Tropical Cyclone Recurvature and Nonrecurvature as Related to Surrounding Wind-Height Fields

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(Manuscript received 29 January 1976, in revised form 28 October 1976)

ABSTRACT

Ten years of rawinsonde data for 30 stations in the western North Pacific have been composited relative to tropical cyclone center positions. This is the same data set described in a previous paper by the same authors. These data were used to study prior (12–72 h) differences in surrounding environmental fields between tropical cyclones which recurved and those which did not. Differences in the wind, height and temperature fields out to 21° radius to the north between these two classes of storms are presented. A strong recurvature correlation is found in the 200 mb wind and height fields at large radii to the north. It is suggested that an operational long-range (2–3 days) tropical cyclone recurvature forecast scheme can be developed using upper tropospheric wind-height data.

1. Introduction

A basic problem of tropical cyclone forecasting is that of determining whether recurvature will occur. Westward moving cyclones will sometimes turn to the north and then to the northeast. This is designated recurvature. Other cyclones will not recurve. Long ago Riehl and Shafer (1944) stated that if the base of the polar westerlies lowers far to the west of a storm in connection with an eastward-moving mid-latitude trough and remains low, northward recurvature results. General synoptic conditions favorable for recurvature have been documented by Dunn and Miller (1964).

Typical flow patterns associated with recurvature are 1) large-amplitude troughs, extending southward from the westerlies and located within a few hundred miles to the west of the storm center, 2) well-marked low-latitude troughs building northward into the westerlies, and 3) weak troughs between two separate high cells.

Flow patterns associated with nonrecurvature include 1) a strong subtropical high to the north of the storm, with a major trough in the westerlies located far to the west of the longitude of the storm, and 2) westerlies zonal, i.e., waves having a very small amplitude at their normal latitudes or further north.

Burroughs and Brand (1972) have also shown how recurvature is related to the strength of the 300 mb winds to the north. Dunn and Miller (1964) further comment that the period when the storm oscillates between the influences of the easterlies and the westerlies is the most critical. When these types of situations exist the forecaster faces a very serious problem of whether to forecast recurvature or not. An incorrect recurvature/nonrecurvature forecast will greatly affect the population areas in the actual storm track, and lead to very large forecast errors. Forecasting recurvature 1–3 days before it takes place is usually very difficult. Thus, basic research on the recurvature problem would seem warranted.

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2. Methodology

This study uses the same composited data set described earlier (George and Gray, 1976) to examine the recurvature problem in the western North Pacific. Twenty-one pairs of tropical cyclone tracks were selected from the data set. Each pair includes one storm that recurved and one that did not. The pairs were selected in a manner such that the earlier portion of each storm track was within 5° latitude of the other. The 21 tracks of recurving storms are shown in Fig. 1, while the nonrecurving storm tracks are depicted in Fig. 2. An example of the paired storms is shown in Fig. 3. Cyclone center positions were obtained from the Joint Typhoon Warning Center (JTWC) best track positions. See report by Gray (1971) for more information on these storms.

For the composite fields a separation point (S) was selected. The S point is arbitrarily defined at the longitude where the recurving storm track begins to deviate significantly from the nonrecurving track and

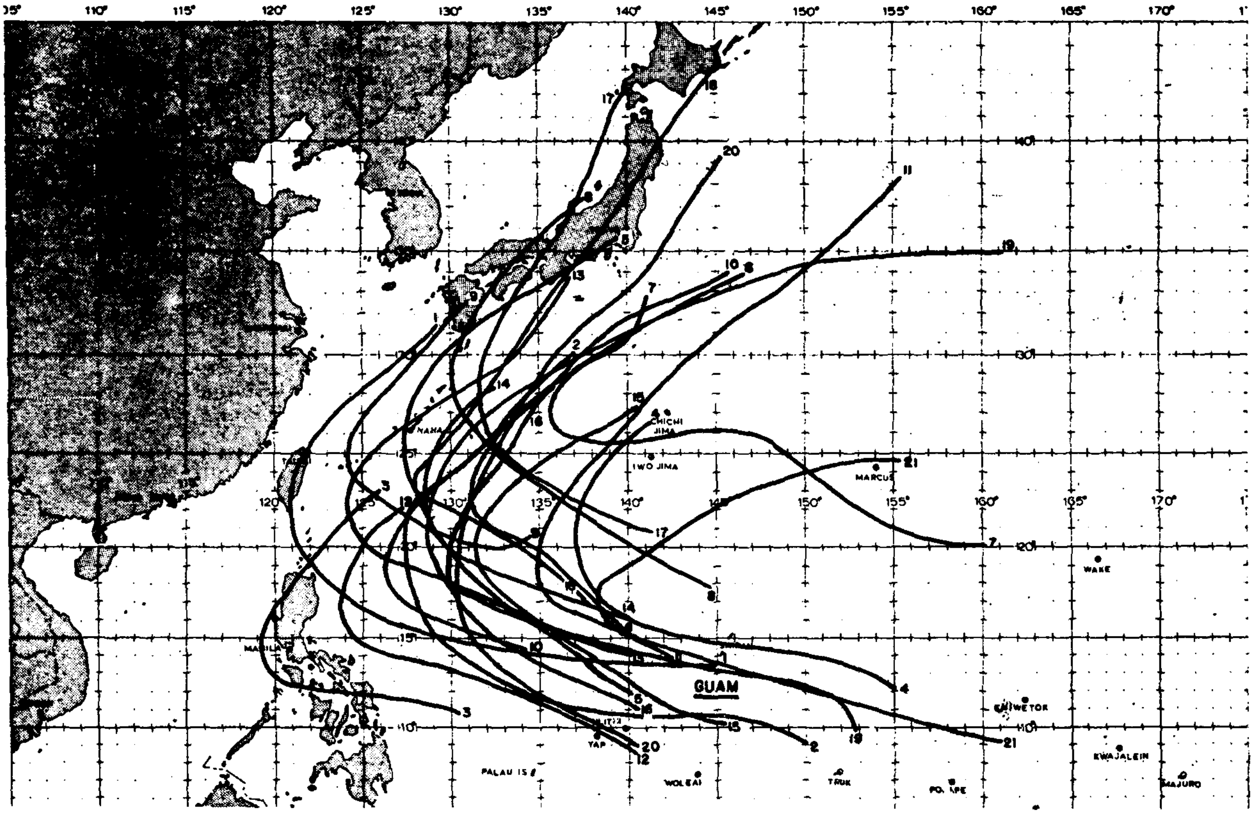

FIG. 1. Actual tracks of the 21 recurving storms. (Number at beginning and end of track refers to *storm name* and date as given in Table 1.)

