ESSA WBTM TDL 34

A UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

ESSA Technical Memorandum WBTM TDL 34

U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
Weather Bureau

An Objective Method for Forecasting Winds Over Lake Erie and Lake Ontario

CELSO S. BARRIENTOS

Systems
Development Office

SILVER SPRING
MARYLAND

August 1970

ESSA TECHNICAL MEMORANDA

Weather Bureau, Techniques Development Laboratory Series

The primary purpose of the Techniques Development Laboratory of the Office of Systems Development is to translate increases in basic knowledge in meteorology and allied disciplines into improved operating techniques and procedures. To achieve this goal, TDL conducts and sponsors applied research and development aimed at improvement of diagnostic and prognostic methods for producing weather information. The laboratory carries out studies both for the general improvement of prediction methodology used in the National Meteorological Service System and for more effective utilization of weather forecasts by the ultimate user.

ESSA Technical Memoranda in the Weather Bureau Techniques Development Laboratory series facilitate rapid distribution of material which may be preliminary in nature and which may be published formally elsewhere at a later date. The first five papers in the TDL series are part of the former Weather Bureau Technical Notes series.

Papers listed below are available from the Clearinghouse for Federal Scientific and Technical Information, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, Va. 22151. Price: $3.00 hard copy; $0.65 microfiche. Order by accession number shown in parentheses at end of each entry.

TN 10 TDL 1 Objective Prediction of Daily Surface Temperature. William H. Klein, Curtis W. Crockett, and Carlos R. Dunn, October 1965. (PB-168 590)

TN 11 TDL 2 Hurricane Cindy Galveston Bay Tides. N. A. Pore, A. T. Angelo, and J. G. Taylor, September 1965. (PB-168 608)

TN 29 TDL 3 Atmospheric Effects on Re-Entry Vehicle Dispersions. Karl R. Johannessen, December 1965. (PB-169 381)

TN 45 TDL 4 A Synoptic Climatology of Winter Precipitation from 700-mb. Lows for the Intermountain Areas of the West. D. L. Jorgensen, W. H. Klein, and A. F. Korte, May 1966. (PB-170 635)

TN 47 TDL 5 Hemispheric Specification of Sea Level Pressure from Numerical 700-mb. Height Forecasts. William H. Klein and Billy M. Lewis, June 1966. (PB-173 091)

WBTM TDL 6 A Fortran Program for the Calculation of Hourly Values of Astronomical Tide and Time and Height of High and Low Water. N. A. Pore and R. A. Cummings, January 1967. (PB-174 660)

WBTM TDL 7 Numerical Experiments Leading to the Design of Optimum Global Meteorological Networks. M. A. Alaka and F. Lewis, February 1967. (PB-174 497)

WBTM TDL 8 An Experiment in the Use of the Balance Equation in the Tropics. M. A. Alaka, D. T. Rubsam, and G. E. Fisher, March 1967. (PB-174 501)

WBTM TDL 9 A Survey of Studies of Aerological Network Requirements. M. A. Alaka, May 1967. (PB-174 984)

WBTM TDL 10 Objective Determination of Sea Level Pressure from Upper Level Heights. William Klein, Frank Lewis, and John Stackpole, May 1967. (PB-179 949)

WBTM TDL 11 Short Range, Subsynoptic Surface Weather Prediction. H. R. Glahn and D. A. Lowry, July 1967. (PB-175 772)

WBTM TDL 12 Charts Giving Station Precipitation in the Plateau States from 700-Mb. Lows During Winter. D. L. Jorgensen, A. F. Korte, and J. A. Bunce, Jr., October 1967. (PB-176 742)

WBTM TDL 13 Interim Report on Sea and Swell Forecasting. N. A. Pore and W. S. Richardson, December 1967. (PB-177 038)

WBTM TDL 14 Meteorological Analysis of 1964-65 ICAO Turbulence Data. DeVer Colson, September 1968. (PB-180 268)

WBTM TDL 15 Prediction of Temperature and Dew Point by Three-Dimensional Trajectories. Ronald M. Reap, September 1968. (PB-180 727)

(Continued on inside back cover)

U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
Weather Bureau

ESSA Technical Memorandum WBTM TDL 34

AN OBJECTIVE METHOD FOR FORECASTING WINDS OVER LAKE ERIE AND LAKE ONTARIO

Celso S. Barrientos

Systems Development Office
Techniques Development Laboratory

Silver Spring, Md.
August 1970

UDC 551.509.322(285:71:73)

551.509.322	Wind forecasts
(285:71:73)	Great Lakes

CONTENTS

AN OBJECTIVE METHOD FOR FORECASTING WINDS OVER LAKE ERIE AND LAKE ONTARIO

Celso S. Barrientos

ABSTRACT

An objective method for forecasting surface winds over Lake Erie and Lake Ontario is presented. The developmental data consisted of 1000-mb geostrophic wind and sea-level pressure forecasts from the Subsynoptic Advection Model for eight United States cities near the two lakes, as well as marine observations made by anemometer-equipped vessels during the 1968 boating season. Two sets of regression equations for forecasting wind speed were derived by applying screening regression. The first yields wind speed by vectorial additon of two directional components; the second yields wind speed directly. Comparison further verifies that wind speed forecasts made by combining components are negatively biased. The resulting operational program is described, and plans for future development are discussed.

1. INTRODUCTION

One of the important marine weather problems in the area of the Great Lakes is the description and prediction of winds over the lakes. At synoptic times, the wind pattern over the land areas around the lakes is adequately described from land-based observations. However, over-water observations are deficient because of several logistical and technical difficulties. Some of these are: the observations are taken from irregularly spaced moving ships, the data are sparsely distributed both in time and space, some of the instruments are substandard, and the reports are delayed in transmission. As a result, the over-water wind is usually deduced from the land-based data.

