DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, Secretary

WEATHER BUREAU
F. W. REICHELDERFER, Chief

MONTHLY WEATHER REVIEW

JAMES E. CASKEY, JR., Editor

Volume 86
Number 6

JUNE 1958

Closed August 15, 1958
Issued September 15, 1958

A METHOD FOR FORECASTING THE MAXIMUM SURGE AT BOSTON DUE TO EXTRATROPICAL STORMS

ANTHONY E. TANCRETO

Weather Bureau Office, Boston, Mass.

[Manuscript received October 18, 1957; revised April 28, 1958]

ABSTRACT

An empirical relationship between computed significant wave height and height of extratropical storm surge at Boston is found. The relationship is expressed as a linear regression equation for forecasting surge height from significant wave height as computed from the Bretschneider graph.

1. INTRODUCTION

Abnormal elevations of the sea surface along coastal regions may accompany both tropical and extratropical storms. The rise of the sea surface induced by meteorological factors is frequently referred to as the storm surge, while the normal rise and fall is called the predicted or normal tide. The predicted tide is based both on astronomical theory and on a series of observations which include a climatic factor. No satisfactory method of completely separating these effects is now available. However, the contribution of the climatic term is usually small and has no practical importance in the forecast problem [1]. For this type of investigation the term storm surge is defined as the departure of the observed tide from the predicted tide.

The most devastating surges along the coast of the United States have been generated by hurricanes. Severe extratropical storms have, however, induced surges which are comparable in magnitude with those accompanying some of the less intense hurricanes. The available tide data indicate that many sections of coastal United States are particularly vulnerable to storm surges associated with extratropical storms, and that maximum surge heights along the east coast of New England have been a direct result of these storms [2]. The intense storm of November 29–30, 1945, produced a surge of 5.3 feet at Boston and caused damage estimated at about $1,000,000. Had this storm struck at spring tide, rather than at neap tide, coastal damage due to inundation and heavy seas would have far exceeded this figure.[1]

The purpose of this paper is to present a technique which would adequately predict the height of the surges accompanying extratropical storms. As shown by Harris [3] and Reid and Wilson [4], the magnitude and lateral extent of the storm surge associated with tropical storms along the open coast are dependent mainly upon the wind field, pressure reduction, size and speed of the storm, configuration of the coastline, and bottom topography near the coast. Local effects, such as convergence and divergence in bays, seiching, and local set-up, will further affect the storm surge. Since each of the above meteorological parameters may individually induce an abnormality in the elevation of the sea surface, and since the other factors tend only to modify this abnormality, one may logically conclude that the extratropical storm surge also will be dependent upon all the factors listed above, although, in all probability, the order of their importance may not be

[1] Form 1014, U. S. Weather Bureau, Boston, Mass., Nov. 29, 1945.

