COUPLED APPLICATION EXAMPLES: MODELING OF TROPICAL CYCLONES

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Motivation

- “The lack of skill in hurricane intensity forecasts may be attributed to:
  - Deficiencies in current models,
  - Insufficient grid resolution,
  - Inadequate surface/boundary layer formulations
  - Lack of full coupling to a dynamic ocean”
  — BAMS (Chen et al. 2007)

Outline

- Idealized TC (JOE_TC)
  - Configuration
  - Results
- Hurricane Ivan
  - Configuration, Case Design
  - Initialization Methods
  - Results
- Hurricane Irene
  - Results
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Idealized COAWST Experiments

- Idealized Configuration
  - Closed ocean basin
  - 200 points in X, 150 in Y
  - 12 km grid spacing among all 3 models
  - Run from 1-6 September (00Z)

Idealized COAWST Experiments

- TC located at X=150, Y=75
- Moving westward at 5 m s\(^{-1}\) (background wind field)
- Bathymetry along X:
  - 50-69, \(dz/dx = -10\text{m}/\text{12km}\)
  - 70-89, \(dz/dx = -40\text{m}/\text{12km}\)
  - 90-197, \(z = 1000\text{m}\)

Idealized COAWST Experiments

- Idealized TC
  - Initialized using an Idealized TC algorithm developed by Kevin Hill (MEAS)
  - Developed an asymmetrical vortex, Kwok and Chan (2005)
  - Maximum wind of initial vortex is set to 20 m s\(^{-1}\), 50 km from center
    - Horizontal wind profile set by Chan and Williams (1987)
  - SST defined to be 29 °C
  - Simulation run on an \(f\)-plane, \(f\) defined to 20 °N
### Idealized COAWST Experiments

#### ROMS Configuration
- 3-D advection
- Coriolis
- Viscosity
- Mellor-Yamada level-2.5 closure scheme
- No nesting
- 21 vertical levels
- 25 s timestep
- Closed ocean basin – no boundary conditions

#### WRF Configuration
- 200x150, 12km spacing, 31 vertical levels
- 75 s timestep
- MP - Lin, et. al scheme
- No nesting
- Kain-Fritsch cumulus parameterization scheme
- Radiation: RRTM (longwave) and Dudhia (shortwave) schemes (every 10 minutes)
- Monin-Obukhov (Eta) surface layer physics
- Thermal Diffusion land surface physics
- Mellor-Yamada-Janjic TKE PBL scheme (every timestep)

#### SWAN Configuration
- Configured on a Cartesian grid
- Direction computed in a circular grid with 36 10° bins
- Waves represented with a PSD between 1s and 25s, broken into 24 1s bins
- Waves computed in 5-dimensions: west-east, south-north, period, wavelength, and direction of propagation
- Depth induced breaking constant set to 0.73
  - The ratio of wave height to water depth required to break waves
- Wind waves created using Komen formulation
- Backward-in-space, backward-in-time advection scheme
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Idealized COAWST Experiments

- Results
  - Right-side SST bias

- Results
  - Track
    - Northward Drift strongest in C, weakest in A, B is in the middle

- Results
  - Wave-induced SST Cooling

Case A
Case B
Case C
Idealized COAWST Experiments

Results

Intensity
- A: 924 hPa
- B: 960 hPa
- C: 967 hPa

Size

Significant Wave Heights
Idealized COAWST Experiments

- Results
  - Significant Wave Heights

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Ivan Motivation

- Analyzing NHC Forecast Error
  - 9-45% better track forecast than in previous 10 yrs
  - 8 to 71% worse strength forecast than in previous 10 yrs
  - Ivan experienced frequent, and unpredicted changes in intensity over its lifetime

<table>
<thead>
<tr>
<th>Forecast Error</th>
<th>F12</th>
<th>F24</th>
<th>F36</th>
<th>F48</th>
<th>F72</th>
<th>F96</th>
<th>F120</th>
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</thead>
<tbody>
<tr>
<td>Track (km)</td>
<td>44</td>
<td>87</td>
<td>146</td>
<td>200</td>
<td>298</td>
<td>411</td>
<td>535</td>
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<tr>
<td>Track, 10-yr Avg (km)</td>
<td>81</td>
<td>144</td>
<td>207</td>
<td>270</td>
<td>402</td>
<td>459</td>
<td>591</td>
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<tr>
<td>Track, Improvement</td>
<td>45%</td>
<td>60%</td>
<td>29%</td>
<td>26%</td>
<td>26%</td>
<td>15%</td>
<td>9%</td>
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<tr>
<td>Strength (ms⁻¹)</td>
<td>4.6</td>
<td>6.2</td>
<td>6.7</td>
<td>6.2</td>
<td>7.7</td>
<td>12.3</td>
<td>18.5</td>
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<tr>
<td>Strength 10-yr Avg. (ms⁻¹)</td>
<td>3.1</td>
<td>5.1</td>
<td>6.2</td>
<td>7.7</td>
<td>9.8</td>
<td>10.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Strength, Improvement</td>
<td>-50%</td>
<td>-20%</td>
<td>-8%</td>
<td>20%</td>
<td>-20%</td>
<td>-71%</td>
<td></td>
</tr>
</tbody>
</table>

