Waves in Hurricane Juan

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Hurricane Juan made landfall at 12:10 a.m. ADT, Monday, September 29, between Prospect and Peggy's Cove, Nova Scotia, and then moved northward across the central portion of the province, passing over Northumberland Strait and Prince Edward Island. This was a Category 2 hurricane, the largest storm to pass over these coastal areas in several decades. Associated high ocean waves were experienced in coastal waters, lashing shoreline villages and beaches from Peggy's Cove to Sheet Harbour. Growing to epic proportions on the Scotian Shelf, the height of these waves exceeded the 100-year return wave, based on the present climatology.

Scientists at Bedford Institute of Oceanography (BIO) are presently involved in programs to test and evaluate modern state-of-the-art, high-resolution wave-forecast model systems for the northwest Atlantic. This work is funded to address issues related to safety concerns of the oil and gas offshore industry, coastal transport, fisheries, Coast Guard Search and Rescue, recreational boating, and coastal development. The first real-time test of these high-resolution wave forecast models, for this region, was Hurricane Juan. Maximum winds exceeded 150 km/h, gusting to 176 km/h, with the maximum wind core passing over Halifax Regional Municipality.

Accurate wave forecasts are dependent on reliable forecast wind fields. At BIO, winds are routinely downloaded from Fleet Numerical Meteorological and Oceanographic Center (FNMOC) in Monterey, California, because we are the pre-operational wave-forecasting component of GoMOOS (Gulf of Maine Ocean Observing System, www.gomoos.org). These winds are from the USA Navy COAMPS (Coupled Ocean Atmosphere Model Prediction System), and for Hurricane Juan they were of particularly high quality. Figures 1a-c presents COAMPS winds at 00 UTC on 29 September (9:00p.m. ADT on September 28), in comparison with blended scatterometer winds, using Florida State University satellite-wind algorithms, and Canadian Hurricane Centre (CHC) storm track analysis. The COAMPS storm track appears to be slightly to the east of that presented by scatterometer data and the CHC analysis, a feature that is qualitatively and quantitatively consistent with the COAMPS wind fields.

The BIO wave model system for GoMOOS consists of nested grids. These include a fine mesh 0.1° resolution grid for the Gulf of Maine, nested within an intermediate 0.2° resolution grid for the northwest Atlantic, which is nested within a 1.0° coarse resolution North Atlantic grid. The operational Wavewatch III (WW3) model developed by the USA National Centers for Environmental Prediction (NCEP) was implemented for the coarse- and intermediate-resolution grids. Variations of this overall nesting formulation are presently being evaluated and reconstructed to better address the needs of Atlantic Canada offshore interests. We report results from the intermediate-resolution grid for this discussion of Hurricane Juan.

The GoMOOS composite wave model routinely produced 48-hour wave forecasts, every 12 hours, before and during the passage of Juan. In the aftermath of the power blackout that followed Juan, the forecast system was able to continue for a day, until 30 September, at which time the computer was shutdown because BIO's back-up power was beginning to fail. As shown in Figures 2a-b, the wave model forecasts suggest significant wave heights (Hs) of almost 12 m for Scotian Shelf, at 00 UTC 29 September. Along the Eastern Shore of Nova Scotia, Hs wave heights as high as 10 m were predicted for coastal areas. These forecasts compare well with available measured wave heights. Waves were observed to pass at least 2 m over the sea wall at Peggy's Cove, which is 2 m high and located on a ridge that is 5 m above sea level, crashing through the village and causing extensive damage.