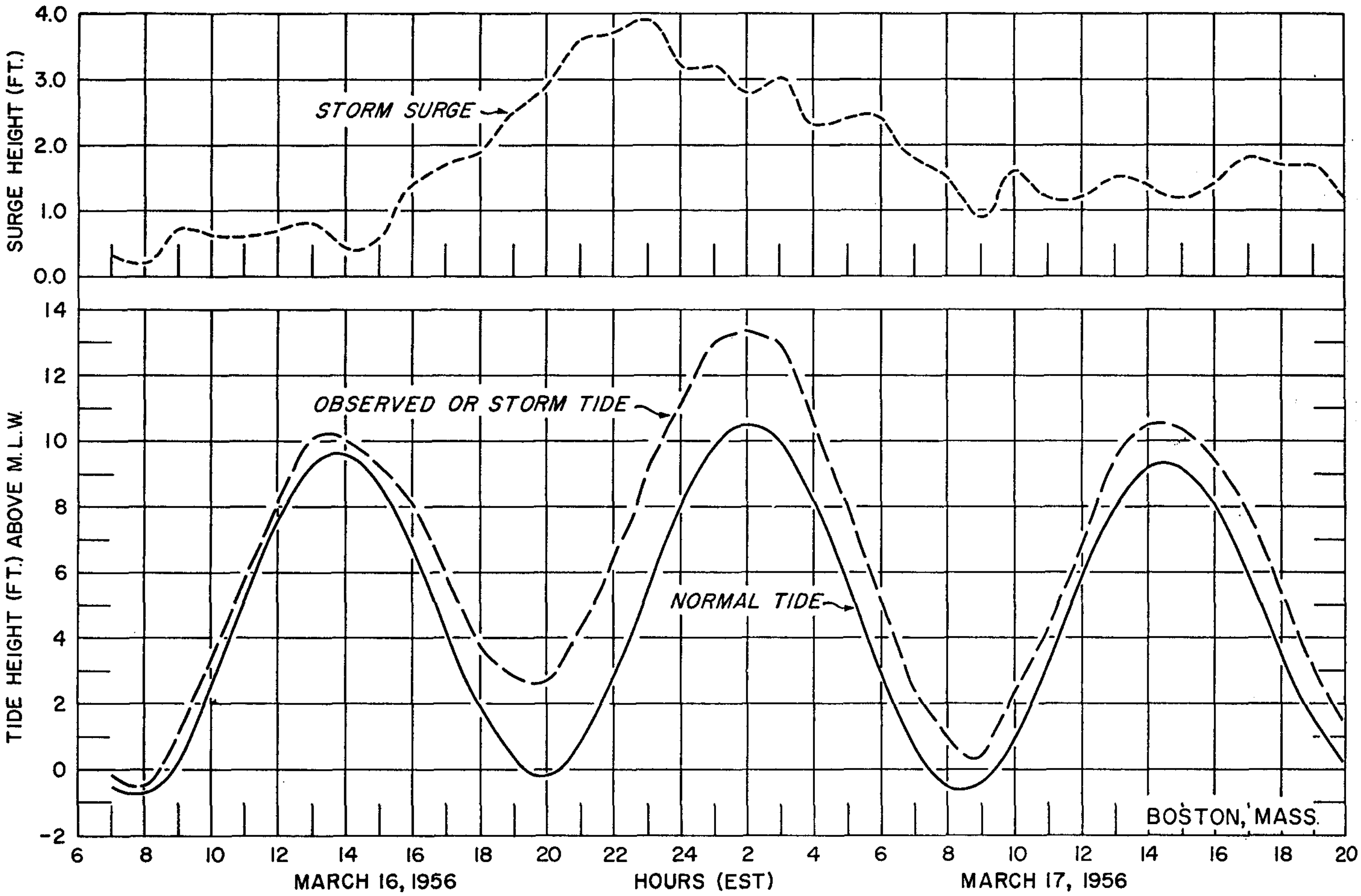

FIGURE 1.—The lower curves illustrate the periodicity and range of the normal and storm tide for the storm of March 16–17, 1956. The upper curve represents the resultant storm surge on an expanded vertical scale.

the same. To eliminate the variation in local effects, coastal configuration, and bottom topography, the study was restricted to one location.

Figure 1 illustrates an actual case at Boston of the periodicity and magnitude of the predicted and actual tides, and the resultant storm surge. Note that the range in the predicted tide at Boston on this date was about 10.5 feet (the mean range is 9.5 feet), more than twice that of the storm surge. The large tidal range further complicates the flood prediction problem by demanding very accurate timing of the storm surge. Had the storm surge occurred a few hours earlier, coastal flooding would have been negligible.

2. DATA

Research on the problem of storm surges is hampered by the lack of quantitative data in the proper form. Only the departures of the actual tide from the normal tide at times of high and low water are readily obtainable from tidal records of the U. S. Coast and Geodetic Survey. Where the mean tidal range is large, these data seldom indicate the maximum surge heights. To obtain the required data, the hourly values of the normal tide must be computed for each day in which a storm surge may have occurred. This computation is slow and tedious without the aid of a tide prediction machine. Hourly predictions of the tide, as well as the hourly observed tide heights, were obtained from the U. S. Coast and Geodetic Survey for storm periods in 1953, 1954, 1955, and for eight additional severe storms of other years, a total of 45 cases. These data were used in the study, along with the 6-hourly surface weather maps on file at the U. S. Weather Bureau, East Boston, Mass.

3. SYNOPTIC INVESTIGATION

The sea level weather maps associated with storm surges in excess of 2 feet were examined for possible stratification by weather types, and for characteristic features. No marked separation by types was possible. In most cases, 12 hours prior to the occurrence of the maximum surge at Boston, a storm was centered near or off the middle Atlantic coast, and a strong east-west or southeast-northwest ridge was located not too far north of New England. For example, see figure 2.

