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GREAT LAKES NEARSHORE WIND PREDICTIONS FROM GREAT LAKES MOS WIND GUIDANCE

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ABSTRACT

Marine forecasters on the Great Lakes are charged with the responsibility of forecasting wind conditions over the lakes and near the shore. Ship reports and forecast guidance are available for wind conditions which occur 5 or more n mi from shore, and wind observations are available at the coast, but little objective guidance is available within 5 n mi of the shore. This report attempts to fill that void.

Winds at selected coastal stations have been compared and related to winds over the Great Lakes near those stations. Statistical relationships have been derived for various stratifications of the data, and a procedure has been developed to forecast coastal winds from wind forecast guidance over the lakes under specific conditions. The capabilities and limitations of the procedure are discussed, and examples of its use are given.

1. INTRODUCTION

Marine forecasters on the Great Lakes are charged with the responsibility of forecasting wind conditions over the lakes and near the shore. Ship reports and forecast guidance are available for wind conditions which occur 5 or more n mi from shore, and wind observations are available at the coast at many Marine Reporting Stations (MARS). However, little objective forecast guidance is available for the nearshore (within 5 n mi of the lake shore) region. This report is an attempt to provide additional guidance for the nearshore and coastal areas of the Great Lakes.

Winds at coastal stations shown in Fig. 1 have been compared and related to winds over the Great Lakes. The Great Lakes have been divided into 12 sectors (also shown in Fig. 1) which are identical to the sectors used for the Model Output Statistics (MOS) forecast guidance over the lakes. The sectors are described more fully by Feit and Barrientos (1974). The coastal station winds have been statistically related to the overlake winds in the sector nearest the coastal station for various stratifications of the data, and a procedure has been developed to forecast coastal winds from the MOS wind forecast guidance under specific conditions. Not all conditions can be forecast from the information in this report. The capabilities and limitations of the forecast procedure are discussed, and examples of its use are given.

I have included a selected bibliography as an Appendix to provide sources for additional information of interest to Great Lakes forecasters. The bibliography is not exhaustive, but it does contain many major works on Great Lakes forecasting or climatology which are readily accessible from professional journals or other widely distributed publications.

2. DATA

A. Coastal Data

MARS data for coastal stations around the Great Lakes have been archived by the Techniques Development Laboratory since March 1980. For this study, data for calendar year 1981 were used. Only stations with reasonably good exposures were chosen. Fig. 1 shows the station locations and call letters. Also shown are the 12 lake sectors for MOS wind guidance and their centers. Only observations for 0000, 0600, 1200, and 1800 GMT were used, so the MARS and ship observations could be matched. Table 1 gives the names, call letters, locations, and elevations above mean sea level for MARS and lake sector center positions.

B. Ship Data

Only data from ships in the Great Lakes Marine Observation (MAOB) Program were used. These data were treated as if they were observed at the center of the lake sector; in actuality, they may have been observed in any part of the sector. The data were sorted and filtered so that only one observation in any given sector was used for a particular synoptic hour (0000, 0600, 1200, and 1800 GMT). If more than one observation occurred in a sector for a given time, the observation with the highest wind speed was used. This procedure is the same one used to derive the MOS wind forecast equations for the Great Lakes. For further details see National Weather Service (1983).

C. Data Matching

Table 2 shows the data used to determine the matched sample. Given are the call letters of the MARS stations, the sample size for each station's data, the name of the MOS lake sectors, the sample size of the MAOB data for each sector, and the matched sample size for each station. In each sector, ship data have been matched with data for each station. The total number of matched observations was 2762.

D. Data Stratification

Data were stratified into three categories: (1) $\theta_d \leq 90°$, where θ_d is the difference in degrees between the wind direction over the lake (MAOB ship observation), θ_L, and the wind direction at the coast (MARS observation), θ_c; (2) $\theta_d > 90°$; and (3) s_L and/or $s_c = 0$, where s_L is the wind speed over the lake, and s_c is the wind speed at the coast.

Category (1) was further divided into three groups: θ_L onshore, θ_L offshore, or θ_L parallel with the shore. Table 3 gives the wind directions at each station necessary for θ_L to be considered onshore, offshore, or parallel with shore. Each group was divided into subgroups according to whether $s_c \leq s_L$, or not. Catgory (2) was divided into two groups depending on whether $s_c \leq s_L$ or not, and category (3) was divided into three groups: $s_L = 0$, $s_c = 0$, and $s_c = s_L = 0$.

