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THE TROPICAL UPPER TROPOSPHERIC TROUGH AS A SECONDARY SOURCE OF TYPHOONS AND A PRIMARY SOURCE OF TRADEWIND DISTURBANCES

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Project 6698
Task 669802

FINAL REPORT

Period Covered: 1 February 1964 thru 31 January 1967

March 1967

Contract Monitor: Thomas Keegan

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Prepared for
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
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ABSTRACT

Surface and 250 mb analyses for a 9-day summer period over the North Pacific, together with satellite photographs, are shown to illustrate (1) the development of a typhoon and a tropical storm from cyclonic cells in the tropical upper tropospheric trough, and (2) the dominance of the trough in producing tradewind weather.

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1. Introduction

The summertime upper tropospheric trough was first depicted as a climatological feature of the tropical North Pacific Ocean by Dean (1956) in analyses of the monthly mean 30,000-foot resultant winds for 1955. His analyses were for the Pacific Ocean westward of the Hawaiian Islands (155W). He called it the North Pacific trough. Ramage (1959) used mean resultant winds and mean latitudinal pressure height profiles at 200 mb to show that a summer upper trough exists in the Mid-Pacific from Alaska to Indonesia but is not a feature of the eastern North Pacific or the North Atlantic. He named it the Mid-Pacific trough. Sadler (1963a) utilized meteorological satellite photographs and increased wind observations from jet aircraft to show that the summer upper trough is a dominant circulation feature of the entire North Pacific and North Atlantic Oceans. Aspliden _et al_. (1966) analyzed averaged wind observations from jet aircraft over the North Atlantic during August 1963 and found the upper trough to be a climatological feature across the North Atlantic from Spain through the Gulf of Mexico. The summer upper tropospheric trough is also an important feature in the Southern Hemisphere (Dean, 1956; Sadler, 1966) but is not as well defined or persistent.

The tropical upper tropospheric trough (TUTT) over the North Pacific is commonly referred to as the Mid-Pacific trough (MPT) after Ramage. Through support of this Contract and the prior AFCRL Contract No. AF 19(604)-6156, considerable emphasis has been placed on this upper trough. Sadler (1964) has shown that its role in maintaining a steady southwesterly current in the upper troposphere over the Hawaiian Islands is a major factor in protecting this area from hurricanes which track westward from the developing region southwest of Mexico.

Sadler (1963b), by examining the satellite pictures of the early stages of Western Pacific storms during the summer season, discovered that some of the cloud vortices had an anomalous appearance and were observed as vortices by the satellite before having an obvious surface circulation. These storms were north of 20N and had erratic tracks in relation to the majority of typhoon tracks.

Shiroma and Sadler (1965) presented a case history of typhoon development from a downward penetrating cyclonic cell within the trough, and showed the differences in the satellite-observed gross cloud features between the storms having initial development within the low-level trough and those developing from upper cyclonic cells which penetrate into the basic easterly current north of the low-level trough in the Western Pacific. They speculated that many of the tropical storms and typhoons had their initial origin from cells in the upper trough.

2. General Discussion

It is difficult, and in most cases impossible, to verify this difference in storm origin from the available conventional data. Figure 1 shows the approximate mean positions of the MPT and the low-level trough in August. They are close together in the western Pacific.

Storms which originate south of Guam between Kwajalein and Yap can usually be classified as forming in the low-level trough. Those originating north of Guam, in particular near 20N and northward, are more difficult to classify due to lack of conventional data. However, the satellite studies, referenced previously, strongly suggest that they have an origin from cells in the upper-level trough. Some indirect support of this difference in origin is also contained in the historical typhoon tracks. Figure 2 is a plot of typhoon tracks during the latter half of August for the twelve-year period 1953-1964 (JTWC, 1965). Two distinct types of tracks are shown. Tracks of typhoons which have their origin near the mean position of the low-level trough tend toward the west-northwest with little or no recurvature, whereas the tracks of typhoons whose origin is near 20N or northward (circled in Fig. 2) are more erratic and tend, initially, in a more northerly or even northeasterly direction. These differences in track have previously been attributed merely to the latitude of development. However, if the storms which form near 20N and northward originate in the low-level trough--which is simply displaced farther northward than normal--with all other considerations remaining equal there is no logical reason why all or even the majority should have an initial northerly track. The dominant circulation feature controlling the steering layer in the mid and upper troposphere would be the sub-tropical ridge which in mid-summer remains northward of 30N.

However, if the MPT extends into the western Pacific with sufficient intensity for cyclonic cell penetration to the surface, and subsequent storm development, the entire tropospheric flow is upset. Under these circumstances large meridional components around the cell and a broad westerly current to the south of the MPT exist in the upper troposphere in the latitudinal region 15N to 20N. Such conditions produce an entirely different "steering layer" and consequently different storm tracks.

There is an annual variation in the mean monthly position of the MPT, as shown by Figure 3. By utilizing the wind steadiness together with the wind direction and speed, it is possible to obtain its mean position to within about 5° of latitude and to ascertain its degree of extension into the extreme western Pacific, i.e., note the difference between July 1957 and July 1958. In addition to the seasonal and annual variations in the position and orientation of the MPT there is of course a daily or synoptic change. Cyclonic cells move along the trough, usually in a westward direction. These cells can be easily identified if they pass over or near an observing station

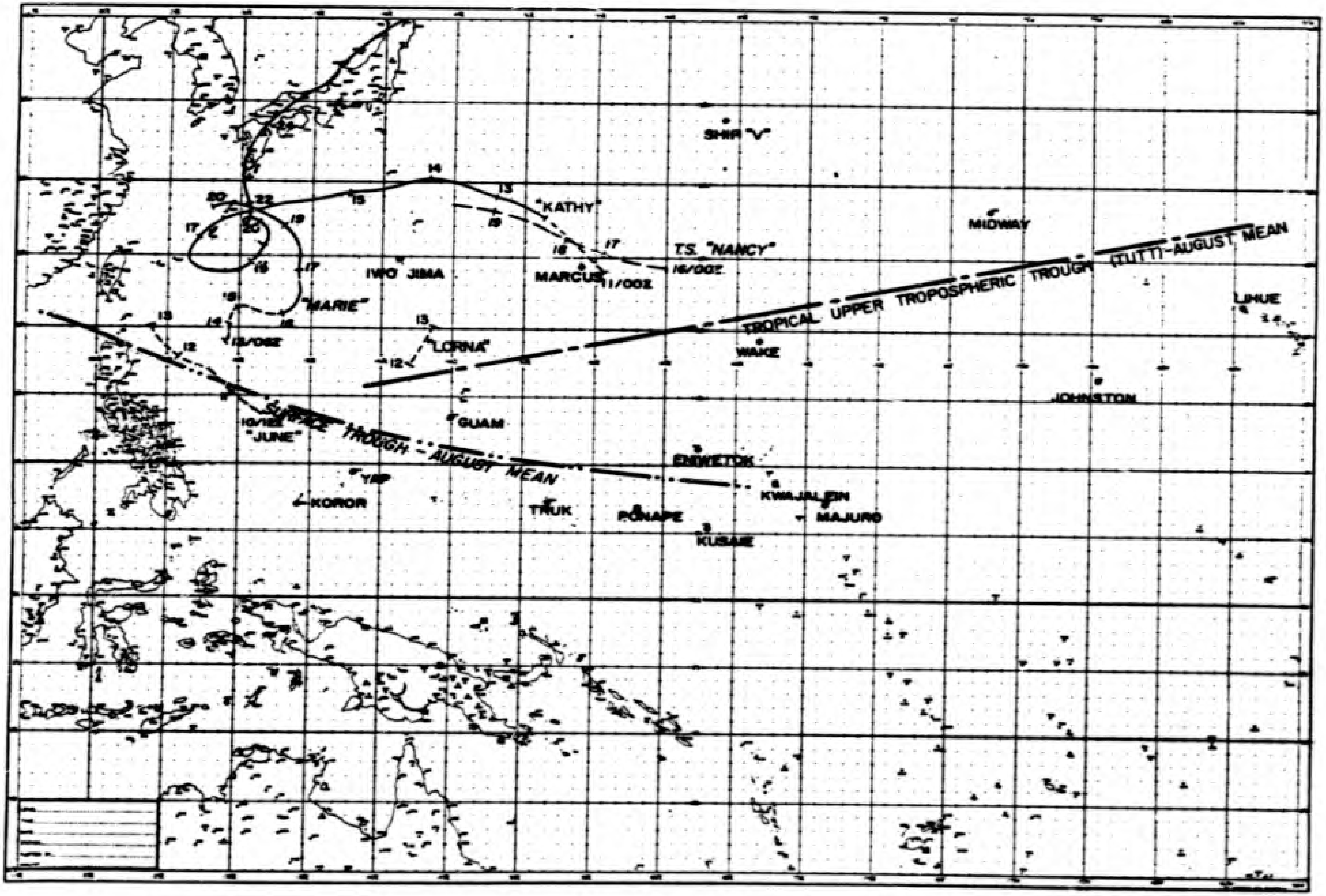

Fig. 1. Station locator; August mean position of low-level trough and upper-tropospheric trough; tracks of typhoons Marie and Kathy and tropical storms Nancy, June, and Lorna (Tracks from JTWC, 1965).

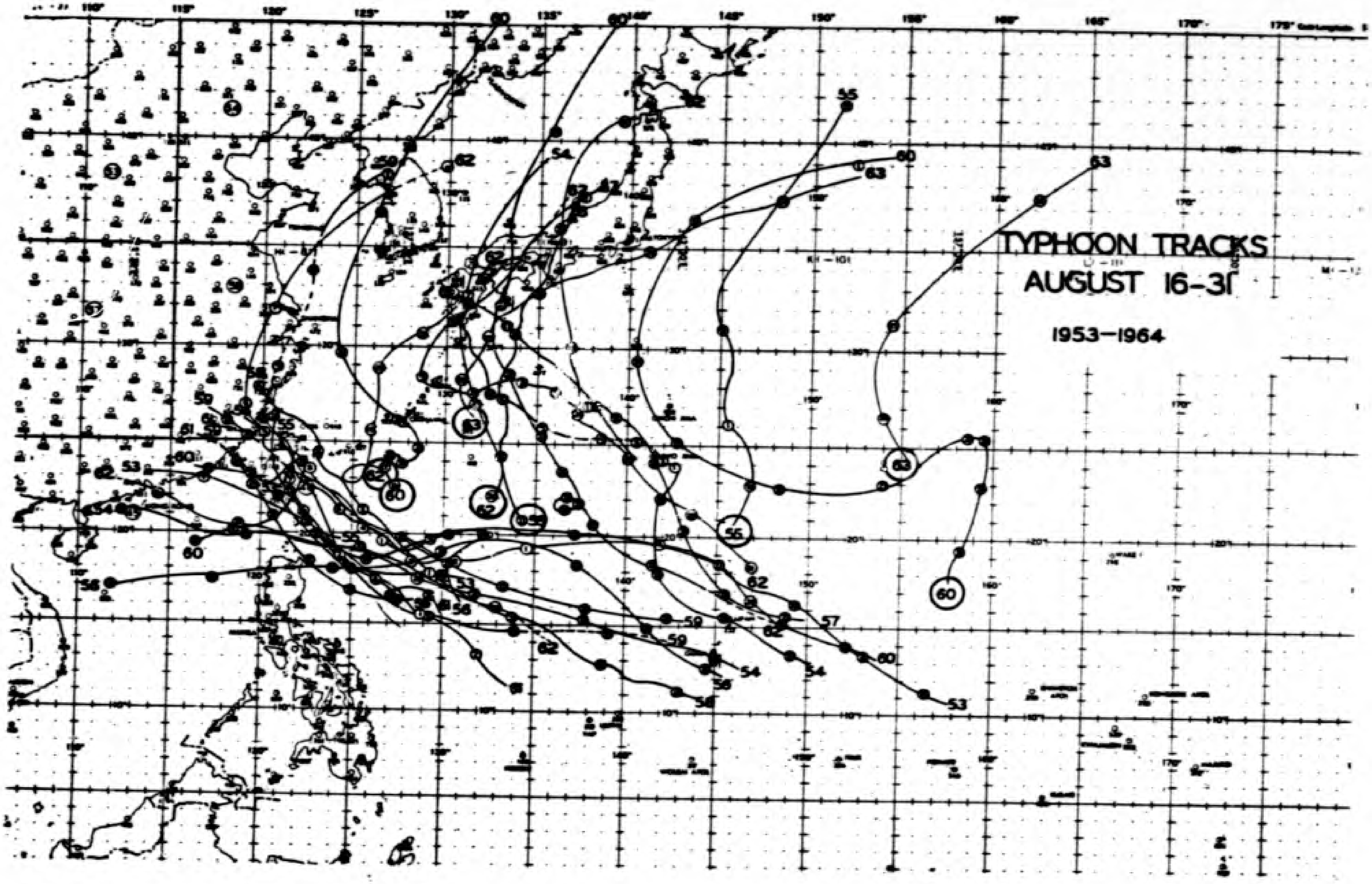

Fig. 2. Typhoon tracks, 1953-1964, for the two-week period August 16-31 (from JTWC, 1966).

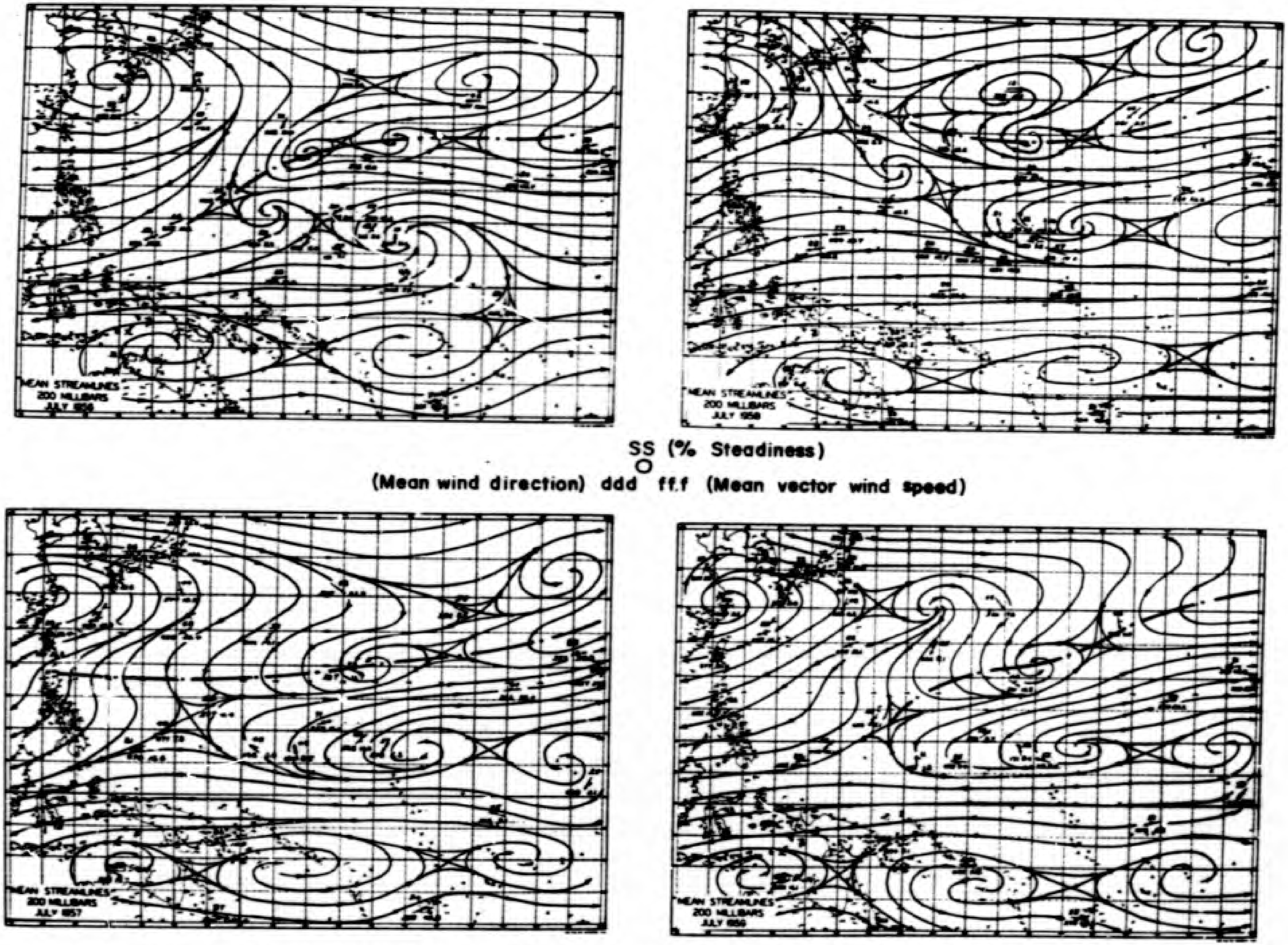

Fig. 3. Mean July 200 mb streamline. Analyses for the years 1956-1959. The position of MPT is shown as a heavy dash-dot line. Plotting model is as shown in center of figure.

such as Wake or Midway (Shiroma and Sadler, 1965), but are commonly "lost" as they move west of 165E into the data-sparse region bounded by Wake, Eniwetok, Guam, Philippine Islands, Okinawa, Iwo Jima, and Marcus (Fig. 1). This vast region lies off the major airline and shipping routes.

During mid-August 1964 the MPT was quite marked across the Pacific. In the western Pacific it was positioned near 25N. This northerly position (near Marcus) made it possible to observe the development of typhoon Kathy and tropical storm Nancy from westward-moving cells within the MPT. The low-level trough remained close to its normal position and was also quite active. During the week beginning 11 August there were 5 storms of varying degrees of intensity in the western Pacific (Fig. 1), but since more than 10 degrees of latitude separated the two troughs the storms were easily separated as to origin.

