Reprinted from CHESAPEAKE SCIENCE
Vol. 1, No. 3-4, December 1960
Printed in U.S.A.

Chesapeake Bay Hurricane Surges

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ABSTRACT

Storm surges of hurricanes passing west of Chesapeake Bay are compared to surges generated by hurricanes passing east of the bay. The surges of each type storm are quite different, as the western storms cause highest surges in the northern portion of the bay and the eastern storms produce highest surges in the southern portion.

Introduction

Although the hurricane tides of Chesapeake Bay do not attain the proportions of those that occasionally occur in other areas, they are nevertheless important. Piers, wharves, buildings, fishing and pleasure boats have been damaged, the shoreline has undergone accelerated erosion and farmland has been flooded. The most destructive hurricane affecting Chesapeake Bay (August 1933) caused an estimated $17,000,000 damage in the area, according to the U. S. Army Corps of Engineers (1956).

This study was undertaken to show qualitatively the dependence of the storm tide upon the path of the hurricane. The storm tides of hurricanes passing near but east of the bay are compared to the tides of those passing near but west of the bay and it is found that the tides of each type storm fit a definite pattern, significantly different from each other.

The data examined are values of the storm surge, defined as the difference between the observed storm tide and the predicted astronomical tide. The height of the actual tide depends upon the phase of the predicted tide during storm surge conditions as well as the storm surge. A given storm surge will have more practical importance if it occurs at time of predicted high tide rather than at time of predicted low tide.

Generation and Modification of the Storm Surge

Among storm surge generation and modification factors (Harris, 1956; and Hubert and Clark, 1955), the following are considered significant in Chesapeake Bay:

1. Wind set-up, which is the result of wind stress on the surface of the water, the stress being proportional to the square of the wind speed and inversely proportional to the water depth.

2. The transport of water in the direction of wave motion by the short period wind waves, resulting as the water particles advance at a slightly higher speed at the top of the particle orbit.

3. The atmospheric pressure effect, often called the inverted barometer effect, which is the rise of the water surface in the area of minimum atmospheric pressure (approximately 13.6 inches of water per inch of mercury pressure drop).

4. The storm speed, which enters into dynamic amplification of the storm surge due to resonance between the natural frequency of the bay and the storm surge.

5. The variable depth of the water, resulting in modification of the surge as it progresses in the bay, similar in manner to the shoaling effect of bathymetric conditions on short period wind waves.

6. Convergence or divergence of the storm surge, a modification important at locations such as in estuaries of varying width.

The Data

The 35 hurricanes that came close enough to the bay from 1929 through 1958 to be suspected of producing storm surges were investigated. The storm surge features of several of these storms are shown in Figs. 1–5. The hydrographs show the difference between the actual storm tide as recorded by the Coast and Geodetic Survey recording tide gages and the predicted astronomical

tide, based on hourly values of both the observations and predictions. The seasonal anomalies in sea level have been removed from these data by the method described by Harris (1959). The dotted portions of several of the hydrographs indicate estimated data during periods of malfunctioning tide gages. The small triangles above and below the hydrographs for Baltimore and Hampton Roads respectively give the times of high or low predicted astronomical tide as taken from the Tide Tables (U. S. Coast and Geodetic Survey (1955)). Some of the hydrographs are supplemented with wind observations from nearby weather stations. The storm paths, 12 hour positions and storm stages were obtained from Cry, et al., (1959). The inserted barometric pressure charts show some of the synoptic features of the storms while they were in the bay area.

The maximum storm surges will occur only by coincidence at tide gage locations. However, the gage records are useful for comparing the surges of various storms.

Dependence of Storm Surge upon Hurricane Path

It is not surprising that hurricanes which pass on opposite sides of Chesapeake Bay would produce storm surges of different characteristics because of the resulting opposite wind directions over the bay. Hurricanes which passed west of the bay, east of longitude 80° W., but not crossing over it were classed as the western type (Figs. 1 and 2), whereas those that passed east of the Bay but west of the points 35° N., 73° W. and 40° N., 68° W., proceeding in a north or northeast direction were of the eastern type (Figs. 3 and 4).

The storm surges of the western type storms progress from the mouth to the head of the bay with the magnitude of the surge generally increasing northward. It should be noted that the astronomical tide range decreases from the mouth to head of the bay. This is in contrast to the situation when hurricanes pass just to the west of Narragansett Bay, where the storm surge heights in various parts of the bay are proportional to the mean tide range.

