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PREDICTED WINDS FOR CHESAPEAKE BAY FROM LFM AND OBSERVATIONAL DATA

Kurt W. Hess and Peter J. Pytlowany

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ABSTRACT. Observed overwater winds from two stations on Chesapeake Bay have been filtered to remove high frequency variability and compared to LFM output at nearby grid points. Stepwise linear regression was then used to develop predictive equations for the overwater winds using modeled winds and pressures for input. With three LFM variables, regression equations explained from 64 to 71 percent of the variance in the u and v wind components and from 50 to 52 percent of the wind speed variance for Holland Island Bar Light and York Spit stations.

1. INTRODUCTION

The Marine Environmental Assessment Division (MEAD) has been routinely collecting and analyzing wind data for coastal and estuarine areas. Recent advances in circulation modeling of Chesapeake Bay (Hess, 1986) have highlighted the need for a better understanding of the wind distribution over the Bay. Wind observations from coastal, land-based, stations, while being generally available, do not adequately represent overwater winds because of large differences between ground and sea surface roughness, and because topographic features tend to alter local wind flow. The present study was begun to develope predictive equations for Chesapeake Bay overwater winds based on the output of the National Weather Service's Limited-area, Fine-mesh Model (LFM). These model data are regularly archived in MEAD and are easily accessible. Observational wind data for offshore Bay stations used for this study were collected by the National Ocean Service (NOS) during their survey of the Bay during 1981 - 1983.

A correlation of observed land-based coastal winds with overwater winds in Chesapeake Bay for a limited time period was performed by Goodrich (1985). He compared filtered wind data from an overwater station at Holland Island Bar to similar data from the Patuxent Naval Air Station (Fig. 1.). The overwater site was 5 kilometers from the nearest land and 39 kilometers from Patuxent River. Data from both stations were decomposed