Figures 4 through 21 depict the streamline analyses for the surface and 250 mb levels for the period 10-18 August. The entire North Pacific is shown, at the expense of ready readability of data, to illustrate the daily change in the position and orientation of the MPT. The 250 mb position of the MPT is shown on the surface chart as a dash-dot line. Shown on both the surface and 250 mb charts are the available TIROS data as extracted from the operational nephanalyses prepared by the National Environmental Satellite Center. The reported heavy overcast (+C) is shown by cross-hatched lines and the broken to overcast (C) is shown by hatched lines. Due to the large number of aircraft wind reports near the 250 mb level it is felt that the MPT is located accurately to within 120 miles over most of its length; however, the position determinations of individual cyclonic cells along the MPT are subject to much greater error. Some of the cells shown on the analyses may not even exist since positive identification can only be made if they pass through the network near an observing station. Others have been positioned with the TIROS data to conform to the cloud model presented here in section 8. Those which have been identified and will be discussed there have been given male names to distinguish them from systems developing in the low-level trough. Therefore MPT cyclones which later become typhoons or tropical storms will have double names.

3. Kirk-Kathy

On 10 August the MPT was well established and extended across the Pacific from the California coast to Okinawa (Fig. 4). The two systems of immediate interest, Kirk and Noel, are not easily positioned along the MPT. Kirk is just east of Marcus and Noel is somewhere east of Midway. From the available data on Figure 5 they probably have not penetrated to the surface as cyclonic vortices, however, the lower portion of Kirk has been analyzed as an induced surface-trough.

The low-level monsoon trough extends from the Philippines to beyond Kwajalein. Tropical storm June is forming in the trough northwest of Yap.

At 0000Z on 11 August Kirk passed just north of Marcus at the 250 mb level (Fig. 6). The drop in surface pressure and the freshening and backing of the surface wind to NNE at Marcus would suggest that Kirk had penetrated to the surface as a vortex (Fig. 7). The timing of passage at Marcus and the slope of the system is better illustrated in the time-altitude cross section of the wind field in Figure 22. The long-dash line shows the penetration downward of the westerlies and the short-dash line indicates the time of passage of Kirk's center. The slope of the system is in excess of 12 hours between 250 mb and surface. This will be converted to a distance slope in a later discussion. The slope is toward the southeast from aloft.

4. Noel-Nancy

Noel tracked westward just south of Midway near 1200Z, 11 August (Figs. 6, 8, and 23). The system sloped southeast with decreasing height such that its associated surface system passed south of Midway near 1200Z on 12 August (Figs. 7, 9, 11, and 23). A satellite view of Noel at 0221Z on 12 August is shown in Figure 26. The surface observation from Midway indicates the main cloud mass is mostly thick altostratus and cirrus with some cumulus underneath producing light showers. The principal convective activity is interpreted (no surface reports) to be south and east of the main mass.

Noel moved westward in an area of few ship's reports, thus making it difficult to ascertain the character of its associated surface system. However, ship's reports of west winds northwest of Hawaii on the 11th and just west of Midway on the 14th, and a calm south of Midway on the 12th, indicate that Noel or Oscar, or both, were penetrating to the surface as vortices. The first indication of Noel's surface intensification was at 0000Z, 16 August. A ship near 25N, 161E reported 20-kt southwest winds, a pressure of 1005.8 mb and a rain squall. Noel-Nancy passed north of Marcus on 17 August on a northwest track, and was dropped by JTWC from tropical storm status on 19 August (Fig. 1).

5. Oscar

Oscar was first indicated as the follow-on system behind Noel on 12 August. A ship rawinsonde observation at 22N, 170W, two aircraft reports, and a TIROS picture helped to fix its position to a fair degree of accuracy (Fig. 8). Aircraft reports and good TIROS pictures on 15 August and 16 August (Figs. 27 and 28) established its track as tending northwest. Ship wind reports on 15 August, as well as the TIROS

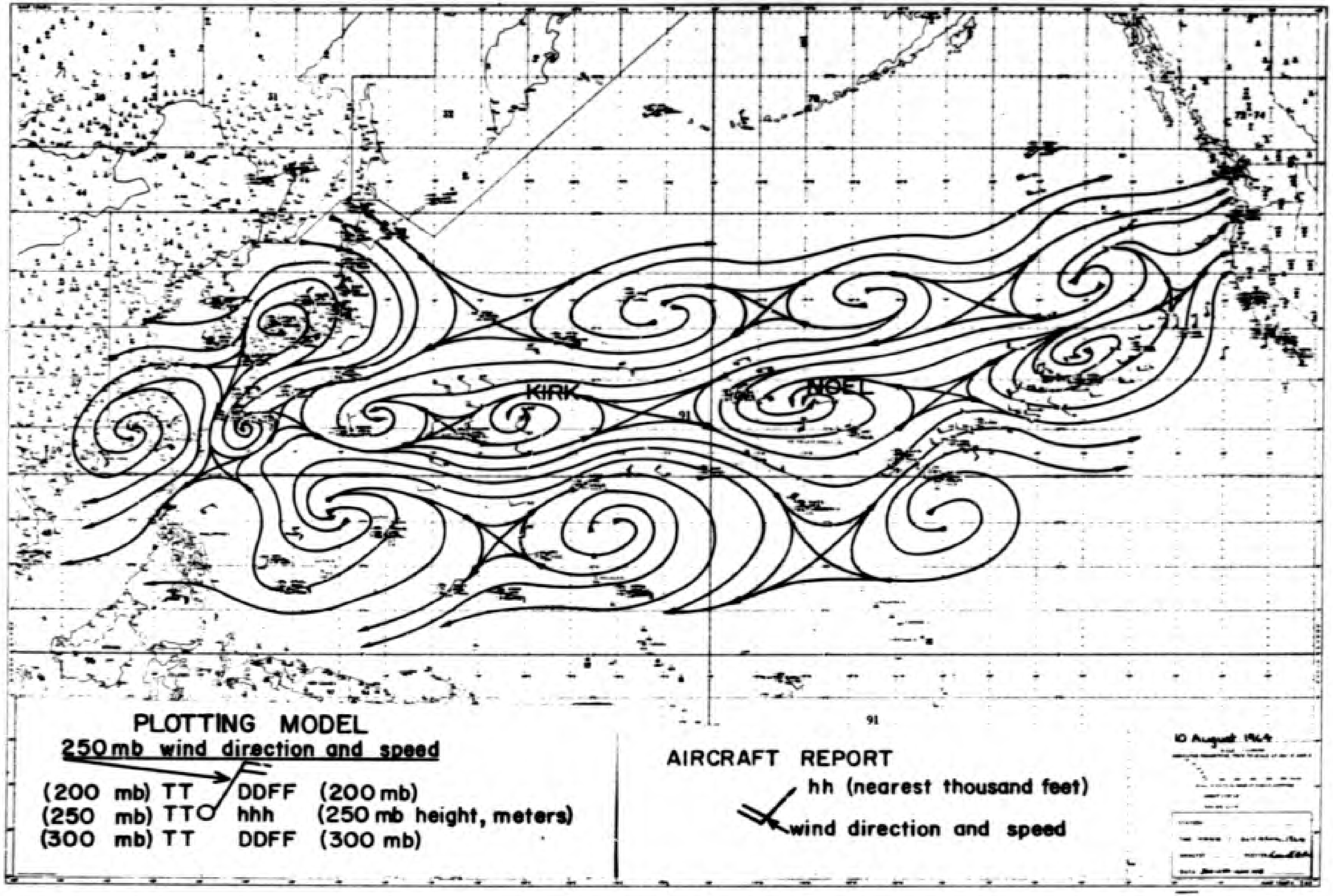

Fig. 4. 250 mb streamline analysis for 0000Z 10 August 1964. The 20N latitude line is darkened for easier reference.

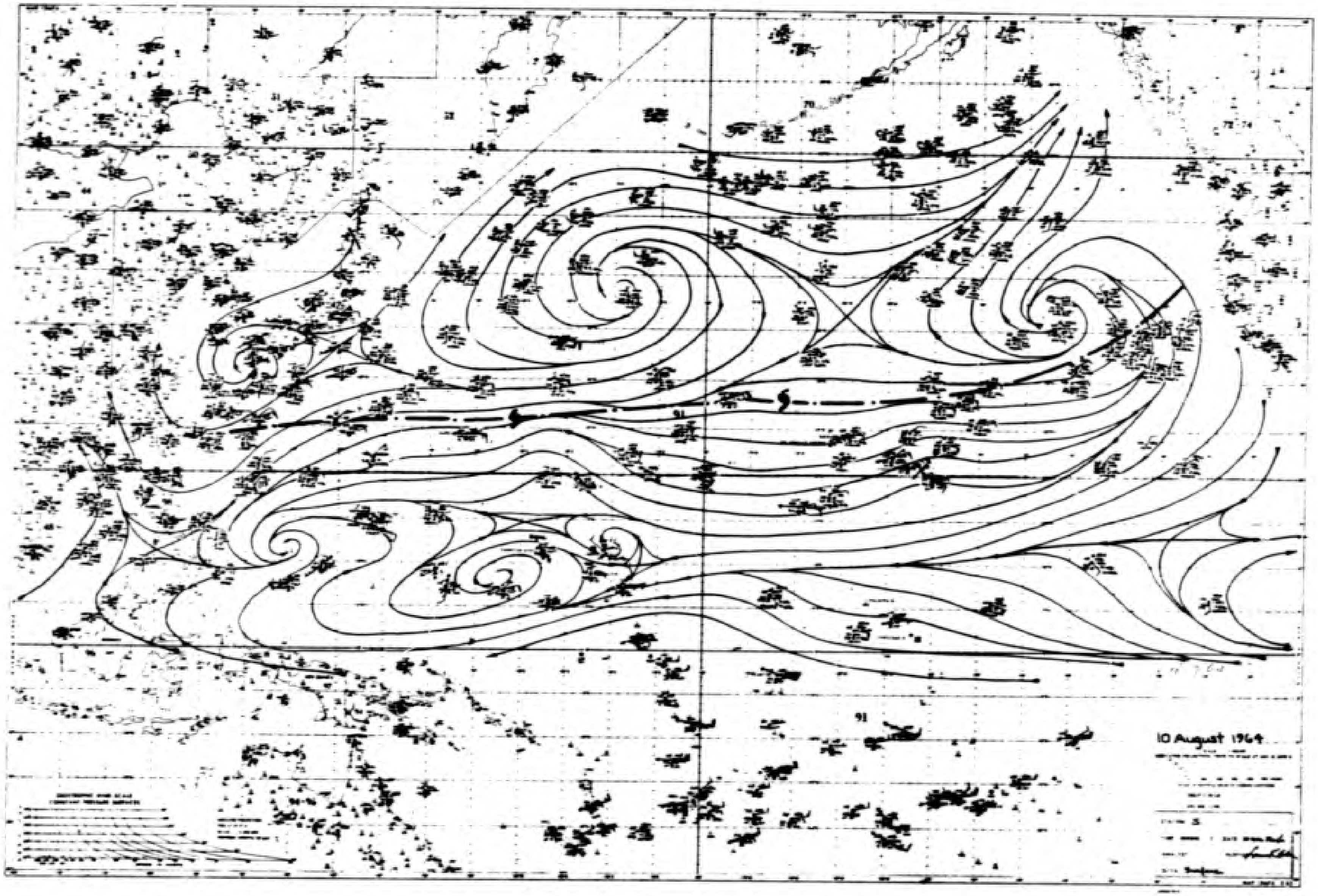

Fig. 5. Surface streamline analysis for 0000Z 10 August 1964. TUTT position shown as a dash-dot line and the position of cells of interest along TUTT are shown as solid center storm symbols.

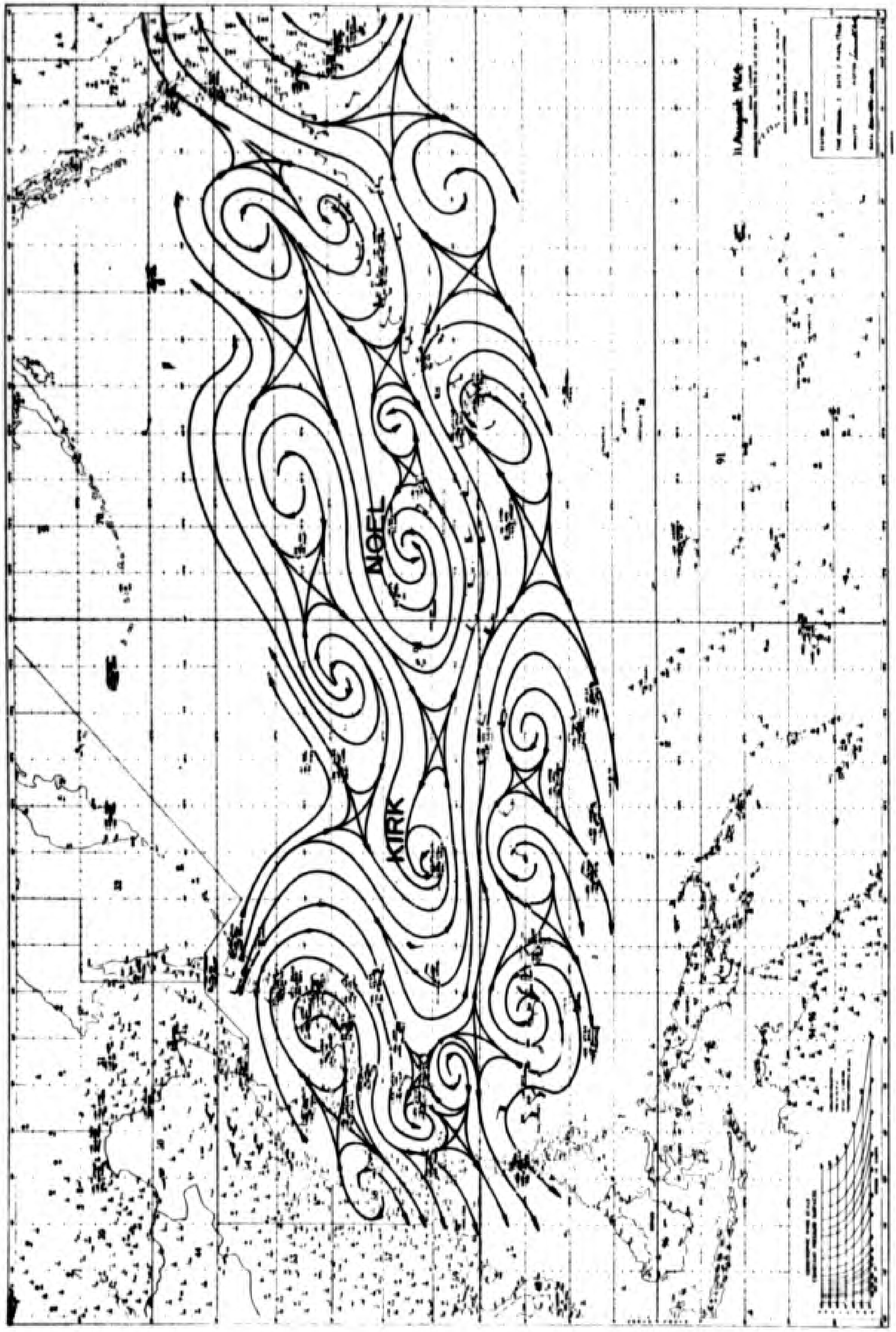

Fig. 6. Same as Figure 4, for 11 August.

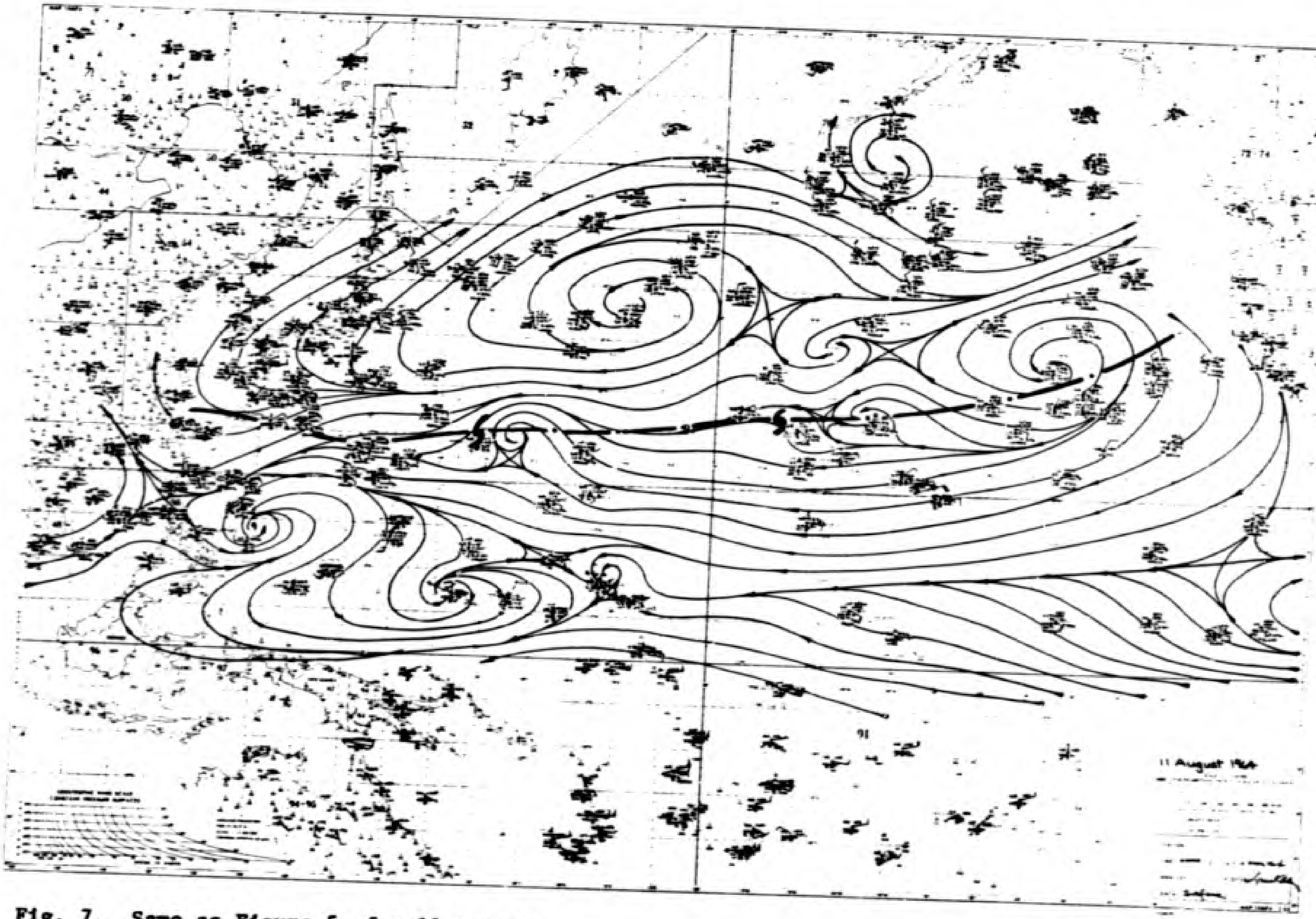

Fig. 7. Same as Figure 5, for 11 August.

