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THE LOW-LEVEL STRUCTURE OF WEAK TROPICAL WAVES

(A PRELIMINARY REPORT)

by

ROBERT W. FETT
ROLAND E. NAGLE
AND
LCDR WALTER F. MITCHELL, USN

MARCH 1973

ENVIRONMENTAL PREDICTION RESEARCH FACILITY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA 93940

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NAVAL POSTGRADUATE SCHOOL
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A Preliminary Report

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ROBERT W. FETT
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ABSTRACT

High resolution satellite data, ESSA-5 data and wind data derived from the Applications Technology Satellites (ATS), indicate that weak tropical waves characteristically have associated centers of maximum relative vorticity west of the bisector of the "inverted V" cloud pattern. Two examples of the high resolution satellite views are shown and discussed. Upper-air analyses and a time-section analysis for an ESSA-5 series used to define the original inverted V cloud pattern are examined. These analyses confirm that a trough axis placed on the west side of the inverted V cloud pattern fits the data more consistently than a trough or streamline axis which bisects this pattern. Finally, objective analyses of an Atlantic inverted V cloud pattern based on winds extracted from geosynchronous satellite views are shown. These analyses indicate that an area of maximum relative vorticity exists on the west side of the inverted V cloud pattern. An anticyclone is found south of the inverted V apex contrary to the inverted V model which requires a trough rather than a ridge or anticyclone in this area. The results of this study suggest that the original inverted V model relating to easterly waves requires modification.

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I. INTRODUCTION

As daily views of the tropics became commonplace during the latter part of the 1960's it was noted that a northward bulge of the inter-tropical convergence zone (ITC) appeared to be associated with the earliest stages of weak tropical waves. Frank (1969) proposed a model based on these observations placing a trough axis bisecting the bulging area, defined by a cloud pattern, which he referred to as the "inverted V." The model Frank described is shown in Figure 1. As indicated, this model gives a weather distribution at variance with Riehl's classical easterly wave model (1954). According to Riehl, wave motion without change of shape should result in major cloudiness being restricted to one side or another of the wave axis depending on the speed of the basic easterly current relative to the speed of movement of the wave. The normal pattern observed is wave movement slower than the basic easterly current. This should result in major convergence and cloudiness to the east of the wave axis and not symetrically distributed west and east as shown by Frank. This paper re-examines the concept of the inverted V cloud pattern proposed by Frank in the light of some new evidence and more detailed analysis of some of the original examples.

2. HIGH RESOLUTION PICTURES OF "INVERTED V's"

Recently acquired high resolution data show details of tropical wave structure which would have been difficult to detect in earlier satellite views. Figure 2 shows a weak tropical wave in the eastern Pacific on October 8, 1971. Many of the delicate lines which define a center of vorticity near 14N, 169W are undetected in satellite views of lesser resolution. The cloud pattern shown in this picture corresponds well with Frank's inverted V model except that the trough axis or wind shift line would be anticipated near the longitude bisecting the area of maximum relative vorticity (indicated by the arrow in Figure 2), rather than the inverted V pattern 5 degrees of longitude to the east. Figure 3 shows another example of this phenomenon in a more advanced state of development, in a picture taken on October 3, 1971. Note the very intense convection evident near the center of maximum relative vorticity defined by the intricate cloud lines curving northward south of the vortex area. Again the bisector of the inverted V cloud pattern would be an illogical choice for trough axis placement.

3. A RE-EXAMINATION OF SOME EARLY ESSA-5 INVERTED V EXAMPLES

Figure 4 is an ESSA-5 view of an inverted V cloud pattern used as an example in Frank's original article. The similarity of this pattern to the high resolution views of Figures 2 and 3 should be noted. If this similarity is more than coincidental, the faint cyclonic swirl centered near 12.5N and 55.5W would suggest a trough axis or center of vorticity in this area rather than near 50W as suggested by the inverted V cloud model. Figure 5, the Miami 700 mb analysis for July 11, 1967, 1200 GMT, (approximately 7 hours prior to the picture presented as Figure 5) shows winds backing along the Lesser Antilles as the trough axis approached these stations. By 0000 GMT on July 12, 1967, the 700 mb analysis (Figure 6) indicates that a wind shift had occurred at Barbados (13.3N, 59.5W) and a wave axis is indicated near 62W. A time-section for this station (Figure 7) verifies that a pronounced wave passed Barbados between July 11, 1967 at 1200 GMT, and July 12, 1967 at 0000 GMT. Yet, according to the inverted V cloud model applied to the satellite picture for July 12, 1967 at 1940 GMT (Figure 8), the trough would just be approaching the station at that time with the major cloudy area to the west of the trough. It is of interest to note that the disturbance at this time precisely fits the Stage A category proposed by Fett (1966) (Figure 9). According to the Stage A model, the wave axis should be in the open area extending N-S along the western portion of the cloud boundary. 700 mb data (Figure 10) approximately 7 hours prior to the picture presented as Figure 8 confirm this interpretation. From these data it would be difficult to place a trough axis near 55-58W (dashed line in Figure 8) as the inverted V cloud model would imply.

4. AN OBJECTIVE ANALYSIS OF AN INVERTED CLOUD PATTERN

The availability of geosynchronous satellite data over the tropics provides an unequalled opportunity to study the dynamics of weak tropical waves. With pictures taken approximately every 25 minutes it is possible to animate the entire sequence in "movie" fashion and from the movie determine the trajectory of cloud elements during any given interval of time. Poteat (1972) has shown that the motions of low level and cirrus level clouds, as measured from the geosynchronous film sequences, are highly correlated to conventionally observed winds in the tropics at 2-3000 ft and at the 200 mb level. Thus, for the first time in meteorological history, we have a means of filling data-sparse areas not only with cloudiness estimates but with reliable estimates of the field of motion.

A sample of 55 inverted V cloud pattern cases have been selected for such analysis. These will form the basis for a detailed report on the structure and development of tropical waves to be presented at a later date. For the purposes of this preliminary report, an example of one of these systems observed by ATS-3 on August 20, 1972 is shown in Figure 11. According to the inverted V cloud model, a wave axis would be anticipated near 37W. Consistent with our previous discussions, a location about 4 or 5 degrees further to the west would be preferred. Figure 12 shows the cloud motion vectors and inferred wind field derived from the ATS movie. These vectors and the streamline analysis show a cyclonic center west of the inverted V axis near 13N and 41W; contrary to the expectation of finding a trough south of the inverted V apex we find an anticyclone!

This case is quite similar to the other 54 inverted V cases under analysis at this time. An objective analysis program based on a 2-degree mesh interval developed by Endlich and Mancuso, and re-written and modified for the Control Data 6600 computer by Roland E. Nagle, was applied to the ATS winds extracted for the August 20, 1972 case. Figures 13 through 16 shows the results of this analysis which may prove representative of the structure of many weak tropical waves. The analysis reveals westerly wind components south of the apex of the inverted V (Figure 13); strong southerly flow in the same area, with northerly flow on all sides (Figure 14). The effect of this motion produces convergence in the NE quadrant of the disturbance, and divergence in the western quadrants and south of the inverted V apex (Figure 15). A center of vorticity is well defined on the west side of the wave (Figure 16).

5. CONCLUSION

Some important details concerning the structure of weak tropical waves has been revealed by this study. The inverted V cloud pattern seems to be an important feature of weak tropical waves in both the Atlantic and the Pacific. However, the model should be modified to incorporate a vorticity center west of this pattern and the position of trough axis should be shifted to correspond with this center. Preliminary evidence indicates that diverging southerly flow, and in some instances a small anticyclone, exists south of the inverted V apex. Further research will be devoted to verifying this latter hypothesis and to the development of a more complete model incorporating upper level as well as lower level flow and possibly distinguishing between systems based on changes in intensity.