The storm surge heights of the western type storms are given in Table 1 along with the time lag for the surge to travel from Hampton Roads to Baltimore and the 12 hour northward movement of the storm while in the bay area. In each of these storms the highest surge occurred at Baltimore. A lag in the surge from Hampton Roads to Baltimore of about 11 to 21 hours occurs with a slight inverse relationship between this lag and the northward movement of the storm.

Two peaks in the storm surge at Baltimore and Annapolis accompany about half of the western type storms. The first occurs near the time of storm passage and the second from 4 to 7 hours later. Sufficient data are not available to confidently determine the reason for the two peaks.

As the storms of the eastern type approach northerly wind components build up the surge in the southern part of the bay. During most of these storms the surge level drops in the northern part of the bay because of the northerly winds, with the most pronounced drop at Baltimore and almost as much drop at Annapolis. Table 2 is a tabulation of the eastern type storm surges and shows the maximum surge to occur in the Norfolk area, quite opposite to the maximum surge location of the western type storms. The initial drop at the northern stations is shown by the negative values in the table.

Other Storms

Hurricane Connie of 1955 (Fig. 5) is somewhat between the two types discussed above, as its path approximately coincided with the axis of the Chesapeake Bay. The resulting surge at Baltimore of 5.4 feet was surpassed only by the 7.0 surge of the August 1933 storm. A rise in the surge curve, which appears to have been caused by the increase in the onshore wind component over the ocean near the mouth of the bay and over the bay itself about 12 hours before storm passage, preceded the main surge at all stations and was most prominent at the southern stations.

The inverted barometer effect was more important for Connie than for the other storms because the storm center passed near the axis of the bay. The recorded mini-

