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Subject: EAST COAST EXTRATROPICAL STORM SURGE AND BEACH EROSION GUIDANCE

Science Division, Silver Spring, MD 20910

This bulletin, which was prepared by Mr. Lawrence D. Burroughs of the Environmental Modeling Center of the National Centers for Environmental Prediction (NCEP) and Dr. Wilson A. Shaffer of the Techniques Development Laboratory, describes the automated statistical extratropical storm surge guidance for 12 points along the east coast of the United States from Portland, Maine to Charleston, South Carolina (National Weather Service, 1978a) and beach erosion guidance for east coast beaches from Maine through South Carolina (National Weather Service, 1980). The storm surge guidance uses sea level pressure forecasts from the Regional Analysis and Forecast System (RAFS) (National Weather Service 1985). This bulletin also discusses the development and demise of the east coast marine guidance package (National Weather Service 1979b).

Prior to withdrawal of the Limited-area Fine Mesh (LFM) model (Newell and Deaven 1981) from the NCEP operational job stream, the east coast storm surge system was changed to use RAFS output. These changes were implemented in March 1993.

In November 1993, the part titles of the forecast bulletin were changed to include NGM (Nested Grid Model - the model used in the RAFS) BASED. Finally, in March 1994, the World Meteorological Organization (WMO) bulletin header for these guidance products was changed from FZUS3 KWBC to FQUS21 KWBC.

This bulletin describes these remaining east coast guidance products, discusses the major changes in the system since 1979, and supersedes Technical Procedures Bulletins No. 226, 278, and 280 (National Weather Service 1978a, 1979b, and 1980), which are now operationally obsolete.

U.S. DEPARTMENT OF COMMERCE **National Oceanic and Atmospheric Administration**

EAST COAST EXTRATROPICAL STORM SURGE AND BEACH EROSION GUIDANCE[1]

by L. D. Burroughs[2] and W. A. Shaffer[3]

1. INTRODUCTION

In 1979 the Techniques Development Laboratory (TDL) was requested by the NWS Eastern Region Headquarters (ERH) to combine several existing marine guidance products into a unified guidance package which would be more convenient and useful to marine forecasters at coastal forecast offices along the east coast of the United States (U.S.) (National Weather Service 1979). These guidance products were included in two bulletins: one for LFM-based products (FZUS3); the other for one Primitive Equation (PE) (Shuman and Hovermale 1968)-based product (FZUS5). The FZUS3 consisted of five parts: extratropical storm surge forecasts, beach erosion forecasts, boundary layer wind and mean potential temperature forecasts, coastal statistical wind forecasts, and Chesapeake Bay statistical wind forecasts. The FZUS5 contained wind-wave and swell height forecasts for 18 PE grid points off the east coast of the U.S.

This Technical Procedures Bulletin documents the changes that have occurred in the various parts of the east coast marine guidance package. It also refocuses attention on the two remaining parts: the extratropical storm surge guidance and the beach erosion guidance. The other parts have disappeared from the original guidance package for various reasons described below.

a. Extratropical Storm Surge Guidance

Extratropical storm surges can be potentially dangerous to coastal communities and businesses along the east coast of the U.S. They are defined as the difference between the measured water level and the astronomical tide and are primarily caused by wind stress on the water surface. The surge, which is modified by the nearshore bathymetry and the shoreline, is superimposed on the astronomical tide to give the total water level or “storm tides”.

In October 1971 the first extratropical storm surge bulletin was dispatched. The guidance was PE-based and statistically derived; there were 10 stations from Portland, Maine to Norfolk, Virginia included in it (Pore *et al.* 1974). Charleston, South Carolina was added in the mid 1970s. In February 1978 this guidance was changed to be LFM-based, and another station (Avon, North Carolina) was added (National Weather Service, 1978a). Richardson *et al.* (1979) verified the storm surge forecasts and found that those for Charleston were not very good. Richardson and Boggio (1980) rederived the forecast equation for Charleston and implemented it in September of that year. Since then there has been little change to the system, except as noted in section d below. **This technique is not applicable to tropical storm surges.**

b. Beach Erosion Guidance

The Atlantic has been changing beaches along the east coast for thousands of years. These changes are part of a natural process in which a dynamical balance between the beaches and ocean is maintained. By advancing and retreating, beaches respond to winds, tides, waves, breakers, swell, and long-term changes in sea-level. Rates of

