Next Generation HWRF

HYCOM coupling

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1. Introduction to HYCOM coupling & Background
2. HYCOM Hurricane Domains
3. Initial and Boundary Conditions
4. Forecast Comparisons between Non-coupled and Coupled runs: Western North Pacific Typhoons 2012-2013
5. TC Forecasting: Sensitivity of SST
6. Importance of Initial Conditions: Seasonal and Spatial Variability
7. Importance of Realistic Ocean Simulations
8. Lessons Learned - Recommendations
9. Future Plans for Improvement of TC forecasting
An experimental model proposed for next generation HWRF

- One of ocean models chosen for ocean model impact study as a Hurricane Forecast Improvement Project (HFIP) initiative.
- Forecast skills have been demonstrated
  - for the North Atlantic and Eastern North Pacific hurricanes (Kim et al., 2014), since 2009; and
  - for the Western North Pacific Typhoons (Kim et al. 2015), since 2012.
- Realistic and idealized configurations, along with diagnostic and graphic codes, exist in DTC SVN, but currently HYCOM coupling framework is not supported by DTC yet.
### 1. HYCOM coupling

**Ocean model components of HWRF**

<table>
<thead>
<tr>
<th></th>
<th>POM</th>
<th>HYCOM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dynamics &amp; Numerics</strong></td>
<td>Hydrostatic, free-surface, primitive equations on C grid</td>
<td>1/12-degree</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23 hybrid sigma &amp; Z</td>
</tr>
<tr>
<td><strong>Mixing Physics</strong></td>
<td>Mellor-Yamada 2.5 closure</td>
<td>KPP</td>
</tr>
<tr>
<td><strong>Initialization</strong></td>
<td>Monthly GDEM3 Climatology + daily GDAS SST assimilation + Feature Model</td>
<td>6 hourly NCODA-HYCOM analysis</td>
</tr>
<tr>
<td><strong>Lateral Boundary Values</strong></td>
<td>Adjusted T/S fields</td>
<td>3 hourly 2D and 6 hourly 3D global RTOFS* forecasts</td>
</tr>
</tbody>
</table>

*: RTOFS = Real-Time Ocean Forecast System producing 2-day nowcasts and 8-day forecasts each day

HYCOM is the community model (but not HYCOM coupling), having NRL as the primary developer. *Reference at https://hycom.org*
domains vs. all tc storms 1851-2006

2. HYCOM Hurricane Domains

Tracks and Intensity of All Tropical Storms

- **NHC**: North Atlantic (blue), Eastern North Pacific (red), Central North Pacific (not shown).
- **JTWC**: Western North Pacific (green), Eastern South Indian/Western South Pacific (grey), North Indian (black), and South Indian (pink).

www.meted.ucar.edu, edited by Hyun-Sook Kim
2. HYCOM Hurricane Domains

**Domains vs. Boundary Currents**

**Major thermal fronts in each basin:**

meandering and shedding eddies in meso scales by baroclinic instabilities

1. **North Atlantic (blue):** North Equatorial Current, Loop Current, Gulf Stream, Canary Current
2. **Eastern North Pacific (red):** Equatorial Countercurrent, California Current
3. **Western North Pacific (green):** Kuroshio Current, the North & Equatorial Current
4. **North Indian Ocean (black):** North Equatorial Current, Somali Current, coastal upwelling
5. **South Indian Ocean (pink):** South Equatorial Current, Agulhas Current
6. **Western South Indian/Eastern South Pacific (grey):** East Australian Current & West Australian Current

[www.rapid.ac.uk/background.php](http://www.rapid.ac.uk/background.php), edited by Hyun-Sook Kim
3. Initial and Boundary Conditions

Components and Data Flow

Exchange Variables
A: sea surface temperature (SST)
B:
1. Precipitation
2. Atmospheric pressure
3. Heat fluxes – Sensible, latent, total radiation, and net shortwave radiation
4. Wind stress

ic = initial Conditions
bc = boundary conditions
CS/WS = cold/warm start
DA = data assimilation
GFS = Global Forecast System
GSI = Gridpoint Statistical Interpolation

Pink Shade – future plan
3. Initial and Boundary Conditions

HYCOM for 2-way coupling to HWRF

1) IC/BC from real-time global RTOFS (Real-Time Ocean Forecast System). RTOFS uses the same eddy-resolving HYCOM dynamics and physics solutions on 1/12-degree horizontal and 36 vertical layers.