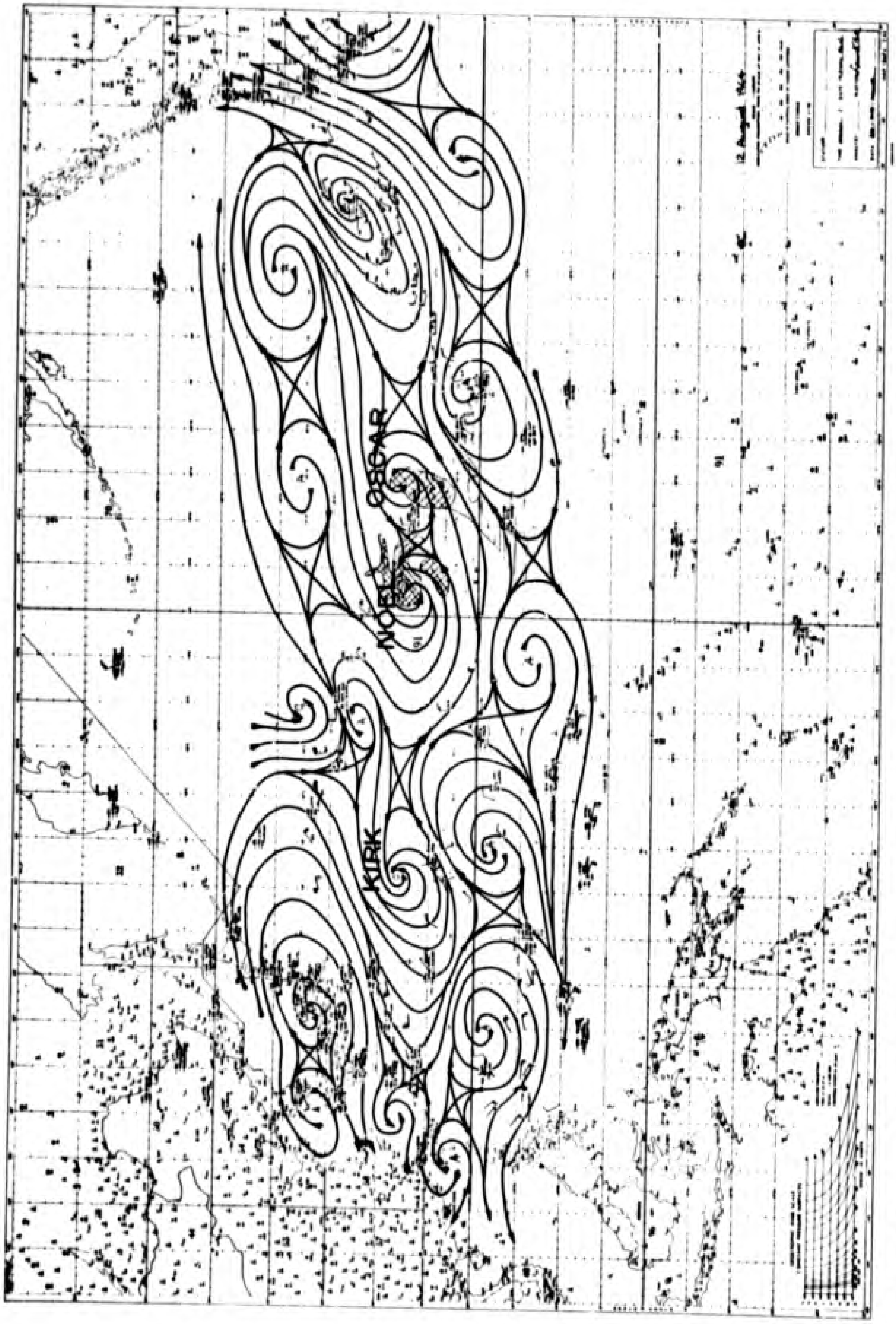

Fig. 8. Same as Figure 4, for 12 August. See text for explanation of hatched areas.

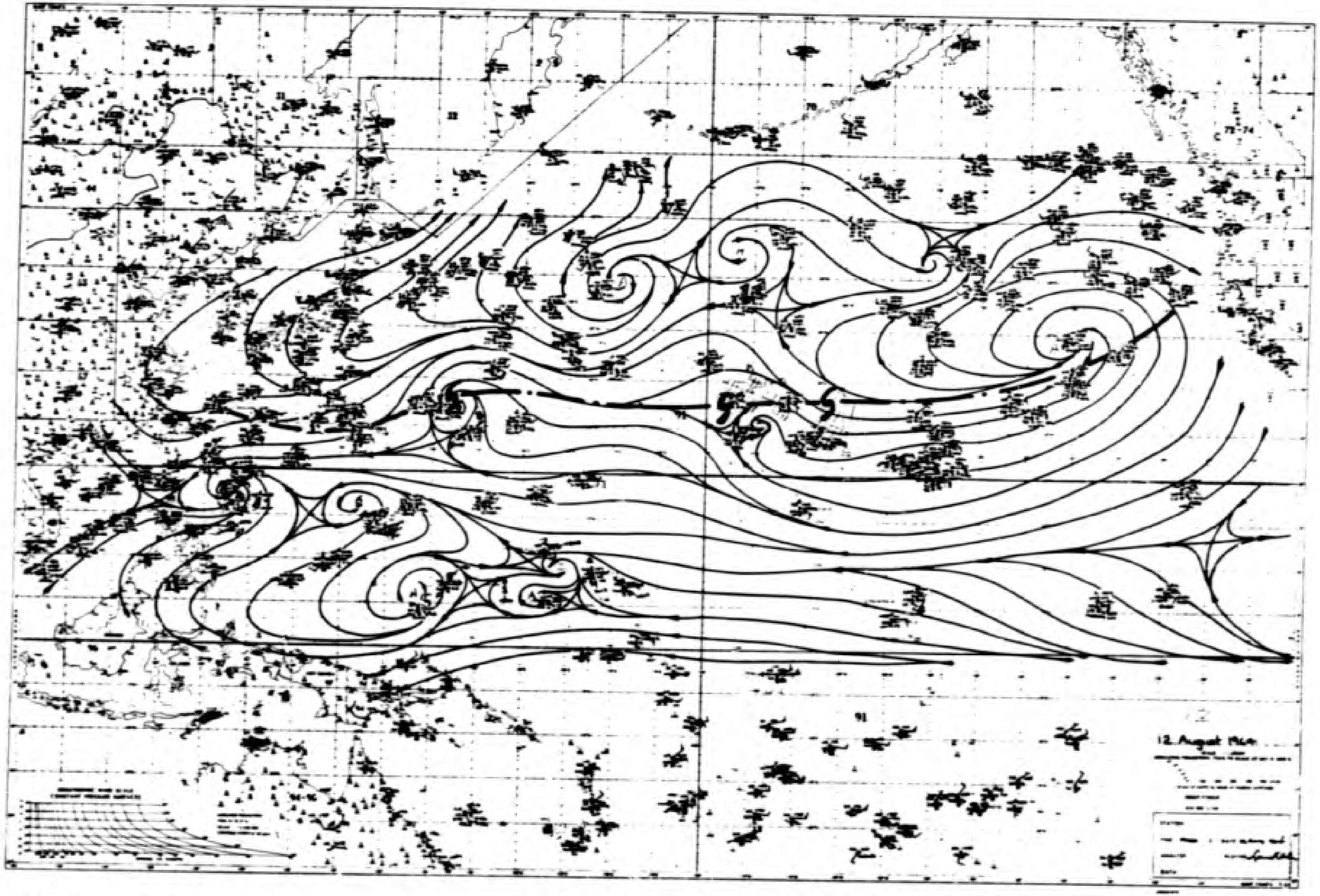

Fig. 9. Same as Figure 5, for 12 August.

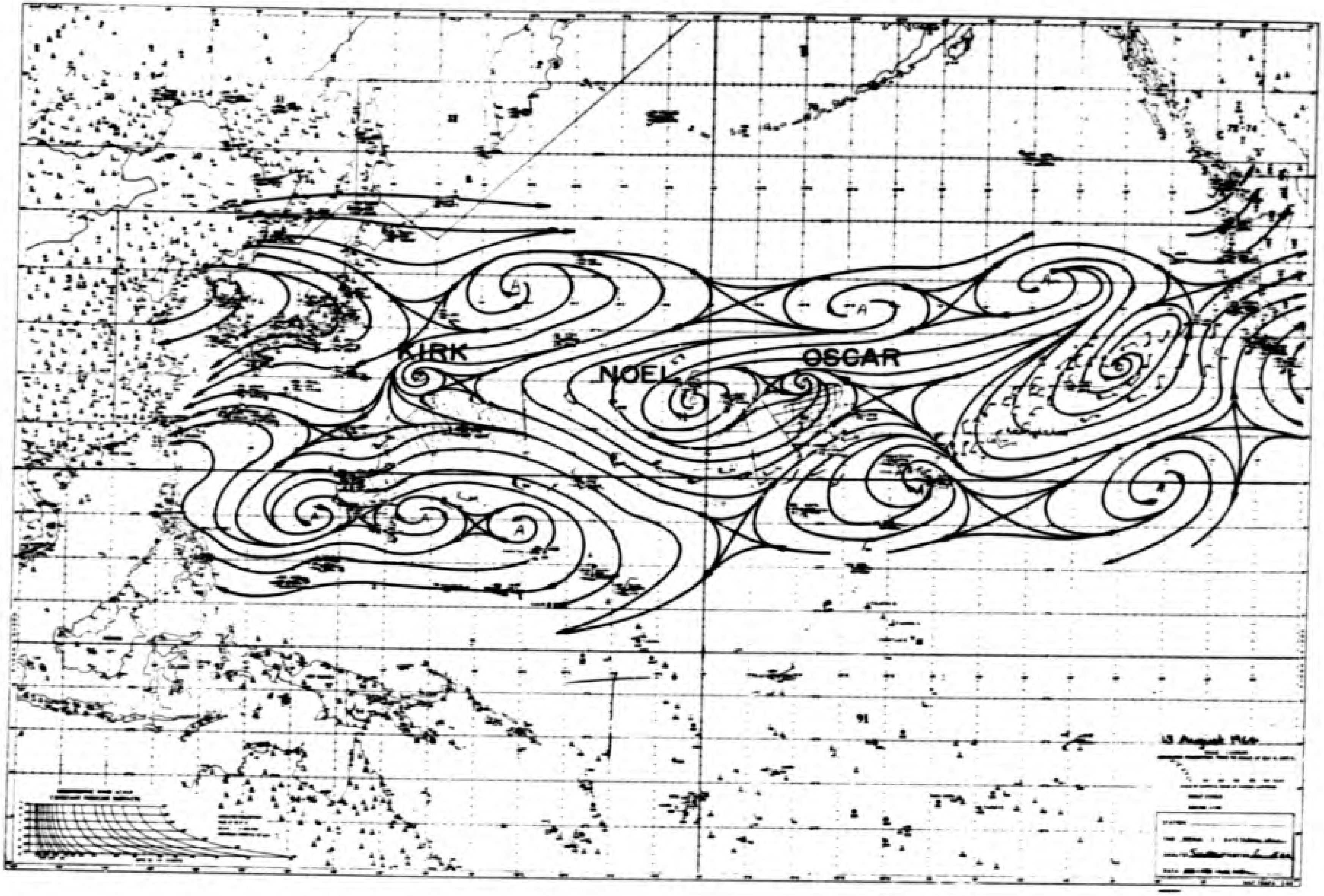

Fig. 10. Same as Figure 4, for 13 August.

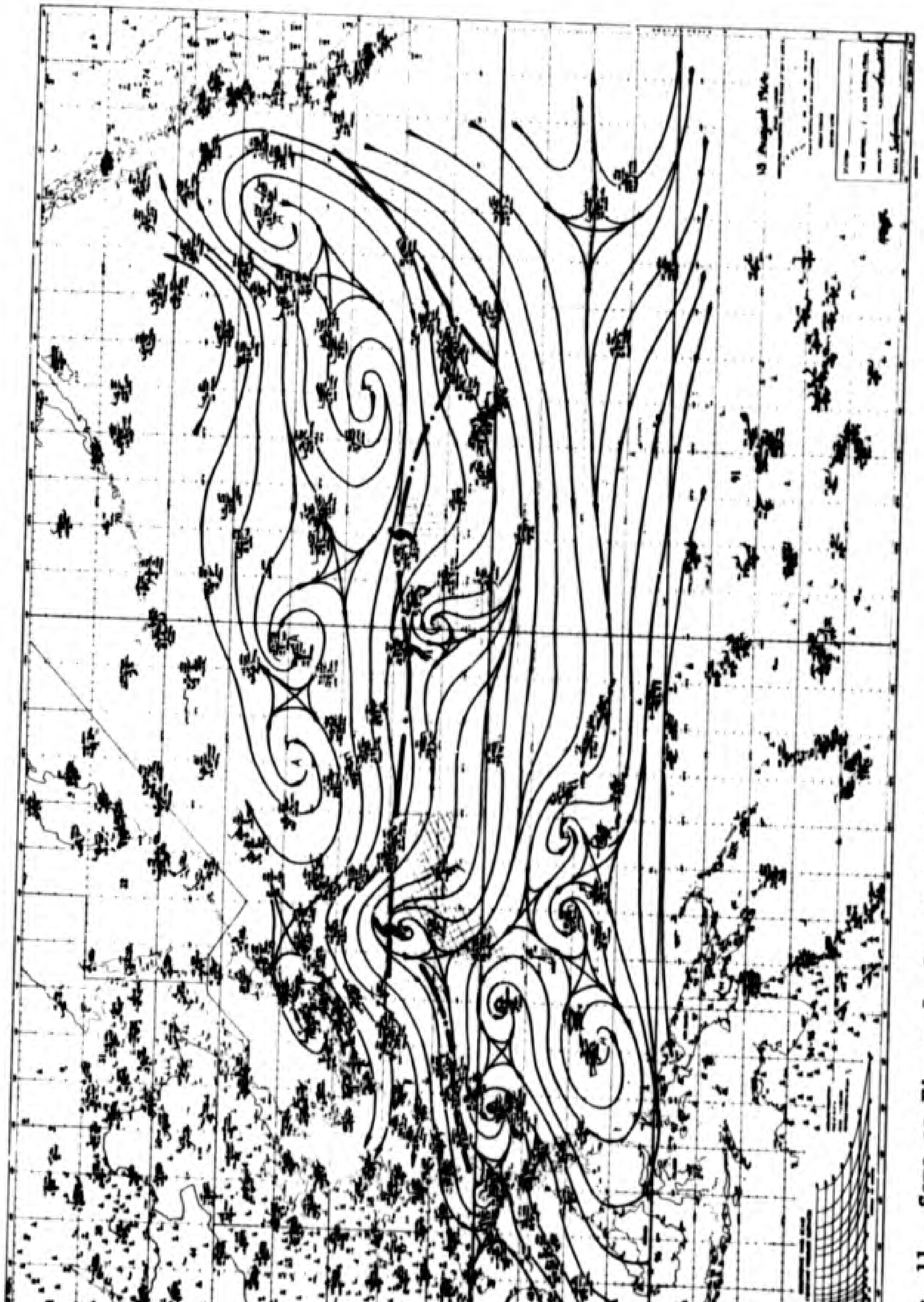

Fig. 11. Same as Figure 5, for 13 August.

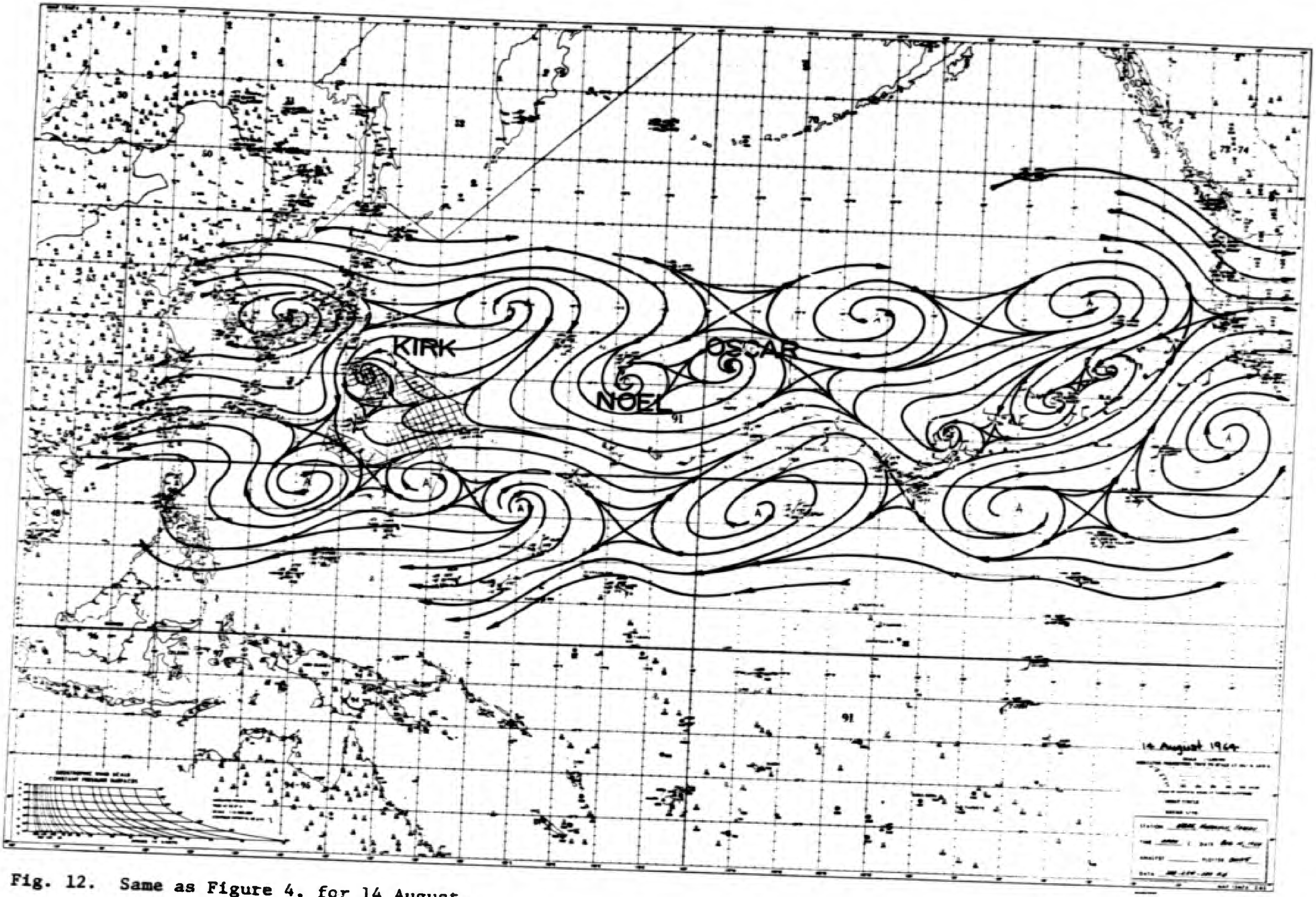

Fig. 12. Same as Figure 4, for 14 August.