The charts did clearly show in all cases strong winds with an easterly component along and off the southern New England coast. In addition, the fetch (the stretch

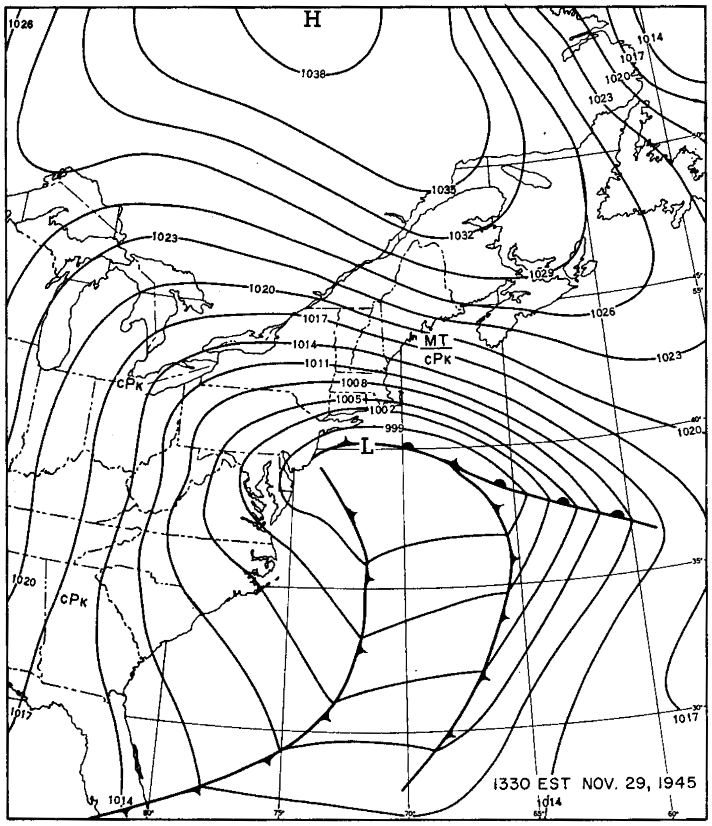

FIGURE 2.—Sectional sea level map, 1330 EST, November 29, 1945.

of water over which a wind of nearly constant direction is blowing) off the Massachusetts coast was relatively large. Since the total energy imparted by a given wind over a given fetch may be limited by the interval of time the wind is blowing, the duration time must also be considered as a factor affecting the height of the storm surge. Thus it appears that the extratropical surge may be related to certain synoptic features, namely: wind force, wind duration, and fetch.

Sverdrup and Munk [5], in studying the transfer of energy from wind to wave, derived equations which relate wave height to wind velocity, wind duration, and fetch. Then, with the aid of empirical data, they developed graphs [6 and 7] for forecasting the height of significant wind waves and swell. If one considers that the significant wave heights [2] at the end of the fetch are indicative of the energy imparted to the water over the fetch, and that they are, further, an indication or index of the intensity of the storm for that area, it seems reasonable to suspect there should be some relationship between the height of the waves and the magnitude of the storm surge.

4. RELATING SIGNIFICANT WAVE HEIGHT TO STORM SURGE HEIGHT

The significant wave heights were computed by 6-hourly periods, using the so-called Bretschneider-Revised

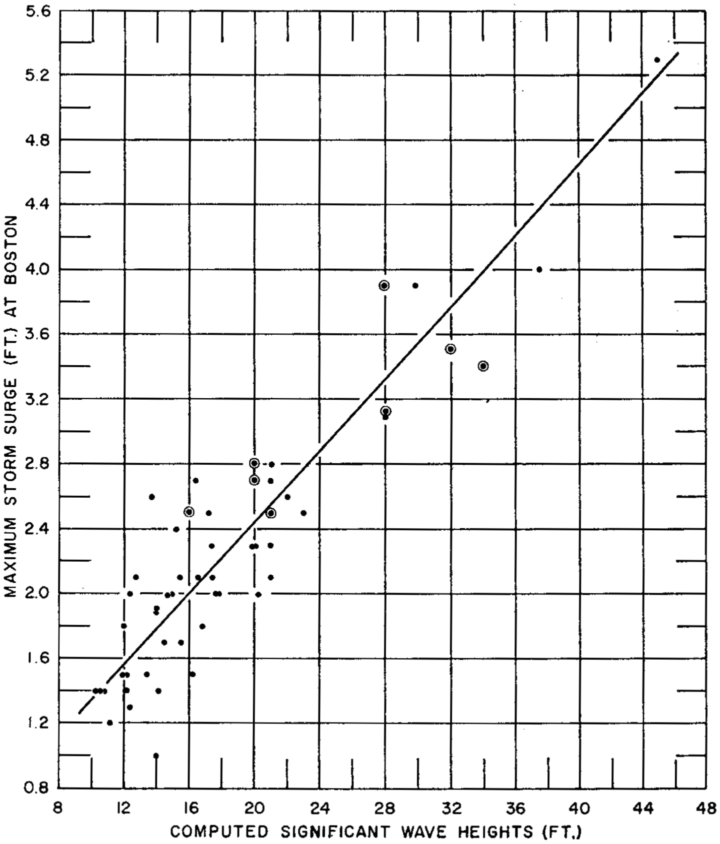

FIGURE 3.—The maximum storm surge at Boston as a function of the computed offshore wave heights. The dependent data are plotted as dots and the independent as encircled dots.

