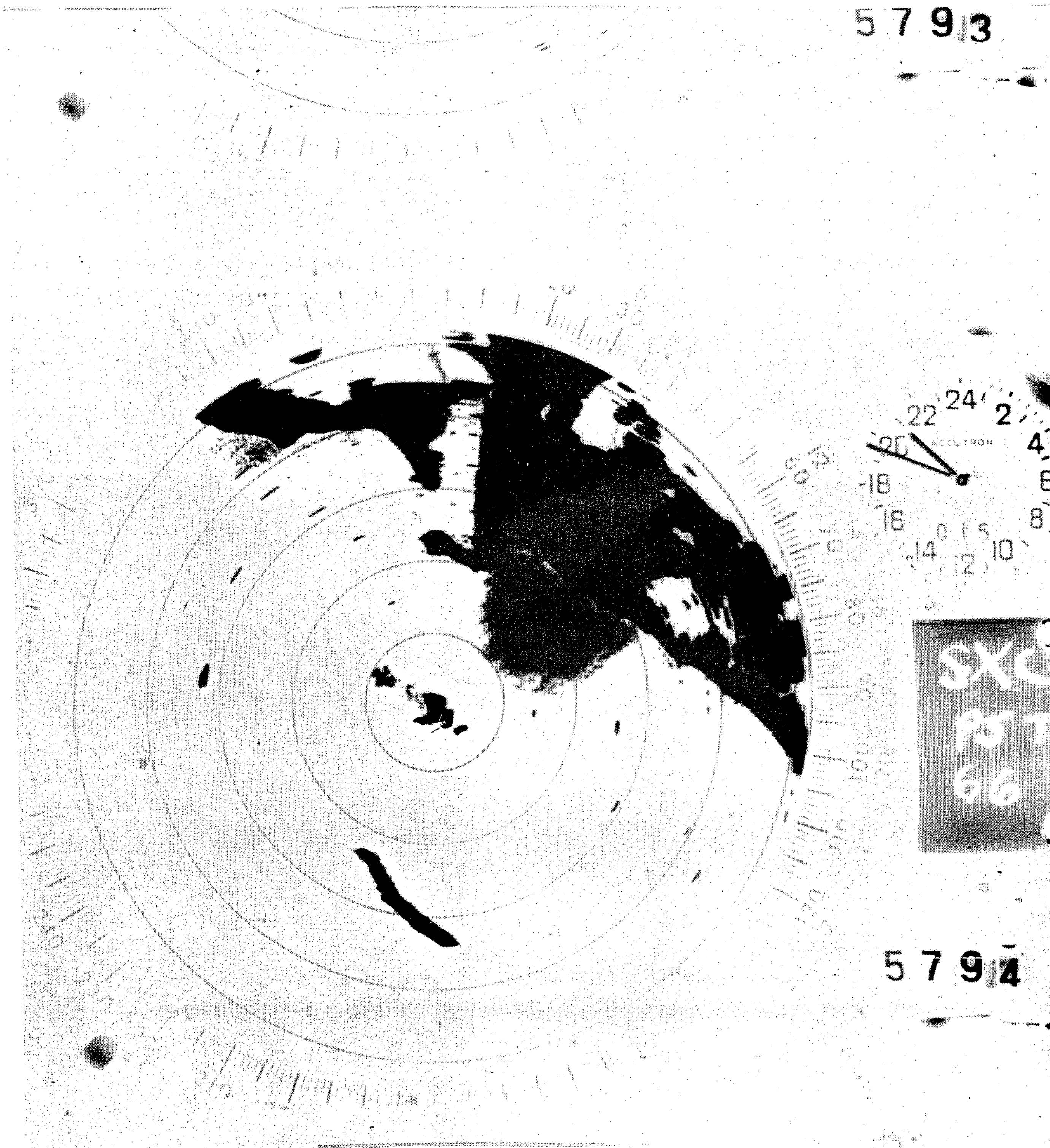

FIGURE 24 - CATALINA RADAR, 1948 PST, JANUARY 16, 1966

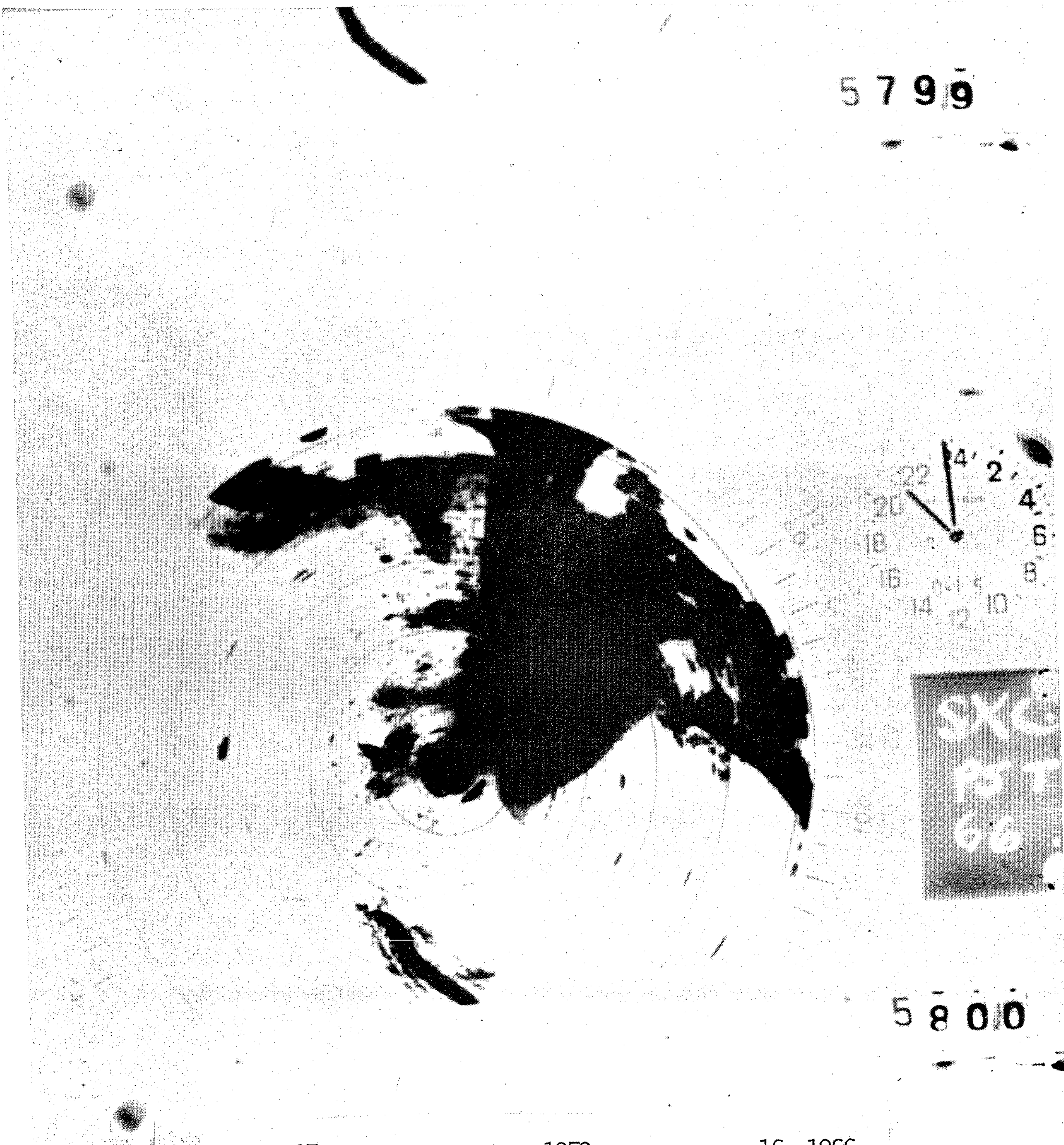

FIGURE 25 - CATALINA RADAR, 1959 PST, JANUARY 16, 1966

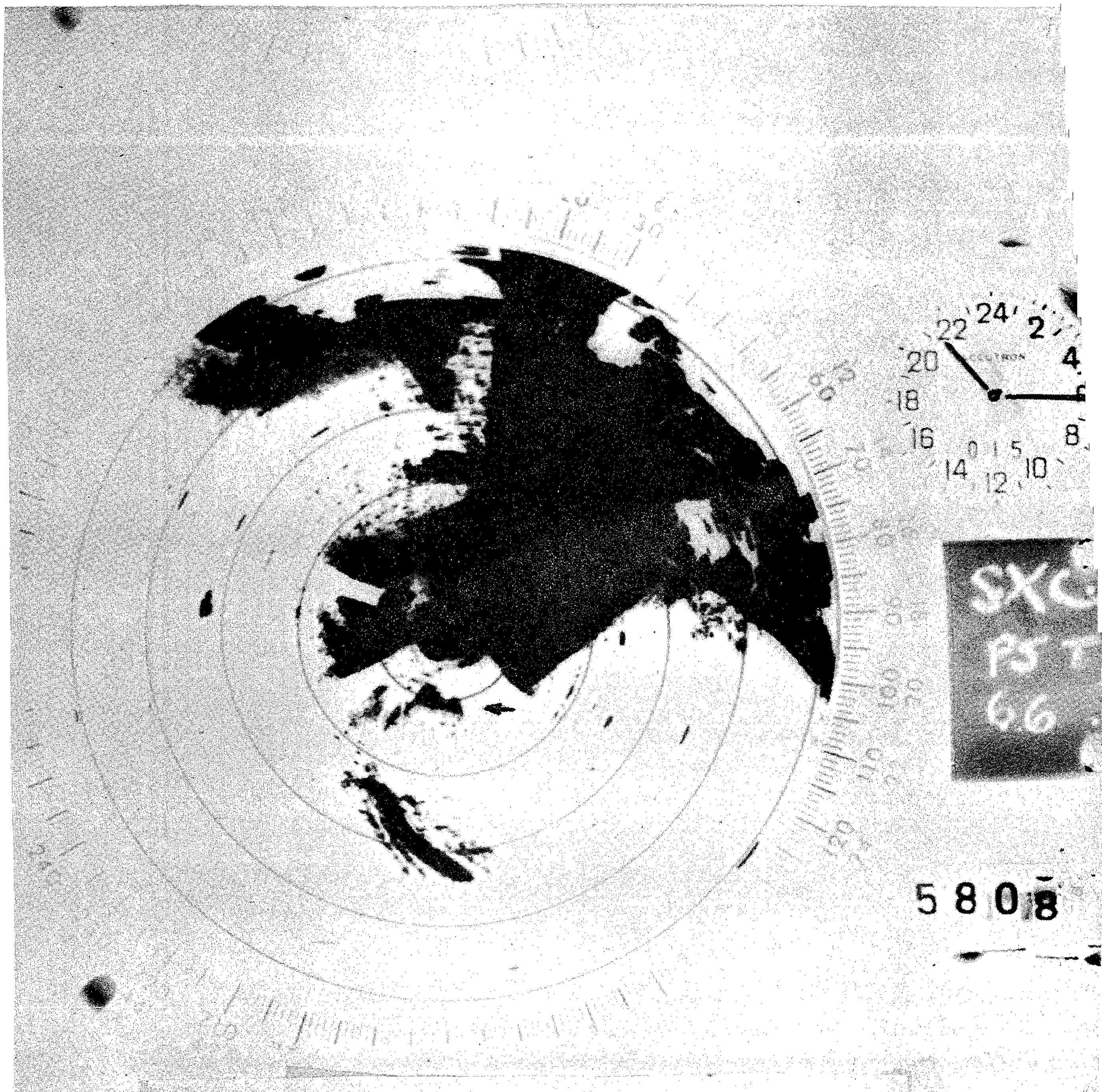

FIGURE 26 - CATALINA RADAR, 2015 PST, JANUARY 16, 1966

Western Region Technical Memoranda (Continued):

No. 24 Historical and Climatological Study of Grinnell Glacier, Montana. Richard A. Dightman. July 1967.

No. 25 Verification of Operational Probability of Precipitation Forecasts, April 1966 - March 1967. W. W. Dickey. October 1967.