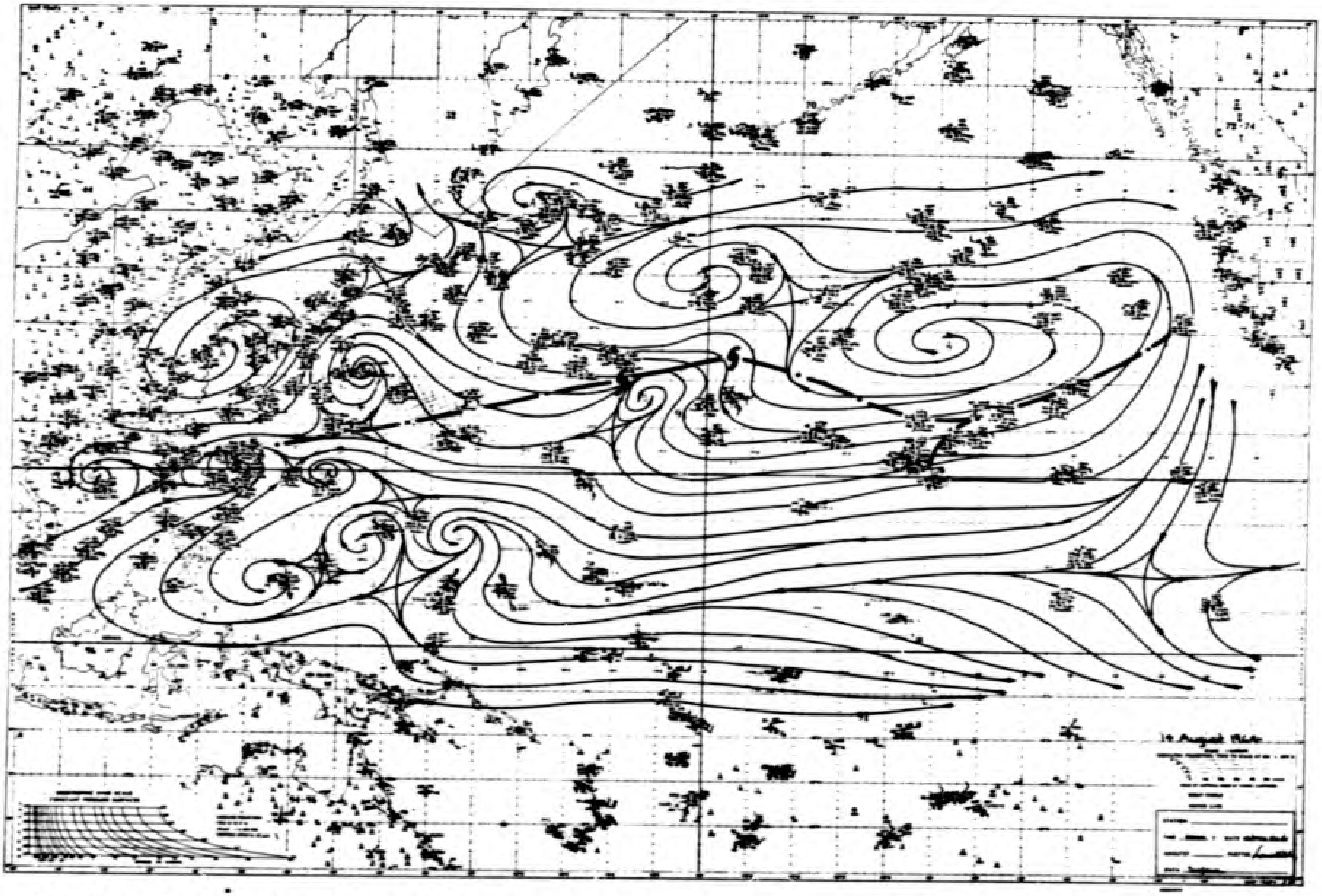

Fig. 13. Same as Figure 5, for 14 August.

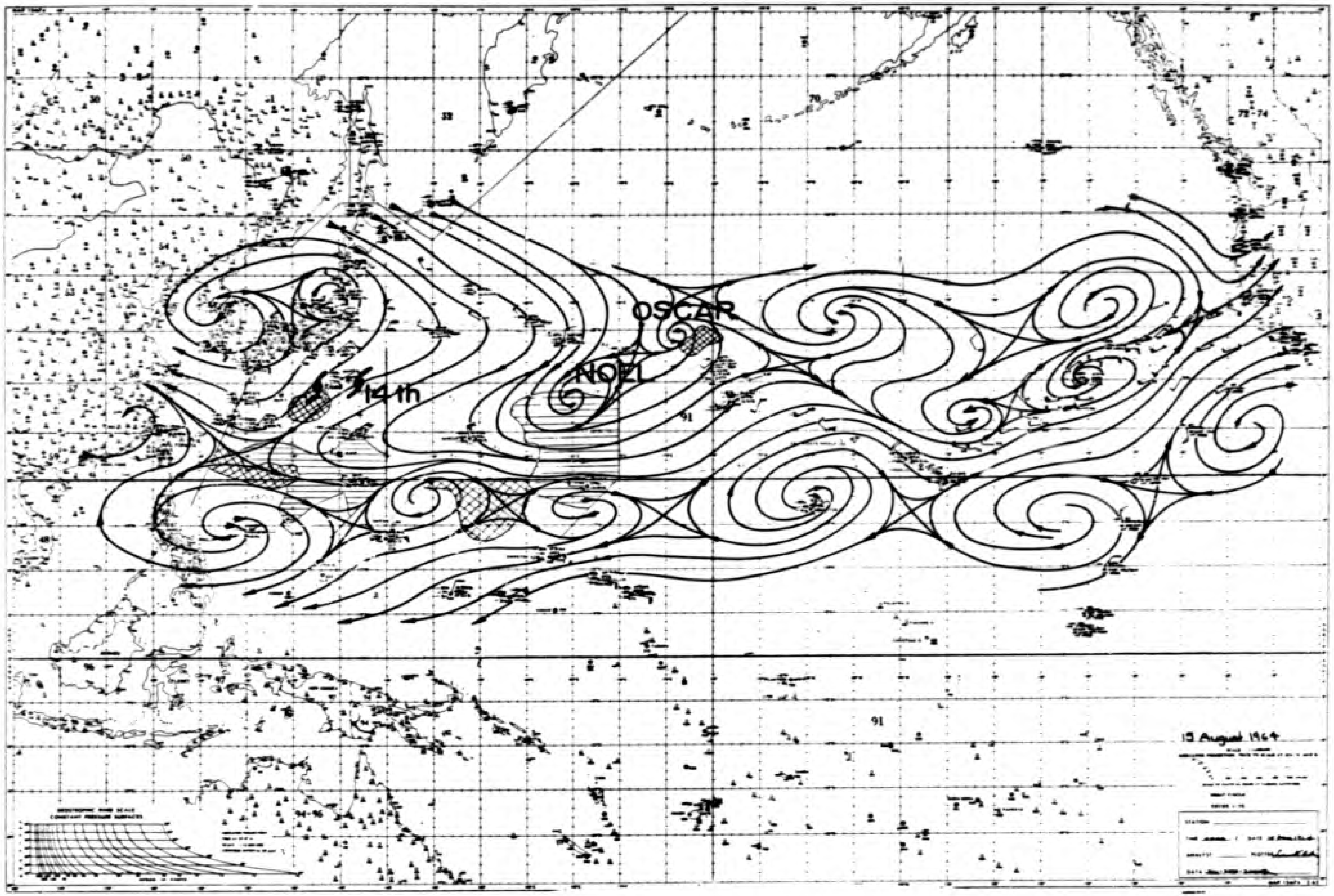

Fig. 14. Same as Figure 4, for 15 August.

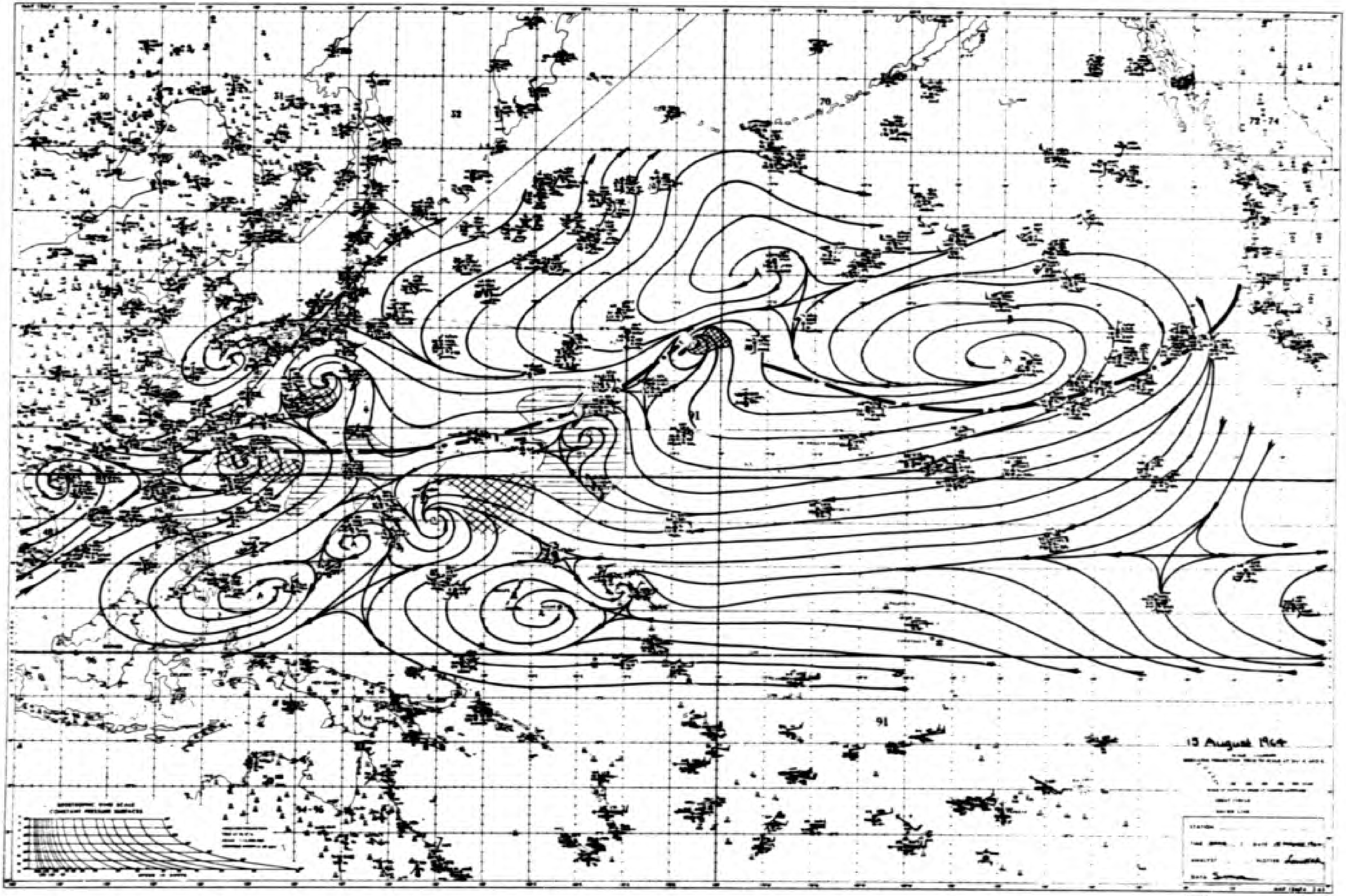

Fig. 15. Same as Figure 5. for 15 August.

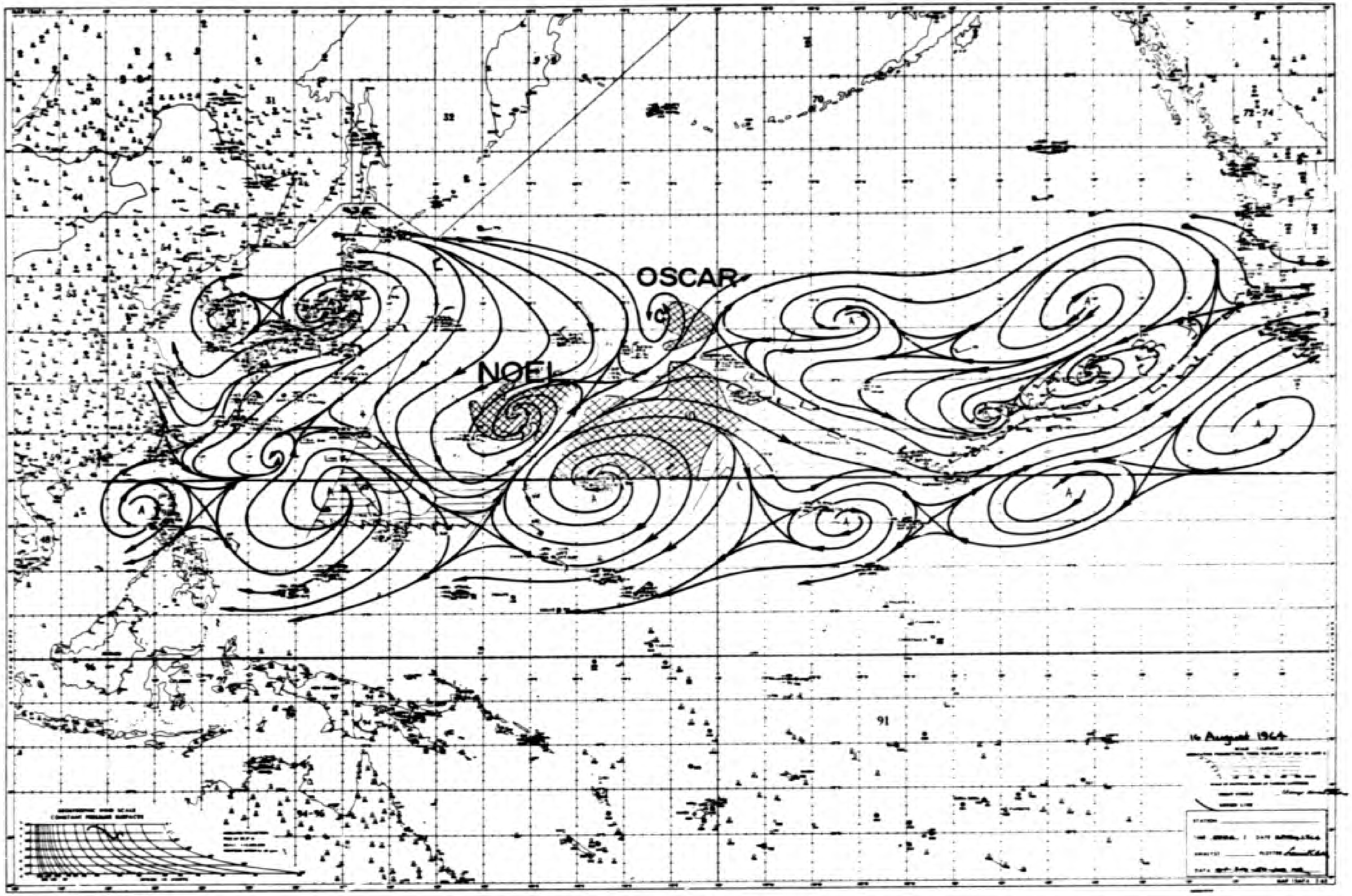

Fig. 16. Same as Figure 4, for 16 August.

