EVALUATION AND COMPARISON
OF TROPICAL ANALYSES DURING DST-5 AND DST-6

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1. INTRODUCTION

Data systems Tests (DST) 5 and 6 were conducted to assess the adequacy of the global data base for numerical analysis and forecasting and in the process to determine the impact of meteorological satellite data. A voluminous literature has accumulated on the evaluation of satellite data, particularly satellite soundings, and their impact on analysis and forecasting; however, the verdict is not yet clear. Ghil et al., 1979; Atlas et al., 1979; and Atlas, 1979 reported modest improvement in analyses and forecasts using satellite data with the Goddard Laboratory for Atmospheric Sciences (GLAS) models and in selected cases the satellite soundings provided critical data in particular weather situations which led to significant positive impacts relative to either the GLAS or National Meteorological Center (NMC) models using no satellite data. Tracton and McPherson, 1977; Miller and Hayden, 1978; and Tracton et al., 1980 reported no significant improvement with NMC models and even a negative impact during DST-5 tests. The results of these exhaustive tests indicate that the satellite data impact is probably model- and season-dependent but definitely dependent on the method of data assimilation and the numerical model used to produce the analyses or initial conditions. None of the tests have included an evaluation of the satellite data impact in the tropics for this is a much more difficult task. The pressure height gradients are small and there is little "ground truth" for evaluating the global soundings. The primary analysis within the tropics must be of the wind field and the satellite contribution is restricted to essentially two levels and only a portion of the globe unless there is a dedicated program of bogusing data from polar-orbiting satellites. The only extensive tropical forecast experiment was for a 5-day period in 1965 (Miyakoda et al., 1974). The results were mixed--good and bad. For the first 24-hour forecast the initial conditions of the height and wind fields at all 10 levels were determined by an experienced analyst. The first 24 hour forecast of the tropical precipitation pattern, based on this subjective analysis, compared well with observations of deep convective cloudiness observed by satellite. This severe test indicated that the model structure and physics were capable of an adequate forecast given the proper initial conditions. However, subsequent forecasts, based on updated numerical model analysis and initialization, deteriorated rapidly. This one test supports the contention of Atlas (1979) that the impact of satellite data depends primarily on improving the initial conditions and not on differences in forecast models.

This report discusses a limited exercise to evaluate the adequacy of the DST data base for analyses in the tropics. A few days of subjective analyses at two levels are compared with numerical analyses from the models of the Goddard Laboratory for Atmospheric Science (GLAS), National Meteorological Center (NMC), and NMC modified by the University of Hawaii under a separate study conducted by Murakami (Sumi, 1980). The comparisons are both subjective and objective. Subjective comparisons were made of the vorticity and divergence fields as well as the wind fields and synoptic systems. The energetics of the upper troposphere over selected regions determined by Sumi (1980) for the different analyses are also discussed here. In addition, GLAS tropical analyses and the utility of satellite soundings and derived winds in subjective tropical analyses are evaluated.

2. DATA AND ANALYSIS

(1) Data Base

The primary data base was the level II-b data compiled for the DST-5 and DST-6. The file contained (a) conventional data received at NMC enhanced by extending the cutoff time to 10 hours; (b) VTPR soundings; (c) cloud motion vectors together with an enhanced set provided by NESS; (d) a special set of cloud motion vectors determined at University of Wisconsin; (3) Nimbus 6 soundings specially processed by GISS; (f) aircraft reports from specially equipped wide-bodied aircraft (AIDS); and (g) TWERLE data processed at NCAR.

While the data set was impressive, it must be emphasized that no special effort, beyond extending the cutoff time to 10 hours, was made to enhance the conventional data base and regular aircraft reports. The greatest effect of this is reflected in the tropical regions where the normally scanty data stem from a combination of factors such as (1) relatively fewer stations; (2) missed observations; (3) poor communications; and (4) lack of a program for collecting AIREPs by most tropical weather services (Figs. 1 and 2). In Fig. 1 our analysis over Africa at 250 mb for 00 GMT, 3 September is based on only five rawin observations supplemented by time and space continuity, climatology, bogused winds estimated from satellite cloud photographs and a few satellite winds in the Atlantic. Figure 2 shows the aircraft wind observations available for 12 GMT, 15 August 1974 during the GATE. No special AIDS data are included. It is unlikely that air traffic decreased between 1974 and 1975.

Compared with Africa the data over South America were as sparse; however, the satellite winds from NESS and Wisconsin permitted a reasonable analysis at 250 mb. At 850 mb adequate analysis was impossible over either South America or Africa.

The primary data base was supplemented by satellite photographs from three sources: (1) the global band tropical mercator projection mosaics of NOAA-4 from NESS; (2) high resolution DMSP orbital strips borrowed from the archives of the World Data Center A for Glaciology; and (3) GOES West pictures from the NESS station in Honolulu. These were used to locate and estimate the intensity of synoptic systems such as tropical cyclones, tropical upper tropospheric troughs (TUTT) and embedded upper tropospheric cyclones, troughs, ridges, jet streams, lower tropospheric convergence zones, mid-latitude lows and fronts. Through established subjective models, wind fields were inferred from the cloud patterns (Anderson et al., 1969; Sadler, 1963, 1976a, 1976b, 1978). As an example, the direction and speed of the easterly jet entering the east side of Fig. 1 in the equatorial zone was inferred from the satellite-observed cirrus clouds. This jet, extending from south of India, persisted and on the next day (4 September) penetrated into equatorial Africa; 55 kt winds were observed at 250 mb at Nairobi. The increase from less than 10 kts on 3 September to greater than 50 kts on 4 September could not have been adequately interpreted without the history of the jet obtained from the satellite-observed cirrus. This anomalous jet, which deviated considerably from climatology, will be referred to later in a discussion of the energetics.

(2) Selection of Period and Levels for Analysis

The days for analysis within each DST period were selected mostly on the basis of the tropical synoptic activity as revealed by the global satellite pictures. The selected DST-5 period of 30 August - 4 September 1975 contained seven tropical cyclones in various stages of development and a well-developed TUTT in the North Atlantic and the North Pacific. In the eastern Pacific, Hurricane Katrina attained an intensity of 115 kts, Jewell became a minimum strength hurricane and the remnants of Ilsa passed north of Hawaii. Hurricane Doris formed north of 30N in the Central Atlantic and Hurricane Caroline traversed the Gulf of Mexico and entered Mexico. Typhoon Tess formed near Guam and tropical storm Susan formed southeast of Japan.

The DST-6 period of 29 February - 3 March 1976 contained a typhoon off northeast Australia and a well-developed TUTT in the southeast Pacific. In addition a deep trough in the westerlies with a strong frontal system passed through Hawaii.

The standard levels of 850 mb and 250 mb were chosen for analysis to maximize the data by utilizing low- and high-level satellite cloud motion vectors and aircraft reports which are concentrated near the 250 mb level.

(3) <u>Data Plotting, Analysis and Grid Point Data Extraction</u>

A large scale (1:15,000,000) map, even though unwieldy (8 ft long) and time consuming in line drawing, was necessary to accommodate the large volume of satellite cloud motion vectors processed from GOES East and West over the Western Hemisphere. The II-b data were plotted with varying plotting models to distinguish the different data types and sources.

The analyst then noted on the charts information which was obtained from other sources--the position and intensity of tropical cyclones from published sources and the global satellite pictures; the position and intensity of other satellite-observed significant cloud masses associated with tropical disturbances, convergence zones, TUTTs, monsoons, fronts, trade winds, etc.; estimated winds from the polar-orbiting satellites outside the area covered by the geostationary satellites; the position of other surface features such as subtropical highs and ridges from the NMC global band surface analysis.

The wind direction and speed were then analyzed using overlying acetate and various-colored grease pencils. This method facilitates the overlaying and ajustment of analyses to assure time, space and vertical continuity.

After completion of all analyses, they were traced onto the plotted charts and grid point data were manually extracted at 2.5° grid spacing for subsequent use in comparison with other analyses and derived fields.

The satellite sounding data were plotted on separate charts of the same scale and analyzed for thickness and temperature patterns. No analyses were available for the reference level (1000 mb); therefore, height analyses of the constant pressure surfaces were not accomplished.

3. EVALUATION OF DATA BASE FOR SUBJECTIVE ANALYSES

Prior to evaluating and comparing various tropical analysis schemes, suitability of the data for subjective analysis should be commented on. Subjective tropical analysis by an experienced analyst working in a research mode should be superior to an objective tropical analysis for many obvious reasons; however, the quality of both is dependent on data; the greater the quantity and quality of data the more alike the analyses become and converge on the true solution. Even though I selected the levels of maximum data (excluding the surface) for this exercise, on the global scale there remained large areas with very few data; as discussed in the introduction, analysis over these areas by any method is little better than climatology.