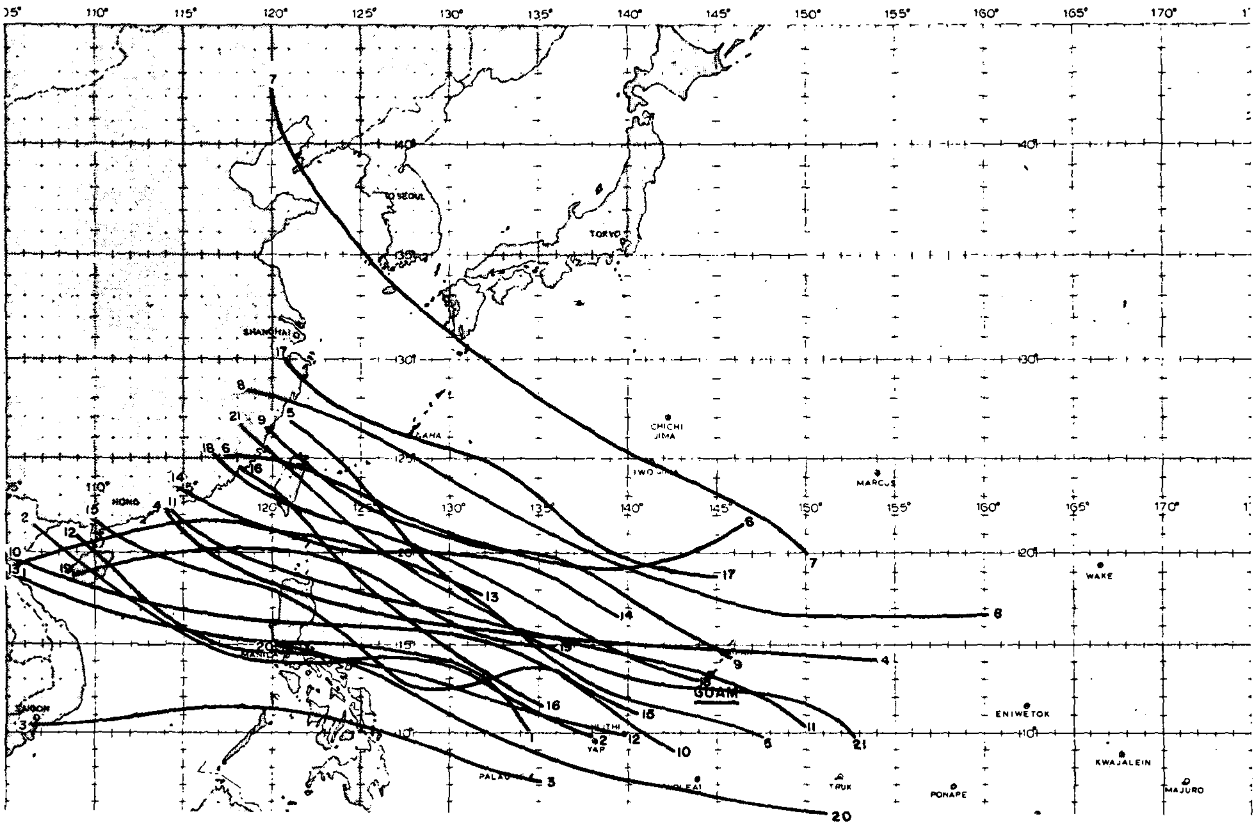

FIG. 2. As in Fig. 1 except for 21 nonrecurving storms.