There are various reasons why wind data over the lakes are desired. Foremost is the requirement of the lake forecaster for a good knowledge of the wind field to support his own service to the public. He should be able to provide wind, current, and wave forecasts to commercial shippers and recreational boaters. Also, he should be in a position to provide information on the water level fluctuations caused by wind which seriously affect navigation, water supply for power development, and other domestic uses, particularly on Lake Erie (Richardson and Pore 1969). Wind information is also important in studying many physical processes occurring over the lakes, for example, evaporation; the formation, movement, and dissipation of ice; air and water pollution; interface exchanges; etc.

In recent years, use of the Great Lakes for commercial shipping and recreational purposes has increased considerably. It is the responsibility of the Weather Bureau to provide users of the lakes with the marine forecasts necessary for their planning and safety. At the beginning of the 1968 Great Lakes boating season (April 1), the Chicago Weather Bureau Forecast Office

(WBFO) started issuing the Great Lakes marine forecasts (MAFORS). On October 17, 1968, the responsibility for issuing MAFORS for Lake Erie and Lake Ontario was transferred to the Cleveland WBFO. Subsequently, on April 1, 1969, the forecasting task for Lake Huron and Lake St. Clair was assigned to the Detroit WBFO.

This report gives the results of a study undertaken by the Marine Techniques Section, Techniques Development Laboratory (TDL), which was requested by the Weather Bureau Eastern Region. The main objective of the study was to derive a technique based on the Subsynoptic Advection Model (SAM) output for forecasting winds over Lake Erie and Lake Ontario. Details about SAM can be found in a recent paper by Glahn, Lowry, and Hollenbaugh (1969). The method developed is intended for use in issuing wind forecasts over the lakes. Our initial motivation was based on an assumption that a better wave forecast on the lakes would depend on the quality of the wind forecast. However, it is now apparent that the wind forecast over inland and coastal waters is, in itself, important, as discussed above.

The first step in any forecasting problem is to find suitable initial and boundary conditions. In the case of forecasting winds over the Great Lakes, a relationship between the over-land observations and the over-water winds has to be found in order to deduce the initial conditions over the water. Earlier studies have approached the problem of defining the over-lake wind by finding an empirical relationship between the winds over the water and the simultaneously observed winds over the land. This is generally accomplished by evaluating a wind ratio, $R = S_w/S_l$, where S_w is the wind speed over water and S_l the wind speed over land. The ratio R includes all the various influences which cause the wind over water to vary from wind over land, that is, difference in frictional effect between land and water, difference in processes at the interfaces, difference in atmospheric stability, etc. In a study of southwesterly winds on Lake Erie and their effect on set-up and seiche activity, Hunt (1958) was one of the first to employ the wind ratio technique. He used the data from commercial shipping for the navigation seasons of 1950-56 and found an average value for R of 1.59. Later study by Richards, Dragert and McIntyre (1966) produced an annual average value of 1.56 for R. Thus, if a good representation of the over-water wind as a function of the land-based data is found, the prediction problem may be properly treated.

There are three main statistical methods of developing objective forecast techniques (Klein 1969). These are: (1) the classical method, (2) the perfect prog method, and (3) the imperfect prog method. The first method requires only the initial conditions (analyses or observations) to give a forecast at some later time. The second method uses information at a later time, in addition to present and past data. The third method is similar to the second method but uses some forecast data in developing its objective technique.

The first and second methods employ a long period of observed historical data to develop the desired forecasting relationships. Examples of the classical method are the scatter diagrams used as local objective aids at many stations. The classical method was employed with marked success by Thompson (1950) in forecasting rainfall in the Los Angeles area.

A good example of the perfect prog method is the study by Richardson and Pore (1969) in predicting the abnormal water levels of Lake Erie at Buffalo and Toledo. They used sea-level pressure historical data to derive regression equations for forecasting the abnormal water levels. To implement their technique, forecast sea-level pressures were used in the computations of the predicted values.

Glahn, Lowry, and Hollenbaugh (1969) suggested the acronym MOS (Model Output Statistics) for the imperfect prog method, since it matches the output of numerical models with observations and then computes prediction equations. The imperfect prog method was used in deriving the probability of precipitation (PoP) during a 12-hour "today" period in winter as a function of saturation deficits and sea-level pressure predicted by SAM (Glahn and Lowry 1969). The third method has the distinct disadvantage that any changes in the model on which it is based will necessitate changes in the forecast procedure.

For this study the imperfect prog method was adopted. The development sample was made up of the 1968 marine observations (MAOBS) and SAM outputs. The MAOBS were matched with SAM data, and regression equations were derived. The method used and the results of the study are discussed in the following text.

2. DATA

The marine observations (MAOBS) were obtained from the National Climatic Center, Asheville, North Carolina. The MAOBS are those taken by anemometer-equipped vessels during the 1968 boating season. The vessels were participating in the Great Lakes observation program coordinated by the Cleveland WBFO since 1960. The data for Lake Erie and Lake Ontario were separated and edited; only those MAOBS with wave observations were used. The resulting developmental sample covers the period from April through November 1968.

The SAM forecasts are recorded on magnetic tapes. The "today" SAM forecasts for the period 07Z to 24Z have been saved since April 4, 1967. The "tonight" SAM forecasts covering the period 19Z to 12Z the following day have been available since June 8, 1968. Thirty-five meteorological variables for 228 cities in the area covered by SAM are recorded on the magnetic tapes. The data for eight of the cities were of interest to this study.

All eight of the cities are in the United States and are on the southern sides of the lakes (fig. 1). It is rather unfortunate that the data for some Canadian cities on the northern sides of the lakes have not been saved. In mid-1969 this situation improved considerably with the initiation of a TDL project called the Primitive Equation and Trajectory Model Output Statistics, better known by its acronym PEATMOS, which saves the data at grid points from the PE (Shuman and Hovermale 1968) and Trajectory (Reap 1968) models. An interpolation program is being developed which will give the desired values for any location within the United States.