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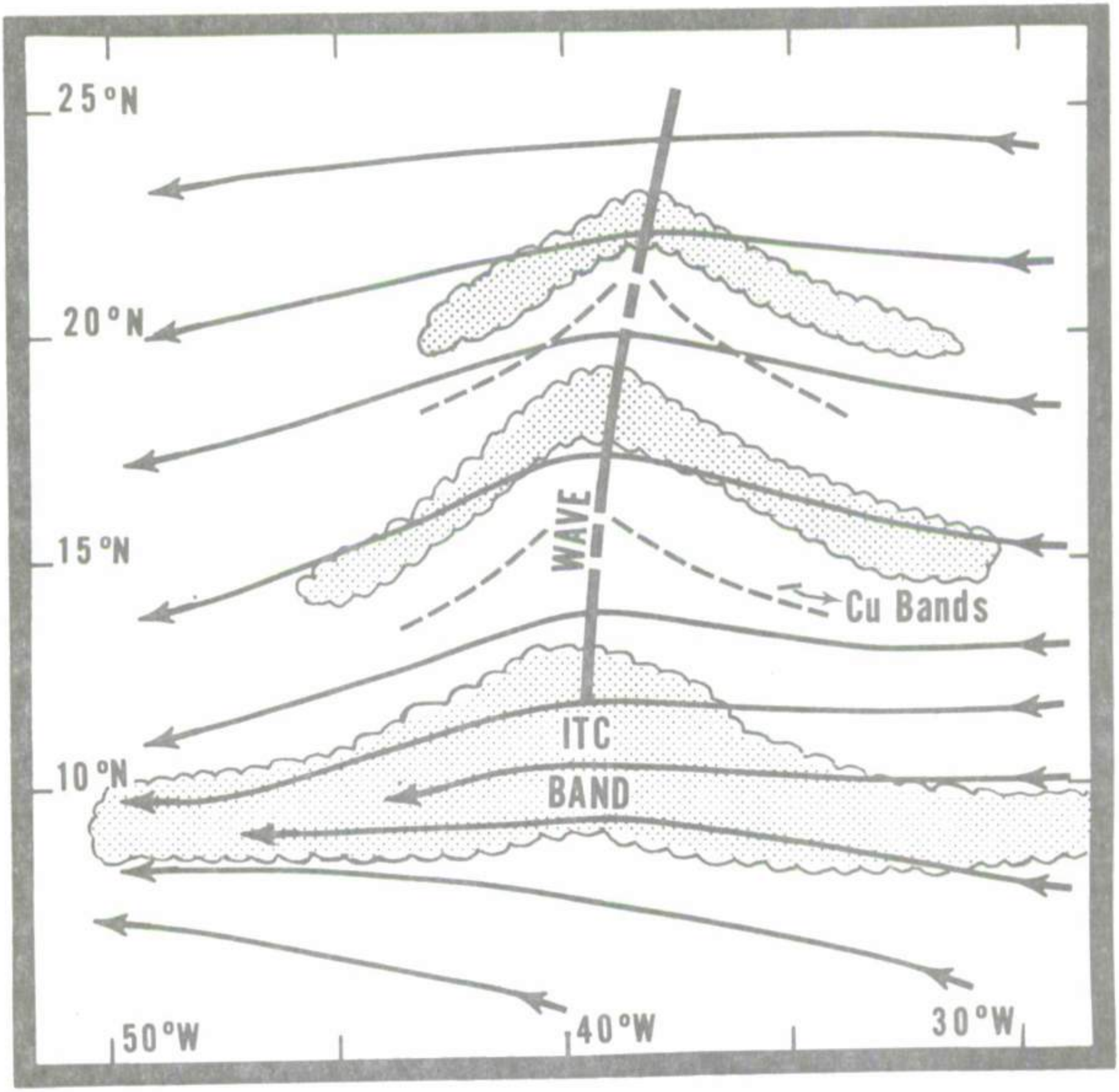

Figure 1. A schematic proposed by N. Frank showing the relationship between the lower tropospheric flow and the inverted V cloud pattern.

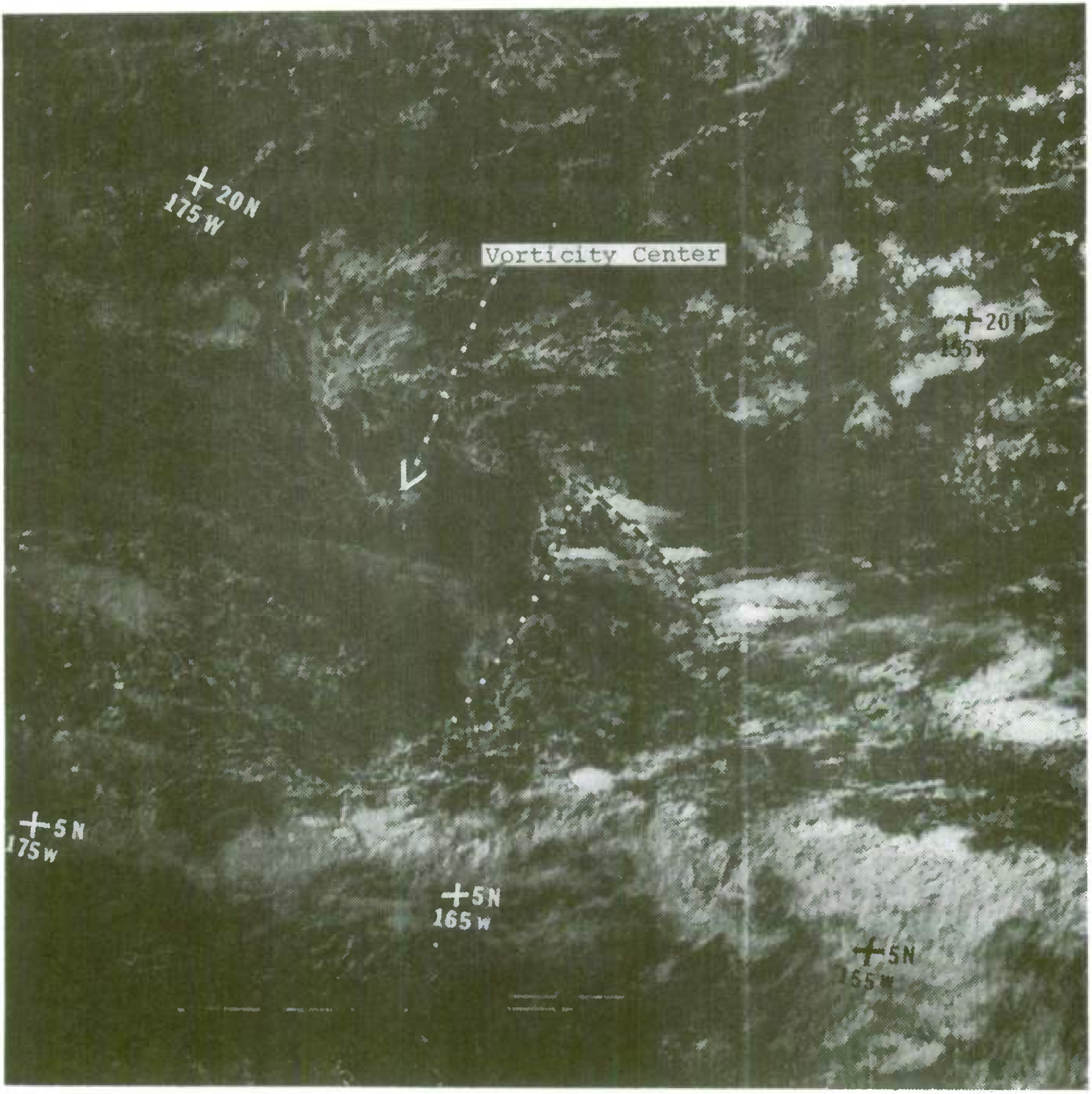

Figure 2. A high resolution view of a tropical wave on October 8, 1971 at 1849 GMT. This view acquired from a military system has a resolution of approximately 1/3 n mi.

