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IMPROVED BEACH EROSION FORECASTS FOR THE U.S. EAST COAST

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1. INTRODUCTION

In my last Office Note on storm-related beach erosion (Richardson, 1978), I presented a forecast technique which was implemented by the National Weather Service in the fall of 1978 (National Weather Service, 1978). This statistically derived technique forecasts storm-related beach erosion intensities in qualitative terms (none, minor, moderate, major, and severe). Erosion intensities are forecast with a set of equations which was based upon linear and powers-of-two intensity scales. These scales and associated qualitative terms are shown in Fig. 1.

During 1978-79 the beach erosion forecast technique overforecast erosion intensities for the Maine and Mass. coasts, especially during higher than normal spring tide conditions. While erosion forecasts are made for east coast states from Maine through S.C., the overforecasting problem most often occurred at Maine and Mass. This paper discusses this problem and presents new forecast equations which should help eliminate the problem. I've also included verification results which are based upon these new equations.

2. THE OVERFORECASTING PROBLEM

In checking into the overforecasting problem, "crying severe and major erosion when there is none," this is what I've found. The forecast equations which were implemented last fall contain duration predictors. To refresh your memory, these predictions are the number of consecutive high tides (approximately 12.4 hours apart) that critical values are reached or exceeded. Critical values are defined by the amplitude of the mean spring tide and storm surge heights at representative tide gages. A list of these tide gages, the amplitudes of the mean spring tides at these gages, and critical values used to determine generalized and variable duration predictors are shown in Table 1. The generalized and variable duration predictors are discussed by Richardson (1978).

Unusually high spring tides may be 25 percent higher than normal spring tides. This translates into astronomical tide heights which are 1.5 ft above normal spring tides at representative tide gages for Maine and Mass. At representative tide gages for states south of Mass. the differences between unusually high spring tides and normal spring tides are only about 0.6 ft.

During unusually high spring tides at Portland, Maine, and Boston, Mass., very small storm surges cause critical values to be reached. When critical values are reached during a number of consecutive high tides, the erosion equations forecast severe and major erosion. If these critical values are reached during low storm surge conditions, the erosion intensities are overforecast. These intensities are overforecast because the agent responsible for "eating away" at the beach is the energy contained in the storm surge and not the energy associated with the rise and fall of the astronomical tide. Unusually high spring tides cause much less of a problem at states south of Mass. There is less of a problem because unusually high spring tides are not that much different from mean spring tides at these states.

3. SOLUTION

A solution to the overforecasting problem at Maine and Mass. is a new beach erosion equation for these states which does not contain duration predictors. Before this new equation was derived, I carefully checked Maine and Mass. beach erosion data. Of the 82 pieces of data, 11 were inconsistent. By inconsistent I mean, only one state reported erosion when storm track, high tides, and storm surge heights indicated erosion along the coasts of both states. The 11 pieces of data which indicated no erosion at one or the other states (6 for Maine and 5 for Mass.) were removed from the development sample.

The new equation which I derived by statistical screening from the 71 pieces of data is:

$$\text{BE(Maine and Mass.)} = -1.06 + 0.04\ \text{MT}^2 + 0.09\ \text{MS}^2, \tag{1}$$

where BE is beach erosion intensity (linear scale of 0 through 4, see Fig. 1), MT is maximum tide height (ft) above mean sea level (m.s.l.), and MS is maximum storm surge height (ft). The third predictor which would have been selected was a duration prediction. However, screening was stopped before this predictor was selected, since this predictor was responsible for the overforecasting problem. The duration predictor would have reduced the variance of erosion intensity by only an additional 1.3 percent.

As you may recall the set of equations implemented in 1978 was:

$$\text{BE(Maine and Mass.)} = 1.34 + 0.24\ \text{MT} + 0.09\ \text{MS}^2 + 0.54\text{D} + 0.12\text{VD}, \tag{2}$$

$$\text{BE(R.I. through S.C.)} = -0.66 + 0.35\text{D} + 0.16\ \text{MS} + 0.23\text{VD} + 0.15\ \text{MT}, \tag{3}$$

$$\text{BE2(all states)} = -0.23 + 1.44\text{D} + 0.13\ \text{MS}^2 + 0.70\text{VD} + 0.23\ \text{MT}, \tag{4}$$

where BE is beach erosion intensity (scale of 0 through 4), BE2 is beach erosion intensity (scale of 1 through 16, see Fig. 1), D is generalized duration, MS is maximum storm surge height (ft), VD is variable duration, and MT is maximum tide height (ft) above m.s.l.