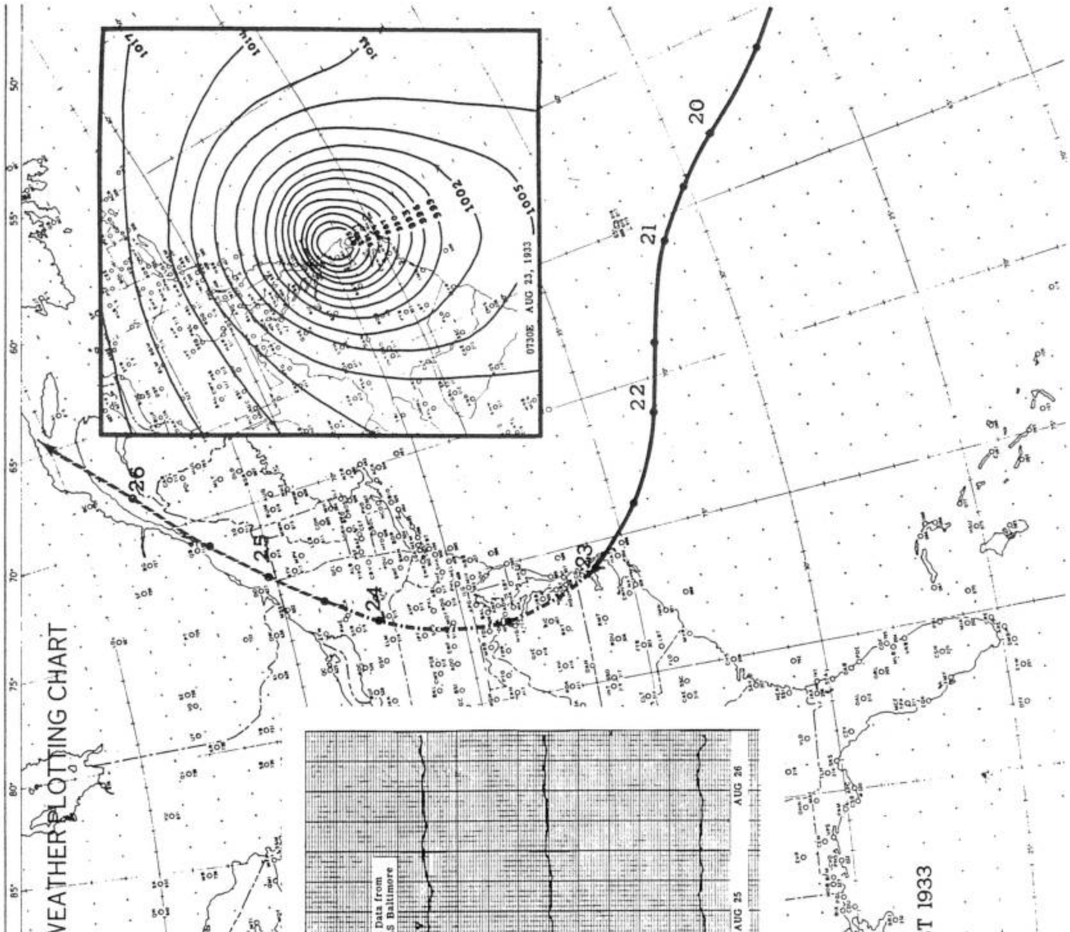

FIG. 1.—Storm surge of August 23–24, 1933. Hydrographs show differences in feet between observed tide and predicted astronomical tide. Insert shows the surface pressure pattern with isobars labeled in millibars.