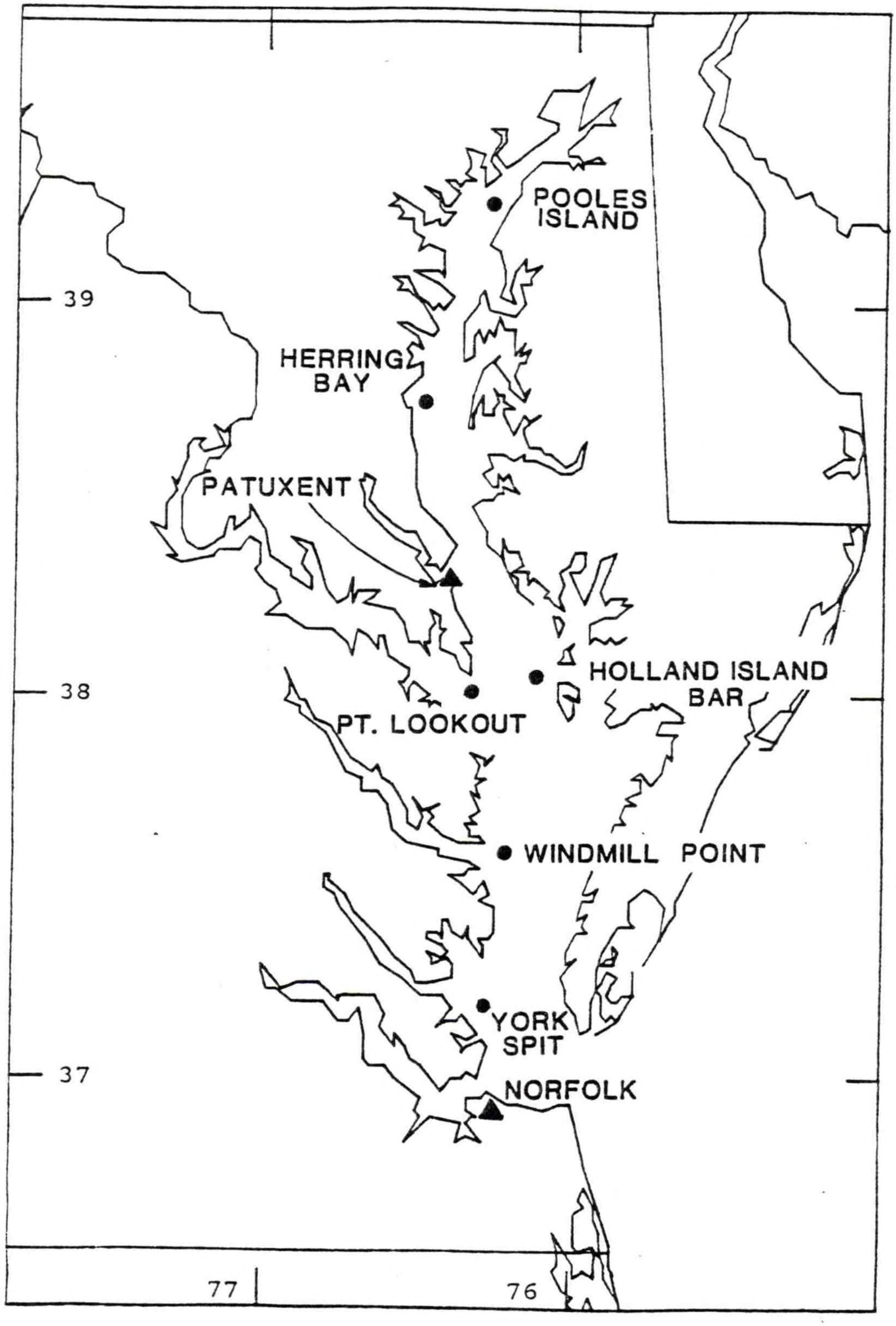

Figure 1. Map of Chesapeake Bay showing the location of the overwater wind stations (●) and Norfolk and Patuxent Naval Air Stations (▲).

into north-south and east-west components and lowpass filtered. Ratios of the overwater to coastal wind speeds on a frequency basis (Fig. 2.) show that the north-south overwater wind component is stronger by a factor of approximately 2.5, and the overwater east-west component is stronger by a factor of approximately 1.5. A linear regression of the unfiltered components gave similar results, with the north-south component stronger by a factor of 2.05 and the east-west by 1.43. These factors are larger than unity because of the lower friction of the water surface compared to the land surface. The reason for the difference in the two factors at each station (Goodrich, 1985) is the longer overwater fetch in the north-south direction as compared to the east-west direction. Because of these speed and direction differences, overland winds are not a good substitute for overwater winds.

Local, single-station observed winds can be correlated to NWS model output, as discussed by Glahn (1970). He pointed out that separate regression equations for the u (eastward) and v (northward) components will minimize mean square vector error, but that a third equation for the speed is required to minimize errors in wind magnitude.

Equations for predicting overwater, continental shelf winds in the Chesapeake Bay region from LFM output using Glahn's (1970) techniques were generated by Reeves and Pytlowany (1985). They developed regression equations for observed winds at two buoys outside the Bay mouth as part of a study of data from 15 NOAA buoys off the east, Gulf, and west coasts, using twice-daily model output. The observed winds used in that study are over the continental shelf, however, and are not representative of over-Bay winds.

Equations for predicting overland winds in the region around Chesapeake Bay from LFM output are discussed by Johnson et al. (1986). They developed regression equations for the u and v components, and the speed of the winds at the Norfolk Naval Air Station, Patuxent Naval Air Station, and Baltimore-Washington International Airport based on the LFM output of U and V components, wind speed (S), and atmospheric pressure (P) for the model's boundary layer (the lowest 50 millibars). The data were taken from April 1982.

The present study was begun to use the above regression techniques to correlate LFM data with observed NOS wind data from overwater stations to develop predictive equations for Chesapeake Bay winds.

