NORTHBOUND TROPICAL CYCLONE

A Case History

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[Manuscript received February 9, 1962; revised April 12, 1962]

ABSTRACT

A case history of a small east coast tropical cyclone of September 14–15, 1961, is presented. Track, intensity, winds, and damage are summarized. Intensification and acceleration of the Low as it moved northward along the coast caused storm-force winds on the east side of the center. Some of the forecasting problems associated with the cyclone are discussed.

1. INTRODUCTION

From time to time the eastern seaboard of the United States is battered by storms of tropical origin which deepen on moving northward and reach near-hurricane intensity in northern latitudes. These are usually of quite small size and weak intensity in tropical waters and may cause only heavy rain along the coast. When they do intensify they may cause considerable damage, particularly as the intensification is frequently unexpected. This paper is a résumé of such a storm which moved along the east coast on September 14–15, 1961, and did intensify north of latitude 40° N. It appears that the divergence pattern may be a clue in forecasting deepening.

2. TIROS III DATA

During the period from September 9 to 12, 1961, TIROS III was well oriented for photographing the area south and east of Florida. On each of these days, nephanalyses from the photographs indicated a vortex present just east of the Bahamas. It is not possible to determine in what portion of the atmosphere these vortices were located, nor even if they were one and the same. Figure 1 is a reproduction of the nephanalysis for September 9 and

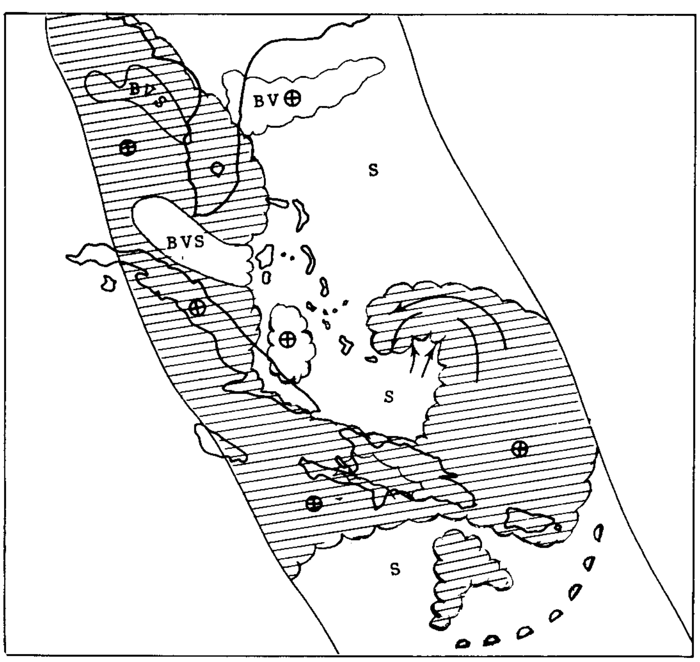


Figure 1.—Copy of TIROS III nephanalysis, September 9, 2120 GMT. Orbit 854R/O853. Arrows indicate cyclonic circulation east of Cuba.

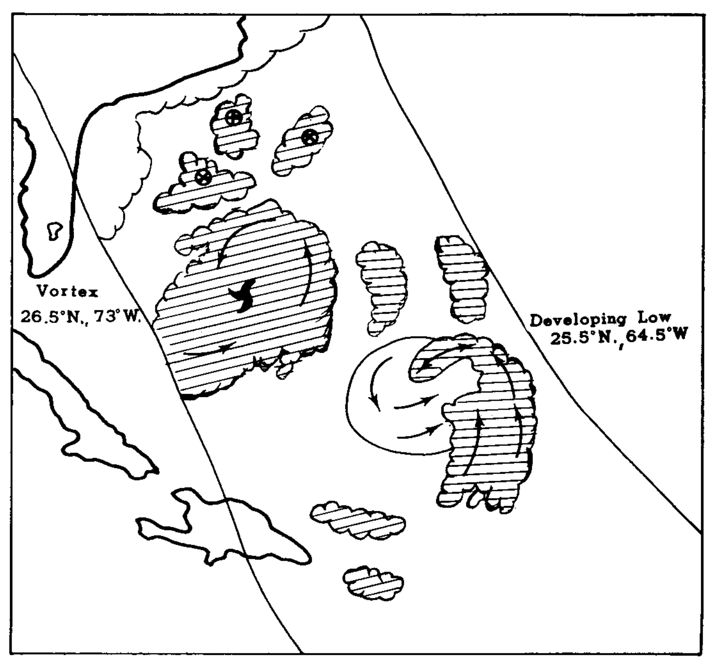


Figure 2.—Copy of TIROS III nephanalysis, September 12, 1935 GMT. Orbit 896R/O895. Two cyclonic circulations are indicated. The northwestern one may be the same as shown in figure 1.

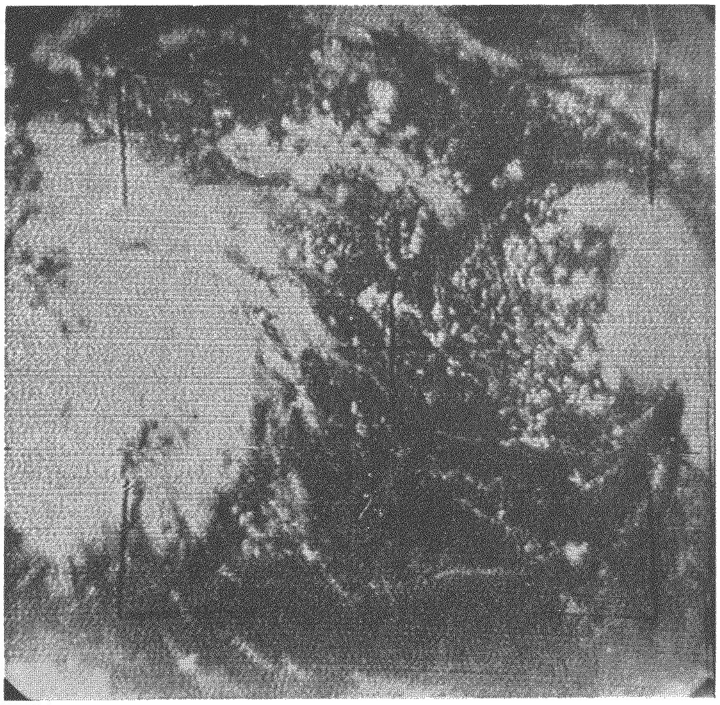


FIGURE 3.—TIROS III, frame 15, orbit 896, showing the two vortices of figure 2.