E. Computed Parameters

Two parameters were computed from raw data: the air/lake temperature difference ($\Delta T = T_a - T_L$) and the ratio of s_c to s_L (R_c). ΔT is used to relate stability to wind speed and direction. R_c is used to compute s_c from s_L. I also computed the difference of θ_c with respect to θ_L. I planned to develop a correction factor ($\Delta\theta$) for θ_L, so θ_c could be computed from it; however, the variance of $\Delta\theta$ was large compared to the mean. Therefore, $\Delta\theta$ would have been of little practical value, so its computation has not been included in the report.

Air-Lake Temperature Difference

In order to compute ΔT, 99 observations were dropped from the matched sample because of missing air and/or lake temperatures. This reduced the sample size to 2663. ΔT ranged from -26.0°C to 20.0°C with a mean of 0.66°C and standard deviation of 5.06°C for the sample.

Ratio of Coastal Wind Speed to Overlake Wind Speed

R_c (s_c/s_L) is the inverse of the ratio (R) used by Richards et al. (1966) and Phillips and Irbe (1978). Their intent was to determine the overlake wind by using the overland wind. My intent is the reverse. Their restrictions on how R is computed are more stringent than mine. For example, Richards et al. (1966) computed R only if the wind directions were within 30° of each other. I have computed R_c whenever $\theta_d \leq 90°$. I did so because the sample size was larger and most frontal systems were excluded. Richards et al. (1966) also stratified their data by fetch length but found that R changed little with fetch length greater than 25 n mi. I have not stratified by fetch length because the distances between most of the MARS locations and the MOS sector centers are greater than 25 n mi, the ship data are assumed to occur at the sector centers, the MOS forecasts are for the sector centers, and the sample size remains large. Richards et al. (1966) only investigated winds which blew from shore onto the lake. I have investigated winds blowing offshore and onshore. The characteristics of each is somewhat different and must be known in order to forecast nearshore winds. They did not stratify the winds according to whether $s_c \leq s_L$ or not. To aid forecasters, I stratified.

It should be noted that, for wind speeds above 16 kt, Richards et al. (1966), Resio and Vincent (1977), and Phillips and Irbe (1978) found R approaches 1.0. This is not the case with the MARS data. The reason is that the MARS wind speed observations appear to be significantly lower than the airport data used in those studies for high wind speeds over the lakes. This can be inferred from the information in Table 4 which shows a comparison of s_c and s_L when θ_L is offshore. Included in the comparison are the means, standard deviations, ranges of values, and sample sizes by station.

The MARS wind instruments at the stations used in this study are located either on top of buildings or on lighthouses along the lake shore. In some instances, these instruments may be below the tree line or otherwise blocked from the true wind. Further, turbulence around the structures on which the instruments are located may produce wind speed observations that are lower than the actual wind speed. Nevertheless, these data are the only data available at the shore. I believe their use in this study does not negate the usefulness of the results.

3. DATA ANALYSIS

The analysis of the data included relating ΔT and R_c to s_L and θ_L for each stratification of the data, except calm winds. s_L was classified into seven groups: $\leq$ 7 kt, 8 to 12 kt, 13 to 17 kt, 18 to 22 kt, 23 to 27 kt, 28 to 32 kt, and > 32 kt. ΔT represents the stability and was classified into five groups: very unstable ($\leq$ - 8.5°C), unstable (-8.4°C to -2.9°C), neutral (-2.8°C to 2.8°C), stable (2.9°C to 8.4°C), and very stable ($\geq$ 8.5°C). Table 5 shows how the data were stratified. The three major categories are $\theta_d \leq 90°$, $\theta_d > 90°$, and calm winds. In addition, I stratified according to whether $s_c \leq s_L$, or not. Winds with $s_c \leq s_L$ occur 80 percent of the time and may result from the difference in surface friction between the land and water, from stronger pressure gradients over the lake than near the shore, or from discontinuities (frontal or otherwise) over the lake.

A. $\theta_d \leq 90°$

This category comprises 80 percent of the data. Table 3 shows the directions of θ_L which were considered onshore, offshore, and parallel to the shore for each station.

θ_L Onshore

Table 6 shows the relationship of R_c to s_L and stability and a comparison of the results for $s_c \leq s_L$ and $s_c > s_L$. For both $s_c \leq s_L$ and $s_c > s_L$, R_c generally decreases as s_L increases, and no relationship between R_c and stability is apparent. For $s_c \leq s_L$, 75 percent of the observations below 13 kt occur with stable or neutral conditions; 84 percent of the observations above 22 kt occur with neutral or unstable, and a crossover occurs between 13 and 22 kt. For $s_c > s_L$, 77 percent of the observations occur with stable or neutral conditions, and only two observations occur above 22 kt.

