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

Zhan Zhang and Vijay Tallapragada
EMC/NCEP/NOAA/DOC

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

Second Workshop on Understanding Climate Change from Data

University of Minnesota, Minneapolis, MN

August 6-7, 2012

Acknowledgements

- HWRF Team: Vijay Tallapragada - Team Leader

  Young Kwon, Qingfu Liu, Samuel Trahan, Chanh Kieu, Weiguo Wang,

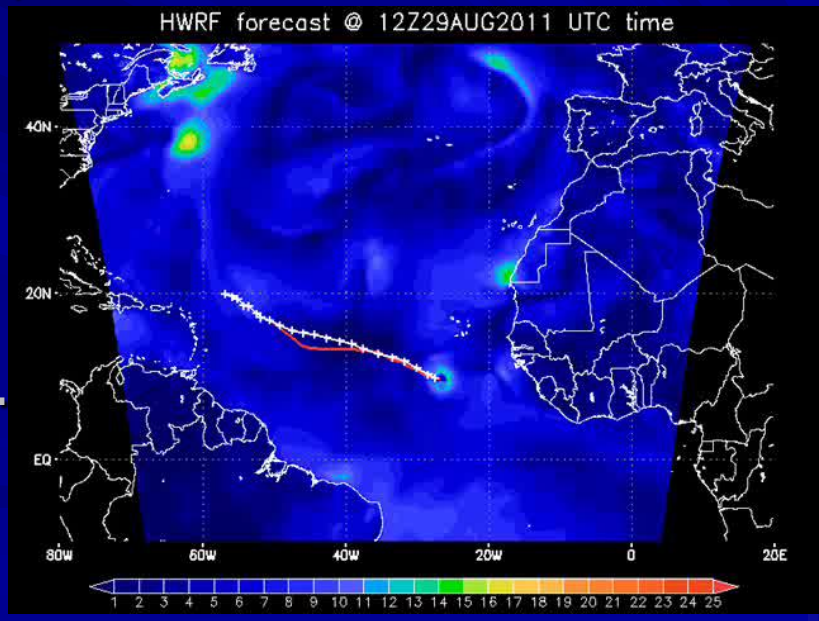
- **2012 HWRF upgrade is a result of multi-agency efforts supported by HFIP**
  - ***EMC****: Computational efficiency, nest motion algorithm, physics improvements, 3km initialization and pre-implementation T&E*
  - ***HRD/AOML****: nest motion algorithm, multiple moving nests, PBL upgrades, interpolation 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*

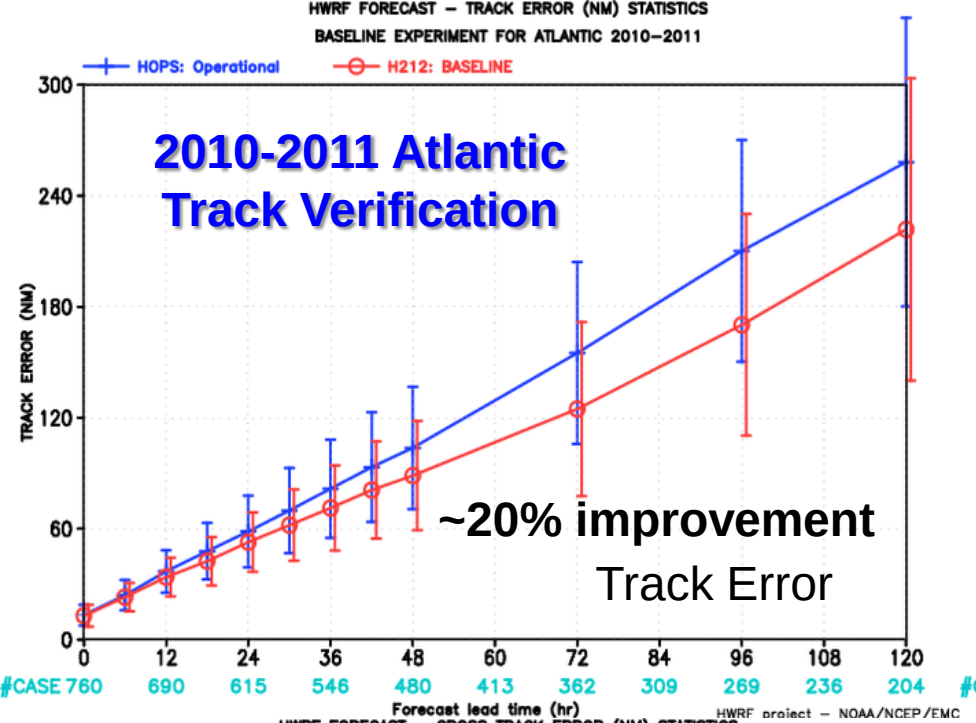
Outline

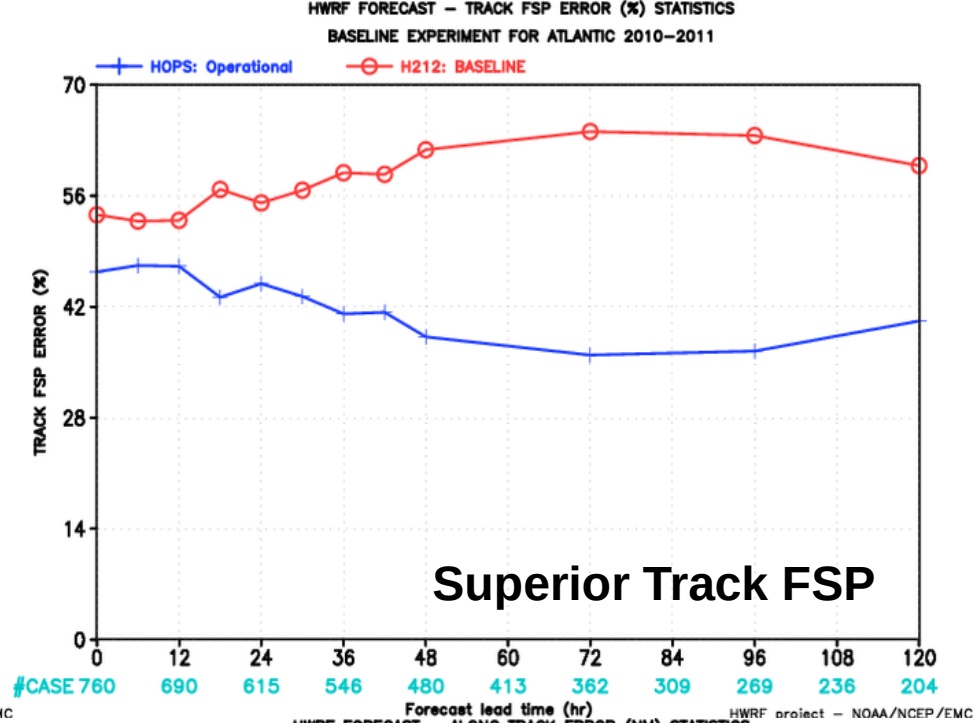
- 2012 Operational Hurricane Model Forecast System (HWRF Model) and its verification;
- Hurricane Ensemble Prediction Research at EMC;
- Ongoing and Future Projects at EMC