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[1]OMB Contribution No. 106

[2]National Centers for Environmental Prediction, National Weather Service, Washington, D.C. 20233

[3]Techniques Development Laboratory, National Weather Service, Silver Spring, Maryland 20910

beach accretion (advancing beach with respect to the ocean) and beach erosion (retreating beach) may be measured in months, while rates related to storms are measured in days or hours.

TDL developed an automated technique which was first implemented in November 1976 and can be used to forecast qualitative estimates of the beach erosion with the shortest of these time scales, extratropical storm-related beach erosion. This guidance forecasted beach erosion for oceanic coastlines from Maine to Virginia (National Weather Service 1976). In October 1978 beach erosion forecasts for the oceanic coastlines of North and South Carolina were added to the guidance, and the forecast equations were changed (Richardson 1978 and National Weather Service 1978b). Verification of the guidance showed there was an overforecasting problem along the coasts of Maine and Massachusetts. As a result the forecast equations were rederived and applied differently than the previous equation set had been and were implemented in December 1979 (Richardson 1980 and National Weather Service 1980). Since 1979 there have been few changes to the system, except as noted in section d below. **This technique is not applicable to tropical storm related beach erosion.**

c. Other Guidance Products

1) Boundary Layer Parameters. As a part of the ERH request, boundary layer wind and mean potential temperature forecasts at 35 LFM grid points were included. These forecasts continued to be included as a part of the FZUS3 bulletin until they were deemed no longer necessary and were removed in March 1993. Their value declined after 20 m wind forecasts at selected grid points along the east and west coasts of the U.S. from the Aviation (AVN) version of the Global Spectral Model became available in late 1986 (National Weather Service 1986b). This product was superseded by an AFOS graphic wind forecast product in October 1988 (Gemmill and Kidwell 1990).

2) Coastal Wind Forecasts. Wind forecasts along the east coast are important to a variety of commercial, recreational, and governmental interests. In July 1974 automated wind forecasts based on Model Output Statistics (Glahn and Lowry 1972) were introduced at eight locations along the east coast of the U.S. (National Weather Service 1974). The forecast equations were PE-based and are described by Feit (1976) in some detail. In 1979 these equations were rederived with LFM predictors, one station was dropped due to a lack of data, and one was replaced by a buoy location. In addition six stations on the Chesapeake Bay shore were added to the forecast system (National Weather Service 1979a). These wind forecasts made up two parts of the FZUS3 bulletin. The coastal wind forecast system continued to add stations and expand, and in December 1981 the wind forecasts were dropped from the FZUS3. They were spread out through the FZUS41, FZUS42, and FZUS44 bulletins for east coast stations and the FZUS43 bulletin for Chesapeake Bay stations (Burroughs 1982). The coastal wind forecast system has continued to evolve and expand until it now comprises 99 stations along the coasts of the contiguous U.S. and the state of Alaska (Burroughs 1991).

3) Automated Wind-wave and Swell Forecasts. In 1968 TDL implemented an automated wind-wave and swell forecast program. It was adapted from a program developed by the U.S. Navy (Huber 1957 and 1964) and enhanced by Pore and Richardson (1967 and 1969). It remained as a facsimile (FAX) only product until 1979 when ERH requested that it be included as a part of the east coast guidance package (National Weather Service 1979b). Since it was a PE-based product, a separate bulletin was required which became the FZUS5 bulletin. It gave wind-wave and swell heights at 18 selected PE grid points along the east coast. This product came out about four hours after the FZUS3 bulletin, but still four to five hours ahead of when the FAX product got to field forecast offices. In October 1986 the NOAA Ocean Wave (NOW) model was implemented (National Weather Service 1986a) and the FZUS5 was dropped because it was no longer needed. The NOW model was steadily improved from 1986 to 1994 when it was superseded by the NOAA Wave Model (NOAA/WAM) (Chen 1995).

d. Other Significant Changes

In 1993 the east coast extratropical storm surge guidance and the east coast beach erosion guidance were changed to use RAFS output. These changes were implemented in March of that year.

