Progress in Developing Coupled Tropical Cyclone-Wave-Ocean Models for Operational Implementations at NOAA and Navy

Isaac Ginis
Morris Bender, Tetsu Hara, Richard Yablonsky, Biju Thomas, Yalin Fan, Jian-Wen Bao, Chris Fairall, Laura Bianco

University of Rhode Island, NOAA/GFDL, NOAA/ESRL

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Operational Coupled Tropical Cyclone-Ocean Models

- **2001** – GFDL/POM at NCEP in Atlantic ocean (3D coupling).

- **2004** – GFDL/POM at NCEP in Eastern and Central Pacific (1D coupling).

- **2007** – HWRF/POM at NCEP in Atlantic ocean (3D coupling).

- **2008** – GFDN/POM at FNMOC in Atlantic ocean (3D coupling) and all other oceans (1D coupling).

- **2009** – GFDN/POM at FNMOC in the Northern Pacific ocean (3D coupling).
Conventional Coupling Between Tropical Cyclone and Ocean Models

Atmospheric Model

Wind speed ($U_a$)
Temperature ($T_a$)
Humidity ($q_a$)

Air-Sea Interface

Momentum flux ($\tau$)
Sensible heat flux ($Q_H$)
Latent heat flux ($Q_E$)

Ocean Model

Surface current ($U_s$)
SST ($T_s$)

Momentum flux ($\tau$)

$$\tau = \rho_a C_D (U_a - U_s) (U_a - U_s)$$

$$Q_H = C_H (U_a - U_s) (T_a - T_s)$$

$$Q_E = \frac{L_v}{C_p} C_E (U_a - U_s) (q_a - q_s)$$
Atmospheric Boundary Layer

Wave Boundary (Surface) Layer

Momentum & KE Flux

Turbulence

Sea Sprays

Heat & Humidity Flux

Nonbreaking Waves

Airflow separation

Intermittency

Breaking Waves

Reynolds stress

Wave induced stress

Airflow separation

Intermittency

Ocean Boundary Layer

Stokes drift

Momentum & KE Flux

Langmuir) Turbulence

Gas Flux

Bubbles

Ocean Boundary Layer

Air-Sea Interface

Heat & Humidity Flux

Momentum & KE injection

Intermittency of Momentum & KE injection
New Coupled Tropical Cyclone-Ocean Framework (being implemented into HWRF and GFDN models)

**TC model**: air-sea heat and momentum fluxes and sea spray source functions explicitly include **SST**, **sea-state dependence** and **ocean current effects**.

**Wave model**: is forced by **sea-state dependent momentum flux** and includes **ocean current effects**.

**Ocean model**: is forced by **sea-state dependent momentum fluxes**.
Effect of Wind-Wave-Current Interaction on Hurricane-Generated Waves

Impact of Loop Current and Warm Core Eddy on Hurricane-Generated Surface Waves
Impact of Loop Current and Warm Core Eddy on Hurricane-Generated Surface Waves

WW3 significant wave height difference with and without LC/WCE

21:00 UTC Sept. 14
2:40 UTC Sept. 15

Significant wave height ($H_s$) along flight track

(c)
Impact of Loop Current and Warm Core Eddy on Hurricane-Generated Surface Waves

Ocean current difference with and without LC/WCE

Dominant wave direction

Significant wave height

21:00 UTC Sept. 14

2:40 UTC Sept. 15

Significant wave height

Ocean current difference with and without LC/WCE
Navy’s Operational GFDN Model

• GFDN is run at FNMOC of NOGAPS global model. Ocean model is initialized from Navy’s NCODA analysis

• Model physics changes implemented in GFDN in 2008 compared to NOAA’s GFDL model:
  - Penetrative solar radiation included in ocean model
  - Bug fixed in $C_h$ calculations and coupling interpolation
Development of High-Resolution GFDN

- Atmospheric grid resolutions

**Operational GFDN:**
- Mesh 1: 75°x75° – 1/2° res
- Mesh 2: 11°x11° – 1/6° res
- Mesh 3: 5°x5° – 1/12° res

**High-Resolution GFDN:**
- Mesh 1: 75°x75° – 1/2° res
- Mesh 2: 11°x11° – 1/6° res
- Mesh 3: 5°x5° – 1/18° res

- Princeton Ocean Model grid resolutions

**Operational GFDN:** 1/6°

**High-Resolution GFDN:** 1/12°
Wind Speed Cross-Section (72h)
Katrina: August 25th, 0z forecast
Improved Structure with Higher Resolution

1/12th Degree Resolution

Low Resolution KATRINA Simulation; Initial time: 2005/08/25 00Z
Wind Speed at 72h

1/18th Degree Resolution

High Resolution KATRINA Simulation; Initial time: 2005/08/25 00Z
Wind Speed at 72h
Surface Winds (72 hr)
Katrina: August 25^{th}, 0z forecast
Improved Structure with Higher Resolution

1/12th Degree Resolution

1/18th Degree Resolution
Accumulated precipitation (47-48 hr)
Katrina: August 25th, 0z forecast
Improved Structure with Higher Resolution

1/12th Degree Resolution

1/18th Degree Resolution
Effect of Global Model on GFDN Forecasts in Western Pacific

- 266 forecasts in 2009 were rerun in the Western Pacific using the GFS global model for initial and boundary conditions.

- No changes were made in the ocean model initialization.
Average Track Errors

2009 WESTERN PACIFIC
NUMBER OF CASES: (263, 262, 260, 251, 213, 172, 119)

FORECAST ERROR (NM)

NORMALIZED ERRORS RELATIVE TO CLIPPER

NUMBER OF CASES: (248, 246, 237, 203, 162, 112)

NORMALIZED ERRORS RELATIVE TO CLIPPER

LEAST SKILL

% SKILL RELATIVE TO CLIPPER

MOST SKILL
Track Errors for Each Storm

GFDN (BLACK) FROM NOGAPS VS. GFDN FROM GFS (RED)

72 HOUR

Average 72H Track Error (NM)

GFDN from NOGAPS (black)

GFDN from GFS (red)
Typhoon Nida (25W)

- Nov. 24th, 18z
- Nov. 25th, 12z
- Nov. 26th, 00z
- Nov. 26th, 12z
Average Intensity Error

2009 WESTERN PACIFIC
NUMBER OF CASES: (252, 252, 247, 231, 198, 154, 111)

NORMALIZED ERRORS RELATIVE TO ST5D
Intensity Errors for Each Storm

GFDN from NOGAPS (black)
GFDN from GFS (red)
Conclusions

- Increased horizontal resolution in GFDN model improves horizontal and vertical structures in simulated tropical cyclones. Initial test results suggest that some model physics may need to be retuned for better performance.

- Experimental GFDN runs using GFS global model in the Western Pacific show improved forecasts skill for both track and intensity compared to the operational GFDN model.

- Coupling with the WAVEWATCH wave model and introducing sea spray effects is in progress.
Track Errors in GFDN and GFS for Each Storm

GFS (black)

GFDN from GFS (red)
Typhoon CHOI-WAN (15W)

- Sep. 12th, 12z
- Sep. 12th, 18z
- Sep. 13th, 6z
- Sep. 13th, 18z
2009 ATLANTIC SEASON
NUMBER OF CASES: (67, 55, 45, 39, 21, 12)