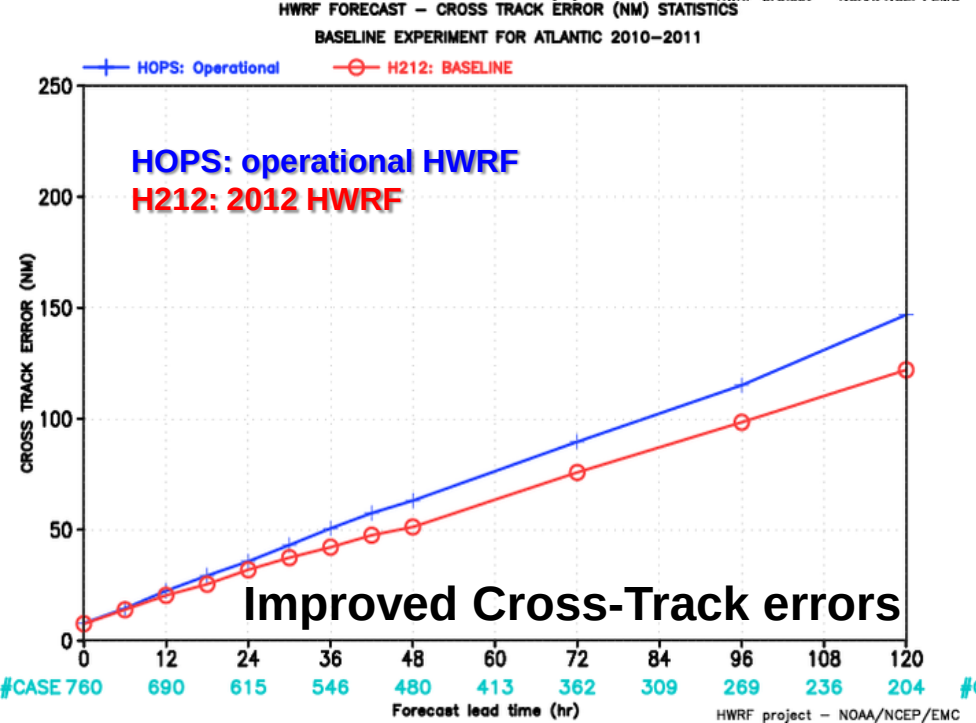
Highlights of the 2012 HWRF Upgrades

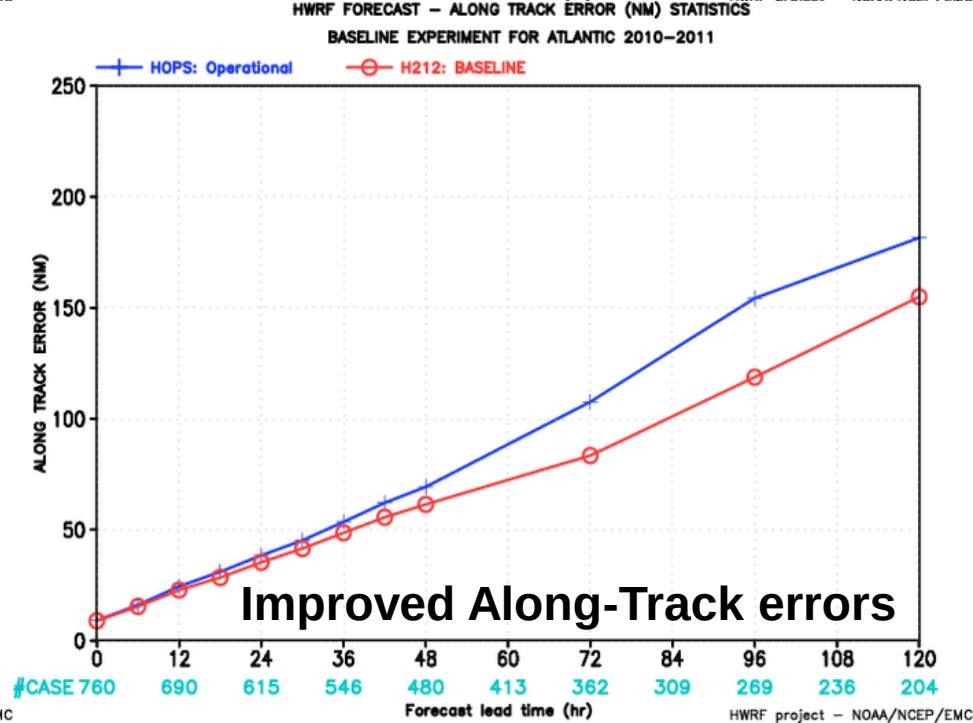
- For the first time, a **high-resolution hurricane model operating at cloud-permitting 3km resolution** is being implemented into NCEP operational system
  - Three atmospheric telescoping nested domains:
  - 27km outer domain 75x75 degree; 9km intermediate nest ~11x10 degree
  - **3km inner-most nest ~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.