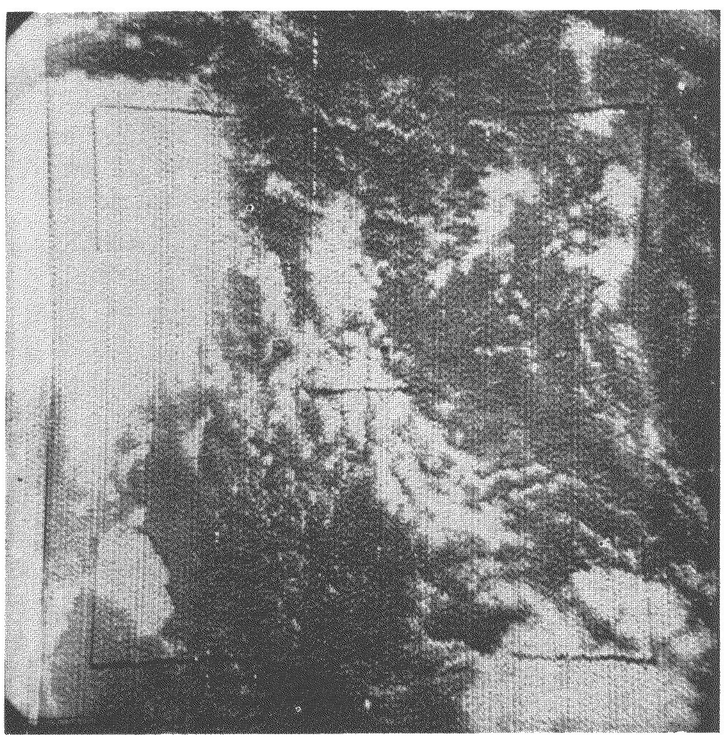


FIGURE 4.—TIROS III, frame 21, orbit 910, September 13. The dense cloud on the left is associated with the cyclonic circulation off Florida.

figure 2 that for September 12. Note that there are apparently two vortices on September 12 (figs. 2 and 3). (It should be noted that this was a period of great hurricane activity. Hurricane Betsy had moved northward in mid-Atlantic, Carla was smashing into Texas, Debbie had been identified, and within a week Esther was destined to threaten the New England coast.)

By September 13 surface reports clearly indicated a cyclonic circulation east of Florida, and the edge of the circulation was again photographed by TIROS III (fig. 4), but while the clouds appear quite dense, the cyclonic circulation is not clearly defined in the reproduction. The photographs from subsequent orbital passes over the storm on September 14 and 15 failed to show any circulation in the general cloudiness in which it was imbedded.

There is a temptation to assume that the western vortex in figure 2 is the same as the vortex in figure 1, but the continuity is not certain. If the identity could have been better verified, earlier warning of tropical cyclone activity along the coast might have been possible.

3. TRACK, WIND, AND DAMAGE

The tropical cyclone crossed the coast of North Carolina just east of Wilmington at about 0600 EST, September 14. At this time it was moving toward the north-northeast at about 18 kt. On the assumption that it would be steered by the 500-mb. flow (fig. 11b), the circulation might have been expected to move along the coast and accelerate. The track (fig. 5) indicates that this would have been a good estimate. The cyclone never moved far from the coastline and perhaps in this way maintained its tropical characteristics, which will be discussed below. From the forecast point of view, one of the problems was the acceleration which was continuous for the 27 hours when it was within the continental limits of the United States. During the final 2 hours it was moving at 60 kt.

While the central pressure continued to decrease as the cyclone moved northward, the reported winds dropped off after it passed Cape Hatteras. Highest gusts there were 38 kt., while Atlantic City recorded no winds of over 15 kt. By the time it reached Long Island, winds had again increased to 38 kt., which was recorded at Suffolk County Air Force Base (see fig. 6) as the center passed by. At about this time the Research Vessel *Eugenie VIII*, of the Woods Hole Oceanographic Institution, was about 80 mi. south-southeast of Block Island, R.I., and some 110 mi. from the storm center. The captain, a man with long experience in small boats at sea, estimated winds of 50 kt. and reported the sea condition as "very rough" and had some difficulty in bringing the vessel about to run before the wind. Point Judith, R.I., recorded gusts to 61 kt. and at Quonset Point, R.I., the carrier *Lake Champlain* parted her lines and drifted away from the dock. An airplane at the Groton (Conn.) Airport tore loose from three 1550-lb. test nylon lines.

At 0500 EST wave heights of 16 ft. were measured at a tower off the south coast of Marthas Vineyard. For a minimum duration of 3 hours, which is probably a maximum in this case, a sustained wind of 55 kt. is required to produce this wave height; for a 2-hour minimum duration, winds over 70 kt. are required. The winds caused

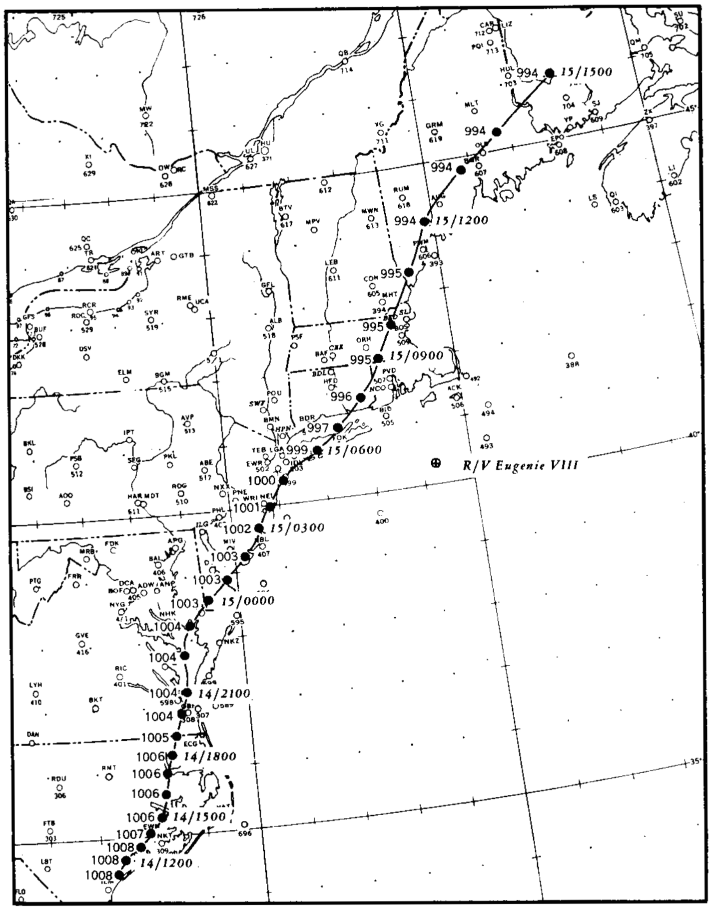


Figure 5.—Hourly positions of the storm from 1100 GMT, September 14 to 1500 GMT, September 15. Numbers to the left of dots are central pressure. The position of R/V *Eugenie VIII* is indicated (see text).

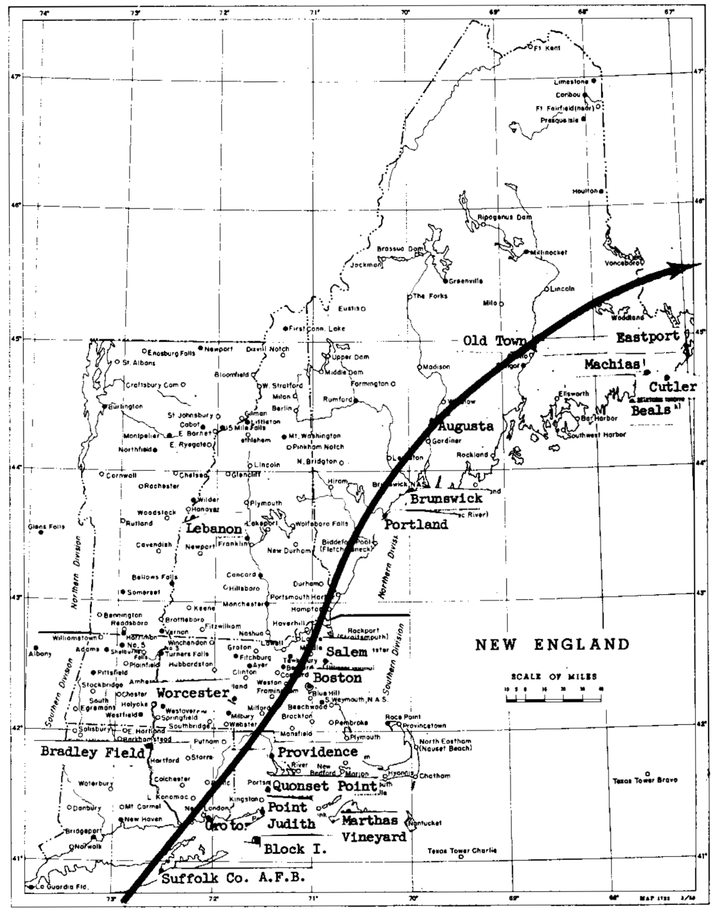


Figure 6.—Location of place names used in the text.