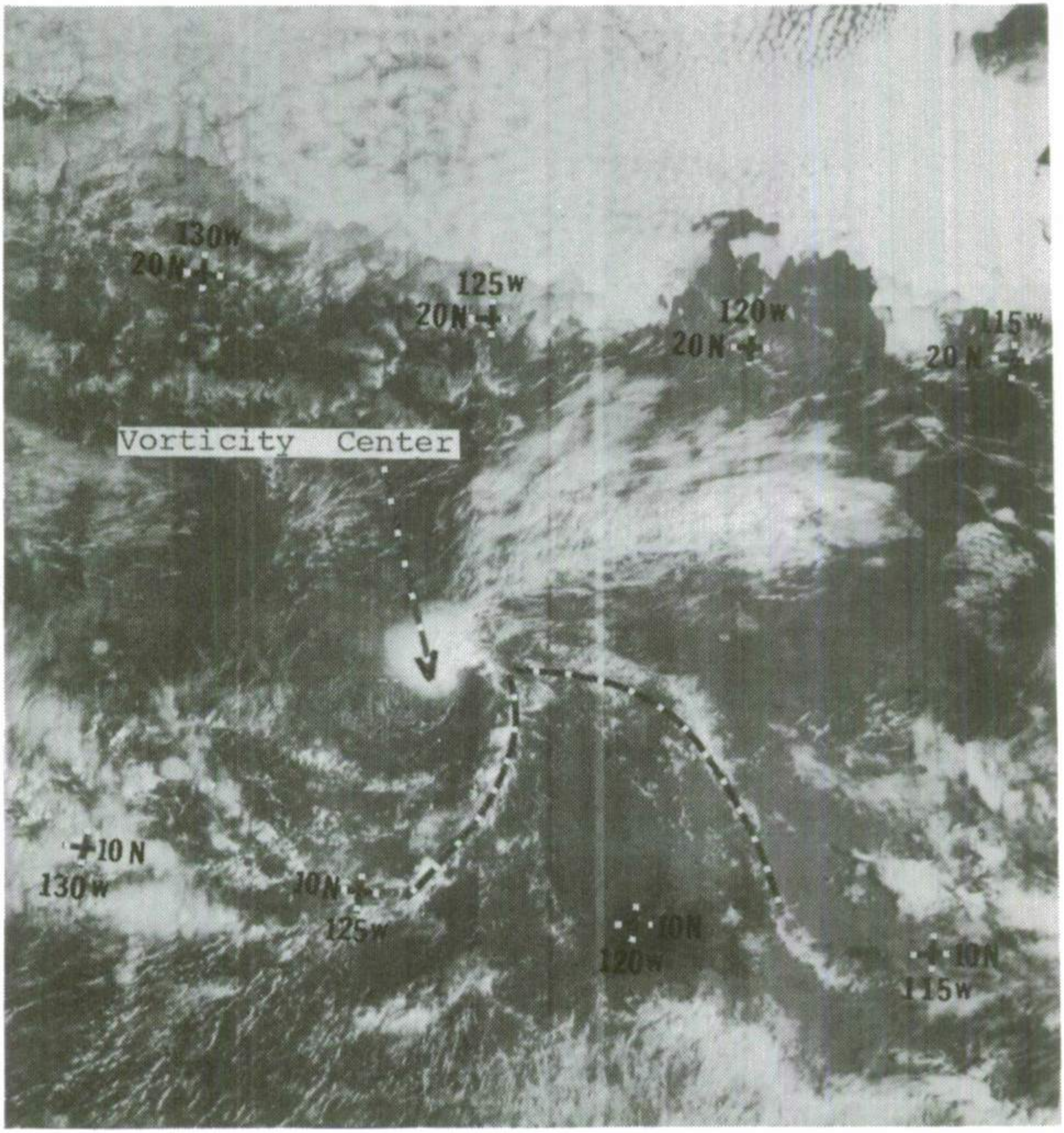

Figure 3. A high resolution view of a tropical wave on October 3, 1971 at 1603 GMT. This view acquired from a military system has a resolution of approximately 1/3 n mi.

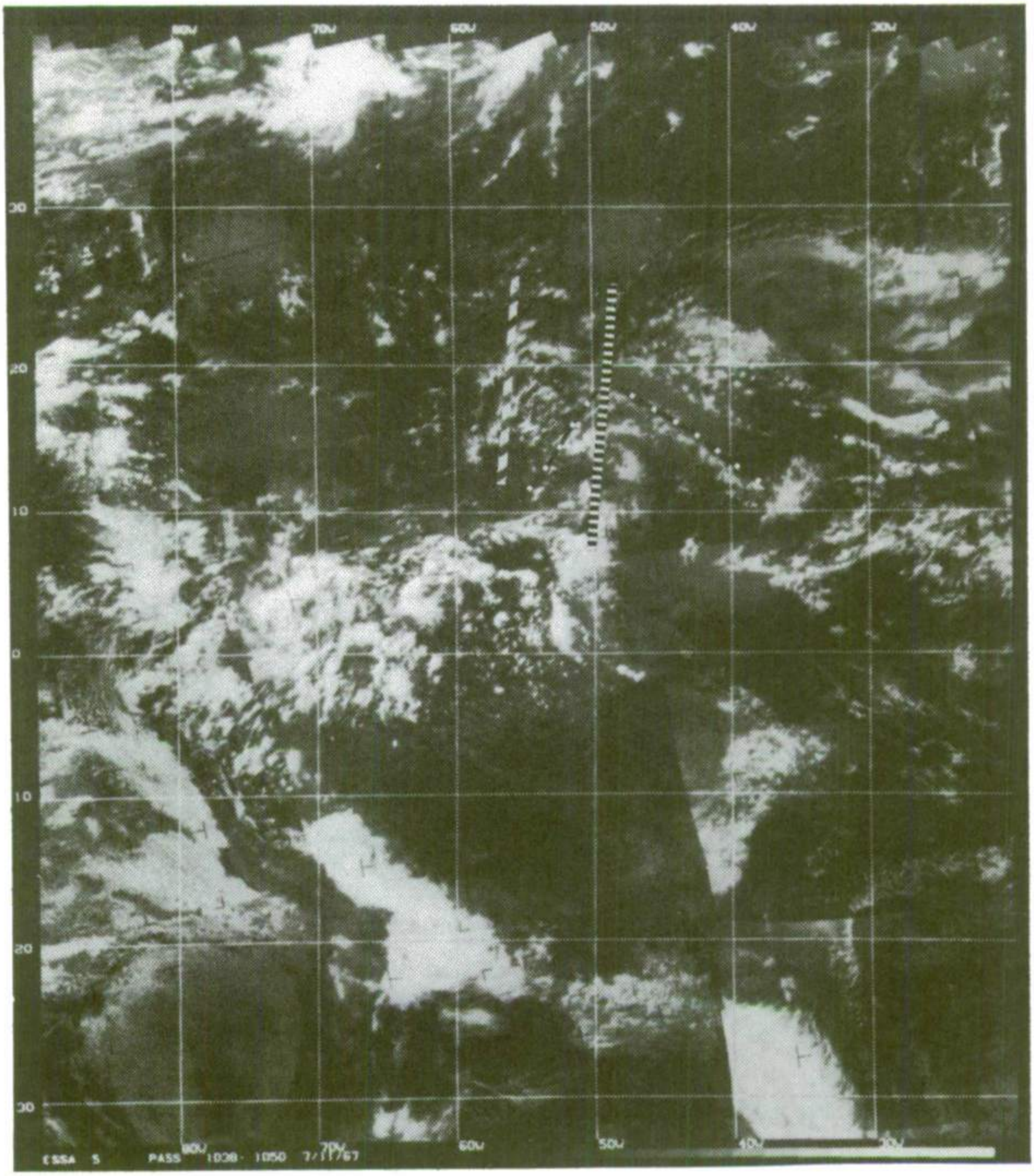

Figure 4. ESSA-5 data over the tropical Atlantic on the afternoon of July 11, 1967. The striped line indicates trough axis suggested by Fett. The dashed line indicates trough axis suggested by the inverted V cloud model.

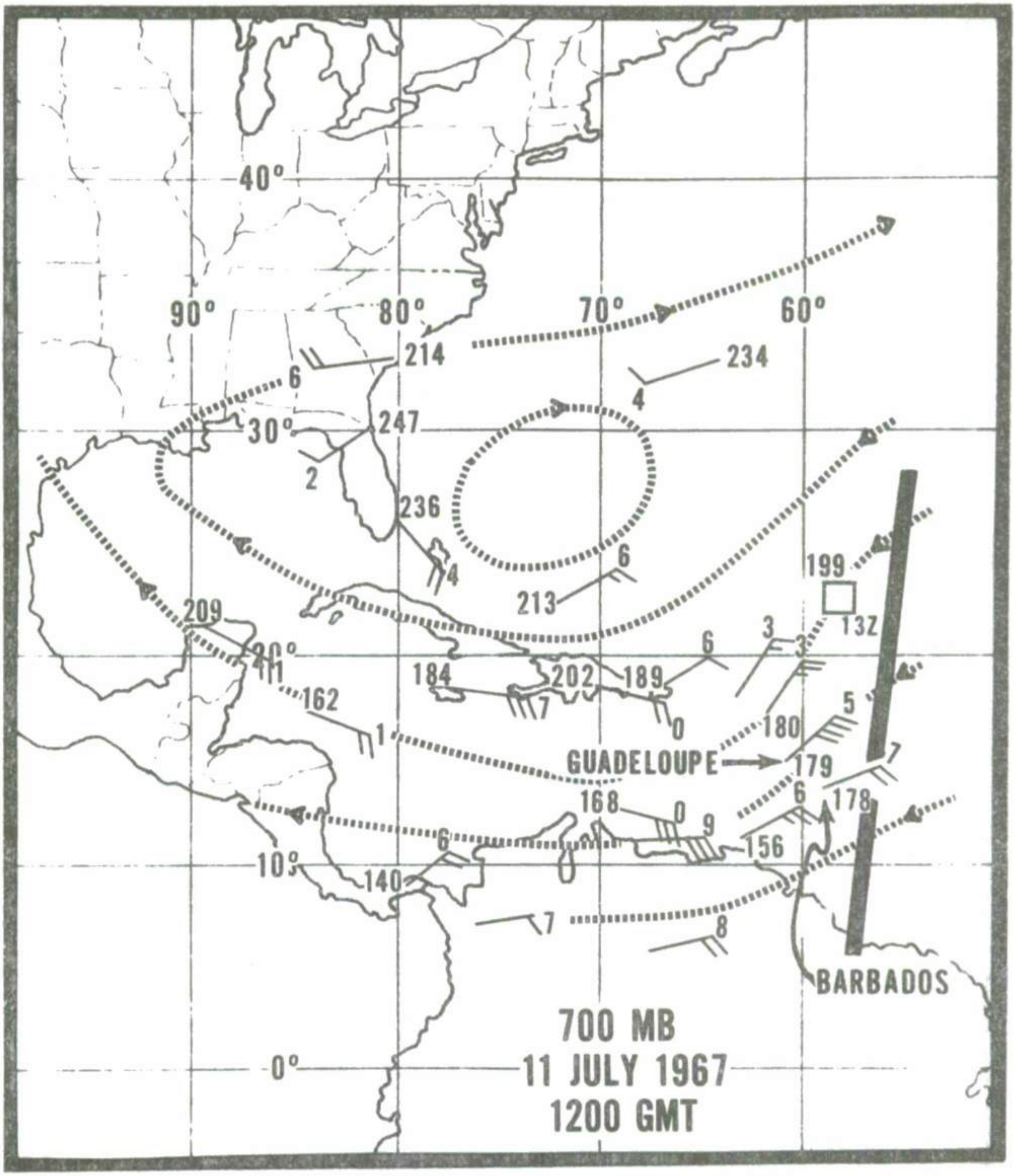

Figure 5. 700 mb data and analysis for 1200 GMT, July 11, 1967, derived from charts prepared by the Tropical Analysis Center, Miami, Florida. Plotted digital data show 700 mb height in meters (first digit omitted) and key designator for wind direction.