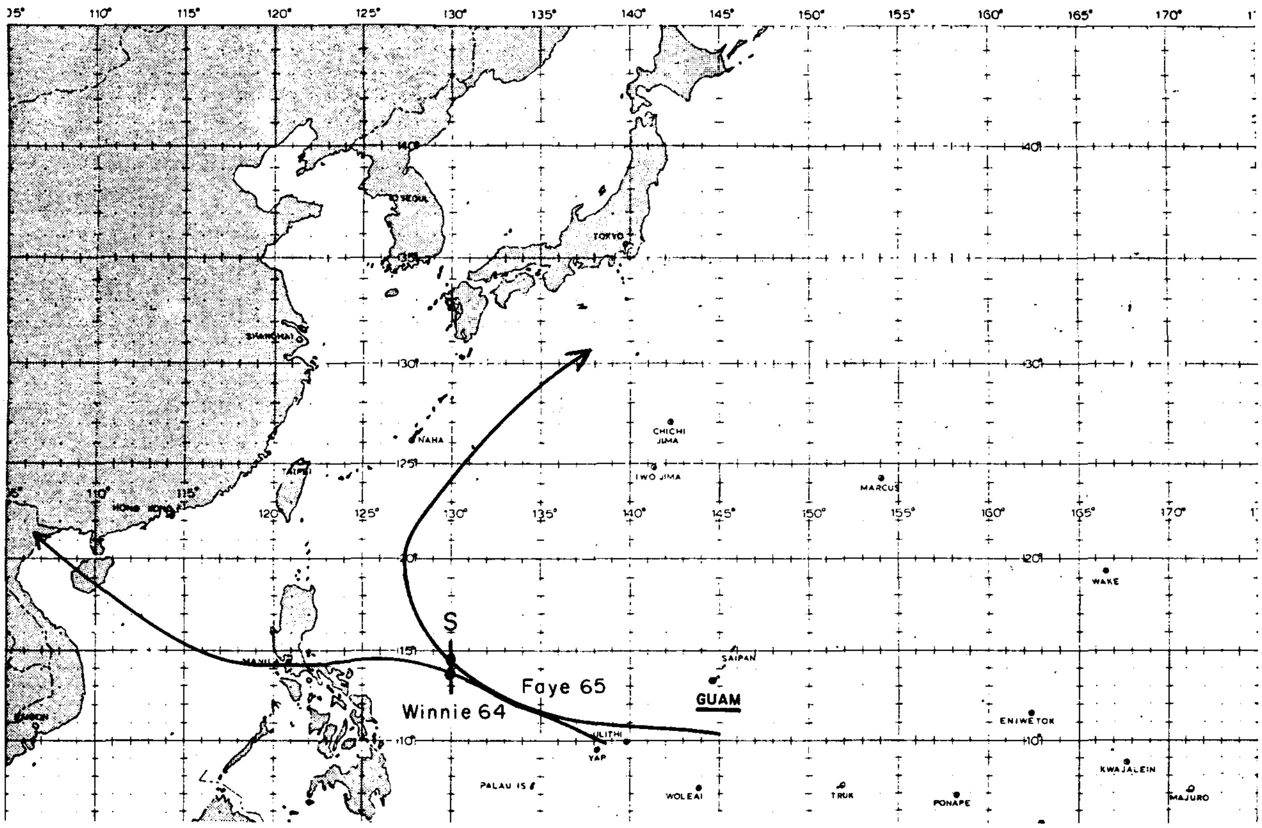

FIG. 3. Example of paired (recurving and nonrecurving) storm tracks. Note the S, or separation, point as discussed in the text.

acquires a northwesterly to northerly component (e.g., see Fig. 3). This is a significant location. It is hypothesized that the surrounding tropospheric flow field 1–3 days before separation time should show a difference between the storms that recurve and those that do not. Rawinsonde data have been composited separately for the recurving storms and nonrecurving storms at the time of the S point, and also prior to and after the S point time.

TABLE 1. Selected storm pairs for recurvature composite study.

Recurving storms				Nonrecurving storms			
Name	Year	Date and time* of S point		Name	Year	Date and time* of S point	
1. Dinah	1965	6/17	00	Clara	1964	10/04	12
2. Faye	1965	11/23	00	Winnie	1964	6/28	00
3. Irma	1966	5/18	00	Lucy	1962	11/28	00
4. Harriet	1967	11/20	00	Patsy	1970	11/16	00
5. Cora	1969	8/18	00	Doris	1964	7/13	12
6. Kit	1963	10/09	00	Clara	1967	7/08	12
7. Opal	1967	9/11	00	Helen	1964	7/31	00
8. Wilda	1964	9/23	00	Elsie	1969	9/25	00
9. Della	1968	9/22	00	Viola	1969	7/26	00
10. Gilda	1962	10/25	12	Emma	1967	11/03	00
11. Hope	1964	10/15	12	Sally	1964	9/06	12
12. Ellen	1961	12/09	00	Joan	1970	10/13	00
13. Olga	1970	7/01	12	Tilda	1964	9/14	00
14. Lucy	1968	6/30	12	Dinah	1962	10/01	12
15. Kim	1968	6/01	12	Freda	1965	7/09	12
16. Kathy	1969	11/07	00	June	1961	8/02	12
17. Shirley	1965	9/08	12	Tilda	1961	10/01	12
18. Trix	1965	9/14	12	Harriet	1965	7/24	12
19. Karen	1962	11/14	00	Faye	1963	9/03	12
20. Kit	1966	6/24	12	Opal	1964	12/12	12
21. Susan	1963	12/26	12	Opel	1962	8/02	12

* GMT.

To assure that the data samples are sufficiently large, it was decided to composite three consecutive 12 h time periods together. For example, data at the time of the separation point (S), data 12 h before this time and data 24 h before were all composited together at selected positions relative to the cyclone centers to give a mean composite time of (S−12). The (S−36) composite data time consists of the three time periods 24, 36 and 48 h before the S point and the (S−60) time data of 48 to 72 h prior to recurvature. Some of the tropical storms of the (S−36) and (S−60) periods were in their early stages of development. Thus, the composite depictions presented in this paper are not for a single time period, but rather for a 24 h combination of time periods. This technique results in typical rawinsonde case counts of 30–50 for grid points to the north of the storm location. Fewer data are available to the south.

The basic compositing grid (see previous paper) was expanded out to 21° radius in order to note large-scale parameter differences which are correlated