This set of three equations is applied in the following manner. The powers-of-two generalized (all states) equation, equation (4), is first used to compute the erosion intensity. This equation was derived with data from Maine to S.C. If an intensity of moderate or greater is computed, the erosion intensity is based on this equation. If the computed intensity is less than moderate, then the linear scale equations (2) and (3), which were derived from data of their respective groups, are used.

I plan to replace equations (2) and (4) of the old set with equations (1) and (5). Equation (3) is unchanged. This set of "new" equations is:

$$BE(\text{Maine and Mass.}) = -1.06 + 0.04\ MT^2 + 0.09\ MS^2, \tag{1}$$

$$BE(\text{R.I. through S.C.}) = -0.66 + 0.35D + 0.16\ MS + 0.23VD + 0.15\ MT, \tag{3}$$

$$BE2(\text{R.I. through S.C.}) = 0.69 + 1.52D + 0.12\ MS^2 + 0.74VD \tag{5}$$

The predictands and predictors in these new equations have the same definitions as the predictands and predictors in the old equations. Equation (1) is the new equation which was derived from Maine and Mass. erosion data. This equation will be used to forecast the erosion intensity for Maine and Mass. A new powers-of-two scale equation, equation (5), will replace the generalized equation, equation (4), of the old set of equations. Equation (5) was derived with data from R.I., N.Y., N.J., Del., Va., N.C., and S.C. Equations (3) and (5) will be applied as follows. Equation (5) is first used to compute the erosion intensity for the oceanic coastline of states south of Mass. If an intensity of moderate or greater is forecast, the erosion intensity is based on this equation. Otherwise, the erosion intensity will be based on equation (3).

4. TEST RESULTS

Twelve independent "erosion events" which occurred or were forecast to occur along the coastal states from Maine through Va. were used to test and compare the new equations ((1), (3), and (5)) with the old equations ((2), (3), and (4)). The equations, new and old, were used to specify the erosion intensity associated with four independent events. That is, the erosion intensities associated with Dec. 20, 1977, Jan. 9, 1978, Feb. 7, 1978, and Apr. 26, 1978, were calculated with observed predictors. For the other eight "erosion events," either moderate or greater erosion occurred or moderate or greater erosion was forecast by the old equations for the Maine and Mass. coasts. The forecast (12-, 24-, 36-, and 48-h) erosion intensities are the maximum intensities forecast without regard to forecast projections.

Observed-specified and observed-forecast contingency tables were constructed with the new and old sets of forecast equations for each group of states. Table 2 contains the observed-specified contingency table for Maine and Mass. This table is based on three independent events (Dec. 20, 1977, Jan. 9, 1978, and Feb. 7, 1978). Erosion categories specified by the old set of equations are shown in parentheses. The new equation shows slight improvement over the old equations in specifying severe erosion. All other categories are specified the same by the old and new equations.

The observed-forecast contingency table for Maine and Mass. for eight independent erosion events which occurred or were forecast to occur during 1978-1979 are shown in Table 3. The old equations forecast severe and major erosion seven times when no erosion is reported. For these times, when no erosion is reported, the new equation forecasts moderate and minor erosion. However, two erosion events which are forecast as no erosion by the old equations are forecast as minor erosion by the new equation. Keep in mind that these forecasts are made with storm surge forecasts; therefore, part of the erosion forecast error may be due to errors in the storm surge forecasts.

Tables 4 and 5 contain the observed-specified and the observed-forecast contingency tables for the states south of Mass. Notice that the old and new equations give the same results. This is not that surprising since equation (3) is used in the old and new sets of equations.

Matrix scores, threat scores, and percent of correct specifications and forecasts were computed from the four contingency tables. These scores were computed by combining the specifications and forecasts for each group of states. Matrix scores (MS) were computed by the following formula.

$$MS = \sum_{i=1}^{5} \sum_{j=1}^{5} f_{ij} \; M_{ij} ,$$

Where f_{ij} are elements in an observed-forecast (5x5) contingency table and M_{ij} are elements of the scoring matrix shown in Table 6.

The threat score $\left[\frac{\#\ \text{hits}}{\#\ \text{forecasts} + \#\ \text{observed} - \#\ \text{hits}}\right]$ is the relative frequency of correctly specifying or forecasting the event in which the event was a threat (Palmer and Allen, 1949). Threatening situations are those in which either severe, major, or moderate erosion occurred, or were specified or forecast to occur.