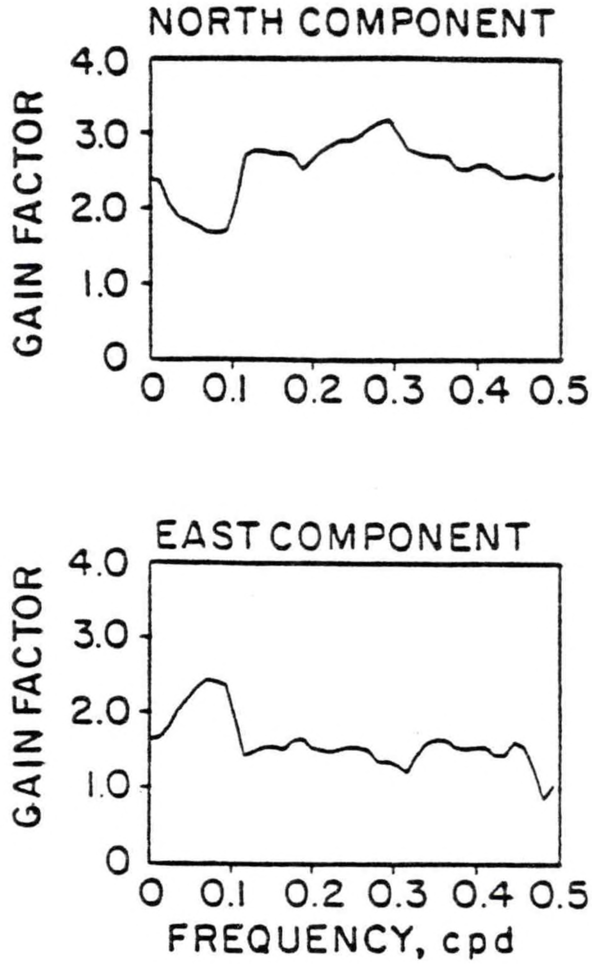

Figure 2. Ratio of overwater (Holland Island Bar Light) to coastal (Patuxent Naval Air Station) winds as a function of frequency (from Goodrich, 1985).

2. DATA SOURCES AND METHODS OF PROCESSING

2.1. LFM Data

Wind and atmospheric pressure data for coastal LFM grid points have been collected in MEAD for use in marine assessment activities (Pytlowany, 1986). The LFM data archived in MEAD consist of twice-daily forecasts (valid for 0600 GMT and 1800 GMT) of winds, pressures, and potential temperatures for the model's boundary layer at 903 model grid points covering coastal (within approximately 600 nautical miles of the shore) overwater locations and some overland stations. This data base covers the period from September 1977 to the present and is readily accessible on the MEAD computer system.

This data base was previously used in the development of equations for predicting land-based winds at the Norfolk and Patuxent Naval Air Stations (Johnson et al., 1986). The same LFM grid locations were selected for this study; their locations and reference numbers are given in Fig. 3. The latitude and longitude of each LFM point are given in Table 1.

The LFM winds predictions used here are for the level closest to the earth's surface, the boundary layer. These winds do not represent surface conditions, but rather the mean over the lowest 50 millibar layer. On the average, this layer is approximately 400 to 500 meters thick, so the boundary layer wind can also be thought of as a wind at the approximate elevation of 200 to 250 meters. As such, the model wind is usually stronger than the surface observation.

For several reasons, the model winds do not adequately represent local conditions. Because of the coarse LFM spatial resolution (165 kilometers in the vicinity of Chesapeake Bay), there is poor representation of the local topography. Therefore, the influence of hills and other terrain features is not included to any significant extent in the LFM data. There is a similar limitation in the surface friction factor, which does not reflect the distribution of land and water in the region. In addition, sea breeze is not included in the model.

2.2. Overwater Wind Data

Near-shore, overwater wind data were collected during NOS's survey of Chesapeake Bay (Browne and Fisher, 1986). During the fall and winter of 1981, data were collected in the middle Bay on the western side of the Bay at Point Lookout and on the eastern side at Holland Island Bar Light (Fig. 1). During the spring, summer, and fall of 1982, data were collected in the lower Bay at York Spit and at Windmill Point, both on the western side. During the spring, summer, and fall of 1983, data were collected