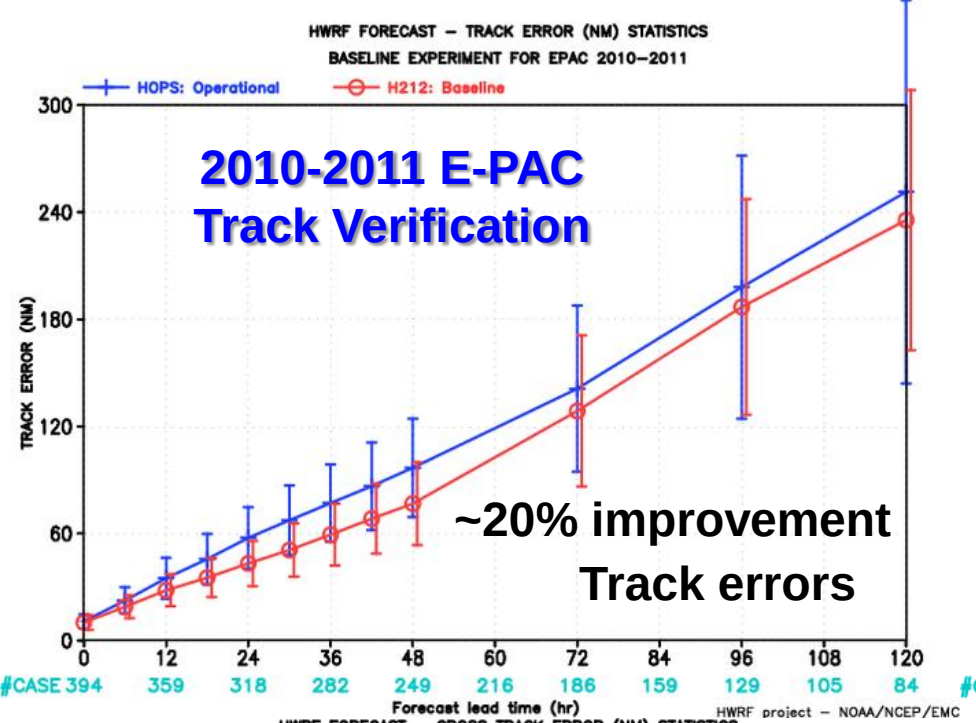


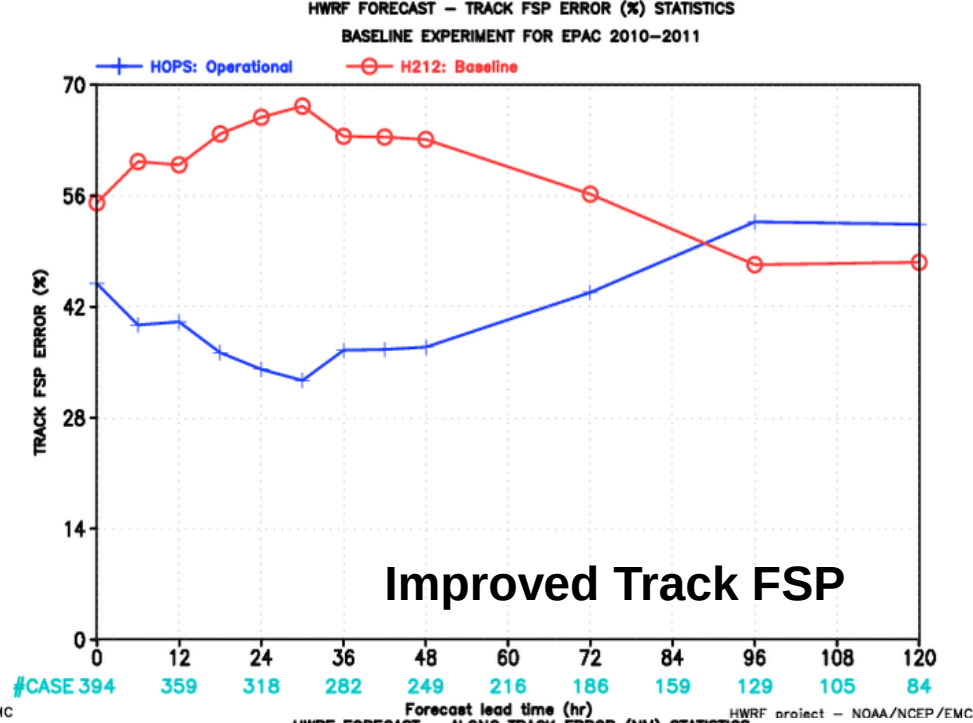

HWRF FORECAST – TRACK ERROR (NM) STATISTICS
BASELINE EXPERIMENT FOR ATLANTIC 2010–2011
HOPS: Operational
H212: BASELINE
2010-2011 Atlantic
Track Verification
~20% improvement
Track Error
TRACK ERROR (NM)
300
240
180
120
60
0
0 12 24 36 48 60 72 84 96 108 120
#CASE 760 690 615 546 480 413 362 309 269 236 204
Forecast lead time (hr)
HWRF project – NOAA/NCEP/EMC

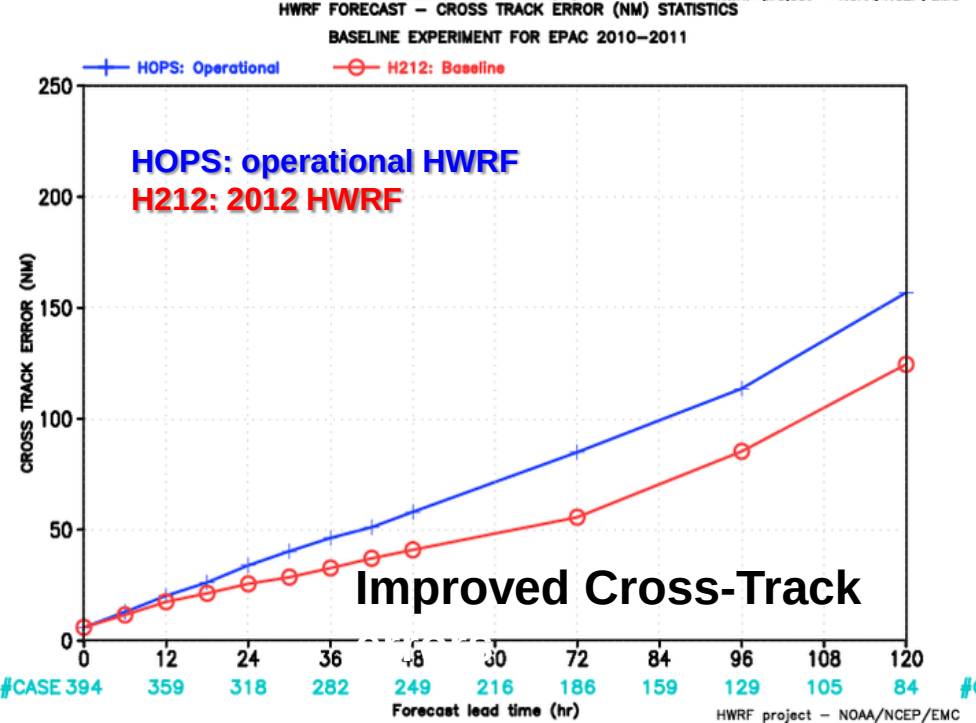

HWRF FORECAST – TRACK FSP ERROR (%) STATISTICS
BASELINE EXPERIMENT FOR ATLANTIC 2010–2011
HOPS: Operational
H212: BASELINE
TRACK FSP ERROR (%)
70
56
42
28
14
0
0 12 24 36 48 60 72 84 96 108 120
#CASE 760 690 615 546 480 413 362 309 269 236 204
Forecast lead time (hr)
Superior Track FSP
HWRF project – NOAA/NCEP/EMC


HWRF FORECAST – CROSS TRACK ERROR (NM) STATISTICS
BASELINE EXPERIMENT FOR ATLANTIC 2010–2011
HOPS: Operational
H212: BASELINE
HOPS: operational HWRF
H212: 2012 HWRF
CROSS TRACK ERROR (NM)
250
200
150
100
50
0
0 12 24 36 48 60 72 84 96 108 120
#CASE 760 690 615 546 480 413 362 309 269 236 204
Forecast lead time (hr)
Improved Cross-Track errors
HWRF project – NOAA/NCEP/EMC


HWRF FORECAST – ALONG TRACK ERROR (NM) STATISTICS
BASELINE EXPERIMENT FOR ATLANTIC 2010–2011
HOPS: Operational
H212: BASELINE
ALONG TRACK ERROR (NM)
250
200
150
100
50
0
0 12 24 36 48 60 72 84 96 108 120
#CASE 760 690 615 546 480 413 362 309 269 236 204
Forecast lead time (hr)
Improved Along-Track errors
HWRF project – NOAA/NCEP/EMC


HWRF FORECAST – TRACK ERROR (NM) STATISTICS
BASELINE EXPERIMENT FOR EPAC 2010–2011
HOPS: Operational
H212: Baseline
2010-2011 E-PAC
Track Verification
~20% improvement
Track errors
TRACK ERROR (NM)
Forecast lead time (hr)
#CASE 394 359 318 282 249 216 186 159 129 105 84
HWRF project – NOAA/NCEP/EMC


HWRF FORECAST – TRACK FSP ERROR (%) STATISTICS
BASELINE EXPERIMENT FOR EPAC 2010–2011
HOPS: Operational
H212: Baseline
Improved Track FSP
TRACK FSP ERROR (%)
Forecast lead time (hr)
#CASE 394 359 318 282 249 216 186 159 129 105 84
HWRF project – NOAA/NCEP/EMC


