AN IMPROVED OBJECTIVE METHOD FOR FORECASTING WIND VELOCITY OVER THE NORTH ATLANTIC OCEAN

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ABSTRACT

A more comprehensive objective wind velocity technique improves upon the current method by more than 20%. Mean geostrophic wind errors of 36 hour 1000 mb progs were determined for 5 knot wind categories. The results represent the combined effect of all wind-influencing factors and are shown to be functions of velocity and season.

1. INTRODUCTION

In the marine environment, wind velocity compared to other weather elements occupies a position of prime importance. Wind strength largely determines sea state and defines the limits of navigation to ocean-going vessels. Thus, the need for improving wind forecasts is a constant challenge to the marine meteorologist. If wind forecasts are to improve, then objective guidance must first improve. Today, objective forecasting techniques are generally accepted to be the nucleus of most forecasting systems.

The main objective guidance for forecasting oceanic winds at the Weather Service Forecast Office (WSFO) in Washington D.C. is the series of 1000 mb forecast charts commonly called surface progs. For the period of study, these progs were based on the National Meteorological Center's (NMC) Primitive Equation model (PE). The PE model underwent refinements and improvements through the years. In January of 1978 the six-layer (6LPE) was replaced by the finer scale seven-layer model (7LPE) (now replaced by the Spectral model). Quite likely the seven-layer PE was the reason for improved automated wind and wave forecasts in 1978 (2). The mean absolute errors (MAE) of both types of forecasts were lower that year than for any year since September 1973 when the verification program began. MAE scores continued low for automated wave forecasts in 1979 for the same reason (3).

The improvement process can be carried a step further by amending the current procedure of utilizing the surface prog. Instead of reducing geostrophic wind (V_g) by a constant 20% for friction, corrections varying with respect to wind magnitude and season were found to lower MAE scores significantly. These variables were developed empirically and represent the combined effect of several wind-influencing factors to be listed later. This paper treats the factors collectively as the apparent cause of forecast error characteristics. Studies regarding the performance of the Spectral model for oceanic wind forecasting have not been made. Nevertheless, results from a limited number of forecasts seem to be compatible with conclusions based on earlier guidance models.

The data base for this study was developed from verification logs of forecasts made by the Marine Section of the WSFO in Washington D.C. (1976-1980) (4). The dependent data covers the summer (June, July and August) and winter (December, January and February) beginning with the summer of 1976 and ending with the summer of 1979. There were 3,461 wind velocity forecast verifications during this time. Indepen- dent data consists of January and July of 1980 with 324 verifications.

2. DESCRIPTION OF CURRENT OBJECTIVE FORECAST AND VERIFICATION SYSTEM

From 36 hour surface progs, geostrophic winds are determined for 10 selected areas on the North Atlantic Ocean. These values are then reduced 20% to account for surface friction $0.80V_g$). The difference between forecast and observed values (F-O) is compiled and a monthly MAE is computed. For comparison, subjective forecasts are also verified at Washington's WSFO. Historically, these forecasts have been consistently 20% to 23% better than objective forecasts.

The 10 selected forecast areas of the North Atlantic are shown in Figure 1. Each circular area has a diameter of 5° latitude. To verify, at least 2 wind observations by merchant vessels must be received from within each of the circular areas. The average value of the observations is then compared with the objective forecast to determine forecast error. In mid 1980 forecast areas and wind categories were revised. Neither dependent nor independent data of this study were included under the revised format.

Because of such an extensive forecast area as portrayed in Figure 1, the number of verifications for any of the 10 forecasting locations is dependent upon season and latitude affecting speed, track and intensity of storms. Figure 2 illustrates the frequency distribution of forecast verifications as a percentage of total possible verifications. A peak in winter and a secondary peak in summer occurred at station 7 which is located near a confluence of shipping lanes to Europe and the Mediterranean. Note also that the location of maximum occurrences was farther south during winter than summer. This fact was likely a consequence of commercial shipping avoiding the major storm tracks of winter. The small number of verifications at some forecast locations may produce a bias in results of this study. Whether the results can be applied to other mid and high latitude oceanic locations remains to be determined.