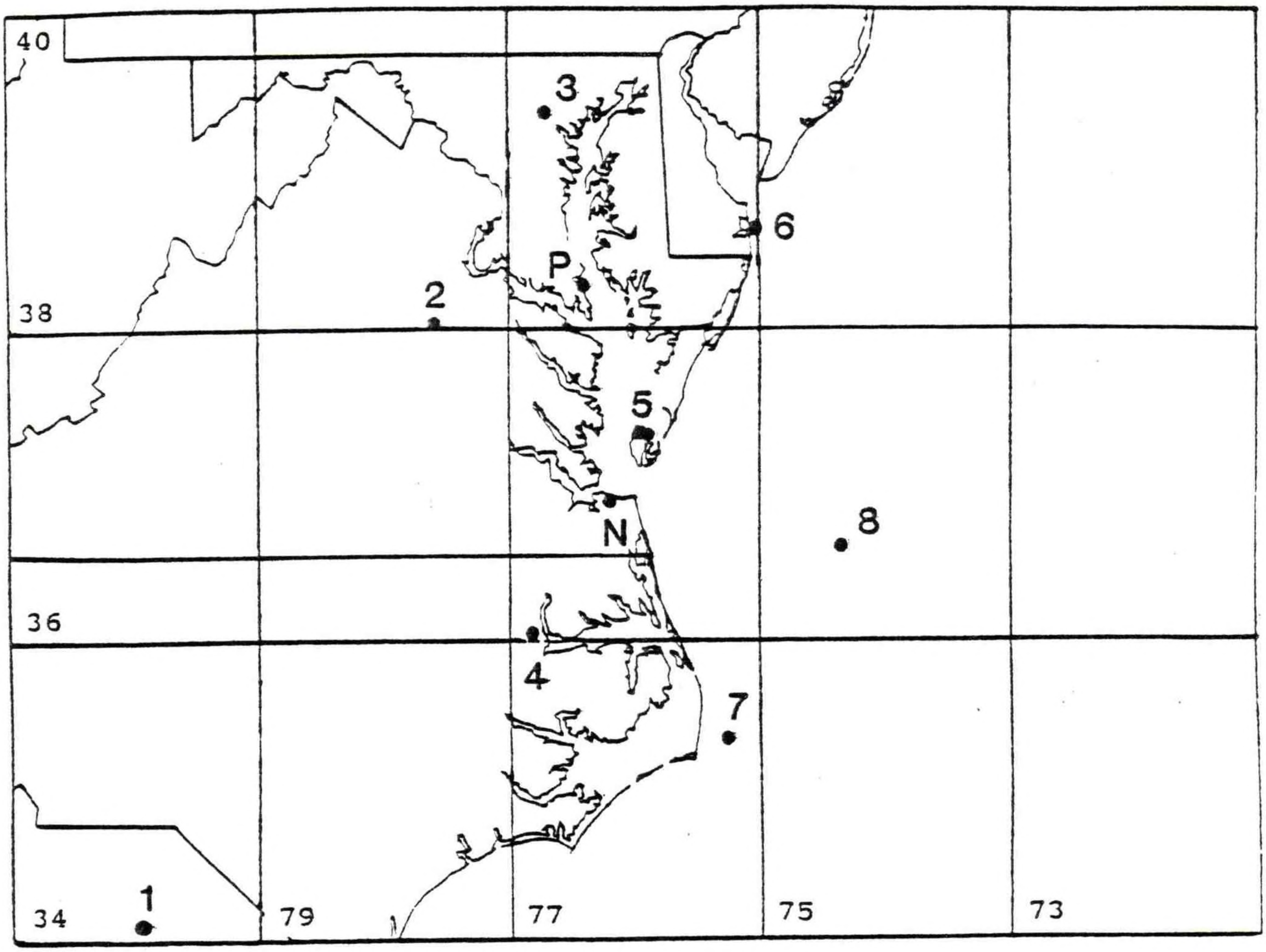

Figure 3. Map of Chesapeake Bay showing the location of the local LFM grid points 1 - 8 (●) and the Patuxent (P) and Norfolk (N) Naval Air Stations.

Table 1. Locations of LFM grid points (see Fig. 3) used in this study.

