JP1.5 DEVELOPMENT OF A COUPLED AIR-LAKE MESOSCALE MODEL FOR OPERATIONAL MARINE FORECASTING IN THE GREAT LAKES REGION

Peter J. Sousounis*[1], G. E. Mann[2], D. J. Schwab[3], and R. B. Wagenmaker[2]

[1]University of Michigan, Ann Arbor, MI
[2]National Weather Service Forecast Office, White Lake, MI
[3]Great Lakes Environmental Research Laboratory, Ann Arbor, MI

1. INTRODUCTION

Recent improvements in operational numerical weather prediction (NWP) models have allowed National Weather Service forecasters across the country to enjoy considerably improved mesoscale forecasts. In the Great Lakes region, many of the mesoscale features that develop are, for one reason or another, forced by the Great Lakes - either individually or as an aggregate. Despite this additional complication, forecasts over land areas have benefited a considerable amount, while marine forecasts - over the adjacent Great Lakes (which essentially surround Michigan) - have benefited little in comparison.

A recent example of a challenging marine forecast occurred during the period 11-15 September 1996, when an intense cut-off low developed over the Great Lakes. The system moved southeastward from Canada but stalled over Lake Huron, where it continued to deepen. By Saturday 14 September, the low had developed an eye and spiral bands of convective showers. In addition, the cyclone briefly produced tropical storm force winds and excessive rain (> 10 cm) that caused local flooding. From a satellite perspective, this system bore a striking resemblance to a hurricane (see Fig. 1 in Miner et al 2000). Because the system moved slowly across the Great Lakes when they were near climatological peak temperature, strong heat and moisture fluxes from the Lakes played an integral role in development (cf Sousounis et al. 2001).

The marine forecast that was issued from the National Weather Service Forecast Office in White Lake, Michigan (DTX) for Lake Huron and Lake St. Clair was certainly an improvement over that from the raw model output, but was still not without error. For example, a forecast that was issued on the afternoon of Friday 13 September at 21 UTC for the coastal waters of Lake Huron called for winds between 15 and 25 kt throughout the ensuing 24 to 36 h forecast period. The marine forecast also called for showers and wave heights of 1-2 m. A small craft advisory was in effect. Instead, observed wind speeds were greater than forecasted near the center of the storm with reports of 30 kt common near shore and gusts to 45 kt at the two buoys on Lake Huron. Numerous sailboats that were participating in the Bayview "Night Race", which is a 50 nautical-mile race on Lake St Clair, reported sustained winds between 30-35 kt with gusts to 45 kt. Several boats were demasted and at least one person suffered a concussion as a result of the high winds and very choppy lake surface. Observed wave heights were also greater than forecast. The two buoys on Lake Huron reported wave heights near 3m. Gale warnings and increased wave height forecasts were not issued by DTX until 21 UTC Saturday 14, when the system had already past its peak intensity. Significant and abrupt decreases in lake surface temperatures, probably from upwelling, contributed to the system's abrupt decrease in strength.

While Great Lakes marine forecasting is relatively more difficult than forecasting for adjacent land masses in the region, it is in some ways more straightforward than forecasting for oceans. For example, multiple swells from very far away can complicate the forecast within an ocean environment. Nevertheless, there are at least two reasons why marine forecasting remains a challenging activity in the Great Lakes region. First, coastal geometry is intricate. Small scale coastal features can generate local convergence/divergence regions that can extend well offshore. These convergence/divergence regions by themselves are difficult to forecast. Second, the presence of strong air-lake fluxes, rapid upwelling, and seiches can create a marine situation that is challenging at best to forecast.

Although a Great Lakes Forecast System currently exists, there are several shortcomings of this system. First, this system as of last year used output from the 32 km Eta as input for a wave model. Second, there is no feedback between the waves that "develop" and the winds that generate them. Third, there are no provisions to allow for (abrupt) changes in lake surface temperature during the forecast. Fourth, the ability of the 32 km Eta model to adequately simulate heat and moisture fluxes from the Great Lakes limits its ability to accurately depict resultant regional pressure patterns and wind fields. Finally, the output from the current wind-wave model is made available only as graphical products for everyone on the World Wide Web. However, it is not available to National Weather Service forecasters in a timely manner, nor in raw (number) and/or interactive format.