HWRF FORECAST – CROSS TRACK ERROR (NM) STATISTICS
BASELINE EXPERIMENT FOR EPAC 2010–2011
HOPS: Operational
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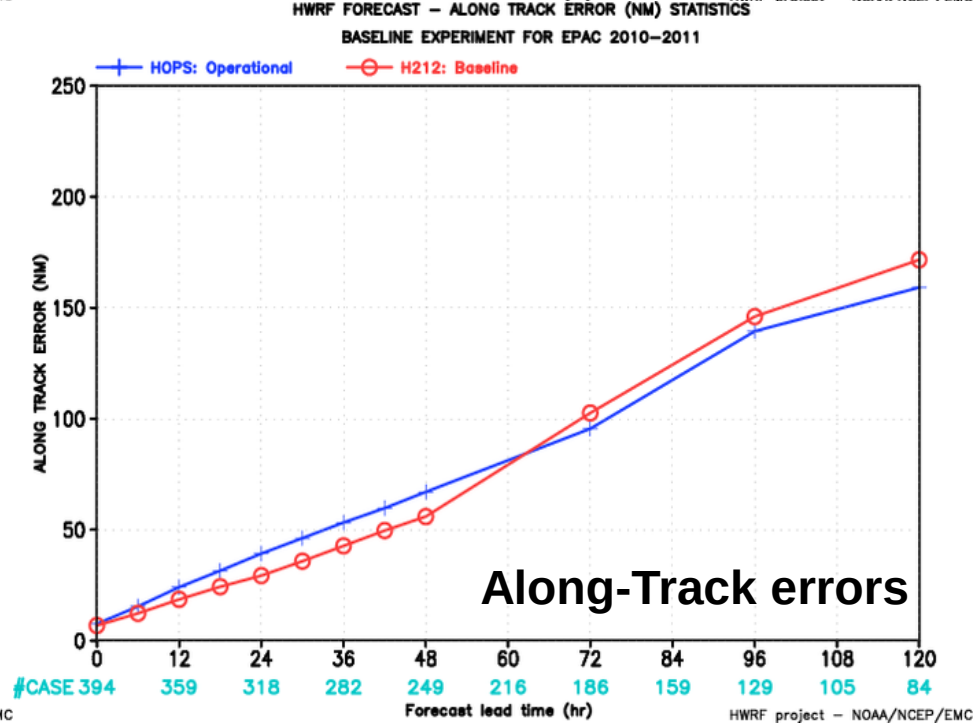
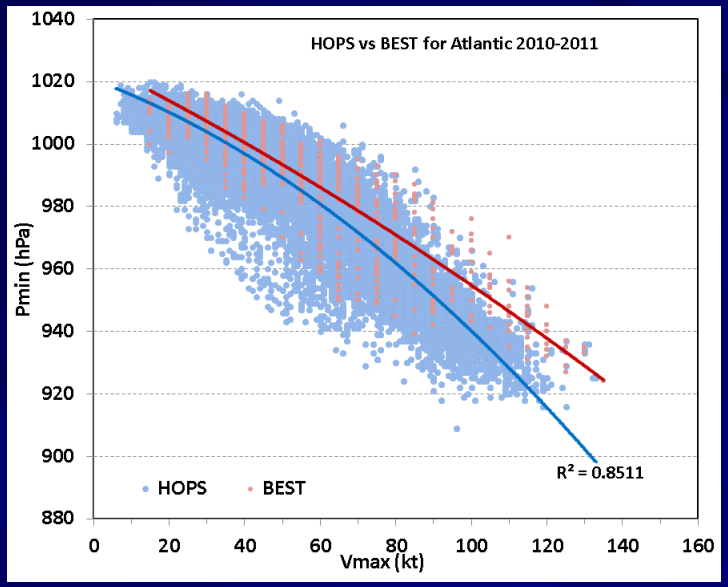
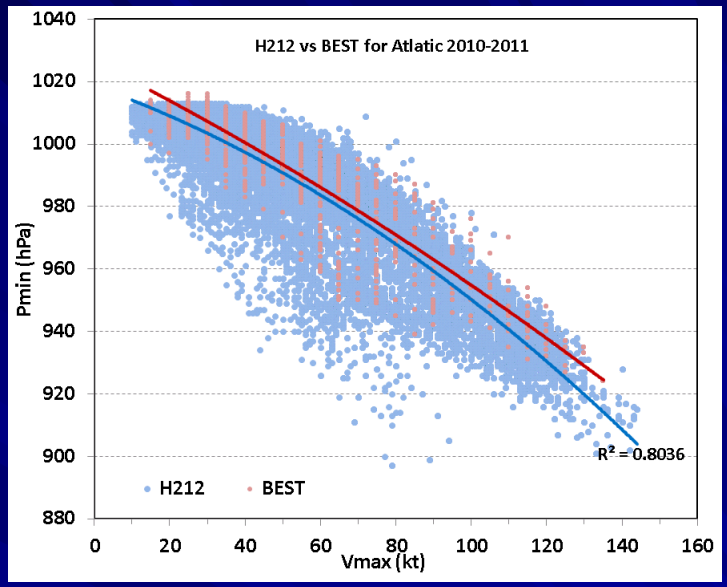
HOPS: operational HWRF
H212: 2012 HWRF
Improved Cross-Track
CROSS TRACK ERROR (NM)
Forecast lead time (hr)
#CASE 394 359 318 282 249 216 186 159 129 105 84
HWRF project – NOAA/NCEP/EMC

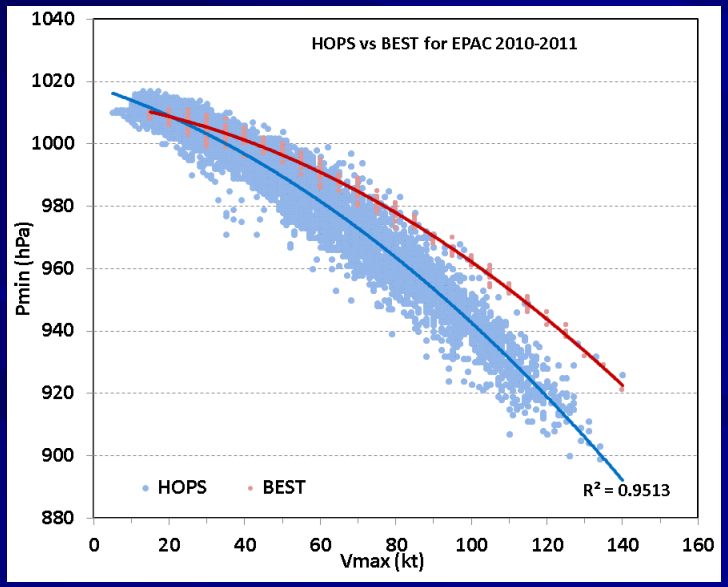

HWRF FORECAST – ALONG TRACK ERROR (NM) STATISTICS
BASELINE EXPERIMENT FOR EPAC 2010–2011
HOPS: Operational
H212: Baseline
Along-Track errors
ALONG TRACK ERROR (NM)
Forecast lead time (hr)
#CASE 394 359 318 282 249 216 186 159 129 105 84
HWRF project – NOAA/NCEP/EMC