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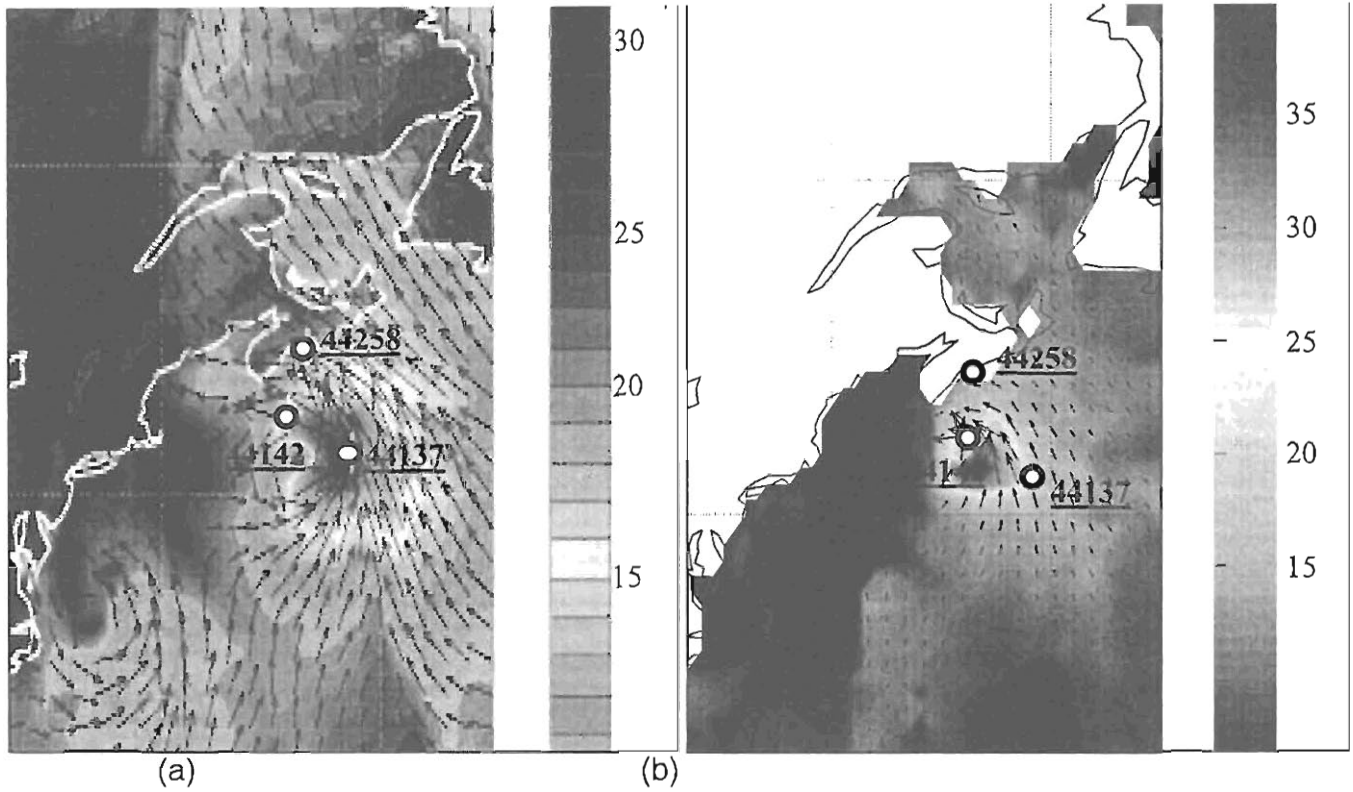

Figure 1. Comparison of wind fields: (a) COAMPS winds at 00 UTC on 29 September, (b) blended scatterometer winds from 18-24 UTC on 28 September.

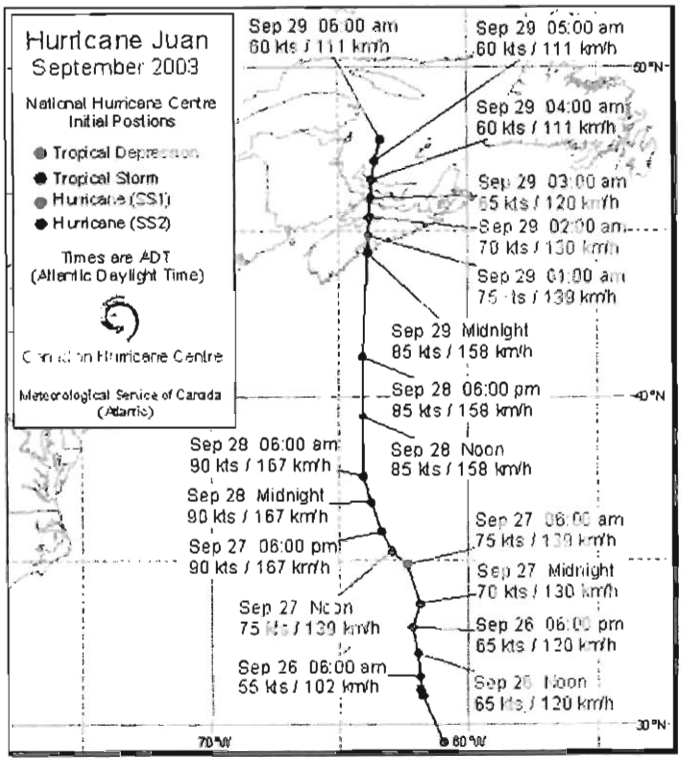

Figure 1c) CHC storm track analysis and peak storm winds from http://www.ns.ec.gc.ca/weather/hurricane/juan/track2_e.gif. MSC buoys are 44142, 44137, and 44258 as indicated. Wind speed units are m/s.

