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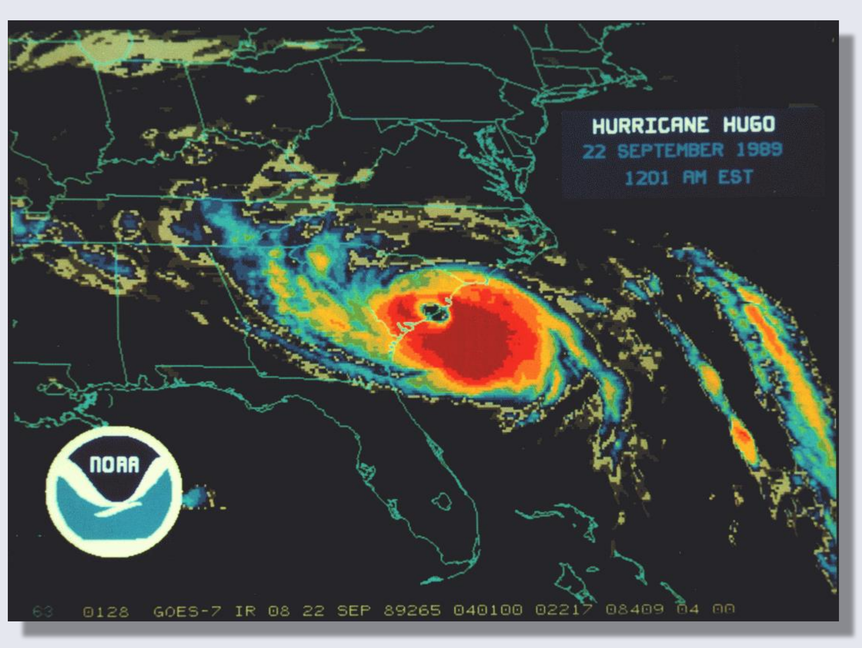
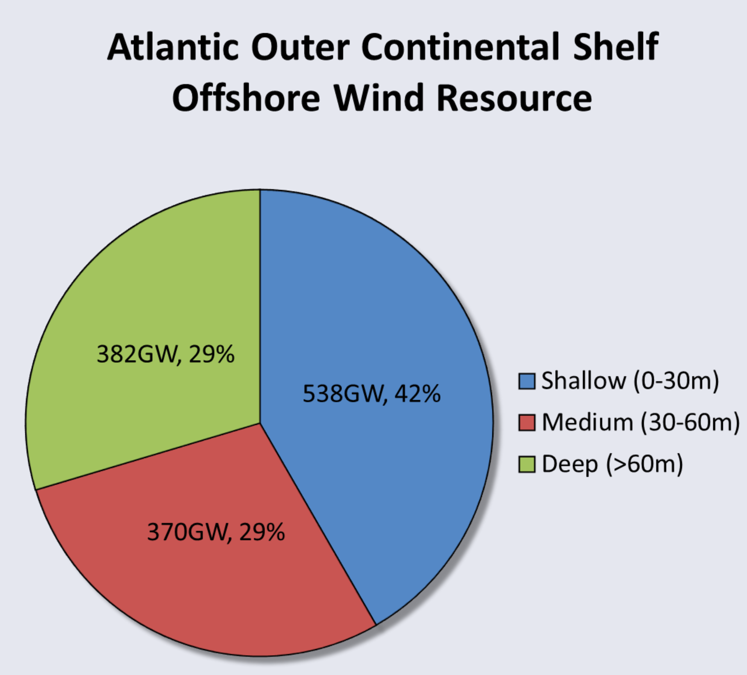
Dynamically Coupled Met-Ocean Model for Integrated Design of Offshore Wind Turbines

Ralph L. Nichols[1], Tingzhuang Yan[2], Shaowu Bao[2], P.T Gayes[2], Len Pietrafesa[2]
[1] Savannah River National Laboratory, Aiken, SC, USA, [2] Coastal Carolina, University, Conway, SC, USA