3. DEVELOPMENT METHOD

The development problem was pursued along two different lines. The first line of approach was the single station method, whereby the relationship between a point on the lake and a station was established. The second approach was the pool method, or the generalized operator approach. The data were pooled, and one generalized relationship valid for different places was derived.

The pool method was adopted because the size of the developmental data sample was small. The method is advantageous in the sense that it increases the size of the development sample by pooling the data. However, the derived regression relationship is more general, with the result that some local effects are lost. As more data become available, the relationship can be modified and made more localized. For some areas, improvements are expected due to inclusion of more local parameters. The generalized operator approach was used in the work of Russo, Enger, and Merriman (1966) on prediction of precipitation probability. The same approach was adopted by Glahn and Lowry (1969) on operational forecasting of precipitation probability for 79 stations in the eastern United States.

A brief summary of the study which used the single station approach is included here as background information. As more data accumulate through the years, we will be refining our method, possibly toward the single station approach. Our discussion will begin with the single station approach and progress to the results of the generalized operator approach.

In processing the data, we used a multiple regression screening program which computes a sequence of multiple regression equations in a stepwise manner. At each step a variable is added to the regression equation. The variable added is the one which has the highest partial correlation with the dependent variable after having removed the effect of the variables which have already been selected. Further discussion of screening regression may be found in Klein (1965) and Glahn and Lowry (1969). The method was popularized by Miller (1958) and has been used in many forecasting problems in meteorology, for example, Klein, Lewis, and Crockett (1962), and Pore (1964).

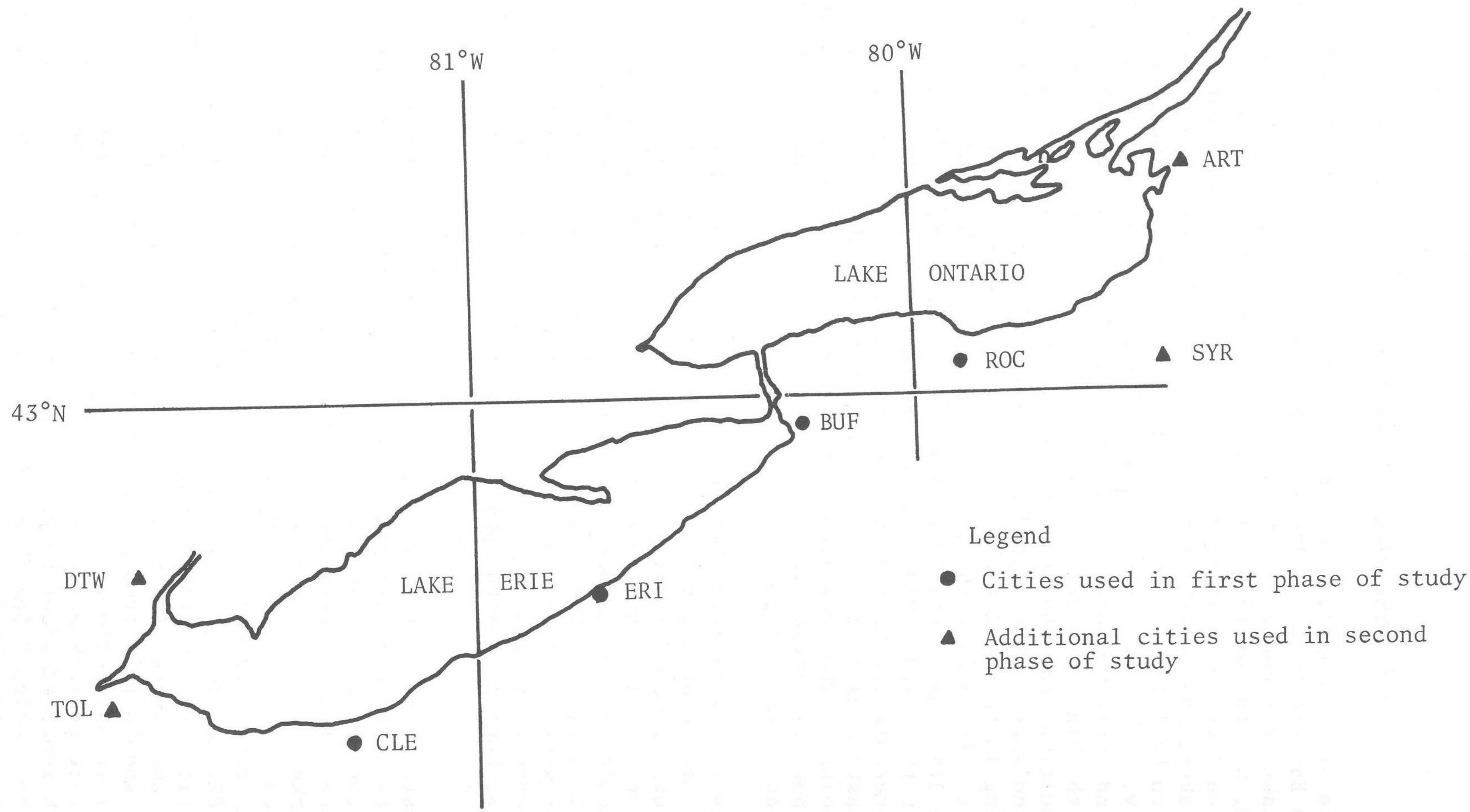

Figure 1. Orientation chart showing locations of cities and division of lakes.