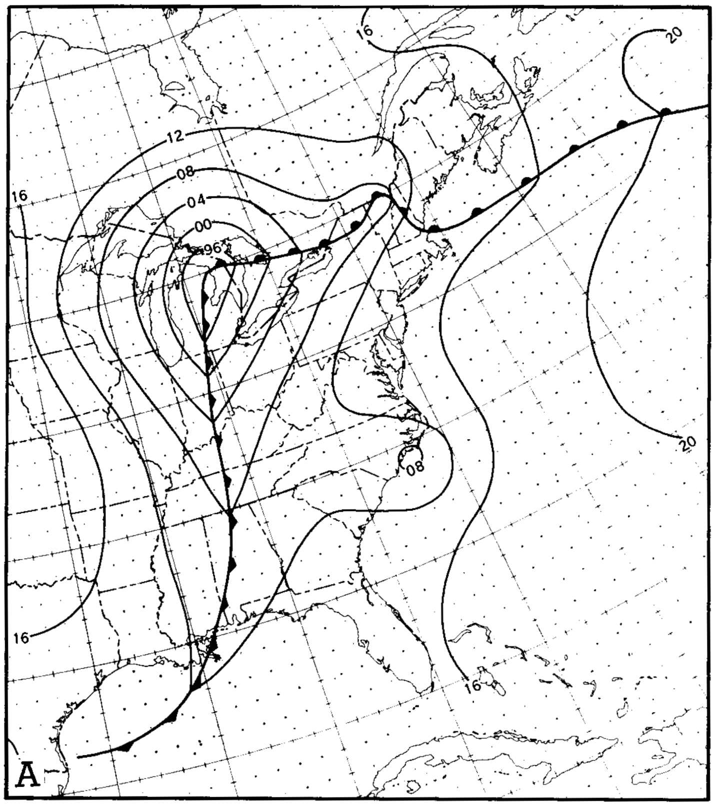
a storm surge of 4.1 ft. in Narragansett Bay. Fortunately the surge arrived at time of low tide, so no serious damage resulted.

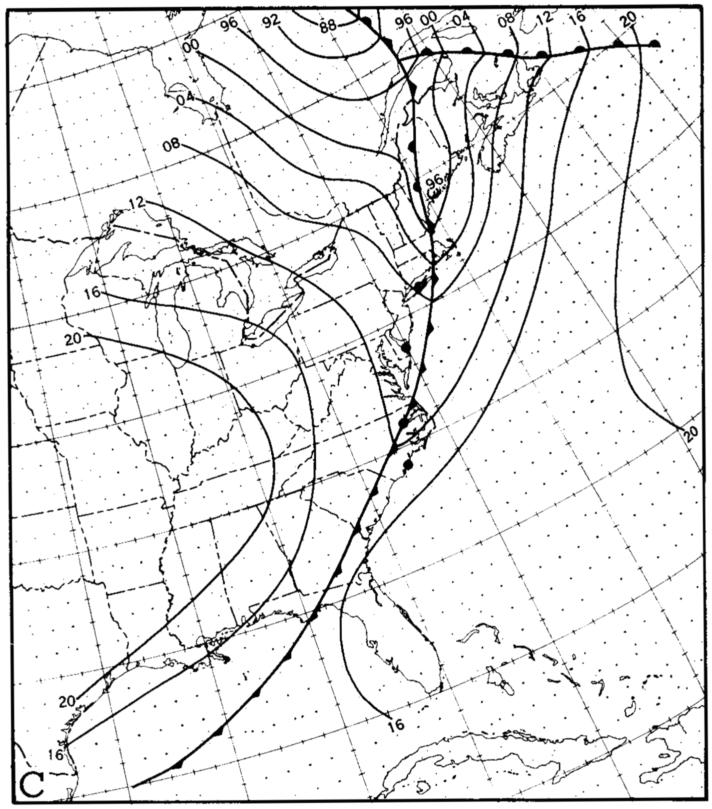
Highest winds and most damage to power lines occurred as the storm sped across eastern Maine. At Beals, Maine, a waterspout was reported, and apparently moved onshore where a new 26 ft. by 52 ft. boatshop was lifted from its foundation and moved 15 ft. Winds at the top of an 800-ft. radio tower at Cutler, Maine, were recorded at 100 m.p.h., while the surface winds were up to 70 m.p.h. There was some evidence of a tornado in the Machias area; most trees were blown down from south to north, while a few were noted to have fallen from west to east and east to west. The triple register at Eastport, Maine, showed a 2-minute wind speed of close to 60 m.p.h. (52 kt.) and 1-minute speed of about 80 m.p.h. (70 kt.). There seems little doubt that the winds reached hurricane force at least occasionally during the time the storm moved across New England. Saint John, New Brunswick, reported gusts to 62 kt. at 1000 EST, and to 70 kt. at 1100. All the highest winds reported were from the south to southwest.

4. SYNOPTIC FEATURES

At 1200 GMT on September 14 (fig. 7a) a deep Low, the remnants of hurricane Carla, was centered over northern Lake Huron with a cold front southward to the Gulf of Mexico and a warm front eastward through New England. Warm air surging up the Hudson and Connecticut River valleys caused a typical bulge in the warm front. The air mass in the warm sector was definitely tropical, with dew points (°F.) in the upper 60's in the Ohio valley and in the 70's along the east coast as far north as New York. Showers and a few thunderstorms were occurring throughout the warm sector with light rain in the vicinity of the tropical Low on the North Carolina coast.

Twelve hours later (fig. 7b) the Low had begun to accelerate and had deepened about 4 mb. No winds of over 20 kt. were reported in the warm sector, except at Texas Tower Charlie, identified as TTC in figure 7b, which reported 25 kt. and a wave height of 5 ft. By 1200 GMT on the 15th (fig. 7c) the storm was near Portland, Maine, and moving at about 40 kt. At this time the cold front was within 30 to 40 mi. of the center, but





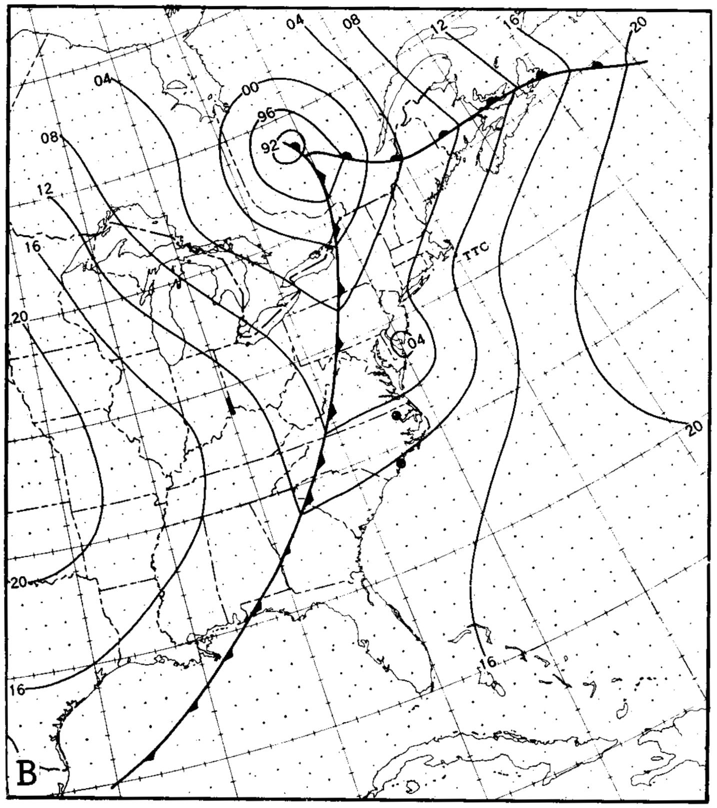


Figure 7.—Surface charts for (a) 1200 GMT, September 14, 1961; (b) 0000 GMT, September 15, 1961; (c) 1200 GMT, September 15, 1961.

the cold air apparently never did move into the Low circulation while the storm was within the United States. This will be discussed in more detail below.