(1) Winds

Within most of the Western Hemisphere, due to the GOES satellites and at least some effort in collecting aircraft observations, the DST data base approaches that needed for an adequate tropical wind analysis at two levels after making the reasonable assumption that the satellite and aircraft winds are representative of the flow at the selected levels of 250 mb and 850 mb. To illustrate the impact of the satellite winds, Eastern Pacific sections of the analyses are shown in Figs. 3 and 4. This is a region of very few conventional observations and prior to the satellite era its meteorology was relatively unknown. The 250 mb analysis for 3 March (Fig. 3) obtained by meshing the few rawinsonde observations (circled), the few aircraft reports west of 180° and a good distribution of satellite winds is probably close to the true solution of this very complex circulation pattern caused by the extensive and strong tropical upper tropospheric trough (TUTT) and two intense midlatitude cyclones. The addition of data would not change the analysis significantly. The 850 mb analysis for 2 September (Fig. 4) with only satellite data over the ocean depicts a simple trade wind flow in the South Pacific and a rather complex monsoon type flow in the North Pacific. The trade wind flow is well sampled but even in the north the few well placed satellite winds in combination with the satellite-observed cloudiness and synoptic modeling of Hurricane Katrina and decayed Hurricane Jewell permits a reasonable analysis.

(2) Soundings

Adequate analyses of the pressure height and temperature fields have never been possible in the tropics due to the sparsity of rawinsonde stations, small gradients, and the mixture of rawinsonde types whose differences or biases are comparable to the synoptic gradients.

In such a situation satellite soundings should have maximum impact. The spatial resolution of the data is good and from the same instrument the gradients should be accurately determined even though the absolute values may be biased. The problem of specifying the height of the reference level remains but even here, due to small pressure gradients, the error should be less than in higher latitudes (except in the vicinity of tropical cyclones). Tropical cyclones must be man-"bogused" into the data base whether it be wind or height analysis. Assuming the soundings are useful in the tropics, the added advantage is their availability for all standard levels.

Our subjective analyses of the thickness field indicate that the satellite soundings can reasonably depict the height field at 250 mb over the tropical oceans. Figure 5 shows an analysis of the 1000-250 mb thickness field from the Nimbus 6 soundings in the Central and Western Pacific on 4 September. Added to the chart are the ridge and trough positions taken from the wind analysis. The positions of the N.H. subtropical ridge (STR) extending from China across Japan and northeastward, the N.H. subequatorial ridge (SER) oriented east-west near 10N, the S.H. ridge from northern Australia to the equator near 175W; the N.H. TUTT system extending across the West Pacific and separating the STR from the SER in eastern China and the omega pattern north of Hawaii are all reasonably well located by the satellite soundings; certainly better than could be obtained by determining the height field only from the few radiosonde stations. How much the pattern would be altered by the addition of the 1000 mb height field is unknown.

It was noted during analyses of the thickness fields that certain areas have repetitive patterns which appear to be caused by strong horizontal near-surface thermal gradients anchored by topography. The best examples are over the mountains of eastern Africa, particularly in Ethiopia. The thickness pattern from 1000 to 850 mb (Fig. 6) is essentially the same as from 1000 to 250 mb (Fig. 7) and the addition of the 1000 mb height would not appreciably alter this relationship over this area. It is highly unlikely that such a strong cold low exists through the troposphere and experience with upper tropospheric winds during GATE (see Fig. 2) indicate that these features are not real but must be due to some flaw in the method or assumptions in producing the soundings.

4. COMPARISONS OF ANALYSES

The plan to use subjective analyses to evaluate data and serve as a common base for comparing objective analyses in the tropics included both subjective and objective methods. The plan to compare the life histories of synoptic systems over a five-day period was not very successful due to the lack of mapped objective analyses for comparison. NMC analyses were requested from the National Climatic Center but were not available for these periods. GLAS analyses were furnished by Dr. Robert Atlas for levels and parameters indicated in the following table.

Standard level	Parameter	Area	Contour interval or representation
surface	pressure	global	4 mb
surface	pressure	N.H. 0 to 180W	4 mb
surface	pressure	N.H. 0 to 180E	4 mb
850 mb	height	global	100 meters
850 mb	temperature	global	5°K
500 mb	height	global	100 meters
500 mb	height	N.H. 0-180W	100 meters
500 mb	wind direction	N.H. 0-180W	arrow, ≈ 5° grid
300 mb	height	global	100 meters
300 mb	height	N.H. 0-180W	100 meters
300 mb	wind direction	N.H. 0-180W	arrow, ≈ 5° grid
300 mb	wind speed	N.H. 0-180W	10 kts
250 mb	height	global	100 meters
250 mb	temperature	global	5°K

Comparisons with the GLAS analyses were not as successful as hoped because of their concentration on the height field. The 100 meter contour intervals are too large for analysis between 30N and 30S; therefore, the tropical systems were not adequately depicted and no time continuity could be established. However, in the couse of attempting the comparison some general features of the GLAS analyses in the tropics were noted and will be discussed later.

In conjunction with a parallel project under the direction of Prof. Murakami, University of Hawaii, comparisons were made between parameters derived from the Level III grid point data of the NMC and University of Hawaii objective analyses and our subjective analyses. The University of Hawaii analysis modified the NMC analysis over data sparse areas by applying a divergence term proportional to the satellite-observed outgoing longwave radiation (Sumi, 1980).

(1) Relative Vorticity

Figure 8 shows the 250 mb subjective analysis at 00 GMT on 1 September 1974 for the section from India eastward to 70W illustrating the typical data distribution and the contrast between the simple flow pattern of the winter hemisphere and the complex pattern of the summer hemisphere. The wind data supplemented by satellite photographs and time continuity were sufficient on which to base reasonable analyses for this section. The lack of satellite winds in the eastern South Pacific on 1 September was not typical of most days. The grid point winds between the equator and 20N on Fig. 8a are from the GLAS 300 mb analysis and will be discussed in a later section.

Figure 9 shows the vorticity field derived from the analysis of Fig. 8 and for comparison Fig. 10 shows the vorticity derived from the Level III NMC 200 mb analysis. In general the vorticity patterns are alike. The main exceptions are in the southern Bay of Bengal, the western North Pacific and the South Pacific in the region centered near 12S and 173E. In general the subjective analysis vorticity is greater than the NMC vorticity. Notable examples are over the southern United States, along the TUTT across the North Pacific and from Japan southwestward to India.

(2) <u>Five-day Averaged Wind Fields and Energetics</u>

Under the Murakami project grid point data from the analyzed wind fields were used to compute divergence, vorticity, streamfunction, velocity potential and energetics over the area from 40E eastward to 100W. The results were reported in Sumi (1980) and selected figures from that report are used herein for additional discussion and to note differences in interpretation of the results. The averaged wind fields are shown in Fig. 11. There is little perceptible difference between the UHM and NMC objective analyses. The subjective analysis, except for being somewhat smoother, is in general agreement with the objective analyses since data are plentiful over most of the area. Major differences are found in the equatorial Indian Ocean and the equatorial Pacific east of 170E. Sumi (1980) attributed the differences in the Indian Ocean to the use of climatology by the subjective analyst; however, this is not correct for the significantly greater wind speeds of the subjective analyses differ from climatology and are due to the use of "bogused" winds obtained from extensive and persistent cirrus streamers observed by satellite (discussed earlier). In the Pacific the subjective analyses maintained the buffer system just north of the equator with resulting west winds along the equator in contrast to east winds in the objective analyses.

These differences in the wind field produced considerable differences in the energy conversions and the eddy kinetic energy fluxes over these regions as reported by Sumi, 1980 (see his Table 1 and Figs. 8 and 9). In the Indian Ocean between the equator and 15S the barotropic energy conversion was negative (barotropically stable) for the subjective analysis and strong positive (barotropically unstable) for the objective analyses. Between the equator and

15N the kinetic energy flux at the eastern boundary of 110E was six times greater in the subjective analysis. In the Pacific between the equator and 15N the kinetic energy flux at the western boundary of 140E was ten times greater in the subjective analysis.

The outgoing longwave radiation (OLR) obtained from satellite data is a gross measure of the area and depth of convective cloud systems in the tropics and is therefore related to the divergence of the upper winds and can be used as an independent check on the quality of wind analyses. The divergent components of the wind fields from Fig. 11 are shown in Fig. 12 together with the five-day averaged OLR. The minimum OLR values, located in the Bay of Bengal and over Borneo, agree best with the divergent flows of the subjective analyses even though OLR was used as a correction factor in the UHM analyses.

5. COMMENTS ON GLAS ANALYSES IN THE TROPICS

The GLAS objective analyses and our subjective analyses could not be adequately compared for reasons stated earlier; however, for those few tropical features which could be compared the GLAS analyses proved unsatisfactory. Some specific examples are:

(1) Tropical Cyclones

None of the six tropical cyclones during the August-September period were adequately depicted on either the surface or 850 mb analyses. On most days there was no evidence of the cyclones at all. Since these systems are seldom reflected in the conventional data network, they must be bogused.

(2) Surface Pressure Analysis

In general the surface pressure analysis was very poor over the tropics, apparently due to unsatisfactory data checking. There were daily examples of isolated "bull's-eye" type circular systems, each obviously caused by a singular poor observation. Extreme examples were a 1020 isolated high on the equator in the Atlantic and a 1016 mb high near a 1004 mb low on the equator in the eastern Pacific. The systems pop in and out of the analyses with, of course, no continuity in time or space.

A good surface pressure analysis is a prerequisite for determining a good reference level for the satellite soundings and it is unfortunate if their ultimate utility in the tropics is limited by the quality of the surface analyses.

(3) <u>300 mb Wind Analyses</u>

A most discouraging feature was the 300 mb wind analysis in the tropical belt since it is presumably based on many observations from satellite wind vectors, aircraft reports and rawins. The GLAS grid point wind direction vectors and interpolated speeds from the 00 GMT 1 September 300 mb analyses are plotted on Fig. 8a. The analysis is very "noisy" with directions "flip flopping" between grid points and speeds varying erratically. One rawin check is afforded by Johnston Island which is very near a grid point. The analyzed and observed directions differ by some 50 degrees. The analysis for this day is typical of the other days and it is difficult to define the problem without more knowledge of the analysis scheme.

(4) The system centers and trough and ridge lines seldom coincide in the pressure and wind analyses. Again, knowledge of the analysis scheme is needed to determine the cause since we do not know if the analyses are independent or if some type of dynamic balance procedure is used.

6. ADDITIONAL COMMENTS

Satellite input to the tropical data base has been impressive and has continued to increase since the DST-5 and DST-6 with the addition of improved soundings, better specification of the SST and more geosynchronous satellites. However, purely objective analysis by any current scheme, even for the few levels of maximum data, does not take full advantage of satellite data and can be considerably improved by experienced human intervention. The impact of satellite soundings, although promising, has yet to be tested.

Beyond the analysis problem is the more formidable one of numerical tropical forecasting which has scarcely been posed much less tested. If our main interest lies in higher latitudes, perhaps we should continue to "wire around" the tropics while posing the question: "What impact would a better tropical analysis have on higher latitude forecasting?" Most meteorologists arbitrarily assume it would have a large effect because the tropical region is the major energy source and the large international programs of GATE and FGGE have been conducted to deal mainly with the tropical problems. However, success in linking the tropical convection scale to the large scale circulation has not been reported from the GATE program. Perhaps a detailed tropical analysis, beyond the proper specification at the interface between the tropics and extratropics, is unnecessary and would have little impact on the quality of midlatitude forecasts. The data collected during the special observing periods of FGGE may be sufficient to address the question and is worthy of consideration.

ACKNOWLEDMENTS

Mr. Hiroshi Nishimoto aided in the analysis, Mr. Louis Oda conducted the data management and plotting and Mrs. S. Arita typed the manuscript.

Appreciation is expressed to Dr. Murakami and Mr. Sumi for their cooperation in integrating the research efforts and for the use of their results.

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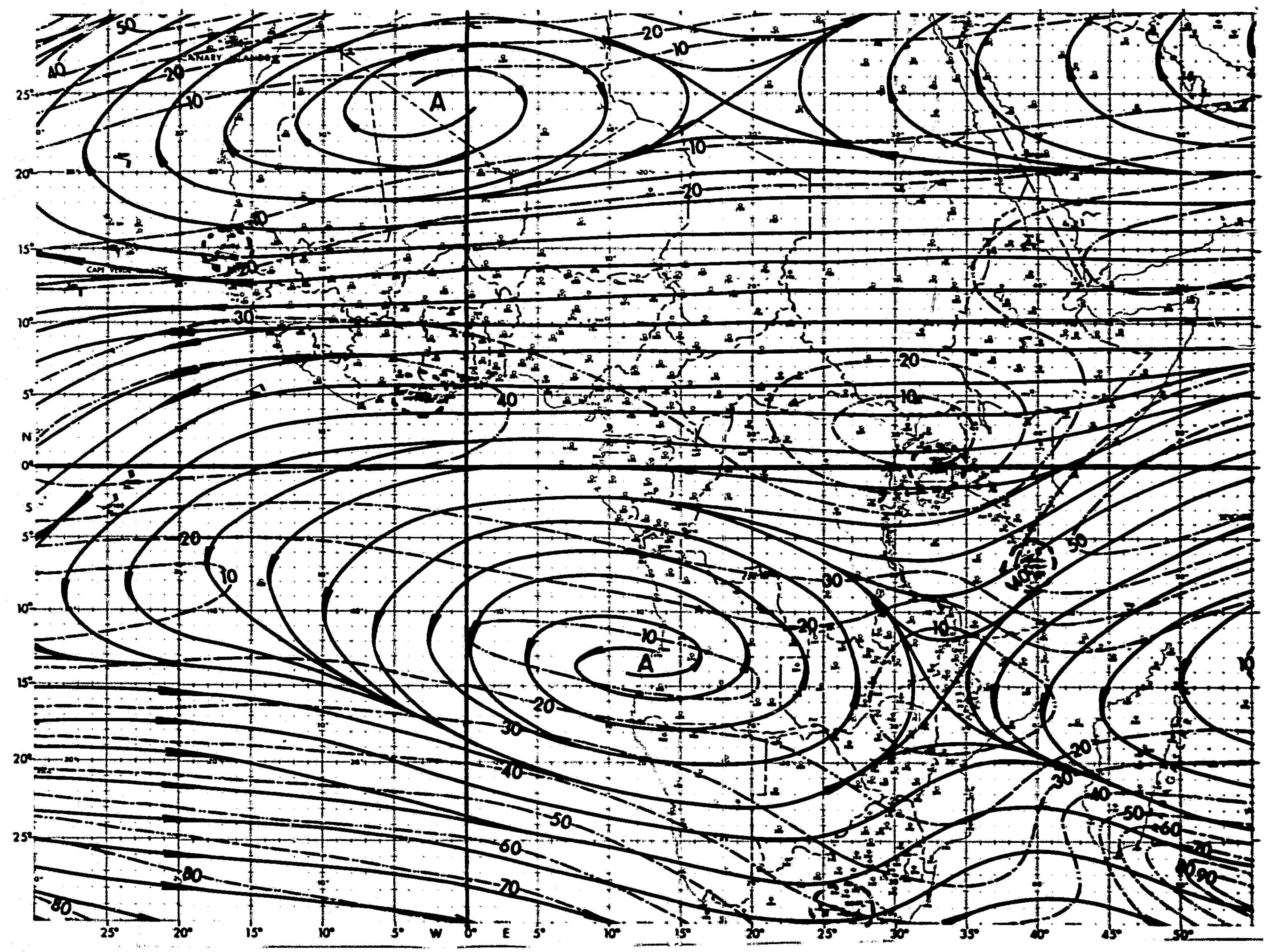

Fig. 1. 250 mb analysis over Africa at 00 GMT, 3 September 1975 illustrating typical sparse data. The five rawin observations are circled.