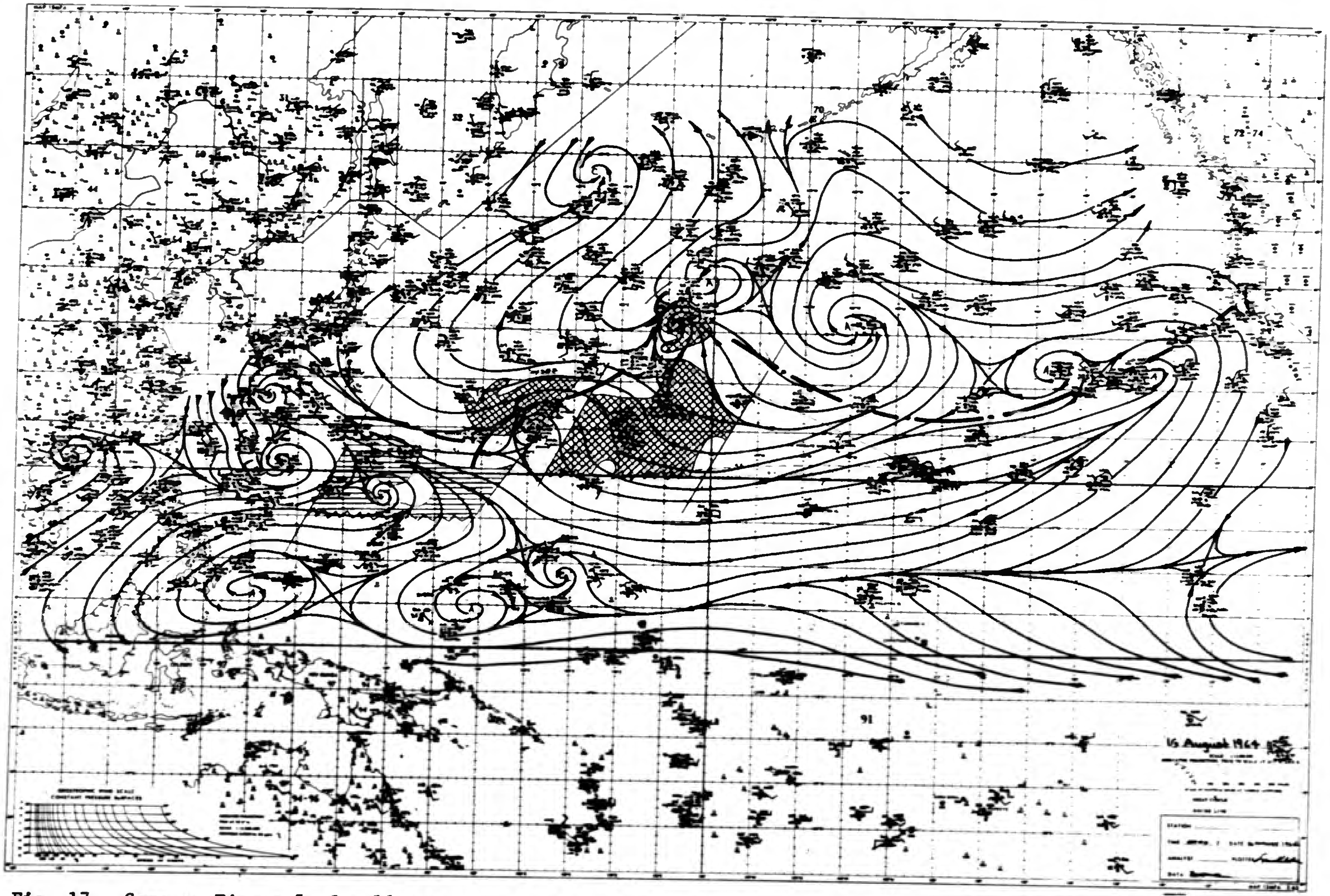

Fig. 17. Same as Figure 5, for 16 August.

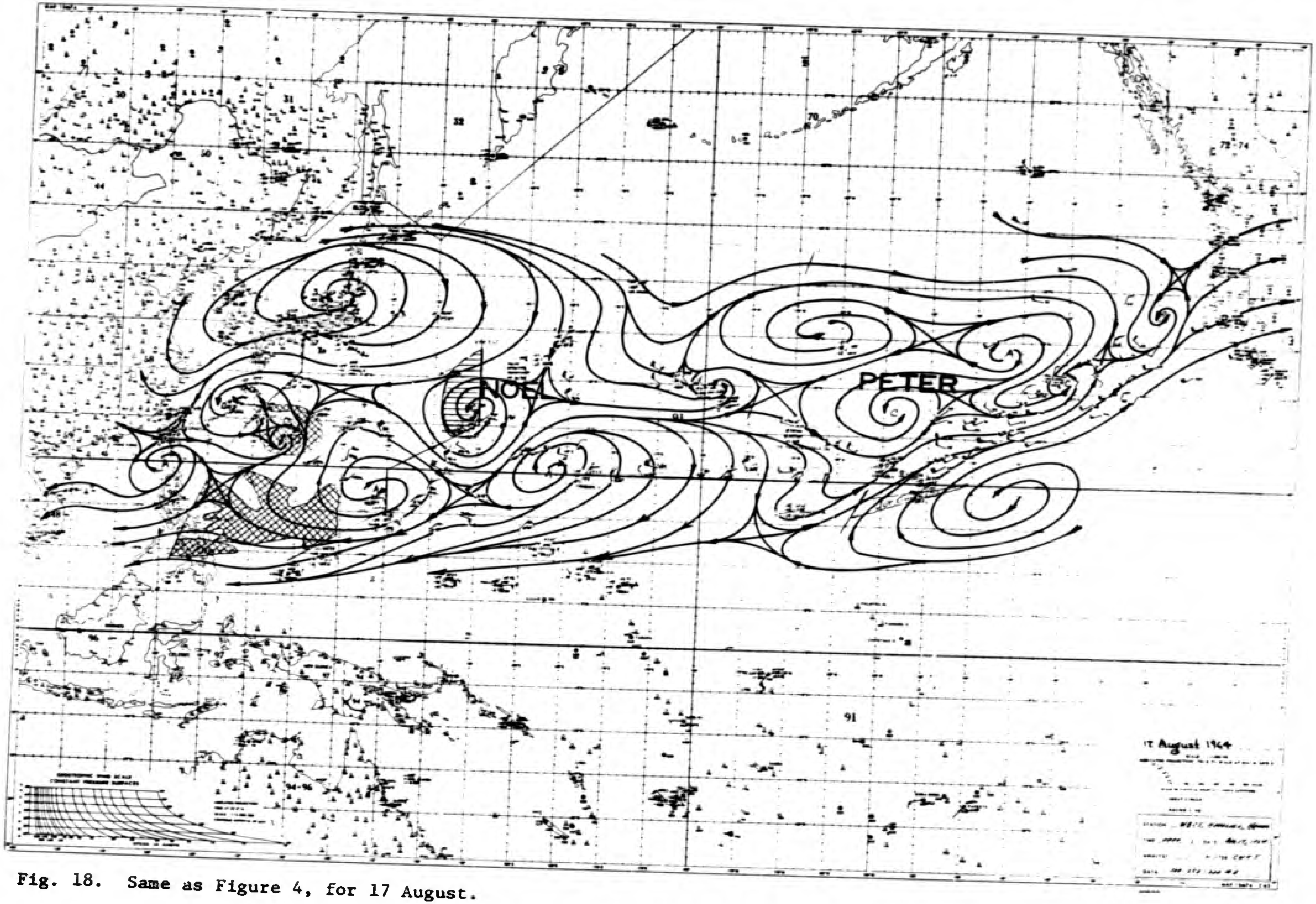

Fig. 18. Same as Figure 4, for 17 August.

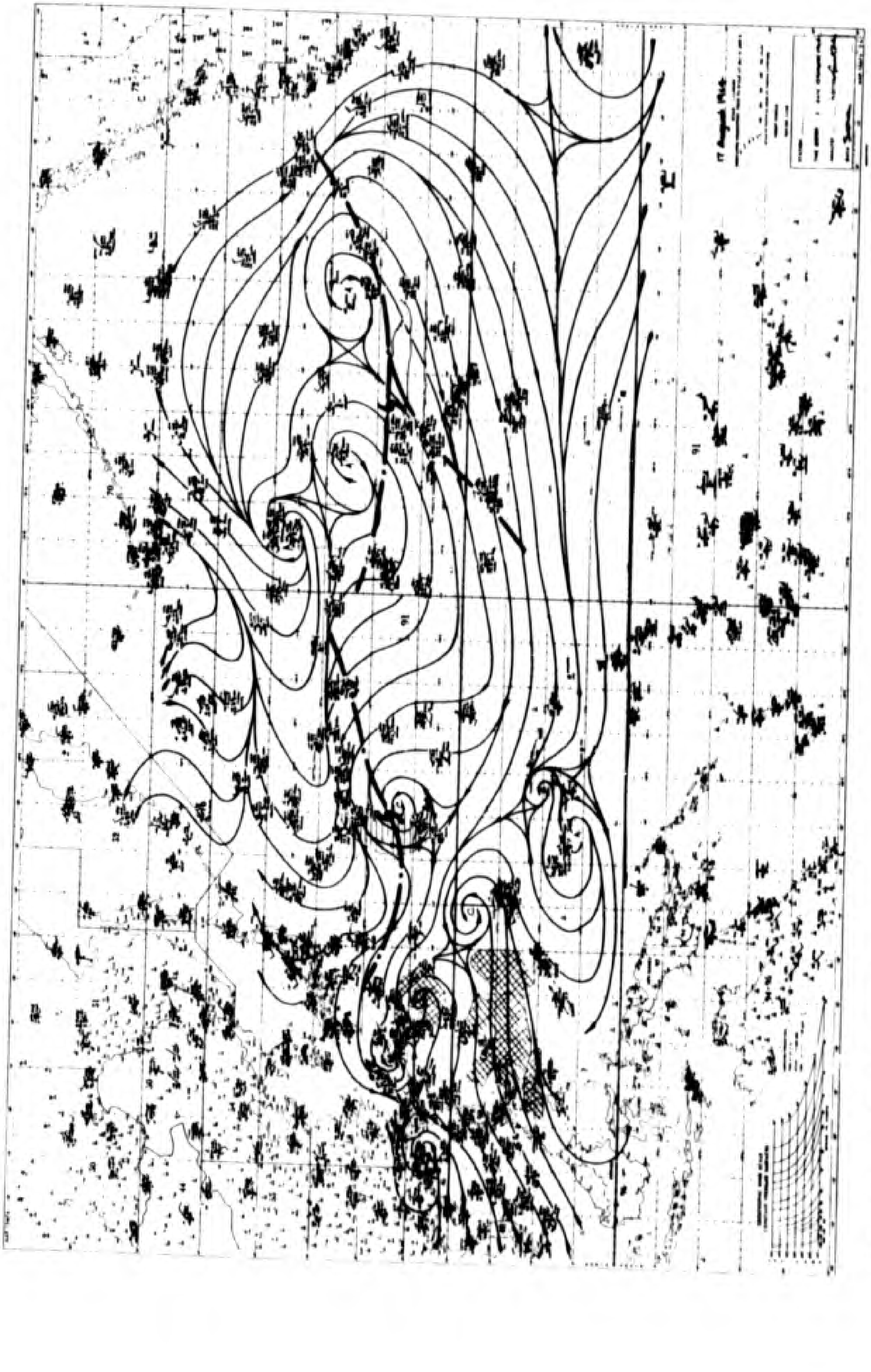

Fig. 19. Same as Figure 5, for 17 August.

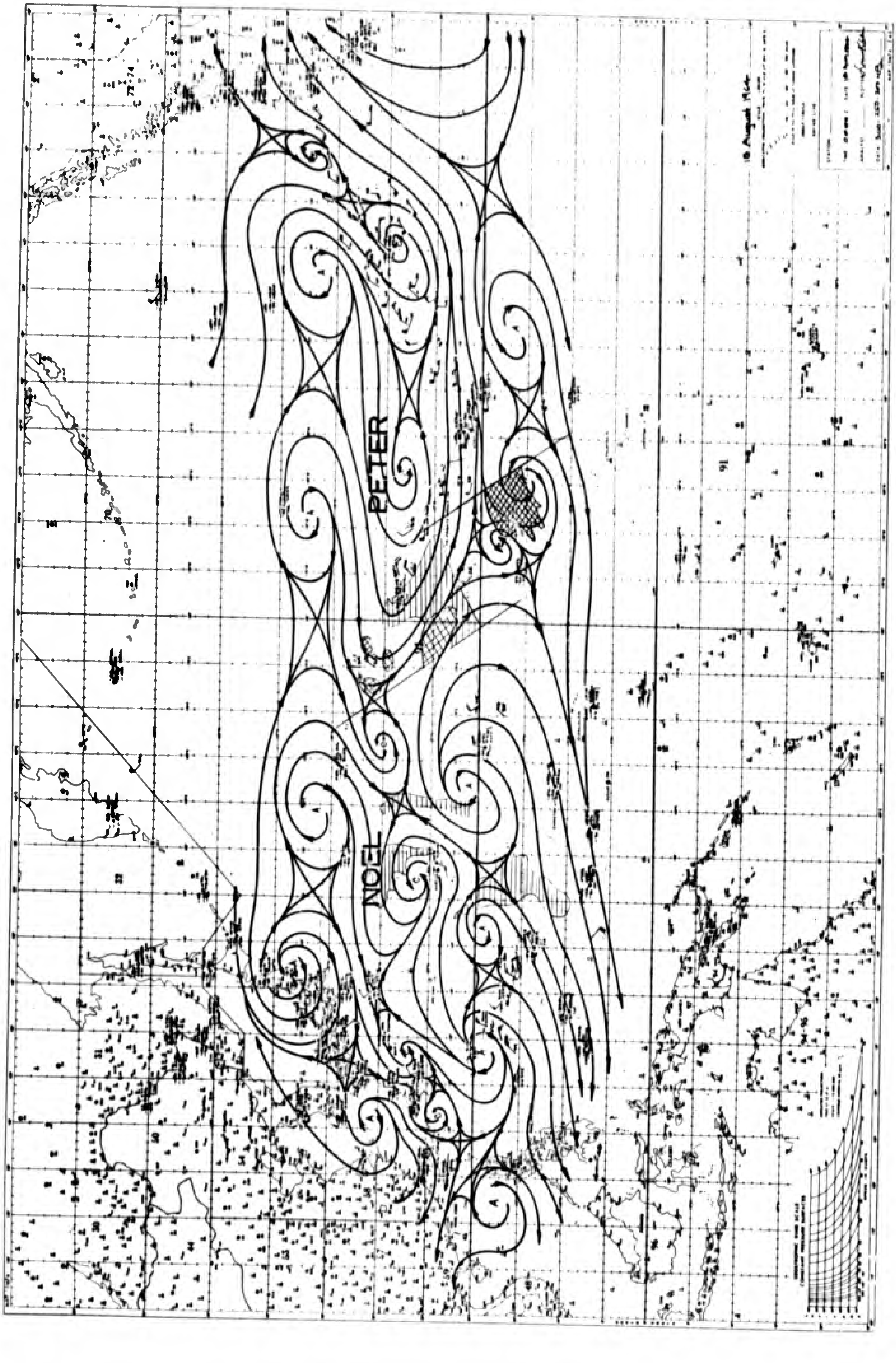

Fig. 20. Same as Figure 4, for 18 August.

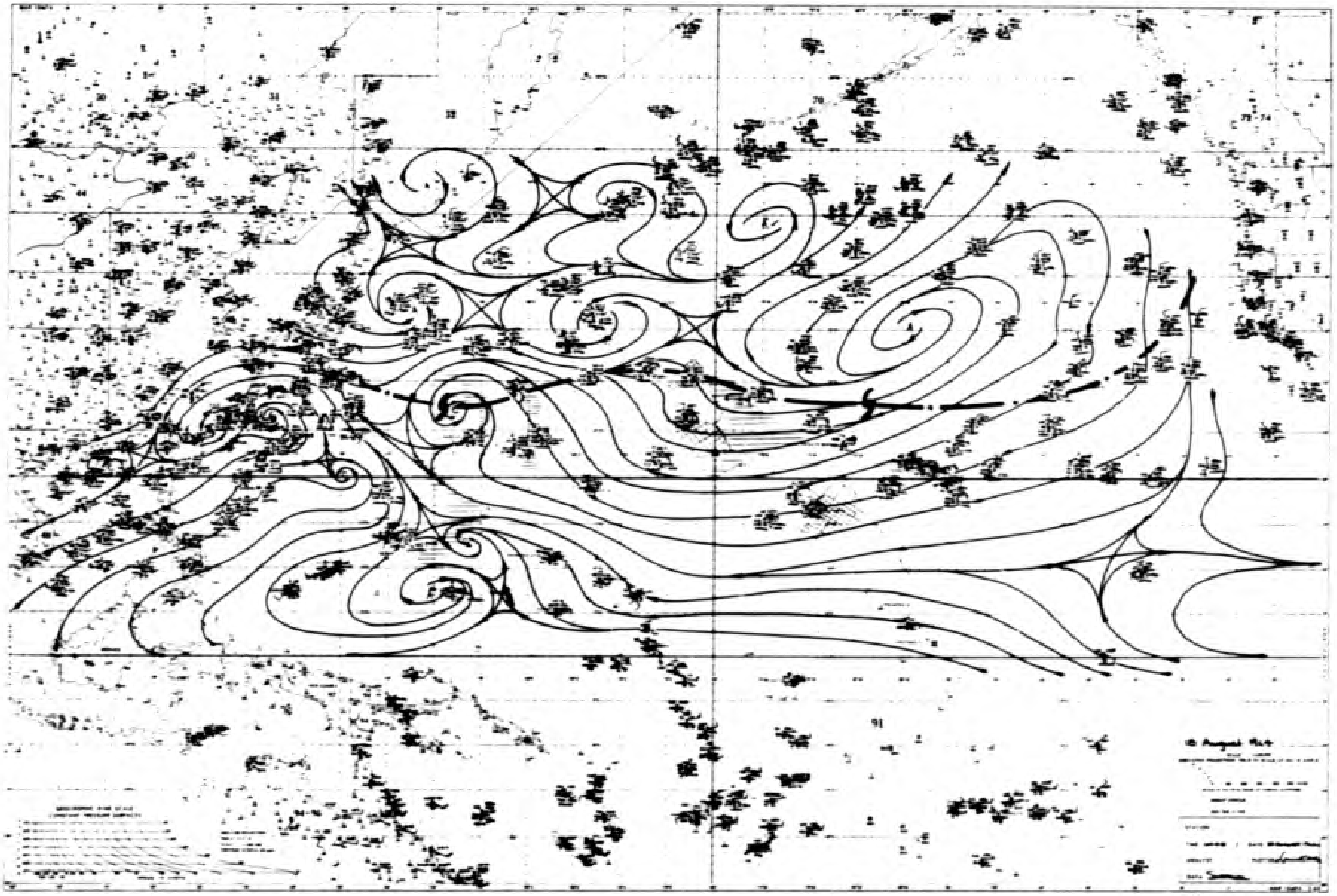

Fig. 21. Same as Figure 5, for 18 August.

picture, show that it penetrated to the surface as a vortex. A ship south of Oscar on 16 August (Fig. 17) reported a light northerly wind and a thunderstorm. From the scarce data available it would appear that Oscar moved out into the mid-latitude westerlies.

6. Speed and Slope of MPT Cyclonic Cells

By using the times of Noel's passage at the 250 mb level at Midway and Marcus (Figs. 23 and 22), the average speed for the six days was calculated as approximately 11 kts. The four-day average speed for Oscar, with less confidence in positioning, was between 11 and 12 kts. These speeds are about the same as the operationally "rule-of-thumb" speeds of 5 degrees per day (11 kts) for these systems in the mid-Pacific.