Abstract

Approximately 70 percent of the United States' offshore wind energy resource exists along the east coast on the outer continental shelf in water <60m deep. This same area is highly susceptible to tropical cyclones with wind speeds ranging from 18m/s for tropical storms to >70ms for category 5 hurricanes. The combination of high wind speeds and shallow water can lead to steep and breaking waves. Steep and breaking waves can produce large slam loads on offshore structures and can be the controlling factor in the design of fixed foundations for offshore wind turbines. New tools are need for integrated met-ocean design of wind turbines are needed to ensure turbines, towers, and foundations can withstand the large dynamic loads that can result from tropical cyclones on the outer continental shelf. A dynamically coupled met-ocean model (DCMoM) was developed from open source models of the atmosphere, waves, and ocean using a software coupling tool Earth System Modeling Framework (EMSF). Results from the coarse mesh model show the spatial variability of design parameters such as significant wave height, wave period, and water depth. These results are presented in the form of maps of significant wave height, slam force, and wave energy dissipation due to wave breaking.



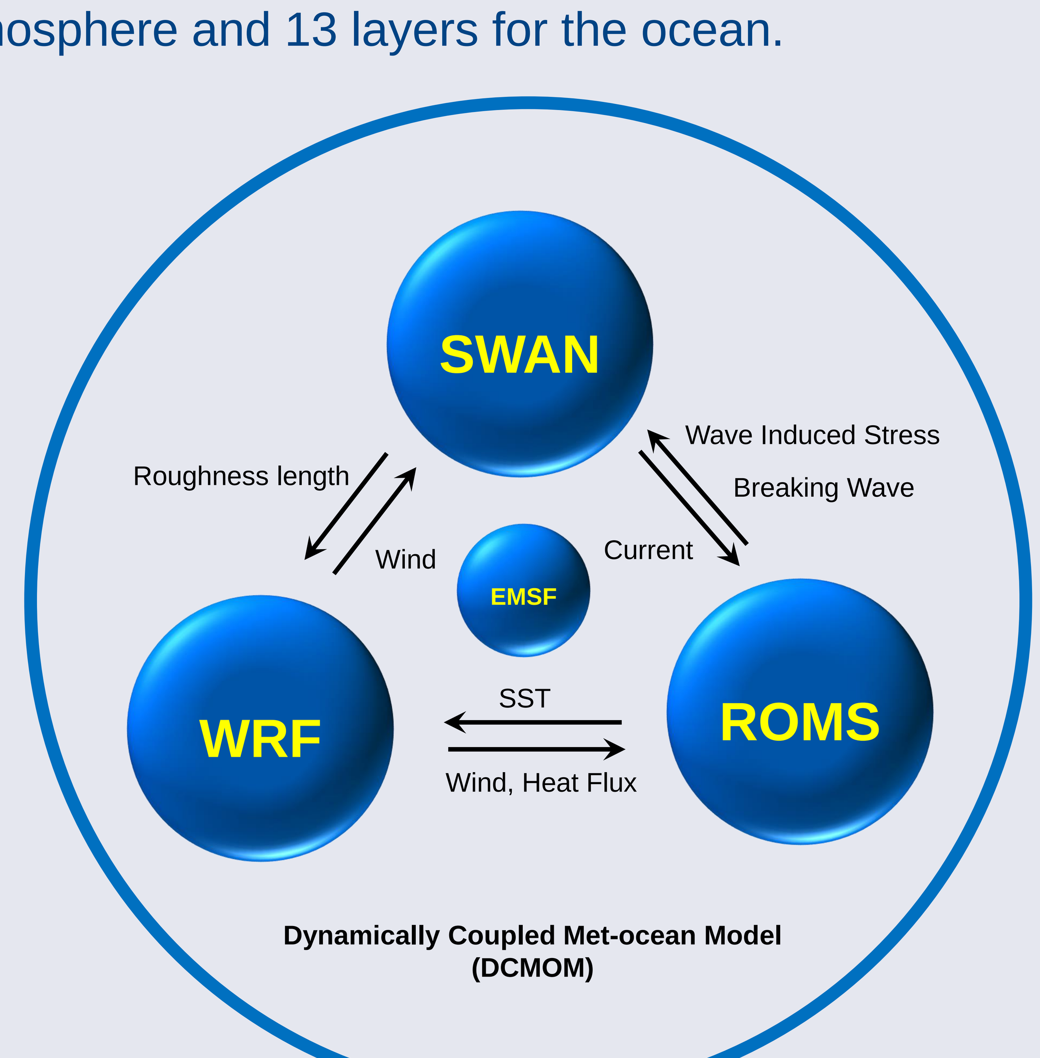


Objectives