θ_L Offshore

Table 7 gives the relationship of R_c to s_L and stability for θ_L offshore and and compares the results for $s_c \leq s_L$ and $s_c > s_L$. For both subgroups, R_c decreases with speed. This decrease is more pronounced than for θ_L onshore. For $s_c \leq s_L$, 78 percent of the observations below 22 kt occur with stable or neutral conditions; 82 percent of the observations above 27 kt occur with neutral or unstable conditions, and there is a crossover between 23 and 27 kt. These limits are higher than for θ_L onshore. For $s_c > s_L$, only two observations occur above 22 kt, and 78 percent of the observations occur with stable or neutral conditions.

θ_L Parallel With Shore

Only 63 observations fall into this category. Of these, 50 are for $s_c \leq s_L$, and 13 are for $s_c > s_L$. For $s_c \leq s_L$, R_c = 0.53, and for $s_c > s_L$, R_c = 1.30. Since the sample sizes are small, these values may not be representative.

B. $\theta_d > 90°$

$\theta_d > 90°$ (16 percent of all observations) may occur for a number of reasons. A few of these include passage of fronts or other discontinuities in the wind field, passage of lows or highs, and development of lake breezes or land breezes. Table 8 shows the frequency of occurrences of various wind speeds with various stabilities for $s_c \leq s_L$ and for $s_c > s_L$. For $s_c > s_L$, no observations have wind speeds above 17 kt, and 86 percent of the observations occur with stable or neutral conditions. For $s_c \leq s_L$, 80 percent of the observations occur with stable or neutral conditions, and 81 percent of the observations occur below 18 kt.

Nineteen percent of all observations in this category are for $s_L \geq 18$ kt. These winds are probably associated with frontal passages or strong low pressure situations. Thirty-five percent occur when $s_c > s_L$; these cases are probably associated with well developed lake breeze/land breeze situations or stable boundary layer conditions over the lake. The remaining 46 percent occur when $s_c \leq s_L < 18$ kt. These probably result from the passage of weak pressure or frontal systems or from the development of weak mesoscale systems over the lakes or along the shore.

C. Calm Winds

This definition includes three conditions: $s_L = 0$, $s_c = 0$, or $s_c = s_L = 0$. The total number of calm winds observed was 104 (4 percent of the total sample). Of these, 44 were for $s_L = 0$; 57 were for $s_c = 0$; and 3 were for $s_c = s_L = 0$. For $s_L = 0$, the observations were fairly evenly distributed by station and month. For $s_c = 0$, this was not the case. Of these observations, 73 percent occurred at Marquette, Mich. An investigation of the topography surrounding the station showed the height to vary from 196 m at the station to 434 m at the airport 13 km west southwest of the station. This leads me to conclude that under some situations, the wind speeds may not be representative. This is particularly true during June, July, and August when winds are usually from the south through west.

4. DISCUSSION

The analysis in Section 3 shows that for 80 percent of the wind observations, $\theta_d \leq 90°$; for 16 percent of the data, $\theta_d > 90°$; and for the remainder, one or both of the winds were calm. It is not my intention to provide totally objective guidance to forecast nearshore winds under all conditions. Rather, it is my aim to provide a means of using the MOS wind guidance over the lakes to predict <u>most</u> nearshore winds. Therefore, I have concentrated on situations where $\theta_d \leq 90°$. Determining s_c from s_L in this group is objective; however, deciding whether $s_c > s_L$, or not is not objective. I have provided some guidance, but the forecaster will have to rely on experience and station procedures to help with these decisions. The procedure at the end of this section will help guide the forecaster to make forecasts of nearshore winds.

A. Wind Speed Correction Factors

Table 9 gives the correction factors for computing s_c from s_L. These factors are the same as R_c, except these were determined by regressing s_L against s_c and forcing the intercept to be zero. A regression package of the Statistical

Analysis System (SAS Institute, 1979) was used. The resulting regressions are of the form

$$s_c = CFs_L,$$

where s_c is the wind at the coast, s_L is the wind over the lake, and CF is the correction factor. Included in the table are the correction factors, sample sizes, and percents of variance explained. All stabilities have been combined because of sample size considerations and the high explained variances without that stratification. In addition, stratification by speed was not made for $s_c > s_L$ because the resulting sample sizes would have been quite small.

B. Forecast Procedure

This procedure is designed to help the forecaster make forecasts of nearshore winds along the Great Lakes. It is reasonably effective when $\theta_d \leq 90°$ and particularly when θ_L is onshore or offshore, not parallel with the shore. It is important to remember that 78 percent of the winds on the Great Lakes occur with $\theta_d \leq 90°$ and θ_L being either onshore or offshore, and, for 85 percent of these observations, $s_c \leq s_L$. The procedure itself is designed to complement the guidance that already exists on station. It is also designed to help the forecaster focus on the total problem and to guide the forecaster in making the forecast. The bibliography in the Appendix may help the forecaster in the areas where the procedure is weak.

