14.4 ADAPTATION OF THE CANADIAN UPDATEABLE MODEL OUTPUT SYSTEM TO FORECASTING MARINE WINDS ON THE GREAT LAKES

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1. INTRODUCTION

The goal of this project is the development of a post-processing system to refine the operational guidance for the marine winds on the Great Lakes produced by the Global Environmental Multiscale (GEM) model of the Meteorological Service of Canada (MSC) at the Canadian Meteorological Centre (CMC). The promising performance reported by Wilson and Vallée (2002) on the Updateable Model Output Statistics (UMOS) system which has been developed and implemented by CMC and the Meteorological Research Branch of the MSC inspired the adaptation of this system to the problem of the marine forecast for the Great Lakes.

In this paper we examine the available observational and model data relevant to the problem at hand. We then sketch the arguments leading to our selection of UMOS as a reasonable approach to the problem and provide a brief outline of the salient features of UMOS. Finally we present some preliminary results, along with an outline of the work remaining and a consideration of some avenues for future exploration.

2. OBSERVATIONAL DATA

The MSC and the National Data Buoy Centre of the National Oceanic and Atmospheric Administration maintain a number of moored weather buoys on the Great Lakes (see fig. 1). Data from some of these buoys is available from as early as 1979, while the latest addition to this network was commissioned as recently as this spring. Those buoys not possessing a record sufficiently large to provide a stable sample for the regression, as well as the buoys on Lake Michigan, were excluded from this study. The buoys considered are listed in Table 1.

Most of these buoys are 3-metre discus buoys, their anemometers situated at a nominal height of 5 metres above the surface of the water, necessitating the correction of the 3-metre buoy windspeeds to 10 metres using Bridget Thomas' (2000) implementation of Walmsley's (1988) height-adjustment algorithm. The resolution of wind speed is 0.1 m/s with an accuracy of ±1.0 m/s, while the direction of the wind is resolved to the nearest degree with an accuracy of ±10°.

The two 12-metre ODAS buoys on Lake Ontario differ from the 3-metre buoys in two important repects. Their anemometers are located 10 metres above the surface of the water and they usually remain in the lake year-round, whereas the 3-metre buoys are retrieved from the water in the fall and re-deployed each spring.

3. APPROACH

Normally the finest scale resolved by the marine forecast issued by the MSC for the Great Lakes is one half of a lake. As is evident from Figure 1, each half of each major lake is monitored by at least one weather buoy and, outside of their period of winter hibernation, these platforms supply in-situ measurements which are generally the most representative of the offshore marine environment, and are therefore heavily relied upon by the forecaster. Complementing this observational data, the GEM forecast fields are interpolated to the buoy sites, providing year-round guidance.

While observational data is available from as early as 1979, the removal of most of the buoys for a significant fraction of the year drastically reduces the size of the observational sample. Predictors for this extended period should ideally be obtained from a constant-resolution analysis such as the NCEP reanalysis. However, the NCEP reanalyses available in the archive at CMC are of rather coarse resolution, only a handful of grid points actually lying within the lakes. In light of these circumstances an alternative to the perfect prog approach was pursued.

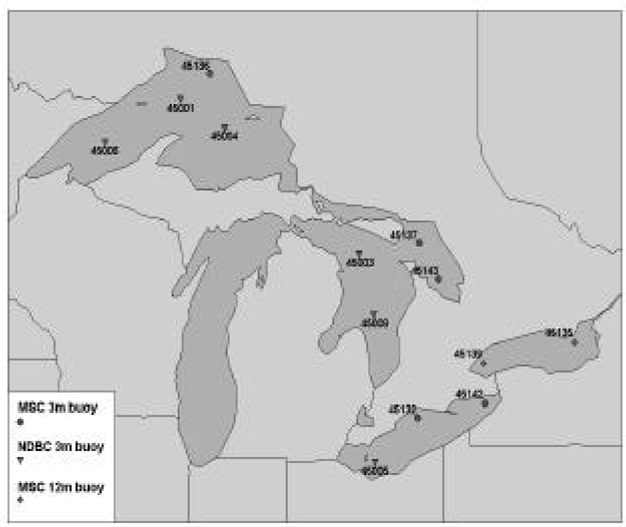

Figure 1. Great Lakes buoys included in this study.