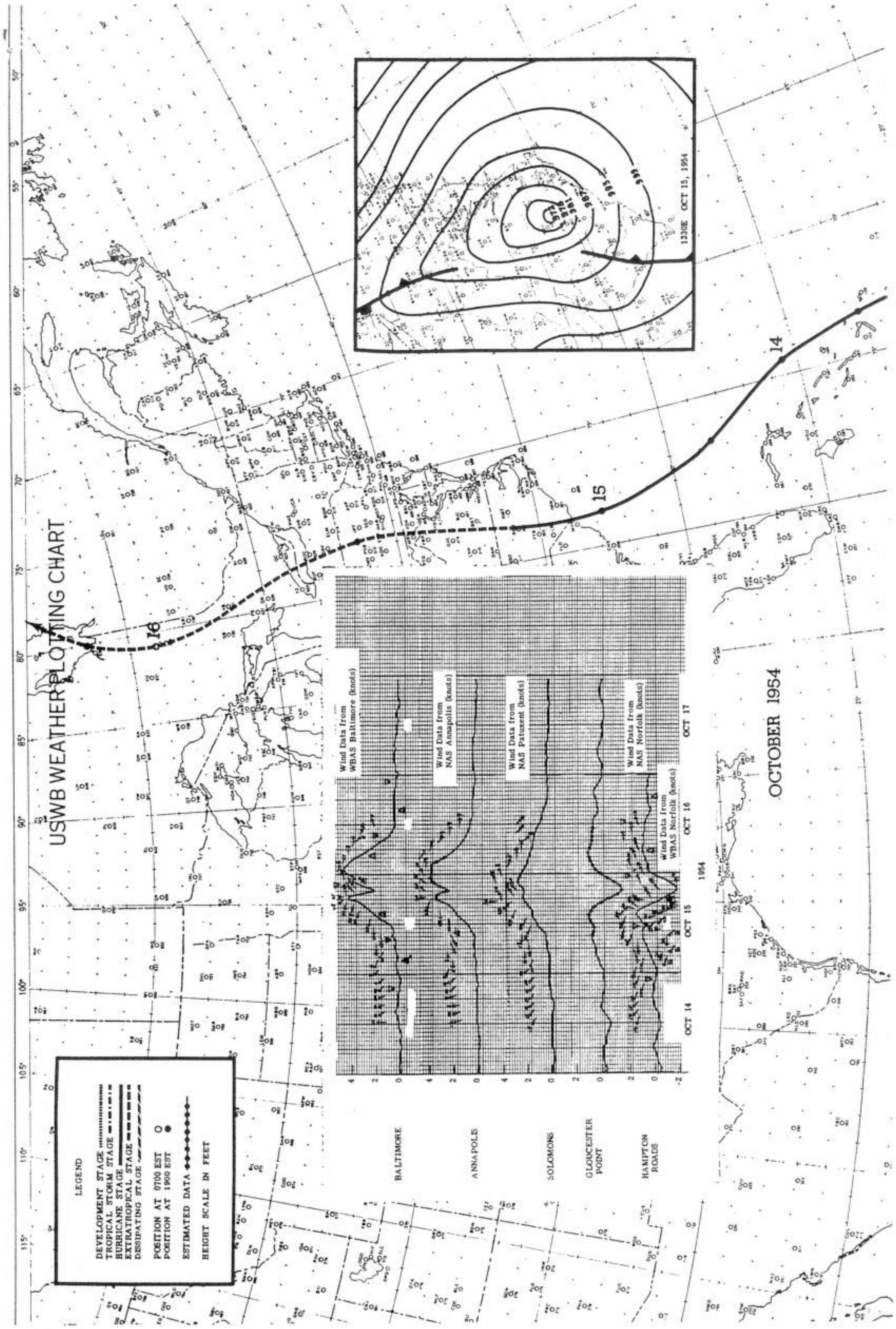

FIG. 2.—Storm surge of October 15–16, 1954. Hydrographs show differences in feet between observed tide and predicted astronomical tide. Insert shows the surface pressure pattern with isobars labeled in millibars.

TABLE 1.—Storm surge data of western type storms in the Chesapeake Bay region. Heights of the peak surge are expressed in feet and corrected for the seasonal anomalies in sea level.

Date	Baltimore	Annapolis	Cambridge	Solomons	Gloucester Point	Hampton Roads	Time Lag Norfolk to Baltimore (Hours)	Twelve Hour Northward Storm Movement (Nautical Miles)
Oct. 2, 1929	3.9	3.6	—	—	—	2.4	18	190
Aug. 23, 1933	7.0	5.5	—	—	—	6.1	18	170
June 19, 1934	—	—	—	—	—	0.8	—	80
Sep. 18, 1945	2.7	2.4	2.3	2.1	—	2.4	17	210
Aug. 29, 1949	1.7	1.4	1.5	0.8	—	−0.2	—	280
Sep. 1, 1952	3.4	2.9	—	1.6	0.5	0.4	13	130
Oct. 15, 1954	4.6	3.9	—	2.8	1.1	1.5	11	510
Aug. 18, 1955	2.9	2.4	—	1.7	1.7	1.0	21	130

TABLE 2.—Storm surge data of eastern type storms in the Chesapeake Bay region. Heights of the peak surge are expressed in feet and corrected for the seasonal anomalies in sea level. The negative values are the initial drops in storm surge at the northern stations.

Date	Baltimore	Annapolis	Cambridge	Solomons	Gloucester Point	Hampton Roads	Portsmouth
Sep. 21, 1938	−3.2, 0.2	−2.2, 0.1	—	−1.4	—	—	1.8
Sep. 1, 1940	0.2	0.2	—	0.2	—	—	0.3
Aug. 20, 1950	0.7	0.7	0.5	0.6	—	0.8	—
Sep. 27, 1956	1.1	1.9	—	2.1	—	3.7	—
Aug. 28, 1958	−1.2, 0.6	—	—	0.6	—	1.1	—
Sep. 14, 1944	−2.1, 0.9	−1.6, 0.7	−0.9, 0.8	−0.6, 0.6	—	3.7	—
Aug. 14, 1953	−2.6, 1.3	−2.4, 1.1	—	−1.5, 1.1	3.1	3.7	—
Aug. 31, 1954	−0.6, 0.7	0.8	—	0.8	1.6	2.6	—
June 26, 1945	−1.1, 0.6	−0.8, 0.8	−0.6, 0.9	0.5	—	2.6	—
Sep. 8, 1934	—	—	—	—	—	0.8	—
Sep. 18, 1936	−5.7, 1.3	−4.2, 1.2	—	—	—	4.9	—
Sep. 16, 1933	0.9	1.0	—	—	—	5.1	—
Oct. 24, 1938	0.7	0.7	—	0.6	—	—	0.7
Sep. 11, 1954	−1.4, 0.5	−1.0, 0.4	—	−0.4, 0.5	2.2	2.9	—

mum pressure at both Baltimore and Patuxent (Naval Air Station) was 975 mb or 35 mb below the average Baltimore pressure for that month which amounts to a barometric effect of 1.2 feet.

Another effect important for Connie was the amplification due to resonance between the Bay and the storm surge. From Proudman (1953), where C is the storm speed

$$\text{Amplification} = \frac{1}{1 - \frac{C^2}{V^2}}$$

(about 13 knots for Connie) and V is the free wave velocity. Estimating the free wave velocity from the speed of the astronomical tide in Chesapeake Bay, one obtains a value of 17 knots. The value agrees with the average speed of the main storm surge between Hampton Roads and Baltimore. These values give an amplification of 2.4.