3.1. The Single Station Approach

The single station approach was adopted following a suggestion by the Weather Bureau Eastern Region. The MAOBS were separated according to the locations on Lake Erie and Lake Ontario. The lakes were divided into halves; longitude 78°W. was the dividing line for Lake Ontario, and 81°W. longitude was the dividing line for Lake Erie. The dividing longitudes approximately bisected the lakes, and we will refer to the resulting parts as the eastern half and western half (fig. 1). The MAOBS, grouped by locations, were sorted chronologically. If there was more than one MAOB at one time, the one with the highest wind speed was used and the remainder removed from the sample. The MAOB with the highest wind speed was selected because it was desired that the method resulting from the study be able to predict the maximum rather than the average wind speed. The procedure was adopted since the requirement for wave forecasting is to predict the highest wave expected for the area covered by the forecast. Regression equations for predicting the winds for each half of each of the lakes were derived by using as predictors the SAM forecasts for the cities near the lakes. MAOBS for the eastern half of Lake Ontario were paired with forecasts for Rochester, the western half of Lake Ontario with Buffalo, the eastern half of Lake Erie with Erie, and the western half of Lake Erie with Cleveland. The locations of the four cities used in the first phase of study are shown by circles in figure 1. In the second phase of the research all eight cities shown in figure 1 were used.

Originally it was planned that the data for each half-lake would be further subdivided according to the difference between air and water temperatures. The grouping would implicitly introduce the air static stability consideration or seasonal characteristics of the atmosphere. The data for Lake Ontario could not be further subdivided in any manner because of the small number of available observations. Therefore, the Lake Ontario data for the entire year were processed together. The Lake Erie MAOBS were also few in number but were sufficient to allow processing in broad bimonthly groupings. These groupings, beginning with April-May, were made for both halves of Lake Erie.

The SAM data used as predictors in this analysis were the sea-level pressure and the 1000-mb geostrophic U (east-west) and V (north-south) components of the winds. These three variables for the eight cities shown in figure 1 were extracted from the SAM history tapes, and the data for the four cities marked by circles were used in the first phase of the study. MAOBS were taken at the four main synoptic times: 00Z, 06Z, 12Z, and 18Z. The "today" SAM forecasts were matched with the MAOBS at the three synoptic times: 12Z, 18Z, and 24Z (or 00Z the following day). Therefore, the forecasts are for different lengths of time. The time discrepancies in the forecasts were not considered; instead, they were treated equally. A more detailed study should further separate the data into times of observations and length of the forecast periods. To do this, different regression equations for different time periods would be used, for example, Glahn and Lowry (1969). The MAOBS which remained after being matched with "today" SAM forecasts were matched with the "tonight" SAM forecasts. These were mostly MAOBS for 06Z which were matched with the forecasts valid at 06Z. The "tonight" set of data for Lake Erie was processed separately. For Lake Erie, there were five sets of data for each half: four sets of "today" data, and one set of the "tonight" data. The screening program was used to derive regression equations of the following form:

$$Y = A_0 + A_1X_1 + A_2X_2 + A_3X_3$$

where Y is the dependent variable (predictand), X's are independent variables (predictors), A_0 is the constant (intercept), and the other A's are coefficients. The terms are arranged in the stepwise manner in which they were selected by the screening program.

3.2. The Generalized Operator Approach

The main problem in the single station approach was the lack of enough data to develop reliable regression equations. This situation could not be remedied in a short time. As an alternative approach, we decided to reduce the SAM data for the cities to forecast values on the lakes. Then we assumed that the forecasts and corresponding MAOBS were for the same locations on the lakes. If this were true, the predictand (observed wind) would bear the same relationship to the predictors (SAM reduced data) for all the locations on the lakes. We adopted this argument and derived a single relationship of the observed winds to the SAM forecast winds reduced for the lakes. Using this procedure, we combined the data for the two lakes and thus increased the size of the sample.

The new problem thus encountered was how to reduce the forecasts given for the cities to values over the lakes. In principle, this could be done by an interpolation-extrapolation procedure. A plane could be fitted to the forecast values at the cities, and then the value for the four points of interest over the lakes could be solved from the equation of the plane. This elaborate interpolation scheme was not adopted because it was felt that the interpolation procedure was not compatible in accuracy with the other assumptions already made. Instead we used the following subjectively determined equations to reduce the SAM forecasts for the cities to values for the lakes:

(a) East Side Ontario
SAM E Ontario = 0.34(ROC) + 0.33(ART) + 0.33(SYR)

(b) West Side Ontario
SAM W Ontario = 0.50(BUF) + 0.50(ROC)

(c) East Side Erie
SAM E Erie = 0.25(CLE) + 0.50(ERI) + 0.25(BUF)

(d) West Side Erie
SAM W Erie = 0.33(CLE) + 0.23(ERI) + 0.22(TOL) + 0.22(DTW)

where the following are the names and corresponding call letters of the cities to which reference is made: Watertown, New York (ART); Buffalo, New York (BUF): Cleveland, Ohio (CLE): Detroit, Michigan (DTW); Erie, Pennsylvania (ERI); Rochester, New York (ROC); Syracuse, New York (SYR); and Toledo, Ohio (TOL).

The largest sample is for West Erie with 324 pairs of MAOBS and SAM forecasts. The smallest sample is for West Ontario with 18. East Erie has 197, and East Ontario has 32. The total sample size for the two lakes is 571. Equations (a), (b), (c) and (d) were used to obtain the U_s and V_s components of the wind forecast by SAM over the lakes. The results of the U and V relationships to SAM U_s and V_s will be called run 1. In order to investigate whether or not a simpler interpolation might be better, two other runs were made. Run 2 made use of equations (a), (b), and (d), but changed (c) to

SAM E Erie = ERI

In run 2, 197 pairs of data were changed. In run 3, equations (a), (b), and (c) were used, but (d) was changed to

SAM W Erie = CLE

This meant changing the predictors of 324 samples that were used in run 1.

In each of the three runs the screening program was used to obtain two equations of the form:

$$U = A_o + A_1U_s + A_2V_s$$

$$V = B_o + B_1V_s + B_2U_s$$

where U and V are the forecast wind components over the half-lakes, U_s and V_s are the interpolated SAM forecasts, and A's and B's are constants.

4. RESULTS AND DISCUSSION

Tables 1 and 2 are the results of the computations which apply the single station approach. Table 1 consists of the regression equations which contain two predictors; table 2 contains the final regression equations with three predictors. The predictand Y's are the wind components and are denoted by "p" subscripts. All the predictors are the SAM forecasts; therefore, the "s" subscripts on the variables were omitted. In column 9, table 2, we included the increase in the reduction of variance by the addition of the third predictor. In comparing tables 1 and 2, note the small amount of improvement gained by the addition of a third predictor.