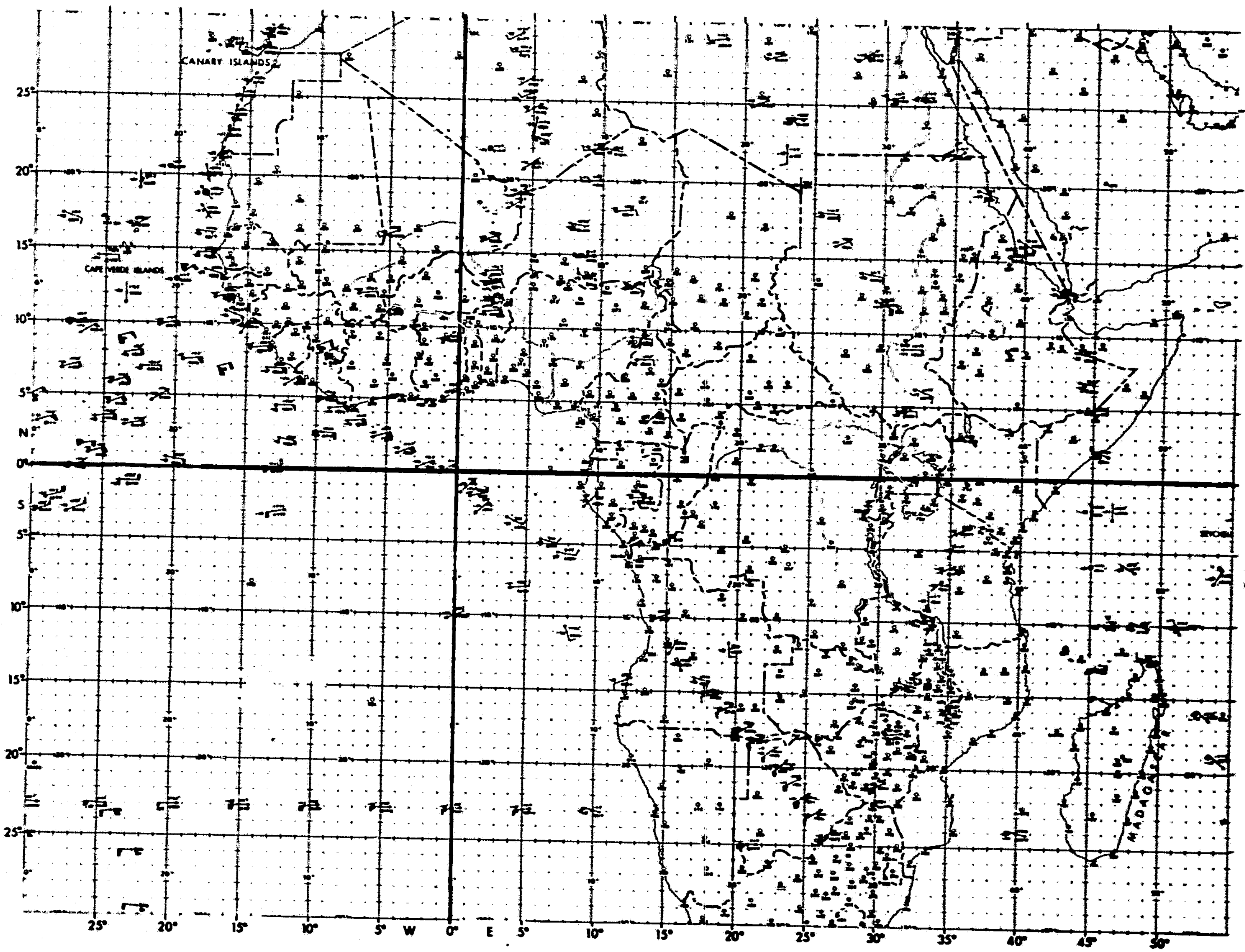

Fig. 2. Aircraft data over Africa near 250 mb for 12 GMT, 15 August 1974 illustrating the typical distribution of the approximately 200 available pilot reports.

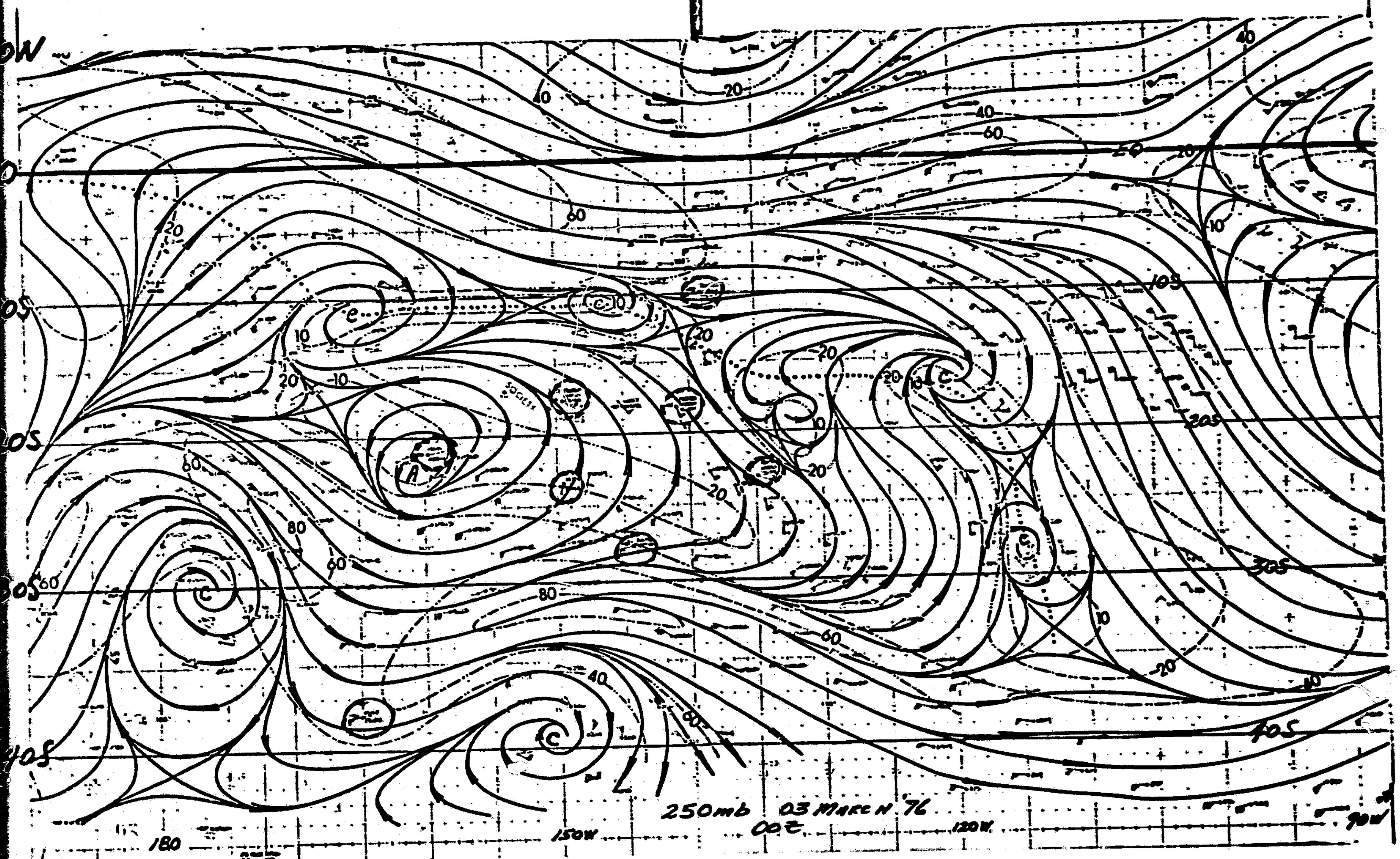

Fig. 3. 250 mb wind analysis over the eastern Pacific Ocean at 00 GMT, 3 March 1976. The few rawinsonde observations are circled. The tropical upper tropospheric trough is noted by the dotted line.

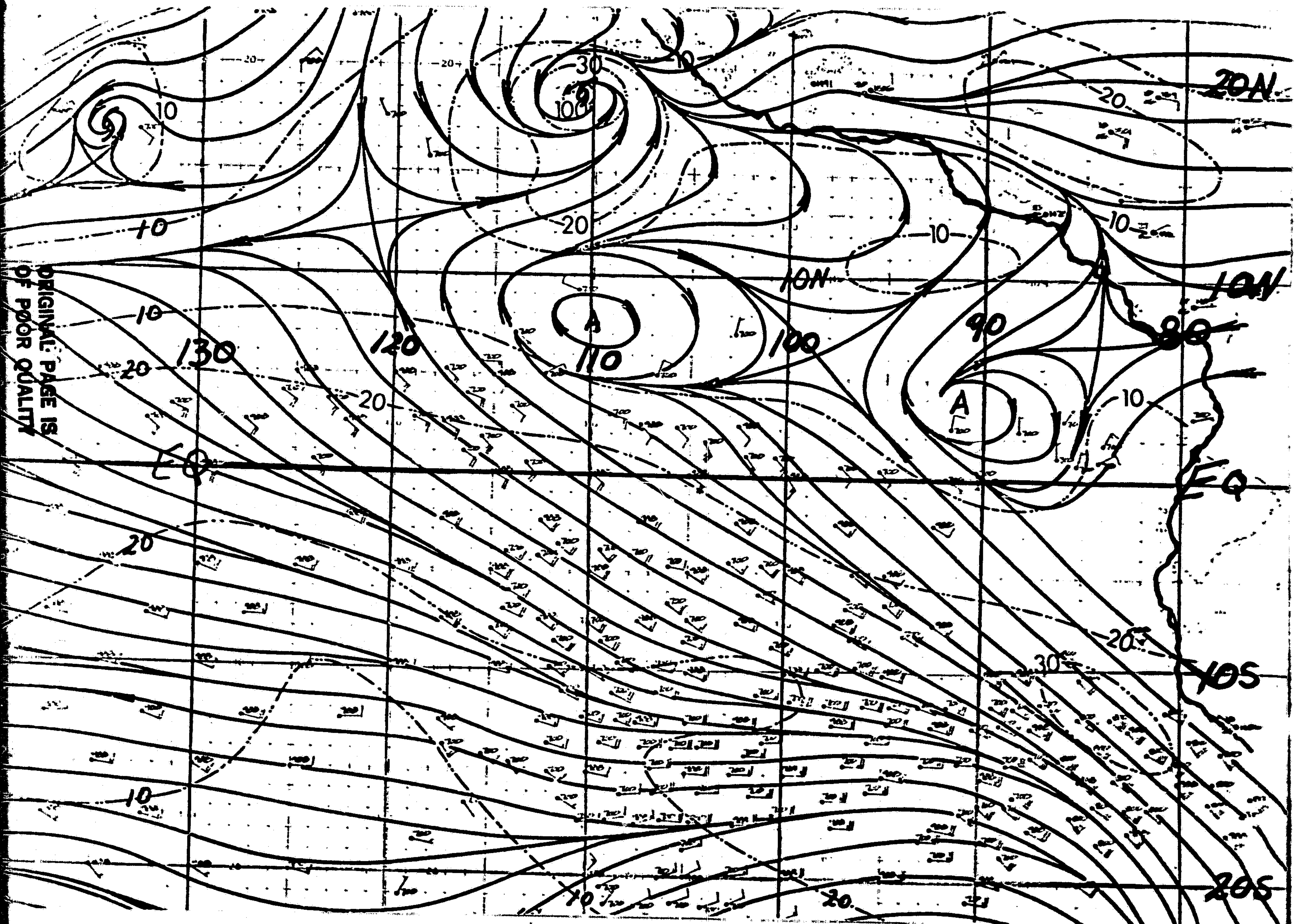

Fig. 4. 850 mb wind analysis over the tropical eastern Pacific Ocean at 00 GMT, 2 September 1975.

