Reprinted from the preprint volume of the ***Conference on Coastal Oceanic and Atmospheric Prediction****, 28 January - 2 February 1996, Atlanta, GA by the American Meteorological Society, Boston, MA*

1.3 GLCFS - A COASTAL FORECASTING SYSTEM FOR THE GREAT LAKES

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1. INTRODUCTION

Increased human activity in the coastal zone has resulted in the need for improved information about physical conditions in the water, including waves, currents, water level fluctuations, and temperatures. The increased power and availability of computers and numerical ocean circulation models, coupled with the real-time availability of data from coastal observing systems, now allows forecasting and prediction systems for the coastal ocean to be developed. This paper describes an operational coastal forecasting system that has been developed for the Great Lakes.

The Great Lakes Coastal Forecasting System (GLCFS) is a real-time coastal prediction system that was developed for daily forecasting of surface water level fluctuations, horizontal and vertical structure of temperature and currents, and wind waves in the Great Lakes. The system uses surface meteorological observations and forecasts from numerical weather prediction models as input. Lake circulation and thermal structure are calculated using a three-dimensional hydrodynamic prediction model. Wind waves are calculated with a parametric wave prediction model. Output from the models is used to provide information on the current state of the lake and to predict changes for the next several days.

The system was originally developed as a demonstration project by Ohio State University and NOAA's Great Lakes Environmental Research Laboratory. The initial implementation of the system in 1993 and 1994 produced daily nowcasts of system variables for Lake Erie from April to December each year (Schwab and Bedford, 1994). In 1995, the system began to use mesoscale meteorological forecasts from NOAA's National Meteorological Center (NMC) Eta model to produce 24 hour forecasts of system variables.

The Great Lakes Coastal Forecasting System is the first regional demonstration of the NOAA Coastal Forecasting System (U.S. Dept. of Commerce, 1993) whose goal is to provide a national capability to measure, understand, and forecast coastal environmental phenomena that impact coastal economics, public safety, and environmental management. This will be accomplished through an end-to-end suite of regional systems that build upon existing NOAA capabilities and infrastructure. This effort is intended to produce high resolution, regionally tailored observational systems, models, and forecasts of coastal environmental phenomena for coastal regimes ranging from estuaries, bays, and harbors to the end of the Exclusive Economic Zone.

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2. SYSTEM DESIGN

The GLCFS is designed to produce nowcasts and forecasts of physical parameters including water levels, currents, temperatures, and waves for all five of the Great Lakes. Lake Erie is the first lake to be fully implemented in the system. The system is also designed for hindcasting and scenario testing. In the forecasting mode, a daily run is made for each lake. The model is run for 48 hours, beginning 24 hours previous to the forecast time, thus generating a 24 hour hindcast and a 24 hour forecast. A forecast period of 24 hours was chosen because we felt that this was a reasonable period for which mesoscale meteorological forecasts could be used with confidence and a period of interest to most Great Lakes users. Observed meteorological conditions are used to specify surface boundary conditions for the first 24 hours of the run. The current and temperature fields from the model at this point in the run are saved to be used as initial conditions for the next day's run. These conditions constitute the 'nowcast' of the present state of the lake. In 1995, we began to incorporate forecasts from NMC's Eta model (Black, 1994) into the system. The 29 km version of the Eta model provides reasonable resolution of the Great Lakes with 28 grid points over Lake Erie. Eta model output fields are obtained over the Internet from NOAA's Information Center FTP Server. Forecasts of overlake meteorological conditions are used as boundary conditions for the second 24 hours of the run. The output of this part of the run constitutes the lake forecast.

Marine meteorological data are obtained from National Weather Service's (NWS) Cleveland Forecast Office for the nowcast portion of the run through a modem connection and the Internet. The data gathering and objective analysis task are performed on a Silicon Graphics (SGI) 4D/30 workstation at OSU. The numerical models are run on the Ohio Supercomputer Center Cray Y-MP8/864 supercomputer. The rendering of 2D maps, conversion to PC bitmap images, and compression to a ZIP file are all done on the SGI workstation. The SGI workstation is also the host for the end users to dial in and download the final images. Currently, six maps and a time trace plot are generated every day for the end users to download to their own PC.