By using these average speeds, the east-west component of the slope of Noel with height can be estimated as it passed Midway and Marcus. At Midway the component was about 250 miles between the surface and 300 mb or approximately 1 to 40. At Marcus it was approximately 1 to 25. The north-south component could not be determined; however, from the analyses of the surface and 250 mb levels, it appeared to have a southerly dip with decreasing height.

7. Development Cycle of the MPT Systems

Depressions which form in the low-level trough are initially cold-cored, but are shallow and confined to the lower troposphere. Through relative motion they can become positioned under a variety of upper tropospheric circulations favorable for the intensification of the depression into a warm-cored tropical storm (Ramage, 1959; Riehl, 1948; Colon and Nightingale, 1963). The MPT systems are not so fortunate for their surface system is only an extension of a cold cyclonic vortex which has its most intense circulation in the upper troposphere. Data have always been insufficient to determine the when and how of the transformation of these systems to a warm-cored storm. Frank (1963) found, for one case storm in the Atlantic, that the upper tropospheric system acted as the source for the surface depression but then separated from it prior to surface intensification. Simpson (1952) also found that there appeared to be a separation between the upper and lower portions of a Kona storm system prior to a warm-cored development in the lower portion. The cold mid-tropospheric cells of the Arabian Sea summer monsoon system occasionally penetrate to the surface (Miller and Keshavamurthy, 1967). Dixit and Jones (1965) commented on one such system which penetrated to the surface near Bombay and exhibited the characteristic wind system of a warm-cored tropical storm without separating from the parent, and much larger, cyclonic cell aloft.

The analyses of Kirk and Noel do not fit the separation concept but do suggest that there is possibly another sequence of events, as follows, which pertains to the few MPT cells that become true warm-cored surface systems. The upper cold cyclonic portion first weakens and decays while the lower portion is maintained as a weakened cyclonic vortex. The remaining vortex is similar to any other low-level vortex and is available for intensification and transformation to a warm-cored system, if all other conditions are favorable.

How is the upper cold cyclonic circulation weakened and destroyed? A contributing factor, though perhaps but a minor one, may be the release of latent heat of condensation by deep convection. Frank (1963) attributed the observed 2°C warming of the mid and upper troposphere during a storm development to this cause. Yanai (1964) observed a 2°C warming, due to the release of latent heat, concentrated in the 400 mb - 300 mb layer during the early development stage of a low-level system. Warming of this magnitude, although sufficient to intensify the existing ridge or anticyclonic cell over or near the developing low-level system, is not sufficient to destroy the upper cold low. The principal factor in the decay is most probably a slow warming by advection as the upper cyclonic cell migrates westward into a region of much higher temperatures in the upper troposphere. A measure of this thermal gradient was obtained on 11 August from three radiosonde observations positioned near the center of the MPT between 166W and 131E (Fig. 6). A plot of their temperatures is shown in Figure 24. The western end is 6C to 9C warmer than the central Pacific portion in the layer 30,000-40,000 ft. Such a directed thermal gradient is also indicated by the mean flow patterns of Figure 3. The cold trough decays westward, giving way to a warm anticyclonic flow in the extreme western Pacific.

The history of Kirk-Kathy lends support to such a proposed sequence of events. The upper tropospheric cyclonic portion of the system could be traced until 14 August (Fig. 12). At this time the surrounding temperatures were -49C, -39C, and -30C at the 200 mb, 250 mb, and 300 mb levels, respectively. During the previous 3-day movement from Marcus Island the immediate environment around the system had warmed by 6C in the upper levels. The upper cyclonic circulation dissipated by 0000Z, 15 August. The remaining low-level cyclonic circulation was under a moderate northeast flow during the 15th and 16th (Figs. 14 and 16), and the upper temperatures increased another 2C to 4C. It should be about this time in the sequence of events that the remaining low level vortex becomes available for reintensification and development. An important point is that prior to this time the intensity of the surface portion of the system should decrease along with the decay of the upper portion.

The intensity of the Kirk-Kathy system was measured by reconnaissance subsequent to 2200Z 12 August. Three methods of intensity documentation are plotted in Figure 25. The system decreased in intensity from the 13th through the 15th. It began to regenerate on late 16 August and by early 18 August was at maximum intensity. The

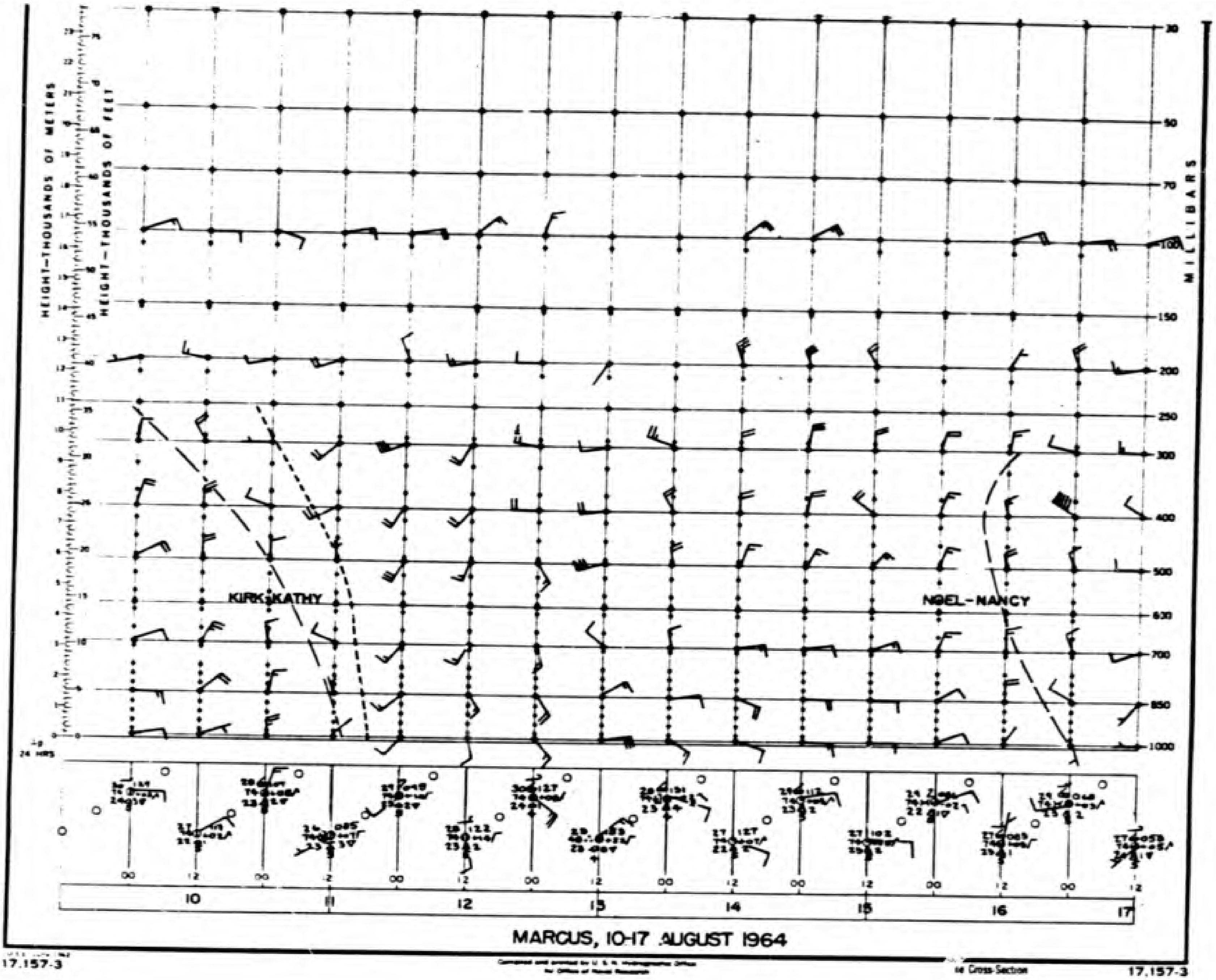

Fig. 22. Time-altitude cross section of wind observations at Marcus Island, 10-17 August 1964. Long-dash line delineates leading edge of west component winds. Short-dash line is time of passage of Kirk-Kathy center north of station.

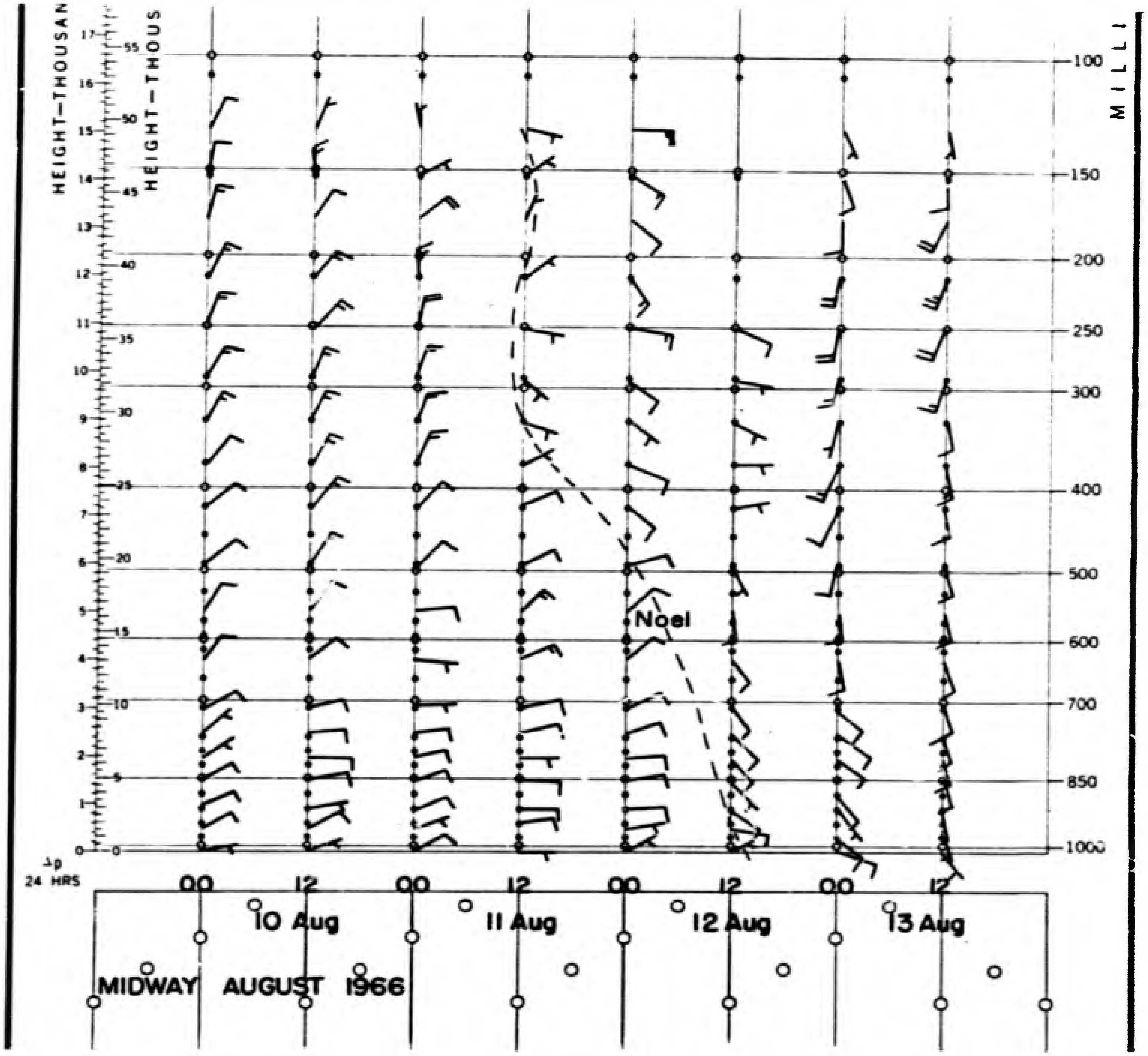

Fig. 23. Same as Figure 22, for Midway Island, 10-13 August 1964. Short-dash line indicates passage of Noel south of station.

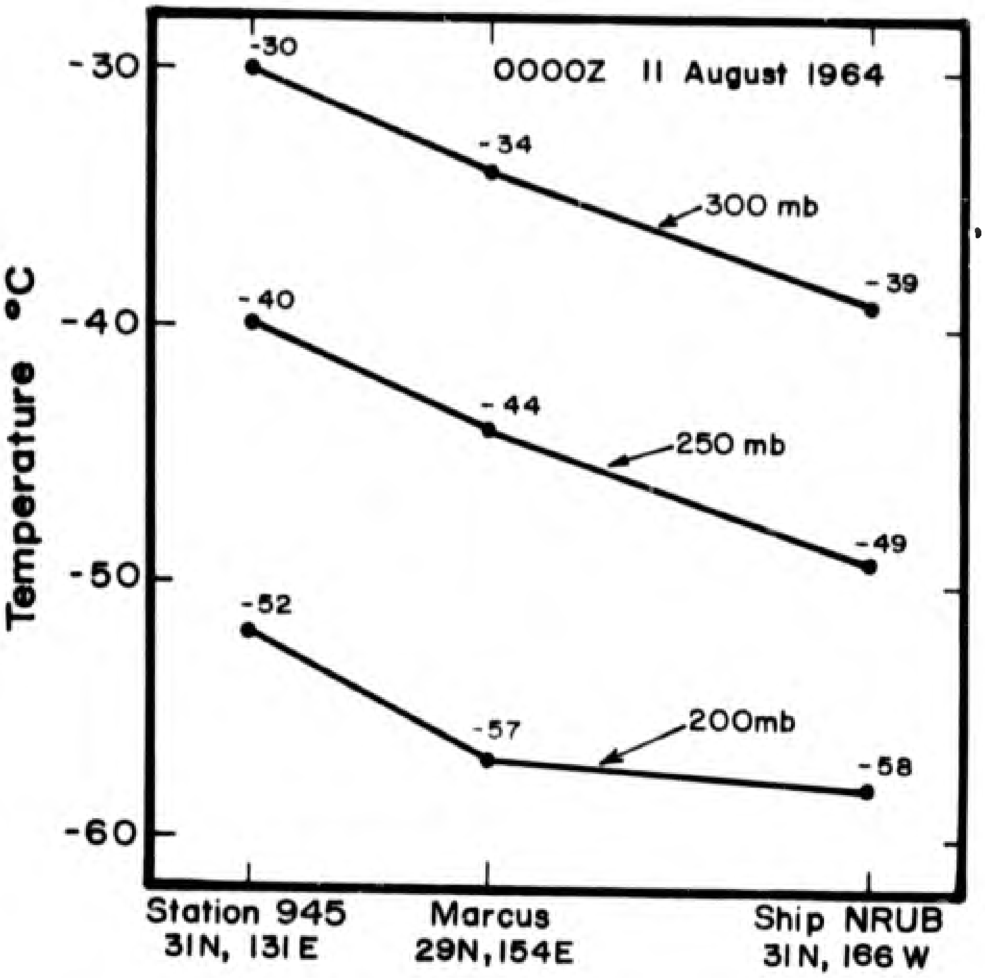

Fig. 24. Upper-tropospheric temperatures along the MPT at 0000Z on 11 August.

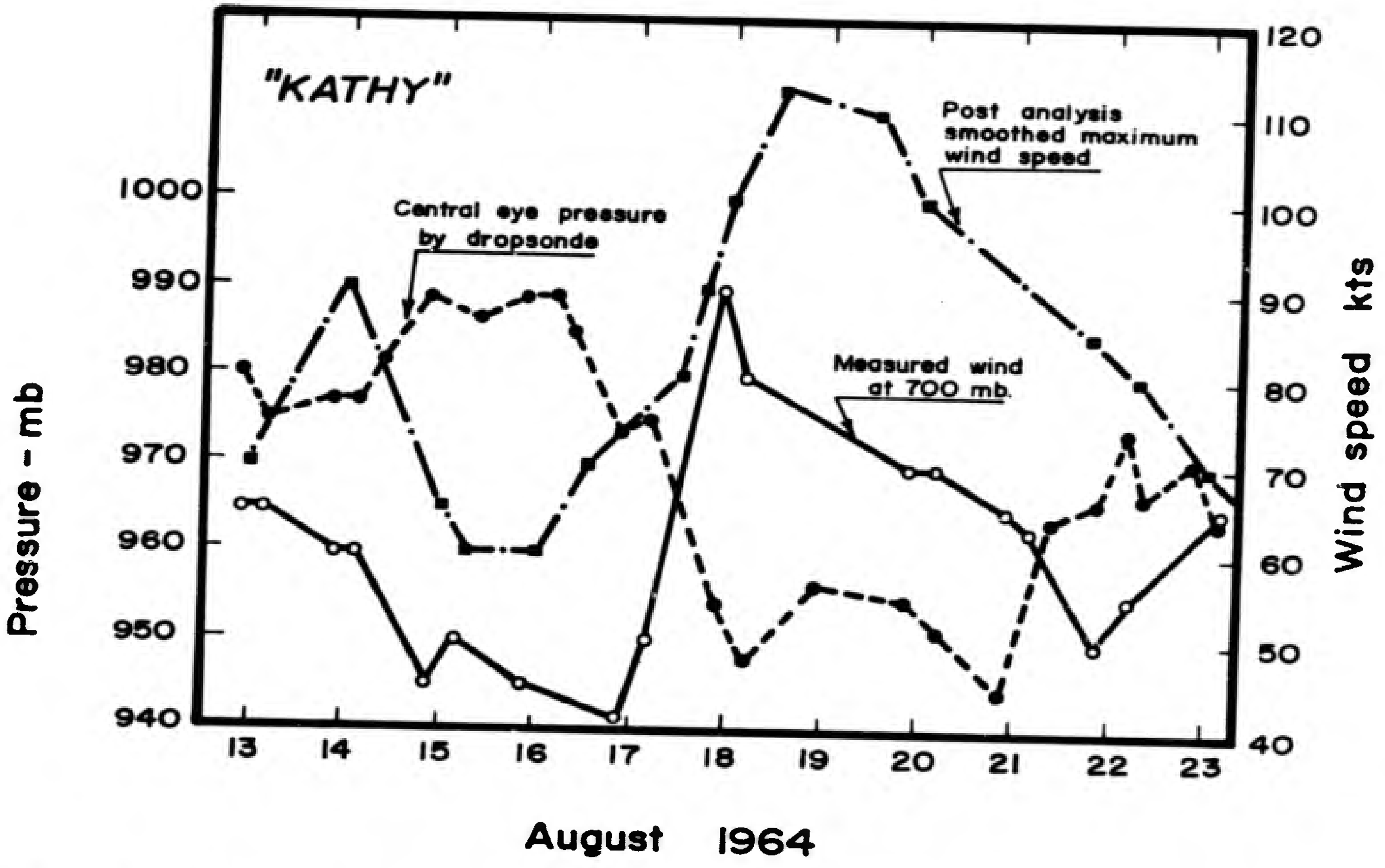

Fig. 25. Intensity variations of Kirk-Kathy, 13-23 August 1964.

complexities of the system during the period 14th through the 16th are best chronicled by the reconnaissance remarks during the eye penetrations and fixes and by an excellent satellite observation. The remarks are identified by time, altitude, and method of eye observation.