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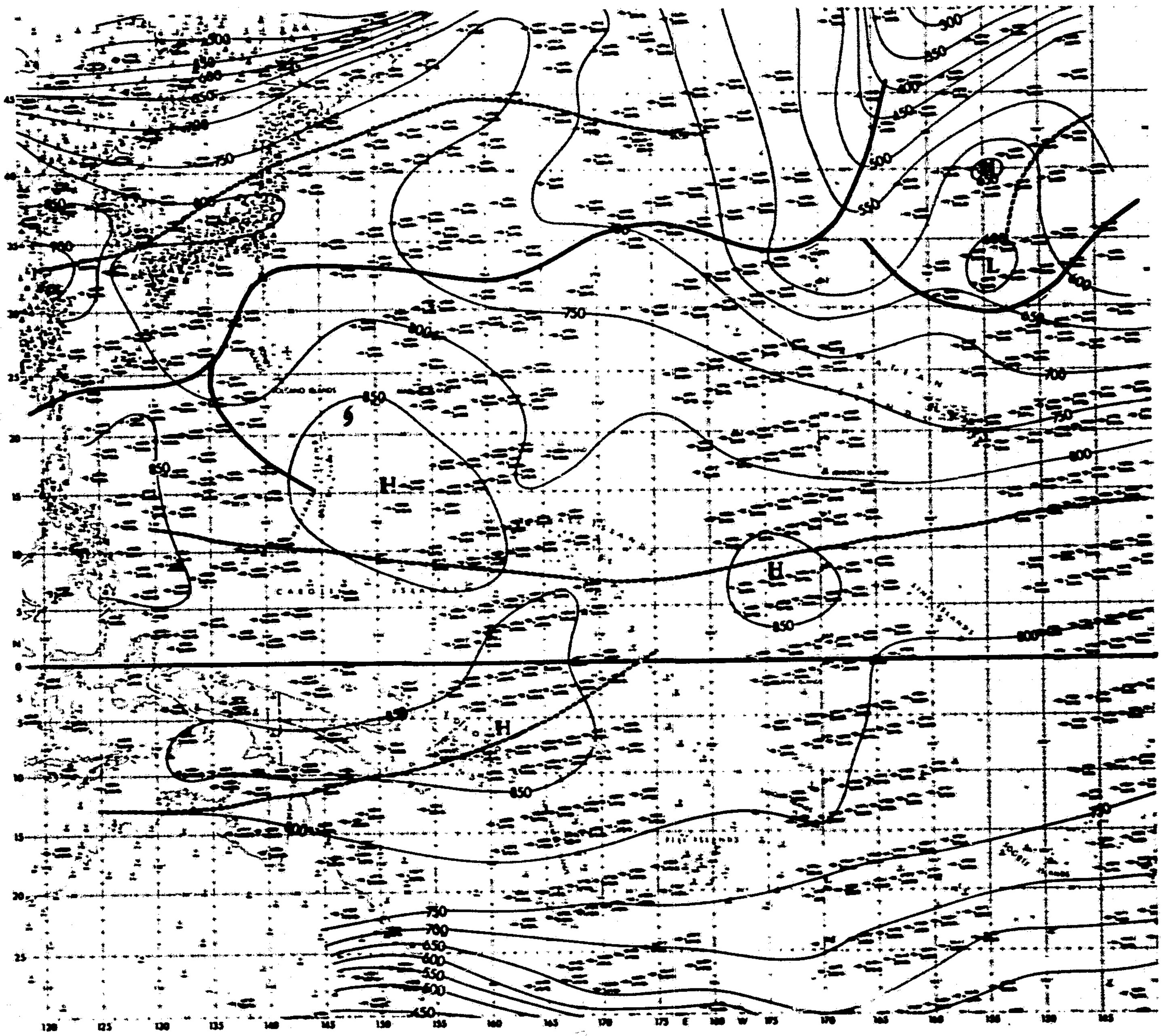

Fig. 5. Analysis of 1000-250 mb thickness pattern from NIMBUS 6 sounding data for 00 GMT, 4 September 1975. Contour interval is 50 m. Positions of 250 mb troughs and ridges from streamline analysis are shown by the heavy solid and dashed lines, respectively.

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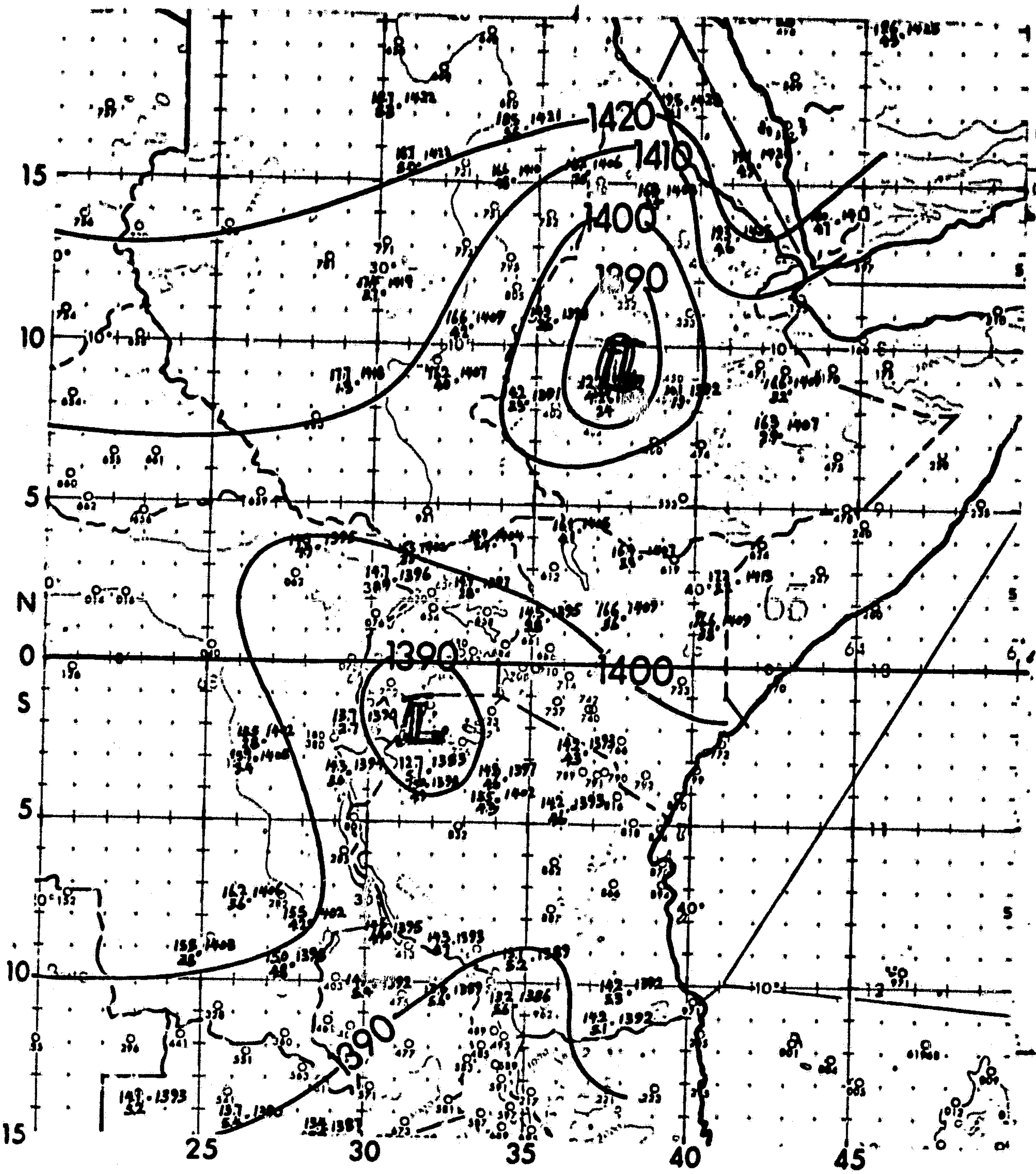

Fig. 6. 1000-850 mb thickness analysis from NIMBUS 6 sounding data for 00 GMT, 31 August 1975. Contour interval is 10 m.