Stewart, 2005

Model Configuration

ROMS Configuration
- SABGOM ROMS is nested inside of the HYCOM/NCODA (Hybrid Coordinate Model/NRL Coupled Ocean Data Assimilation) global model
- Domain encompasses South Atlantic Bight and Gulf of Mexico (SABGOM) with a horizontal resolution of 5 km
- 36 vertical levels, 25 s timestep
- Open boundaries to east and south, closed to west and north
- Mellor and Yamada (1982) scheme to compute vertical turbulent mixing

WRF Configuration
- GFS 1° data used for initialization/LBCs (updated every 6 hours), GFDL merged in initialization
- 500x450x31, 8 km grid spacing, 24 s timestep
- Inner 3-to-1 nest (301x301x31)
- WSM-6 MP scheme
- Kain-Fritsch CP scheme (outer domain only)
- RRTM (LW) and Dudhia (SW) schemes – 8 min
- Monin-Obukov Sfc Physics, Noah LSM
- Mellor-Yamada-Janjić TKE PBL scheme – every timestep

SWAN Configuration
- Lateral Boundary data provided by WaveWatch 3 (WW3) global wave model
- Configured on a Cartesian grid
- Direction computed in a circular grid with 36 10° bins
- Waves represented with a PSD between 1s and 25s, broken into 24 1s bins
- Waves computed in 5-dimensions: west-east, south-north, period, wavelength, and direction of propagation
Model Configuration

- **SWAN Configuration**
  - Depth induced breaking constant set to 0.73
  - The ratio of wave height to water depth to break waves
  - Wind waves created using Komen formulation
  - Backward-in-space, backward-in-time advection scheme

Model Configuration

- **Case Design**
  - Static, Dynamic
    - RTG-SST analysis
      - Gemmill et al. 2007
    - WRF OML
      - Pollard et al. 1973, Davis et al. 2007

Model Configuration

- **2-Way**
  - Zambon, 2009

Model Configuration

- **3-Way**
  - Zambon, 2009
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Model Configuration

- Initialization Methods
  - GFS Only: Base intensity and strength on best runs from initialization

![Graphs showing model comparison for intensity and strength over time.](image)
Model Configuration

- GFDL-GFS Blend (WPS)
  - GFDL data provided from tape by Dr. Bob Hart (FSU)
  - Using WRF Preprocessing System
  - Take meteorological fields from GFDL and fill in missing holes with GFS
  - Both models encompass entire US East domain
  - Resultant blended product is very promising

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Wave Buoy Comparisons

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Irene Motivation

- Compared to the previous 5-years, Hurricane Irene's forecast track demonstrated improvement
  - Climatology and persistence models showed that this storm was relatively “easy” to forecast
- Compared to the previous 5-years, Hurricane Irene's intensity forecast was worse
  - Climatology and persistence models demonstrated lower forecast error
  - Consistently high bias shown as Irene was forecast to maintain Cat-3 intensity through landfall in NC

Irene Ensemble Track Guidance
Irene Ensemble Strength Guidance

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Results – Track
Results – In-situ comparisons

Surface Pressure (in Hz) Time Series (Valid 25–Aug–11 10Z through 28–Aug–11 07Z)

Model
Observed

Results – In-situ comparisons


Model
Observed

Results – In-situ comparisons


Model
Satellite
Observed

Results – In-situ comparisons

Wave Height (m) Time Series (Valid 25–Aug–11 10Z through 28–Aug–11 07Z)

Model
Observed
Conclusions

- 3 Examples of the COAWST model in TC conditions
- Configuration of Idealized (JOE_TC) case
- Configuration of COAWST domains for 2 real cases
  - Initialization improvement using GFDL data
- Hurricane Ivan and Irene (preliminary) results
- Future Improvement
  - Additional coupling (Atmos.-Wave interactions)
  - Further investigation of dynamic processes

Questions?

References:


