Effect of a steep and complex-featured shelf on computed wave spectra.

Juan O. Gonzalez-Lopez[1], J.J. Westerink[1], A. Mercado[2], J.E. Capella[3], J.M. Morell[2], and M. Canals[4]

[1]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, Indiana
[2]Department of Marine Sciences, University of Puerto Rico, Mayaguez, Puerto Rico
[3]Modeling Coordinator, Caribbean Coastal Ocean Observing System
[4]Department of Engineering Science and Materials, University of Puerto Rico, Mayaguez, Puerto Rico

Abstract

The steep and complex bathymetry off the southwestern coast of Puerto Rico provide a natural test bed for examining effects of model resolution on modeling hurricane waves and storm surge. Here, gradients in excess of 1:1 at the shelf break rapidly step into a shallow shelf with numerous bathymetric features of diverse spatial scales. This abrupt progression from deep to shallow waters brings to attention wave propagation and transformation phenomena at scales that are relevant to both hurricane waves and wave-induced circulation modeling. The SWAN+ADCIRC model is used to hindcast Hurricane Georges using an unstructured mesh previously optimized for wind driven storm surge and the results are compared to a loosely-coupled simulation using a 30 meter structured SWAN grid on the continental shelf. Results show that the structured model better represents the wave phenomena, leading to more accurate storm surge water levels. Two dimensional wave spectra are analyzed to explore the effect of resolution on hurricane wave transformation and water level observations are analyzed to explore the effects of resolution on properly solving wave setup on complex bathymetry. These results give insight on developing mesh optimization for coupled unstructured wave-circulation models.

Introduction

Puerto Rico has a diverse coastal geomorphology that ranges from a narrow shelf at the north and southeastern coast to a wider shelf with numerous fringing reefs at the southwestern coast. The wave regime differs greatly at each coast due to the influence of the Atlantic Ocean at the north and the Caribbean Sea at the south coast, as well as the difference between the wave transformation processes that occur in narrow versus wider, reef-featured shelves [3]. Such a great variation in bathymetric features and dynamic ocean processes demand that numerical models capable of solving the dynamics at such varied scales be used.

The southwestern coast combines a wide, reef-featured continental shelf with a steep shelf break with gradients in excess of 1:1 [5]. At such gradients, a spatial resolution in the order of one kilometer at the shelf break causes the unstructured mesh elements to transition abruptly from a depth greater than 400 meters to 20 meters in one element size. While this spatial resolution gives acceptable results for storm surge water surface elevations when the model is forced by tides, winds and gradients of radiation stresses calculated by a structured wave model, when coupling the ADCIRC [6] and SWAN [7] models (SWAN+ADCIRC henceforth) into a single unstructured mesh SWAN generates low-frequency spectral energy at the shelf break that is then propagated through the domain.

This low-frequency spectral energy shows up both as a distorted two dimensional wave spectrum and as anomalous high peak periods that propagate trough the domain. Since SWAN solves the evolution of the two dimensional wave spectrum, this low-frequency spectral energy will affect all variables that are computed from the two dimensional wave spectrum, including the significant wave height and gradients of radiation stress. The correct computation of these variables is critical for the modeling of storm surge and inundation on coastal areas.

Models and methodology

The unstructured, coupled SWAN+ADCIRC [1] model was used to simulate the storm surge water levels and wind waves generated by Hurricane Georges from September 21, 1998 to September 23, 1998 as it moved through Puerto Rico and the U.S. Virgin Islands. Using this model allows for the interaction between the wind, tides, currents, and wave processes while using a single unstructured mesh to run both models. Wind fields were generated using the parametric Holland wind model [2], with asymmetry introduced by adding the hurricane's translation speed to the parametric wind field [4].

Two unstructured meshes were used for the numerical experiments. The first mesh had a resolution of about one kilometer along the shelf break. For purposes of this study the shelf break is defined as the depth drop after the 20 m isobath, which delimits the continental shelf given the steep gradient in the studied area. To explore the effects of mesh resolution on the wave spectrum, the same mesh was refined to a resolution of 50 meters along the shelf break on the southwestern coast of Puerto Rico. A hindcast of Hurricane Georges was then run on both meshes while keeping all other model variables constant.