COAMPS winds were able to capture the timing of Juan's passage correctly, but did not completely simulate the peak storm intensity, or storm track. The actual storm track passed slightly to the west of the simulated COAMPS model forecast track over Scotian Shelf. Therefore, the COAMPS winds are too low at (Meteorological Service of Canada - MSC) buoy 44258 at the mouth of Halifax Harbour (Fig. 3a), and at offshore buoy 44142 (Fig. 3b), and too high at offshore buoy 44137 (Fig.3c), compared to measured winds.

The largest Hs wave heights recorded at buoy 44258 off Halifax Harbour were almost 9 metres (Fig.4a), with maximum waves of about 20 metres. Corresponding wave model estimates from the BIO WW3 implementation appear to underestimate these Hs waves by about 1 m, although the timing of the peak is very nearly correct.

Maximum significant wave heights (Hs) of 12 m were measured at buoy 44142 on western Scotian Slope (Fig. 4b). Although the COAMPS winds and WW3 wave forecast correctly simulated the timing of the storm, the observed Hs peak at this site was underestimated by about 4-5 m, and the observed winds were high by as much as ~15 m/s relative to COAMPS (Fig. 3b). Note however, that 12 m Hs waves were achieved within the WW3 wave field at 00 UTC (Fig. 2a). By comparison, a maximum observed Hs of 7 m, measured at buoy 44137 on eastern Scotian Slope (Fig.4c), was overestimated in the WW3 wave forecast by about 1 m, reflecting a systematic overestimate of the observed wind speed by about 1-2 m/s (Fig.3c). Again the

forecast timing of the storm's passage was excellent at buoy 44137, so that in spite of slight quantitative errors related to storm track, the GoMOOS forecast for Hurricane Juan was essentially correct.

BIO scientists are supporting Environment Canada (EC) weather specialists in the examination of all collected data, including surface wave observations as well as wind data from aircraft and satellite measurements. As information becomes available and we learn more about the storm's nature and impacts, results will be presented in workshops and conferences. A successful outcome of Hurricane Juan would be a collaboration between EC and DFO researchers to formulate and implement reliable models for accurate prediction of marine winds and waves in storms affecting coastal areas of Atlantic Canada.

Acknowledgements

We are grateful to Fleet Numerical Meteorological and Oceanographic Center (FNMOC) in Monterey California for assistance in accessing and using COAMPS wind products, and to Mark Bourassa and Jim O'Brien at Florida State University for satellite-wind blending algorithms and codes. Funding was provided by the Panel on Energy Research and Development (PERD), the Gulf of Maine Ocean Observing System (GoMOOS), the Petroleum Research Atlantic Canada (PRAC), the Canada Foundation for Climate and Atmospheric Studies (CFCAS). Canada Coast Guard New Initiatives Fund (SAR NIF) is supporting an initiative led by Environment Canada that collected aircraft and *in situ* data during Juan.