Table 1: Two-predictor regression equations for wind components over the lakes.

Location	No. of obs.	Y	A_0	A_1X_1	A_2X_2	Total red. of variance	Standard error (knots)
Ontario East-Rochester	32	U_p	-0.88	-0.58V	0.52U	0.66	6.02
		V_p	2.67	0.32U	0.24V	0.33	6.40
West-Buffalo	18	U_p	-1.29	0.59U	-0.72V	0.62	7.59
		V_p	-549.6	0.30U	0.539P	0.20	8.23
Erie-East Today-Erie April-May	42	U_p	1.65	0.49U	-0.44V	0.43	7.27
		V_p	-302.2	0.52U	0.299P	0.48	6.48
June-July	44	U_p	-525.4	0.50U	0.516P	0.40	6.82
		V_p	0.56	0.32U	0.28V	0.28	7.65
Aug.-Sept.	45	U_p	1.22	0.61U	-0.36V	0.61	6.37
		V_p	-2.04	0.64V	0.34U	0.59	5.98
Oct.-Nov.	26	U_p	-0.10	0.59U	-0.38V	0.73	6.17
		V_p	-2.61	0.71V	0.33U	0.68	8.40
Tonight East-Erie	40	U_p	-0.21	0.58U	-0.46V	0.44	7.11
		V_p	0.90	0.85V	0.35U	0.55	8.67
Erie-West Today-Cleveland April-May	66	U_p	0.92	-0.52V	0.49U	0.68	7.25
		V_p	-2.48	0.45V	0.46U	0.46	7.93
June-July	79	U_p	-0.85	0.69U	-0.63V	0.45	7.35
		V_p	-1.37	0.62V	0.36U	0.53	7.66
Aug.-Sept.	57	U_p	-1.04	0.72U	-0.61V	0.68	6.52
		V_p	0.54	0.66V	0.24U	0.32	9.33
Oct.-Nov.	53	U_p	1.65	0.64U	-0.30V	0.55	9.55
		V_p	-7.16	0.81V	0.44U	0.66	8.54
Tonight West-Cleveland	69	U_p	0.97	0.54U	-0.33V	0.50	6.87
		V_p	-2.18	1.09V	0.40U	0.63	7.78

Table 2: Three-predictor regression equations for wind components over the lakes.

Location	No. of obs.	Y	A_0	A_1X_1	A_2X_2	A_3X_3	Total red. of variance	Further red. var. 2-3 predictors	Standard error (knots)
Ontario East-Rochester	32	U_p	374.2	-0.57V	0.44U	-0.368P	0.69	.03	5.76
		V_p	-26.4	0.33U	0.24V	0.028P	0.33	.00	6.39
West-Buffalo	18	U_p	-600.0	0.65U	-0.68V	0.588P	0.67	.05	7.07
		V_p	-563.4	0.30U	0.552P	0.05V	0.20	.00	8.21
Erie-East Today-Erie April-May	42	U_p	143.4	0.47U	-0.41V	-0.139P	0.44	.01	7.23
		V_p	-236.9	0.47U	0.234P	0.12V	0.50	.02	6.36
June-July	44	U_p	-504.9	0.61U	0.496P	-0.35V	0.47	.07	6.41
		V_p	212.0	0.31U	0.27V	-0.208P	0.30	.02	7.57
Aug.-Sept.	45	U_p	680.6	0.55U	-0.31V	-0.667P	0.64	.03	6.11
		V_p	502.0	0.67V	0.30U	-0.495P	0.62	.03	5.83
Oct.-Nov.	26	U_p	246.0	0.58U	-0.34V	-0.242P	0.74	.01	6.09
		V_p	504.0	0.79V	0.31U	-0.498P	0.70	.02	8.13
Tonight East-Erie	40	U_p	554.2	0.51U	-0.40V	-0.544P	0.51	.07	6.71
		V_p	43.9	0.85V	0.35U	-0.042P	0.55	.00	8.67
Erie-West Today-Cleveland April-May	66	U_p	124.6	-0.51V	0.47U	-0.122P	0.68	.00	7.22
		V_p	-58.5	0.45V	0.47U	0.055P	0.46	.00	7.92
June-July	79	U_p	-136.1	0.71U	-0.63V	0.133P	0.45	.00	7.35
		V_p	-153.3	0.61V	0.38U	0.149P	0.53	.00	7.64
Aug.-Sept.	57	U_p	281.7	0.68U	-0.62V	-0.277P	0.68	.00	6.48
		V_p	-353.52	0.68V	0.29U	0.347P	0.33	.01	9.27
Oct.-Nov.	53	U_p	266.3	0.62U	-0.30V	-0.260P	0.56	.01	9.46
		V_p	-173.8	0.81V	0.45U	0.164P	0.67	.01	8.49
Tonight West-Cleveland	69	U_p	349.7	0.50U	-0.31V	-0.342P	0.52	.02	6.70
		V_p	-240.7	1.07V	0.43U	0.234P	0.63	.00	7.72

Table 2 shows that in 21 of 24 equations the sea-level pressure was the last predictor selected. In most sets of data, the first predictor selected by the program was the same wind component that the SAM had forecast for the corresponding city. The reductions of variance were not high. It should be noted that the number of observations for each set of data was small; therefore, the confidence intervals were large. This is the main reason why the single station approach was not adopted.

Table 3 shows the results of the three runs in which the generalized operator approach was used. Run 1 had the highest correlation coefficient, followed by runs 3 and 2 in that order. The differences in the results between runs are fairly small. The east-west wind component U has a higher total reduction of variance than the north-south wind component V in all three runs. All the regression equations have as the first predictor the same SAM variable as the predictand (i.e., U_s to U).