Develop tool for integrated met-ocean design of wind turbines to ensure turbines, towers, and foundations can withstand the large dynamic loads that can result from tropical cyclones on the Atlantic Outer Continental Shelf (AOCS). Results should include spatial and temporal variability of design parameters such as significant wave height, wave period, and water depth. These results can be presented in the form of maps and histograms of significant wave height, slam force, and wave energy dissipation due to wave breaking.

Methods

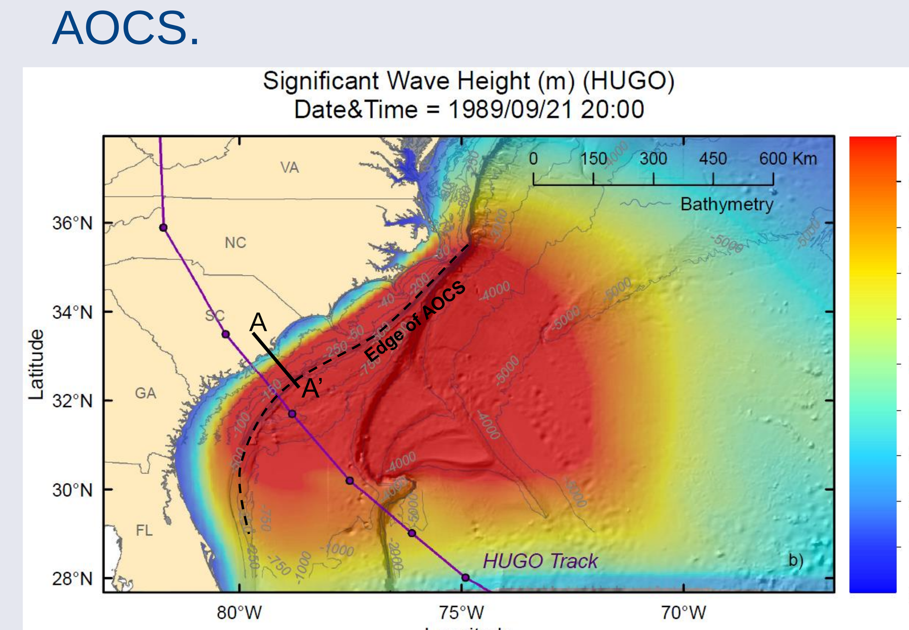
A dynamically coupled met-ocean model (DCMoM) was developed from open source models of the atmosphere, waves, and ocean using a software coupling tool Earth System Modeling Framework (EMSF). The atmospheric model WRF provides wind forcing to SWAN (waves) and ROMS (ocean); ROMS feeds sea-surface temperature (SST) to WRF, SWAN feeds wave parameters to WRF and ROMS, and ROMS and SWAN provide wave breaking simulation (Yan, 2015). The DCMoM was used to simulate 2 hurricanes in the South Atlantic Bight of the AOCS) which extends from Cape Hatteras, NC USA to West Palm Beach, FLA USA. Data from observational buoys operated by the NOAA National Data Buoy Center was used to validate the model. A nested grid (18km->3.8km->0.72km) was used to increase the resolution of the model around to particular areas of interest for offshore wind energy development. The vertical discretization was 28 layers for the atmosphere and 13 layers for the ocean.