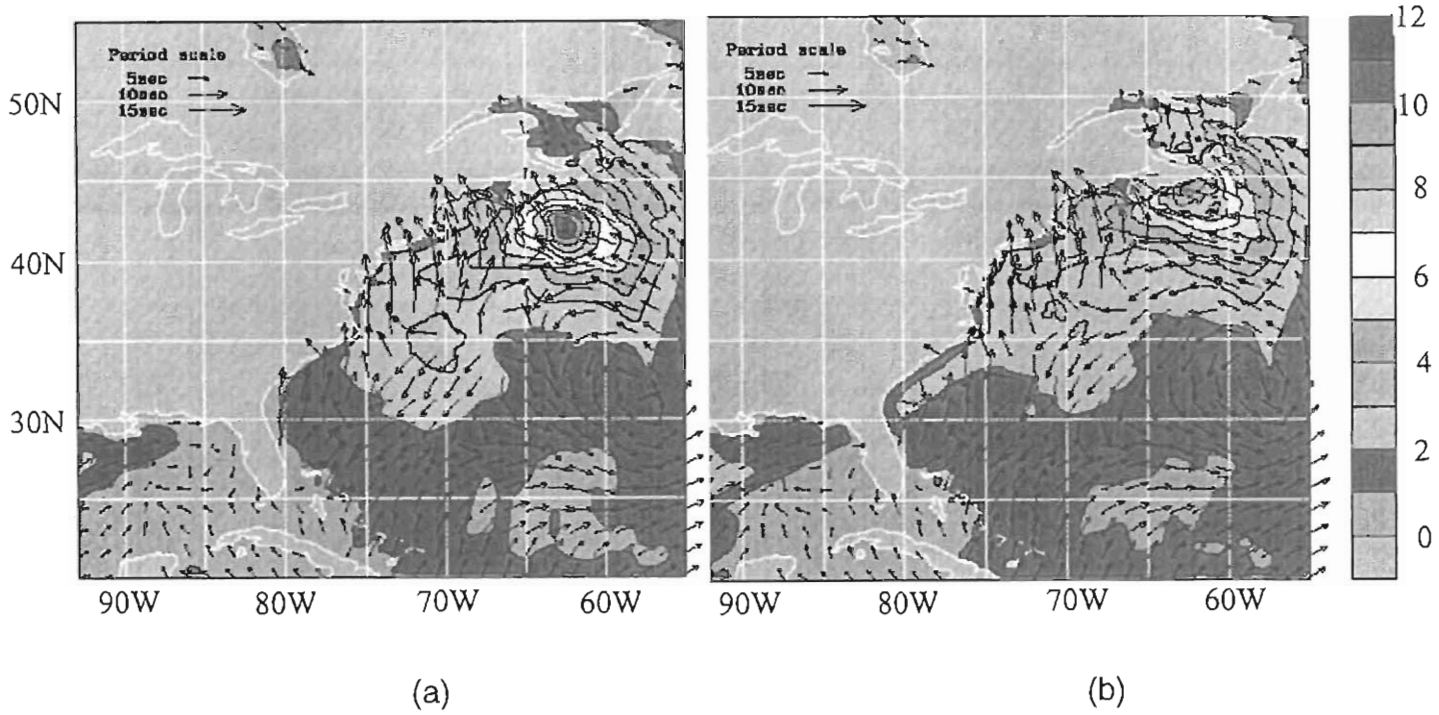

Figure 2. BIO WW3 wave model outputs for (a) 12-h and (b) 18-h forecasts, based on GoMOOS pre-operational run at 12 UTC on 28 September. These forecasts, valid for 00 UTC and 06 UTC 29 September, respectively, indicate the peak wave heights for Juan occurred in the early hours of 29 September. Significant wave heights (contours), wave directions (arrows), and wave periods (length of arrows) are shown.

