Basin-wide HWRF Modeling System with Multiple Movable Nests

--A pathway toward operational implementation

Xuejin Zhang (UM/CIMAS)
Thiago Quirino (AOML/HRD)

Collaborators:
AOML/HRD modeling group
NCEP/EMC HWRF Team
Da-lin Zhang UMD/AOSC

Acknowledgement:
This research funded by NOAA/HFIP (NOAA Award: NA12NWS4680007)

Prepared for HFIP AO annual review, 5 June 2013
Objectives

- Improve both TC track and intensity predictions within the scope of the HWRF operational system for seamless transition to operation
- Enhance structure and rainfall predictions critical to landfall and post-landfall application
- Improve storm-storm/multi-scale interactions
- Provide an alternative pathway for storm-oriented satellite and vortex data assimilation within HWRF system
- Explore application for extended TC track and intensity forecasts (up to 7 days) and genesis
Approaches

• Develop multiple movable nested system to follow multiple storms within HWRF model
• Initialize each storm independently with common environmental circulation (localized vortex initialization)
• Explore storm-oriented parallel integration
Current Operational HWRF

**Single Moving Nest**
- Mediate domain follows the inner most domain
- Nest following centroid MSLP/dynamic pressure minima

**Modeling system**
- Real and idealized case framework
- Flexible physics configuration
- Nest Initialization
- DA

**Operational implementation**
- Dynamic setup for forecast domain based storm position
- Single storm forecast
- Partial cycling (vortex cycling only)
- One-way hybrid DA

Research and operational communities now successfully share common repository and directly work together under HFIP
New Functionality

Multiple movable, two-way interactive nests following multiple storms in the upgraded HWRF system
Hurricane Karl  
Hurricane Igor  
Hurricane Julia

Problem: busy day in tropics

<table>
<thead>
<tr>
<th></th>
<th>1+ storm days</th>
<th>2+ storm days</th>
<th>3+ storm days</th>
<th>4+ storm days</th>
<th>Total storm days</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATL</td>
<td>87.4(57.6%)</td>
<td>31.3(35.8%)</td>
<td>9.6(11.1%)</td>
<td>1.4(1.6%)</td>
<td>151.8</td>
</tr>
<tr>
<td>EP</td>
<td>77.8(48.0%)</td>
<td>25.5(32.8%)</td>
<td>5.4(6.2%)</td>
<td>0.3(0.4%)</td>
<td>161.9</td>
</tr>
<tr>
<td>ATL+EP</td>
<td>124.7(65.1%)</td>
<td>66.2(53.1%)</td>
<td>31.1(35.6%)</td>
<td>10.9(8.8%)</td>
<td>191.6</td>
</tr>
</tbody>
</table>
850hPa Streamlines and Isotachs (kts)

Credit to EMC HWRF webpage http://www.emc.ncep.noaa.gov/gc_wmb/vxt
Retrospective & Real-time Forecasts

• Cycles start from 00Z 05/19/2012 to 00Z 11/04/2012
• Real-time test: Isaac (37 cycles); Sandy (33 cycles)
• Web products:
  – 3 categories (27km environment; 3km moving nest; multi-model)
  – 20 products

https://storm.aoml.noaa.gov/basin
Track error (Atlantic 01-19)
Track error (East Pacific 01-17)
HWRF FORECAST - TRACK ERROR (NM) STATISTICS

STATISTICS FOR A SINGLE CASE - o182012_SANDY

- GFDL: GFDL fact.
- HWRF: Oper HWRF
- HWRM: Basin-scale
- AVNO: GFS forecast

Track Error (NM) vs. Forecast Lead Time (hr)

CASES 23, 21, 23, 23, 19, 17, 15, 13, 11, 9, 7

HWRF project - NOAA/NCEP/EMC
Basin Scale HWRF: Hurricane Sandy Prediction

Improved Scale Interactions and Improved Track and Size Forecasts (25/18Z prediction)

Shading: T at 500 hPa; Contour: GHT at 500 hPa
Vector: Flow averaged between 500 hPa and 200 hPa
(credits to Dr.Hua Chen, AOML/HRD/NRC)
Basin Scale HWRF: Isaac-Ileana-Kirk real-time 3-km predictions

Improved tracks and structure, improved rainfall predictions

Isaac Rainfall: 126 h HWRF Forecast

Isaac Rainfall: 192 h QPF forecast
Trigger mechanism

- Decide forecast configuration from tcvital
  - Number of storms
  - Priority storm if number of storms more than four
  - Forecast length (Need genesis forecast product)

- Set up domain location

- Prepare vortex initialization domains

- Allocate resources (disk space, CPUs, running time, and post-processing resource)
Parallel Basin-scale HWRF