There may be some question as to whether this tropical cyclone should properly be classified as a true tropical storm.[1] It may be that neither the tropical cyclone nor the deepening extratropical Low by themselves would have caused storm-force winds. There is no doubt that storm-force winds did occur, even though at some distance from the center. The circulation of the tropical Low remained very small, with a diameter generally less than 100 mi. Whatever the cause, storm warnings were in order.

5. TROPICAL CHARACTERISTICS

There seems little doubt that this storm was of tropical origin; what is surprising is that it maintained tropical characteristics all the way into Maine. Similar storms, which frequently are steered northeastward by warm sector winds, are "captured" by the cold front and they rapidly become extratropical or are absorbed in the extratropical circulation. An interesting case is reported by Spuhler [1] in which the strongest winds occurred in the left rear sector, associated with the cold front. Pierce [2] showed that cold air also feeds into full hurricanes, and in fact, this is probably the normal course of events when tropical storms move north of about 40° N. latitude in the western Atlantic. The fact that this storm accel-

[1] See note by Gordon E. Dunn following this article.

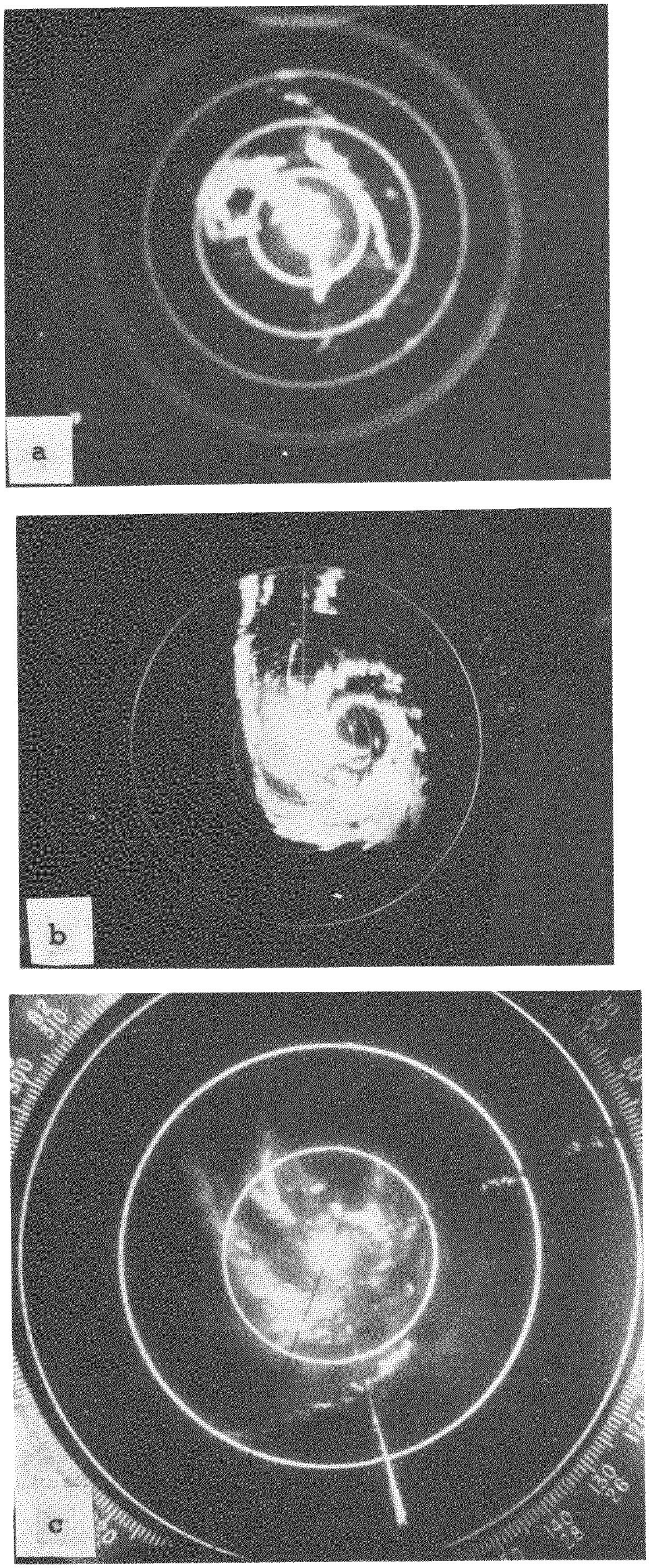


Figure 8.—Radarscope (PPI) photographs. (a) Hatteras, September 14, approximately 1630 GMT. (b) Atlantic City, September 15, 0338 GMT. (c) Blue Hill, September 15, 0947 GMT.

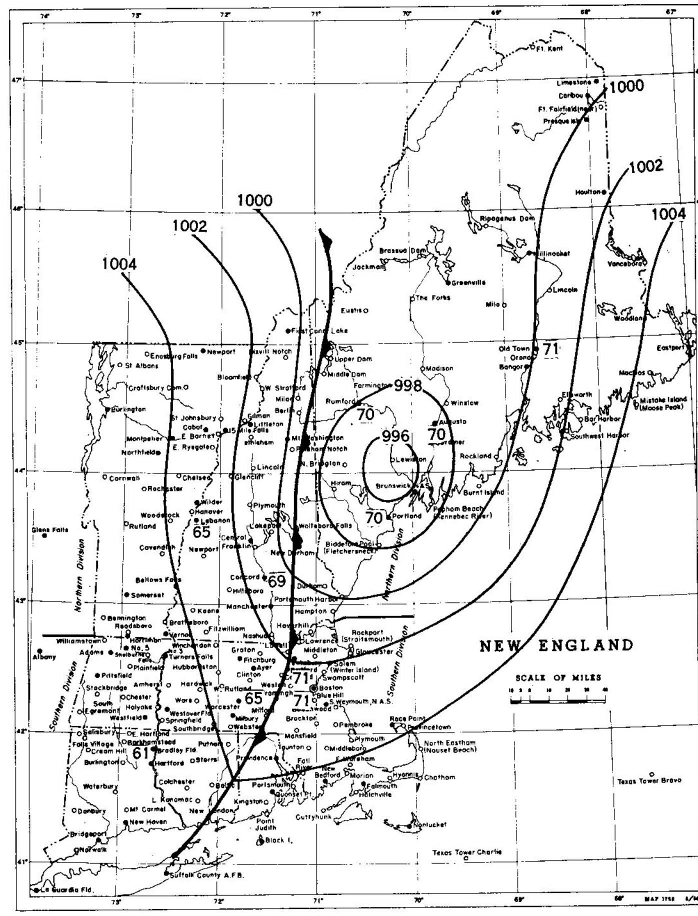


Figure 9.—Surface chart 1200 GMT September 15. Dew point temperatures (°F.) are plotted for selected stations.

erated away from the cold front may explain why it remained tropical so far north.