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	Syno	Label	Location	Latitude	Longtitude	Anemometer height (m)	Distance to shore (km)
1	45001	MSU	Central Superior	48°04'N	87°47'W	5	66
2	45003	NHU	Norther Huron	45°21'N	82°50'W	5	46
3	45004	ESU	Eastern Superior	47°34'N	86°33'W	5	68
4	45005	WER	Western Erie	41°40'N	82°23'W	5	30
5	45006	WSU	Western Superior	47°19'N	89°52'W	5	55
6	45008	SHU	Southern Huron	44°17'N	82°25'W	5	42
7	45132	STA	Central Erie	42°28'N	81°13'W	5	20
8	45135	PRE	Eastern Ontario	43°47'N	76°52'W	10	13
9	45136	SLA	Northern Superior	48°32'N	86°57'W	5	28
10	45137	NGN	N Georgian Bay	45°33'N	81°01'W	5	36
11	45139	WON	Western Ontario	43°24'N	79°27'W	10	16
12	45142	COL	Eastern Erie	42°44'N	79°21'W	5	12
13	45143	SGN	S Georgian Bay	44°57'N	80°38'W	5	22

Table 1. Great Lakes weather buoys included in this study.

An alternative to the perfect prog method is that of model output statistics (MOS). The latter formulation incorporates biases peculiar to the model employed to generate predictors for the regression, whereas the use of observational values as predictors in the perfect prog approach frees it from any dependence on an NWP model, its start time, or the forecast projection. The sharpness of perfect prog forecasts is therefore independent of forecast projection, in contrast to the sharpness of MOS forecasts, which diminishes with increasing projection as the forecasts relax to climatology.

One unequivocal disadvantage of MOS systems in comparison with the perfect prog technique is that the former incur considerably more overhead in their operational implementation (in the application under consideration a MOS system requires 18 regression equations for each site as opposed to the single equation needed in a perfect prog approach). This would certainly have constituted a severe liability a decade or two ago, but in this day and age computer resources are sufficiently plentiful and software sufficiently sophisticated as to render the escalation in complexity accruing to the MOS method of secondary concern.

A much more significant complication, due to the close relationship between the MOS formulation and the NWP model, arises whenever significant changes are made to the latter. As described in Wilson (1985), the concomitant change expected in the covariance between the predictors and the forecast predictand and amongst the predictors themselves, as well as in the bias and variance of these predictors, necessitates the collection of a new sample of matched predictors and predictands, reflecting the statistical characteristics of the new model predictors, in order to feed the regression. This shortcoming of the MOS formulation has been mitigated at the MSC through the implementation of an updateable MOS system, referred to henceforth as UMOS and described in Wilson and Vallée (2002).

UMOS continually updates the regression equations, folding in the predictors from a new NWP model when a sufficient sample size has built up and assigning a higher weight to the sample from the new model in order to accelerate its influence on the regression. By exploiting data from the parallel model runs which typically precede the introduction of any significant change to the operational NWP model at CMC, it is possible to provide MOS forecasts reflecting the statistical characteristics of the new model predictors to the forecaster on the very day that the NWP model change is effected operationally.

Thus a MOS formulation was pursued, using the same forward-step multivariate linear regression (MLR) approach which UMOS uses for continuous predictands such as winds and temperature. The regression equations were developed for the period extending from October, 1998 to August, 2001, during which no significant changes in the operational GEM model occurred. Should the results prove promising the system can then be implemented operationally through UMOS. With much of the necessary infrastructure already in place the adaptation of UMOS to the Great Lakes marine forecasts should be relatively straightforward.

4. MODEL PREDICTORS

From a suite of 177 predictors UMOS retains 36 in the construction of the regression equations to model wind components and speed. For the purposes of this study additional variables were included from the full set of UMOS predictors, while 4 of the 36 actually used by UMOS, namely the orographic wind speed and variables accounting for persistence in the wind speed and components, were excluded.

Introduction of the curvature of the MSL pressure field along with the pressure tendency and its gradients (UMOS uses the laplacian of the pressure tendency) was inspired by Faucher, Burrows and Pandolfo's (1999) reconstruction of a west coast wind climate. Profit was also made of these authors' observation that in addition to (or perhaps instead of) the Julian day (which they used in their study and is also used by UMOS) the first harmonics of this quantity might better serve as a climatological predictor.