Several storms did not fall into either of the two categories and did not produce significant surges in Chesapeake Bay.

Conclusions

Many of the hurricanes affecting Chesapeake Bay can be classified as being one of two distinct types, depending on whether the storm passes to the east or west of the bay. The resulting storm surges of each type are quite similar to each other but distinctively different from those of the other type, with those passing west of the bay producing the highest surges in the northern bay and those passing east of the bay producing maximum surges in the southern bay.

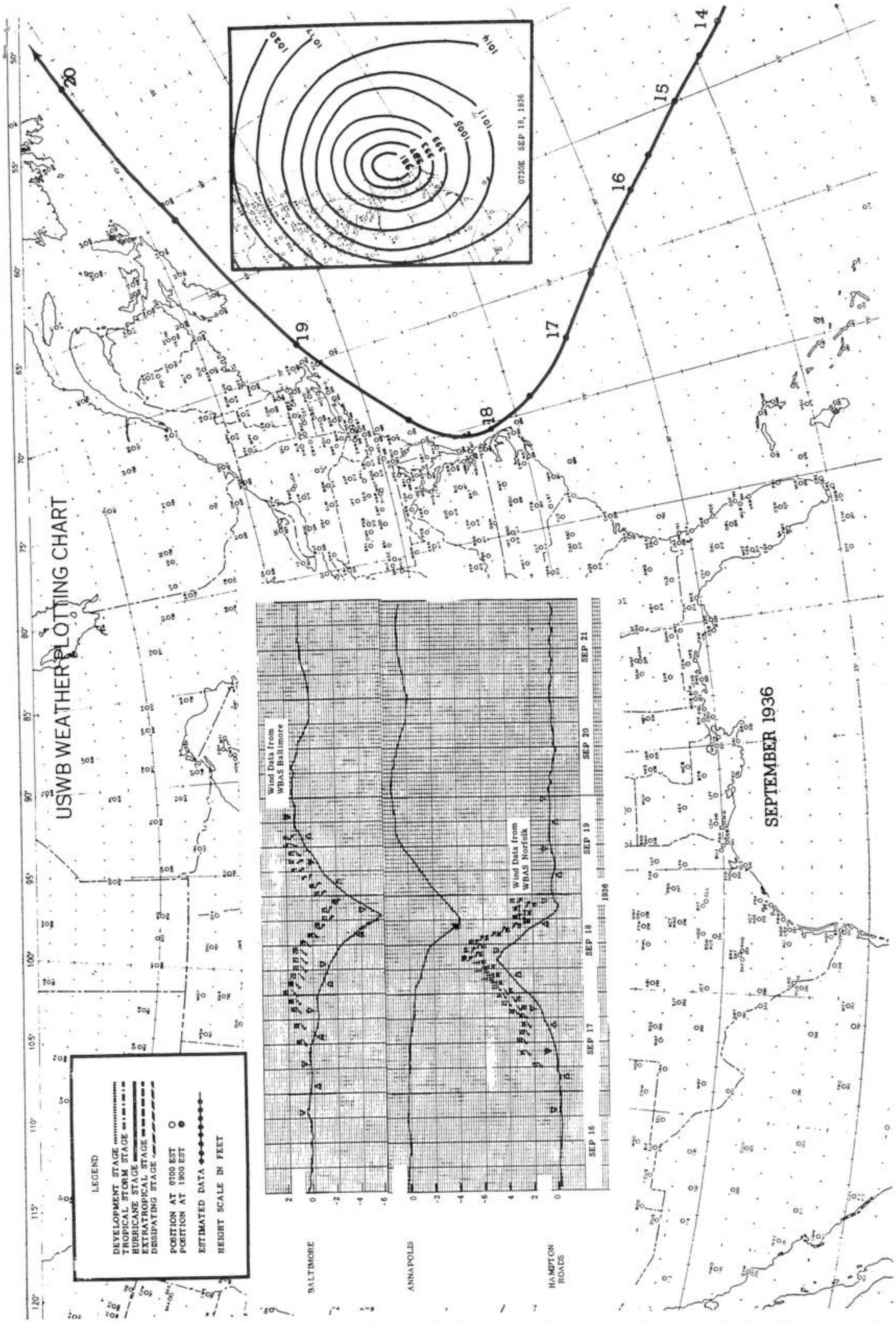

FIG. 3.—Storm surge of September 18–20, 1936. Hydrographs show differences in feet between observed tide and predicted astronomical tide. Insert shows the surface pressure pattern with isobars labeled in millibars.