Table 7 shows matrix scores, threat scores, and percent of correct specifications or forecasts for the old and new equations for each group of states. Scores associated with the old equations are shown in parentheses. The scores associated with the coastal states south of Mass. (R.I. through S.C.) are the same for the old and new equations. A perfect matrix score for these states is 182.

There is a big difference between the scores associated with the old and new equations for Maine and Mass. For example, the matrix score associated with the new equation is 48 points higher than the corresponding score for the old equations. A perfect score for these independent events is 78. The threat score associated with the new equation is 0.17 higher (100 percent better) than the threat score associated with the old equations. However, the percent of correct specifications and forecasts associated with the new equation is a little lower than the one associated with the old equations.

On the basis of these results, the new equations ((1), (3), and (5)) were implemented in December 1979.

5. ACKNOWLEDGMENTS

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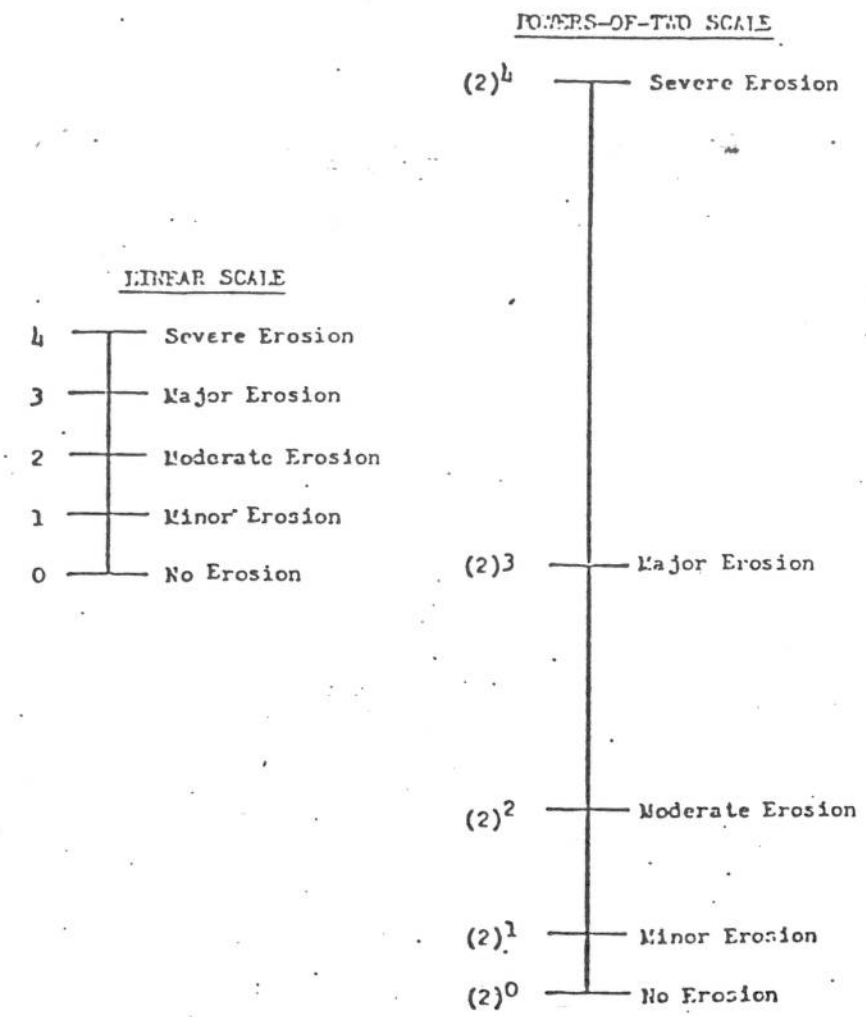

Figure 1. Storm-related erosion intensity scales and associated qualitative terms.

Table 1. Coastal states, associated tide gages, amplitude of the mean spring tide at these gages, and "critical values" used in determining generalized and variable duration terms.