In November 1993 the part tiles of the forecast bulletin were changed to describe the forecast as NGM BASED. Finally, in March 1994, the World Meteorological Organization (WMO) bulletin header for these guidance products was changed from FZUS3 to FQUS21.

In December 1994 TDL implemented a new AVN-based numerical extratropical storm surge model for the east coast. A new bulletin, FQUS23, was created. It contains hourly extratropical storm surge forecasts out to 48-h for 66 stations. The FQUS21 has been continued because it is used as input for the beach erosion problem. Until a new beach erosion product is developed the two storm surge prediction systems will co-exist. Since the FQUS21 product is statistical in nature, it often forecasts a completely different and independent surge forecast.

2. METHOD

The method used to derive the forecast equations for the FQUS21 products (extratropical storm surge and beach erosion) is statistical and is called the "perfect prog" approach (Klein *et al.* 1959). This approach derives regression equations relating observed values of storm surge/beach erosion to analyzed meteorological fields at the same time. These equations are then applied, in a forecast mode, to forecast meteorological fields to yield forecasts of storm surge/beach erosion.

The extratropical storm surge forecast equations were developed by correlating storm surge heights at 0000, 0600, 1200, and 1800 UTC (predictand) with observed sea-level pressure values at PE grid points (predictors). A separate equation was derived for each station.

The beach erosion forecast equations were developed by correlating qualitative estimates of erosion (predictand) with observed meteorological and oceanographic parameters (predictors). Regional equations were derived for groups of stations.

3. DEVELOPMENT AND DEFINITIONS

a. Extratropical Storm Surge Height Forecasts

1) Predictand - Storm Surge Height

The storm surge height is the meteorologically-generated water level fluctuation which has removed from it the astronomical tide height. Storm surge heights at 0000, 0600, 1200, and 1800 UTC were calculated by subtracting the astronomical tide at a given point from the water level measured at that point. The tide gage locations and their owners are given in Table 1 (see also Fig. 1 for locations).The frequency of storm surges varies with location as well as from year to year. However, on the average, a storm surge height of 2 feet or greater occurs at each location about five times a winter (November through April). Usually one of these surge heights exceeds 3 feet.

Table 1. Tide Gage locations and owners.

Owner	Tide Gage Stations
National Ocean Survey	Portland, Maine
	Boston, Massachusetts
	Newport, Rhode Island
	Willets Point, New York
	New York, New York
	Atlantic City, New Jersey
	Breakwater Harbor, Delaware
	Baltimore, Maryland
	Hampton Roads, Virginia
	Avon, North Carolina
	Charleston, South Carolina
Army Corps of Engineers	Stamford, Connecticut

2) Predictors

The predictors of storm surge height at the 12 tide gage locations are sea-level pressures at 6-h intervals at PE grid points along the east coast and over the Atlantic Ocean.

b. Beach Erosion Forecasts

1) Predictand - Beach Erosion Index

Qualitative estimates of erosion (See Table 2) were extracted from the Environmental Data Service publication STORM DATA, and then subjectively converted to numerical values. A numerical value was associated with a qualitative term which reportedly described the intensity of the storm-related beach erosion for a coastal state. The numerical values and their associated qualitative terms are given in Table 2.

Table 2. Qualitative extratropical storm-related beach erosion intensity scale with associated descriptors and numerical scales.