141345Z - 10,000 ft. - radar: Eye diffused and open all quadrants except southeast.

142200Z - 30,000 ft. - radar: Wall cloud northeast quadrant only.

142200Z - 700 mb - penetration: Circular, 40 miles in diameter, open north semicircle.

150335Z - 30,000 ft. - visual: Circular, 50 miles in diameter, open north semicircle, maximum cloud tops, 17,000 ft.

The excellent satellite observation shown in Figure 29 was obtained about two hours after the above reconnaissance observation. It explains the ability to observe visually the open system from an altitude of 30,000 ft. and to report cloud tops of only 17,000 ft. However, an explanation for the bright cirrus cloud shield centered about 150 miles south-southwest of the open vortex is not obvious. Its organization, size, and brightness would seem to indicate an active convective cloud system and even the dominant circulation system; however, a double vortex cannot be confirmed. The surface circulation is rather large (Fig. 15) and the few ship's observations would not negate a double center.

Another possible, and more appealing, explanation is a separation of the upper cirrus mass from the low-level vortex by vertical shear as the upper cyclonic circulation dissipates. On Figure 14 the surface positions are shown for both 14 August and 15 August. The circular cross-hatched area is the cirrus mass on the 15th. The relative movement of a detached cirrus shield from the low-level vortex between 14 August and 15 August is in the proper direction to conform to the upper wind field. A dense cirrus shield did exist over the system on 14 August, as shown by the TIROS photograph of Figure 30.

The base for Navy reconnaissance operations was shifted to Japan on 14 August and this area to the south of the open circulation was not traversed on the 15th or 16th. The Air Force reconnaissance was also from Japan. We have been unable, as yet, to obtain the Air Force reconnaissance observations, but intend to pursue this identification problem if the data permit.

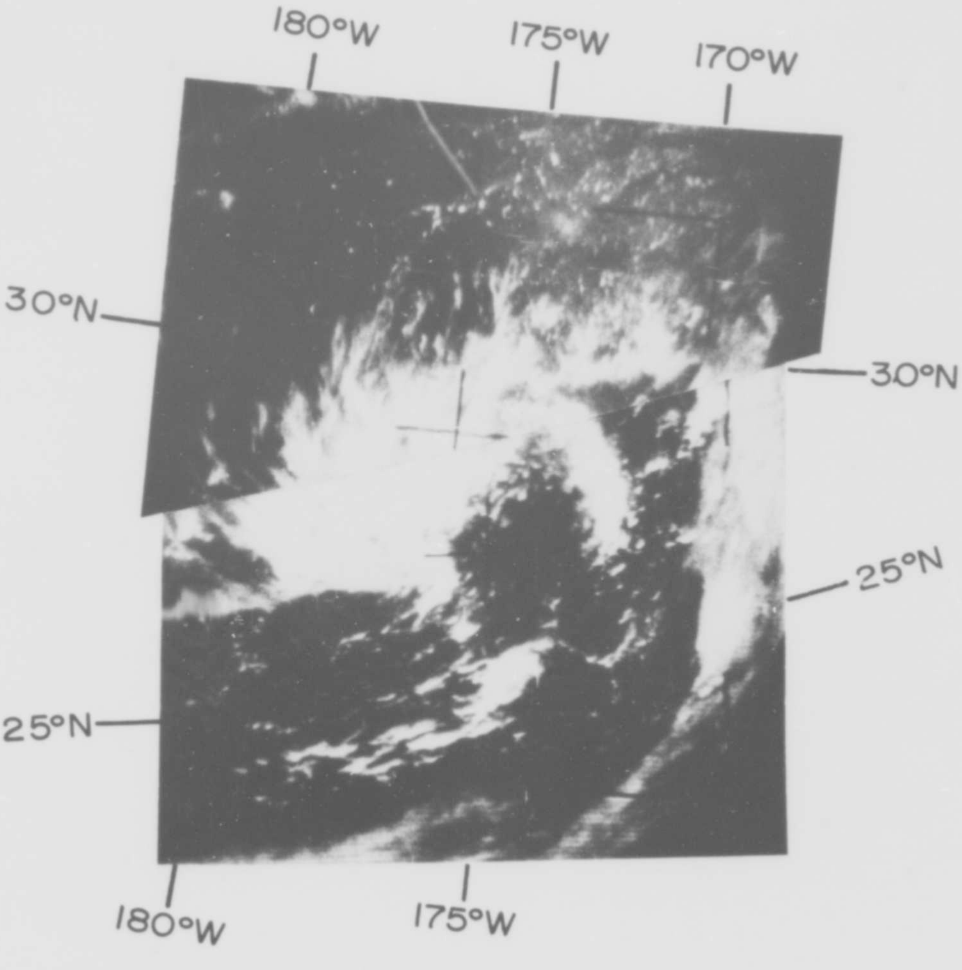

Fig. 26. TIROS VIII view of Noel near 0221Z on 12 August 1964.

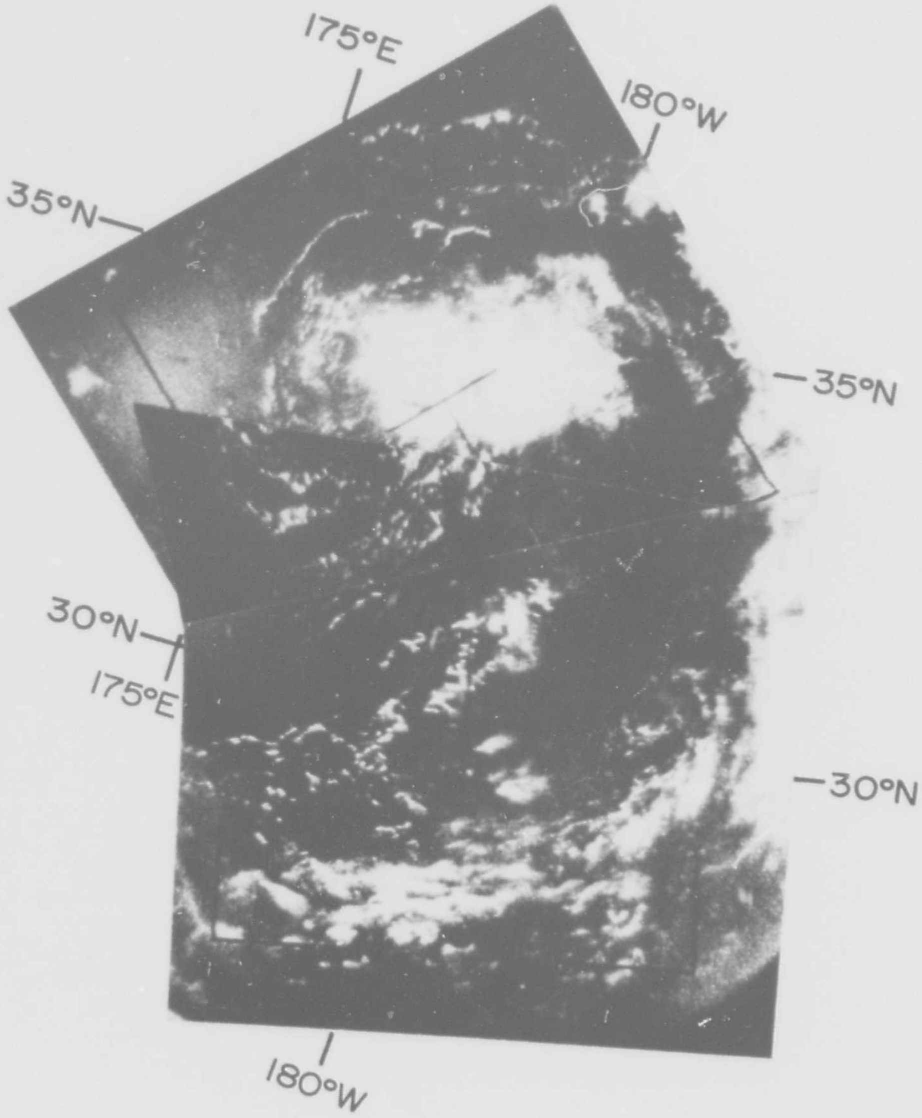

Fig. 27. TIROS VIII view of Oscar near 0130Z on 15 August 1964.

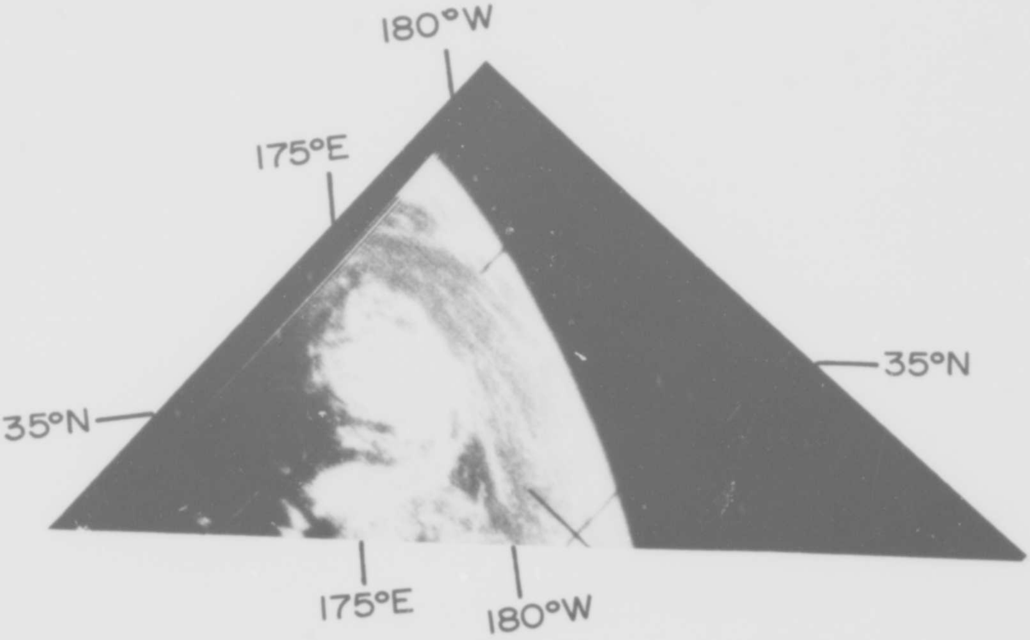

Fig. 28. TIROS VII view of Oscar near 0300Z on 16 August 1964.

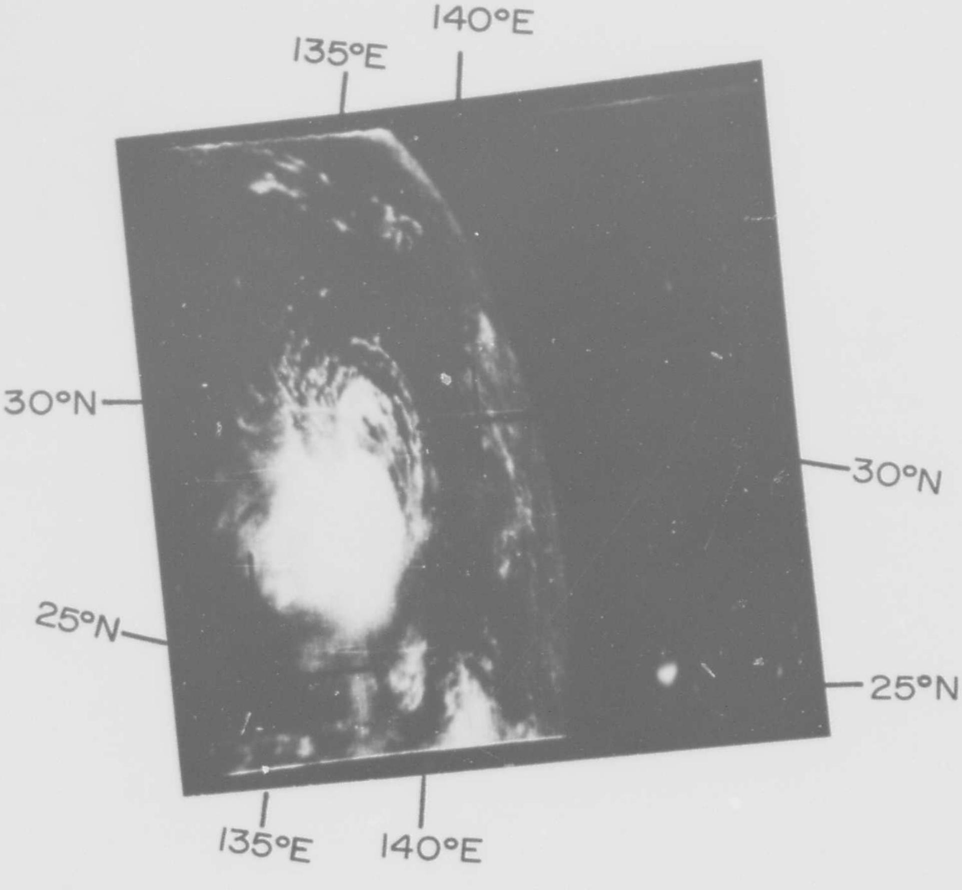

Fig. 29. TIROS VII view of Kathy near 0221Z on 15 August 1964.

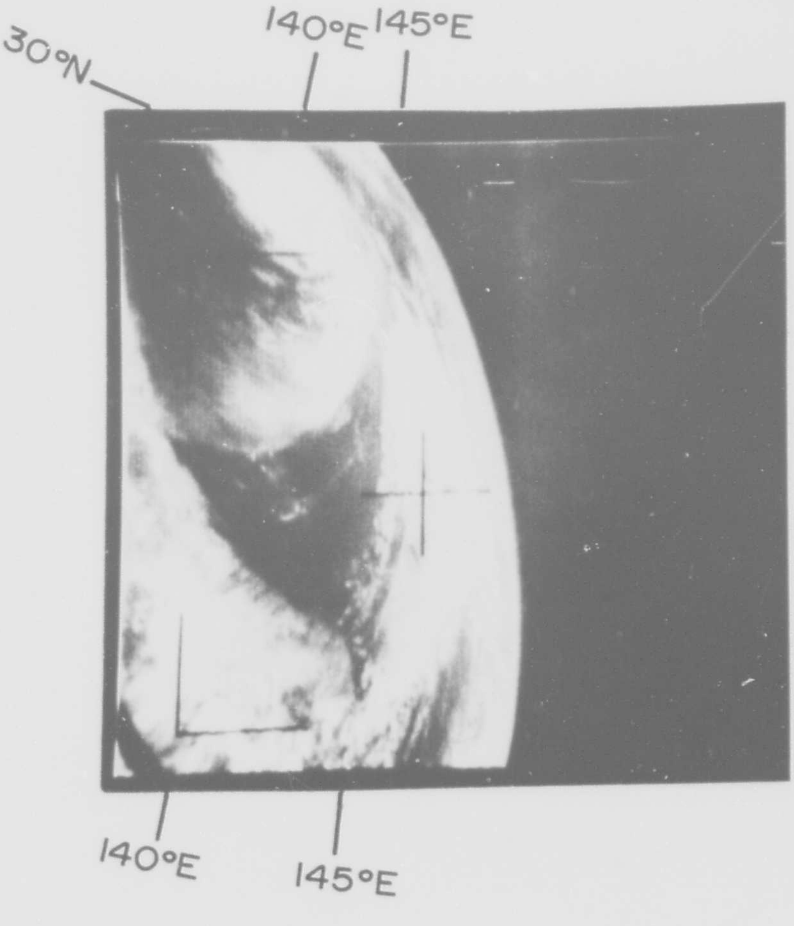

Fig. 30. TIROS VII view of Kathy near 0530Z on 14 August 1964.

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Subsequent reconnaissance penetrations show the surface system continued to decrease in organization through 16 August before reintensification on 17 August.

151000Z - 425 ft. - penetration: Oval, 10 miles, N-S, 20 miles E-W, wall clouds south quadrant only.

152230Z - 29,000 ft. - visual: Circular, 35 miles in diameter, ill-defined.

160400Z - 683 mb - penetration: No eye, multiple 700 mb closed circulations.

162200Z - 700 mb - penetration: Elliptical, 30 miles, N-S, 20 miles E-W, no definite wall clouds, open E-SF.

171040Z - 10,000 ft. - radar: Circular, 16 miles in diameter, closed wall clouds 7 miles thick.

8. MPT Systems and "Tradewind" Weather

Conover and Sadler (1960) and Sadler (1963a) utilized photographs from space together with conventional analyses to show the TUTT to be the major weather-producing system of the tradewind zone. The tradewind zone in this context excludes the equatorial and near-equatorial region whose weather is dominated by the low-level trough systems.

The analyses of Figures 4 through 21 illustrate the typical position of the MPT overlying the low-level tradewind region some 5 to 10 degrees south of the surface ridge line.

Beginning with the pictures from TIROS III in 1961, a continuing effort has been made to determine some of the characteristic cloud systems associated with the MPT. This has not proved to be a simple task for two main reasons:

1. The MPT location, over the open ocean, is far removed from a fixed network of observing stations, and
2. The nature of the cloud systems as viewed from the satellite is highly variable. This variability in cloud type, size, shape, orientation, persistence, and vertical structure is due in turn to the variable character of the upper circulation systems and of the lower tropospheric thermal

structure over which they pass. The variable lower tropospheric thermal structure will be discussed in the next section.