Coastal States	Associated Tide Gage	Amplitude of the Mean Spring Tide (ft)	"critical value" used to determine Generalized Duration (ft)	"critical value" used to determine Variable Duration (ft)
Maine	Portland, Me.	5.2	7.7	6.2
Massachusetts	Boston, Mass.	5.5	8.0	8.0
Rhode Island	Newport, R.I.	2.2	4.7	4.7
New York	New York, N.Y.	2.7	5.2	5.2
New Jersey	Atlantic City, N.J.	2.5	5.0	4.5
Delaware	Breakwater Harbor, Del.	2.5	5.0	4.5
Virginia	Hampton Roads, Va.	1.5	4.0	3.0
North Carolina	Avon, N.C.	*2.0	4.5	3.5
South Carolina	Charleston, S.C.	3.0	5.5	5.0

* Amplitude of the mean spring tide at Cape Hatteras, N.C. (Ocean side)

Table 2. Observed-specified contingency table for Maine and Mass. Categories of erosion are computed by the new equation and the old set of equations for independent erosion events which occurred along the east coast during 1977-78. Erosion categories specified by the old set of equations are shown in parentheses.

Observed Categories	Specified Categories					Total	Percent of Total
	Severe	Major	Moderate	Minor	None		
Severe	(0) 1	(2) 1	(0) 0	(0) 0	(0) 0	2	33.3
Major	(0) 0	(0) 0	(1) 1	(0) 0	(0) 0	1	16.7
Moderate	(0) 0	(0) 0	(1) 1	(0) 0	(0) 0	1	16.7
Minor	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
None	(0) 0	(0) 0	(0) 0	(1) 1	(1) 1	2	33.3
Total	(0) 1	(2) 1	(2) 2	(1) 1	(1) 1	6	100.0

Table 3. Observed-forecast contingency table for Maine and Mass. Categories of erosion are forecast by the new equation and the old set of equations for eight independent "erosion events" which occurred or were forecast to occur along the east coast during 1978-79. Erosion categories forecast by the old set of equations are shown in parentheses.

Observed Categories	Forecast Categories Severe	Major	Moderate	Minor	None	Total	Percent of Total
Severe	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
Major	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
Moderate	(0) 0	(0) 0	(2) 2	(0) 0	(0) 0	2	12.5
Minor	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
None	(4) 0	(3) 0	(3) 4	(1) 9	(3) 1	14	87.5
Total	(4) 0	(3) 0	(5) 6	(1) 9	(3) 1	16	100.0

Table 4. Same as Table 2 except for R.I., N.Y., N.J., Del., Va., and S.C. for four independent events which occurred Dec. 20, 1977; Jan. 9, 1978; Feb. 7, 1978; and Apr. 26, 1978.

Observed Categories	Specified Categories					Total	Percent of Total
	Severe	Major	Moderate	Minor	None		
Severe	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
Major	(1) 1	(2) 2	(2) 2	(0) 0	(0) 0	5	25.0
Moderate	(0) 0	(0) 0	(1) 1	(1) 1	(0) 0	2	10.0
Minor	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
None	(0) 0	(0) 0	(2) 2	(1) 1	(10) 10	13	65.0
Total	(1) 1	(2) 2	(5) 5	(2) 2	(10) 10	20	100.0

Table 5. Same as Table 3 except for R.I., N.Y., N.J., Del., Va., and S.C.

Observed Categories	Forecast Categories Severe	Major	Moderate	Minor	None	Total	Percent of Total
Severe	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
Major	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
Moderate	(0) 0	(0) 0	(2) 2	(0) 0	(0) 0	2	4.2
Minor	(0) 0	(0) 0	(0) 0	(0) 0	(0) 0	0	0.0
None	(0) 0	(1) 1	(7) 7	(2) 2	(36) 36	46	95.8
Total	(0) 0	(1) 1	(9) 9	(2) 2	(36) 36	48	100.0

Table 6. Scoring matrix designed to give heavier weights to the erosion categories that are more difficult to forecast. The score for a correct forecast of severe erosion is given five times more weight than a correct forecast for no erosion.

Observed	Forecast Categories				
Categories	Severe	Major	Moderate	Minor	None
Severe	10	7	4	1	-2
Major	5	8	5	2	-1
Moderate	0	3	6	3	0
Minor	-5	-2	1	4	1
None	-10	-7	-4	-1	2

Table 7. Matrix scores, threat scores, and percent of correct specifications and forecasts associated with the new and old sets of equations. Scores were computed by combining specifications and forecasts for each group of states. Scores associated with the old set of equations are shown in parentheses.

Verification Scores	Maine and Mass.		R.I. through S.C.	
Matrix Score	(-30)	18	(98)	98
Threat Score	(0.16)	0.33	(0.23)	0.23
Percent of correct specifications and forecasts	(32)	27	(75)	75