WAVE MODEL VALIDATION IN THE ST. LAWRENCE RIVER ESTUARY

Denis Jacob[1], Will Perrie[2], Bechara Toulany[2], François Saucier[3], Denis Lefaivre[3] and Viateur Turcotte[1]

[1]Meteorological Service of Canada, Environment Canada, Montréal, Québec, Canada
[2]Fisheries & Oceans Canada, Bedford Institute of Oceanography, Dartmouth, Nova Scotia , Canada
[3]Fisheries & Oceans Canada, Inst. Maurice La Montagne, Mt. Joli, Québec, Canada

1. INTRODUCTION

The most widely used and best-tested ocean wave model in the world is the WAM model of Komen et al. (1994), which is presently the operational MSC model. The code is well documented and highly optimized to run on different computational platforms. The WAM model has been extensively used for forecasting on global and regional scales at many weather forecasting centers around the world. However, modern wave modeling has moved beyond the earlier versions of the WAM model. Updated versions of WAM attempt to address the questions related to shallow water, wave-current interactions, and to account for large waves from extreme storms. These formulations also try to provide a suitably flexible model architecture to allow incorporation of improvements to specific modules of their computer codes.

In this study, we use the PROMISE version of the WAM code (http://www.nbi.ac.uk/promise/) to consider applications where currents and ice may be important. We are specifically interested in investigation of the strong influence of local currents, time-dependent water depth, and changes in the effective fetch on wave development. The wave model code was modified to allow forcing from currents produced by an operational ocean circulation model for these waters, from IML (http://www.osl.gc.ca/). The implementation is on a fine-resolution 5*km*-grid for the lower St. Lawrence River and Gulf. For selected storms, preliminary verifications of the heights of waves forecasts indicate that we can obtain encouraging results. We are able to show that the influence of the currents is important in the estuary of the St. Lawrence River, and also that the role of the forecaster is important to insure that high quality accurate winds are available to drive the wave model. Thus, the PROMISE wave model is shown to offer potential improvements for simulations of wave heights and wave spectra for these waters.

2. OPERATIONAL SET-UP

3.1 Wave Model

The formulation of the wave model follows the PROMISE model (Pre-Operational Modeling in the Seas of Europe). This is a WAM cycle 4 third generation wave model for estuaries and enclosed waters. Specially, this is version MW3, which had been dynamically coupled to the hydro-dynamical model of the University of Leuven, as documented by Padilla-Hernández et al. (1999), through radiation stress. This approach is similar to that of Yin et al. (2002), but does not consider several of the nonlinear processes of Lin and Perrie (2002). For this study, the "two-way" wave-current coupling was removed, allowing only the numerically forecast winds and currents to determine and impact the waves. The original WAM4 model was developed for stationary currents and water depths, using absolute frequency ω as an independent variable in terms of the energy density transport equation. For wave development, the action density conservation equation is

$$\frac{\partial N}{\partial t} + \nabla[(\bar{C}_g)N] + \frac{\partial}{\partial \omega}[C_\omega N] + \frac{\partial}{\partial \theta}(c_\theta N) = \frac{S}{\sigma} \qquad (1)$$

where $N(t,x,y,\omega,\theta)$ is the action density spectrum, t is time, ω is the absolute frequency, θ is the wave propagation direction measured clockwise from true north, $\vec{C}_g$ is the group propagation velocity in geographical space, (x,y) or $\vec{x}$, and (C_ω, C_θ), the group velocities in spectral frequency and directional space. Relative frequency σ is related to absolute frequency ω, by the relation $\omega = \sigma + \vec{k}\cdot\vec{u}$ where $\vec{u}$ is the current vector, $\vec{k}$ the wave number vector, and shallow water dispersion is assumed

$$\sigma^2 = gk\tanh(kd) \tag{2}$$

where g is the acceleration due to gravity.