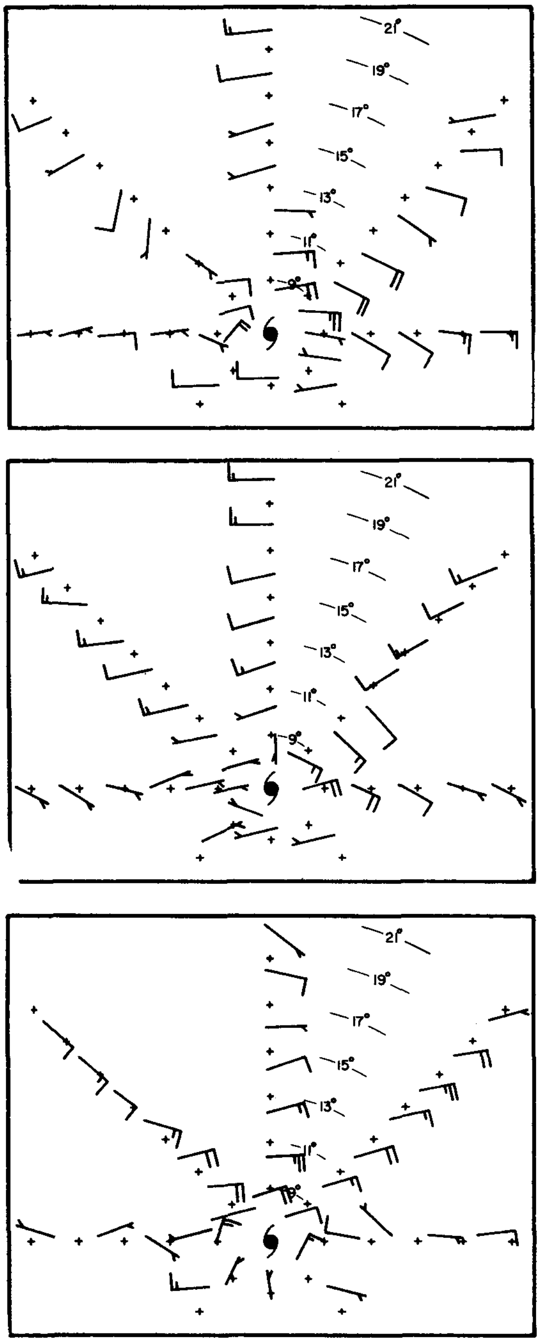

FIG. 4. 700 mb direction and speed composite depictions for nonrecurving storms (top), recurving storms (middle) and nonrecurving minus recurving difference (bottom) at S−60 hours. The grid has been extended out to 21° radius to the north of the storm center. The first data point is not near the center but at 7°–9° radius. No data within 7° radius are shown.

with recurvature. Thus, from the composite fields of height, winds, temperature, etc., basic differences in the overall fields (if they exist) should be discerned between storms that recurve and those that do not. Table 1 lists the storm pairs with the dates and times of the S points on their respective tracks.

3. Recurvature composite results

a. Depiction

It is important to understand the depiction presented in the following figures. The grid has been extended out to 20° radius to the north of the storm center. The first data point shown from the storm center is not near the center but at 7°–9° radius from the storm center. Thus the depiction in this section shows the outer 7°–21° radius from the storm. No data within

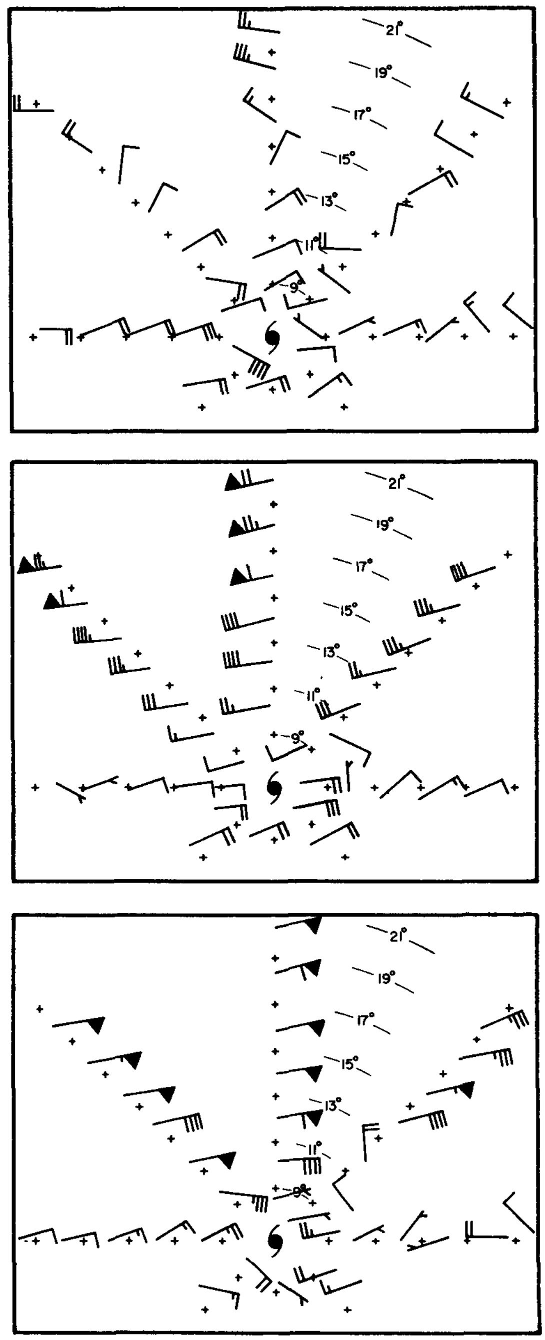

FIG. 5. As in Fig. 4 except for 200 mb direction and speed.

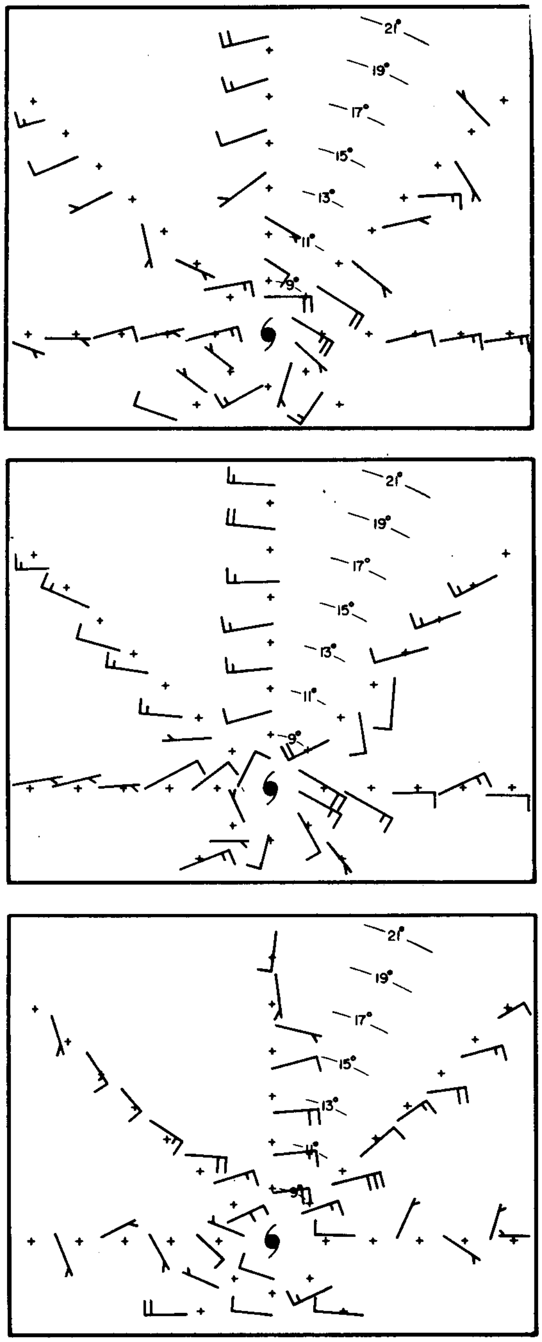

FIG. 6. As in Fig. 4 except at S−36 hours.