A 30 meter spatial resolution structured SWAN grid was created as a best-solution to compare the results obtained from the SWAN+ADCIRC model and explore the effects of spatial resolution when using an unstructured mesh. The 30 meter resolution grid covers an area which includes the coastline, reefs and the shelf break so that all the wave processes on the SWAN model can be solved using the highest resolution available. These results were then used as a baseline for the comparison with the SWAN+ADCIRC model.

Results

Figure 1 shows the computed peak period for a location at 8 m deep when using the SWAN+ADCIRC model with a shelf break resolution of 1 km and 50 m, and structured SWAN with a resolution of 30 m. It is clear that the computed peak period with a shelf break resolution of 1 km reaches the longest period allowed in the model configuration through all the run, while increasing the mesh resolution to 50 m just at the shelf break produces a computed peak period that is similar to that computed when using a structured grid with a uniform resolution of 30 meters through the domain.

The two dimensional wave spectra on Figure 2 shows that the increase in resolution greatly changes the spectral energy computed by the wave model. At the same time it shows that a localized increase in resolution at the shelf break can result in a wave spectrum comparable to one computed with a high resolution structured grid, thus greatly reducing the amount of computational points required to compute the wave spectrum.

Conclusions

A localized increase of mesh resolution at the shelf break when using SWAN+ADCIRC results in a computed two dimensional wave spectra that is comparable to the one computed using a structured SWAN grid of 30 m at the whole domain of interest. This localized increase in resolution at the shelf break also diminished the amount of times at which the computed peak period reached the longest period allowed in the model configuration. Further study is needed to explore the effects of increased resolution on the shelf break at a basin scale on the computed wave spectra and its implications for coupled unstructured wave-circulation model mesh construction.

Acknowledgements

Casey Dietrich at University of Texas - Austin for his support with the SWAN+ADCIRC code. Funding for this work was provided by University of Notre Dame (Jose Fernandez Scholarship) and

the Caribbean Coastal Ocean Observing System (NOAA-IOOS Award No. NA08NOS4730408).

References

[1] JC Dietrich, M. Zijlema, JJ Westerink, LH Holthuijsen, C. Dawson, RA Luettich Jr, RE Jensen, JM Smith, GS Stelling, and GW Stone. Modeling hurricane waves and storm surge using integrally-coupled, scalable computations. *Coastal Engineering*, 2010.

[2] GJ Holland. An analytical model of the wind and pressure profiles in hurricanes. *Mon. Weather Rev.*, 108:1212–1218, 1980.

[3] J. Morelock. Shoreline of Puerto Rico. Technical report, Department of Natural Resources, Puerto Rico, 1978.

[4] M. Peng, L. Xie, and L.J. Pietrafesa. Tropical cyclone induced asymmetry of sea level surge and fall and its presentation in a storm surge model with parametric wind fields. *Ocean Modelling*, 14(1-2):81–101, 2006.

[5] L.A. Taylor, B.W. Eakins, K.S. Carignan, R.R. Warnken, T. Sazonova, and D.C. Schoolcraft. Digital Elevation Models of Puerto Rico: procedures, data sources and analysis. Technical Report NOAA Technical Memorandum NESDIS NGDC- 13, National Geophysical Data Center, 2008.

[6] J.J. Westerink, R.A. Luettich, J.C. Feyen, J.H. Atkinson, C. Dawson, H.J. Roberts, M.D. Powell, J.P. Dunion, E.J. Kubatko, and H. Pourtaheri. A basin-to channel-scale unstructured grid hurricane storm surge model applied to southern louisiana. *Monthly Weather Review*, 136(3):833–864, 2008.

[7] M. Zijlema. Computation of wind-wave spectra in coastal waters with SWAN on unstructured grids. *Coastal Engineering*, 57(3):267–277, 2010.