For time-varying currents and water depths, the action density conservation Equation (1) is transformed into the energy density transport equation,

$$\frac{\partial F}{\partial t} + \nabla[(\vec{C}_g + \vec{u})F] + \sigma\frac{\partial}{\partial\sigma}[C_\sigma \frac{F}{\sigma}] + \frac{\partial}{\partial\theta}(c_\theta F) = S \tag{3}$$

$$N = N(\sigma,\theta,\vec{x},t) = \frac{F(\sigma,\theta,\vec{x},t)}{\sigma} \tag{4}$$

$$C_g = \frac{1}{2}(1 + \frac{2kd}{\sinh 2kd})\frac{\sigma}{k} \qquad ; C_\theta = -\frac{1}{k}(\frac{\partial\sigma}{\partial d}\frac{\partial d}{\partial m} + \vec{k}\cdot\frac{\partial\vec{u}}{\partial m}) \tag{5}$$

$$C_\sigma = \frac{\partial\sigma}{\partial d}(\frac{\partial d}{\partial t} + \vec{u}\cdot\nabla d) - C_g\vec{k}\cdot\frac{\partial\vec{u}}{\partial s} \tag{6}$$

where $F(\sigma,\theta)$ is the spectral density, d, $\vec{k}$, $\vec{u}$ are water depth, wave number vector, velocity vector, s is the space coordinate in the propagation direction, θ the two-dimensional space gradient is ∇, m is the spatial coordinate perpendicular to the propagation direction, θ, and formulations for propagation speed, C_g, C_σ and C_θ are given in terms of the effect of varying depth and currents. Source functions are: $S = S_{in} + S_{nl} + S_{dis} + S_{bot} + S_{dbs}$, including wind-input, nonlinear interactions, white-capping dissipation, bottom friction and depth-limited breaking dissipation. A detailed description of the model is given by Padilla-Hernández et al. (1999).

2.2 Model Set-Up

A 5-km resolution grid is used for the St. Lawrence River estuary, for both the wave model and the operational ocean current model. The forcing wind fields are produced from the operational GEM model at Canadian Meteorological Center (CMC), at 24-km resolution. This is interpolated to 5-km resolution for simulations of this study. Wave model time steps are 2 minutes, with 30-degree angular resolution and 25 frequency bins.

3. NUMERICAL STUDY OF THE ST. LAWRENCE RIVER ESTUARY

The St. Lawrence River Estuary is composed of the lower St. Lawrence River and the Gulf of St. Lawrence. This area has great strategic importance to Québec and Canada because it is not only a vast semi-enclosed sea, it is also the most important water-route linking central Canada to the Atlantic. The fine-resolution grid area, as shown in Figure 1, is the focus of this study. The purpose of this study is to consider the impacts of detailed wind effects and currents on fine-resolution wave estimates for this region. A secondary objective is to offer a feasibility analysis of the potential for the adoption of a coupled wave-current model to make predictions of wave heights in this region.

3.1 Validation Data

The main source for data, to validate wind and wave fields resulting from this study is *in situ* data from a buoy moored at 49.5N, 65.8W, about 20 km north of the Gaspé coast, as shown in Figure 1. This buoy reported wind speed and direction as well as wave heights.

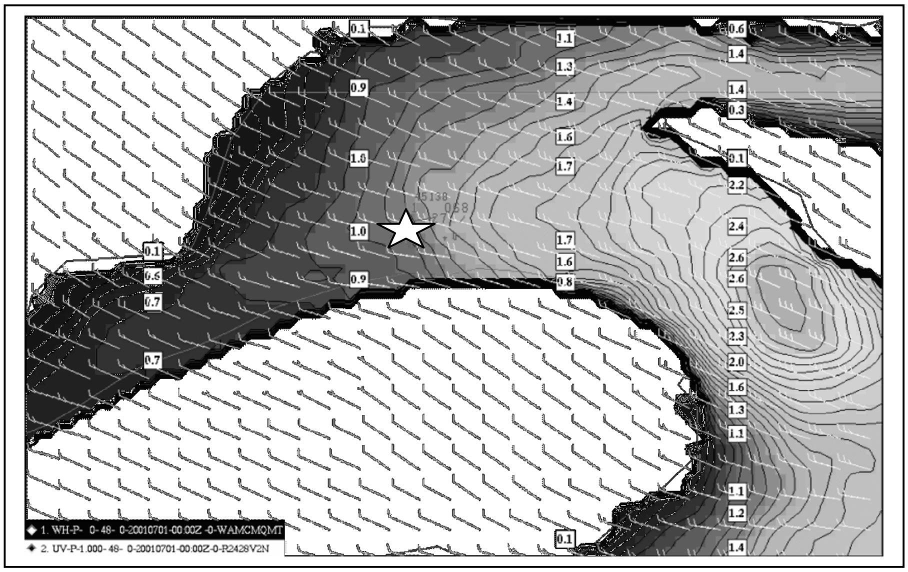

Figure 1. Position of the buoy, ☆, with 24-km winds and wave height contours for the peak of the storm.

3.2 Case Study

Validation of the model was achieved with data collected from a real storm, which occurred on 1-3 July 2001. This event involved cyclonic low passing from west to east, as shown in Figure 2. During the initial phase of the storm, winds at the buoy are southerly with moderate speeds that do not exceed 10*m/*s. With the passage of the central minimum pressure, the wind directions shift by almost 180^o, becoming northerly, and wind speeds briefly exceed 10*m/s*. The shift in wind directions occurs at about hour 35, in the time series shown in Figure 3. This is closely followed by a concomitant increase in wave height.

3.4 Test 1

The baseline study of the storm consists of using winds straight from CMC. The uncoupled wave model did not use currents. The “one-way” coupled wave model uses operational currents from IML. A 48-hour forecast was made with only a cold start, which requires about 9-12 hours to stabilize the atmospheric model.

Results, given in Figure 4 show that model calculations with currents give better results, than without currents, at the buoy location. However there are important discrepancies that remain to be investigated. Note that the impact of currents can give up to 1*m* change in estimated wave heights. Differences between forecast and observed winds correspond well to instances where discrepancies in modeling wave heights occur. This is indicated by Figure 5, comparing observed and forecast wind speeds.

