Marine

EXPERIMENTAL AUTOMATED WAVE FORECASTS FOR THE CHESAPEAKE BAY AND LOWER POTOMAC RIVER

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1. INTRODUCTION

Marine forecasts for the Chesapeake Bay and Lower Potomac River are prepared by the National Weather Service Forecast Office in Washington, D.C. These forecasts include information on wind speed and direction, wind gusts, significant weather, visibility, and waves. The wave conditions are very important to recreational boaters, both sailing and power boat enthusiasts, and to commercial fishermen. Wave conditions are also of some importance to large commercial ships on the bay. The bay is divided into four areas for the preparation of marine forecasts -- north of Baltimore Harbor, Baltimore to Patuxent, Patuxent to Windmill Point, and south of Windmill Point (See Figure 1).

Wave calculations were made for hypothetical wind conditions over the bay at points in the four forecast areas (2). Wind speeds ranged from 5 to 70 knots. A wave forecast method, described in the Shore Protection Manual of the U.S. Army Coastal Engineering Research Center (3) was used in the calculations. Subjective evaluation of the wave calculations led to the next step -- making experimental wave forecasts in real time with wind forecasts from an operational model. This paper is a report on the wave forecast method, forecasts during a recent storm, and future plans.

2. WAVE FORECAST METHOD

The requirement for Chesapeake Bay wave forecasts is for significant wave heights. The Chesapeake Bay is rather shallow and has restricted fetches for many wind directions; it is therefore desirable to use a method which considers the water depth and fetch length. The method referred to above has been adapted for use with the Chesapeake Bay.

The method is based on the work of several researchers over many years. The combined theoretical-empirical procedure of Sverdrup and Munk (4) for deep water wave forecasting is the basis. The Sverdrup-Munk procedure was modified by Bretschneider (5,6) with additional observational data. This work resulted in the Sverdrup-Munk-Bretschneider (SMB) method for deep water wave forecasting in which significant wave height and period depend on wind speed, fetch length, and duration time. Because the depth is important for wave generation in shallow water, the depth should be considered in shallow water wave forecasting. Wave generation in shallow water results in smaller wave heights and shorter wave periods than wave generation in deep water. The method for shallow water wave forecasting considers that wave energy is lost due to bottom friction and percolation.

The forecast equation for wave height is:

$$H = \frac{U^2}{g}\, 0.283 \tanh\left[0.530\left(\frac{gd}{U^2}\right)^{0.75}\right] \tanh\left\{\frac{0.0125\left(\frac{gF}{U^2}\right)^{0.42}}{\tanh\left[0.530\left(\frac{gd}{U^2}\right)^{0.75}\right]}\right\}$$

where H is significant wave height in feet,
g is acceleration of gravity (32.2 ft/s^2),
d is depth of water in ft,
U is wind speed in ft/s, and
F is fetch length in ft.

Wave forecasts are made for the points in each of the four forecast areas of the Chesapeake Bay and for two points in the lower Potomac River. These points are located and identified in Figure 1. Fetch lengths were determined for 24 directions (15° intervals) at the six forecast points by direct measurement from each forecast point to land on navigational charts of the National Ocean Survey (NOS). Some of the measured fetch lengths were corrected for fetch width by the method of Saville (7) which considers that waves are generated not only in the exact direction of the wind but also at various angles to the wind. This results in waves at a point being the summation of wave components from the direction of the wind and other directions. Saville's correction factors for the wind were used, being effective over 90° of a fetch, with the wind effectiveness considered to vary as the cosine of the angle of the wind component. Maximum reduction of fetch length for the six forecast points was to about 40% of the measured fetch. Average depths were estimated for the fetches of the 24 directions for each of the six forecast points. These depths were obtained from navigation charts of the National Ocean Survey. The reduced fetch lengths, along with the measured fetch lengths and the estimated average depths are shown in Table 1. For brevity, this table contains only the values at 45° intervals.

After comparing the 1000-mb wind forecasts of the National Meteorological Center's (NMC's) Limited-area Fine Mesh (LFM) model to available marine observations and synoptic charts, it was decided to use those wind forecasts as input to the wave forecast program. The wind components at the four surrounding LFM grid points are interpolated to the wave forecast points.