Model Predictor	Level(s)	Label
Zonal and meridional wind components Wind speed derived from UU, VV	**Surface, 1000, 925, 850, 700, 500**	**UU, VV UV**
Geostrophic wind components Geostrophic wind speed derived from UG, VG	**Surface, 1000, 925, 850, 700, 500**	**UG, VG WG**
Vertical velocity	**1000, 925, 850, 700, 500**	**WW**
Curvature of the MSL pressure field	**Surface**	**K_n, K_i**
Surface pressure tendency Gradients and divergence of the surface pressure tendency	**Surface Surface**	**D3 DD3X, DD3Y, LT**
Divergence	**Surface, 1000, 925, 850, 700**	**DI**
Meridional shear of the zonal wind component	**1000, 925, 850, 700**	**UY**
Zonal shear of the meridional wind component	**1000, 925, 850, 700**	**VX**
Temperature	**Surface, 1000, 925, 850, 700**	**TT**
Zonal and meridional temperature gradients	**Surface, 1000, 925, 850, 700**	**TX, TY**
Vertical temperature gradient		**TZ**
Temperature advection	**Surface, 1000, 925, 850, 700**	**AT**
Water temperature Water-air temperature difference	 **Surface, 1000, 925, 850, 700**	**TM TMTT**
Zonal, meridional gradients of dewpoint depression	**Surface, 1000, 925, 850, 700**	**DX, DY**
Vorticity advection	**Surface, 1000, 925, 850, 700, 500**	**ZA**
Second order terms coupling TZ with lower level-winds aloft	**1000, 925, 850**	**UVT**
Second order terms coupling TZ with geostrophic winds aloft	**1000, 925, 850**	**WGT**
Julian day First harmonics of Julian day		**JULIAN COS_JUL, SIN_JUL**

Table 2. Potential predictors.

Finally, several second-order terms coupling the winds aloft with the low-level instability were also offered as potential predictors, resulting in the predictor set listed in Table 2.

5. PRELIMINARY RESULTS

The reduction of variance (RV) in the wind components plotted in Fig. 2 for the 00HR projection of the 00Z GEM run exhibits a goodness of fit comparable to the results obtained by Faucher, Burrows and Pandolfo (1999). The RV for the zonal components is consistently between about 80 to 85% for all of the buoys* , while the fit for the meridional component possesses a much wider range. It is tempting to attribute this variability in the fit of the meridional components to an unresolved lake-breeze signal at buoys 8, 9, and 12, which are expected to be particularly susceptible to meridional lake breezes, being situated comparatively near the shore. However, this does not explain the poor fit at buoy 5 (in western Lake Superior) which is greater than 50 km from shore.

The errors in the wind components, computed on an independent sample and displayed in Figs. 3 and 4, are also comparable to Faucher, Burrows, and Pandolfo (1999). The MLR solution improves on the direct model output at all sites except for the western Lake Ontario buoy.

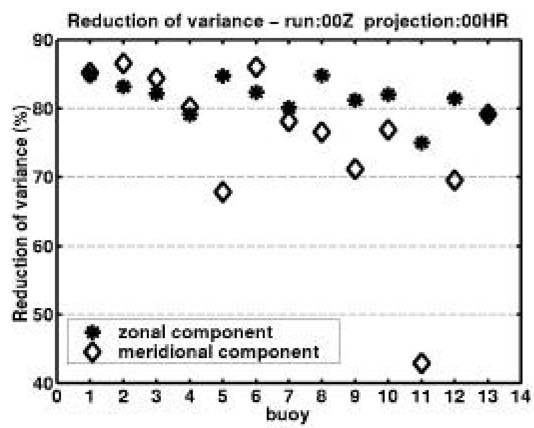

Figure 2. Fit for 00HR projection of 00Z run.

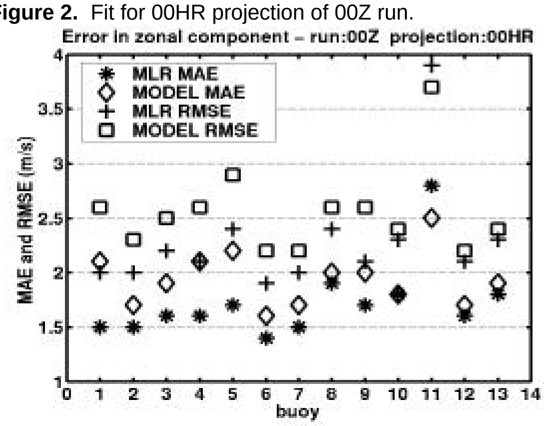

Figure 3. Error in zonal component on independent samples ranging in size from 83 (45139) to 292 (45135).