HOPS vs. H212 P-W relationship

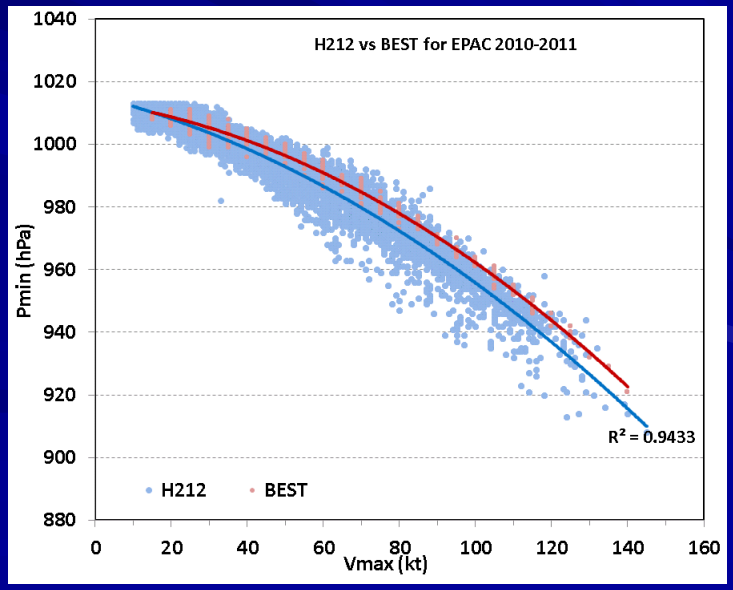


ATLANTIC

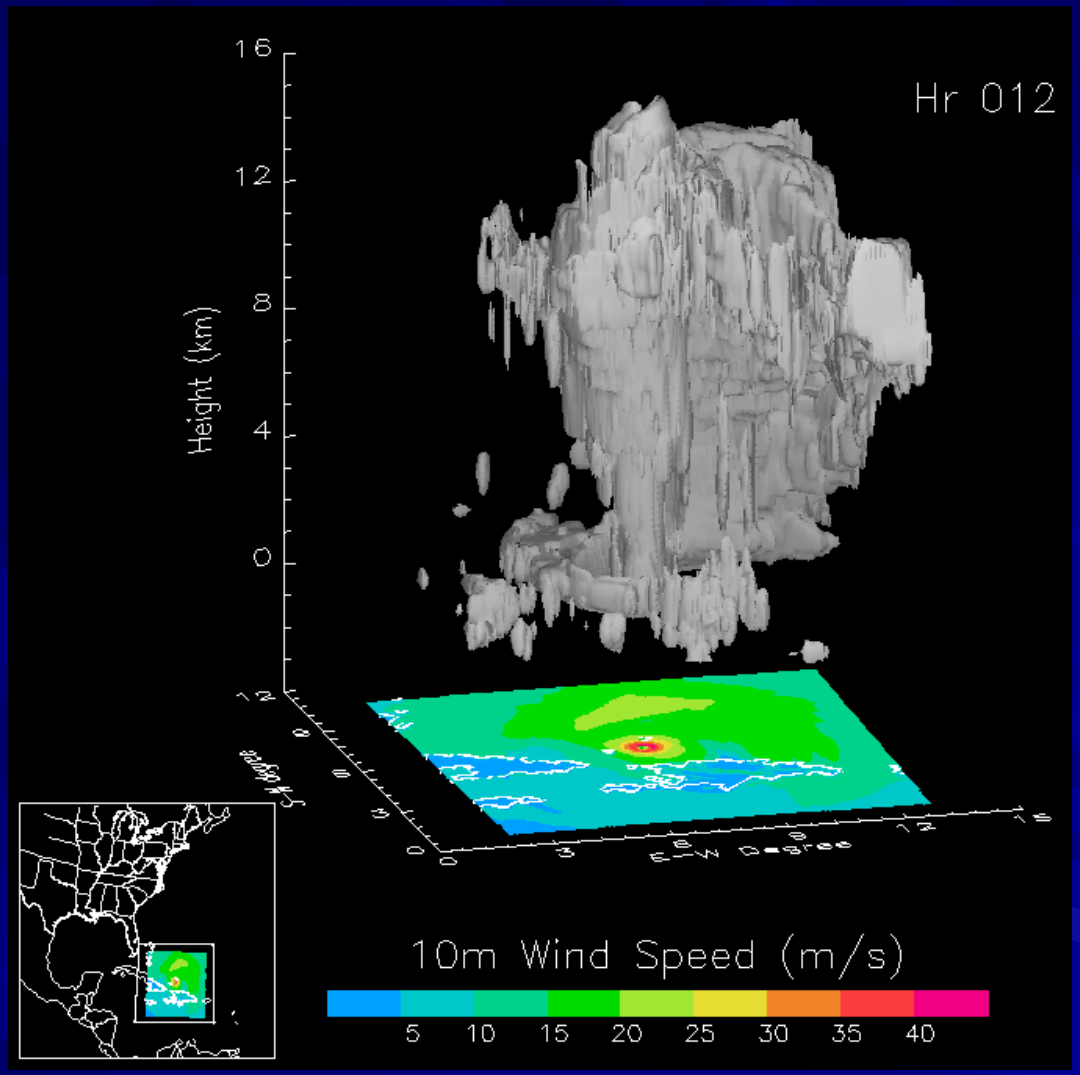




E-PAC



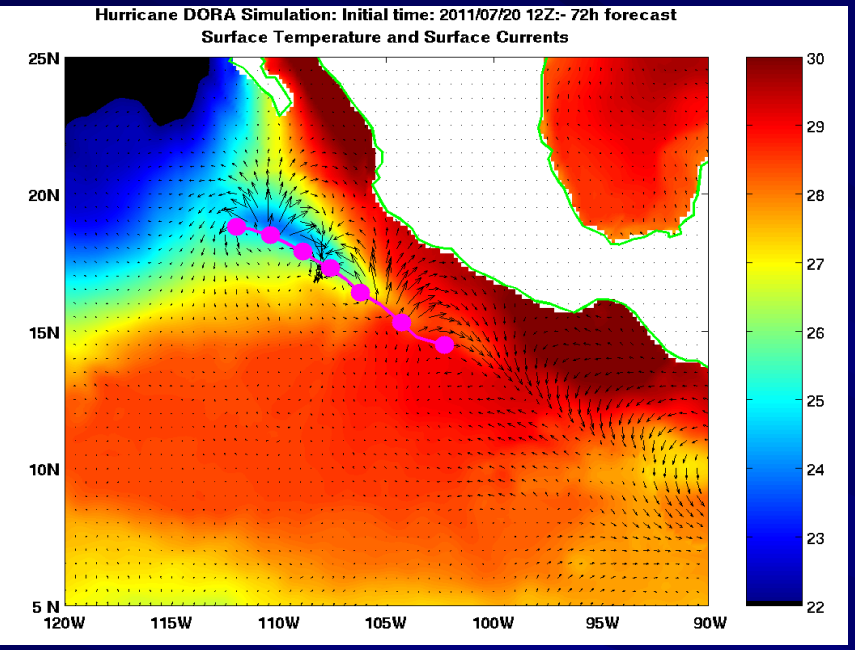
Impact of Physics and Resolution Upgrades



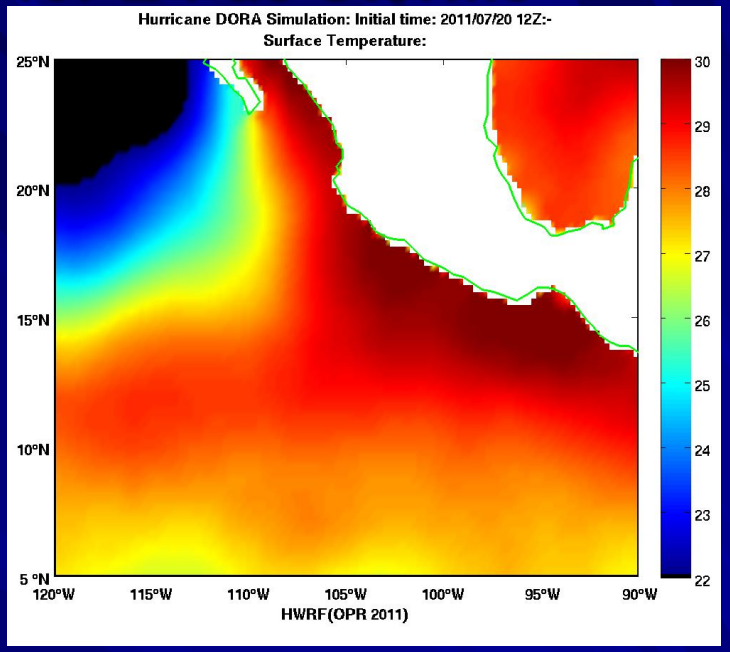
Surface of 10^{-5} kg/kg Total Condensate