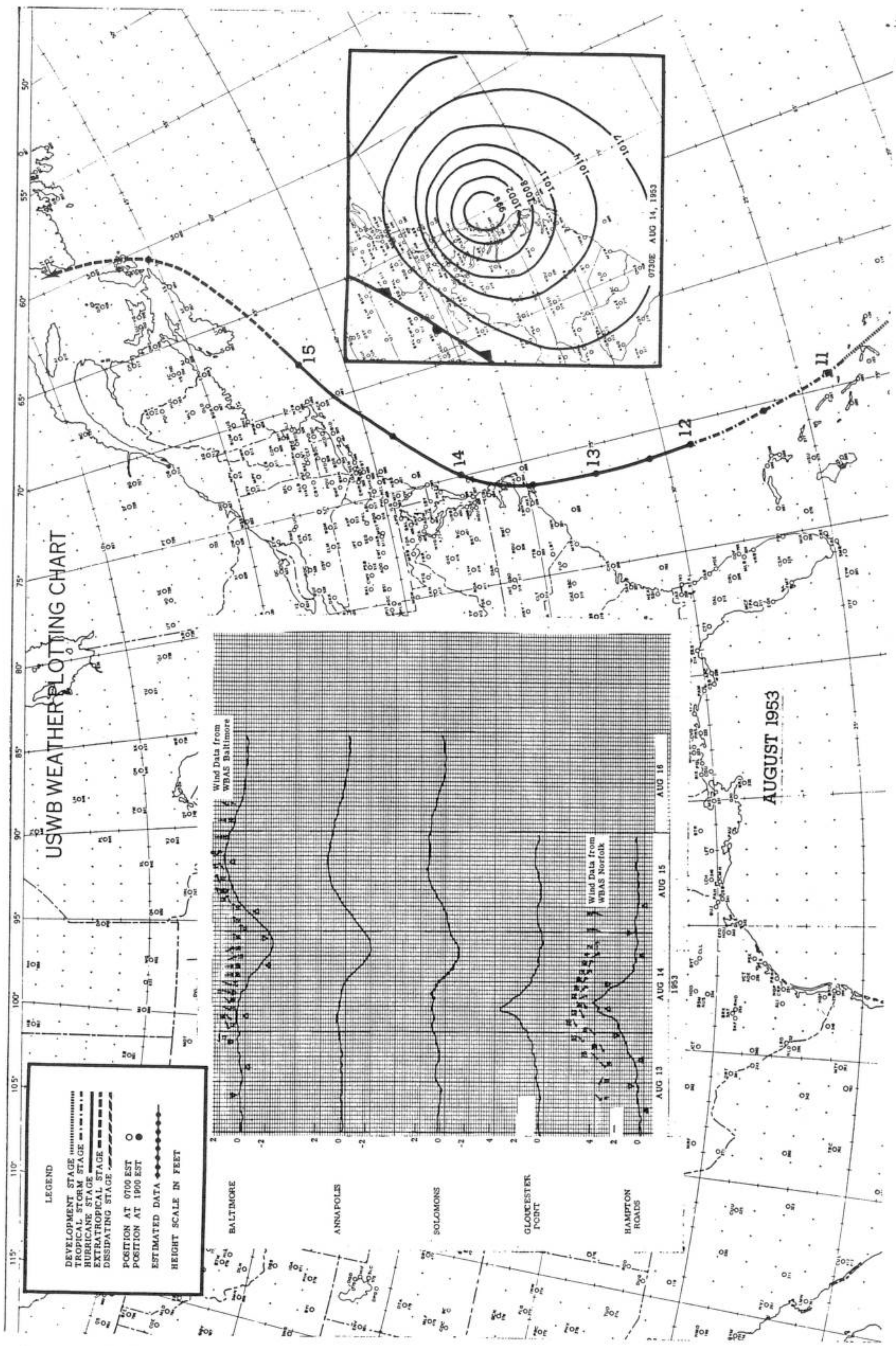

FIG. 4.—Storm surge of August 14–15, 1953. Hydrographs show differences in feet between observed tide and predicted astronomical tide. Insert shows the surface pressure pattern with isobars labeled in millibars.