We do not yet have independent data to test the forecast equations. Therefore, we tested the results on dependent data. We divided the data according to the four locations on the lakes and applied the equations from run 1, since they had the highest total reductions of variance. Results of the test of the prediction equations on dependent data are shown in table 4.

Two scatter diagrams of observed wind component are shown in figures 2 and 3. The figures are for western Lake Erie U and V components, respectively. In both figures the ordinate is the observed wind component, and the abscissa is the value predicted by run 1. The figures illustrate good correlation between the observed wind components and the forecast wind components.

A regression equation for predicting the total wind speed directly, rather than computing the forecast wind components was also derived. The same data used in the pool method were used to derive the following equation:

$$S = 7.73 + 0.481S_s - 0.116V_s$$

where S is the total wind speed, S_s is the interpolated SAM wind speed forecast and V_s is the SAM north-south component forecast. The multiple correlation coefficient of the speed equation is 0.56. This value is smaller than the values associated with the individual components equations.

We now have two methods of forecasting the wind speed: (1) the components method, which predicts the two components first and computes the wind speed by vectorial addition, and (2) the direct or total method, whereby the wind speed is predicted directly by a regression equation. Due to inherent variabilities in any statistical method of forecasting, the components method will tend to underforecast the wind speed (Glahn 1970). Each component equation is associated with a certain variance. If the two components are added vectorially, the resultant speed will tend to be biased negatively. This is confirmed by the values shown in table 5, which are based on dependent data. All values are expressed in knots.

Table 3: Wind forecast equations obtained applying the generalized operator approach

Run 1

	U	V
Total reduction of variance	.5682	.4424
Multiple correlation coefficient	.7538	.6651
Standard error (in knots)	7.33	8.64

$$U_o = 0.731 + 0.587U_s - 0.478V_s$$

$$V_o = -1.338 + 0.550V_s + 0.354U_s$$

Run 2

	U	V
Total reduction of variance	.5585	.4199
Multiple correlation coefficient	.7473	.6480
Standard error (in knots)	7.41	8.81

$$U_o = 1.012 + 0.569U_s - 0.473V_s$$

$$V_o = -1.414 + 0.508V_s + 0.346U_s$$

Run 3

	U	V
Total reduction of variance	.5622	.4315
Multiple correlation coefficient	.7498	.6569
Standard error (in knots)	7.38	8.73

$$U_o = 0.637 + 0.585U_s - 0.467V_s$$

$$V_o = -1.223 + 0.557V_s + 0.344U_s$$

Table 4: Test of the prediction equations on dependent data

Location	Number of samples	Predictand	Reduction of variance	Correlation coefficient
East Ontario	32	U	0.624	.7897
		V	0.305	.5522
West Ontario	18	U	0.618	.7862
		V	0.234	.4838
East Erie	197	U	0.548	.7401
		V	0.415	.6445
West Erie	324	U	0.572	.7565
		V	0.505	.7105

Figure 2: Scatter diagram of observed and predicted U wind components for west Lake Erie. The diagram is for the dependent data from April through November 1968.