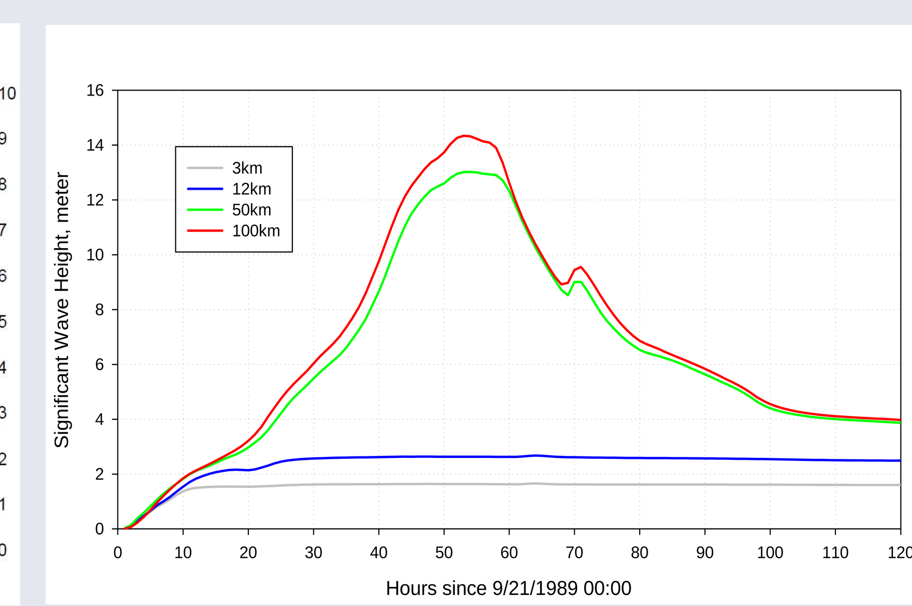
Output from the DCMoM was used with International Standard, ISO 21650 to calculate the slam load on a cylinder with a 0.25m diameter. Histograms of various wave parameters and slam force were prepared to determine the likelihood of different wave load conditions. Output from the fine mesh was used to study the spatial variability of wave height and slam force throughout the proposed project area. Temporal profiles showing the change in significant wave height over time at various distances from shore were developed to further study the temporal variability of wave height at different locations.

Results

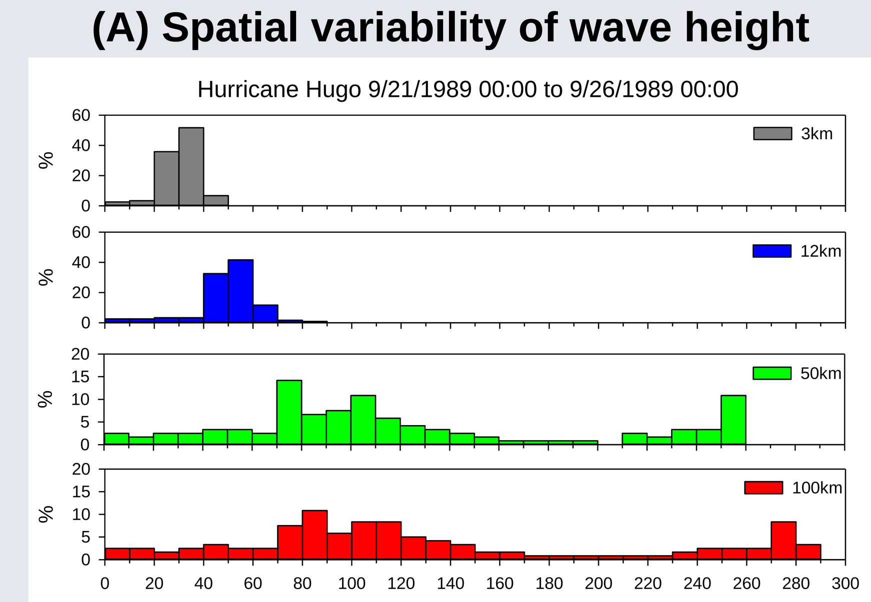
The spatial (Fig. A) and temporal (Fig. B) variability of parameters such as significant wave height, wave period, water depth etc. were calculated for the entire model domain for Hurricane Hugo from 9/21/1989 to 9/26/1989. Histograms showing the frequency of conditions (Fig C.) were also developed from model output. Wave height and period vary significantly along the transect A-A' in Fig. A as shown in Figs. B & C. ISO 21650 slam force slam forces on a 0.25m cylinder from breaking waves decrease rapidly along the same transect (Fig. D) moving onto the AOCS.