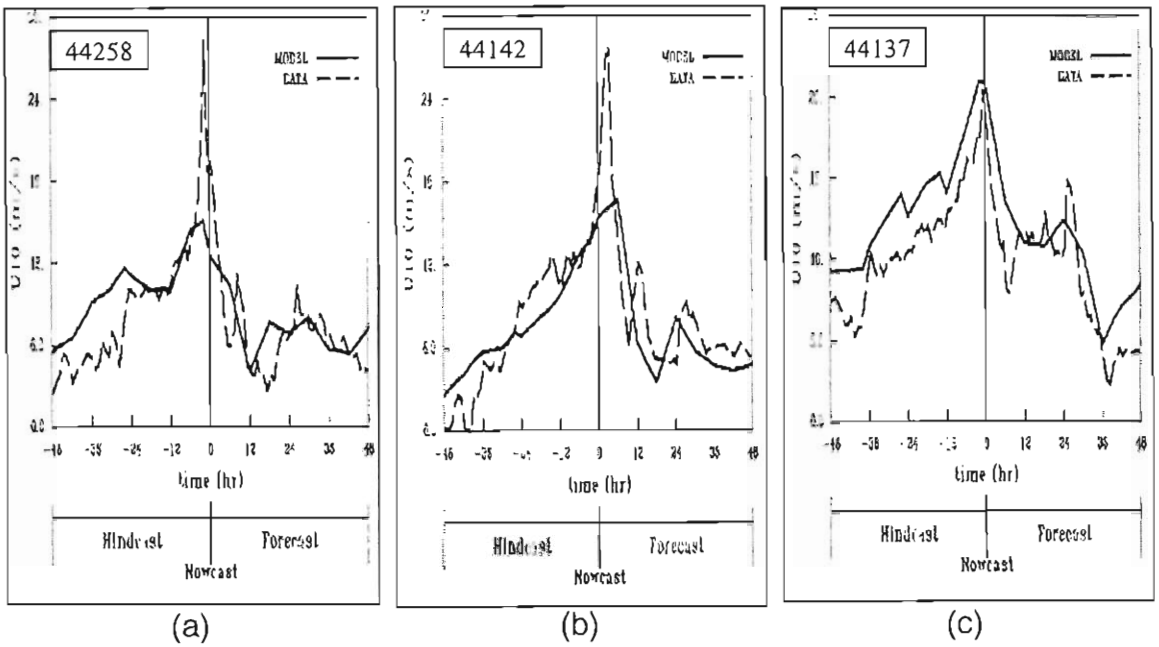

Figure 3. Comparison of COAMPS wind forecasts with observations from operational MSC buoys on Scotian Slope (44137 and 44142) and at the mouth of Halifax Harbour (44258) for 10-m wind speed (U10). Routine forecasts are plotted every 12h, from hindcasts ($-48 \leq t < 0$ hr), nowcast ($t=0$), and forecasts ($0 < t \leq 48$ hr) for each buoy.

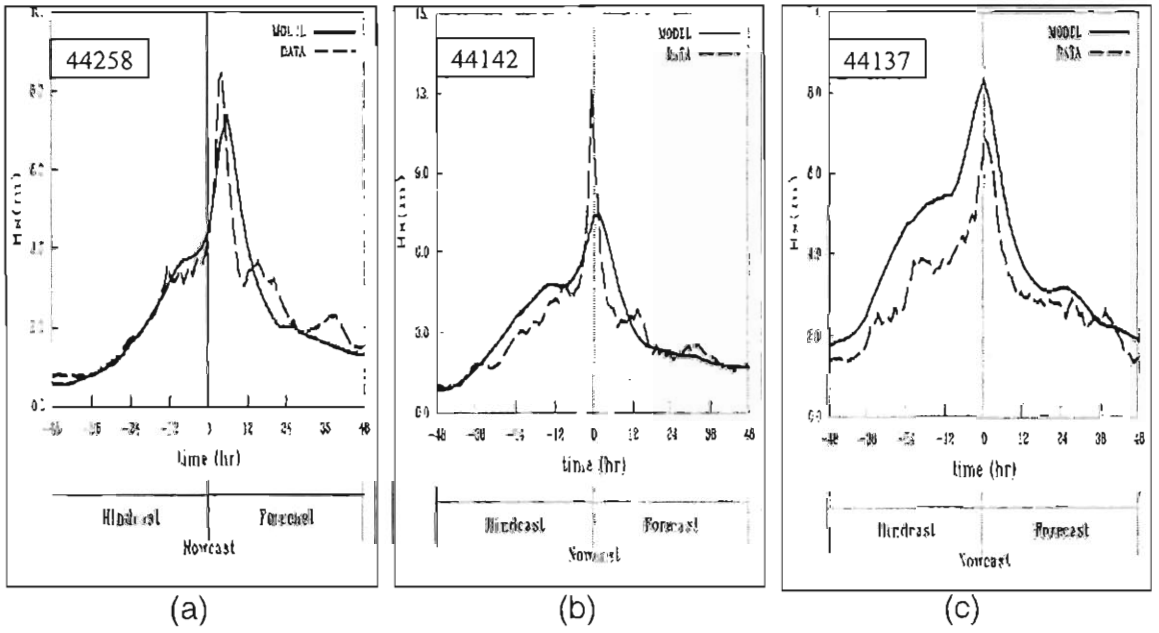

Figure 4. Comparison of wave model forecasts with observations from buoys 44137, 44142 and 44258, for significant wave height (Hs), during Hurricane Juan. Routine forecasts are plotted every 12h, from hindcasts ($-48 \leq t < 0$ hr), nowcast ($t=0$), and forecasts ($0 < t \leq 48$ hr).