7° radius of the storm center are portrayed. The inner 7° radius motion has been described in the previous paper. The wind barb depictions are in meters per second with the single barb representing 5 m s^{-1} and the large triangular barb 25 m s^{-1}. These values can be approximately doubled in order to convert wind speed into knots.

Figs. 4–9 portray the 700 and 200 mb wind fields 12–60 h prior to recurvature. Fig. 4 depicts the composite 700 mb wind field at the (S−60) mean composite time period for nonrecurving and recurving storms, along with the nonrecurving minus recurving difference. Westerlies are located approximately 16–20° to the north of nonrecurving storms. For the recurving storms the westerlies are found at only 10° to the north of the cyclone center and are slightly stronger. As seen, the differential speed difference between the nonrecurving and recurving storms to the north is

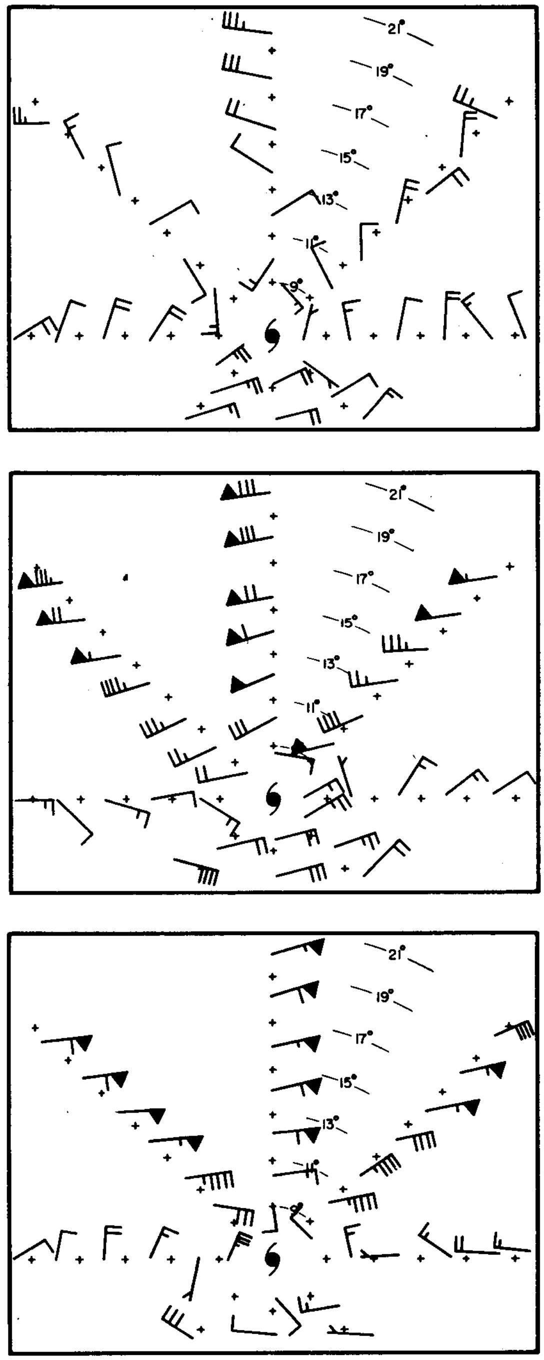

FIG. 7. As in Fig. 5 except at S−36 hours.

5–10 m s^{-1}. Thus, at 48–72 h, or 60 h average time before the separation point, the 700 mb wind field out to 14–16° radius shows slight westerly wind differences for the storms that recurve vs those that do not. The same three depictions for the 24–48 h prior time period, or (S−36), at 700 mb are shown in Fig. 6. At this time period, the westerlies are located approximately 14–16° to the north of the nonrecurving storms, while only 10° to the north for recurving storms. For the recurving storms the

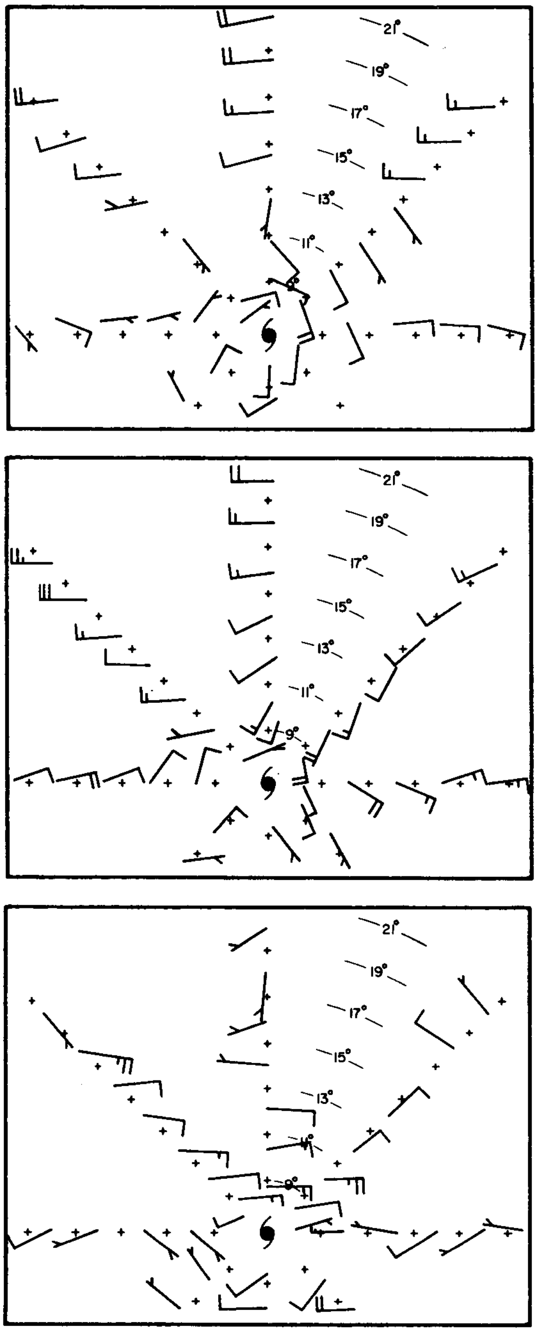

FIG. 8. As in Fig. 4 except at S−12 hours.