This paper describes the recent implementation of a modified version of the existing marine forecast system at the National Weather Service Forecast Office in White Lake, MI (DTX) for improving wind and wave forecasts over the Great Lakes. This paper also describes some plans for further development.

*Corresponding Author Address: Dr. Peter J. Sousounis, University of Michigan, Ann Arbor, MI 48109-2143. Email: sousou@umich.edu.

2. METHODOLOGY

A coupled numerical modeling system is under development. Currently the modeling system consists of a workstation version of the NCEP Eta model and the GLERL/Donelan Wave model (GDM) developed jointly between the Great Lakes Environmental Research Laboratory and Ohio State University. The system is run in real-time at the Detroit/Pontiac National Weather Service Office (WFO DTX). Future plans exist to couple a three dimensional lake circulation model.

The Eta model grid encompasses the Western Great Lakes Region with a 10 km horizontal grid spacing (Eta06), while the GDM model grid is limited to Lake Huron with a 5 km horizontal grid spacing. Atmospheric initial and boundary conditions are provided by the NCEP operational 22 km Eta; and the wave model initialization is provided by the GLERL Great Lakes Coastal Forecast System (GLCFS). The Eta06 has been localized for the Great Lakes Region by reconfiguring the η level distribution for an adjustment in base elevation to improve boundary layer vertical resolution; using a modified Kain-Fritsch convective parameterization designed to include shallow, intense, precipitating convection (i.e., lake-effect snowstorms); and incorporating high resolution (2 km spaced) lake surface temperatures from the Great Lakes Environmental Research laboratory GLSEA analyses.

The GDM was developed jointly at the Canada Centre for Inland Waters and GLERL (Schwab et al., 1984). It is based on the conservation of momentum applied to deep water waves (Donelan, 1977). The wave energy spectrum is constrained to a single-peaked frequency distribution with a cosine squared decrease of energy away from the primary energy direction. The waves are forced by a surface stress that depends on the speed of the wind relative to that of the waves. The model is run on a rectangular grid adapted to the shape(s) of the Great Lakes. This model has been tested and verified on the Great Lakes and is part of the Great Lakes Forecast System (Kelly et al. 1998). The computational time to run this model is a small fraction of that required to run the Eta06.

Initialization of the wave model is accomplished by using output from a nowcast procedure that was developed at GLERL. The procedure involves the use of observed winds from the previous 12 h period as input to the wave model. This procedure is different than those that are typically used for initialization of atmospheric models, for example, which utilize a blend of model output from the previous model run and existing observations. The nowcast procedure developed at GLERL has the advantage of providing more accurate initial conditions for the wave model than can be otherwise obtained.

The model system currently produces forecasts to 48 hours four times daily (00, 06, 12, 18 GMT). Surface layer variables from the Eta06 are used to force the GDM model, which produces forecasts of wave momentum, peak energy frequency, wave direction, and wave height. There is currently no feedback from the GDM to the Eta06. Output from both components are available in the Advanced Weather Interactive Processing System (AWIPS) for use by the DTX forecasting staff. Incorporation into AWIPS allows forecasters to integrate the output with observational and additional numerical datasets. Near-shore (within 5 nautical miles of shore) and open lake (beyond 5 nautical miles of shore) forecasts for Lake Huron are produced, in part, using the Eta06/GDM modeling system. The Eta06 produces more precise and accurate depictions of lake induced flow structures, in comparison to the NCEP operational model suite. These effects include lake/land breeze formations, funneling and channeling, coastal convergence, lake-effect induced convergence zones, and stability effects.

The Eta06/GDM modeling system provides the added mesoscale detail to marine forecasting that is necessary to produce accurate near-shore forecasts and predictions of significant locally induced features over the open lake. Local effects primarily drive marine weather in the Great Lakes. Therefore, the Eta/GDM modeling system provides the forecaster with a more complete picture of the possible influences and results of those local effects.

