Advancements in Operations and Research on Hurricane Modeling and Ensemble Prediction System at EMC/NOAA

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EMC/NCEP/NOAA/DOC

Acknowledgements: HWRF Team Members at EMC, HRD/AOML, DTC, GFDL and URI

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Acknowledgements

- **HWRF Team:** Vijay Tallapragada - Team Leader
  Young Kwon, Qingfu Liu, Samuel Trahan, Chanh Kieu, Weiguo Wang,

- **2012 HWRF upgrade is a result of multi-agency efforts supported by HFIP**
  - **EMC:** Computational efficiency, nest motion algorithm, physics improvements, 3km initialization and pre-implementation T&E
  - **HRD/AOML:** nest motion algorithm, multiple moving nests, PBL upgrades, interpolation routines for initialization, diagnostics.
  - **DTC/NCAR:** code management and subversion based repository, MPI profiling
  - **ESRL:** Physics sensitivity tests and idealized capability
  - **URI:** 1D ocean coupling in Eastern Pacific basin
  - **GFDL:** Knowledge sharing, joint T&E
  - **NHC:** Diagnostics and evaluation of the HWRF pre-implementation tests
Outline

- 2012 Operational Hurricane Model Forecast System (HWRF Model) and its verification;
- Hurricane Ensemble Prediction Research at EMC;
- Ongoing and Future Projects at EMC
Highlights of the 2012 HWRF Upgrades

• For the first time, a high-resolution hurricane model operating at cloud-permitting 3km resolution is being implemented into NCEP operational system
  • Three atmospheric telescoping nested domains:
    • 27km outer domain 75x75 degree; 9km intermediate nest ~11x10 degree
    • 3km inner-most nest ~6x5 degree
  • New centroid based nest motion algorithm;
  • 1-D Ocean coupling in East-Pac;
  • Improved physics & vortex initialization;
  • Upgraded tracker;
  • New high-temporal resolution track and intensity product;
  • New SSMI/S synthetic microwave imagery.
2010-2011 Atlantic Track Verification

~20% improvement in Track Error

Superior Track FSP

Improved Cross-Track errors

Improved Along-Track errors
2010-2011 E-PAC Track Verification

~20% improvement in Track errors

Improved Track FSP

HOPS: operational HWRF
H212: 2012 HWRF

Improved Cross-Track

Along-Track errors
HOPS vs. H212 P-W relationship

ATLANTIC

E-PAC
Impact of Physics and Resolution Upgrades

Surface of $10^{-5}$ kg/kg Total Condensate

Irene 2011082318
Impact of 1-D Ocean Coupling for E-Pac Storms

Hurricane Dora

H212

Hurricane Adrian

Oper. HWRF

Hurricane DORA Simulation: Initial time: 2011/07/20 12Z: 72h forecast
Surface Temperature and Surface Currents

Hurricane DORA Simulation: Initial time: 2011/07/20 12Z:
Surface Temperature:

Hurricane ADRIAN Simulation: Initial time: 2011/06/03 18Z: 48h forecast
Surface Temperature and Surface Currents

Hurricane DORA Simulation: Initial time: 2011/07/20 12Z:
Surface Temperature:
New experimental products from operational HWRF

- Synthetic satellite imagery using a uniform RTM:
  - GOES-13 and GOES-11 Channel 2,3,4,6
  - SSM/I Microwave 37 GHz and 85 GHz V&H

High Temporal Resolution HWRF
ATCF-style output at every time step (5 seconds) at 3km resolution
Are 6-hr outputs representative of the actual model forecast?
What is happening during development and RI within the model?
Development of Hurricane Ensemble Prediction System
Example of Ensemble Track Prediction (Debby, 2012)

Single Model Ensemble Forecasts: GEFS

Track Forecasts from Different Models: ECMWF, GFS, NOGAP, HWRF, GFDL
Uncertainties in Hurricane Model Forecast

- Initial Large Scale Flows;
- Lateral Boundary Conditions;
- Initial Storm Structure;
- Model Physics.

Ensemble Generation Methods:

- Initial Condition based Ensembles
  - Singular Vector Perturbations
  - Ensemble Transfer Re-scale (ETR)
- Model Physics based Ensembles
  - Different Model Physics Package
  - Stochastic Physics Perturbation Tendency (STTP)
- Multi-Model Ensembles
## HWRF-GEFS based Ensemble Experiment

<table>
<thead>
<tr>
<th>Ensemble Member ID</th>
<th>Input Data</th>
<th>Convection Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>GFS (T574L64)</td>
<td>SAS</td>
</tr>
<tr>
<td>M00 – M20</td>
<td>GEFS (T190L28)</td>
<td>SAS</td>
</tr>
<tr>
<td>M21 – M41</td>
<td>GEFS (T190L28)</td>
<td>Kain-Fritsch</td>
</tr>
<tr>
<td>M42 – M62</td>
<td>GEFS (T190L28)</td>
<td>Batts-Miller</td>
</tr>
</tbody>
</table>

- Storm tracks are generally dictated by large scale environment flows;
- Large scale flow uncertainties are included in GEFS;
- The uncertainties in the model physics have great impacts on storm intensity forecasts;

Storms conducted: Earl: 2010082512-2010090412 Alex: 2010062606-2010070106 Celia: 2010061912-2010062812
More than ~15% improvement in track forecasts

Track forecast skills are improved by all sub-sets of ensembles; Ensembles have less impacts on the track forecasts before 48h;
Commonly Used Post-Process Method in Hurricane Ensemble Forecasts

1. Simple consensus: average over all ensemble members
2. Clustering: group ensemble members based on their relative distances;

\[ \hat{f}_h(x) = \frac{1}{n} \sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \]

Where \((x_1, x_2, \ldots, x_n)\) is a set of samples drawn from some distribution with an unknown density \(f\). \(K(*)\) is the kernel. \(h\) is a smoother parameter or bandwidth.

4. Regression Model, used for multi-model ensemble, based on past data training.
Both cluster analysis and Gaussian KDE PDF identified two groups of ensemble tracks: eastward track (most of ensemble members) and westward track (small number of ensemble members).
Ongoing and Future Works

- **HWRF Physics Upgrades include:**
  - MYJ PBL, Roll-Circulation;
  - Multi-moment Microphysics;
  - NOAH LSM;
  - HYCOM Coupling.

- **Basin-Scale Data Assimilation and Forecast System:**
  - GSI/EnKF hybrid Data Assimilation system;
  - Multi-storm in one basin scale System.

- **HWRF Ensemble Prediction System:**
  - GEFS Based HWRF Ensemble Prediction System;
  - Multi-Model, Multi-Physics Ensembles.

- **Ensemble data Post-process:**
  - Kernel Density Estimation;
  - Cluster analysis;
  - Regression model.

HWRF web site: http://www.emc.ncep.noaa.gov/gc_wmb/vxt/