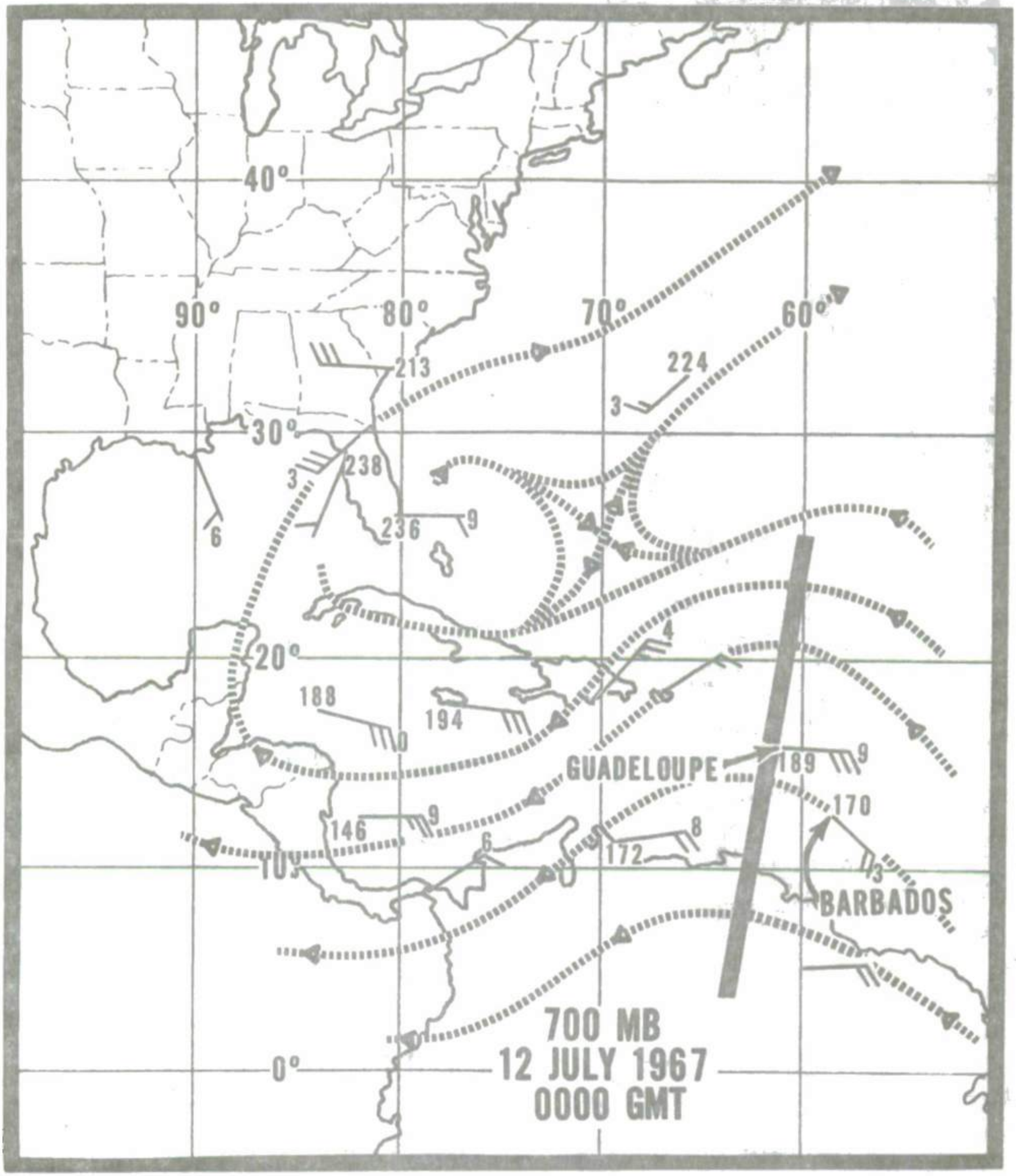

Figure 6. 700 mb data and analysis for 0000 GMT, July 12, 1967, derived from charts prepared by the Tropical Analysis Center, Miami, Florida. Plotted digital data show 700 mb height in meters (first digit omitted) and key designator for wind direction.

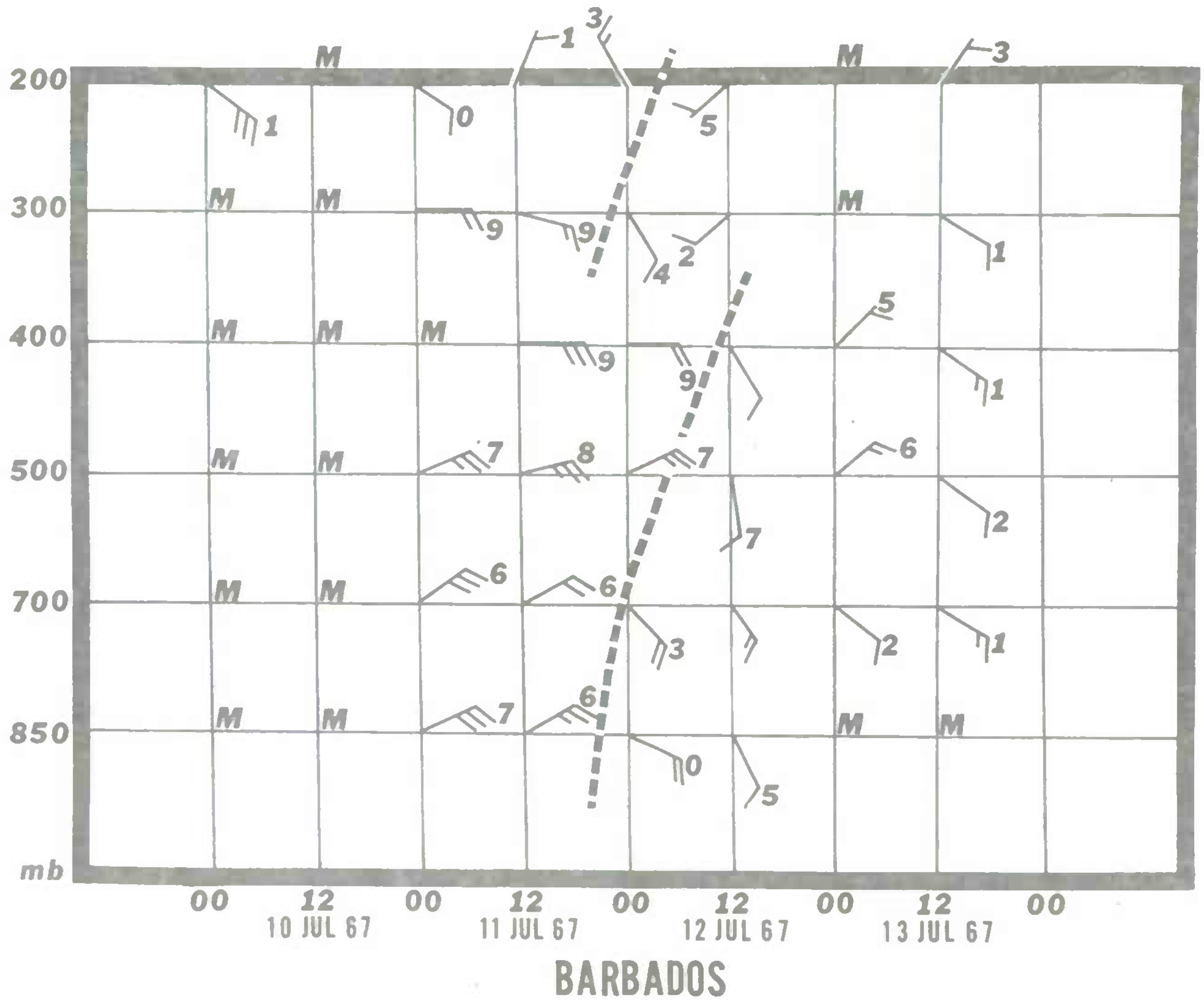

Figure 7. A time-section for Barbados, W. Indies, during the period July 10-14, 1967. Trough position is indicated by dashed line. Data for 0000 GMT, July 13, 1967 are derived from the nearby island of Guadeloupe.