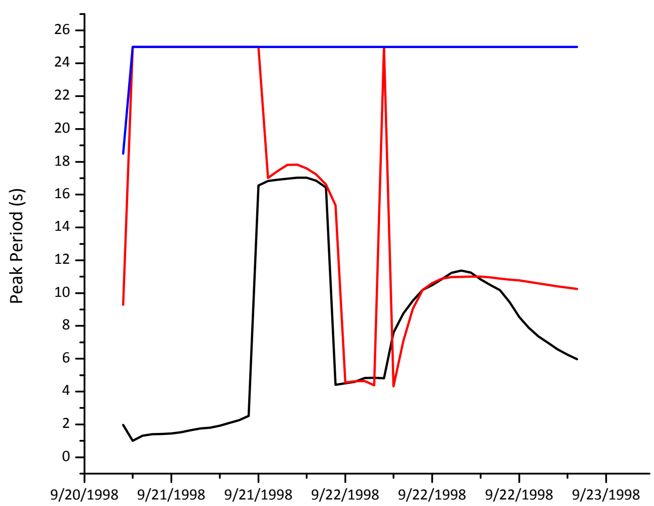
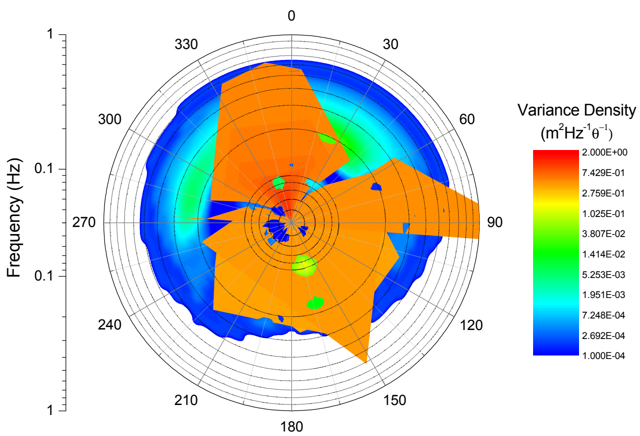
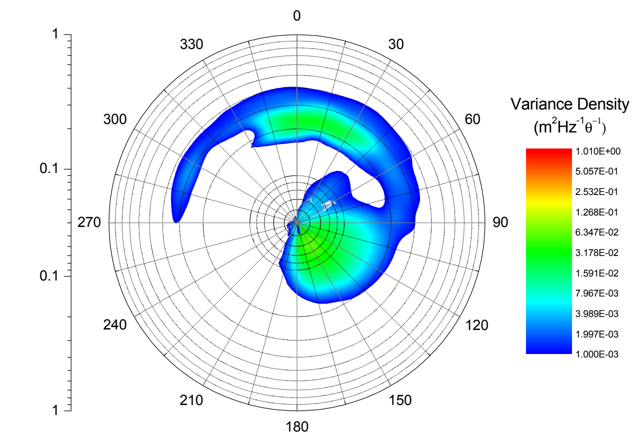


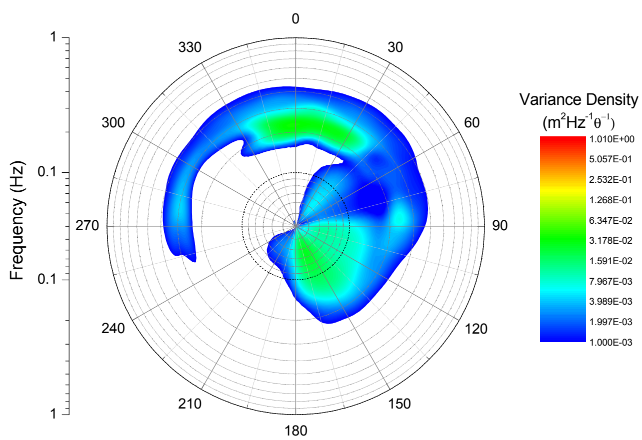
Figure 1: Computed peak periods (s) for SWAN+ADCIRC with 1 km resolution at shelf break (blue) , 50 m resolution at shelf break (red) and structured SWAN with 30 m resolution (black).



(a) 1 km SWAN+ADCIRC



(b) 50 m SWAN+ADCIRC



(c) 30 m SWAN

Figure 2: Computed two dimensional spectra using different mesh resolutions at shelf break.