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High-Precision Simulation Study of Hurricane Juan-Generated Waves in Coastal Shallow Water

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Hurricane Juan generated huge, complex waves in the Northwest Atlantic and in coastal waters off Nova Scotia in late September 2003. This study focuses on the accurate, high-precision simulation of waves generated by Hurricane Juan in coastal waters through the application of the WAVEWATCH III (WW3) and SWAN wave models. Cyclone-generated waves in coastal waters are very complex compared with those in offshore and ocean regions. Two issues are addressed that influence the accurate, high-precision simulation of cyclone-generated waves in coastal waters: (1) the SWAN model's numerical sensitivity during nonstationary simulations in coastal waters; and (2) the incoming two-dimensional wave spectral pattern at the model boundaries.

INTRODUCTION

A detailed discussion of Hurricane Juan's development is given by Fogarty et al. (2006). Juan reached hurricane strength by 1200 Coordinated Universal Time (UTC) on September 26, 2003 near Bermuda and moved northward and then northwestward as a subtropical ridge, which was to the northeast of its location, extended to the west. It reached a maximum wind intensity of 46 m/s at 2100 UTC on September 27 and then turned northward towards Nova Scotia with increasing propagation speed. By 1800 UTC on September 28, Juan was north of the Gulf Stream, and its intensity began to weaken due to the cooler continental shelf waters south of Nova Scotia. However, because of its accelerating translation speed, Juan spent little time over these cooler waters and therefore did not weaken significantly. Juan made landfall near Halifax (0300 UTC on September 29) with sustained winds of 44 m/s. Table 1 gives the detailed storm characteristics of Juan and the best track for Juan from 0300 UTC on September 27 to 0900 UTC on September 29 (Avila, 2012). Figure 1 depicts the variation in the translation speed for Juan, showing a dramatic increase in speed from 2.28 m/s to 20 m/s. This acceleration in translation speed, typical of extratropical hurricanes, allowed the generation of huge, complex waves in deep ocean and coastal areas.

It is well known that the operational forecasts of waves generated by Hurricane Juan tended to have poor quality. For a discussion of the weather forecasts, see McTaggart-Cowan et al. (2006). Errors in forecasted winds led to large errors in forecasted waves (Padilla et al., 2007). Therefore, Xu et al. (2007) carried out a study of these waves. They improved the simulation of Juan's winds by developing a methodology to blend and interpolate simulated winds into wind observations. Moreover, in this approach, they considered the translation speed effect, implementing a high wind speed modulation of the drag coefficient. In this manner, they were able to notably improve the accuracy of the simulated waves. However, problems still remain, especially for waves generated by Juan in coastal shallow water areas, even if the spatial and spectral resolutions are notably increased compared to those of the grids used in operational forecasting. This study focuses on the high-precision simulation of waves generated by Hurricane Juan in shallow waters. Our approach is to explore the nonstationary computation method and to improve the boundary conditions at the edge of the integration grid through the use of observed two-dimensional spectra. Related studies by Perrie et al. (2010a, 2010b, 2013) considered the impact of different parameterizations of nonlinear wave-wave interactions on simulations of waves generated by Juan over the deepwater portion of its life cycle.

Two of the most popular ocean wave models, WAVEWATCH III (WW3) (Tolman, 2002, 2009) and Simulating WAves Nearshore (SWAN) (Booij et al., 1996), were applied to perform wave simulations through the use of data along Hurricane Juan's track. The model behaviors of WW3 and SWAN were studied and compared by Montoya et al. (2013) in the simulation of waves generated by Hurricane Katrina, including spectral wave patterns in the Gulf of Mexico. Until now, wave model studies that considered numerical iteration methodologies in comparison with methods to set the dynamic spectral wave boundaries were still rarely seen in case studies involving intense cyclones. In numerical iteration methodologies, the default setting (one iteration at each time step) for the SWAN wave model is widely used for nonstationary computations in shallow waters. However, for hurricane-generated waves, this setting of one iteration seems questionable when both winds and waves experience dramatic variations; for example, when this default setting is used, the operational forecasting of waves generated by Juan gives results that are biased low (over 40% too low) in shallow waters off Lunenburg Bay. In dynamic spectral wave boundary methods, the accurate simulation of hurricane-generated waves is dependent on the boundary conditions. Two kinds of input boundaries are available for waves generated by Juan in shallow waters in Lunenburg Bay: one uses the observed two-dimensional spectra at a Directional Wave Rider (DWR) buoy

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KEY WORDS: Hurricane Juan, WW3, SWAN, coastal shallow waters, two-dimensional wave spectra.