Point	North Latitude	West Longitude
1	34°06'39"	79°58'59"
2	38 02 13	77 35 32
3	39 21 22	76 41 57
4	36 02 59	76 49 17
5	37 20 14	75 56 43
6	38 37 40	75 01 06
7	35 20 45	75 15 18
8	36 36 19	74 20 57

Table 2. Overwater wind stations, locations, height above water, and period of data collection.

Station	North Latitude	West Longitude	Height (m)	Period (month/day)	Year
Pt. Lookout	38°01'36"	76°19'18"	11.0	9/3 - 12/2	81
Holland Is. Bar Light	38 04 06	76 05 48	10.5	8/29 - 12/2	81
York Spit	37 12 36	76 15 18	10.0	5/21 - 11/24	82
Windmill Pt.	37 35 48	76 14 12	13.0	5/17 - 7/10 8/8 - 9/27	82
Pooles Is.	39 15 42	76 16 42	10.0	3/19 - 4/14	83
Herring Bay	38 44 21	76 30 50	7.0	3/15 - 4/18 4/29 - 7/12 8/9 - 8/30 10/18 - 12/1	83

in the upper Bay at Pooles Island and at Herring Bay on the western side. The stations, their locations, and times the data were collected are shown in Table 2. The data used for this study were supplied by the National Oceanic and Atmospheric Administration's (NOAA's) National Oceanographic Data Center (NODC).

Observations from between 7 and 13 meters above the water surface were recorded every 10 minutes; each observation consisted of the time-averaged wind speed, the maximum wind speed over the 10-minute interval, and the instantaneous values of wind direction, air temperature, and barometric pressure. Speed was measured by a three-cup anemometer, and direction was measured by a wind vane. The temperature sensor was a thermal resistor, and the pressure sensor was an aneroid barometer.

Not all the data that were nominally collected during the survey were used for this study. The observations from 1983 (Pooles Island and Herring Bay) were not included in the NODC archive. Spot checks of the data for Point Lookout and Windmill Point revealed that there were large segments which contained spurious values, so the data from these stations were not used. The remaining data (Holland Island Bar Light and the York Spit) have been inspected for date continuity and outlying values and have been found acceptable.

2.3. Processing the Overwater Wind Data

The first step in the processing was filling in any data gaps. Occasionally gaps occurred between observation periods due to recording equipment changes. Missing data (for up to six consecutive time periods) were replaced by estimates found by linear interpolation between adjacent values.

After a set of continuous data was obtained, it was filtered to remove high frequency components. Filtered data should compare better with the model output, which does not have components at the highest frequencies because of the large interval between saved values (12 hours). The wind data (speed in m/s and direction in degrees, both to tenths) were first decomposed into u (eastward) and v (northward) components, then the components and the speed were filtered.

A computer program (Goodrich, unpublished) which applied a Lanczos filter was used, with a half-power point of 3 hours (i.e., the energy in components with a period of 3 hours are reduced by 50 percent; shorter period components are reduced more). A window of 10 hours was used. Although the filtering characteristics of this particular configuration are not known, we can estimate by analogy with information in Goodrich (1985) that components with periods of 2 hours or shorter will be completely eliminated, and components with periods of about 4 hours will be reduced by 95 percent.

2.4. Regression Analysis

Equations relating the observed wind data to a set of twice-daily independent LFM variables were obtained with a commercially-available stepwise regression procedure (SAS Institute, Inc., 1985). The LFM variables made available were the wind components, the wind speed, and the atmospheric pressure at the eight grid points closest to the study area (Fig. 3).

For the Holland Island Bar data, the nearest LFM grid points are 2, 3, 5, and 6 (locations are given in Table 1). For the York Spit data, the nearest two points are 4 and 5; points 1, 2, 7, and 8 are nearby (point 1 is the nearest land-based point to the south which is collected for the MEAD archive). The model data for each point, i, consists of the velocity components (U_i, V_i), the speed (S_i), and the atmospheric pressure (P_i).