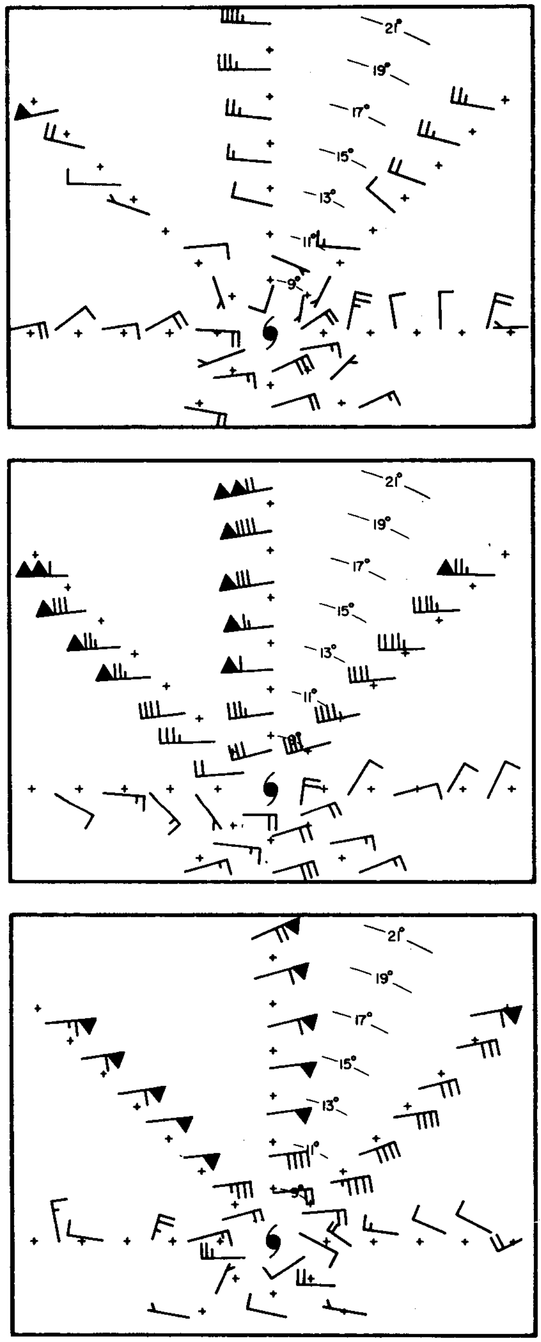

FIG. 9. As in Fig. 5 except at S−12 hours.

westerlies are slightly stronger than for the nonrecurving storms. The difference between the nonrecurving and recurving storms to the north of the center is again 5–10 m s^{-1}. Fig. 8 shows a similar depiction for the (S−12) time period. Though 24 h closer to actual recurvature, there are few differences between the (S−36) and (S−12) time periods. Again at (S−12) the westerlies are deeper and slightly stronger to the north of recurving storms.

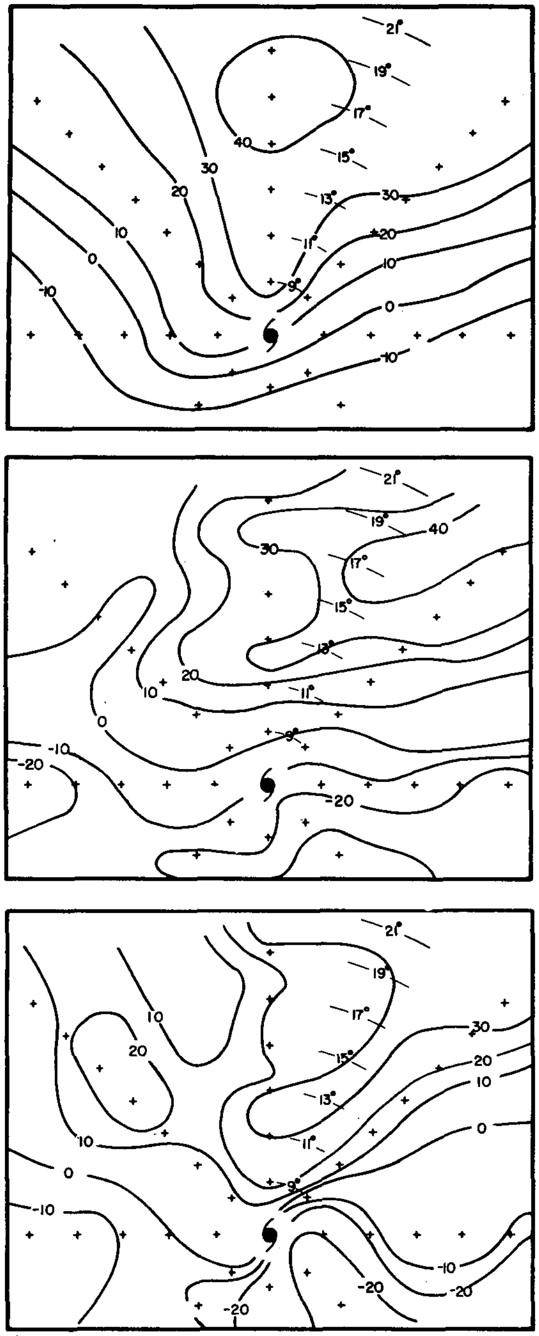

FIG. 10. 700 mb nonrecurving minus recurving storm height difference (m) at S−60 hours (top), S−36 hours (middle) and S−12 hours (bottom).