Irene 2011082318

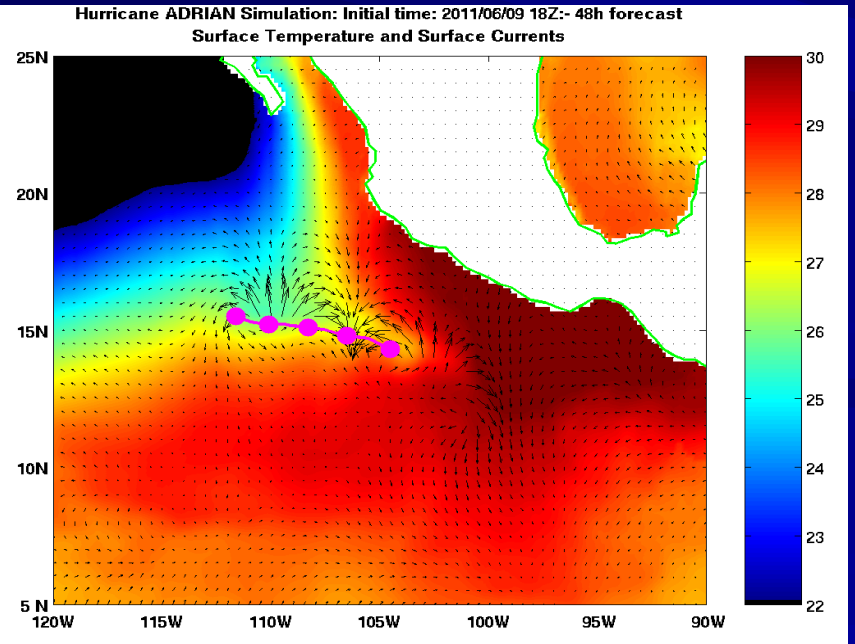
Impact of 1-D Ocean Coupling for E-Pac Storms



Hurricane Dora

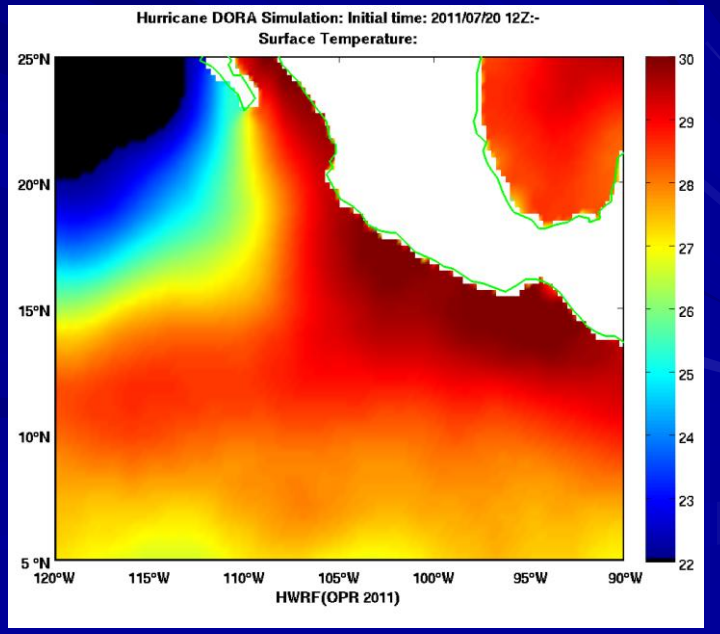


H212



Hurricane Adrian

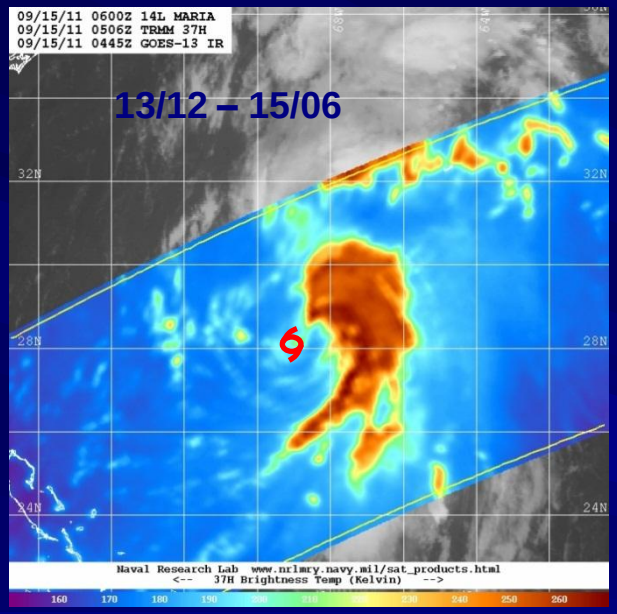
Oper. HWRF



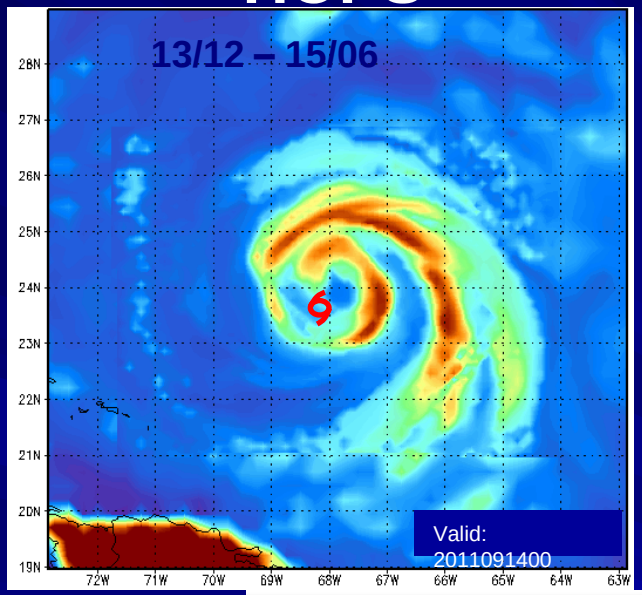
New experimental products from operational HWRF