Intensity	Descriptor	Linear	Non-Linear
Severe	Severe Tremendous Serious	4	2^4
Major	Considerable Widespread Heavy Markedly Badly Much	3	2^3
Moderate	Erosion Some Erosion Erosion of Dunes Beach Erosion Coastal Erosion Dunes Moved Moderate Erosion	2	2^2
Minor	Beach Change Jetty and Pier Damage Some Loose Sand Moved Light Erosion Sea Wall Pounded Heavy Surf Limited Damage Erosion Noted	1	2^1
None	No Mention of Erosion No Erosion	0	2^0

Beginning with March 1962 and continuing through April 1977, all winter STORM DATA volumes (November 1 through April 30) were scanned for the area of concern (Maine through South Carolina). Any time there was mention of erosion or wave damage along one of these states, a numerical intensity of 1, 2, 3, or 4 was assigned to the affected state. The assignment was made in accordance with the descriptive terms shown in Table 2. The intensity values were then used to construct the linear and non-linear (powers-of-two) beach erosion intensity scales also shown in Table 2. The March 1962 storm was chosen as a starting point because erosion reporting procedures were somewhat standardized after that disastrous storm.

2) Predictors

The following meteorological and oceanographic parameters were selected as predictors of beach erosion intensity by a multiple regression screening program.

- *Storm duration* - The number of consecutive high tides (approximately 12.4 hours apart) that water levels reach or exceed critical threshold values. This predictor was **not used** in the Maine and Massachusetts equation because it was found not to contribute to the forecast in these states.

- *Maximum storm surge height and maximum storm surge height squared* - The differences in the hourly observed tide height minus the hourly astronomical tide height at representative National Ocean Survey (NOS) tide gages (See Table 1) were scanned for the maximum difference for each erosional event at each station. Since there was no tide gage located along Maryland's outer coastline, and because reported estimates of erosion for Maryland were similar to reported estimates of erosion for Delaware, the states of Delaware and Maryland were combined (Delmar) and one gage (Breakwater Harbor) was used to represent the tides along the Delaware and Maryland coastlines.

- *Maximum observed tide height above mean sea level and the maximum observed tide height squared*.

A complete discussion of these predictors is given by Richardson (1978).

3) Forecast Equations

Based upon tidal range, the coastlines of Maine and Massachusetts were grouped together, while the coastlines of the other states were placed into a second group. Only one equation is used for the first group - a linear scale equation (0, 1, 2, 3, 4) which does not contain a duration predictor. This predictor was not used because verification with 1978-1979 erosion data showed that this predictor caused the original Maine and Massachusetts equation to greatly overforecast erosion intensities. This overforecasting problem, which is more severe during unusually high astronomical spring tide conditions, is discussed by Richardson (1979). Two equations are used for the second group (Rhode Island through South Carolina coastlines) - a linear scale equation (Richardson 1978) and a powers-of-two scale equation (Richardson 1980).

The equations for the second group are applied as follows. The power-of-two scale equation is used first. If an intensity of moderate or greater is forecast, the forecast intensity is based on this equation. If the beach erosion is forecast to be less than moderate, then the linear scale equation is used.

4. FORECAST CONTENT AND DISSEMINATION

The FQUS21 bulletin consists of 2 parts. The parts are for forecasts of extratropical storm surge and beach erosion. Figure 2 gives a sample of this bulletin.

The extratropical storm surge forecasts are expressed in feet and shown for projections of 0- to 48-h at 6-h intervals for 12 locations from Portland, Maine to Charleston, South Carolina (see Table 1 and Fig. 1).

Qualitative forecasts of extratropical storm-related beach erosion are presented for each state from Maine through South Carolina and given for projections of 0- to 48-h at 12-h intervals. Terms used to describe the erosion are NONE, MINOR, MODERATE, MAJOR, and SEVERE. If no erosion is forecast for any of the states during the 48-h forecast period, an abbreviated message replaces the forecast matrix. The abbreviated message is "NO SIGNIFICANT EROSION EXPECTED FOR THE NEXT 48 HOURS."

The FQUS21 bulletin is available on AFOS at approximately 0330 and 1600 UTC daily. It is retained in the AFOS system until overwritten by new information. The bulletin can be obtained by calling up NMCMRPECS. It is also available to Domestic Data Service subscribers via the Family of Services.