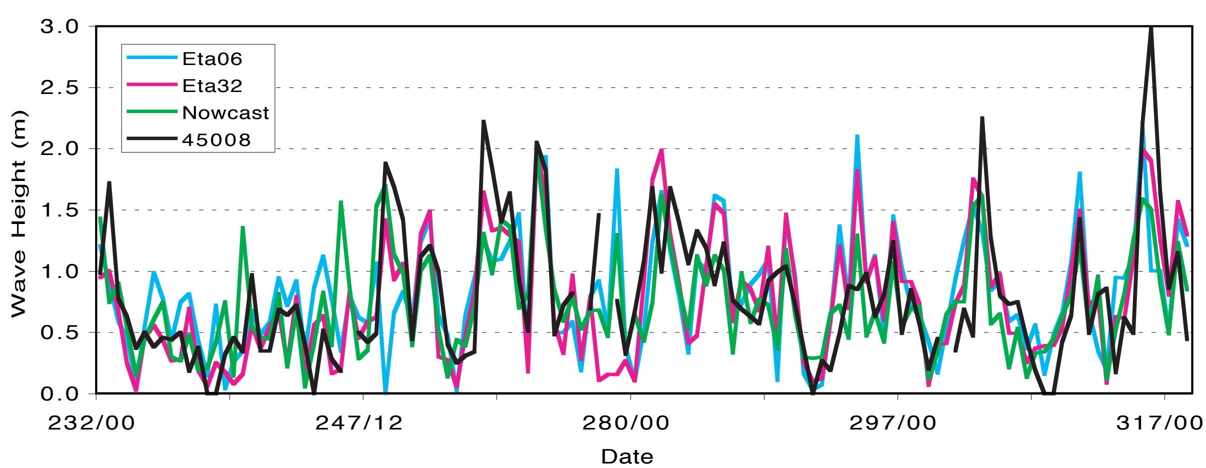

FIG. 1. Time series of 24 h model forecasts, Nowcasts, and Buoy 45008 observations of wave height for the period JD 232/00 UTC JD 317/00 UTC.