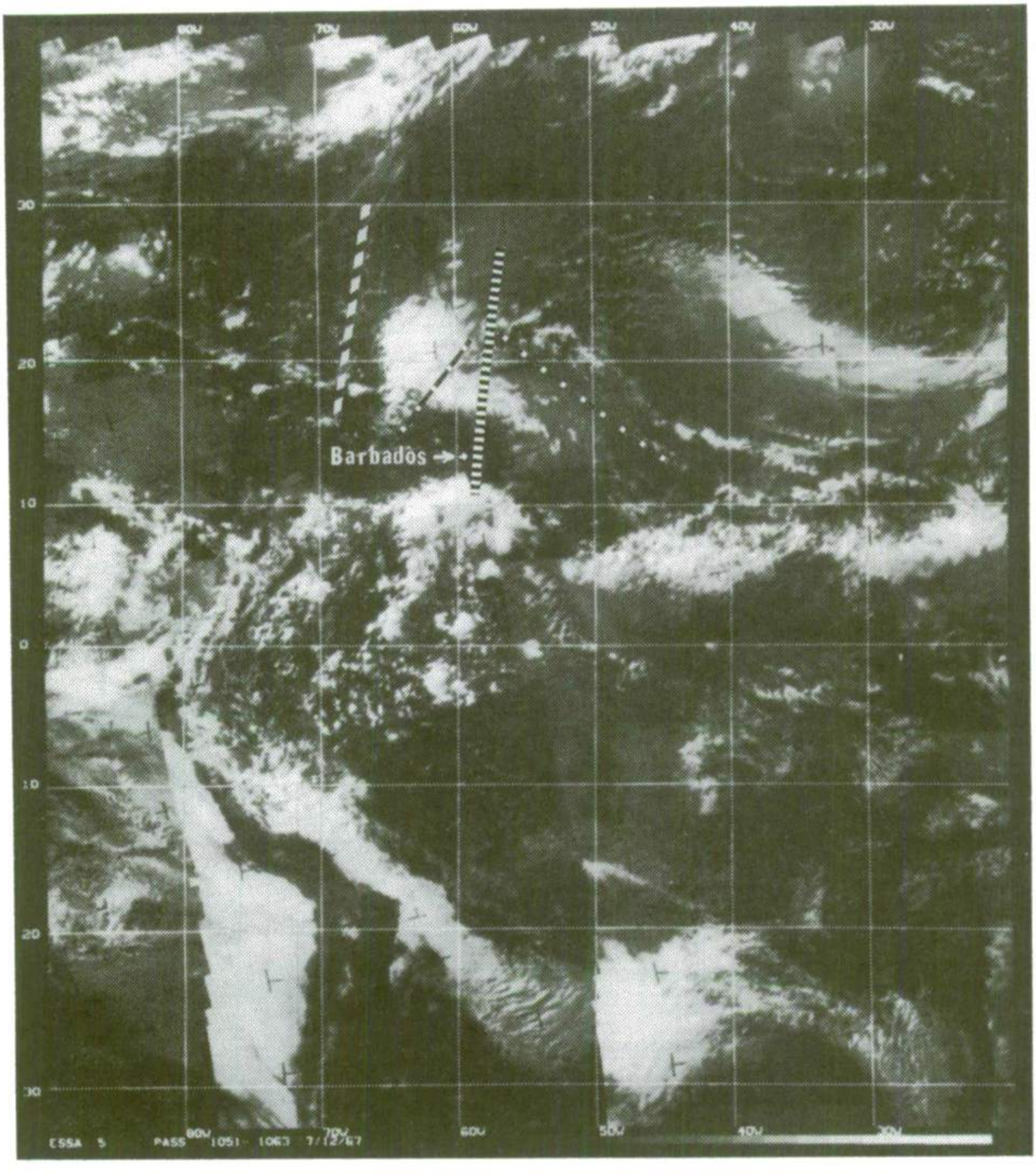

Figure 8. ESSA-5 data over the tropical Atlantic on the afternoon of July 12, 1967. The striped line indicates trough axis suggested by Fett. The dashed line indicates trough axis suggested by the inverted V cloud model.

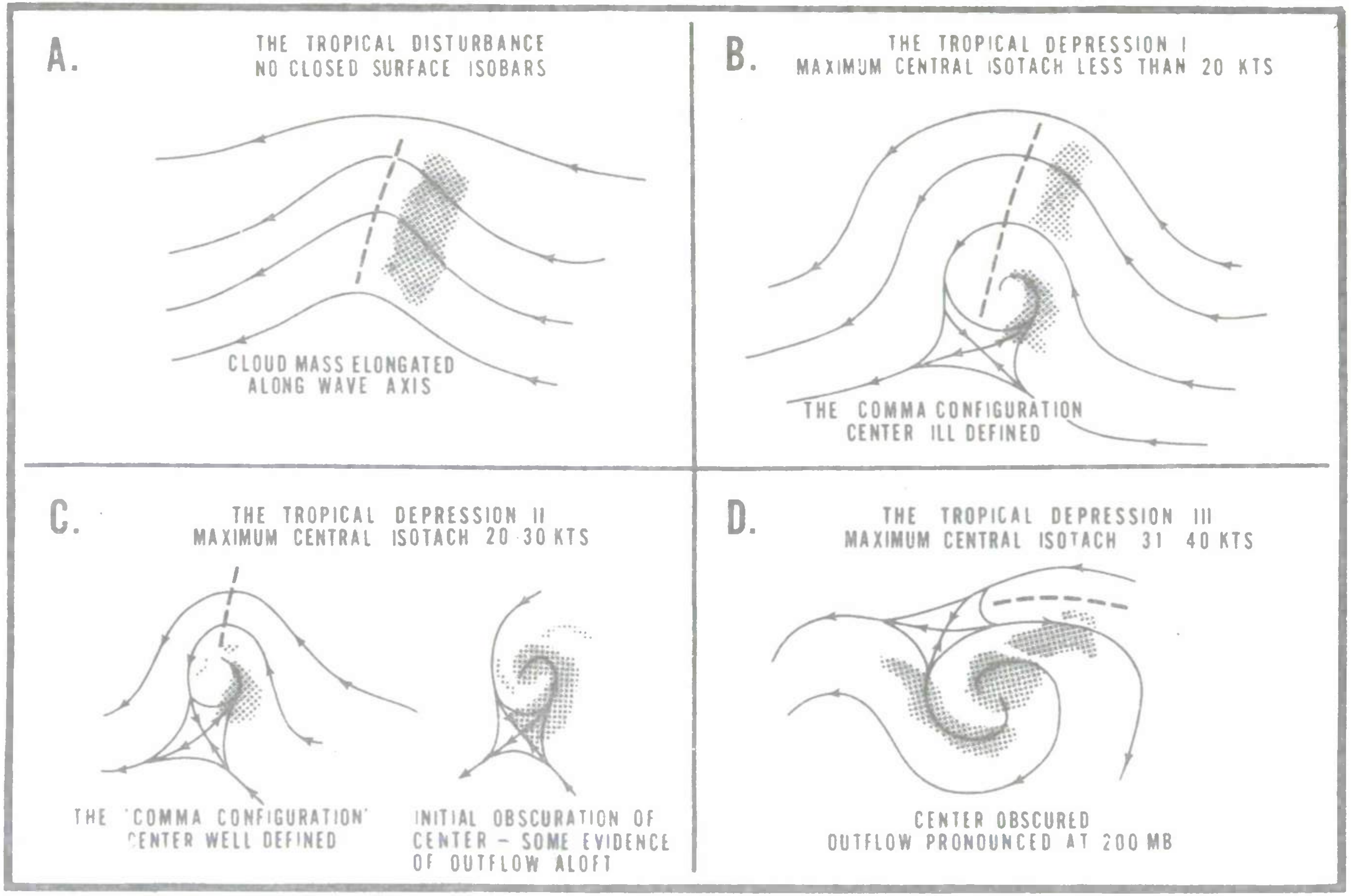

Figure 9. A model describing the cloudiness distribution associated with the formative stages of tropical cyclone development. The model applies to formative tropical cyclones of the Northern Hemisphere embedded in easterly flow. In Stages A, B and C, the typical gradient wind streamline pattern is superimposed over the shaded TIROS observed cloudy areas. In Stage D, the typical 200 mb streamline pattern is shown.