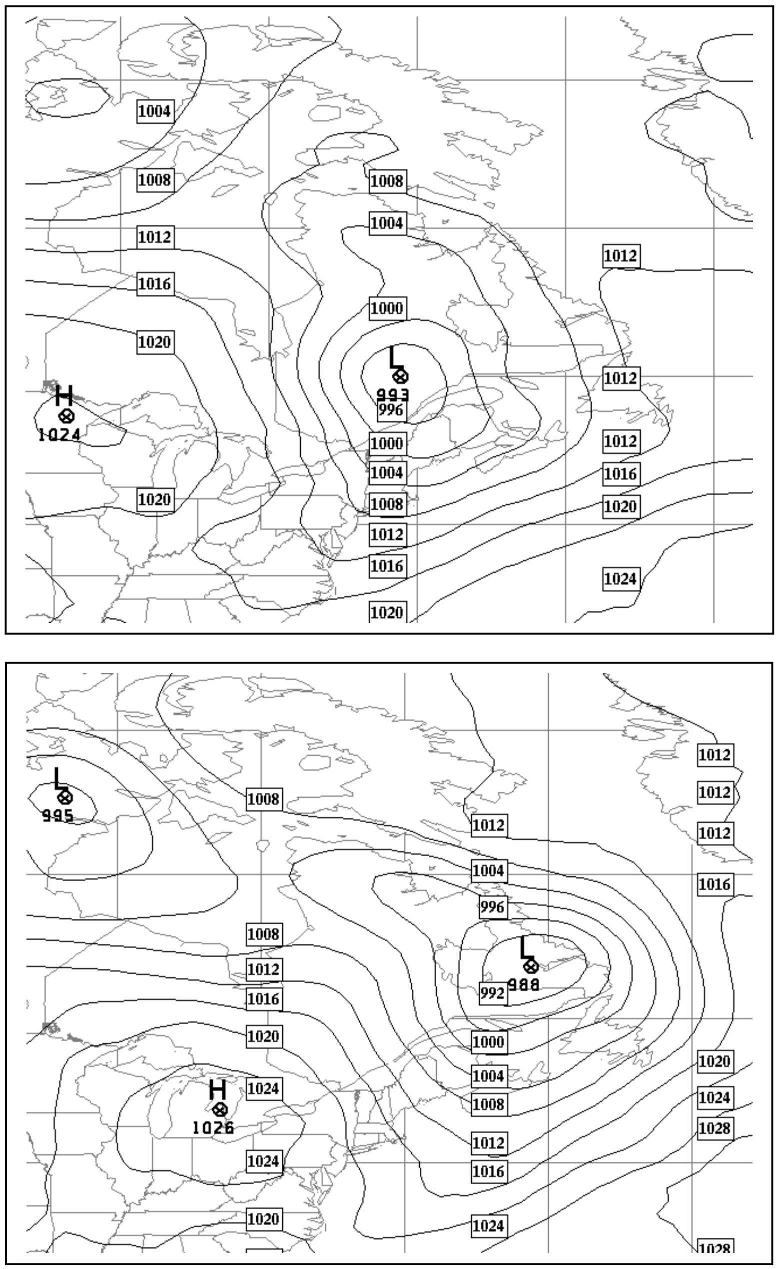

Figure 2. Evolution of the synoptic situation on July 2 at 00 and 18 UTC.

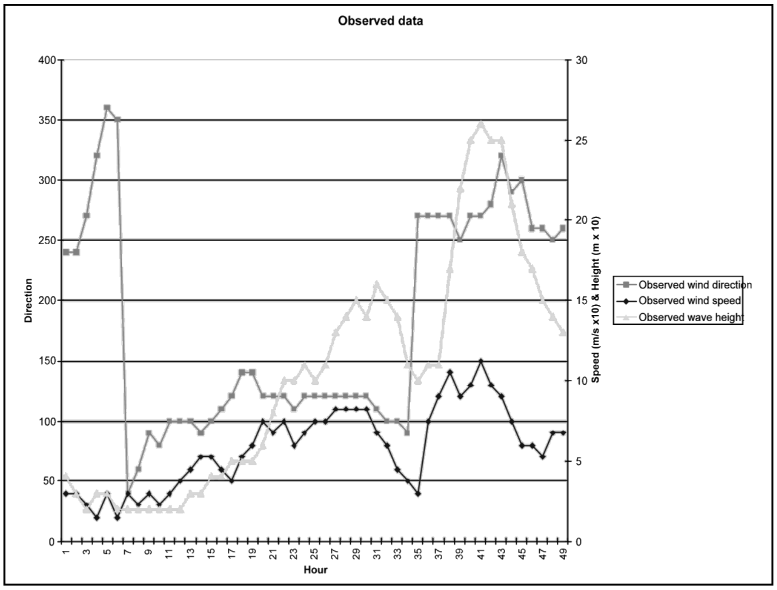

Figure 3. Time series of wind speed and direction and wave height at the position of the buoy, during the storm.