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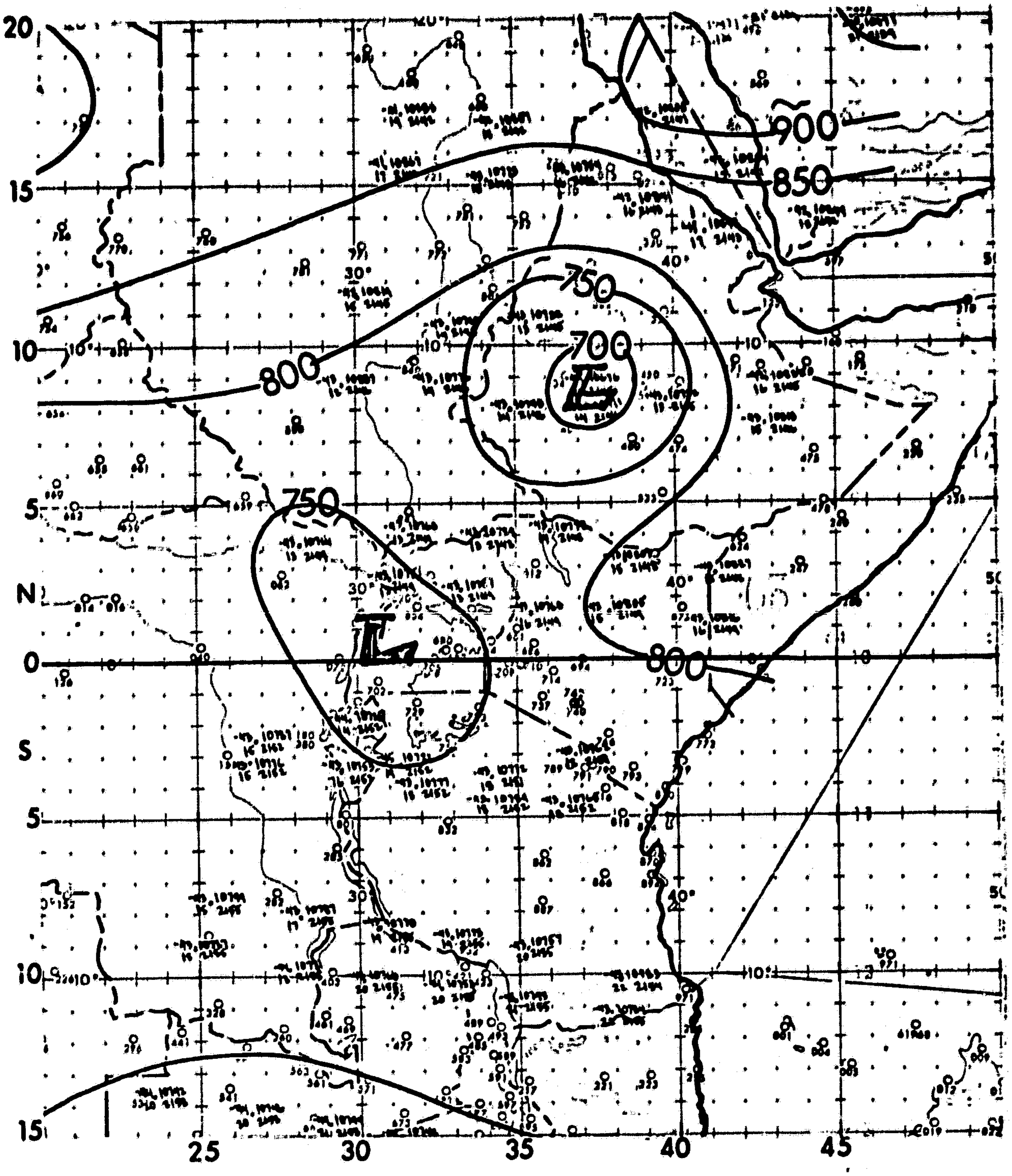

Fig. 7. 1000-250 mb thickness analysis from NIMBUS 6 sounding data for 00 GMT, 31 August 1975. Contour interval is 50 m.

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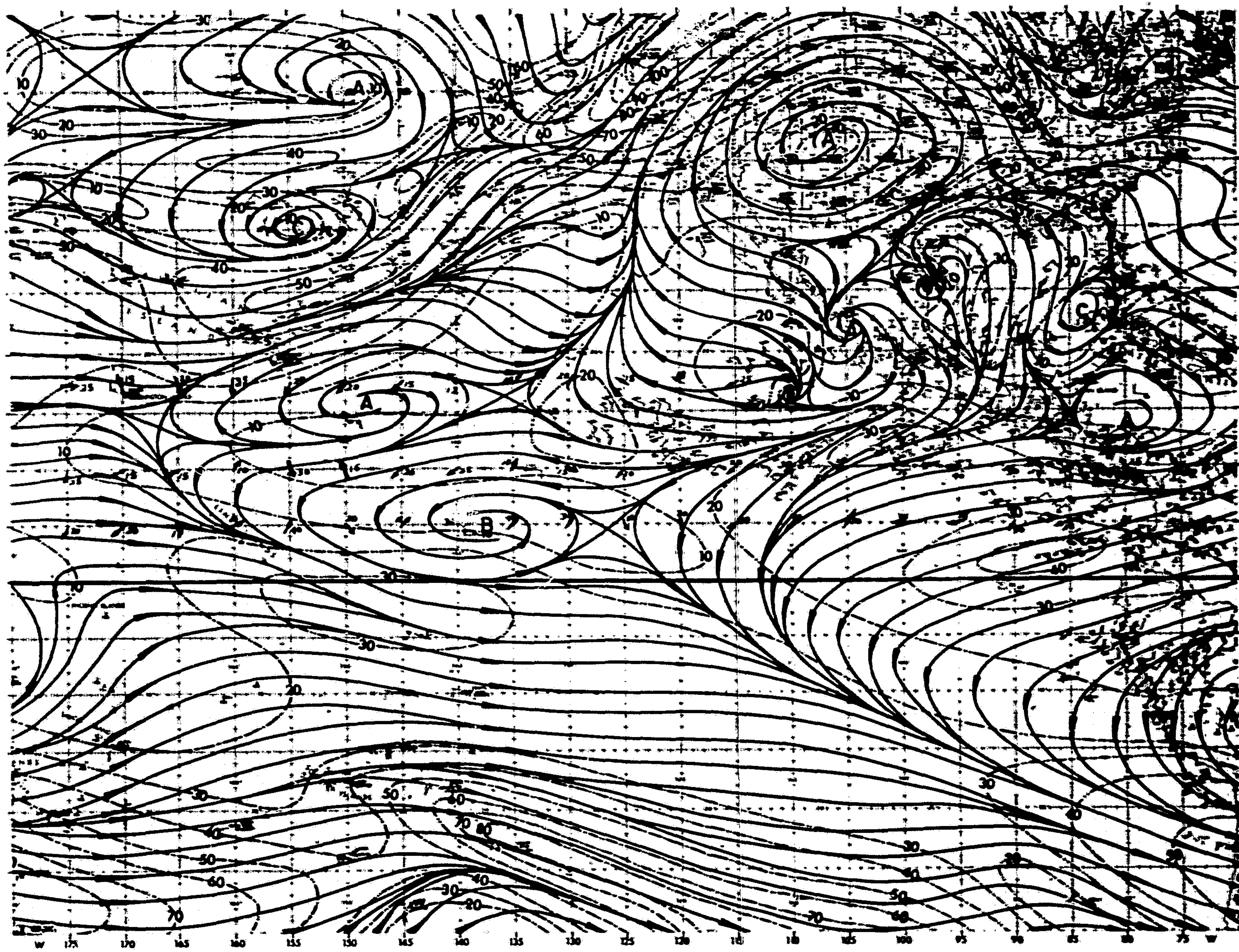

Fig. 8a. 250 mb wind analysis at 00 GMT, 1 September 1975 from 70 W to 180.