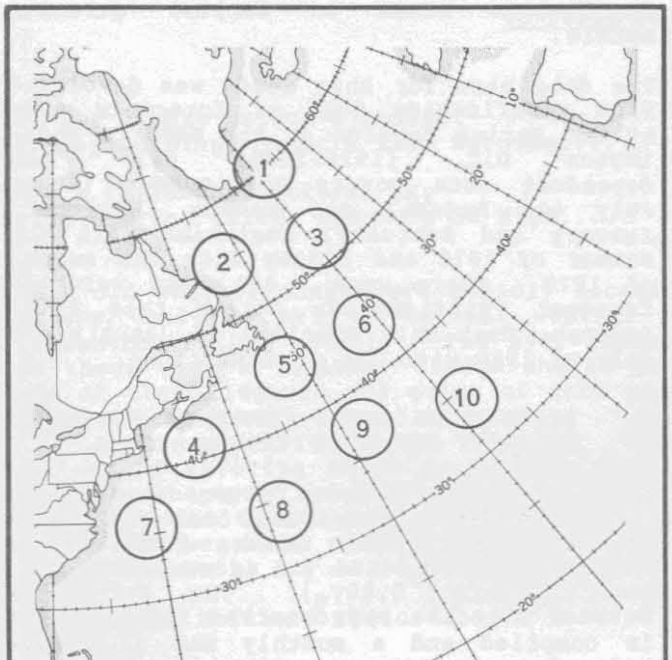

Figure 1. Location and size of areas designated by WSFO Washington for forecasting and verifying wind.

The necessity for recognizing seasonal influence on wind velocity becomes evident in Figure 3. Here, the average monthly total of gale force (34-47 knots) and storm force (48-63 knots) wind observations are shown. Obviously, there were well-defined periods of activity and inactivity on the North Atlantic from September 1973 through December 1979.

3. PROFILE OF CURRENT OBJECTIVE FORECAST ERRORS

Tables I and II show the frequency distribution and magnitude of objective forecast

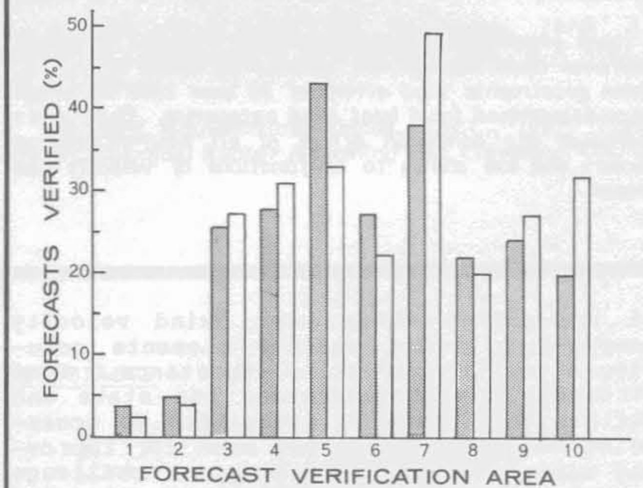

Figure 2. Frequency of verified wind forecasts as percentage of total forecasts for areas defined in Figure 1. Summer shown as shaded bars and winter, open bars for period Sept 1973-Dec 1979.

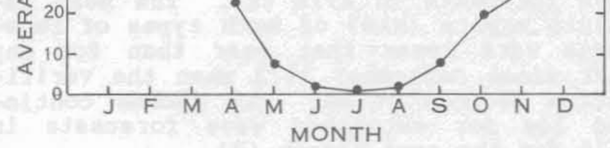

Figure 3. Monthly average wind verifications with gale or storm force velocity (34-63 knots), Sept 1973-Dec 1979.

