Advances in the modeling of tropical cyclone-ocean interactions

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GFDL Hurricane Science Symposium
May 2, 2017
Early research on air-sea interaction with the GFDL hurricane model

Developing a version of the Princeton Ocean Model for tropical cyclones, POM-TC, and its coupling to the GFDL hurricane model.


1996-1999 A coupled air-sea numerical model for improving operational prediction of Gulf of Mexico and Western Atlantic hurricanes.
First simulations of the ocean response to idealized hurricanes using POM-TC

Cross-section of temperature anomalies normal to the storm track

First simulations of the ocean response to real hurricanes using POM-TC
Developing a multi-nested ocean model based on the GFDL hurricane model numerics

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First GFDL-POM coupled simulations of real hurricanes

First intensity error analysis of multiple storm simulations with GFDL-POM coupled model

Fig. 24. Comparison between the operational and coupled GFDL model, for the average forecast error of minimum central pressure (hPa) at all forecast time periods, for 135 forecasts run during the 1998 Atlantic hurricane season. The comparison is made for seven categories of storm intensity.

Further research on hurricane-ocean interaction and transition of GFDL-POM coupled model to operations

2000-2003 Air-sea fluxes at high wind speeds with application to tropical cyclone intensity prediction.

2001-2003, Transition of a coupled hurricane-ocean model to operational forecasting at the National Centers for Environmental Prediction.

Collaborative Science Technology, and Applied Research (CSTAR) Program

The CSTAR Program represents a NOAA/NWS effort to create a cost-effective transition from basic and applied research to operations and services through collaborative research between operational forecasters and academic institutions which have expertise in the environmental sciences. These activities engage researchers and students in applied research of interest to the operational meteorological community and improve the accuracy of forecasts and warnings of environmental hazards by applying scientific knowledge and information to operational products and services.
URI Students and Post-docs who contributed to the development and transition to operations the coupled GFDL-POM system

Sergei Frolov
Ray Richardson
Clark Rowley
Biju Thomas

“That was my first taste of operational modeling, and I've made a career of developing, transitioning, and maintaining ocean and coupled forecast systems.” Clark Rowley (NRL)
First operational POM-TC Atlantic domains

- 23 vertical sigma levels, 18 km grid spacing
- POM-TC was run on 1 (one) CPU!
Improving ocean model initialization:
feature-based modeling approach

Feature-based initialization of the Loop Current and eddies in the Gulf of Mexico

Example of feature-based of initialization

75-m Temperature (Sept. GDEM)

TPC 26°C depth on 15 Sept. 2005

75-m Temperature AFTER assimilation

(1) Start with monthly climatology

(3) Assimilate SST analysis

(4) Spin-up ocean currents

(2) Adjust LC position & add warm- and cold-core eddies info derived from altimetry

Future Hurricane Rita track

Yablonsky and Ginis (2008)
Examples of improved initial vertical temperature structure in LC and warm-core eddy

Loop Current

Warm-Core Eddy

Yablonsky and Ginis (2008)
Effect of the Loop Current on Hurricane Katrina Intensity

GFDL forecast Initialized Aug. 26, 18Z

Central Pressure

Climatological Loop Current

Initialized Loop Current

Minimum sea-level pressure (hPa)

Aug.26,18Z Aug.28,15Z Aug.30,12Z
GFDL Hurricane Model Forecast of Hurricane Katrina (2005)
Warm-core ring is not just high ocean heat content

Can a WCR’s circulation modify hurricane-core SST cooling?

Prescribed translation speed

Hurricane vortex

Homogeneous initial SST

Warm core ring evident in subsurface temperature field

Vary position of ring relative to storm track
Effect of WCR location on SST and Currents in an idealized hurricane

Hurricanes have historically translated at speed < 5 m s\(^{-1}\) 73% and < 2 m s\(^{-1}\) 16% of the time in Gulf of Mexico

Speed < 5 m s\(^{-1}\) 62% and < 2 m s\(^{-1}\) 12% of the time in western tropical North Atlantic

Developing parallel version of POM-TC (MPIPOM-TC)

POM community code development

1977 pmod → 1994 pom → 2004 pom2k → 2012 sbPOM


URI’s new MPIPOM-TC

URI-based code development

MPIPOM domains worldwide

- MPIPOM-TC uses MPI software to run efficiently on multiple processors, allowing for both higher grid resolution and a larger ocean domain than POM-TC

- MPIPOM-TC accepts flexible initialization options (currently runs off RTOFS operationally in HWRF)
Research on air-sea fluxes in hurricanes with explicit wave coupling

Motivation: air-sea fluxes and turbulent mixing above/below sea surface are significantly modified by surface waves in high wind conditions.

Image courtesy of Fabrice Veron
Sea-state dependent drag coefficient under hurricane conditions

Wind-Wave-Current Interaction in hurricanes

Wind

Ocean currents

Surface waves

Sea state

\( \vec{\tau}_{air} \neq \vec{\tau}_{c} \)

Atmosphere

Ocean


Wave-driven Langmuir turbulence in hurricane conditions

Atmospheric model: air-sea fluxes depend on sea state
Wave model: forced by sea state dependent wind forcing
Ocean model: forced by sea state dependent wind stress modified by growing or decaying wave fields and Coriolis-Stokes effect. Turbulent mixing is modified by the Stokes drift (Langmiur turbulence).
Examples of sea state dependent $C_d$ with explicit wave coupling

RMS = 70 km, $U_{10\text{max}} = 65$ m/s
Summary

• Close collaboration between GFDL and URI has been instrumental in the success of the GFDL coupled hurricane model.

• Support by NOAA Joint Hurricane Testbed and HFIP provided to URI was critical for transitioning the hurricane research at URI to operations.

• The MPIPOM-TC has been successfully transitioned from the GFDL hurricane model to the operational HWRF coupled system.