The process of making a forecast requires examination of regional and local data, synoptic analyses, and numerical and statistical guidance. The information pertaining to a given forecast problem must be assimilated and evaluated, and, based on this evaluation, the forecast is made.

To forecast nearshore winds along the Great Lakes, the following stepwise procedure is offered:

1) Gather the coastal and ship observations of interest, the synoptic analyses over the region, the numerical prognoses over the region, the Great Lakes MOS wind forecast guidance, and any other procedures or appropriate information needed. Other procedures may include: how to forecast lake breeze/land breeze conditions, how to forecast coastal winds when very stable boundary layer conditions exist over the lake in question, or how to predict what happens to a squall line or front as it interacts with the lake environment.

2) Determine if $\theta_d > 90°$, or if $s_L = 0$, $s_c = 0$, or $s_c = s_L = 0$ for any projection of the Great Lakes MOS wind guidance. If you determine any of these conditions will exist, go to step 4) to proceed for that projection. Otherwise continue.

3) Determine if θ_L will be onshore, offshore, or parallel with shore.

   3.1) Estimate whether $s_c \leq s_L$ or $s_c > s_L$. Remember $s_c > s_L$ occurs 17, 13, and 21 percent of the time for θ_L onshore, offshore, or parallel with shore respectively. There are three major reasons for $s_c > s_L$: lake breeze/land breeze situations, stronger pressure gradients along the shore than over the lake, or frontal or other discontinuities near shore. For lake breeze/land breeze situations, $s_C > s_L$ from about 1100 to 1700 LST or from 2300 to 0500 LST, respectively (Holland et al., 1981).

3.1.1) When θ_L is onshore or offshore, use Table 9 to compute s_C from s_L for each projection. The MOS sector forecasts are used for s_L.

3.1.2) When θ_L is parallel with shore, the correction factors are 0.53 for $s_C \leq s_L$ and 1.30 for $s_C > s_L$. The percentages of explained variance are 0.89 and 0.92, respectively, and the sample sizes are 50 and 13, respectively. Caution should be used because these values may not be representative due to these small sample sizes.

3.2) Determine wind direction.

3.2.1) If $s_C \leq s_L$ and θ_L is either onshore or offshore, then θ_L can, in general, be substituted for θ_C. This is not necessarily true, so examine all the information available.

3.2.2) If $s_C > s_L$ and θ_L is either onshore or offshore, or θ_L is parallel to the shore, then go to step 4).

4) Use other pertinent procedures or reference material to help make the forecast for the projection in question.

4.1) For lake breeze/land breeze situations, θ_C tends to veer with time throughout the day/night (Olsson, et al., 1968).

4.2) When θ_L is parallel with the coast, θ_C is also parallel only 16 percent of the time. The rest of the time θ_C is either onshore or offshore depending on the situation.

5) Summarize the results and make the nearshore forecast.

C. Examples

Two examples will be given: one for no lake breeze and one where lake breeze conditions are possible. The same MOS guidance will be used for each. Assume you are marine forecaster at the Weather Service Forecast Office, Cleveland, Ohio; the air flow is from the south to southwest; it is summer, and the pressure gradient is weak. Table 10 gives the MOS guidance for the east and west portions of Lake Erie for the 1200 GMT cycle.

Non-Lake Breeze Example

In this situation you have decided that there is insufficient heating inland to promote a lake breeze. Since you're forecasting for the nearshore region of southern Lake Erie, the wind direction forecast by the MOS guidance is offshore.

Having checked all your guidance, analyses, and other data, you accept the MOS guidance as it stands. Because you have determined that there will be no lake breeze, you also decide whether or not $s_c \leq s_L$. By using Table 9 together with the foregoing decisions, the MOS forecasts in Table 10 can be converted to their nearshore equivalents which are given in Table 11. From Table 11 it is evident that a nearshore wind forecast of south to southwest, 5 to 10 kt for the next 24 to 48 hours is reasonable.

Lake Breeze Example

As the marine forecaster, you have decided conditions are right for development of a lake breeze. After checking all pertinent meteorological information, you accept the MOS guidance. You also decide that the lake breeze will be stronger than the flow over the lake, so for the 6- and 30-h projections (times of lake breeze), you will use the information in the $s_c > s_L$ portions of Table 9. You use the station procedure for determining the lake breeze direction. At all other projections, you use the $s_c \leq s_L$ portion of both Table 9 and use the MOS wind direction. Table 12 shows the results of the computation. Since the direction of the lake breeze opposes the prevailing flow and varies in direction during the day, a wind forecast of variable 5 to 15 kt daytime and southerly 5 to 10 kt nighttime for the next 24 to 48 hours is reasonable.