For a wave forecast at a particular time, the wind during the previous 30 hours is considered. Therefore, the computer program for forecasting waves maintains a history of the wind at each forecast point. This wind history is updated following each operational forecast run of the program.

Duration time, in wave forecasting procedures, is generally considered to be the time that the wind has blown from about the same direction over the fetch. In manual wave forecasting, duration can be estimated by examination of successive surface weather charts for significant wind direction changes in the fetch area. In this automated wave forecast method, duration time is determined by checking the wind direction at 6-h intervals before the valid time of the wave forecast. This method of determining duration is similar to that of Hubert (8) and is used by the Techniques Development Laboratory for Great Lakes wave forecasting (9). A search is made for a shift of 45° or more from the wind at forecast valid time. With wind direction available at 6, 12, 18, 24, and 30 hours before forecast time, duration is estimated to be 3, 9, 15, 21, 27, or 33 hours.

The wind speed used is an effective wind speed, which is determined in a manner similar to that of Hubert (8) by weighting the winds over the duration time such that the winds closest to forecast time are weighted the heaviest. Each wind value is weighted in such a way that it counts as much in the wave generation process as all the previous winds that occurred in the duration time. The effective wind speeds for the various duration times are determined by the following equations:

(duration = 3 h)
$$EWS = 0.5S_0 + 0.5S_{-6}$$

(duration = 9 h)
$$EWS = 0.5S_0 + 0.25S_{-6} + 0.25S_{-12}$$

(duration = 15 h)
$$EWS = 0.5S_0 + 0.25S_{-6} + 0.125S_{-12} + 0.125S_{-18}$$

(duration = 21 h)
$$EWS = 0.5S_0 + 0.25S_{-6} + 0.125S_{-12} + 0.0625S_{-18} + 0.0625S_{-24}$$

(duration = 27 and 33 h)
$$EWS = 0.5S_0 + 0.25S_{-6} + 0.125S_{-12} + 0.0625S_{-18} + 0.03125S_{-24} + 0.03125S_{-30}$$

where EWS is the effective wind speed (kt) over the duration time and S is the wind speed at a particular time. The subscript of the wind speed is the time in hours of the wind before the valid time of the wave forecast. The effective wind speed equation for duration of 27 hours is also used for 33-h duration.

The wave height for a particular wind speed can be limited by either the fetch length or duration time unless both of these are great enough for fully developed wave conditions to exist. In manual wave forecast procedures, it is common to enter a wave forecast graph with the wind speed, duration time, and fetch length, and to use for the wave forecast the lowest height indicated for either the duration time or fetch length. In automating the method, we do not have access to the wave forecast graphs directly. Since we are limiting the wave forecasts to a small number of duration times (3, 9, 15, 21, 27, and 33 hours) and because the duration curves are straight lines when plotted on logarithmic graphs of wind speed, we have determined the following equations for effective fetch for each of the duration times:

(duration = 3 h)
$$\log(EF) = 0.195 + 0.719 \log(EWS),$$

(duration = 9 h)
$$\log(EF) = 0.794 + 0.725 \log(EWS),$$

(duration = 15 h)
$$\log(EF) = 0.985 + 0.800 \log(EWS),$$

(duration = 21 h)
$$\log(EF) = 1.196 + 0.758 \log(EWS),$$

(duration = 27)

$$\log(EF) = 1.317 + 0.769 \log(EWS),$$

(duration = 33 h)

$$\log(EF) = 1.432 + 0.758 \log(EWS),$$

where EF is effective fetch (n mi) and EWS is effective wind speed (kt).

The smaller of the two fetches, the actual fetch or the effective fetch, is used in the wave height forecast equation for F. In this manner, wave generation is being considered limited by either fetch length or duration time. This consideration of duration time and effective fetch is similar to that in the Great Lakes operational wave forecast program of the Techniques Development Laboratory (9).