- **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

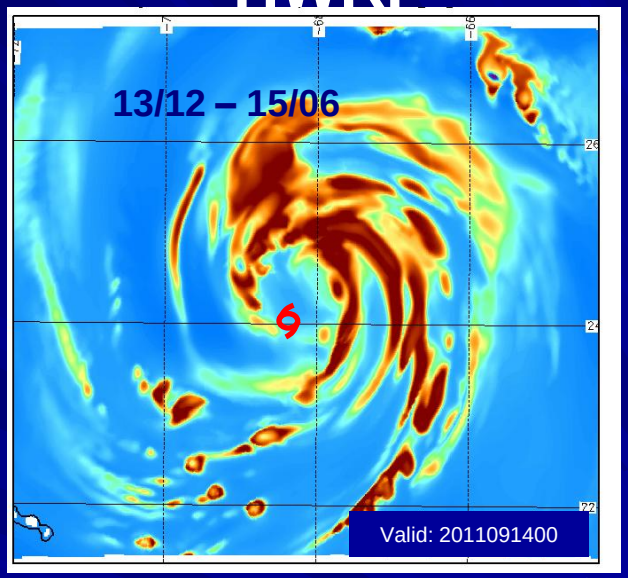
Observed



Simulated 9 km HOPS



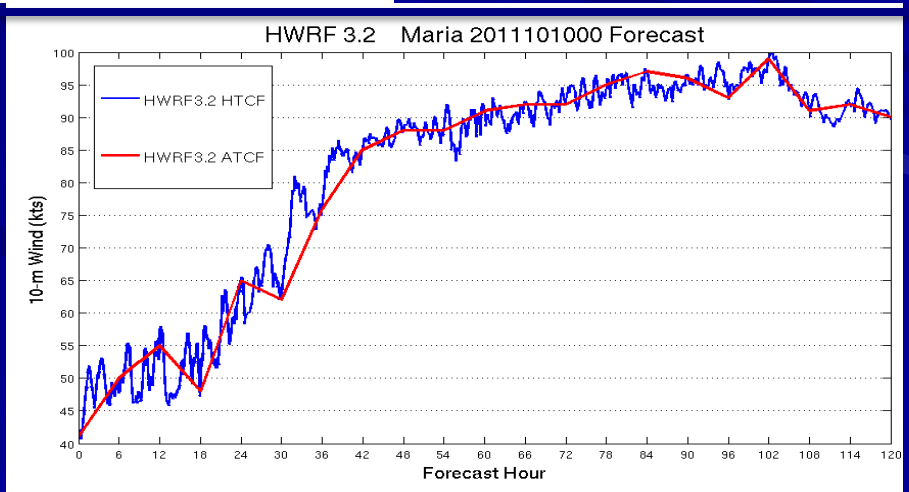
Simulated 3 km HWRF



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

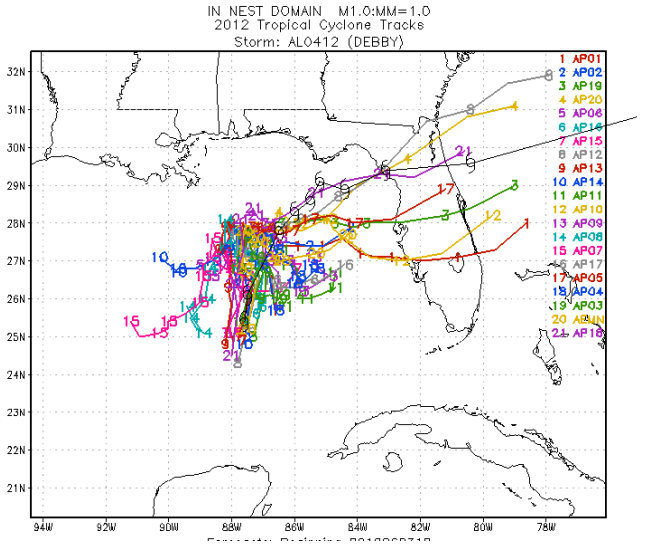
Example of Ensemble Track Prediction (Debby, 2012)

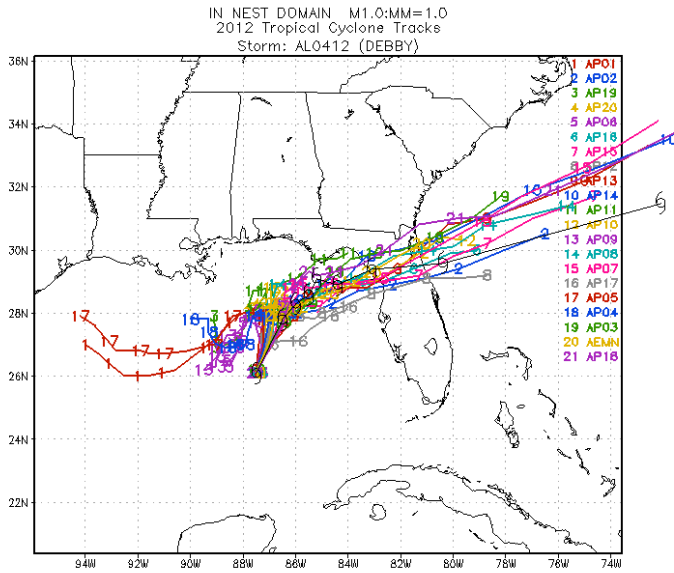
Single Model Ensemble Forecasts: GEFS

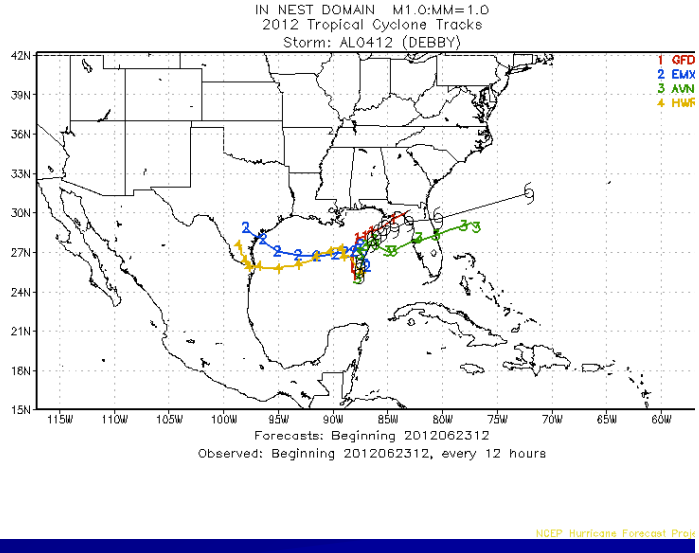
Track Forecasts from Different Models: ECMWF, GFS, NOGAP, HWRF,GFDL