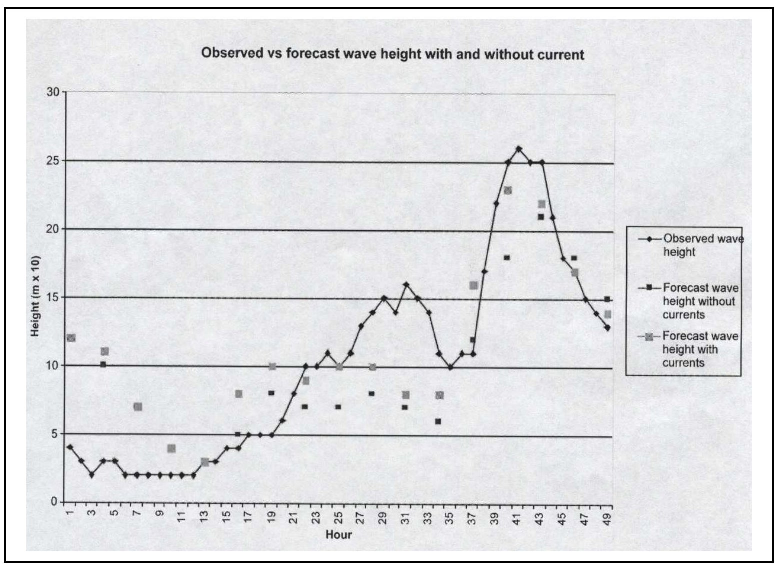

Figure 4. Test 1 results: time series of observed wave heights, compared to coupled and uncoupled model outputs.

3.5 Test 2

In this case, in both simulations, currents are "one-way" coupled to the wave model in the sense that no wave information is passed back to impact the ocean current model. One run uses CMC winds, as in Test 1. In the second run, winds are modified by the forecaster. Both simulations assume a 48-hour forecast, starting with a cold start. Figure 6 presents a comparison of CMC winds, observed buoy winds and forecaster modified winds.

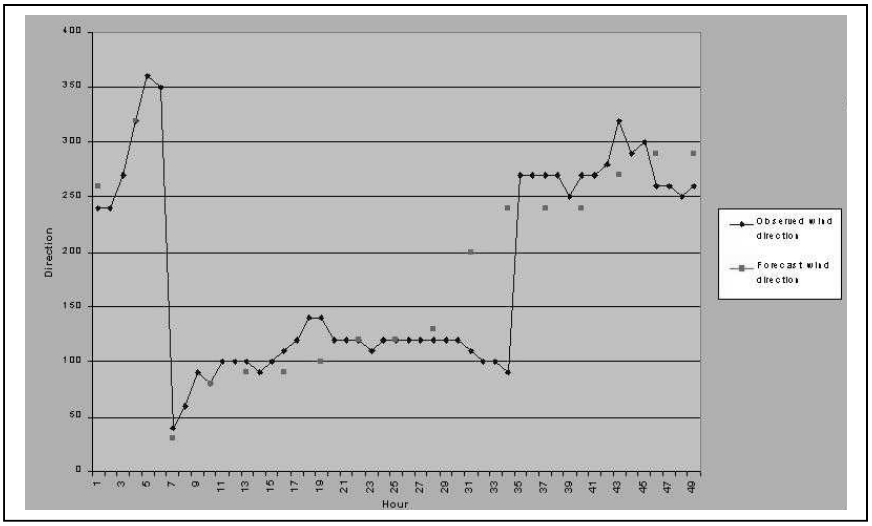

Figure 5. Test 1: Comparison of CMC forecast winds to observed buoy winds.

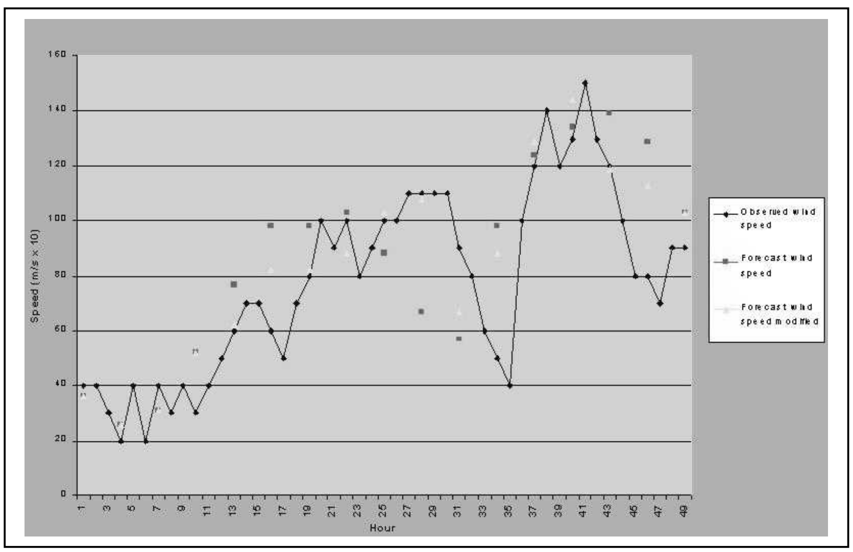

Figure 6. Forecaster modified Test 2 winds, compared to CMC output wind speeds and buoy observations.