5. OPERATIONAL CONSIDERATIONS

a. Extratropical Storm Surge Forecasts

Storm surge forecasts at the 12 coastal locations may serve as useful forecast guidance at other coastal locations. For example, surges observed at New Bedford, Massachusetts and Providence, Rhode Island are very similar to those observed at Newport, Rhode Island. Therefore, the storm surge forecasts for Newport can be used as guidance in forecasting surges at New Bedford and Providence. Richardson (1979) shows that the storm surge forecasts for Breakwater Harbor, Delaware can be used as guidance for Ocean City, Maryland as well. Comparisons of storm surges at other locations may reveal additional useful similarities.

The RAFS-based extratropical storm surge guidance will continue to be provided until there is an AVN-based beach erosion guidance product available. There may be discrepancies between the two systems, and forecasters will have to decide which guidance is better in a given instance and adjust their forecasts accordingly.

b. Beach Erosion Forecasts

This guidance gives only a "regional beach erosion picture" in qualitative terms for the oceanic coastline of an entire state. The erosion along the coastline of a state has great spatial and temporal variability due to the nearshore bathymetry which is complicated by longshore and onshore-offshore bar migration. The nearshore bathymetry acts as a complex system of lenses which focus erosive waves at one location while dissipating wave energy and even building the beach at adjoining locations. Even though erosion has great spatial and temporal variability, forecasters should note which coastal communities have suffered erosion damage in the past, for they may continue to be erosion-prone in the future.

The sample period used in deriving the beach erosion equations was from 1962 to 1977. There were 49 storms during this period which caused erosion along some portion of the outer coastlines of these states (Maine through South Carolina) during the winter seasons (November 1 through April 30). The greatest number of erosion events occurred during November, December, and February. January had the smallest number of events.

During these 16 winter seasons, Maine and Massachusetts experienced about two erosion events per season. For this same time period, New York had one event per season, while Rhode Island, New Jersey, Delaware and Maryland, Virginia, North Carolina and South Carolina experienced about one event every two seasons. As for the intensity of erosion (minor, moderate, major, and severe), New York and New Jersey had severe erosion about once every five seasons. The other states experienced severe erosion about one-half that often, or about one time every 10 seasons.

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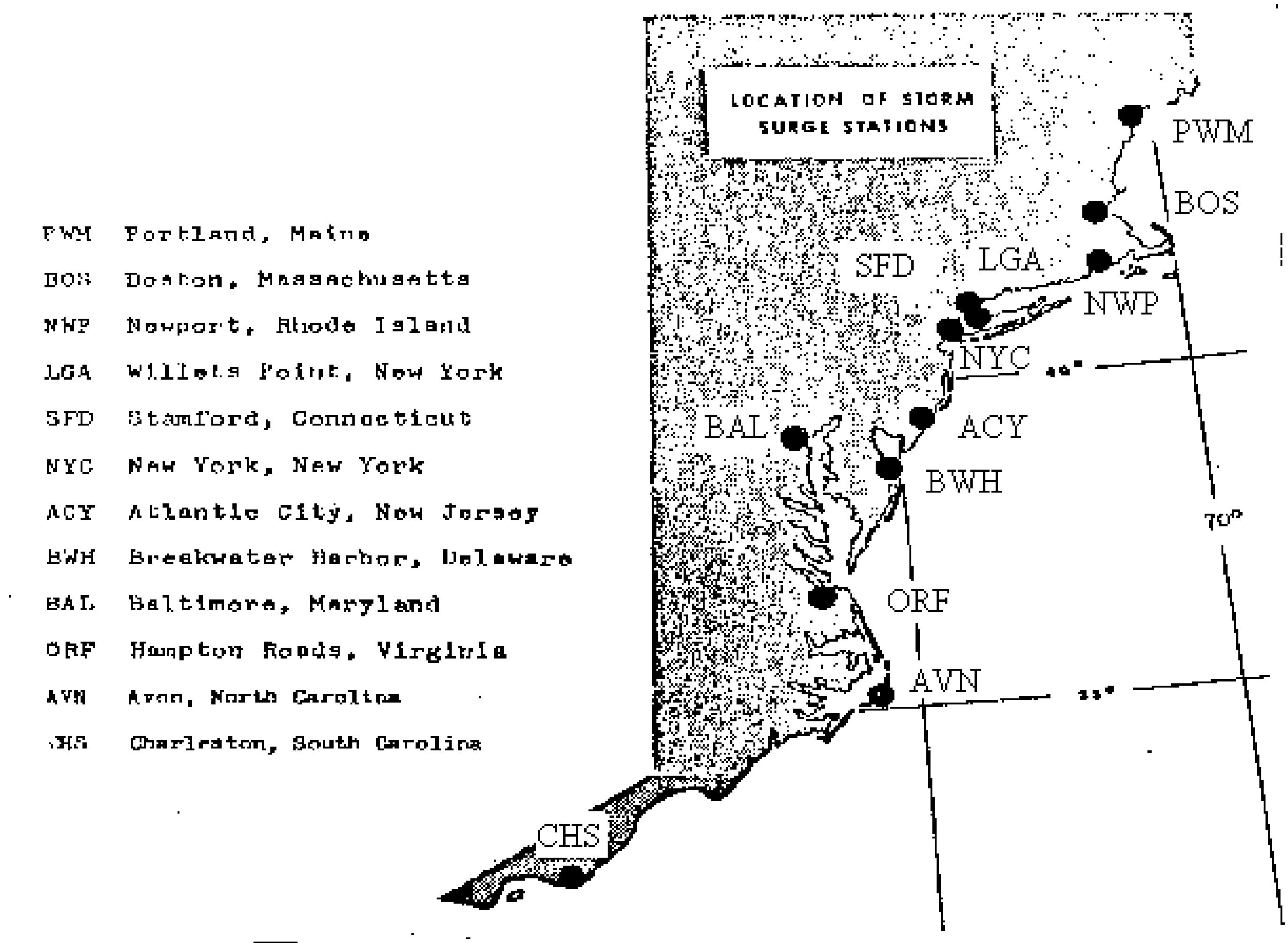