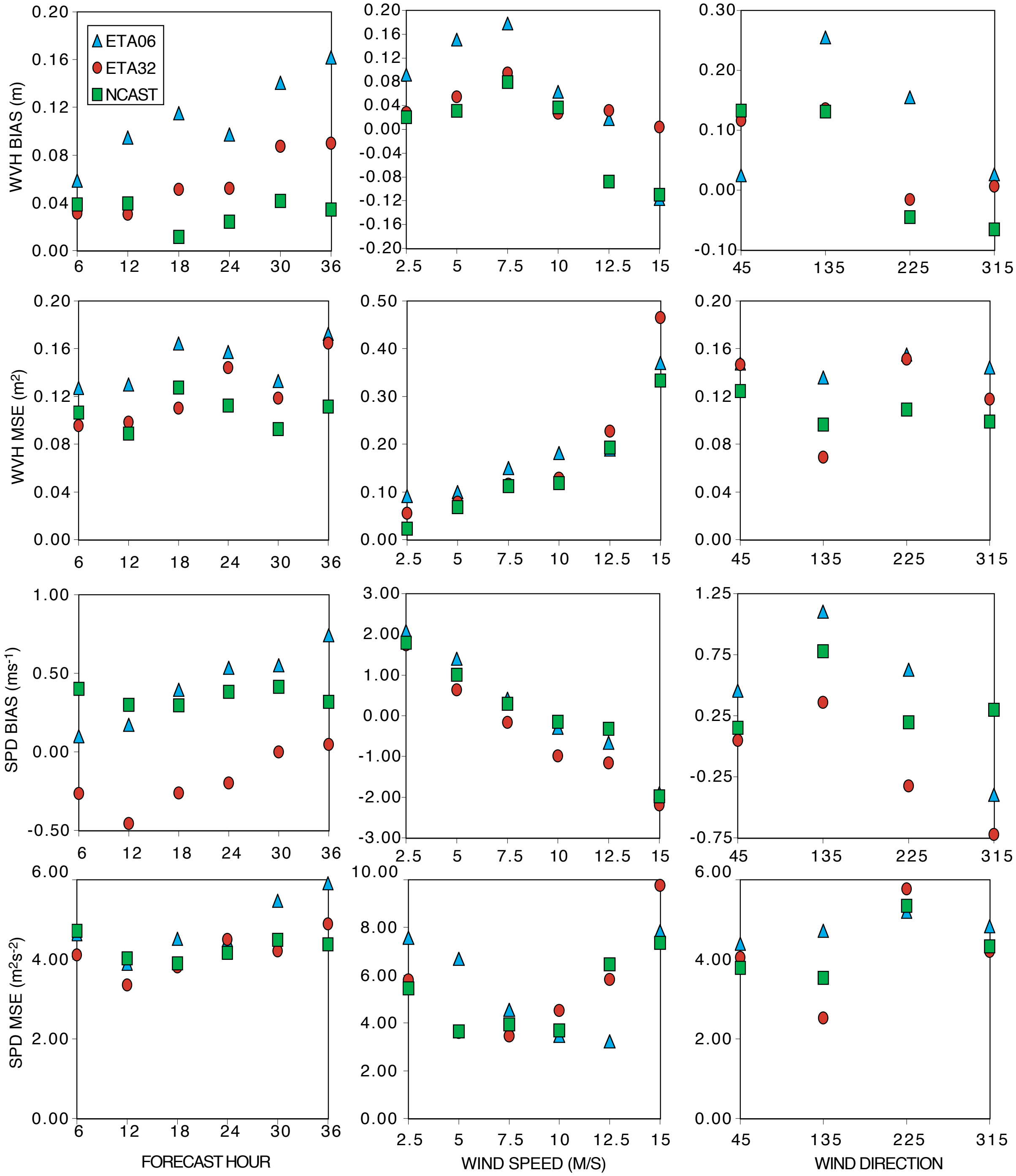

Fig. 2. Eta06, Eta32, and Nowcast biases and mean square errors relative to Buoy 45003 observations partitioned according to forecast hour (left), wind speed (middle), and wind direction (right).

3. RESULTS

Validation of the Eta06/GDM was accomplished for wave height (WVH) and wind speed (SPD) forecasts using data from two buoys on Lake Huron: 45003 located at 45.3N 82.8W and 45008 located at 44.3N 82.4W; Nowcast data; and output from a 32 km version of the operational Eta (Eta32) for a 90 day period from late-summer to mid-fall from the year 2000.

The Eta06 and Eta32 generated comparably accurate 24 h forecasts at the buoys (cf. Fig. 1) for the period examined. Relative to the buoy observations, the Eta06 WVH biases and mean square errors were slightly higher than those from the Eta32 for all forecast hours, and all but the highest wind speeds. When forecasts were partitioned by wind direction, the Eta06 WVH forecast biases were smaller for northerly flow situations although the mean square errors were larger.