No. 26 A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis. January 1968.

No. 27 Objective Minimum Temperature Forecasting for Helena, Montana. D. E. Olsen. February 1968.

No. 28** Weather Extremes. R. J. Schmidli. April 1968.

No. 29 Small-Scale Analysis and Prediction. Philip Williams, Jr. May 1968.

No. 30 Numerical Weather Prediction and Synoptic Meteorology. Capt. Thomas D. Murphy, U.S.A.F. May 1968.

No. 31 Precipitation Detection Probabilities by Salt Lake ARTC Radars. Robert K. Belesky. July 1968.

No. 32 Probability Forecasting. Harold S. Ayer. July 1968.

No. 33 Objective Forecasting. Philip Williams, Jr. August 1968.

No. 34 The WSR-57 Radar Program at Missoula, Montana. R. Granger. October 1968.

No. 35 Joint ESSA/FAA ARTC Radar Weather Surveillance Program. Herbert P. Benner and DeVon B. Smith. December 1968.

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No. 38 Climate of Phoenix, Arizona. R. J. Schmidli, P. C. Kangieser, and R. S. Ingram. April 1969.

No. 39 Upper-Air Lows Over Northwestern United States. A. L. Jacobson. April 1969.

No. 40 The Man-Machine Mix in Applied Weather Forecasting in the 1970s. L. W. Snellman. August 1969.

No. 41 High Resolution Radiosonde Observations. W.W. Johnson. August 1969.