At times the MPT exists as a shear line for considerable distances with no apparent large cyclonic cells, whereas at other times, such as during the period discussed in this report, it is dominated by large cells. In addition, the penetration depth of the cells varies from being entirely confined to the upper troposphere to extreme penetration to the surface level. But despite these variables there still are broad general features which have been observed by the satellites. These features are:

1. The major cloud systems are south of the trough line. If not directly associated with a cyclonic cell system, they may extend, or even be removed, a considerable distance from the trough; but mainly they are confined to the westerly flow between the near-equatorial upper ridge line and the MPT.

2. The more intense convective cloud systems are associated with the cyclonic cells. Figure 31 is a circulation model of these cyclonic systems in the central Pacific together with a schematic of common satellite-observed cloud features. The essential features of the model are:

    a. A slope in the vertical. This slope is usually toward the southeast with decreasing height.

    b. The surface circulation observed is dependent upon the areal extent, intensity, and penetration depth of the upper cell.

The penetration intensity in Figure 31 is moderate to strong. In (a) the vortex has penetrated through the 700 mb level and shows in the surface level as an induced trough, whereas in (b) the penetration is to the surface as a vortex in the tradewind easterlies. Again, in some systems the surface circulation does not show in the direction field but only in the speed field, whereas in others there may be no indication of the upper system either in surface wind speed or in direction (Palmer <u>et al</u>., 1956). Pulsations in the penetration depth of the system can produce waves and weak vortices that alternately appear and disappear at the surface level, which can lead to surface analysis difficulties if an upper tropospheric analysis is not available.

    c. The surface circulation, whatever its character, is an integral part of the MPT system and neither forms independently nor moves, through relative motion, under or away from the MPT system. Even if the upper system is moving eastward (which is not uncommon during the transition seasons in the Hawaiian region) the surface trough or vortex will move upstream against

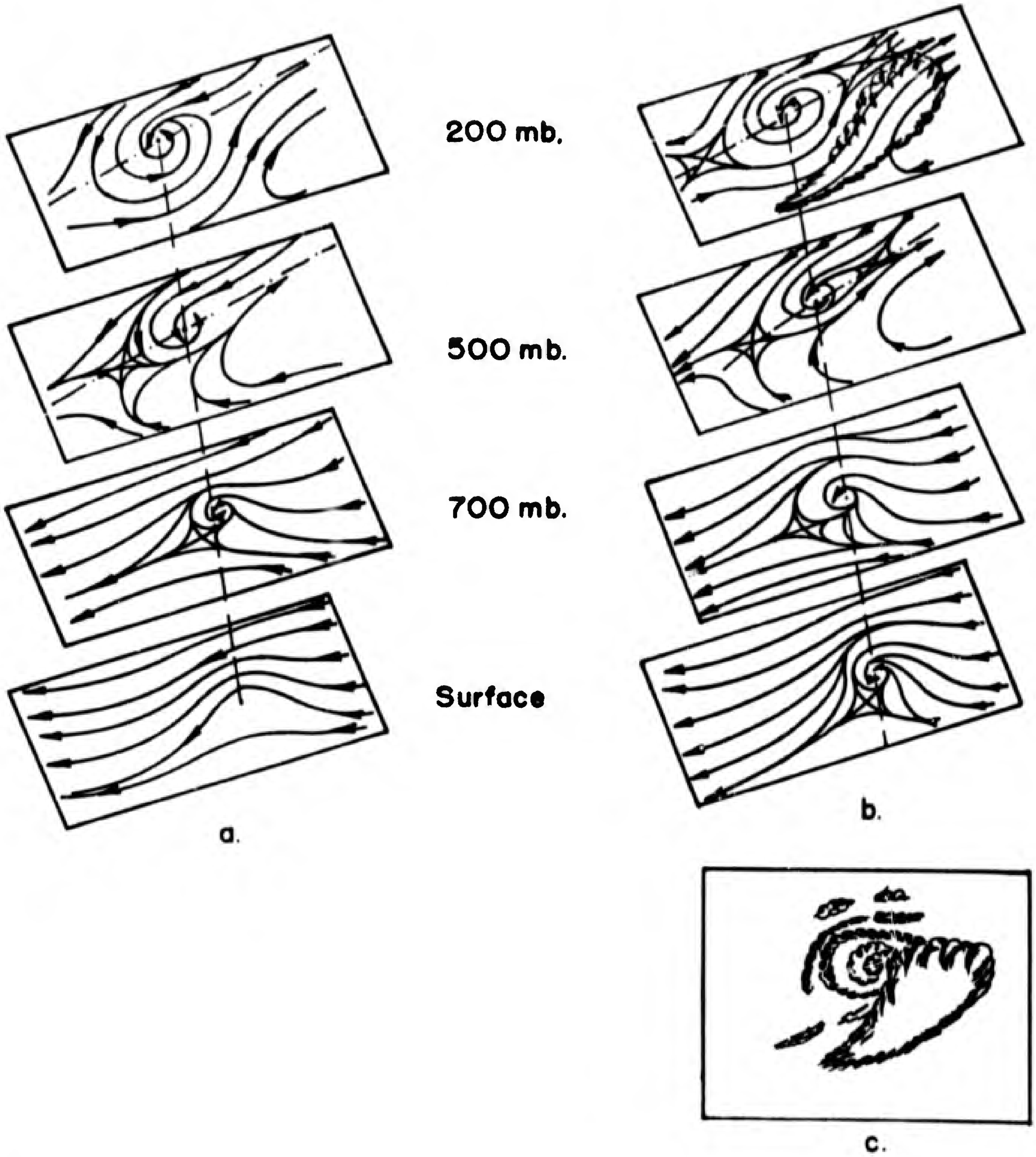

Fig. 31. Three-dimensional structure of the MPT systems with commonly observed cloud system.

the low-level easterlies.

d. The observed cloud system depends on the penetration intensity, geographic location, and slope of the system. Figure 31c is a schematic plan view of the cloud system of a moderate-to-strong cell in the central Pacific which has a southeast slope with decreasing altitude. The view is shown under Figure 31b, but is equally applicable to Figure 31a. The low-level convergence and major cloud system is in the east sector of the surface system, and, because of the slope, it is under the divergent region of the upper circulation. The observed vortex cloud pattern is best associated with a level near 700 mb. This vortex pattern is often weaker than shown in the schematic or may even be obscured by the major cloud mass. The view of Oscar on 15 August, shown in Figure 27, is a fairly good example.

9. Longitudinal Variation in the MPT Systems and Associated Weather

The centers of action in the MPT are the organized embedded cyclonic cells which move westward during the summer. There is, in general, a variation along the MPT in the intensity of the associated lower tropospheric systems and the resultant weather. The effect on the lower troposphere increases westward, however, the intensity of the MPT cells--as measured by their cyclonic vorticity--does not increase westward. By inspection of the 250 mb charts it is obvious that both the shear and curvature terms are as large in the eastern Pacific as in the central Pacific, and even larger than in the western Pacific. The intensifying surface effect westward is attributed to the varying conditions in the lower troposphere which the cells traverse.

The largest factor influencing the lower tropospheric thermal structure is probably the sea surface temperature. Figure 32 shows the mean sea surface temperatures for August in the north Pacific (Wyrtki, 1966). There is a large east-west gradient from the eastern Pacific to Midway. West of Midway the temperatures are quite warm and the 26C isotherm extends into high latitudes. The gradient west of Midway is oriented more in a north-south direction.

Figure 33 is a plot of the observed atmospheric thermal structure for the stations--Ship N, Midway, Marcus, and Guam—on 10 August, 1964. This day is typical of the 9-day period and is probably close to the average August conditions. All of these stations are within the tropics, by most definitions, yet there are large differences in the lower tropospheric thermal structure.

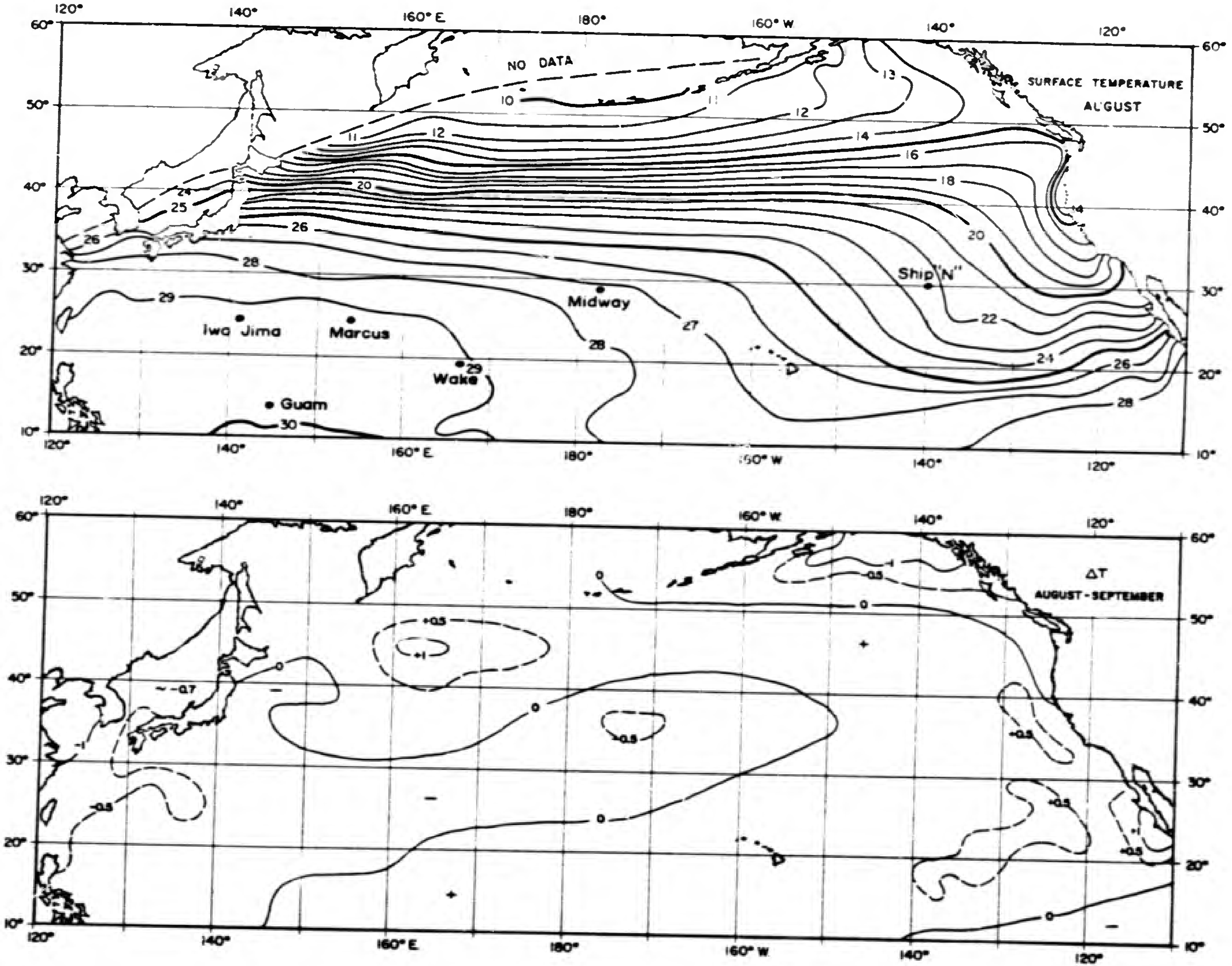

Fig. 32. Mean August sea surface temperature and mean monthly change between August and September (Wyrtki, 1966).

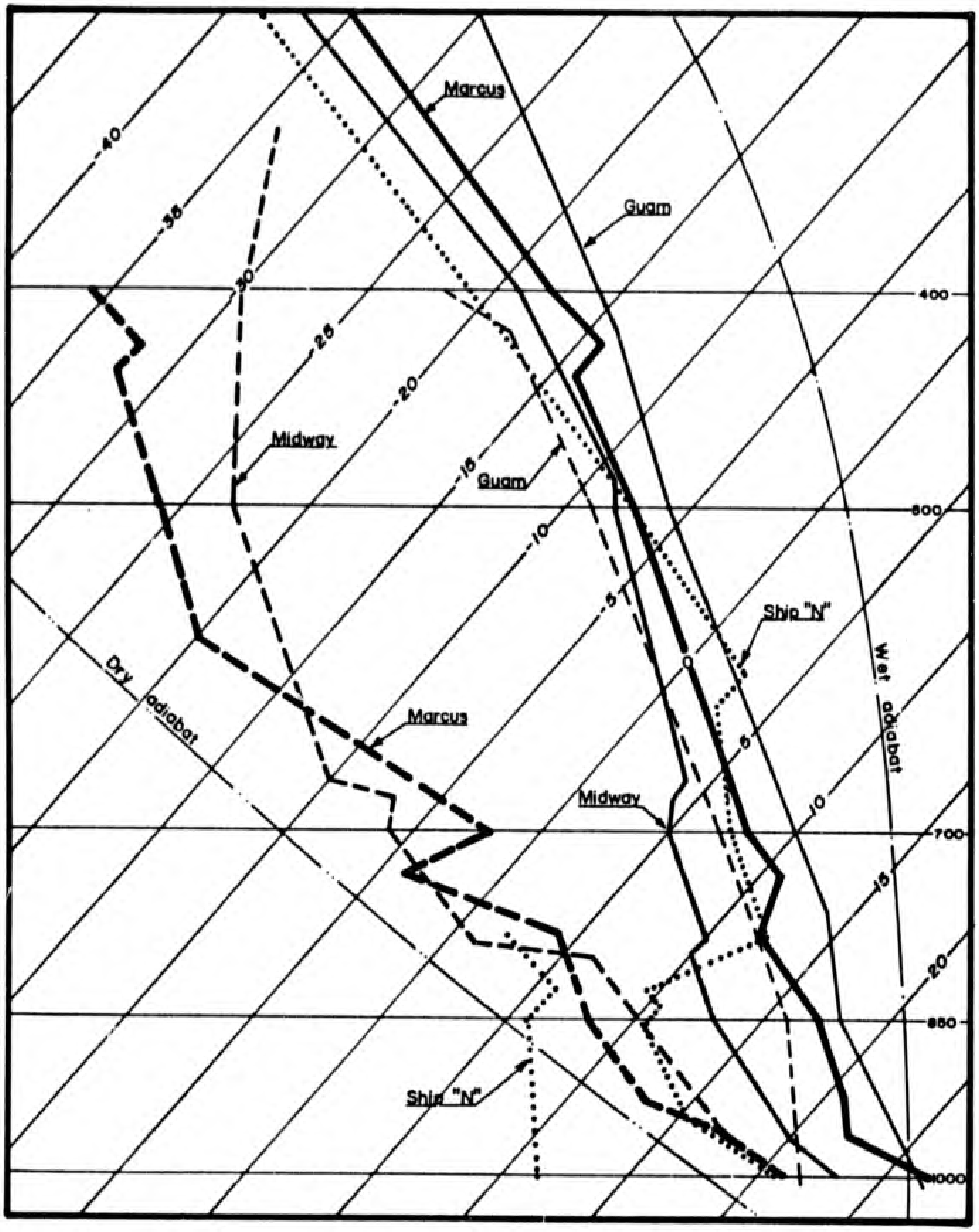

Fig. 33. Skew-T plot of temperature and dew point temperature for the stations indicated on 10 August 1964.

In the eastern North Pacific the MPT cells lie over a cold sea surface, a high surface pressure, a low intense inversion, and a shallow moist surface layer. Ordinarily, without the upper trough influence, clouds in this area would be low thin stratus or strato-cumulus. However, during the 9-day period, with the MPT persistent in the area, precipitation was reported at 0000Z on eight days in the surface anticyclone near weather ship Nan (30N, 140W) and on four out of seven observations at the weather ship itself. No surface pressures were below 1022 mb.

Relative to the eastern Pacific area (Ship N), the Midway Island area has a weaker and higher low-level inversion, a deeper moist layer, a slightly lower surface pressure, and a 5C greater mean August sea temperature. Satellite observations of the cloud systems of the MPT cyclones in this area have been presented in Figures 26-28. There is widespread convective activity and an organized cloud system; however, the energy of the systems is seldom sufficient to produce and sustain a surface cyclone of any significant intensity. Surface circulations of even 25 kts are very rare east of Midway.

West of Midway the surface pressure field continues to decrease toward the west along with the slight increase of the mean sea surface temperatures. The lower troposphere at Marcus is much warmer than at Midway but the moisture content remains low and typical of the trade-wind area.

The MPT surface systems occasionally attain tropical storm intensity in the areas of Marcus and Iwo Jima but seldom reach typhoon intensity (JTWC, 1965, 1966). They are normally on a north-of-west track and the parent upper cells move into a decay region as did Noel-Nancy. Kathy is probably a rare exception, in these latitudes, of a surface system moving into a region favorable for reintensification. The Fujiwara (1923) effect of Marie was perhaps instrumental in changing the track of Kirk-Kathy from a northwest to southwest direction and subsequently a cyclonic loop. This complete revolution of one storm around another is also a rare event. Nature seems to have a built-in mechanism for spacing storms within the same source region such as the low-level trough. The chance for interaction is increased if the storms have different source regions--as had Marie and Kathy.

The MPT cells which penetrate into the warm moist non-tradewind atmosphere south of approximately 20N in the western Pacific (Guam sounding, Fig. 33) would have the available energy source for the maintenance and intensification of a surface system upon decay of the upper cyclonic cell. Typhoon climatology would support such a secondary source of typhoons but positive verification is difficult for reasons previously discussed.

Satellite observations will be of great aid in the problem of detection and identification of cyclones, and an increase can be expected in the named tropical storms (excluding typhoons) and numbered depressions for the summer months in the region north of 20N between the longitudes of Wake and Japan.

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13 ABSTRACT

Surface and 250 mb analyses for a 9-day summer period over the North Pacific, together with satellite photographs, are shown to illustrate (1) the development of a typhoon and a tropical storm from cyclonic cells in the tropical upper tropospheric trough, and (2) the dominance of the trough in producing tradewind weather.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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