The stepwise regression proceeds as follows. On the first pass, the single predictor variable (U_i, V_i, S_i, or P_i) which reduces the unexplained variance by the largest amount is selected, and the coefficient, intercept, and explained variance are calculated. On the second pass, the variable chosen in the first step is automatically used, and another variable which along with the first explains the most variance is selected. The process continues until all available variables have been selected. In each equation, the predictor variables are listed in the order of selection (Table 3). We have chosen the equation with at most three variables; application of the F test shows that these results are significant at or above the 98 percent confidence level.

3. RESULTS AND DISCUSSION

3.1. Influence of Filtering

The first test performed was an inspection of the regression equations for both unfiltered and filtered data for Holland Island Bar (Table 3). Although filtering generally improved the regression, the improvement was small (only a few percent); the filtering process is therefore not essential to obtaining useful results in this investigation.

Table 3. Comparison of regression equations for Holland Island Bar winds using unfiltered and filtered data, and for York Spit using filtered data. Here u and U are the eastward components of the overwater and the LFM winds, respectively; v and V the northward components of the overwater and the LFM winds, respectively; s and S the wind speeds of the overwater and the LFM winds, respectively. P is the surface atmospheric pressure, and the subscripts denote the grid location shown in Fig. 3. R^2 is the percentage of variance explained.

Filtering	Equations	R^2
Holland Island Bar Light		
Unfiltered	$u = -.30 + 0.38U_3 + 0.15V_2 + 0.35U_6$	69
	$v = 2.72 + 0.83V_2 - 0.90S_6 + 0.54S_5$	66
	$s = 2.11 + 0.40S_3 + 0.27S_6 + 0.08U_6$	50
Filtered	$u = -.30 + 0.41U_3 + 0.15V_2 + 0.33U_6$	71
	$v = 2.83 + 0.81V_2 - 0.83S_6 + 0.45S_2$	67
	$s = 2.33 + 0.62S_3 - 0.07V_5 + 0.07U_6$	50
York Spit		
Filtered	$u = 1.55 + 0.47U_5 - 0.728P_2 + 0.727P_1$	65
	$v = 2.65 + 0.42V_5 - 0.32S_4 + 0.42V_5$	64
	$s = 0.97 + 0.23S_5 + 0.39S_2 + 0.18S_1$	52

3.2. Results for Holland Island Bar and York Spit Winds

Results for the filtered Holland Island Bar and York Spit data are shown in Table 3. The equations are statistically significant and are acceptable for the following additional reasons. The amount of explained variance, 66 to 71 percent for the u and v components, is relatively high. The constant term in each equation is relatively small, indicating that predicted overwater winds will be small for light LFM winds. Also, in each case the first variable chosen from the LFM set matched the type of variable being regressed (i.e., in the u-equation, the first LFM variable was U), showing a basic consistancy in the selection process. The coefficient of the first LFM variable chosen was always less than unity, which is consistant with the fact that LFM winds are usually stronger than surface winds.

Some of the parameters warrent further explanation. At each location, the R^2 value for the u equation tends to be higher than that for the v equation. This is because the mean value of u is larger than the mean value of v (i.e., the tendency at this latitude for the winds to be from the west). Also, at each location the R^2 value for the speed equation is lower than those for the u and v equations, a common result in wind analysis. Finally, the two pressure variables in the York Spit u equation show the influence of the geostrophic wind as a predictor.

4. FUTURE PLANS

The next step in this study is to obtain observed hourly winds at Norfolk and Patuxent Naval Air Stations for the same time periods for which there are overwater wind observations. It may then be possible to find useful correlations between these data which would allow prediction of overwater winds on an hourly basis.

Further examination of the overwater wind data may lead to discovery of useful information in the two stations not used, Pt. Lookout and Windmill Pt. These data would give a better picture of the wind regime over the lower Bay.

With the information on winds at several overwater locations, it may be possible to generate a method for interpolating speeds and directions over the whole Bay, given either overland winds from a few stations or from LFM grid points.

5. ACKNOWLEDGMENTS

Dr. David Goodrich provided many valuable comments on the wind data, its quality, and methods of analysis. Mr. Robert Gelfeld of NODC supplied the overwater wind data used in this study, and Mr. David Browne of NOS supplied supplemental wind data. Drs. Celso Barrientos and David Johnson provided important insights into the regression process and the resulting equations.

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