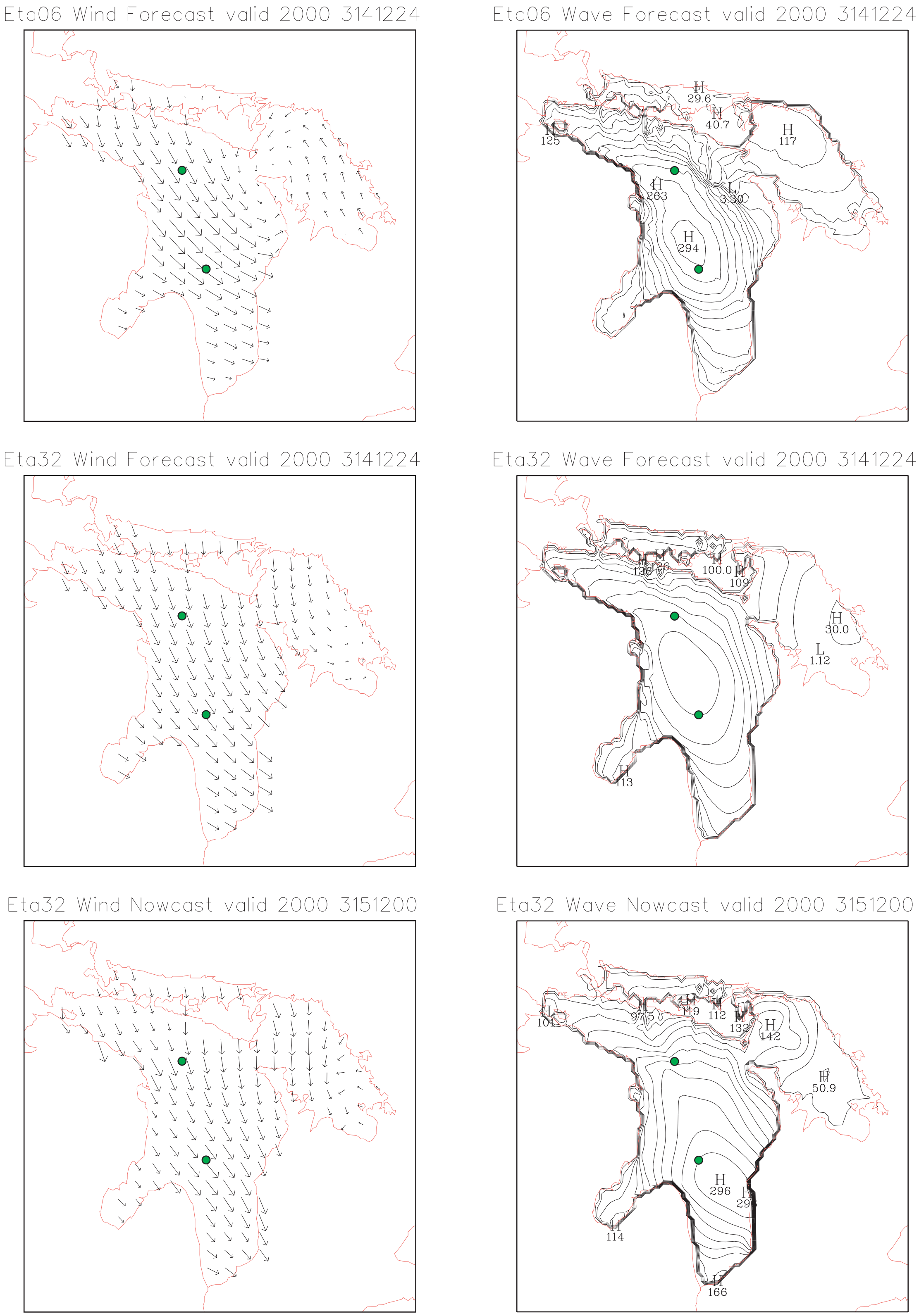

Fig. 3. Wind (left column – gridlength arrow is 10 ms^{-1}) and wave height (right column– contour interval is 25 m) 24 h forecasts from Eta06 (top row) and Eta32 (middle row) and Nowcast conditions (bottom row) valid at JD315/00 UTC. Circles in each panel represent locations of Buoys 45003 (northern) and 45008 (southern).

In general the SPD biases are qualitatively similar to the WVH biases because of the relationship between wind speed and wave height. It is interesting therefore that the Eta32 WVH biases are positive despite negative biases in SPD – especially since the Buoy anemometer height is 5 m rather than 10 m. It is also interesting that the Eta06 SPD forecasts have smaller biases than the Eta32 SPD forecasts. The mean square errors for the Eta06 are almost always larger than those for the Eta32 at both buoy locations for SPD or WVH forecasts – independent of forecast hour, wind speed, or wind direction. The results suggest that the Eta06 provides better wind forecasts during strong northwesterly flow situations. The biases and mean square errors at Buoy 45008 were similar to those at Buoy 45003.

A critical aspect of marine forecasting is the small craft advisory – issued when winds are expected to be in the range of 7.5-12.5 ms^{-1}. Additionally, 24 hr forecasts are perhaps the most noticed – especially by recreational boaters – who use such information to plan the following day's (e.g., weekend activities). The 24 h Critical Success Indices (CSIs) for the Eta06 were higher than those for the Eta32 for both >7.5 ms^{-1} wind speed and > 1 m wave height forecasts at 24 h at Buoy 45008 (CSI06WVH24H = 0.597 vs CSI32WVH24H = 0.537 and CSI06SPD24H = 0.661 vs CSI32SPD24H = 0.554) but lower at other forecasted hours (CSI06WVHALL = 0.528 vs CSI32WVHALL = 0.606 and CSI06SPDALL = 0.562 vs CSI32SPDALL = 0.569).