Major differences in the wind fields can be seen at the 200 mb level. Fig. 5 depicts the composite 200 mb wind field at the (S−60) mean composite time period for nonrecurving and recurving storms, along with the nonrecurving minus recurving difference. Figs. 7 and 9 show the same for the (S−36) and (S−12) time periods, respectively. It is readily apparent that a significant 200 mb difference between storms that recurve and those that do not is the width and strength of the westerlies to the north of the storm at a distance of 10–20° radius. At (S−60) nonrecurving storms do not have westerlies within 16° of their center, while the recurving storms have the westerlies at 10° radius to the north. At (S−36) the westerlies are closer to the storm center and stronger for both categories of storms. This trend continues as shown by the (S−12) time period. The three time period differences between the nonrecurving and re-

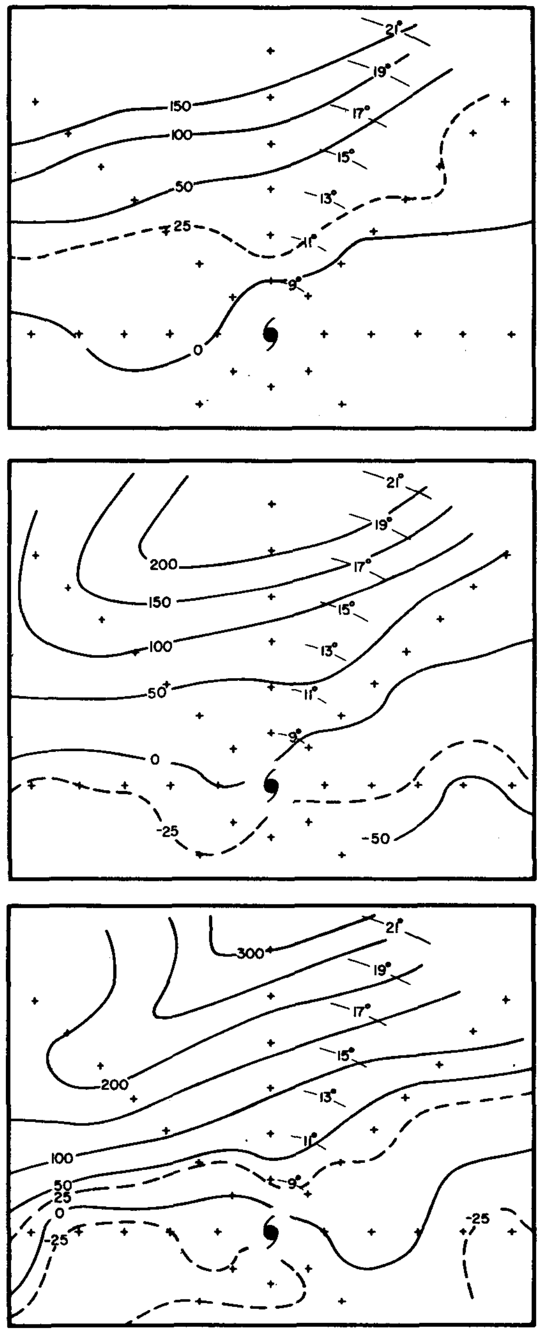

FIG. 11. As in Fig. 10 except for the 200 mb level.

TABLE 2. Summary of nonrecurving minus recurving parameter differences.

Parameter	S-60	S-36	S-12
700 mb zonal wind field	4–8 m s^{-1} at 8–12° radius (NW–NE)	4–8 m s^{-1} at 8–12° radius (NW–NE)	4–8 m s^{-1} at 8–12° radius (NW–NE)
200 mb zonal wind field	20–24 m s^{-1} at 14–20° radius (NW–NE)	24–28 m s^{-1} at 14–20° radius (NW–NE)	30–36 m s^{-1} at 14–20° radius (NW–NE)
700 mb meridional wind field	2–4 m s^{-1} at 14–20° radius (NW-N)	2–4 m s^{-1} at 8–20° radius (N-NE)	2–4 m s^{-1} at 8–16° radius (NE)
200 mb meridional wind field	10–12 m s^{-1} at 12–20° radius (NW-N)	12–16 m s^{-1} at 12–20° radius (N-NE)	12–14 m s^{-1} at 12–20° radius (W-NE)
700 mb height field	40 m at 16–18° radius (N)	40 m at 16–20° radius (N-NE)	30 m at 16–20° radius (N-NE)
200 mb height field	>150 m at 18–20° radius (NW-N)	>200 m at 18–20° radius (N)	>300 m at 18–20° radius (N)
700 mb temperature field	4°C at 18–20° radius (NW-N)	6°C at 18–20° radius (NW-N)	8°C at 18–20° radius (NW-N)
200 mb temperature field	1°C at 18–20° radius (NW-N)	2°C at 18–20° radius (NW-N)	2°C at 18–20° radius (NW-N)

curving storms range up to 30–36 m s^{-1} to the north of the storm. Thus, it appears that even at an average time period of 60 h before the point at which the recurving storms begin to shift their courses and when these systems are only in an early stage of development, their 200 mb wind fields are significantly different from those storms which do not recurve. Thus a gain in recurvature forecasting skill may be possible at a long time range. These upper level westerly wind differences are not greatly surprising. Forecasters have always qualitatively known that the westerlies are stronger and closer to the recurving storm. To the authors' knowledge, however, there has not been any explicit documentation of these differences. Also, it is doubtful that it was generally known that the flow field differences were so large 48–72 h before recurvature.