• Issues
  – Sequential integration of multiple high-resolution nests (Slow)
  – Limited scalability
• Solutions
  – Parallel high-resolution nests of each storm
• Technical roadmap
  – Use P-threads to integrate multiple nest-pairs in parallel
    • Free OpenMP to be used to further speed up model code
  – Make integration related routines and MPI calls thread-safe
  – Make RSL thread safe to support parallel halo updates by multiple domains
  – Synchronize/sequentialize access by multiple domains to non-thread safe code:
    • Avoid bottlenecks imposed by existing multi-threaded MPI implementations
    • Provides a mechanism for progressive code parallelization without the need to modify every routine in the model to achieve any speed gains
      – Example: Synchronized access to I/O, forcing, and feedback routines
The basin-scale HWRF system

Interactions between the two storms through interactions with the parent domain

Two-way interaction

Parallel TC one

Parallel TC two
<table>
<thead>
<tr>
<th>Number of Nest Domains</th>
<th>27 km</th>
<th>27-9-3 km</th>
<th>27-9-3 km</th>
<th>27-9-3 km</th>
<th>27-9-3 km</th>
<th>27-9-3 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Clock Time (original)</td>
<td>~50 mins</td>
<td>~137 mins</td>
<td>~256 mins</td>
<td>Not scalable</td>
<td>~150 mins</td>
<td>~363 mins</td>
</tr>
<tr>
<td>Wall Clock Time (New)</td>
<td>~137 mins</td>
<td>~137 mins</td>
<td>~213 mins</td>
<td>~150 mins</td>
<td>~363 mins</td>
<td>~430 mins</td>
</tr>
<tr>
<td>CPUs</td>
<td>196</td>
<td>196</td>
<td>196</td>
<td>376</td>
<td>196</td>
<td>196</td>
</tr>
</tbody>
</table>

Current code is scalable and shows huge potential for transition to operation. More resource is required for further speed-up and testing.
## Basin-scale Model Configurations

<table>
<thead>
<tr>
<th></th>
<th>2013 HWRF Operational</th>
<th>Basin-scale Model (Stream 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Domain</strong></td>
<td>27 KM: 77.76° X 77.76°</td>
<td>27 KM: 178.20° X 77.58°</td>
</tr>
<tr>
<td></td>
<td>9 KM: 10.56° X 10.2°</td>
<td>9 KM: 10.56° X 10.2°</td>
</tr>
<tr>
<td></td>
<td>3 KM: 6.12° X 5.42°</td>
<td>3 KM: 6.12° X 5.42°</td>
</tr>
<tr>
<td><strong>Vortex Initialization</strong></td>
<td><strong>Modified Vortex Initialization at 3 KM and Hybrid DA</strong></td>
<td><strong>Modified Vortex Initialization at 3 KM and GSI DA</strong></td>
</tr>
<tr>
<td><strong>Cycling</strong></td>
<td>Yes (9-3 km vortex only)</td>
<td>Yes (cycle 9-3 km vortex each storm)</td>
</tr>
<tr>
<td><strong>Ocean Coupling</strong></td>
<td>27-9 KM: Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>3 KM: No, Downscaled</td>
<td></td>
</tr>
</tbody>
</table>

### Physics schemes

<table>
<thead>
<tr>
<th><strong>Microphysics</strong></th>
<th><strong>Modified Ferrier (High-Res)</strong></th>
<th><strong>Modified Ferrier (High-Res)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiation</strong></td>
<td>GFDL</td>
<td>GFDL</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td>GFDL (High_res)</td>
<td>GFDL (High_res)</td>
</tr>
<tr>
<td><strong>PBL Scheme</strong></td>
<td>2012 GFS (High_res)</td>
<td>2012 GFS (High_res)</td>
</tr>
<tr>
<td><strong>Convection</strong></td>
<td><strong>SAS (High-Res), No CP (3 KM), Shallow Convection</strong></td>
<td><strong>SAS (High-Res), No CP (3 KM), Shallow Convection</strong></td>
</tr>
<tr>
<td><strong>Land Surface</strong></td>
<td>GFDL Slab</td>
<td>GFDL Slab</td>
</tr>
<tr>
<td><strong>GWD</strong></td>
<td>Yes(27km); No(9-3km)</td>
<td>Yes(27km); No(9-3km)</td>
</tr>
</tbody>
</table>
Summary of work accomplished

• Completed movable nests for multiple storms
• Implemented 2013 HWRF upgrade to basin-scale modeling system
• Implemented localized vortex initialization for multiple storms and cycling
• Accelerated code efficiency
Ongoing work

• Integrated system testing through retrospective cases (2012 season)
• Implement new parallel algorithm to 2013 HWRF model
• Efficiency and scalability testing
• Run system in real-time for 2013 season (Stream 2 advancement)
• Production and dissemination
Challenges

- Further optimize the code to meet the operational time requirements
- Urgent need of computing resource during the season to demonstrate on-going advancements
Conclusion

• Development of the integrated modeling system is completed and the system is showing great promise for transitions
• Intensity and structure verifications are ongoing for the retrospective runs
• Forecast efficiency will be critical to the pathway toward operational implementation