Table I. Total summer occurrence and magnitude of objective forecast error for 5 knot wind categories, 1974-1979, showing corresponding mean error (F-O) and standard deviation (S_x).

FCST	ERROR (F - O)														A	B
(kt)	-35	-30	-25	-20	-15	-10	- 5	0	+ 5	+10	+15	+20	+25	+30	$(\overline{F-O})$	S_x
5				2	14	70	203	58							-5.66	4.09
10				3	4	56	235	357	83	5					-1.87	4.27
15					5	6	56	132	133	38	5	1			+1.93	5.25
20				1	3	3	12	29	53	33	3				+3.54	6.20
25						1	1	11	13	18	10				+7.04	5.81
30									5	12	9	2			+11.4	4.20
35									1	1		1			+11.7	6.24
40												1			+20.0	0.0

Table II. Total winter occurrence and magnitude of objective forecast error for 5 knot wind categories, 1974-1979, showing corresponding mean error (F-O) and standard deviation (S_x).

FCST	ERROR (F-O)														A	B
(kt)	-35	-30	-25	-20	-15	-10	- 5	0	+ 5	+10	+15	+20	+25	+30	$(\overline{F-O})$	S_x
5			3	7	14	28	41	1							-9.68	5.50
10	1		6	19	36	74	118	73	12						-7.01	6.58
15	1	1	2	2	28	41	68	83	45	6					-3.75	7.13
20				5	10	44	72	86	52	27	2				-1.64	6.88
25		1			5	20	39	63	40	33	6	1			+0.67	7.26
30		1	2	1	4	10	36	64	53	53	30	3	1		+3.45	8.23
35			1		1	2	7	13	31	19	16	7	2		+6.87	8.34
40			1		1	1	1	8	15	25	19	3	6		+9.56	8.49
45								2	6	4	10	5	7		+14.6	7.61
50									4	4	4	9	3	2	+16.7	7.33
55									1	1		2	2	2	+20.6	8.45
60												2			+20.0	0.0

errors for summer and winter respectively. Operationally, forecasts and verifications are made to the nearest 5 knots. Some of these 5 knot wind categories have a considerable range of error even though frequency at the extremes may be slight. To give consideration to all occurrences, the mean error for each category was determined (Column A). Corresponding Standard Deviations have been listed in Column B.

Figure 4 illustrates the distribution of objective forecast error with respect to $0.08V_g$. Departures from the smoothed curves were minor with the largest variations occurring at strong velocities. At this high range the number of verifications was small. The diagram shows that the objective wind forecasts were overforecast for winds 15 knots or greater in summer and 25 knots in winter, with errors larger in summer than in winter. This behavior seems consistent with the seasons; i.e., greater stability exists in summer because water temperatures are cooler than the air. Similarly, less stability is

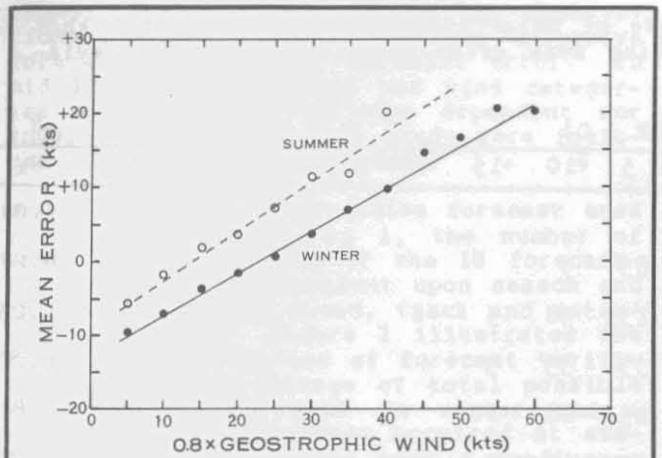

Figure 4. Mean error distribution of current objective wind forecast system (0.8 X 1000 mb geostrophic wind) for summer and winter, Sept 1973-Dec 1979.