Storm detection (SD) reports from coastal radars indicated that the spiral band structure was observable from Cape Hatteras northward until the storm passed out of the Nantucket radar range. While the Hatteras SD reports did not indicate spiral bands per se, one report (1700 GMT, September 14) indicated a line of echoes which, when plotted, formed a spiral. Atlantic City, New York, and Nantucket SD's all included reports of spiral bands and an open center. Figure 8 shows selected radarscope photographs which indicate the spiral band structure.

Further indications that cold air did not reach the storm center are shown on the enlarged surface chart for 1200 GMT on September 15 (fig. 9). Dew points at that time were uniformly between 69° and 71° F. at Portland, Augusta, and Rumford compared to the low 60's in the cold air as seen in the figure. This is unlike the storm Spuhler [1] reported and also unlike the hurricane of 1938 (see Pierce [2]) when frontal systems quite definitely moved into the circulation.

Other, less conclusive, evidence of the tropical nature of the Low is found in the barograph traces (fig. 10).

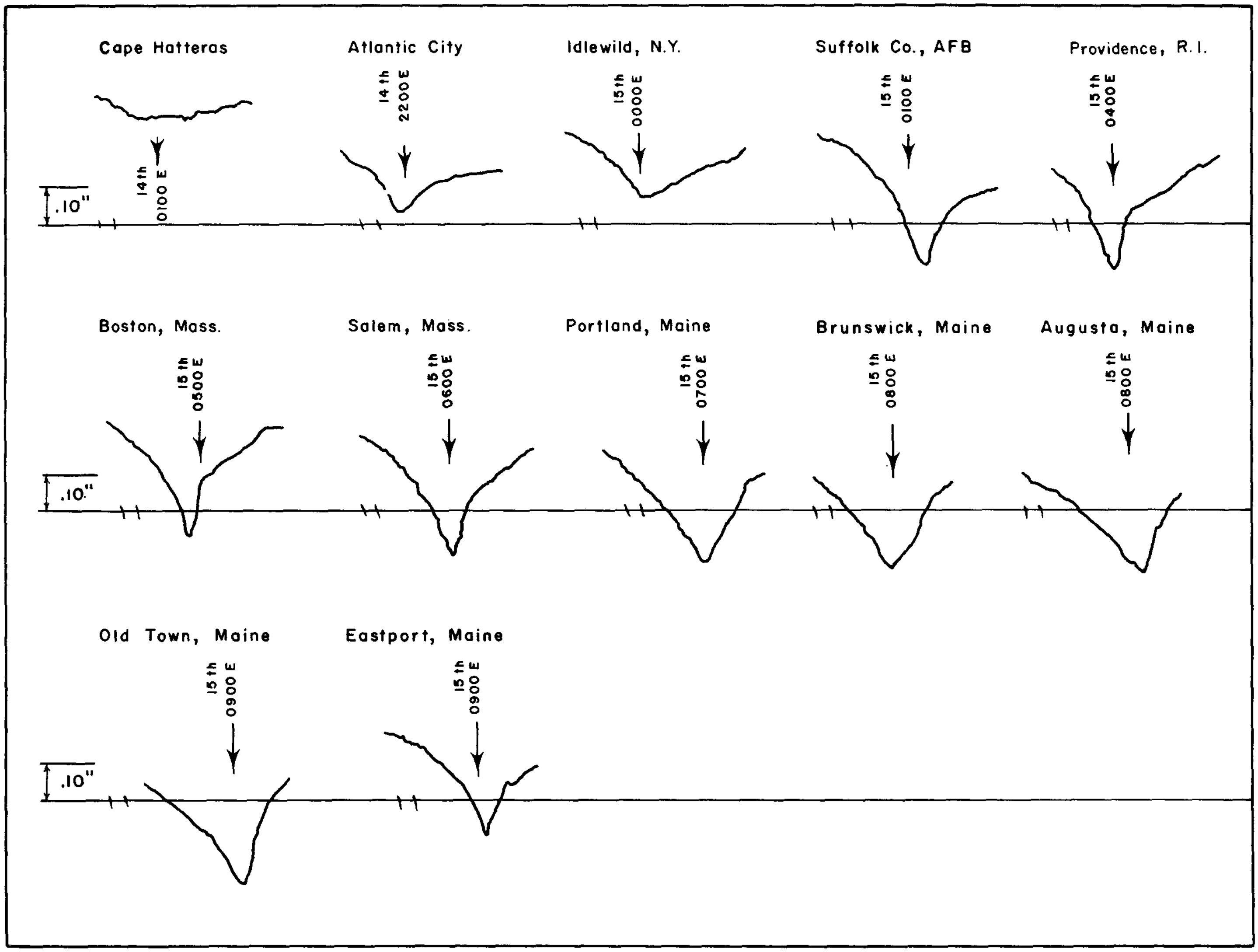


FIGURE 10.—Barograph traces. Hatch marks on horizontal line indicate one hour.

The Hatteras trace is not particularly noteworthy, but does indicate that the cyclonic circulation was small, since the center passed within 60 mi. of the station. It was also quite weak at this time. The Atlantic City trace indicates a little more development, but it was not really until the Low passed Suffolk County Air Force Base that the trace took on the appearance of a tropical storm passage. The pattern was repeated at Providence, Boston, and Salem.

The barograph traces from the Maine stations, except for Eastport, appear to lose the steep-sidedness which is so typical of tropical storm traces. The storm passed within 10 to 20 mi. of Portland, Brunswick, Augusta, and Old Town, but was three times that distance from Eastport. The broader traces are probably due to the proximity of the frontal trough which was intensifying at this time. This influence would not have been felt at Eastport.

6. REMARKS ON FORECASTING

It is obvious that this storm presented a forecasting problem to the Northeastern States. The presence of the Low on the North Carolina coast during the early morning of September 14 could hardly be ignored, even though its size and strength did not indicate a serious threat. Strongest winds were in the eastern quadrant, with maximum gusts reported as 26 to 30 kt. On the assumption that 500 mb. is a good steering level in such cases, from the chart for 1200 GMT September 14 (fig. 11b) one would expect that the Low would move on a track close to the coastline. An increase in speed would seem likely as the Low moved into the southwesterly flow ahead of the oncoming trough. There was some danger that it might intensify when it encountered the cold front somewhere in southern New England.