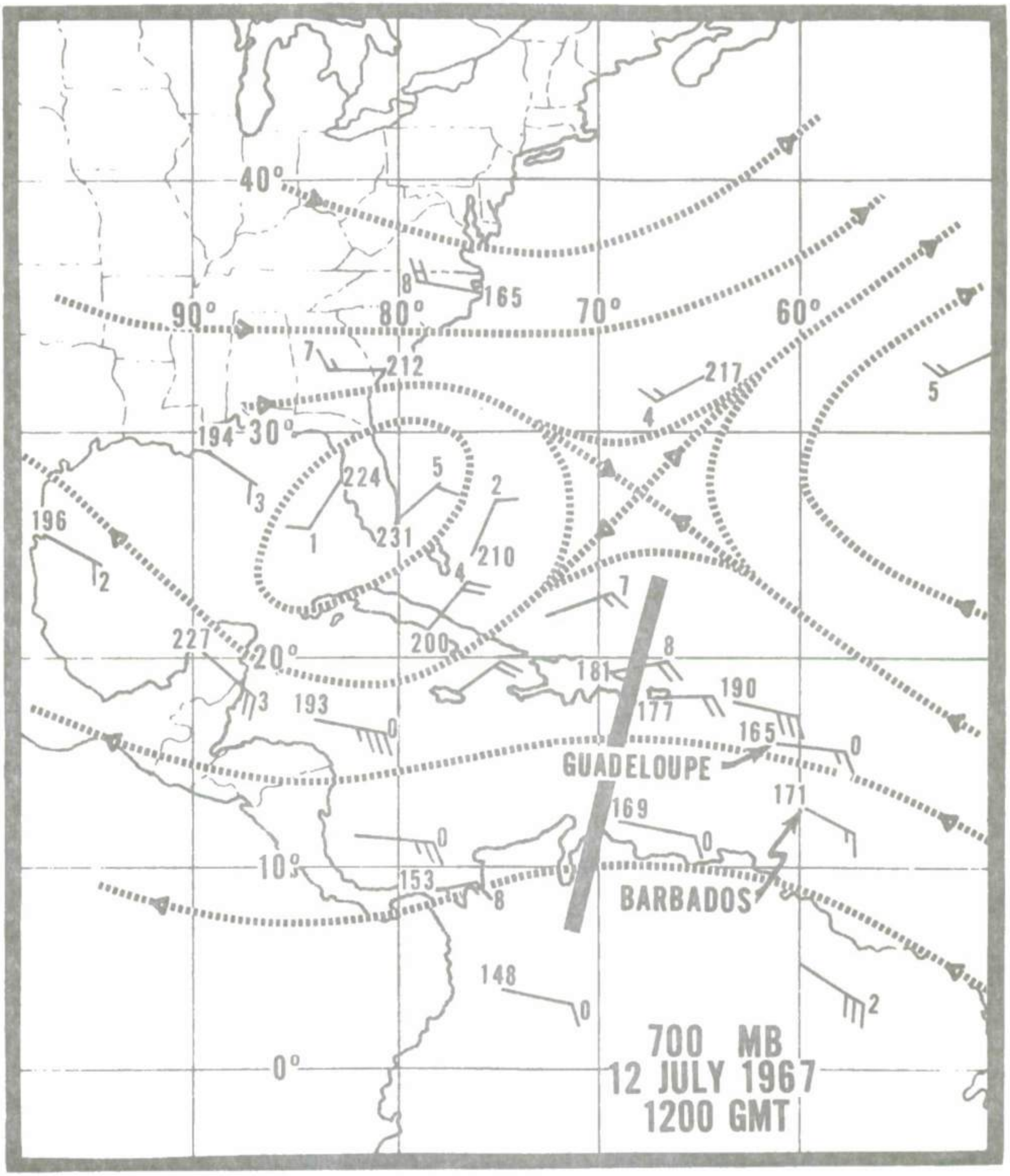

Figure 10. 700 mb data and analysis for 1200 GMT, July 12, 1967, derived from charts prepared by the Tropical Analysis Center, Miami, Florida. Plotted digital data show 700 mb height in meters (first digit omitted) and key designator for wind direction.

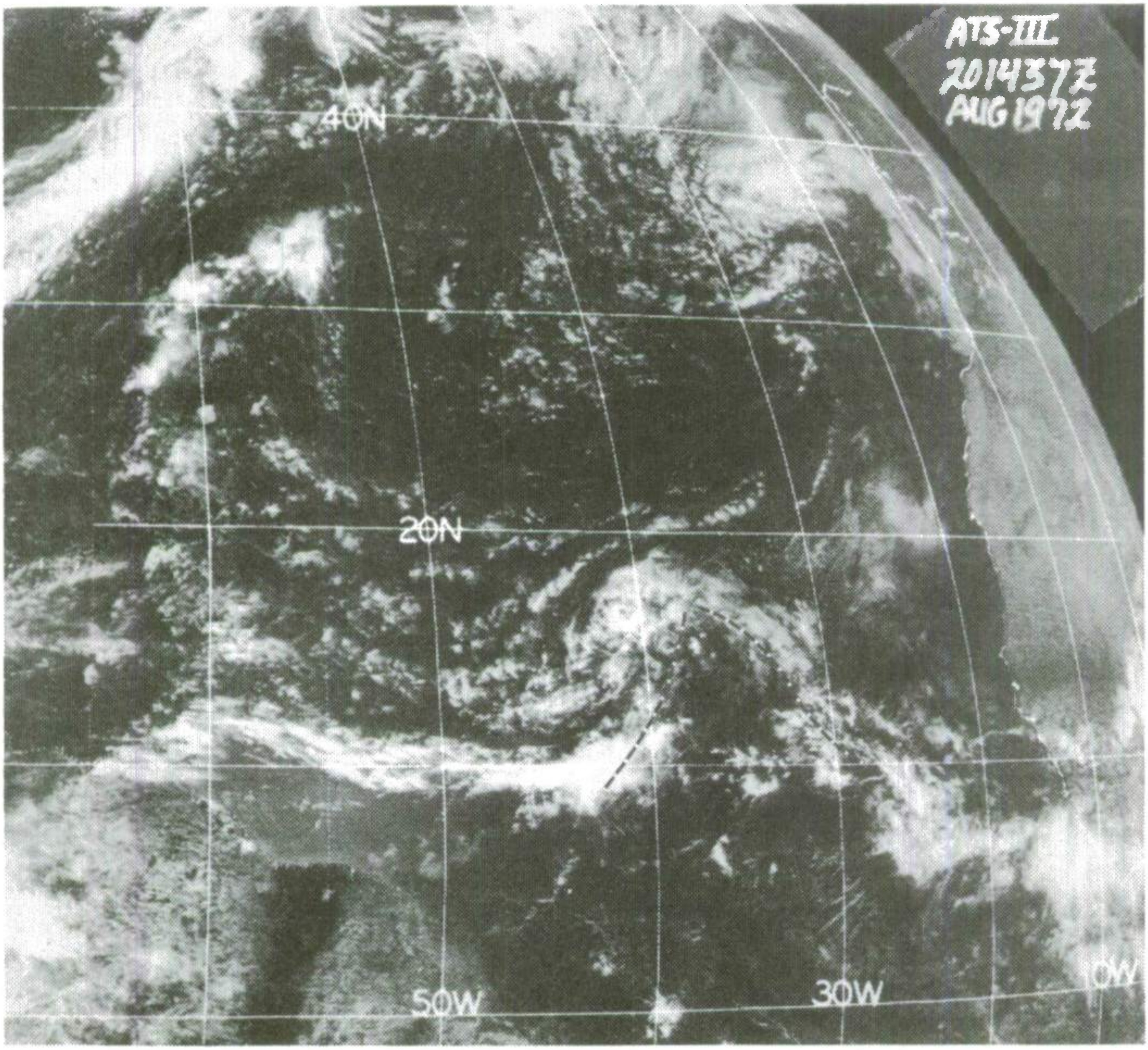

Figure 11. An ATS-3 (Applications Technology Satellite) view of an inverted V cloud pattern in the Atlantic on August 20, 1972 at 1719 GMT.