3. THE FORECAST MESSAGE

The forecast message is transmitted to a computer terminal near the Washington Forecast Office. It is quite short and requires only about a half page of printout. A sample message is shown in Figure 2. The first few lines identify the product. The sixth line gives the time of the forecast. Next, the general location of each forecast point is given. These are followed by the wind history and forecasts for the six points. The wind history back 30 hours and the forecasts to 36 hours in advance are shown at 6-h intervals. The wave forecasts to 36 hours for the six points are expressed in feet. Missing wave height forecasts, because of insufficient wind history, are indicated by 99.0.

4. A SAMPLE FORECAST CASE

The wave forecasts valid at 1200 GMT on October 25, 1982 have been chosen for display because at that time there was an intense low pressure center located near Cape Hatteras. This, of course, caused strong winds over the Chesapeake Bay. The storm approached from the south, off the coasts of Florida and Georgia. The surface chart for 1200 GMT on October 25 is shown in Figure 3.

The available observations for 1200 GMT on October 25 are shown in Figure 4. Wind directions were north to northeast with wind speeds ranging from 15 to 45 knots. Wave observations were available for only two locations; these observations were 3 feet at Thomas Point and 6 feet at Cove Point.

The 12-, 24-, and 36-h wave forecasts for the six forecast points, valid at 1200 GMT on October 25, are shown in Figures 5, 6, and 7 respectively. The wind forecasts of the LFM model, which were used by the wave forecast program, are also shown in these figures. The wind forecasts for 12 and 24 hours ranged from about 25 to 35 knots from the north-northeast. These wind forecasts are in fair agreement with the wind observations. The wave forecasts decreased somewhat from the 12-h to the 24-h to the 36-h forecast. The highest wave forecast in these figures is 7.1 feet at the point in the southern portion of the bay (Point 4). This forecast shows the importance of a long fetch length in the wave forecast process. Unfortunately, it's not possible to adequately verify such forecasts. Perhaps at some future time wind and wave observations on the bay will be available from buoys. A series of 4 or 5 buoys on Chesapeake Bay would be very helpful for operational forecasting as well as verification.

5. FUTURE PLANS

If the automated wave forecast system proves to be helpful to marine forecasters for operational forecasting, perhaps a more convenient way of communicating the information to the Forecast Office, such as AFOS, can be arranged. Additional forecast points could be added to the method simply by providing fetch and depth information to the program.

The wave forecasts are, of course, very dependent on wind information and other types of wind forecasts could be used experimentally. Marine forecasters could provide their own subjective wind forecasts to the program through AFOS.

This method is quite similar to that used for the Great Lakes and it is conceivable that it can be used for other large bays.

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Figure 1. Locations of wave forecast points in the Chesapeake Bay and lower Potomac River, and the division points for forecast products.

MARINE GUIDANCE FOR WSFO WASHINGTON
ATTENTION - MARINE FOCAL POINT
CHESAPEAKE BAY AND LOWER POTOMAC
WIND (LFM) AND WAVE FORECASTS

FORECAST TIME
YEAR 83 MONTH 1 DAY 18 HOUR 12 GMT

POINT 1 IS NORTH OF BALTIMORE HARBOR
POINT 2 IS BALTIMORE TO PATUXENT
POINT 3 IS PATUXENT TO WINDMILL POINT
POINT 4 IS SOUTH OF WINDMILL POINT
POINT 5 IS LOWER POTOMAC NEAR POINT LOOKOUT
POINT 6 IS LOWER POTOMAC NEAR COLONIAL BEACH

LFM WIND FORECASTS - DIR AND SPEED IN KNOTS

	POINT 1		POINT 2		POINT 3		POINT 4		POINT 5		POINT 6	
-30 HR	281.	17.	284.	15.	286.	15.	289.	15.	286.	15.	286.	14.
-24 HR	285.	18.	280.	16.	281.	15.	280.	13.	279.	15.	275.	15.
-18 HR	278.	14.	280.	13.	284.	14.	288.	14.	283.	13.	281.	13.
-12 HR	322.	14.	323.	13.	317.	11.	308.	10.	320.	11.	325.	12.
-06 HR	302.	18.	308.	17.	314.	17.	320.	18.	314.	17.	313.	17.
+00 HR	329.	21.	331.	20.	337.	19.	342.	18.	337.	19.	335.	19.
+06 HR	307.	23.	308.	23.	310.	23.	313.	22.	310.	23.	309.	23.
+12 HR	309.	25.	308.	25.	308.	26.	307.	27.	308.	26.	308.	25.
+18 HR	309.	25.	310.	25.	313.	25.	315.	24.	312.	24.	311.	24.
+24 HR	309.	26.	310.	25.	310.	25.	311.	24.	310.	24.	311.	24.
+30 HR	308.	24.	308.	23.	308.	24.	309.	24.	308.	23.	308.	22.
+36 HR	317.	22.	320.	21.	322.	22.	325.	22.	323.	21.	324.	20.