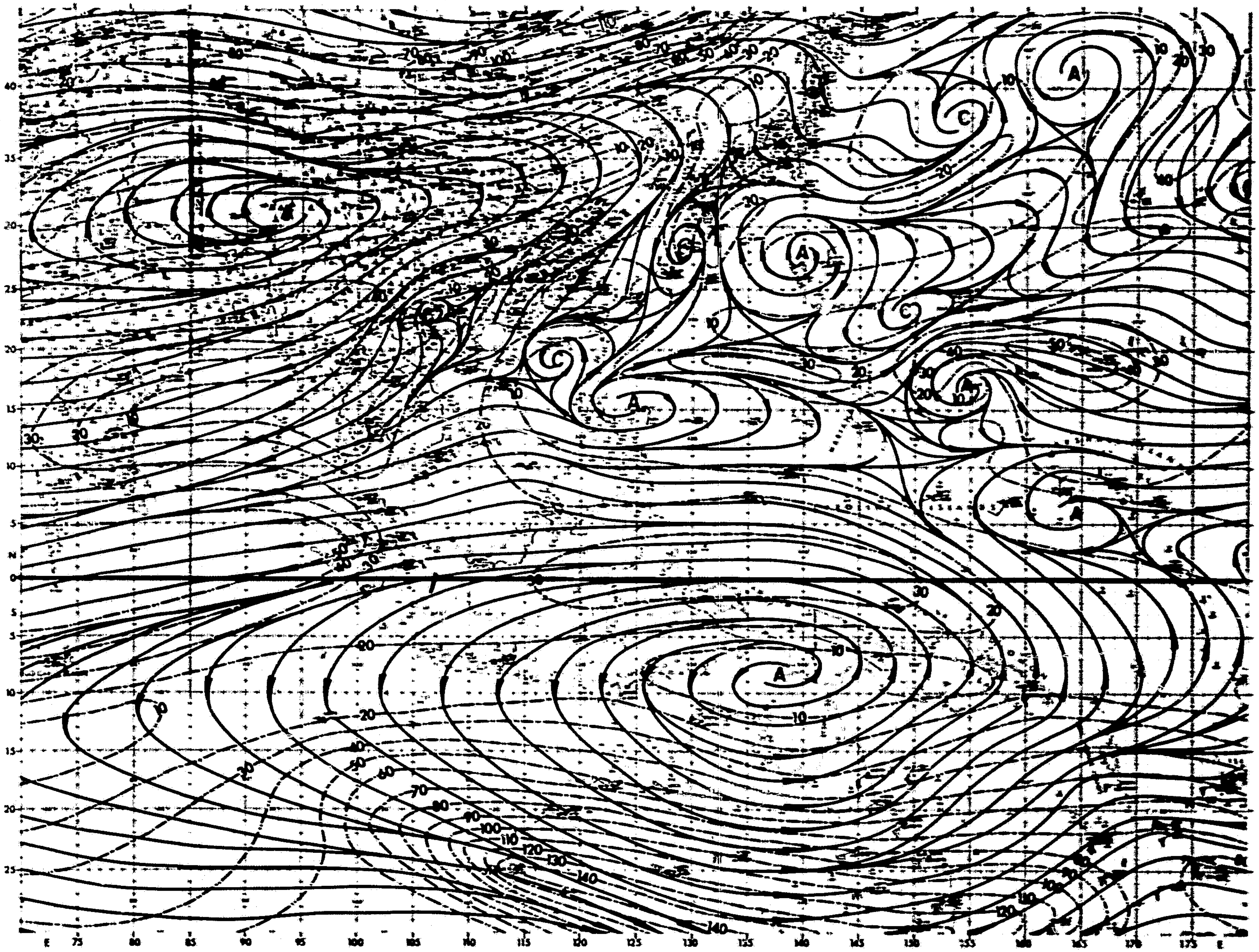

Fig. 8b. 250 mb wind analysis at 00 GMT, 1 September 1975 from 180 to 70E.

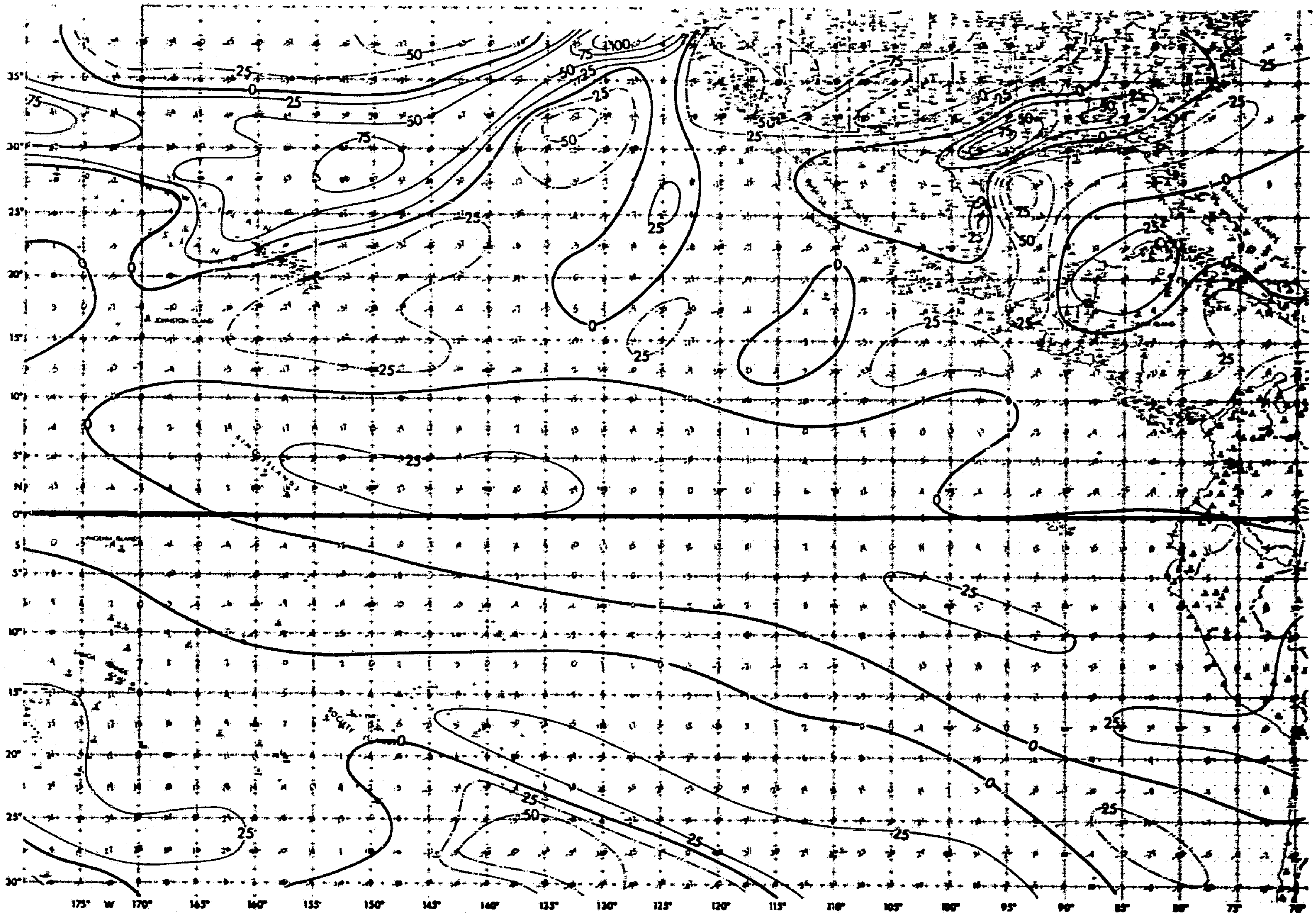

Fig. 9a. 250 mb relative vorticity at 00 GMT, 1 September derived from analysis of Fig. 8a. Positive values (N.H.) are thin solid lines.

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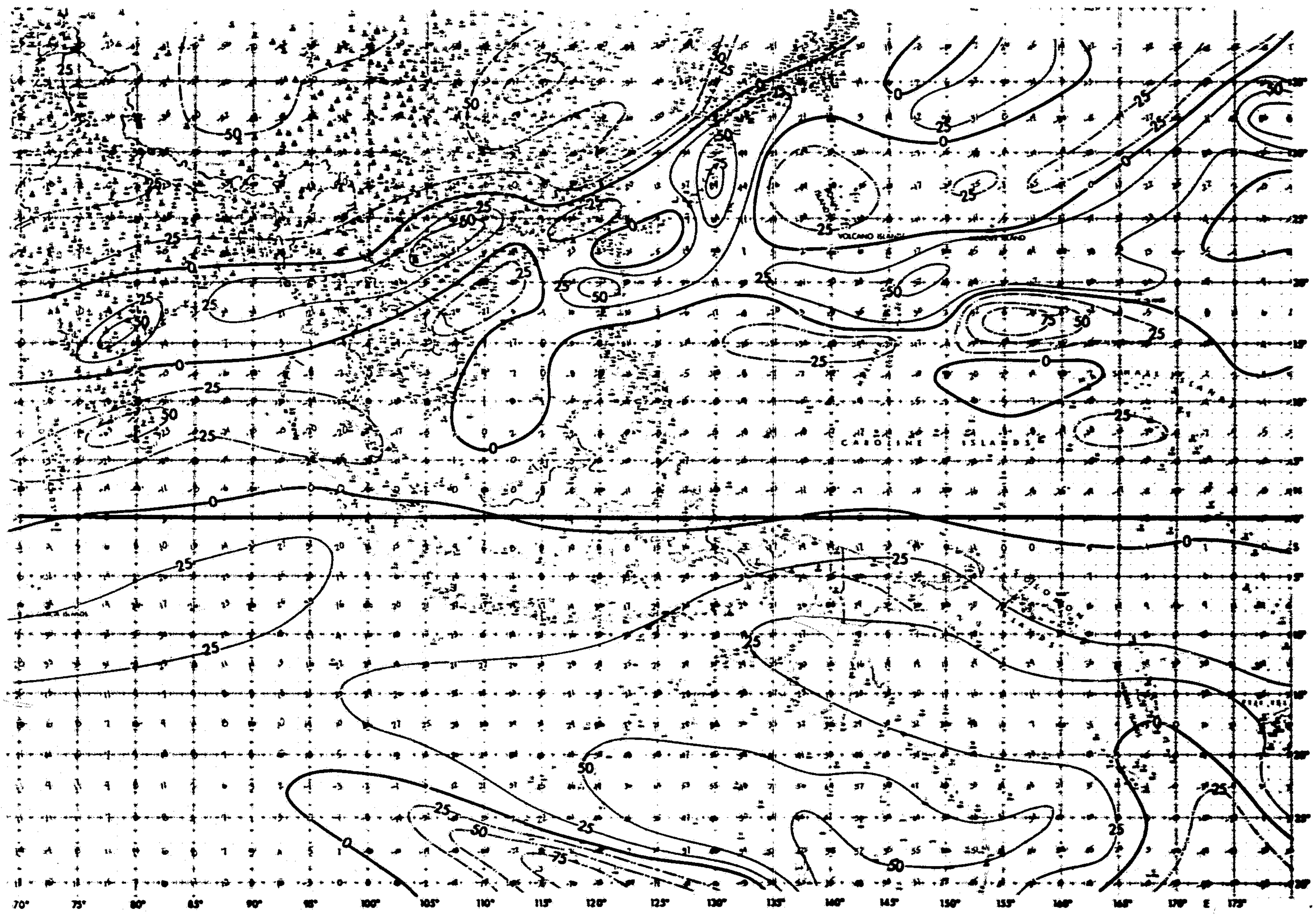

Fig. 9b. 250 mb relative vorticity at 00 GMT, 1 September derived from analysis of Fig. 8b.