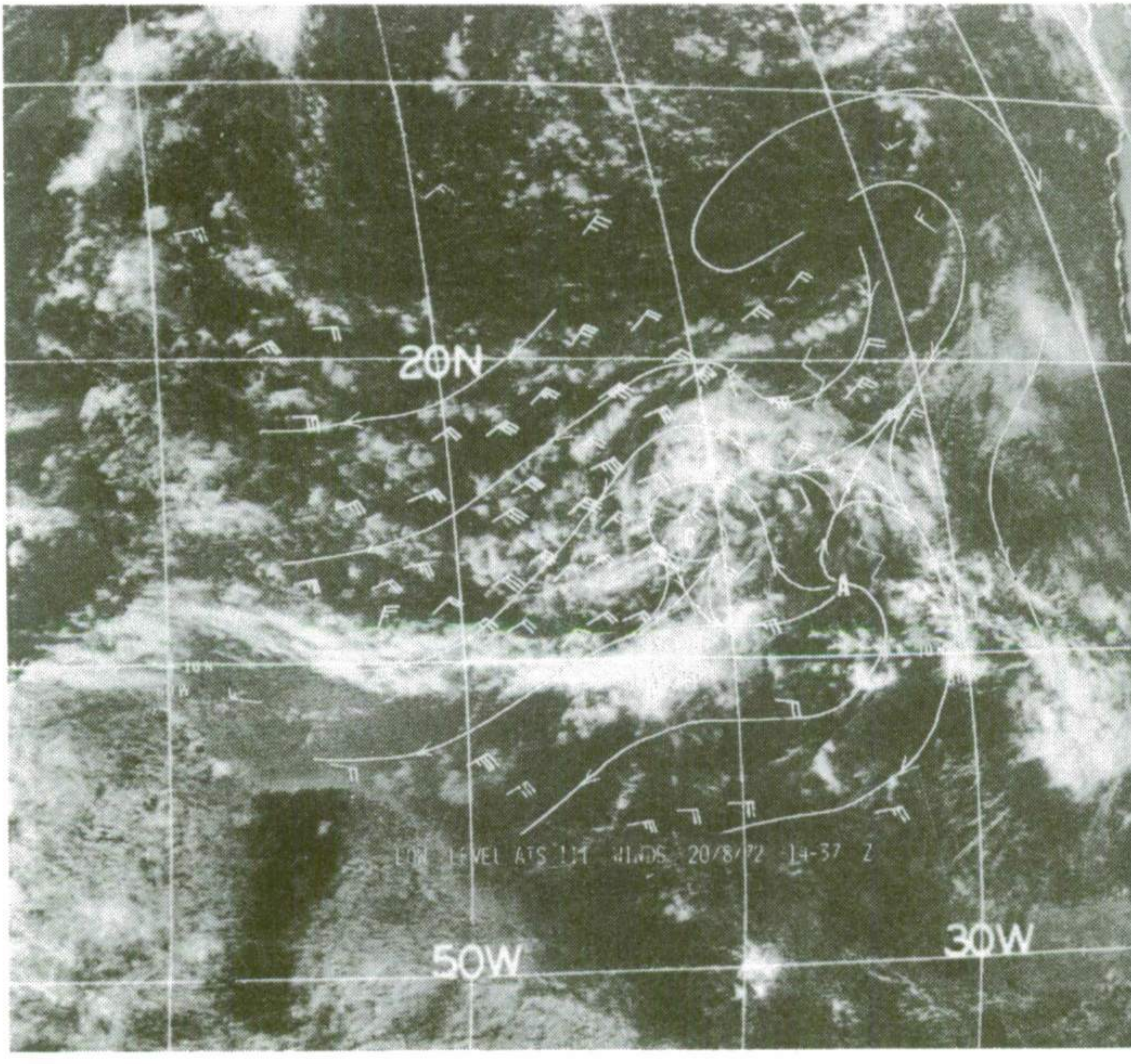

Figure 12. Cloud motion vectors and streamline analysis derived from a "movie-loop" analysis of ATS-3 pictures received on August 20, 1972.

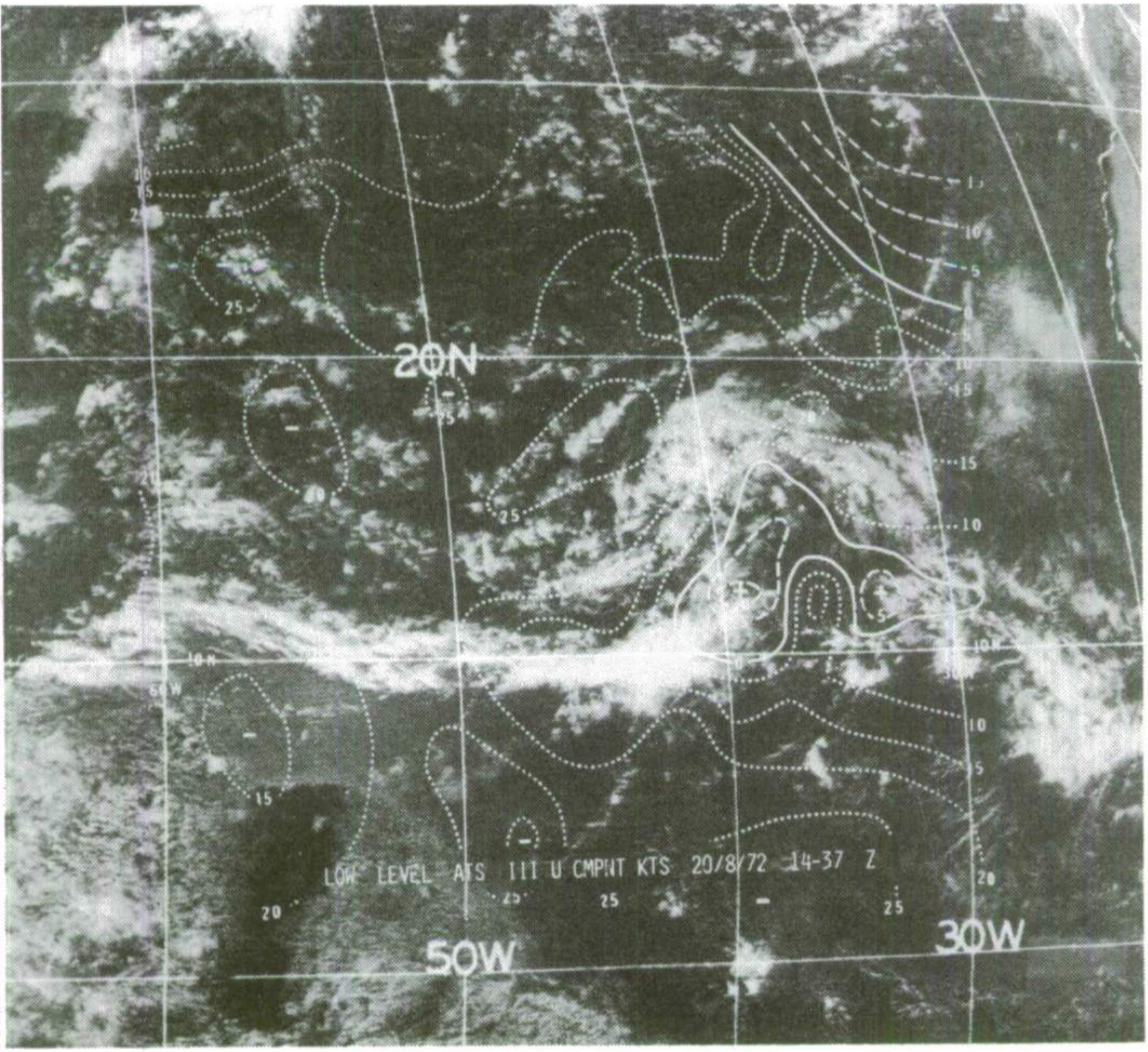

Figure 13. "U" component analysis of cloud vectors extracted for the August 20, 1972 inverted V example. The dotted lines indicate east wind isotachs. The dashed lines indicate west wind isotachs. The zero U component isotach is drawn as a solid line.

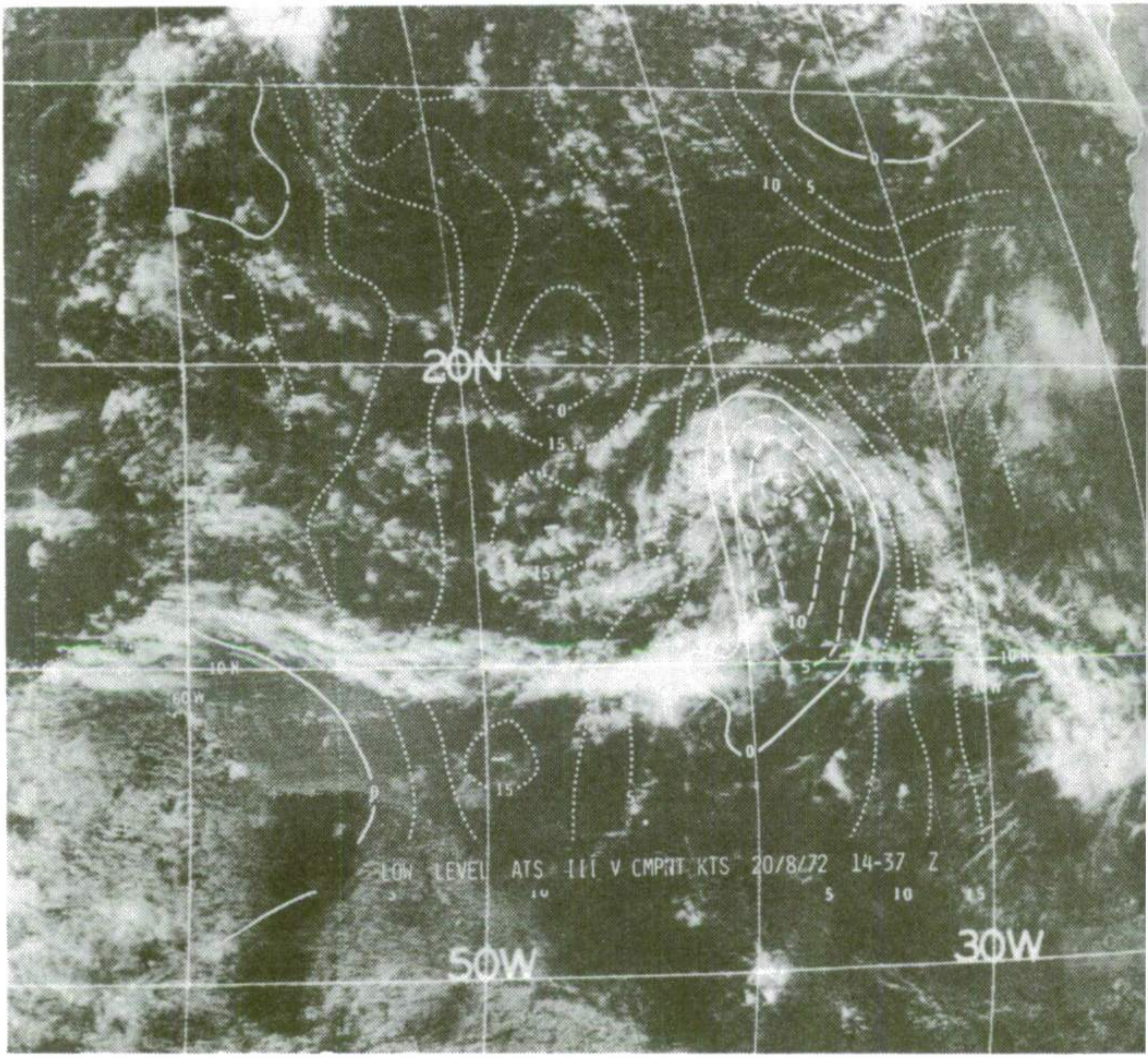

Figure 14. A "V" component analysis of cloud vectors extracted for the August 20, 1972 inverted V example. The dotted lines indicate north wind isotachs. The dashed lines indicate south wind isotachs. The zero V component isotach is drawn as a solid line.