D. Additional Comments

The procedure was developed from data at particular coastal stations and in particular lake sectors. Because the sample size was small in east and west Lake Ontario and east Lake Erie and non-existent in north and south Lake Huron, north Lake Michigan, and east and west Lake Superior, forecasters may be hesitant to use the procedure in those sectors. However, the procedure was generalized by using all the data; therefore, the sample size was large. Further, there is no reason to believe that wind characteristics are any different in the lake sectors where data were sparce or nonexistent than in the sectors where data were plentiful. Therefore, I see no reason not to extend the use of the procedure to lake sectors where little or no data were available for development. However, the procedure has not been tested with independent data or in the field.

5. SUMMARY

In this report, coastal and ship wind observations have been matched and related to each other for various stratifications of wind speed, wind direction, and stability. From the analysis of the matched data set, a procedure has been developed to help forecasters prepare forecasts of nearshore winds from the Great Lakes MOS wind guidance. While the procedure is limited in its capabilities, it does provide additional guidance to the forecaster, and it provides a set of items to consider before making the forecast.

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APPENDIX

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Table 1. MARS stations and the corresponding MOS lake sectors used in this study.

Station					MOS Lake Sector			
Name	Call Letters	Latitude	Longitude	Elevation	Name	Latitude	Longitude	Elevation
Oswego, N.Y.	28G	43°28'N	76°31'W	78	E. Ontario	43°30'N	77°00'W	74
Rochester, N.Y.	26G	43°15'N	77°36'W	82	E. Ontario	43°30'N	77°00'W	74
Niagara, N.Y.	13G	43°16'N	79°04'W	80	W. Ontario	43°30'N	78°40'W	74
Ashtabula, Ohio	20G	41°55'N	80°48'W	179	E. Erie	42°24'N	80°00'W	173
Lorain, Ohio	27G	41°28'N	82°11'W	177	W. Erie	41°50'N	82°00'W	173
St. Joseph, Mich.	20C	42°07'N	86°29'W	177	S. Michigan	42°24'N	87°00'W	176
Michigan City, Ind.	18C	41°43'N	86°55'W	177	S. Michigan	42°24'N	87°00'W	176
Milwaukee, Wisc.	15C	43°01'N	87°57'W	181	C. Michigan	44°00'N	87°00'W	176
Sheboygan, Wisc.	21C	43°45'N	87°42'W	192	C. Michigan	44°00'N	87°00'W	176
Marquette, Mich.	34Y	46°33'N	87°23'W	196	C. Superior	47°54'N	88°00'W	183
Portage, Mich.	32Y	47°14'N	88°38'W	190	C. Superior	47°54'N	88°00'W	183

Table 2. Data used in creating the matched sample. Data at 6-h intervals span the period January 15 through December 26, 1981.

Station Call Letters	Station Sample	MOS Lake Sector	Ship Sample	Matched Sample
28G	344	E. Ontario	7	2
26G	330	E. Ontario		2
13G	298	W. Ontario	7	1
20G	250	E. Erie	110	25
27G	1073	W. Erie	766	561
20C	581	S. Michigan	587	261
18C	606	S. Michigan		261
15C	873	C. Michigan	840	515
21C	836	C. Michigan		515
34Y	606	C. Superior	841	325
32Y	547	C. Superior		294
Total 11	6344		3158	2762

Table 3. Wind directions classified as onshore, offshore, or parallel with shore for each station used in this study. Wind directions are given clockwise; for example, 270°-090° means from 270° through 360° to 090°.

Station Call Letters	Wind Direction		
	Onshore	Offshore	Parallel with Shore
28G	240-050	060-230	None
26G	310-080	090-300	None
13G	280-060	080-260	070 and 270
20G	260-060	080-240	070 and 250
27G	260-060	080-240	070 and 250
20C	210-020	040-200	030
18C	250-040	060-240	050
15C	030-150	160-010	020
21C	160-330	340-150	None
34Y	010-080	100-350	090 and 360
32Y	240-040	050-230	None

Table 4. Comparison of s_L and s_c for each station when θ_L is offshore.