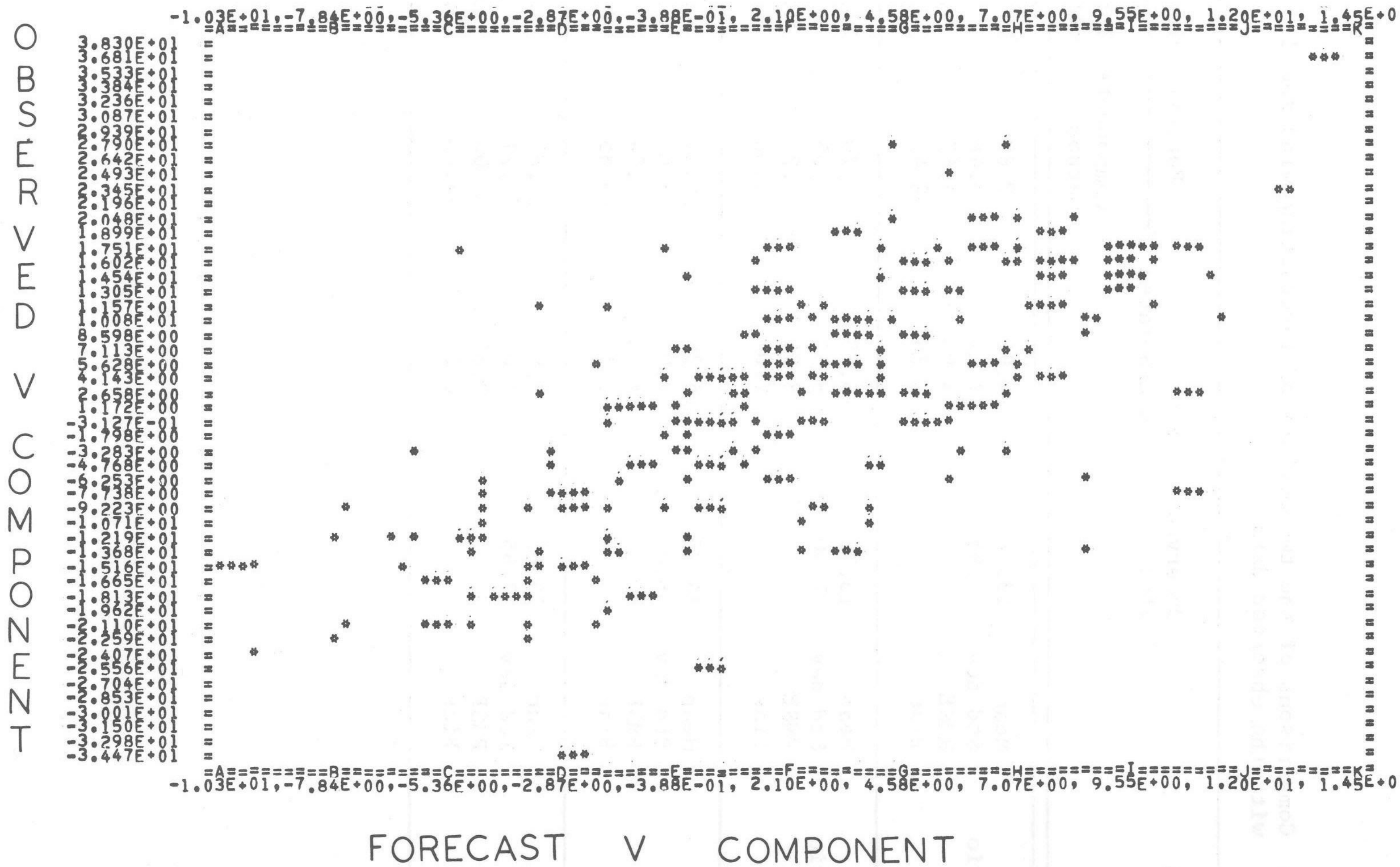

Figure 3: Scatter diagram of observed and predicted V wind components for west Lake Erie. The diagram is for the dependent data from April through November 1968.

Table 5: Comparisons of the two methods of forecasting wind speed with the observed data

Location		Observed wind	SAM interpolated	Forecast wind: Components method	Forecast wind: Total method
	Mean	13.16	14.92	10.69	15.23
East Ontario	Std dev	5.95	7.11	5.48	4.02
(32 Obs)	RMSE		4.93	4.67	4.60
	Bias		1.76	-2.47	2.07
	Mean	13.78	15.78	11.20	15.36
West Ontario	Std dev	7.30	8.52	5.85	4.15
(18 Obs)	RMSE		8.98	8.23	7.57
	Bias		2.00	-2.58	1.58
	Mean	14.25	15.38	10.40	14.80
East Erie	Std dev	6.99	9.01	6.07	4.24
(197 Obs)	RMSE		8.46	7.54	5.98
	Bias		1.13	-3.85	0.54
	Mean	15.65	15.94	10.85	15.03
West Erie	Std dev	7.85	9.00	6.21	4.24
(324 Obs)	RMSE		7.87	8.03	6.34
	Bias		0.29	-4.80	-0.62

Several points should be noted concerning table 5. The means of the SAM interpolated forecasts over the lakes are nearly the same as the observed mean wind speed. A modified wind ratio R (R = observed wind/SAM interpolated wind), is nearly unity. We should remember that the SAM wind is the 1000-mb geostrophic, which is larger than the true surface wind. We can examine closely the two locations on Lake Erie because the sample sizes are adequate. The RMSE's by the components method are about 1.5 knots higher than by the total method. The components method underforecast by about four knots, while the total method has a bias of less than one knot. This underforecasting of the wind speed by the components method is real, as shown by Glahn (1970).

The component regression equations from the generalized operator approach were put into operation at NMC in Suitland on December 9, 1969. (We might point out that the results shown in table 5 were not available when the program became operational). The component method was subsequently replaced by the total wind speed method on May 5, 1970. A message is sent twice a day to WBFO Cleveland via RAWARC Teletypewriter Circuit. A sample forecast message for one day is shown in figure 4. The forecasts are coded in ddff format, where dd is the direction from which the wind is coming in tens of degrees, and ff is the wind speed in whole knots. If the wind is 100 knots or greater, 50 is added to dd, and ff is the wind speed in excess of 100. The forecasts are for every three hours for five forecast times and are based on the latest available SAM forecasts. For example, the forecast for 1200Z on the "today" message is based on the SAM run made only 4 hours earlier. Therefore, we expect the technique to have fairly good skill.

5. FUTURE PLANS

We plan to verify the regression equations with the 1969 MAOBS. The wind speed forecasts will continue to be made by the total wind speed regression equation method. The component regression equations will only be used in forecasting the wind direction.

The 1968 and 1969 MAOBS will be used to derive new sets of regression equations. We are investigating the possibility of using more predictors from SAM and the PE models, for example, winds for higher levels, temperature difference between the surface and 850 mb, etc.

We plan to have an operational wind forecast system for all of the Great Lakes similar to the one now used for Lake Erie and Lake Ontario. Parallel with the wind forecast technique development, we are investigating the wave forecasting problems on the Great Lakes. We will examine present methods of wave forecasting and possible modifications of them. We will also investigate the need for developing a new wave forecasting method for the lakes.

ACKNOWLEDGMENTS

The author is deeply grateful to Dr. H. R. Glahn, Mr. N. A. Pore, Lt. J. M. McClelland, USESSA, and Mr. W. S. Richardson for their helpful review of the report. Mr. G. Hollenbaugh assisted in collection of developmental data. Miss M. Dalton, Mr. H. Perrotti, Miss M. Torchinsky and Mrs. R. C. Lopresti prepared the manuscript for printing.

FZUS2 KWBC 220700

WIND FORECASTS LAKES ERIE AND ONTARIO BASED ON SAM TODAY

LOCATION	1200Z	1500Z	1800Z	2100Z	2400Z
EAST ONTARIO	2719	2819	2817	2815	2811
WEST ONTARIO	2719	2716	2712	2708	2403
EAST ERIE	2612	2508	2103	1306	1213
WEST ERIE	2306	1804	1309	1217	1125

FZUS2 KWBC 221900

WIND FORFCASTS LAKES ERIE AND ONIARIO BASED ON SAM IONIGHT

LOCATION	2400Z	0300Z	0600Z	0900Z	1200Z
EAST ONTARIO	2807	2704	1503	1313	1324
WEST ONTARIO	2602	1206	1217	1228	1336
EAST ERIE	1214	1222	1229	1331	1429
WEST ERIE	1225	1230	1331	1427	1622

Figure 4: Teletypewriter message produced by the operational program for April 22, 1970.

REFERENCES

Glahn, H. R., "A Method for Predicting Surface Winds," ESSA Technical Memorandum WBTM TDL 29, March 1970, 18 pp.