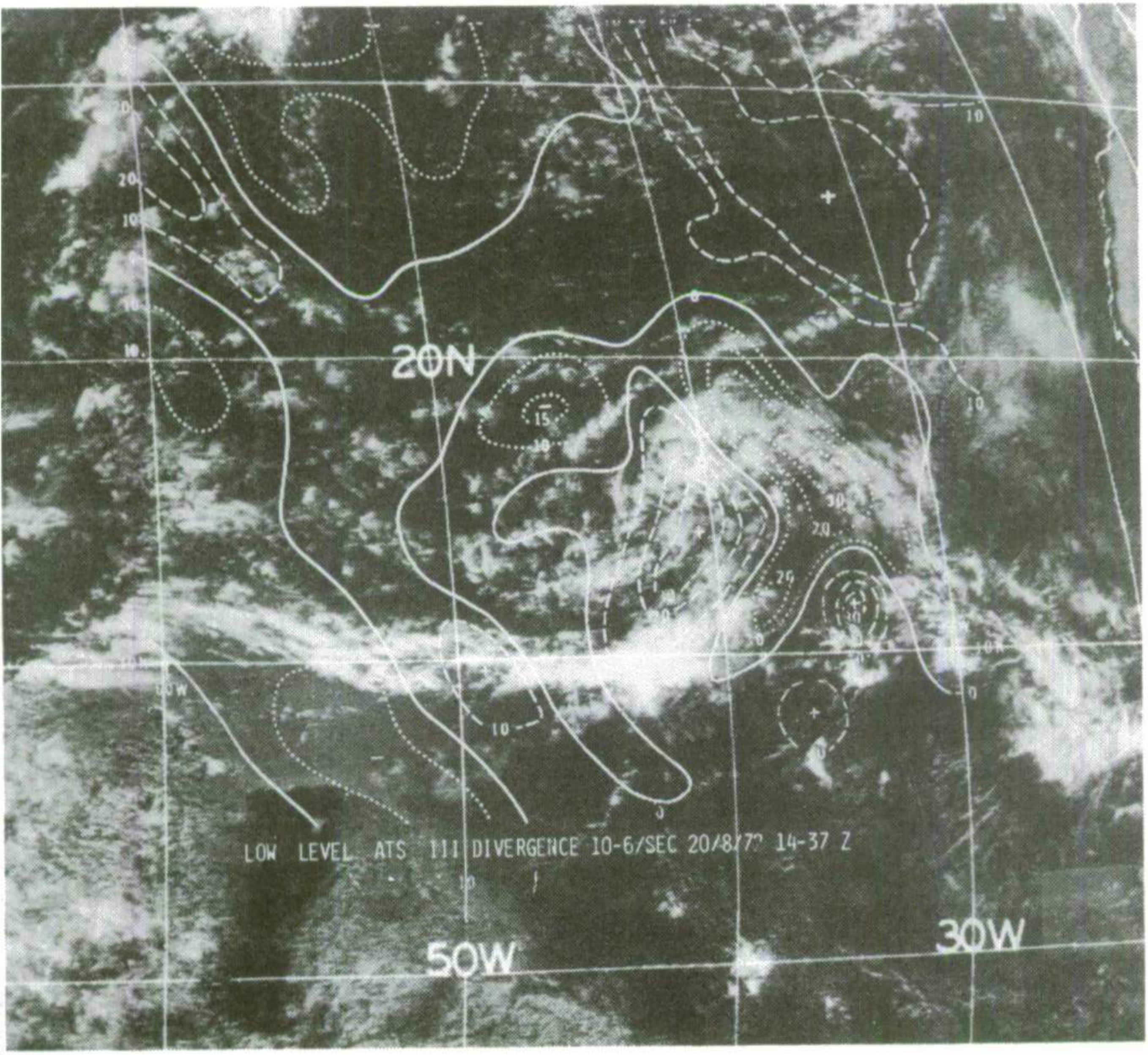

Figure 15. A divergence analysis for the August 20, 1972 inverted V example. Dotted lines indicate convergent areas. Dashed lines indicate divergent areas (units of 10^{-6} see^{-1}). The contour of zero divergence is drawn as a solid line.

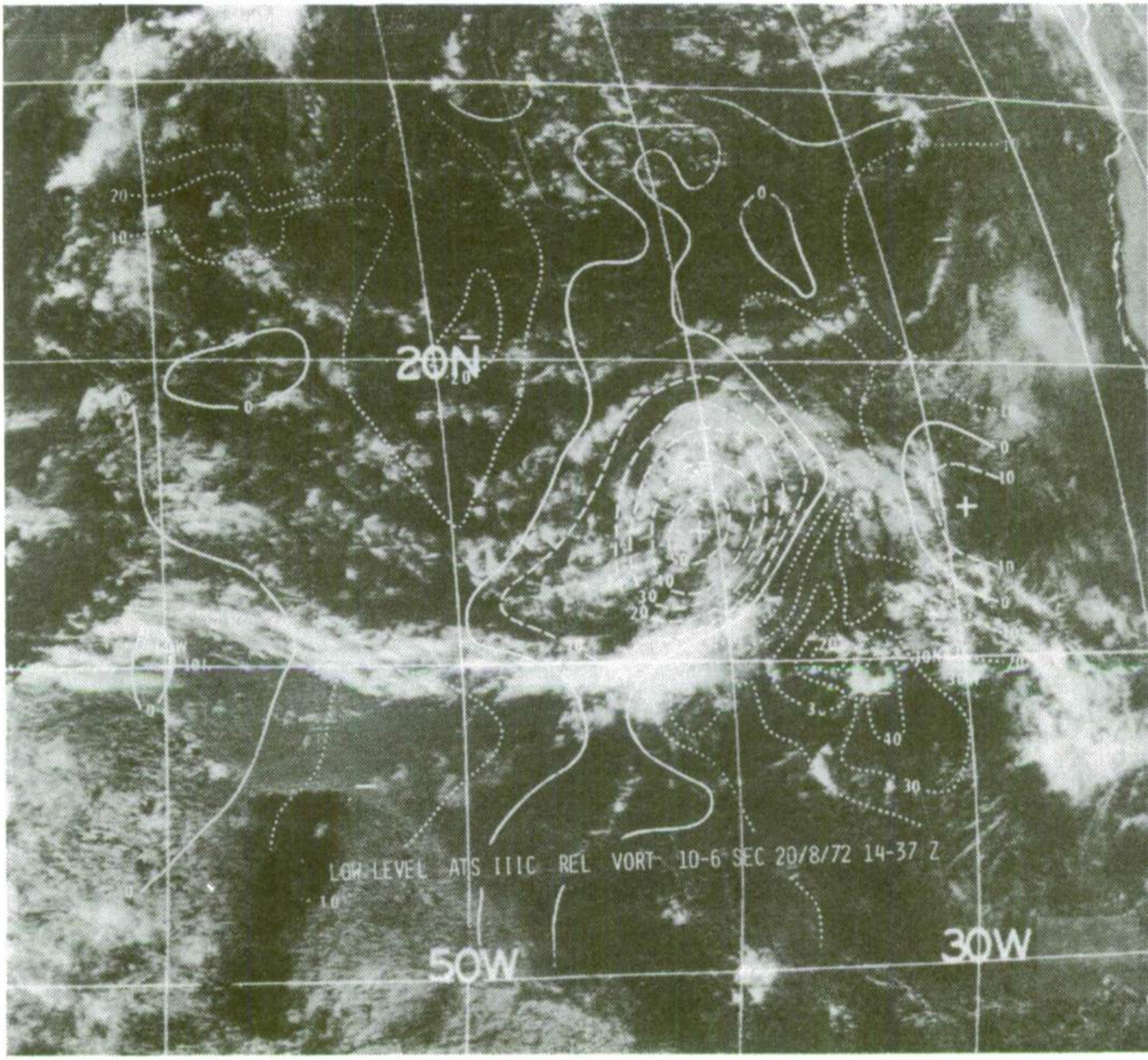

Figure 16. An analysis of the field of relative vorticity (units 10^{-6} sec^{-1}) for the August 20, 1972 inverted V example. Dotted lines indicate areas of negative or anticyclonic vorticity. Dashed lines indicate areas of positive or cyclonic vorticity. The solid line indicates zero vorticity.

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13. ABSTRACT

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