An interesting divergence pattern is evident on the

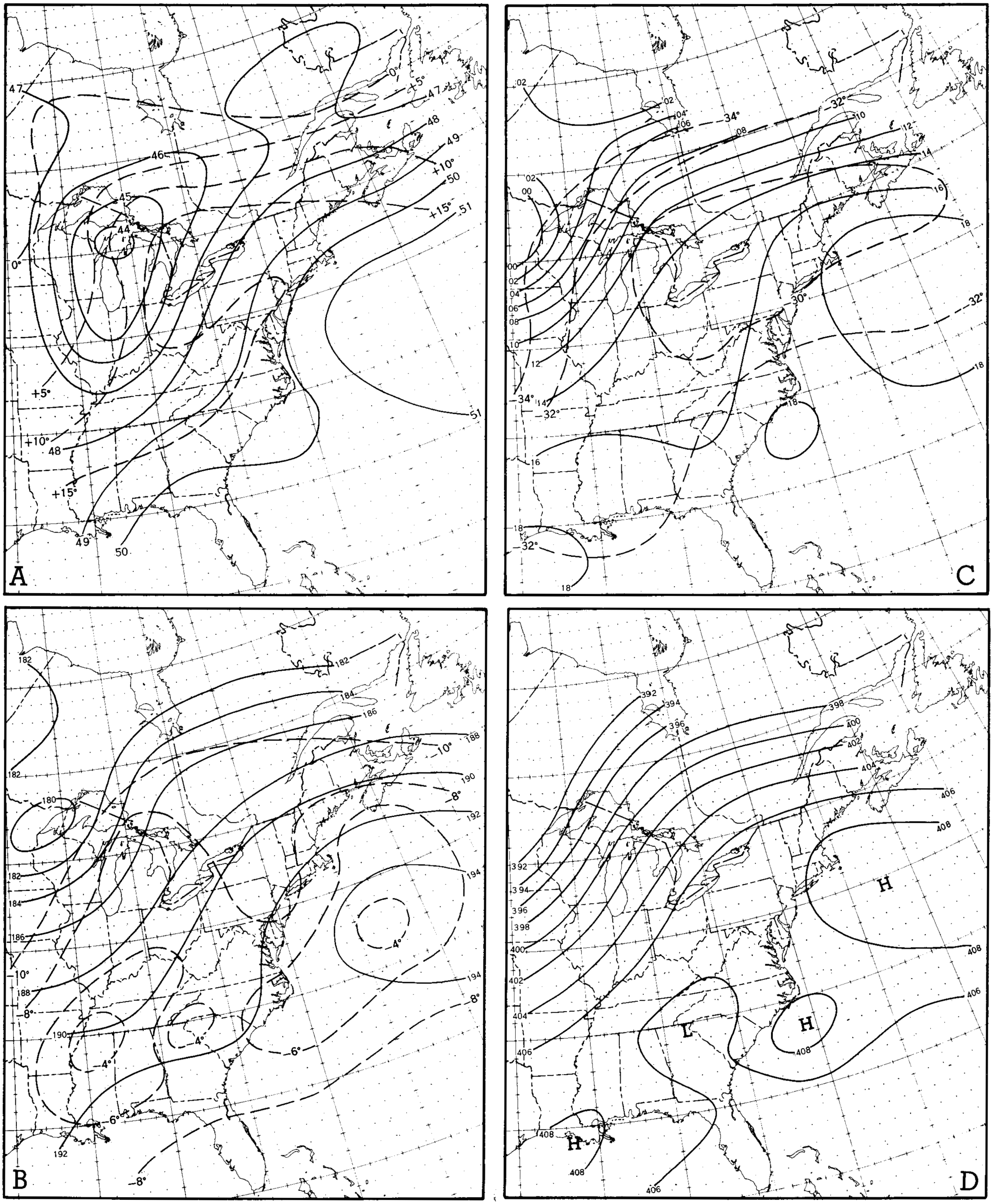


Figure 11.—Upper air charts for September 14, 1200 gmt. Solid lines are contours labeled in 100's of feet. Dashed lines are isotherms labeled in degrees Celsius. (a) 850 mb.; (b) 500 mb.; (c) 300 mb.; (d) 200 mb.

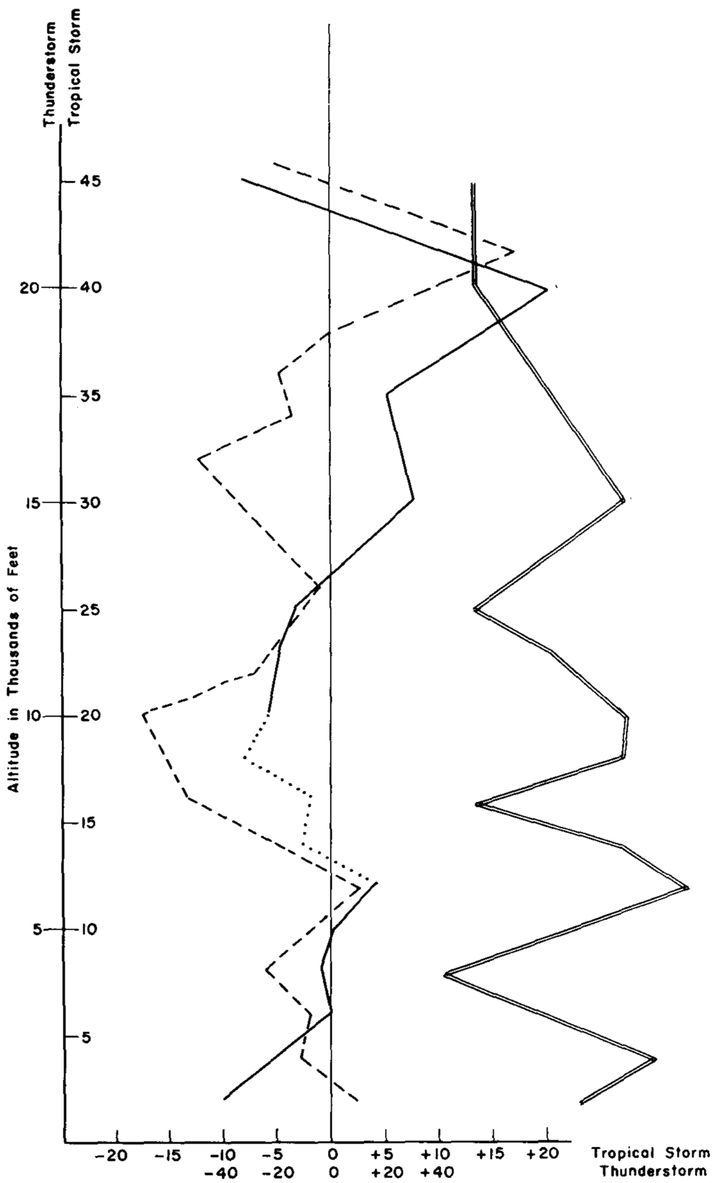


FIGURE 12.—Comparison of divergence in the tropical storm and in four Ohio thunderstorms. Ordinate is altitude, with the thunderstorm scale to left of line, tropical storm scale to right. Abcissa is divergence in percent change of area per hour. Solid line—tropical storm at 1200 GMT, September 14 (dots indicate interpolated data); dashed line—average of four Ohio thunderstorms, double line—tropical storm at 0000 GMT, September 15.

upper air charts (fig. 11), with a fairly well-defined trough at 850 and 500 mb., and an increasingly strong anticyclonic circulation at 300 and 200 mb. Using the Bellamy method [3], divergence was computed in the Greensboro-Hatteras-Charleston triangle from 2,000 to 45,000 ft. Unfortunately, some of the winds from Hatteras were missing, but a linear interpolation gave reasonable-looking results. The computations indicate convergence up to 25,000 ft., quite strong divergence between 30,000 and 40,000 ft., and convergence again at 45,000 ft.—all within the troposphere. This divergence pattern shows some interesting similarities to that found in thunderstorms. Figure 12 compares the computed divergence (the computation methods are identical) with that measured in Ohio thunderstorms in which heavy rain had not reached the ground (see [4], p. 33). In order to make the comparison the vertical scale was halved and the horizontal scale quadrupled for the thunderstorm. Since the comparison is based on one tropical storm computation and the average of four Ohio thunderstorms, it would be less than prudent to generalize.