Predictions start during April of each year, at which time the lakes are usually isothermal, and cease at the end of December when the shipping and recreational seasons are over, and ice begins to form on the lakes. The system was debugged and run on an intermittent basis in 1992. In 1993 and 1994, nowcasts for Lake Erie were produced and disseminated every day from 1 April to 31 December. In 1995, nowcasts and 24 hour forecasts are being generated daily.

Fig. 1 is a schematic diagram of the functional components of the GLCFS. The primary data required to nowcast and forecast coastal circulation and thermal structure are (1) initial conditions for the current, temperature, and water level fields, (2) observations of overlake meteorological conditions for the last 24 hours, (3) forecasts of surface heat flux and wind stress for the next 24 hours, and (4) forecasts of lateral (inflow and outflow) boundary conditions. The initial velocity and temperature fields for each day's run are taken as the computed fields from yesterday's run at 24 hours previous to today's initialization time. The model is then run with analyzed wind stress and heat flux fields from the 24 hours previous to today's initialization time as forcing functions to produce a 'nowcast' of current lake conditions. This can also be considered a data assimilation step as it incorporates all available observational data into the initialization of the circulation model. In the current operational system, forecast surface conditions for the next 24 hours (wind stress and heat flux) are provided from the Eta Model to generate current and temperature forecasts. At present, there is no feedback from the circulation model to the atmospheric model for the short duration of the forecast.

3. DATA ACQUISITION AND ANALYSIS

In order to calculate heat and momentum flux fields over the water surface for the lake circulation model, it is necessary to estimate wind and temperature fields at model grid points for the hindcast and forecast portions of each run. The surface observations for the hindcast part of the run are obtained from a network of NOAA's National Weather Service and Canadian Atmospheric Environment Service observation stations around the Great Lakes. These observations form the basis for generating gridded overwater wind and temperature fields. Forecasts of surface fields from the Eta model provide input for the forecast part of the run.

The irregularly spaced surface observations are first adjusted to be representative of overwater conditions at 10 m anemometer height. For the hindcast part of the run, surface fluxes of heat and momentum are estimated at each grid point using empirical formulations for incoming solar radiation (attenuated by cloud cover), sensible heat flux, latent heat flux, and longwave radiation. For the forecast part of the run, the surface wind stress and heat fluxes are taken directly from model output fields at 3 hour intervals. Marine observations for the Great Lakes are compiled hourly at the Cleveland NWS office and downloaded via modem and Internet connections. Eta model outputs are obtained once a day over the Internet from the NOAA Information Center FTP server.

4. NUMERICAL MODELS

As shown in the schematic in Fig. 1, two types of models are currently used in the GLCFS: 1) a numerical model for calculating velocity, temperature, and water level distribution, and 2) a wave model for calculating the wave height, period, and direction fields. The 2D tributary model is still under development. The numerical circulation model used in the GLCFS is a three-dimensional ocean circulation model developed at Princeton University for coastal ocean applications by Blumberg and Mellor (1987) and subsequently adapted for Great Lakes use at GLERL and OSU. This model is also being used to develop an East Coast Coastal Forecasting System for the Atlantic Coast of the United States (ECFS Group, 1994). The model is driven by time-dependent surface boundary conditions for wind stress and heat flux. The physical parameters predicted by the model are the three-dimensional velocity distributions, the temperature field, and the free surface water level.

The wave model used in the GLCFS is a parametric model developed jointly at the Canada Centre for Inland Waters and GLERL (Schwab et al., 1984). In this model, the wave energy spectrum is constrained to a single-peaked frequency distribution and a single dominant wave direction with a cosine squared decrease of energy away from the primary direction. The wave momentum transport equation is used instead of wave energy so that the predicted parameters in the numerical model are the two components of wave momentum, and the peak energy frequency, from which wave direction and wave height can be derived. The forcing function for the wave model is the wind field at 10 m anemometer height, which is derived from the meteorological observations or forecasts using a marine boundary layer profile method.