2) IC uses NCODA*-HYCOM analysis and available for any cycle.

3) BC uses 5.25 day forecasts from daily RTOFS products.


* NCODA: Navy Coupled Ocean Data Assimilation
4. Non-coupled vs. coupled (HYCOM) Typhoon Forecasts for 2012-2013

Two Seasons Combined

- Track: Little difference
- Intensity: 2 kt/3 hPa
- Bias in $V_{\text{max}}$ and $P_{\text{min}}$ is worse by coupling than control.
- Similar negative bias observed in other studies, e.g., Wada (2010).
4. Non-coupled vs. coupled (HYCOM) Typhoon Forecasts for 2012-2013

Seasonal Variations

- MAE: HYCOM coupling (cpl) has smaller MAE (<16 kt), compared to non-coupled (ctl).
- Bias: HYCOM coupling shows a consistent bias.
- Seasonal variability in forecast is probably related to the large scale variations.
4. SST cooling comparison

Comparison against daily TMI & AMSRE OI SST

**HYCOM SST**
- Similar cold wake (~26°C) at a similar degree of cooling (~3°C)
- Mesoscale variability

**GFS SST**
- No change in GFS SST
- No cold wake and no cooling
- No Mesoscale variability

**Statistics @ day 5 for Jelawat 18W: cycle=2012092200**

**HYCOM SST**
- Similar magnitude of mean
- Higher correlation coefficient (0.899)
- Lower RMSD (0.6) and STD (0.5).
4. Non-coupled vs. Coupled

▶ SST feedback: Ocean Coupling changes the TC thermodynamics/dynamics loop.

▶ SST cooling is real, and important to TC intensity

**Maximum Potential Intensity and SST**

Maximum Potential Intensity (Emanuel 2003)

\[ V_{\text{max}}^2 \propto \frac{(T_1 - T_2)}{C_d T_2} F_h \]

- \( T_1 = \text{SST} \)
- \( T_2 = \text{outflow temperature} \)
- \( C_d = \text{drag coefficient} \)
- \( F_h = (LHT + SHT) \) the surface flux of enthalpy

\( T_1, \) LHT, SHT, \( C_d \) and (Ch) are either explicitly or implicitly related with SST.

**Using non-coupled HWRF** for Initial SST and location, size and strength of a **warm pool**

**Sources:**
- NCODA SST from 2010-2014
- GDEM September climatology

**Best Forecast** was achieved with NCODA 2014 dataset.

**Better Intensity Forecast with**

a. Larger and warmer beneath the storm
b. Stronger temperature gradient along the track

For example, at 96 h, wrt BT

\[ \Delta P_{\text{min}} = 4 \text{ hPa (2014/2012)} \text{ vs. } 28 \text{ hPa} \]

\[ \Delta V_{\text{min}} = -15 \text{ kt (2014/2012)} \text{ vs. } -30 \text{ kt} \]
6. Importance of oceanic initial conditions: Seasonal and Spatial variations

**East North Pacific 2015 Season**

*El Nino*

Early season – NiNo index 1-2
Mid and Late season – NiNo index 3-4

Also, body of warm water residing at 20N, expanding southwestward over time ➔ set up unseasonally warm SST in the tropics.

Further extends favorable conditions for TCs in later season.
6. Importance of oceanic initial conditions: Seasonal and Spatial variations

Blanca: Intensity Forecast Verification

1. 2015 HYCOM coupling (H5Y2) performed the best, showing small MAE (< 18 kt) and small bias, followed by H214 (2014 operational HWRF was run before the 2015 season).

2. GFDL performed the worst.

3. 2015 HWRF (HCTL=H215) performed worse, especially for early lead hours (< 48 h), than 2014 HWRF.

4. COAMPS-TC (COTC) performance was between HWRF and GFDL for Vmax. But, Vmax bias, and Pmin MAE and bias were quite different.
6. Importance of oceanic initial conditions: Seasonal and Spatial variations

Blanca: 2015 HYCOM coupling vs. POM coupling

- **Intensity**: Between HYCOM (red) and POM coupling (blue), the former performs better at higher winds or lower pressure (dashed ovals).