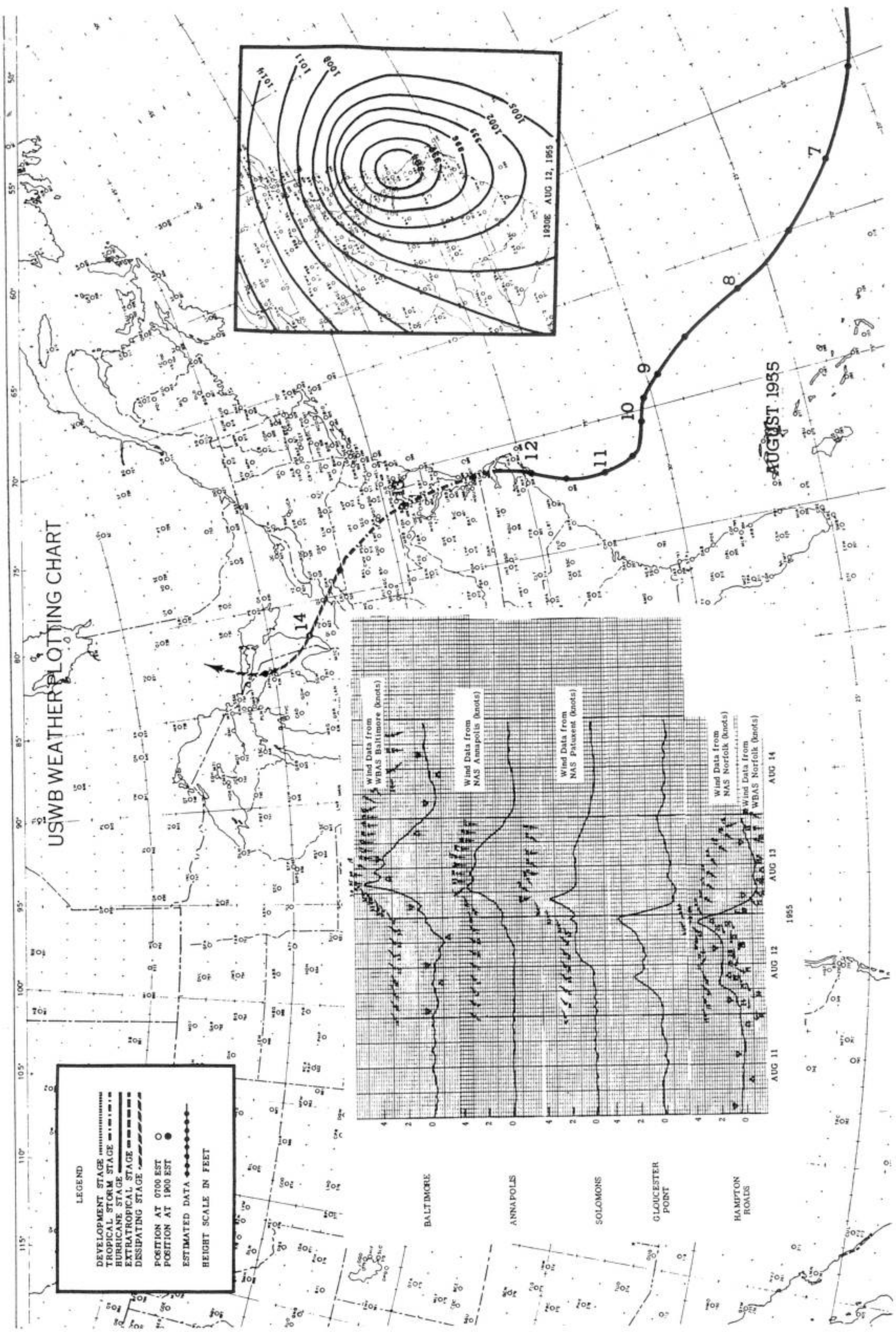

Fig. 5.—Storm surge of August 12–13, 1955. Hydrographs show differences in feet between observed tide and predicted astronomical tide. Insert shows the surface pressure pattern with isobars labeled in millibars.

Acknowledgment:—I wish to express my appreciation to the Coast and Geodetic Survey for the tide data and to Mr. D. L. Harris of the Weather Bureau Storm Surge Research Unit for suggestions.

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