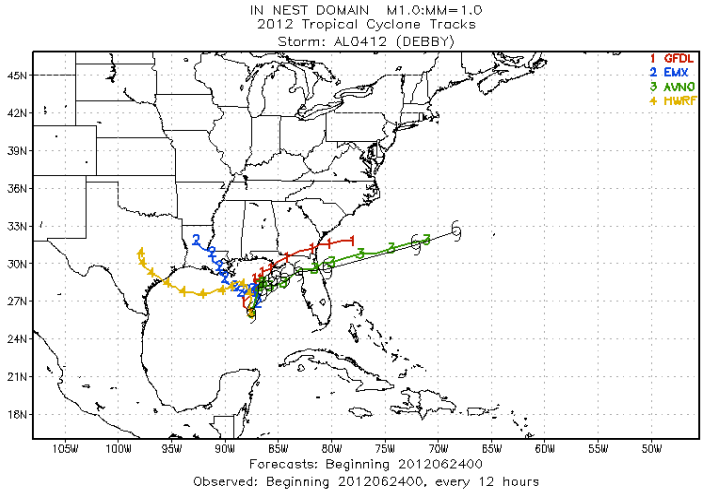
20120623 12Z

20120624 00Z









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

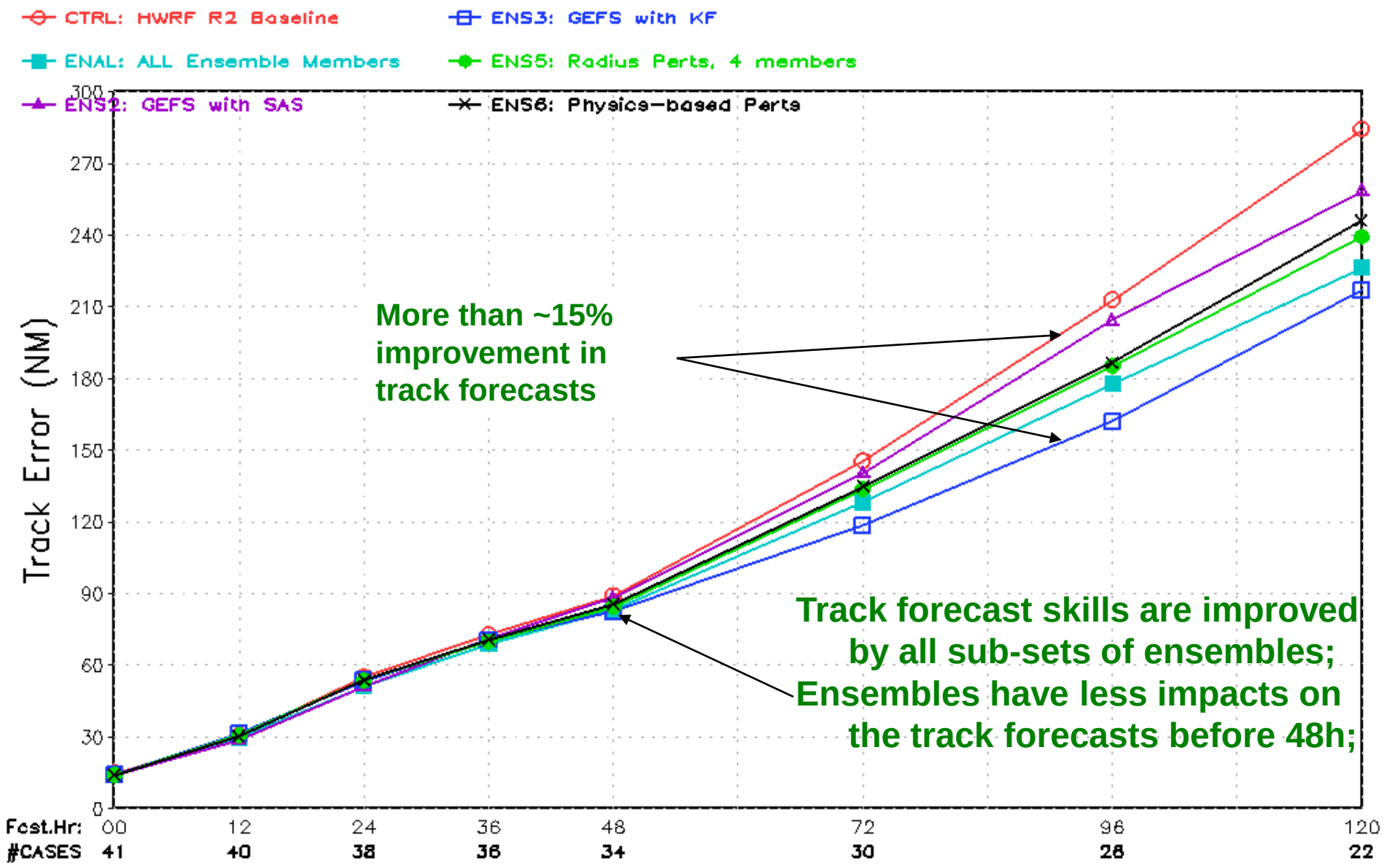
Ensemble Member ID	Input Data	Convection Scheme
Control	GFS (T574L64)	SAS
M00 – M20	GEFS (T190L28)	SAS
M21 – M41	GEFS (T190L28)	Kain-Fritsch
M42 – M62	GEFS (T190L28)	Batts-Miller

- 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

Average Track Errors (NM)

Statistics Plots – Ensembles for Storm Earl



Commonly Used Post-Process Method in Hurricane Ensemble Forecasts

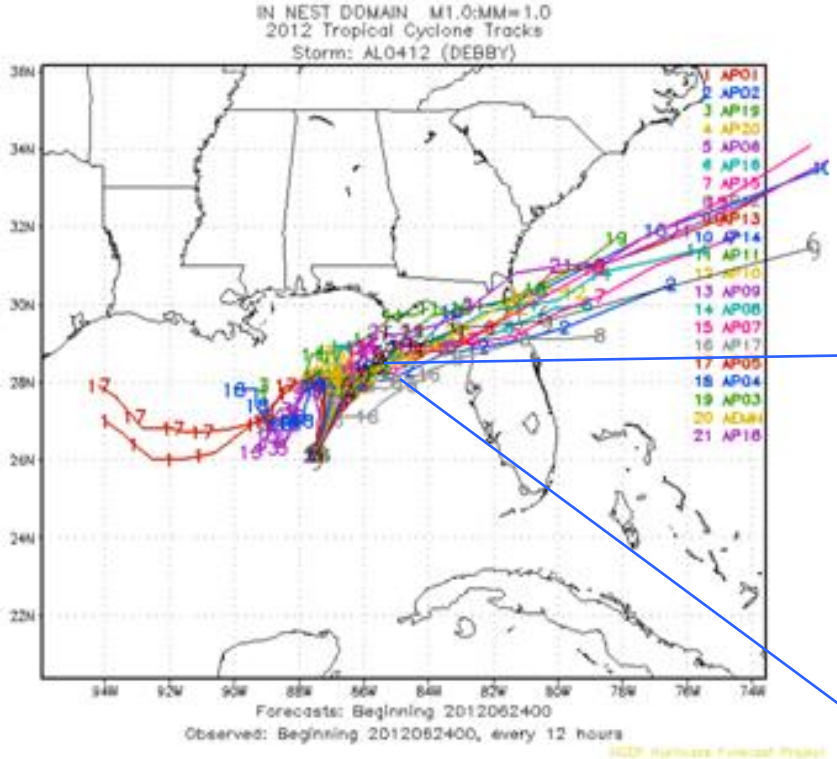
1. Simple consensus: average over all ensemble members
2. Clustering: group ensemble members based on their relative distances;
3. Kernel Density Estimation (KDE):

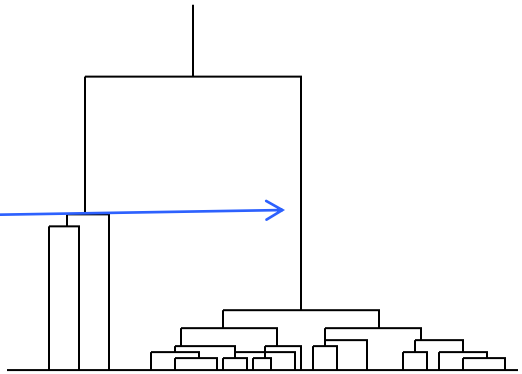
$$\hat{f}_h(x) = \frac{1}{n}\sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{x - x_i}{h})$$

Where $(x_1, x_{2,}..., x_n)$ 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.

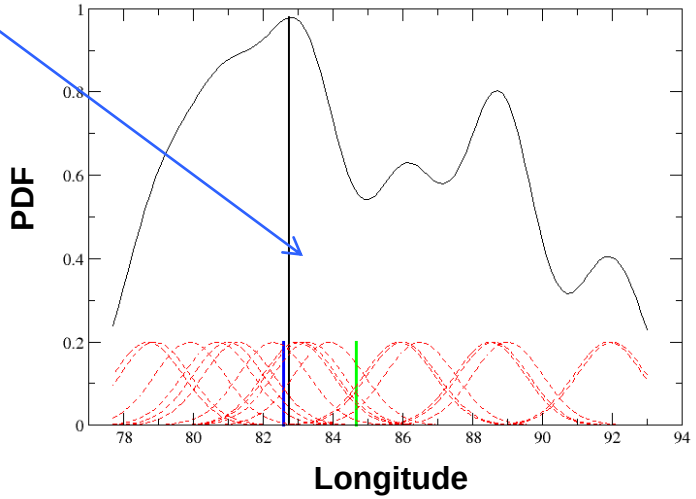
Cluster Analysis





01 17 16

Kernel Density Estimated PDF



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/

Basin Scale HWRF with Multi Moving Nest Domains