Explicit Air-Sea Momentum Exchange in Coupled Atmosphere-Wave-Ocean Simulations of Tropical Cyclones

Milan Curcic and Shuyi S. Chen

University of Miami
Rosenstiel School of Marine and Atmospheric Science
Division of Meteorology and Physical Oceanography
4600 Rickenbacker Causeway
Miami, 33149 Florida

Introduction

Motivation: Air-sea momentum fluxes in coupled atmosphere-ocean models are typically parameterized as function of wind speed-dependent drag coefficient. However, the momentum fluxes are strongly sea-state dependent, especially in complex tropical cyclone (TC) conditions where wind, waves and currents interact on short time scales. Explicit and conservative treatment of wave growth and dissipation is necessary to accurately represent wind and ocean stress.

Goals: Quantify the impacts of explicit wave-dependent air-sea fluxes on TC evolution and structure using a fully coupled Atmosphere-Wave-Ocean (AWO) model with a unified air-sea interface and identify what physical processes of wind-wave-current interaction are most significant for TCs.

Approach: Develop a high resolution, fully-coupled AWO model and apply it to simulate TCs Ike (2008) and Isaac (2012) with different levels of wind-wave-current coupling. Investigate the impacts of current-wave interaction and wind and ocean stress separation on TC evolution.

Conceptual model

Atmosphere momentum (WRF):
\[
\frac{\partial (pu)}{\partial t} + \nabla \cdot (pu \mathbf{v}) + 2\Omega \times (pu) = -\nabla p + \tau_A + \nabla^2 \mathbf{v} - \mathbf{F}_A
\]

Wave energy balance (UMWM):
\[
\frac{\partial E}{\partial t} + \frac{\partial (\mathbf{u} E)}{\partial x} + \frac{\partial (\mathbf{k} E)}{\partial y} + \frac{\partial (\mathbf{h} E)}{\partial z} = \rho \omega \left( \mathbf{S}_{\text{sw}} + \mathbf{S}_{\text{sc}} + \mathbf{S}_{\text{es}} + \mathbf{S}_{\text{sw}} + \mathbf{S}_{\text{sc}} \right)
\]

Ocean momentum (HYCOM):
\[
\frac{\partial (pu)}{\partial t} + \nabla \cdot (pu \mathbf{v}) + 2\Omega \times (pu) = -\nabla p + \tau_A + \nabla^2 \mathbf{v} - \mathbf{F}_A
\]

Main features:
1) Vectorial wind-wave and wave-current coupling;
2) Currents effect on waves;
3) Wind stress and ocean stress separation.

Conclusions

1. Explicit calculation of surface waves and the unified air-sea interface allow for conservative treatment of wind-wave and wave-current momentum fluxes.
2. The ocean currents advect the surface waves and reduce the wave growth in high winds, decreasing wave heights by ~10% and wind stress by ~15-20%. Current effects on waves act as a positive feedback on TC wind speed intensity.
3. Inside the storm, the ocean stress is reduced by approximately 10% relative to the wind stress, reducing Eulerian current shear and vertical mixing in the storm. This mechanism results in higher SST near the storm, enhancing enthalpy fluxes and providing a positive feedback on TC wind speed intensity.

Acknowledgements: We thank Mark Donelan (UM), Timothy Campbell (NRL) and John Michalakes (NOAA) who provided valuable assistance with the development of UMC. This research is supported by the National Oceanographic Partnership Program (NOPP) under the Office of Naval Research grant (N00014-10-1-1062) and the Gulf of Mexico Research Initiative (GoMRI) research grant (SAI1207GOMRI005).