* The anomalous results for the buoy in western Lake Ontario will require further investigation.

Degradation of the fit with increasing forecast projection is clear from the plot in Fig. 5 for buoy 45001, while it can be seen from Fig. 6 that the results obtained from the regression equations for the buoy in eastern Lake Ontario have nicely corrected for the negative bias in the windspeed from the direct model output of the 00Z run.

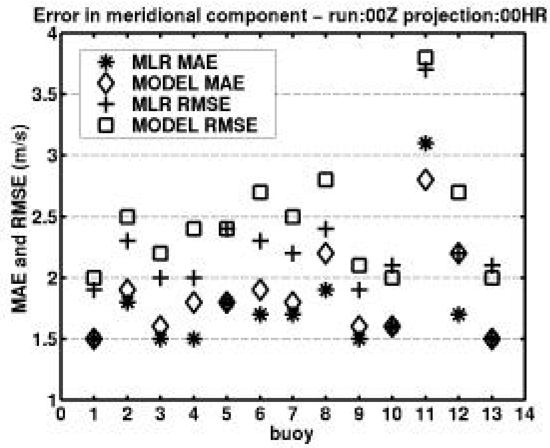

Figure 4. Error in meridional component on independent samples ranging in size from 83 (45139) to 292 (45135).

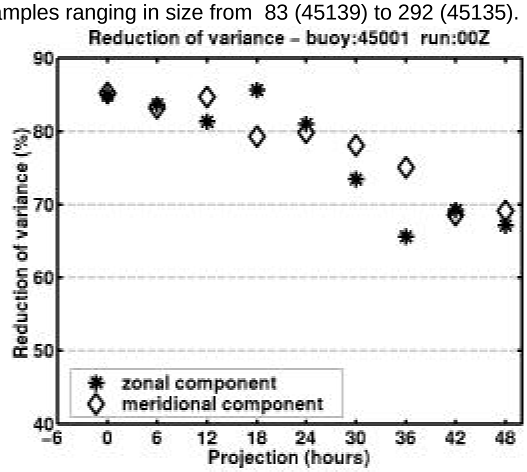

Figure 5. Reduction of variance in central Lake Superior.

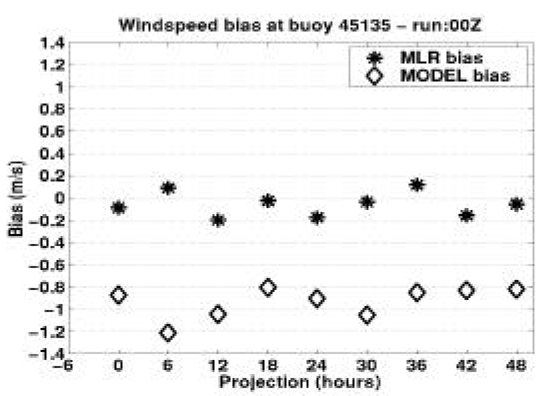

Figure 6. Windspeed bias in eastern Lake Ontario on independent samples of from 292 to 306 points.

6. CONCLUSIONS AND FUTURE WORK

From the results obtained in this study it appears that forward stepwise MLR improves on direct model output for the winds on the Great Lakes at the buoy positions listed in Table 1 (with the possible exception of the buoy in western Lake Ontario). Inasmuch as the data was extracted from a database already in the format required by UMOS, the implementation of this solution within the UMOS framework should be straightforward. A preliminary set of model predictors can be submitted based on this work, supplemented by persistence.

The possibility of an unresolved lake breeze signal remains, and further investigation of the effects of including predictors to capture lake breeze will be pursued. In addition, the impact of pooling samples of buoy observations matched with their corresponding predictors at more than one location on a given lake (eg. pooling the samples at buoys 45135 and 45139 on Lake Ontario) remains to be explored. Such pooling may filter out finer scale features which are presently contaminating the signal, permitting a better fit of synoptic and grosser mesoscale signals, as well as reducing the time required to acquire samples which are sufficiently large to generate stable regression equations.

7. ACKNOWLEDGEMENTS

This work was funded in part through the New Search and Rescue Initiatives Fund administered by the National Search and Rescue Secretariat of the Government of Canada. The corresponding author would also like to thank Krystyna Czaja and Brian Clark for their assistance in the preparation of this document, and Bridget Thomas for provinding the computer code used to vertically adjust the buoy winds.

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