5. PRODUCTS

Output from the numerical model consists of all relevant two-dimensional and three-dimensional fields at hourly intervals. Post-processing routines run on workstations at OSU and GLERL to generate several types of products. The main products are a set of two-dimensional color maps of various fields predicted by the GLCFS. These maps are generated each morning and represent the current state of the lakes and a 24 hour forecast. The maps include water surface elevation, wind speed and direction, surface water temperature, vertically averaged current, and wave height and direction. In addition, a time series plot of hourly water levels at three stations in the lake is produced to show the history for the last 5 days.

A sample output map of temperature cross sections is shown in Fig. 2. This map is a nowcast for 8:00 EDT on August 23, 1995. In the shallow western basin of Lake Erie, the surface mixed layer extends all the way to the lake bottom. In the central and eastern basins, a thermocline is present between 60 and 80 ft.

The map products are stored in a computer-readable format for downloading via dial-in or Internet access to the OSU computer system. They are also available through GLERL to users of the NOAA CoastWatch network (Schwab et al., 1992) in the Great Lakes region. In addition, we have developed a PC-based menu-driven application called GLFSview that runs under Microsoft Windows, and a hypertext network access application for users connected to the Internet to simplify the downloading, browsing, printing, and display of the GLCFS map products (Chu et al., 1994).

6. EVALUATION OF RESULTS

Calibration and assessment of the forecasting system are ongoing tasks. We are using a combination of hindcasting simulations and a daily comparison of observed and predicted temperatures and water levels to test the model.

Daily average water surface temperatures computed by the model during 1993 for two points in Lake Erie are shown in Fig. 3 along with water temperature measurements from two semi-permanent weather buoys moored at these locations. Also shown is the average deviation from the daily mean at each hour of the day at the two locations. The model tends to underestimate surface temperature in the spring (Julian Days 130-150), but correctly simulates peak surface temperatures of 23-25° C in the summer. The early fall cooling (Julian Days 260-280) at buoy 45132 is more rapid than the model simulation, but again the model recovers in the late fall. The average diurnal surface temperature fluctuation at the two buoys is matched quite well in both amplitude and phase by the model simulations. In summary, the comparison shows that the model is able to reproduce observed surface water temperatures with reasonable fidelity in Lake Erie, although the reasons for some discrepancies in the spring and fall need to be investigated further. This comparison gives us confidence that the formulations we use for surface heat flux and temperature advection in the model are generally adequate.

7. SUMMARY AND CONCLUSIONS

This paper has described the design and implementation for Lake Erie of the Great Lakes Coastal Forecasting System, a real-time system for predicting lake circulation and thermal structure in the Great Lakes. The system is designed around a three-dimensional lake circulation model that calculates surface water level fluctuation and three-dimensional current and temperature fields. Input to the system consists of wind, air temperature, moisture, and cloud fields, which are obtained from satellite imagery, routine surface weather observations, and meteorological forecasts. The numerical lake circulation model can run on a supercomputer for high resolution (2 km) grids, or a workstation for lower resolution (5 km) grids. Output from the model is stored in a machine-independent format so that products based on model output fields can be generated on other computers.

The initial implementation of the system produces daily nowcasts and 24 hour forecasts of water level fluctuation, temperature, and circulation for Lake Erie. Full implementation of the system will include: 1) extension to all five lakes, and 2) input from meteorological forecast models to provide 2-day forecasts of lake conditions. The fully implemented system will be useful for hazard forecasting, enhancement of commercial and recreational activity, and natural resource preservation activities. The system will be used both for forecasting, especially for the hazard avoidance and enhancement activities, and for hindcasting, especially for the planning and preservation activities.

Acknowledgments

This work was supported in part by the NOAA Coastal Ocean Program, the Ohio Sea Grant Program, and the NOAA-University of Michigan Cooperative Institute for Limnology and Ecosystems Research. GLERL contribution 976.