Class	Station	Sample Size	s_L(kt)			s_c(kt)		
			Mean	Standard Deviation	Range	Mean	Standard Deviation	Range
$s_c \leq s_L$	28G	2	25.5	11.5	14.0-37.0	11.0	1.0	10.0-12.0
	26G	2	25.5	11.5	14.0-37.0	12.5	7.5	5.0-20.0
	20G	7	17.6	6.3	11.0-30.0	9.6	5.1	5.0-21.0
	27G	149	15.9	7.6	4.0-44.0	7.8	3.7	1.0-20.0
	20C	100	17.2	7.3	4.0-42.0	7.9	3.4	2.0-22.0
	18C	109	16.6	6.8	4.0-42.0	8.6	3.3	3.0-18.0
	15C	168	17.7	8.4	4.0-45.0	9.2	5.1	2.0-25.0
	21C	260	18.6	8.7	4.0-45.0	8.7	4.3	2.0-28.0
	34Y	129	18.6	8.0	5.0-52.0	10.5	5.3	4.0-35.0
	32Y	101	17.0	7.6	3.0-34.0	7.8	3.5	2.0-16.0
$s_c > s_L$	20G	2	18.0	6.0	12.0-24.0	23.5	5.5	18.0-29.0
	27G	17	6.5	3.2	2.0-15.0	10.8	4.4	5.0-21.0
	20C	15	6.1	3.1	3.0-16.0	8.5	3.3	4.0-18.0
	18C	12	7.2	3.5	3.0-16.0	9.3	3.6	4.0-18.0
	15C	23	7.8	4.8	3.0-22.0	11.2	5.0	5.0-24.0
	21C	34	8.7	5.0	2.0-25.0	12.5	5.6	5.0-28.0
	34Y	38	8.1	3.5	3.0-20.0	11.4	4.5	5.0-25.0
	32Y	16	6.9	1.9	3.0- 9.0	9.4	2.1	5.0-14.0

Table 5. Stratification of matched data sample. θ_L is the wind direction over the lake; θ_d is the difference in wind direction between the wind at the coast and the wind over the lake; s_L is the wind speed over the lake, and s_c is the wind speed at the coast.

Stratifications	Sample Sizes		
	Division	Group	Subgroup
$\theta_d \leq 90^o$	2133		
θ_L onshore		886	
$s_c \leq s_L$			734
$s_c > s_L$			152
θ_L offshore		1184	
$s_c \leq s_L$			1027
$s_c > s_L$			157
θ_L parallel with shore		63	
$s_c \leq s_L$			50
$s_c > s_L$			13
Calm winds	104		
$s_L = 0$		44	
$s_c = 0$		57	
$s_c = s_L = 0$		3	
$\theta_d > 90^o$	426		
$s_c \leq s_L$		315	
$s_c > s_L$		111	
Total	2663	2663	2133

Table 6. The relationship of R_c (s_c/s_L) to categories of s_L (kt) and stability for θ_L onshore. The number following the solidus (/) is the sample size.

Class	Stability	Speed (s_L)							All Speeds
		$\leq$ 7	8 - 12	13 - 17	18 - 22	23 - 27	28 - 32	> 32	
$s_c \leq s_L$	Very Unstable	-	0.75/ 1	0.62/ 9	0.52/ 6	0.60/ 8	0.44/ 5	0.53/ 4	0.56/ 33
	Unstable	0.77/ 8	0.61/40	0.52/36	0.51/40	0.54/41	0.50/22	0.45/29	0.54/216
	Neutral	0.70/19	0.61/61	0.58/62	0.59/68	0.46/43	0.49/19	0.45/26	0.57/298
	Stable	0.83/12	0.65/40	0.53/32	0.49/41	0.48/20	0.46/ 8	0.22/ 1	0.56/154
	Very Stable	0.73/ 2	0.66/11	0.54/ 5	0.47/ 7	0.33/ 6	0.53/ 1	0.24/ 1	0.53/ 33
	All Stabilities	0.75/41	0.63/153	0.56/144	0.54/162	0.50/118	0.49/55	0.45/61	0.55/734
$s_c > s_L$	Very Unstable	3.29/ 2	-	1.71/ 2	1.19/4	-	-	-	1.85/ 8
	Unstable	2.32/ 7	1.33/14	1.26/ 5	1.10/1	1.07/1	-	-	1.55/ 28
	Neutral	1.99/29	1.33/20	1.21/11	1.18/5	-	-	1.14/1	1.58/ 66
	Stable	1.64/23	1.32/13	1.18/ 4	1.06/1	-	-	-	1.48/ 41
	Very Stable	1.75/ 4	1.39/ 4	1.50/ 1	-	-	-	-	1.56/ 9
	All Stabilities	1.92/65	1.33/51	1.27/23	1.16/11	1.07/1	-	1.14/1	1.56/152

Table 7. Same as Table 6 except for θ_L offshore.