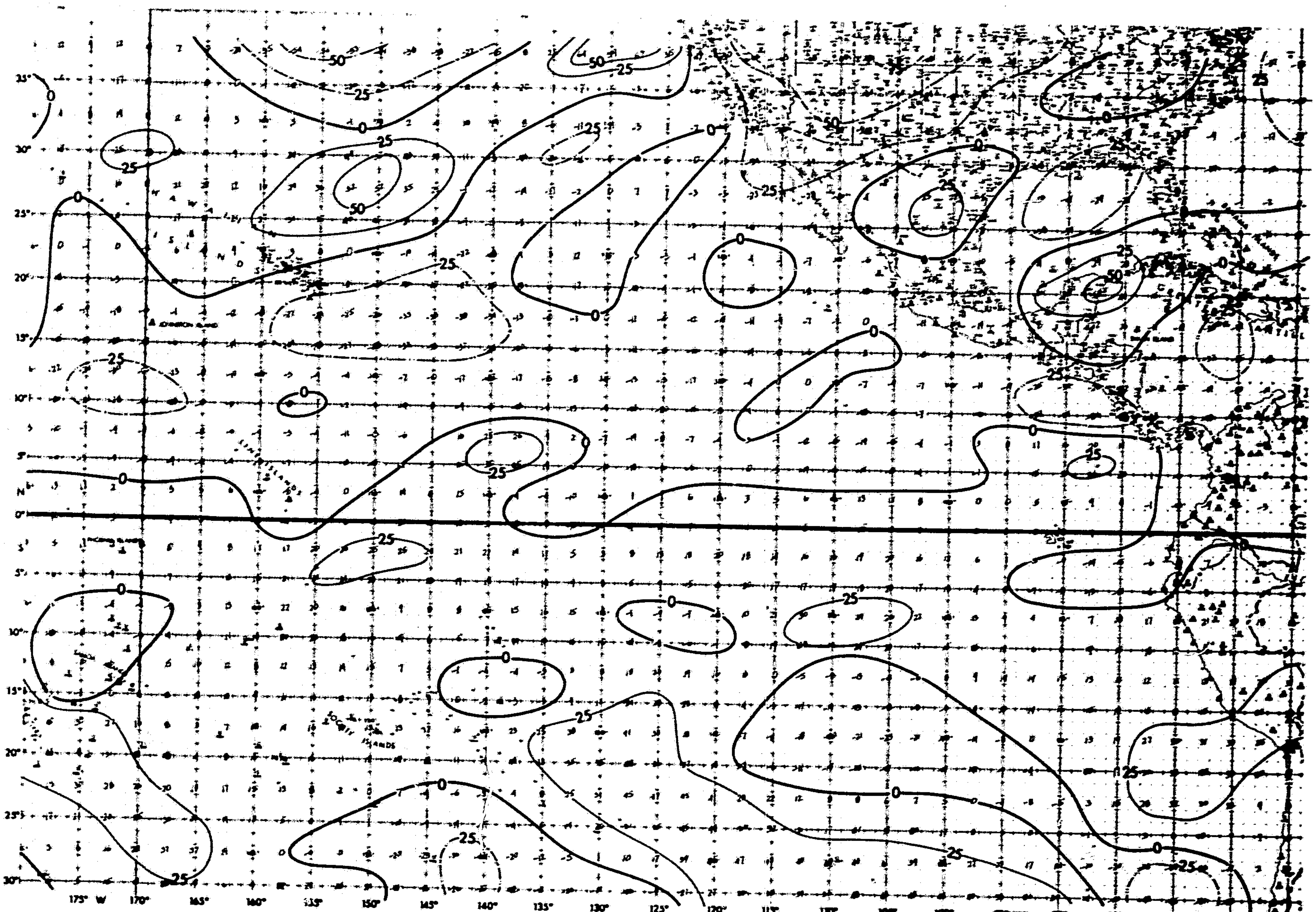

Fig. 10a. ?00 mb relative vorticity at 00 GMT, 1 September derived from NMC analysis.

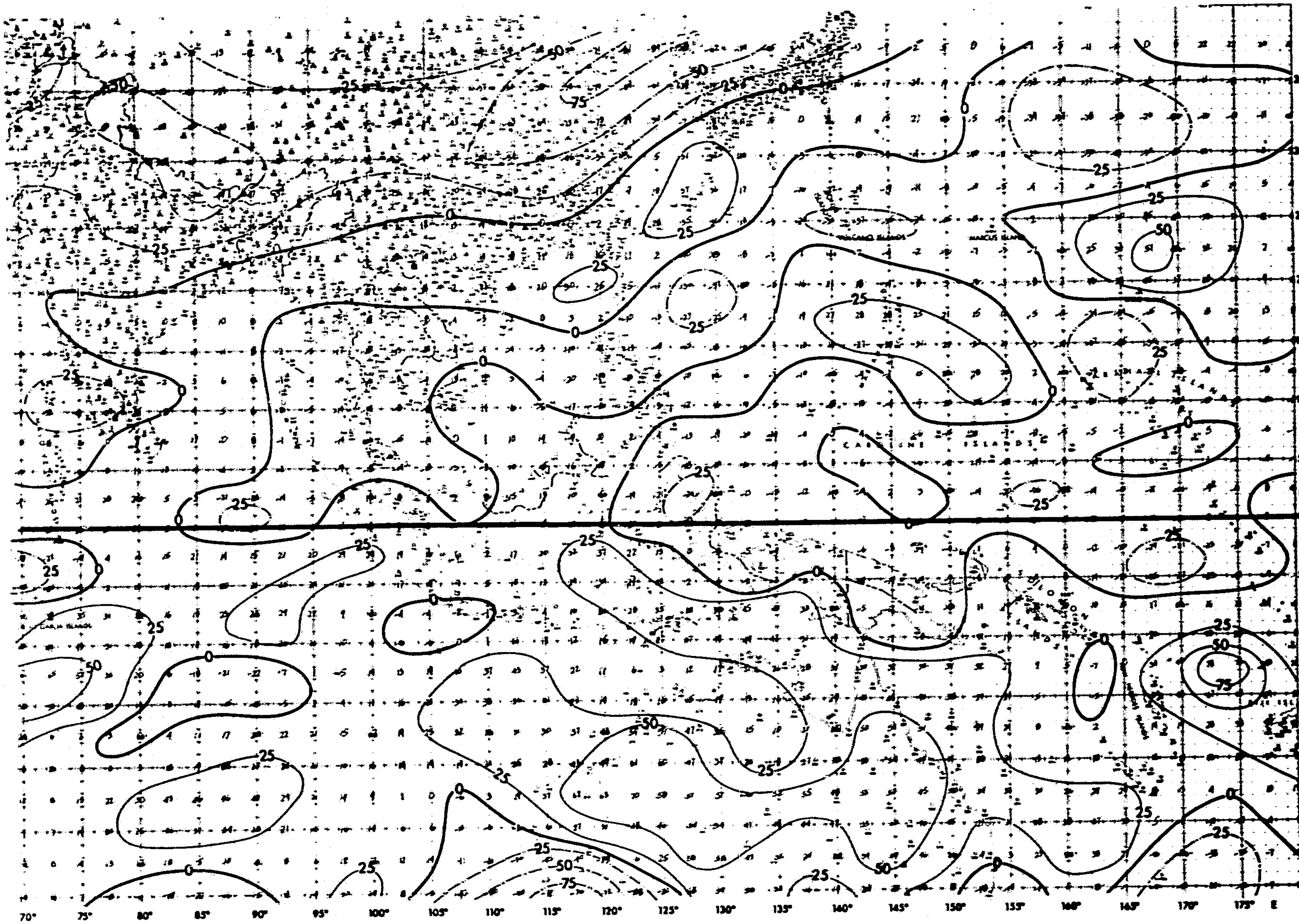

Fig. 10b. 200 mb relative vorticity at 00 GMT, 1 September derived from NMC analysis.