At least 60 h before the first northward change in a recurving storm's westerly movement, the 200 mb wind field is a strong indicator as to whether a storm is likely to recurve or not. Recurving vs nonrecurving storm differences are somewhat accentuated at the (S−36) and (S−12) time periods.

b. Height

The height difference fields for the 700 and 200 mb levels are shown in Figs. 10 and 11. At 200 mb for the (S−60) time period and 18–20° radius to the north, the nonrecurving storms have heights which are over 150 m greater than the recurving storms. This height difference increases to over 200 m at (S−36) and to over 300 m at the (S−12) time period. This is a substantial difference. At approximately 24–72 h prior to the separation point for a recurving storm there is a large height gradient between the storm and 20° radius to the north of the storm. From this it would seem feasible that height differences of these magnitudes detected at some prior time period would be a good indication that within 60, 36 and 12 h, respectively, a tropical storm is likely to begin to recurve. The 700 mb charts show differential gradients of only 40 m to the north and northeast of the storm center at 16–20° radii. Generally, both levels and time periods show that for nonrecurving storms, the relative heights are significantly higher to the north. Again, the 200 mb difference fields are much more indicative of recurvature.

c. Temperature

The temperature differences between the two stratifications for the 700 and 200 mb levels were also studied. At 200 mb there was little nonrecurving/recurving composite difference in temperature (only 1–2°C) to the north and northwest at any of the time periods. At 700 mb and (S−60), however, there was a 4°C differential gradient which increased to 6°C at the (S−36) time period and to 8°C at (S−12). From 12–60 h before the separation point, the outer radii synoptic field at 700 mb is 4–8°C colder for storms that recurve than for storms that do not recurve. Thus, in contrast to the wind field results, the lower troposphere is a better indicator of recurvature as far as the temperature field is concerned. Table 2 summarizes the above discussed parameter differences.

d. Recurvature minus nonrecurvature zonal and meridional geostrophic wind components

Recurvature minus nonrecurvature geostrophic zonal and meridional wind components which are calculated from the differential height gradients northwest through northeast of storm centers and east to west across the storm centers are shown in Figs. 12 and 13. At 200 mb the zonal geostrophic environmental flow from 10° to 20° across the recurving storms shows a significantly larger component than for the nonrecurving storms. At

700 mb these geostrophic zonal differences gradually decrease with radius and are only 1–2 m s^{-1} at radii $>10°$.

Recurving minus nonrecurving storm meridional geostrophic wind differences are less pronounced than zonal values, but at 200 mb are still quite indicative of recurvature at large radii. 700 mb geostrophic differences beyond 10° are near zero. These 200 mb geostrophic flow differences at large radii indicate a degree of possible forecasting potential. It is apparent that at large radii the 200 mb height field is a much better indicator of recurvature than the 700 mb level.

4. Summary

The results of this study indicate that 12–60 h prior to a significant change in cyclone track, there occur large-scale parameter differences at upper tropospheric levels and at large radii. The implications of these results for improved recurvature forecasting appear encouraging. With further research these differences can likely be incorporated into an operational forecasting procedure. Many of the current recurvature forecasting schemes are based on 850–500 mb flow fields. By contrast this study shows the large benefit that is likely to be derived by use of upper troposphere wind-height data at large radii. This has been shown to be a far stronger indicator of recurvature than the lower tropospheric flow. The results of this paper for west Pacific cyclones should be valid in the western Atlantic and in other tropical regions. For more information on this research, please see the more detailed project report of George (1975) on this subject.

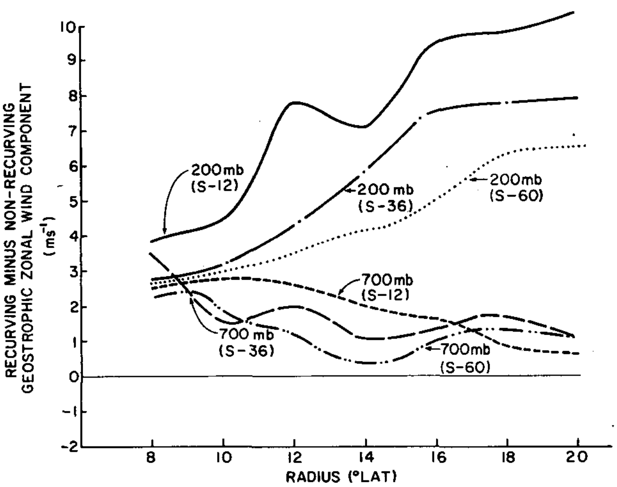

FIG. 12. Recurving minus nonrecurving geostrophic zonal wind component across the cyclones, based on N–S height gradients at various radii.

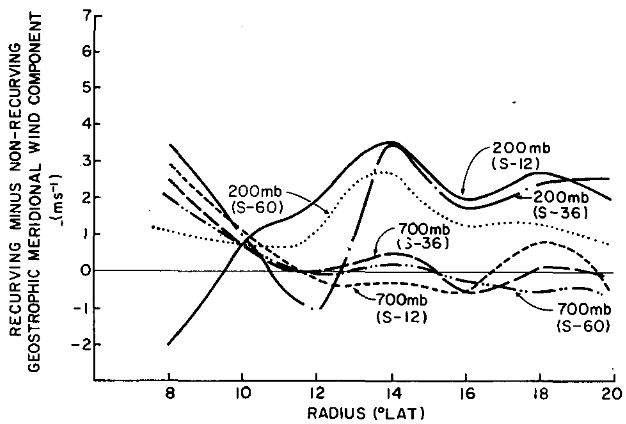

FIG. 13. Recurving minus nonrecurving geostrophic meridional wind component across the cyclones, based on E–W height gradients at various radii.

Acknowledgments. This research was accomplished while the first author was enrolled in the U. S. Air Force Institute of Technology meteorology program at Colorado State University, and has been largely supported by NOAA research Grant 04-5-022-14. The punching of the Japanese rawinsonde data was accomplished through arrangement with the U. S. Navy Environment Prediction Research Facility.

This study was made possible by the special computer programming expertise of Messrs. Edwin Buzzell and Charles Solomon. Gratitude is extended to Dr. William M. Frank and Major Charles P. Arnold for enlightening discussions. Mrs. Barbara Brumit and Ms. Genevra Metcalf assisted in the data reduction and manuscript preparation.

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