Glahn, H. R., and D. A. Lowry, "An Operational Method for Objectively Forecasting Probability of Precipitation," ESSA Technical Memorandum WBTM TDL-27, October 1969, 24 pp.

Glahn, H. R., D. A. Lowry, and G. W. Hollenbaugh, "An Operational Subsynoptic Advection Model," ESSA Technical Memorandum WBTM TDL 23, July 1969, 26 pp.

Hunt, I. A., "Winds, Wind Set-Ups, and Seiches on Lake Erie," Paper presented to Second National Conference in Applied Meteorology, Engineering, September 10, 1958, 37 pp.

Klein, W. H., "Application of Synoptic Climatology and Short-Range Numerical Prediction to Five-Day Forecasting," Research Paper No. 46, Weather Bureau, June 1965, 109 pp.

Klein, W. H., "The Computer's Role in Weather Forecasting." Paper presented at the 1969 Meteorological Technical Exchange Conference, July 14-17, 1969, Colorado Springs, Colorado, Air Weather Service Technical Report 217, pp. 144-153.

Klein, W. H., B. M. Lewis, and C. W. Crockett, "Objective Forecasts of Daily and Mean Surface Temperature," Monthly Weather Review, Vol. 90, No. 1, January 1962, pp. 11-17.

Miller, R. G., "The Screening Procedure" (in "Studies in Statistical Weather Prediction"), Final Report, Contract No. AF19 (604)-1590 (Edited by B. Shorr), The Travelers Research Center, Inc., Hartford, Conn., December 31, 1958, pp. 86-95.

Pore, N. A., "The Relation of Wind and Pressure to Extratropical Storm Surges at Atlantic City," Journal of Applied Meteorology, Vol. 3, No. 2, April 1964, pp. 155-163.

Reap, R. M., "Prediction of Temperature and Dew Point by Three-Dimensional Trajectories," ESSA Technical Memorandum WBTM TDL 15, September 1968, 20 pp.

Richards, T. L., H. Dragert, and D. R. McIntyre, "Influence of Atmospheric Stability and Over-Water Fetch on Winds Over the Lower Great Lakes," Monthly Weather Review, Vol. 94, No. 7, July 1966, pp. 448-453.

Richardson, W. S., and N. A. Pore, "A Lake Erie Storm Surge Forecasting Technique," ESSA Technical Memorandum WBTM TDL 24, August 1969, 23 pp.

Russo, J. A., I. Enger, and G. T. Merriman, "A Statistical Approach to the 12-48-hr. Prediction of Precipitation Probability," Final Report, Contract Cwb-11100, The Travelers Research Center, Inc., Hartford, Conn., August 1966, 107 pp.

Shuman, F. G., and J. B. Hovermale, "An Operational Six-Layer Primitive Equation Model," Journal of Applied Meteorology, Vol. 7, No. 4, August 1968, pp. 525-547.

Thompson, J. C., "A Numerical Method for Forecasting Rainfall in the Los Angeles Area," Monthly Weather Review, Vol. 78, No. 7, July 1950, pp. 113-124.

(Continued from inside front cover)

WBTM TDL 16 Objective Visibility Forecasting Techniques Based on Surface and Tower Observations. Donald M. Gales, October 1968. (PB-180 479)

WBTM TDL 17 Second Interim Report on Sea and Swell Forecasting. N. A. Pore and Lt. W. S. Richardson, USESSA, January 1969. (PB-182 273)

WBTM TDL 18 Conditional Probabilities of Precipitation Amounts in the Conterminous United States. Donald L. Jorgensen, William H. Klein, and Charles F. Roberts, March 1969. (PB-183 144)

WBTM TDL 19 An Operationally Oriented Small-Scale 500-Millibar Height Analysis. Harry R. Glahn and George W. Hollenbaugh, March 1969. (PB-184 111)

WBTM TDL 20 A Comparison of Two Methods of Reducing Truncation Error. Robert J. Bermowitz, May 1969. (PB-184 741)

WBTM TDL 21 Automatic Decoding of Hourly Weather Reports. George W. Hollenbaugh, Harry R. Glahn, and Dale A. Lowry, July 1969. (PB-185 806)

WBTM TDL 22 An Operationally Oriented Objective Analysis Program. Harry R. Glahn, George W. Hollenbaugh, and Dale A. Lowry, July 1969. (PB-186 129)

WBTM TDL 23 An Operational Subsynoptic Advection Model. Harry R. Glahn, Dale A. Lowry, and George W. Hollenbaugh, July 1969. (PB-186 389)

WBTM TDL 24 A Lake Erie Storm Surge Forecasting Technique. William S. Richardson and N. Arthur Pore, August 1969. (PB-185 778)

WBTM TDL 25 Charts Giving Station Precipitation in the Plateau States From 850- and 500-Millibar Lows During Winter. August F. Korte, Donald L. Jorgensen, and William H. Klein, September 1969. (PB-187 476)

WBTM TDL 26 Computer Forecasts of Maximum and Minimum Surface Temperatures. William H. Klein, Frank Lewis, and George P. Casely, October 1969. (PB-189 105)

WBTM TDL 27 An Operational Method for Objectively Forecasting Probability of Precipitation. Harry R. Glahn and Dale A. Lowry, October 1969. (PB-188 660)

WBTM TDL 28 Techniques for Forecasting Low Water Occurrences at Baltimore and Norfolk. Lt. (jg) James M. McClelland, USESSA, March 1970. (PB-191 744)

WBTM TDL 29 A Method for Predicting Surface Winds. Harry R. Glahn, March 1970. (PB-191 745)

WBTM TDL 30 Reserved.

WBTM TDL 31 Persistence of Precipitation at 108 Cities in the Conterminous United States. Donald L. Jorgensen and William H. Klein, May 1970.

WBTM TDL 32 Computer-Produced Worded Forecasts. Harry R. Glahn, June 1970.

WBTM TDL 33 Calculation of Precipitable Water. L. P. Harrison, June 1970.