Class	Stability	Speed (s_L)							All Speeds
		≤ 7	8 - 12	13 - 17	18 - 22	23 - 27	28 - 32	> 32	
$s_c \leq s_L$	Very Unstable	1.00/ 1	0.46/ 2	0.49/ 8	0.56/ 5	0.50/11	0.43/ 3	0.53/ 6	0.52/ 36
	Unstable	0.82/19	0.65/49	0.54/43	0.44/ 48	0.49/25	0.44/15	0.41/26	0.54/225
	Neutral	0.77/42	0.66/91	0.50/96	0.47/113	0.44/52	0.44/31	0.34/17	0.53/441
	Stable	0.81/19	0.66/62	0.55/63	0.46/ 79	0.49/24	0.40/16	0.31/ 1	0.55/269
	Very Stable	0.76/ 6	0.77/15	0.54/ 9	0.55/ 17	0.38/ 9	0.53/ 2	0.26/ 2	0.59/ 60
	All Stabilities	0.79/87	0.66/219	0.53/219	0.47/262	0.46/121	0.43/67	0.39/52	0.54/1027
$s_c > s_L$	Very Unstable	-	-	1.12/1	1.27/1	-	-	-	1.20/ 2
	Unstable	2.10/13	1.39/14	1.15/3	-	1.12/1	-	-	1.70/ 31
	Neutral	1.74/30	1.36/22	1.32/2	1.10/4	1.21/1	-	-	1.53/ 59
	Stable	1.73/23	1.42/20	1.12/1	1.25/1	-	-	-	1.56/ 45
	Very Stable	1.54/10	1.30/10	-	-	-	-	-	1.42/ 20
	All Stabilities	1.79/76	1.37/66	1.20/7	1.16/6	1.16/2	-	-	1.56/157

Table 8. The relationship of s_L to stability by frequency of occurrence for cases where $\theta_d > 90°$.

Class	Stability	Speed (s_L)							All Speeds
		≤ 7	3 - 12	13 - 17	18 - 22	23 - 27	28 - 32	> 32	
$s_c \leq s_L$	Very Unstable	1	1	1	-	-	-	-	3
	Unstable	14	20	11	6	6	1	2	60
	Neutral	22	63	24	16	6	2	4	137
	Stable	18	39	21	10	5	-	1	94
	Very Stable	6	9	5	1	0	-	-	21
	All Stabilities	61	132	62	33	17	3	7	315
$s_c > s_L$	Very Unstable	2	-	-	-	-	-	-	2
	Unstable	11	3	-	-	-	-	-	14
	Neutral	33	10	1	-	-	-	-	44
	Stable	33	7	1	-	-	-	-	41
	Very Stable	9	1	-	-	-	-	-	10
	All Stabilities	80	21	2	-	-	-	-	111

Table 9. Wind speed correction factors for various classes of s_L when θ_L is either onshore or offshore and $s_c \leq s_L$ or $s_c > s_L$. Only one speed class is shown for $s_c > s_L$ because of the high explained variance and small sample size.

Division	Parameter	$s_c \leq s_L$								$s_c > s_L$
		≤ 7	8 - 12	13 - 17	18 - 22	23 - 27	28 - 32	> 32	All Speeds	
θ_L Onshore	Correction Factor	0.76	0.62	0.55	0.54	0.50	0.49	0.45	0.50	1.29
	Sample size	41	153	144	160	118	55	61	734	152
	Explained Variance (%)	93	88	88	82	86	82	85	85	94
θ_L Offshore	Correction Factor	0.78	0.65	0.52	0.46	0.46	0.43	0.39	0.47	1.33
	Sample Size	87	219	219	262	121	67	52	1027	157
	Explained Variance (%)	94	91	88	85	86	91	84	86	94

Table 10. Sample MOS wind forecasts for Lake Erie for the 1200 GMT cycle.

Projection	06	12	18	24	30	36	42	48
East Lake Erie	2208	2207	1608	1809	2010	2010	1809	1909
West Lake Erie	1708	1707	1609	1711	1912	2012	1810	2010

Table 11. Sample nearshore wind forecasts. Wind speed forecasts are from Table 10 with adjustments from Table 9 for θ_L offshore and $s_c \leq s_L$. Wind directions correspond to MOS wind directions for all projections in Table 10.