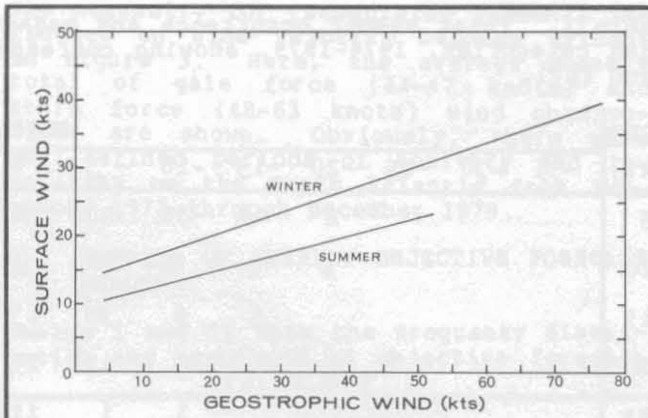

Figure 5. Nomogram for converting 1000 mb geostrophic wind to surface wind over the North Atlantic Ocean.

present during winter since air is colder than water and stronger winds aloft are more likely to be brought to the surface. Winds brought to the surface would have velocities more consistent with the 1000 mb gradient and result in smaller mean errors. (The term "stability" used in this paper refers to air-sea temperature differences rather than atmospheric stability). In the lower velocity range (15 knots or less) a reversal of error characteristics takes place: undercasting produces larger errors during winter. Since wind velocities less than 7 m/sec (13.6 knots) over water become aerodynamically smooth, wind energy is not transferrable to wavelets, the transfer medium (5). Thus, wind stress, equivalent to friction here, is diminished and stronger winds are observed than forecast. The small but relatively larger errors in winter at low wind speeds are likely indicative of gustiness which is proportionally larger at low velocities.

As previously stated, the distribution of objective forecast errors is regarded to be a function of the combined effect of various wind-determining factors. No attempt will be made to evaluate the weight of any separate influence. The following list provides the reader of possible contributing factors (6):

1. Observational errors and local wind speed differences
2. Geostrophic wind measurements
3. Curvature of isobars
4. Surface friction and stability
5. Isallobaric gradient
6. Difluence and confluence of isobars
7. Horizontal shear of geostrophic wind.

Of these variables, items 2, 3 and 4 are more practical to anticipate and therefore worthy of further study.

4. PROPOSED NOMOGRAM

Figure 5 shows the forecasting aid achieved by this study, illustrating the relationship of geostrophic wind to surface wind. Given a geostrophic wind value, the forecaster can read surface wind directly. The summer and winter curves are derived from data inherent to Figure 4. In the earlier diagram, observed wind, implied by the error for a given $0.08V_g$ speed, is plotted with respect to the corresponding full geostrophic wind speed. Selection of the proper curve is made on the basis of existing air and water temperature differences - air temperature warmer than water, use the "summer" curve, etc.

5. RELIABILITY OF THE NOMOGRAM

A study of winds over Lake Michigan by Strong and Bellaire (7) lends support to the probability that the error curves of Figure 4 are realistic. The two authors describe a linear increase of the ratio of geostrophic wind to ship wind (V_g/V_s) at speeds from 20 to 60 knots. (Values for V_s were estimated from the Strong and Bellaire curve.) Table III indicates that their ratios for very unstable conditions (Column b) are in good agreement with ratios derived from the winter curve of Figure 5 (Column d). Strong and Bellaire identify very unstable conditions to exist when air temperatures are more than 10°F colder than water temperatures. In this paper, the winter curve also represents colder air than water but without further definition.

With dependent data, Table IV shows improvement of the Nomogram over the exist-

Table III. Relationship of geostrophic wind (V_g) to ship wind (V_s) or surface wind (V_o) with respect to Strong and Bellaire's study and author's Nomogram.