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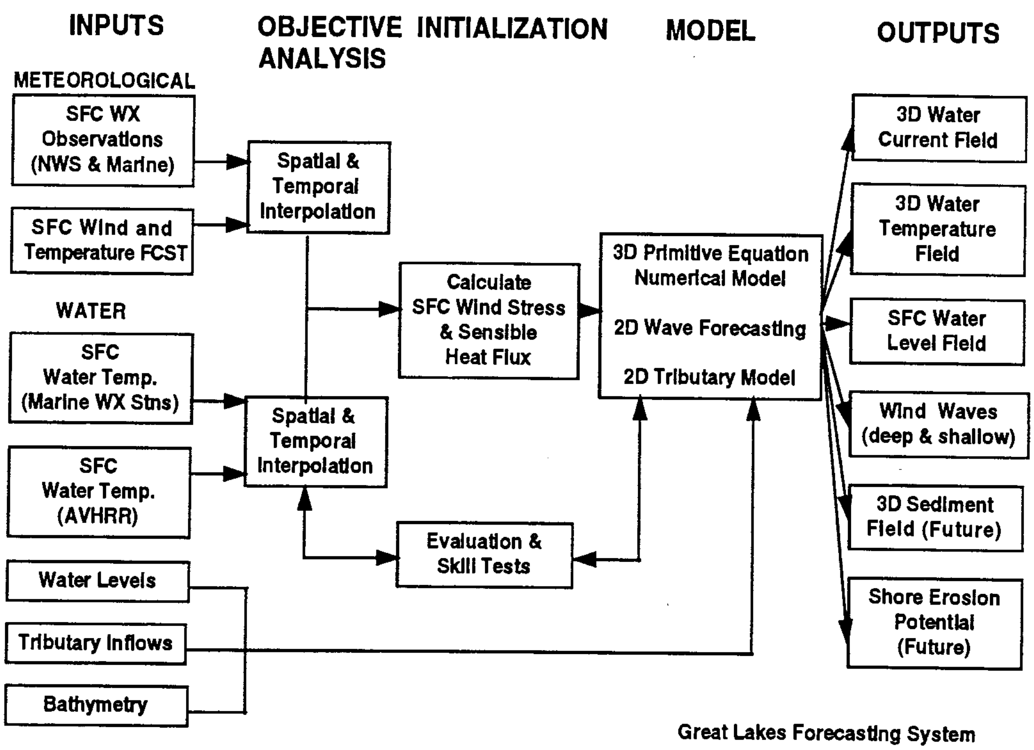