TDL WAVE FORECASTS (FEET)

	PT1	PT2	PT3	PT4	PT5	PT6
+00 HR	1.2	1.9	2.4	2.4	1.5	1.5
+06 HR	1.3	2.0	2.7	1.9	2.0	1.9
+12 HR	1.4	2.3	3.1	2.2	2.4	2.1
+18 HR	1.5	2.4	3.3	2.3	2.4	2.2
+24 HR	1.6	2.5	3.4	2.3	2.5	2.2
+30 HR	1.5	2.4	3.3	2.4	2.4	2.2
+36 HR	1.4	2.3	3.2	2.6	2.1	1.9

Figure 2. Sample wind and wave forecast message for Chesapeake Bay and lower Potomac River.

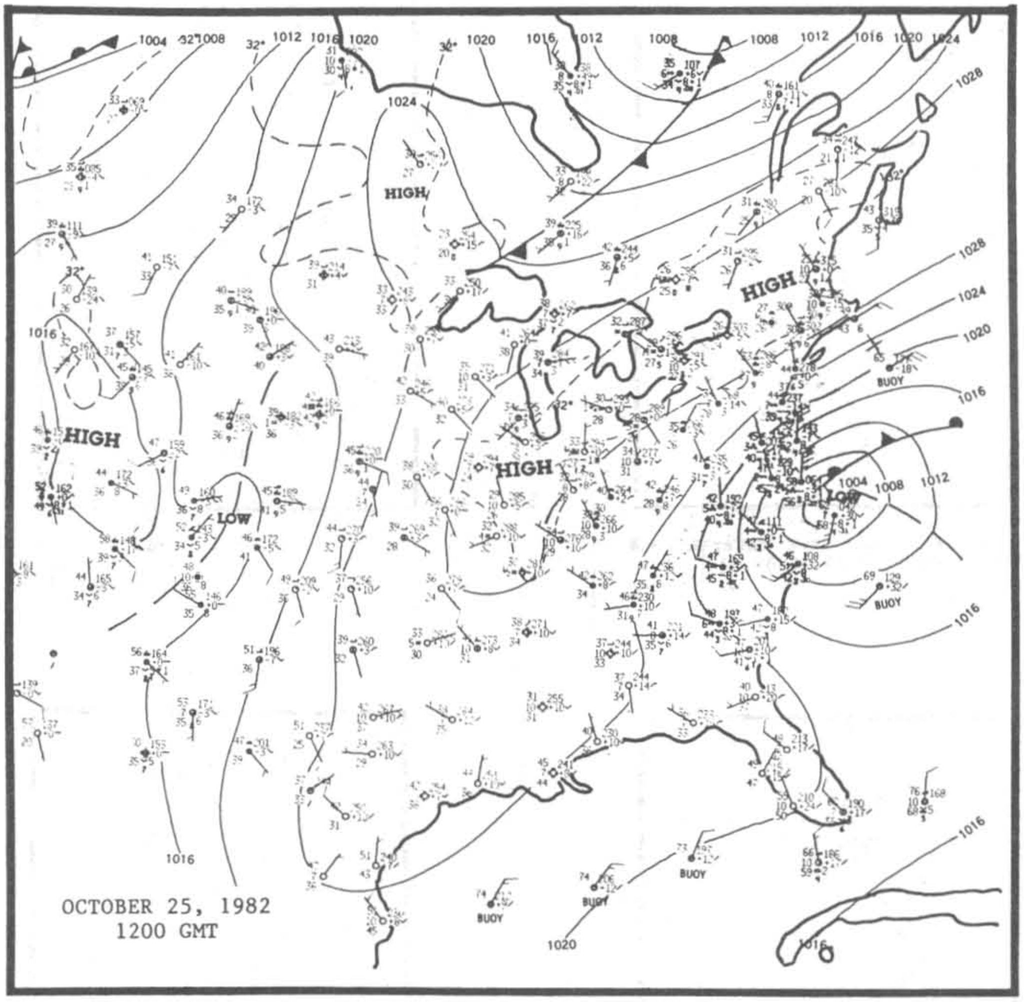

Figure 3. Surface weather chart for 1200 GMT on October 25, 1982.