1 MON/YR	2 PE MAE	3 NOMO MAE	4 % IMPRVMT OF NOMOGRAM SUM	5 % IMPRVMT OF NOMOGRAM WIN	6 SUBJ MAE
JUL 76	3.69	2.81	23.8		2.97
JAN 77	8.36	5.51		34.1	5.58
JUL 77	4.54	3.33	26.7		3.49
JAN 78	6.19	5.10		17.6	4.68
JUL 78	3.57	3.29	7.8		3.01
JAN 79	6.35	5.33		16.4	5.42
JUL 79	4.54	2.95	35.0		3.42
AVERAGE	5.32	4.05	23.3	22.7	4.08

Table IV. Mean absolute error (MAE) performance of proposed objective system (NOMO MAE) compared with current system (PE MAE) and subjective forecasts (SUBJ MAE).

	STRONG & BELLAIRE		NOMOGRAM	
	a	b	c	d
V_g	V_s	V_g/V_s	V_o	V_g/V_o
20	18.5	1.08	19.8	0.995
30	22.5	1.33	23.3	1.27
40	25.0	1.6	26.8	1.48
50	27.0	1.85	30.4	1.65
60	31.0	1.94	33.8	1.77

ing objective method. The PE's mean absolute errors for January and July (Column 2) are compared with errors that would be obtained by using the Nomogram (Column 3). The Nomogram's annual average is 23.8% better than the PE's. The table indicates that improvement was realized for both seasons in each year of the study. Interestingly, Table IV also shows that the average MAE of the Nomogram - 4.05 in Column 3 - approximates the average subjective MAE of the Washington forecasting staff - 4.08 in Column 6. Normally subjective forecasts have been better than objective ones.

The Nomogram was tested on an independent data sample as well and found to have a similar performance. The independent data included January and July of 1980 with the following MAE performance:

	PE MAE	NOMO. MAE	PERCENT IMPROVE-MENT
January 1980	7.83	5.60	28.5
July 1980	4.85	4.10	15.5
Average	6.34	4.85	23.5

6. CONCLUSIONS

By using the Nomogram developed in this study, mean absolute errors were more than 20% lower than values obtained by the existing objective method. These results applied to both dependent and independent data samples. The reliability of the proposed system easily lends itself to computer application. For weak or strong gradient areas where observations are scarce, the technique can be used to make forecasts with confidence. The computer-potential of this proposed system also allows determination of individual nomograms for each of the 10 forecasting areas if desired.

Subjective forecasts at WSFO Washington have been consistently better than objective forecasts in the past. Since the performance of the new objective system is equivalent to that of subjective forecasts now, perhaps subjective forecasts in the future can be improved accordingly.

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REFERENCES AND FOOTNOTES

1. Mr. Brown was serving as a marine forecaster at WSFO Washington at the time of his retirement in 1980. He has written a number of papers relating to marine weather, and saw extensive duty with the Atlantic Weather Patrol earlier in his career. Currently, he is a partner with Intercon Weather Consultants.

2. Pore, N. A., S. F. Brown, 1980a: Improvement in the National Weather Service's North Atlantic Wind and Wave Forecasts. Preprints Second Conference On Coastal Meteorology, Los Angeles, Amer. Meteor Soc., pp. 54-57.

3. Pore, N. A., S. F. Brown, 1980b: Improvement in the National Weather Service's North Atlantic Wave Forecasts. National Weather Digest, Vol. 5, No. 4, pp. 39-42.

4. Marine Forecast Verification Logs, 1976-1980, National Weather Service Forecast Office, Washington D.C.

5. Wu, Jin, 1969: On Wind-Wave Interactions. Tech. Report 23-27, Office of Naval Research, Dept. of the Navy.

6. Handbook on Wave Analysis and Forecasting, 1976: Wind-Field Analysis, Chapter 2, World Meteorological Organization, WMO-No. 446, 9pp.

7. Strong, A. E., F. R. Bellaire, 1965: The Effect of Air Stability on Wind and Waves. Pub. No. 13, Great Lakes Research Division, U. of Michigan, pp. 283-289.