Figure 1 - The 12 east coast locations for which extratropical storm surge forecasts are made.

FQUS21 KWBC 150000

NGM BASED STORM SURGE FCST FT (INVALID FOR TROPICAL STORMS)

	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z
PWM	0.6	0.8	0.8	0.5	0.5	0.4	0.2	0.1	0.2
BOS	0.3	0.5	0.5	0.2	0.2	0.0	-0.0	-0.1	0.0
NWP	0.8	0.9	0.9	1.0	0.9	0.8	0.6	0.6	0.6
SFD	0.4	0.3	0.4	-0.4	-0.5	-0.6	--0.4	-0.4	-0.1
LGA	0.7	0.9	0.9	1.0	0.6	0.4	0.2	0.0	0.0
NYC	1.0	1.2	1.2	1.4	1.1	1.2	1.0	0.9	0.8
ACY	0.8	0.9	0.9	1.0	1.1	1.2	1.1	1.0	1.1
BWH	0.9	1.0	1.0	1.2	1.3	1.4	1.3	1.3	1.2
BAL	0.9	1.2	1.5	1.5	1.4	1.4	1.4	1.3	1.1
ORF	0.8	1.0	1.1	1.4	1.9	1.9	2.0	1.9	1.8
AVN	1.0	1.0	1.2	1.3	1.5	1.5	1.5	1.5	1.3
CHS	1.4	2.0	1.8	1.7	1.6	1.2	1.1	0.9	0.8

BEACH EROSION GUIDANCE FOR EAST COAST STATES

INVALID FOR TROPICAL STORMS

	00Z	12Z	00Z	12Z	00Z
ME.	NONE	NONE	NONE	NONE	NONE
MASS.	NONE	NONE	NONE	NONE	NONE
R.I.	NONE	NONE	NONE	NONE	NONE
N.Y.	NONE	NONE	NONE	NONE	NONE
N.J.	NONE	NONE	NONE	NONE	NONE
DELMAR.	NONE	NONE	NONE	NONE	NONE
VA.	NONE	NONE	MINOR	MODERATE	NONE
N.C.	NONE	NONE	NONE	NONE	NONE
S.C.	NONE	NONE	NONE	NONE	NONE

P>Figure 2. A sample FQUS21 bulletin. When no beach erosion is expected, the second part of the bulletin is abbreviated. See text for details.