- **$U_T$ (storm translation speed)**: Over-estimate for slow and under-estimate for fast moving storm (more so for HYCOM).

Scatter plots for $V_{\text{max}}$, $P_{\text{min}}$, and $U_T$
6. Importance of oceanic initial conditions: Seasonal and Spatial variations

SST Cooling & Intensity using HWRF and HWRF-HYCOM

- **SST cooling over 24 h (entire cycle) in the storm field:**
  - POM - 9.1 (3.6-17.6)°C for 62 kt/975 hPa
  - HYCOM - 11.0 (3.6-13.1)°C for 77 kt/964 hPa

- **SST cooling in environment:**
  - POM – uniform cooling (-0.5°C)
  - HYCOM – large variation of cooling and warming responsible for primarily advection
6. Importance of oceanic initial conditions: Seasonal and Spatial variations

Subsurface Temperature Structure

- **POM coupling**
  - Shallower and colder upper layer, with 23.3°C of maximum temperature at 80 m.
  - Higher Ekman pumping.
  - Features of warm core are more intensive and expansive in horizontal.
  - Depth of 26°C (Z26) is 20-25 m deeper ➔ higher Ocean Heat Content.

- **HYCOM coupling**
  - Deeper and warmer upper layer, with 28.8°C of maximum temperature at 80 m.

**Note:**
- **POM**: 80 m
- **HYCOM**: 80 m
7. Importance of Realistic Ocean Simulations

Example for upwelling and interactions with the Kuroshio Current

Soulik (2013) cycle=2013/7/10 00Z

Temperature Section
Northward Velocity Section

 Taiwanese

Blues (cold wake), Reds (northward, blue-southward)

Forecast

Upwelling and interactions with the Kuroshio Current in Taiwan.
Better physics should result in better models

But, there are more subtle reasons too:

- Coupling forces you to take a closer look at details of the constituent models, in ways that are often complementary to the way the models are conventionally validated.

- This often leads to systematic improvement of the constituent models. That often has a positive impact on the component models, even if the impact on the actual coupling is found to be minimal.

Kim et al. 20
1. Focus on best possible description of physical states for all models.
   ▶ Better physics makes for a better model. However, better physics in a well tuned model will almost always detune the model in a coupled framework.

2. Deal with de-tuning of model due to “improved” physics in two ways, which makes most sense.
   ▶ Deal with this as bias treatment in coupler (quick and dirty).
   ▶ Retune as possible, particularly when individual processes are documented to describe nature better (long term systematic approach).

3. We need to have a set of metrics for HWRF that reflects these mentioned above: Track and intensity verification alone will never work.

4. Coupled model makes further development of modeling system a little more complicated.
   ▶ This is an unavoidable side effect of doing things physically better.
5. The key for coupled modeling is in the fluxes. A weather model with a fixed or climatological SST is constrained in terms of systematic seasonal and climate shifts. But, in a coupled model, there is no constraint to the ocean state and also to the weather model. Hence, spurious drifts of the SST and mixed layer in general in the ocean will result in spurious drifts in the weather model, with a strong possibility of (nonlinear) feedback.

6. Developing a coupled model is a cyclic process:
   - First emphasis on getting the ocean right.
   - In the process, many issues with HWRF were revealed.
     - Not necessarily major issues, but critical for realistic coupling with a realistic ocean model.
     - Climatology based ocean model component appears less sensitive to these errors as ocean responses are suppressed to gain a more robust system.
   - Fixes and updates require a revisit to make sure that all ocean responses are realistic.
   - … and this will never stop…
9. Future Plans for Improvement of TC forecastings

Processes in the Air-Sea Interface

http://www.whoi.edu/science/AOPE/dept/CBLASTmain.html

This is a simplified version of reality!
3-way coupling HWRF-HYCOM-WW3

1. HWRF:
   a) Surface stress modified by effects of sea state, directionality of wind and wave, and surface currents

2. WAVEWATCH III (WW3):
   a) Forced by sea-state dependent wind stress, including effects of ocean currents

3. HYCOM:
   a) Forced by sea-state dependent wind stress, modified by growing/decaying waves and Coriolis-Stokes forcing
   b) Turbulent mixing modulated by the Stokes drift (Langmuir turbulence)

Data Assimilation in a coupled framework
Currently GSI for HWRF, and NCODA for HYCOM, in separate.