Results of Test 2 are given in Figure 7. This shows that notable improvements follow from the forecaster modified winds, compared to routine CMC winds. As a result of this test, the operational implementation links the wave model with Scribe-marine for consistencies between forecast wave heights and winds. This is in conjunction with operational currents from IML. On an operational basis, the forecaster will modify the winds with Scribe-marine. If wind modifications exceed 10 *kts* (5 *m/s*), or 30 degrees, new winds are used by the wave model. New wave heights as well as the new winds forecasts are going to be put back into Scribe-marine interface. Moreover, a new GRIB file would be sent to the operational desk and to IML.

4. CONCLUSIONS

For good wave forecasting in the St. Lawrence River Estuary, we need good wind forecasts, in conjunction with good estimates of currents, and the input of an experienced forecaster. Present plans include the initialization of the forecast with the previous 12-hours wave height forecasts in order to diminish the spin-up effect. We also plan to continue to improve the code to reduce computation time. This will be followed closely with implementation for James and Hudson Bays, as well as the Great Lakes, for Ontario Region. Ice interactions are to be added during the 2002-03 winter timeframe.

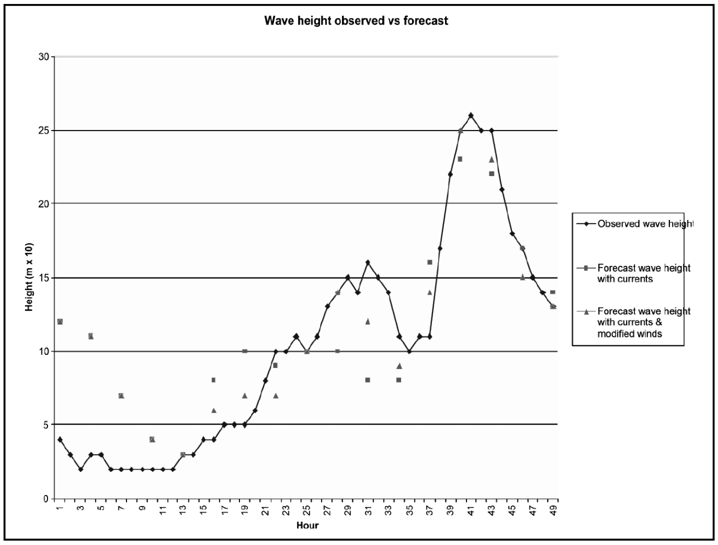

Figure 7. Test 2 results comparing observed wave heights to wave height estimates resulting from the model driven by CMC winds, and wave estimates resulting from forecaster-adjusted winds.

ACKNOWLEDGEMENTS

This project was supported by the Coast Guard SAR NIF. We also gratefully acknowledge funding from the Panel on Energy Research and Development (PERD).

REFERENCES

Komen, G. J., Cavaleri, L., Donelan, M., Hasselmann, K., Hasselmann, S., and Janssen, P.A.E.M., 1994: Dynamics and Modelling of Ocean Waves, Cambridge Unversity Press, 532 pp.

Lin, R.-Q. and Perrie, W., 2002: Wave-current interactions in an idealized tidal estuary. In press in *J. Geophys. Res.*

Padilla-Hernández, R., Ozer, J., Monbaliu, J., Osuna, P., and Flather, R., 1999: Development of a generic module for the combined modelling of tides, surges and waves. http://www.nbi.ac.uk/promise.

Yin Baoshu, Perrie, W., HouYijun, Lin Xiang, Cheng Minghua, 2002: The impact of radiation stress in a coupled wave-tide-surge model. *Proceedings of This Workshop.*