Figure 1. Flowchart for operation of Great Lakes Coastal Forecasting System

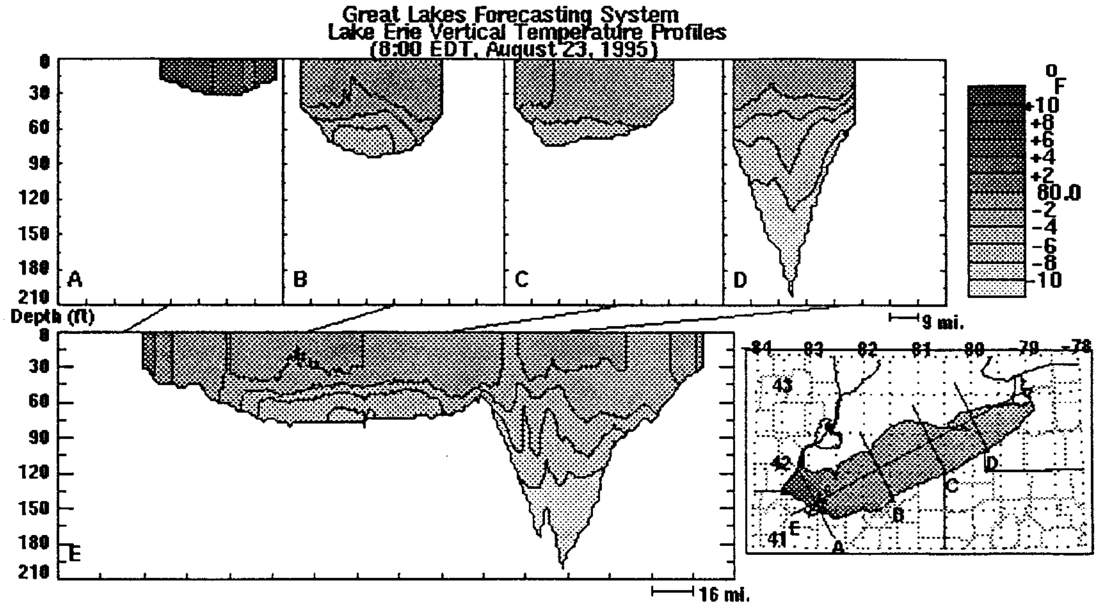

Figure 2. Sample of output map product from Great Lakes Coastal Forecasting System for 8:00 EDT on August 23, 1995.

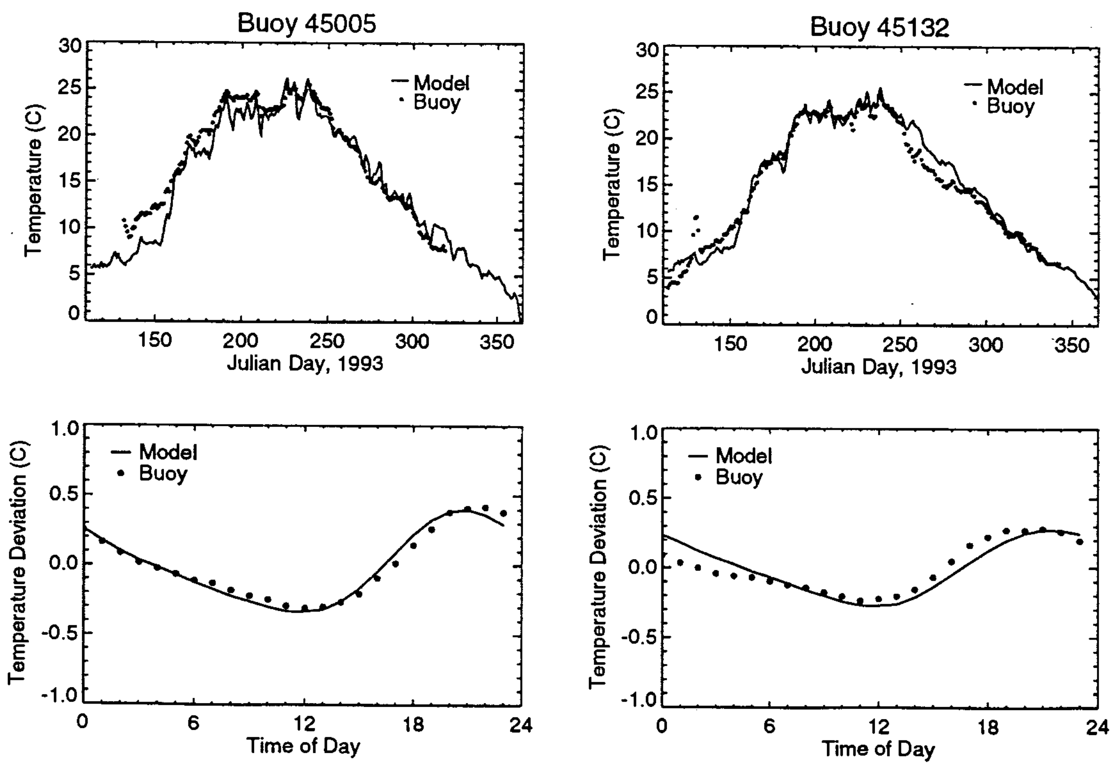

Figure 3. Comparison of observed (dots) and nowcast (line) water temperatures at two locations in Lake Erie during 1993. The upper panel is the daily mean temperature and the lower panel is the average deviation from the daily mean for each hour of the day (the diurnal cycle).