Average biases and mean square errors do not highlight the improvements that the Eta06 provides thus far because the situations where the Eta06 performs better than the Eta32 were not present in statistically large numbers for the period examined. One example where the Eta06 produced better wave height forecasts is shown in Fig. 3. The synoptic situation was characterized by an intensifying low moving northeastward across the region in November, when operational models typically underrepresent the impacts of the Great Lakes (cf. Sousounis and Fritsch 1994) in part because the coarse resolution does not allow enough aggregate heating to retard the northeastward progress of the low. The Eta32 24 h forecast valid on JD 315 12 UTC illustrates that tendency – e.g., that the low would progress far enough to the northeast so that northwesterly flow would occur over all of Lake Huron. The corresponding wave height forecast is consistent: wave heights in excess of 2 m would characterize much of central Lake Huron. Over Georgian Bay, wave heights would be considerably less, owing to the forecasted weaker northwesterly flow, the previous southeasterly flow, and the low center moving to the central north shore of Lake Erie. The Eta06 24 h forecast valid for the same time suggests that the low would not advance as far eastward; specifically, that the closed cyclonic circulation centered at the tip of the Bruce Peninsula would allow northwesterly flow over the main part of Lake Huron but would maintain southeasterly flow over Georgian Bay. As a result, the wave height forecast from the Eta06 was consistent with that from the Eta32 over the main part of Lake Huron, but very different over Georgian Bay. The Nowcast valid on JD 315 12 UTC suggests that the Eta06 performed significantly better than the Eta32 over Georgian Bay. Wave height forecasts from the Eta32 for northern Georgian Bay – at the end of a long fetch from the southeast - were almost 100 cm too low. The Eta06 wave heights in this region were significantly better but still about 20 cm too low.

4. CLOSING REMARKS

The project described involves the modification and implementation of an existing high-resolution marine forecast system for the Great Lakes. The activity is unique from four perspectives. First, the system is being implemented within the National Weather Service Forecast Office(s) and the forecasters are encouraged strongly to incorporate the results within their daily forecast activities. Second, the coupled system uses a high-resolution workstation version of the Eta model. Even with such high resolution, the model runs very fast on a PC at DTX. Third, the proposed system involves a collaborative effort between the University of Michigan in Ann Arbor, Michigan, the NWS Forecast Office in White Lake, Michigan, and the NOAA Great Lakes Environmental Research Laboratory (GLERL) also in Ann Arbor, Michigan. Fourth, the effort involves the coupling of the Eta06 with a lake circulation model. Thus, lake surface temperatures will be able to change during the forecast - a feature which is potentially important as suggested by the September 1996 case described in the Introduction.

Acknowledgements. This study was supported by a UCAR Agreement UCAR S99-18118 to the University of Michigan.

REFERENCES

Donelan, M. A., 1977: A simple numerical model for wave and wind stress prediction. Unpublished manuscript. National Water Research Institute, Burlington, Ontario, Canada. 28pp.

Kelley, J. G., J.S. Hobgood, K.W. Bedford, and D.J. Schwab, 1998: Generation of three-dimensional lake model forecasts for Lake Erie. Wea. Forecast, **13**, 659-687.

Miner, T., P. J. Sousounis, G. E. Mann, and J. Wallman, 2000: Hurricane Huron. Bull. Amer. Meteor. Soc, **81**, 223 - 236.

Schwab, D. J., J.R. Bennett, and E.W. Lynn, 1984: A two-dimensional lake wave prediction system. NOAA Technical Memorandum ERL GLERL-51, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 70pp.

Sousounis, P. J., G. E. Mann, J. Wallman, and T. Miner, 2001: Hurricane Huron: An example of an extreme lake aggregate effect in autumn. Mon. Wea. Rev., **129**, 401-419.

Sousounis, P. J., and J. M. Fritsch, 1994: Lake aggregate mesoscale disturbances. Part II: A case study of the effects on regional and synoptic scale weather systems. Bull. Amer. Meteor. Soc., **75**, 1793-1812.