Sverdrup-Munk Method [8]. For the sake of objectivity these values were not modified, although it is generally acknowledged that the method tends to overforecast wave heights for the higher wind values.

The relationship between the height of the storm surge and the computed wave heights offshore at the time of maximum surge at Boston is shown in figure 3. Considering only those cases represented by the dots, the regression equation obtained by the method of least squares is

$$S_h = .24 + .11\ H,$$

where S_h is the height of the surge and H is the significant wave height, both measured in feet. The correlation coefficient is 0.88.

It is apparent from this figure that there are few data to support the curve above the 3-foot level. Fortunately, immediately prior to the completion of this paper, eight additional cases developed. These are the encircled points in figure 3. It is clear that these cases lend support to the derived relationship. Of particular significance is the confirmation of the curve in the region of sparse data.

In an attempt to improve the prediction equation, the data were stratified into two classes determined by the predominant wind flow over the fetch, namely, east and northeast. This stratification did not significantly im-

[2] The significant wave height is defined as the average of the heights of the one-third highest waves observed at a given time.

prove the predictions. It did reveal that eight of the nine storm surge cases in excess of 3 feet occurred with an easterly flow. This is not surprising, since the fetch from other directions is limited by land.

A test was also made with the 1954 and 1955 data to estimate the barometric effect, using the formula suggested by Redfield and Miller [9]. No improvement in the scattering was evident. This does not necessarily imply that the barometric effect does not play a part in the development of extratropical storm surges, but does suggest that, within the range of the data, its contribution is small and cannot be detected.

5. CONCLUSIONS

The results of this investigation indicate that the wave heights computed from the Bretschneider graph give a reasonable estimate of the storm surge at Boston. Similar relationships can be readily developed for other coastal points where storm surge data are available. However, at some localities with a different exposure to the sea, it may be necessary first to stratify the data according to wind direction.

It should be pointed out that, in actual practice, the effectiveness of this method will depend largely upon the accuracy of the prognosis of the surface circulation patterns from which the significant wave heights are computed. On several occasions during the winter of 1957–58, this technique was applied on an operational basis. When the surface prognostic chart was reasonably accurate, the predictions made from figure 3 were very satisfactory.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Mr. Samuel Penn for his helpful suggestions.

REFERENCES

1. U. S. Weather Bureau, "Survey of Meteorological Factors Pertinent to Reduction of Loss of Life and Property in Hurricane Situations," *National Hurricane Research Project Report* No. 5, Washington, D. C., March 1957, 87 pp.
2. D. L. Harris and C. V. Lindsay, "An Index of Tide Gages and Tide Gage Records for the Atlantic and Gulf Coasts of the United States," *National Hurricane Research Project Report* No. 7, U. S. Weather Bureau, Washington, D. C., May 1957, 104 pp.
3. D. L. Harris, "Some Problems Involved in the Study of Storm Surges," *National Hurricane Research Project Report* No. 4, U. S. Weather Bureau, Washington, D. C., December 1956, 30 pp.
4. R. O. Reid and B. W. Wilson, "Compendium of Results of Storm Tide and Wave Analysis for Full Hurricane Conditions at Freeport, Texas," Texas A. and M. Research Foundation, *A. and M. Project 91*, 1954.
5. H. U. Sverdrup and W. H. Munk, "Wind, Sea, and Swell: Theory of Relations for Forecasting," Hydrographic Office, U. S. Navy, *H. O. Publication* No. 601, 1947, 44 pp.
6. Hydrographic Office, U. S. Navy, "Wind Waves and Swell Principles in Forecasting," *H. O. Misc.* 11,275, 1944.
7. Hydrographic Office, U. S. Navy, "Techniques for Forecasting Wind Waves and Swell," *H. O. Publication* No. 604, 1951, 37 pp.
8. C. L. Bretschneider, "Revised Wave Forecasting Curves and Procedure," *U. S. Navy Technical Report* No. 155-47, University of California, 1951, 28 pp.
9. A. C. Redfield and A. R. Miller, "Memorandum on Water Levels Accompanying Atlantic Coast Hurricanes," Woods Hole Oceanographic Institution, Reference No. 55-28, June 1955, 14 pp.