On the 0000 GMT September 15 charts (fig. 13) a trough was still evident at 850 and 500 mb., but the higher-level anticyclone had disappeared and only a very weak ridge can be identified. The divergence was computed in the Norfolk-Washington-Idlewild triangle which, although rather elongated, was the only suitable triangle which included the storm center. The results indicated divergence at *all* levels from 2,000 ft. to the tropopause (fig. 12). This is rather surprising, and may be due to the assumption in the Bellamy method that the variation of the wind is linear, spatially, in the triangle. Deepening took place shortly after this, with the central pressure dropping 5 mb. in the 4 hr. from 0300 to 0700 GMT (fig. 5). This is not very much deepening, since the general pressure fall due to the approaching frontal trough amounted to about 3 mb. per 4 hr. This figure was computed using the trough movement and an estimate of the undisturbed pressure gradient. The total change in central pressure of the storm between latitudes 35° and 45° is about twice the winter "average" as computed by James [5].

A measure of the "intensity" or circulation of the Low was computed using the simple formula

$$I=(\tfrac{1}{4})(p_N+p_E+p_S+p_W)-p_0$$

where p_N, p_E, p_S, and p_W are sea level pressures 60 n.mi. north, east, south, and west of the center, and p_0 is the central pressure. A plot of this parameter (fig. 14) indicates that the most rapid intensification took place at about 0700 GMT when the storm was crossing the waters south of New England. It was this deepening and the storm's rapid movement adding to the strength of the winds, which caused the damage to New England and raised winds offshore to hurricane force.

In a study of the development which occurred when hurricane Hazel moved up the east coast, Petterssen [6] used a moving coordinate technique to show pressure falls due to development. The intensification took place in an extra-tropical storm, and it was shown that the center of maximum development was 250 to 400 mi. in advance of the center of the hurricane (see [6], fig. 17.3G). Similar development fields were computed for the present case, and these are shown in figure 15. The main development was evidently associated with the extratropical cyclone, but the tropical cyclone center did accelerate toward the secondary development center which appeared

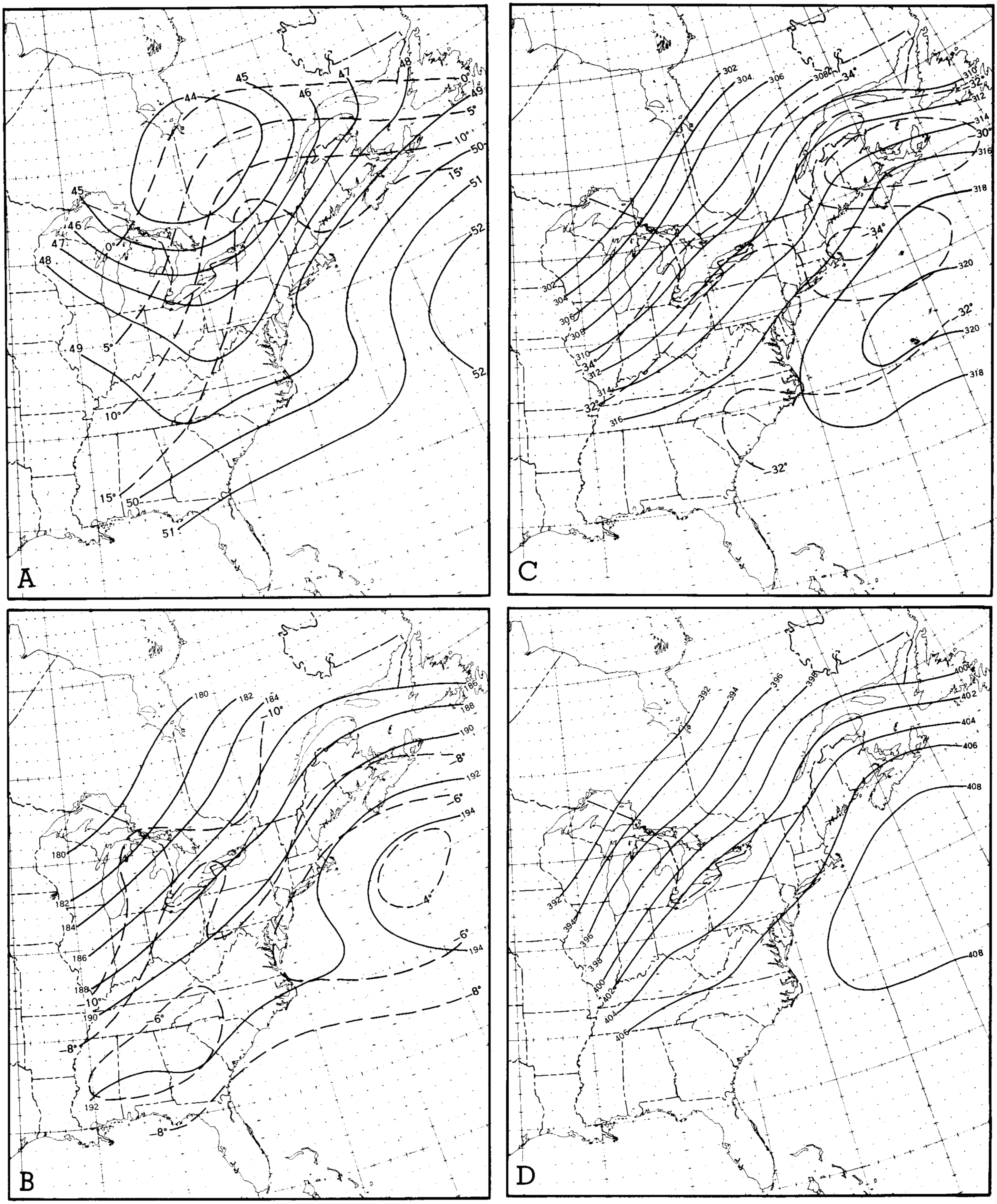


Figure 13.—Upper air charts for September 15, 0000 gmt. (See fig. 11 for explanation). (a) 850 mb.; (b) 500 mb.; (c) 300 mb.; (d) 200 mb.

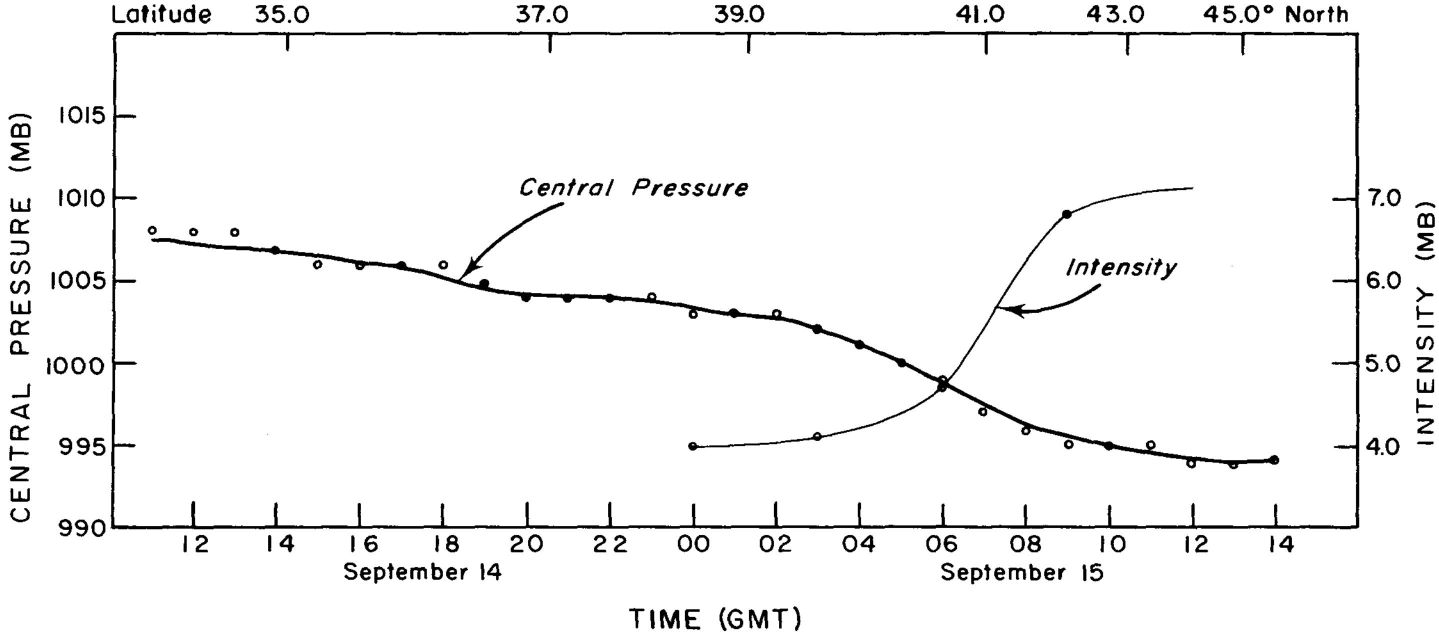


FIGURE 14.—Plot of central pressure and intensity with time.