Projection	06	12	18	24	30	36	42	48
East Lake Erie	SW05	SW05	SSE05	S06	SSW06	SSW06	S06	SSW06
West Lake Erie	S05	S05	SSE06	S07	SSW08	SSW08	S06	SSW06

Table 12. Sample nearshore wind forecasts. Wind speed forecasts are from Table 10 with adjustments from Table 9 for θ_L onshore and $s_c > s_L$ at the 06- and 30-h projections and θ_L offshore and $s_c \leq s_c$ at all other projections. Wind directions correspond to MOS wind directions for all projections except 06- and 30-h. Wind directions at those hours would come from local forecast procedures and are left blank here.

Projection	06	12	18	24	30	36	42	48
East Lake Erie	--10	SW05	SSE05	S06	--13	SSW06	S06	SSW06
West Lake Erie	--10	S05	SSE06	S07	--15	SSW08	S06	SSW06

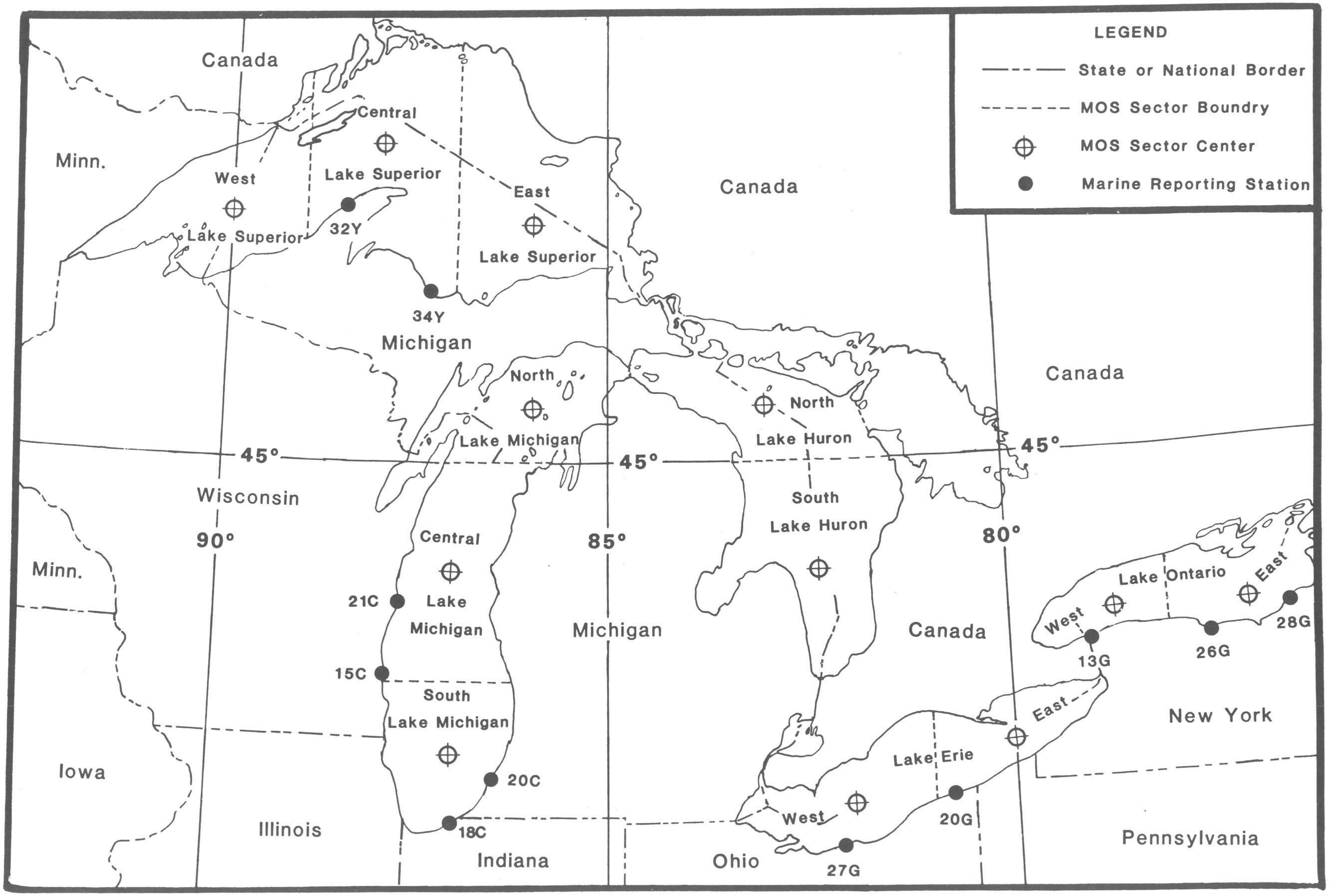

Figure 1. Locations of Marine Reporting Stations (MARS) used in this study. Also shown are the Great Lakes MOS sectors and their centers.

(Continued from inside front cover)

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