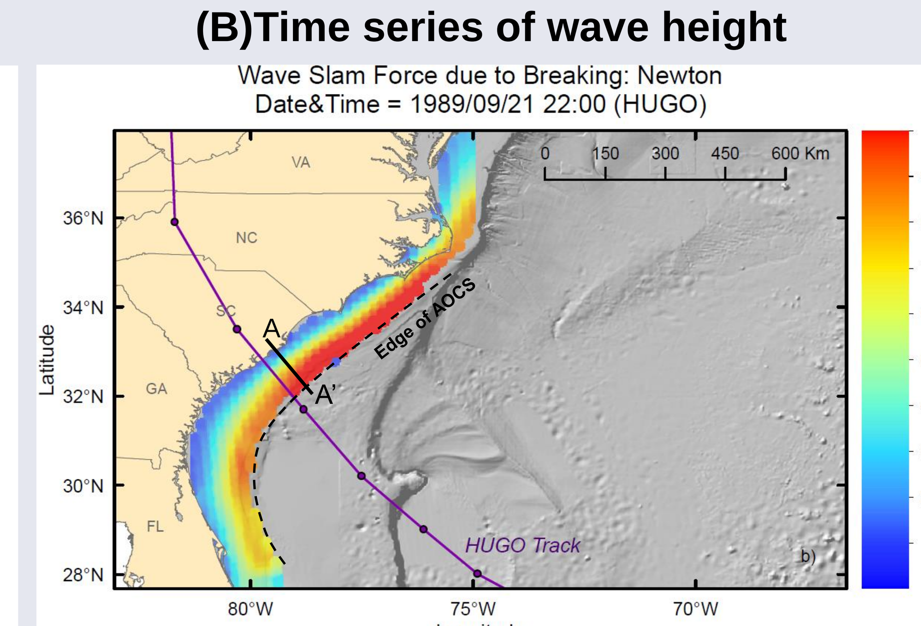
(A) Spatial variability of wave height



(B)Time series of wave height



(C) Histograms of wave period



(D) Spatial variability of slam forces

As storms move northwest from deep water up onto the AOCS the rapid change in water depth produces steep waves which break 50-100 km offshore beyond potential offshore wind energy sites. Wave height and period decrease significantly moving toward the shore. Smaller waves reform on the AOCS but are limited in height by water depth and resulting slam forces are decreased due to shallow water.

Conclusions

The DCMoM provided valuable insight into the spatial and temporal variability of waves and slam forces during Hurricane Hugo on the Atlantic Outer Continental Shelf. Wave height and period decreased as the hurricane moved northwest from deep water into the shallow water on the outer continental shelf. The shallow water resulted in breaking waves and controlled the wave height as waves reformed after breaking. The largest slam forces were experienced 50-100km on the steep slope at the edge of the outer continental shelf.

Maps prepared using DCMoM output can be used to identify high risk areas and improve our understanding of the met-ocean environment.

References

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2. ISO 21650. 2007 International Standard: Actions from Waves and currents on coastal structures.

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Contact: Ralph L. Nichols
Sr. Fellow Engineer
Savannah River National Laboratory
Aiken, SC 29808
p 803.725.5228 c 803.646.4178
email ralph.nichols@srnl.doe.gov