during the period 1800 GMT September 14 to 0000 GMT, September 15 (fig. 15b). Even during the period 0600–1200 GMT, September 15 (fig. 15d), the storm was about 270 mi. from the development center in northern Maine. The development term, as determined by this method, remained nearly constant over the low center after about 2100 GMT, September 14 (fig. 15b). It seems reasonable that this resulted in the noted deepening and intensification.

7. SUMMARY

This tropical cyclone, while not an unusual occurrence along the east coast, differed from similar situations in three respects. First, no frontal system moved into the Low or developed in it; second, it intensified rather strongly as it moved northward; third, it accelerated continuously while it was identifiable over land. The unexpected increase in circulation was apparently due partly to general deepening in the area and partly to the unusual divergence pattern over the storm itself. The continued acceleration as it moved up the east coast presented a difficult forecast problem as far as timing was concerned. Considering that this Low passed within 30 mi. of perhaps 30 million people, it is remarkable and fortunate that only a few injuries and no deaths were attributable to it.

ACKNOWLEDGMENTS

The writer wishes to express thanks for special assistance from Messrs. A. E. Tancreto and R. E. Lynde. Information supplied by Captain John F. Pike, Captain Harry Siebert, and Mr. Robert Foley, all of the Woods Hole Oceanographic Institution, was most important in this study and sincere thanks are hereby given.

REFERENCES

1. Walter S. Spuhler, "Intensification of a Tropical Storm at Higher Latitude," *Monthly Weather Review*, vol. 85, No. 8, Aug. 1957, pp. 273–278.
2. Charles H. Pierce, "The Meteorological History of the New England Hurricane of September 21, 1938," *Monthly Weather Review*, vol. 67, No. 8, Aug. 1939, pp. 237–285.
3. John C. Bellamy, "Objective Calculations of Divergence, Vertical Velocity and Vorticity," *Bulletin of the American Meteorological Society*, vol. 30, No. 2, Feb. 1949, pp. 45–49.
4. U.S. Weather Bureau, *The Thunderstorm*, Washington, D.C., June 1949, 287 pp.
5. R. W. James, "The Latitude Dependence of Intensity in Cyclones and Anticyclones," *Journal of Meteorology*, vol. 9, No. 4, Aug. 1952, pp. 243–251.
6. Sverre Petterssen, *Weather Analysis and Forecasting*, 2d edition, vol. 1, McGraw-Hill Book Co., Inc., New York, 1956, 428 pp.

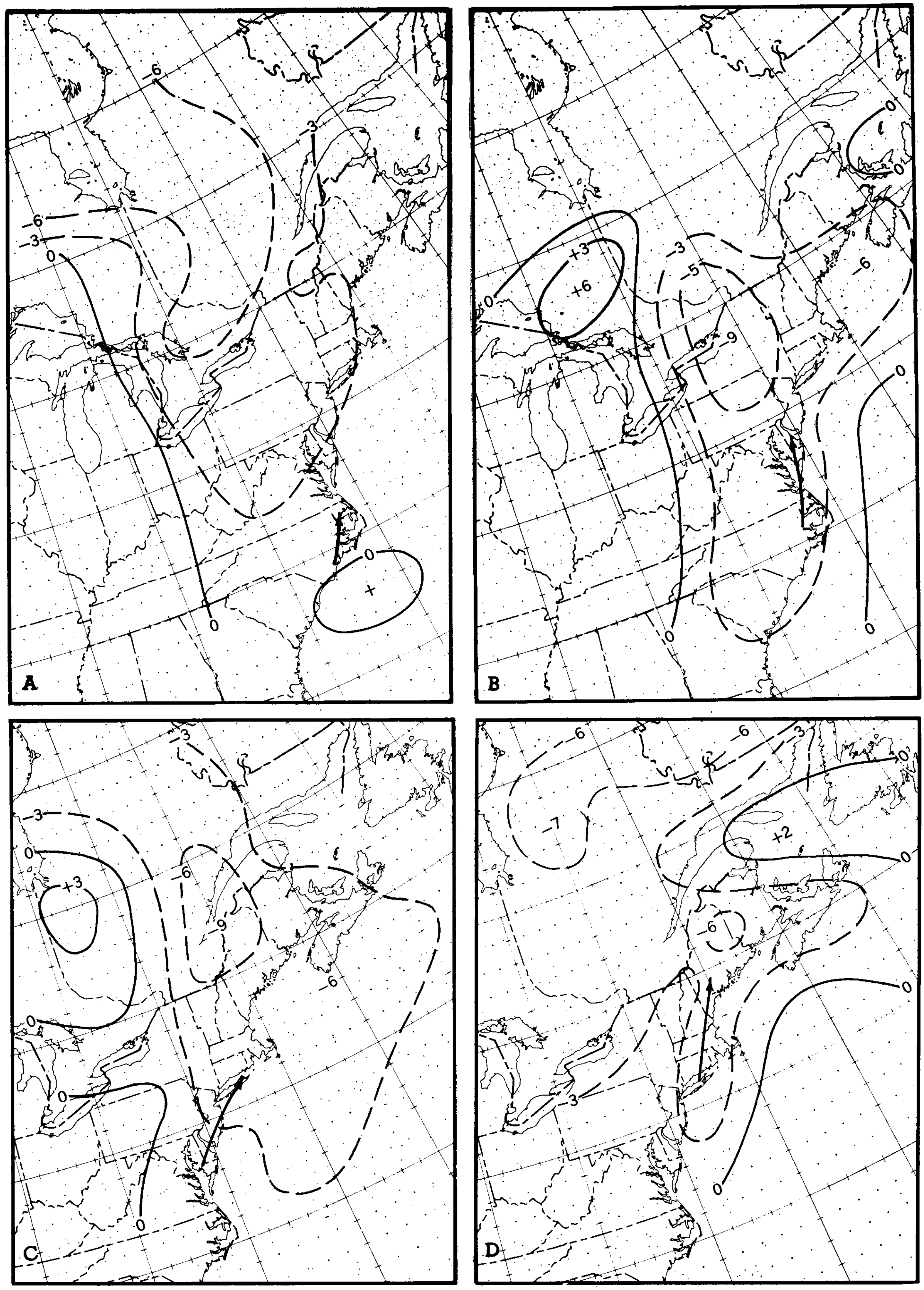


Figure 15.—Surface pressure changes due to development. Heavy arrow indicates movement of storm during the period indicated: (a) 1200 to 1800 GMT, September 14; (b) 1800 GMT, September 14 to 0000 GMT, September 15; (c) 0000 to 0600 GMT, September 15; (d) 0600 to 1200 GMT, September 15.