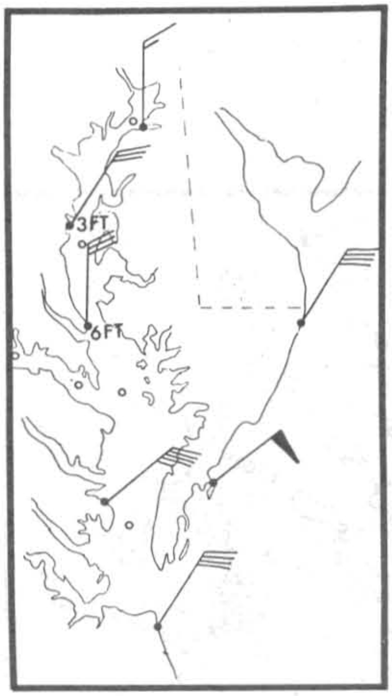

Figure 4. Wind and wave observations for 1200 GMT on October 25, 1982.

Figure 5. Twelve-hour forecasts of wind and waves valid at 1200 GMT on October 25, 1982. Wind forecasts are 1000-mb LFM winds interpolated to the wave forecast points.

Figure 6. Same as Figure 5, except 24-h forecasts.

Figure 7. Same as Figure 5, except 36-h forecasts.

Table 1. Estimated average depth, measured fetch lengths, and corrected fetch lengths for the six forecast points.

Point 1 39°24'N 76°05'W				Point 2 38°45'N 76°25'W			
Dir.	Depth	Fetch	Corrected Fetch	Dir.	Depth	Fetch	Corrected Fetch
0°	10 ft	2 n mi	-	0°	45 ft	15 n mi	7 n mi
45	15	5	4 n mi	45	30	14	6
90	20	2	-	90	5	4	-
135	15	3	2	135	20	5	-
180	20	2	-	180	70	20	13
225	25	6	4	225	35	7	-
270	10	4	3	270	30	6	-
315	10	2	-	315	35	5	-
Point 3 38°00'N 76°10'W				**Point 4 37°20'N 76°10'W**			
Dir.	Depth	Fetch	Corrected Fetch	Dir.	Depth	Fetch	Corrected Fetch
0°	25 ft	14 n mi	-	0°	40 ft	54 n mi	28 n mi
45	25	8	-	45	40	14	-
90	25	6	-	90	45	7	-
135	15	10	-	135	40	11	-
180	40	65	26	180	30	24	18
225	45	7	-	225	25	15	-
270	40	14	7	270	30	5	-
315	40	11	-	315	25	5	-
Point 5 38°03'N 76°25'W				**Point 6 38°13'N 76°50'W**			
Dir.	Depth	Fetch	Corrected Fetch	Dir.	Depth	Fetch	Corrected Fetch
0°	40 ft	3 n mi	-	0°	15 ft	7 n mi	2 n mi
45	40	3	-	45	20	2	-
90	45	3	-	90	20	4	-
135	35	33	15	135	20	4	-
180	30	5	-	180	20	3	-
225	20	4	-	225	20	3	-
270	35	5	-	270	20	6	5
315	40	7	5	315	20	6	5

REFERENCES AND FOOTNOTES

1. Mr. Pore received B.S. and M.S. degrees in Meteorology from Pennsylvania State University in 1953 and 1954. He has served as Aerographer's Mate in the U.S. Navy, oceanographer in the Naval Oceanographic Office, and meteorologist in the National Weather Service. He served as Chief of the Marine Techniques Branch of the Techniques Development Laboratory, until his retirement in 1983..

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