Regional Hurricane Model Advancements at NCEP/EMC: FY2012 Implementation of High-Resolution 3km Triple-Nested HWRF

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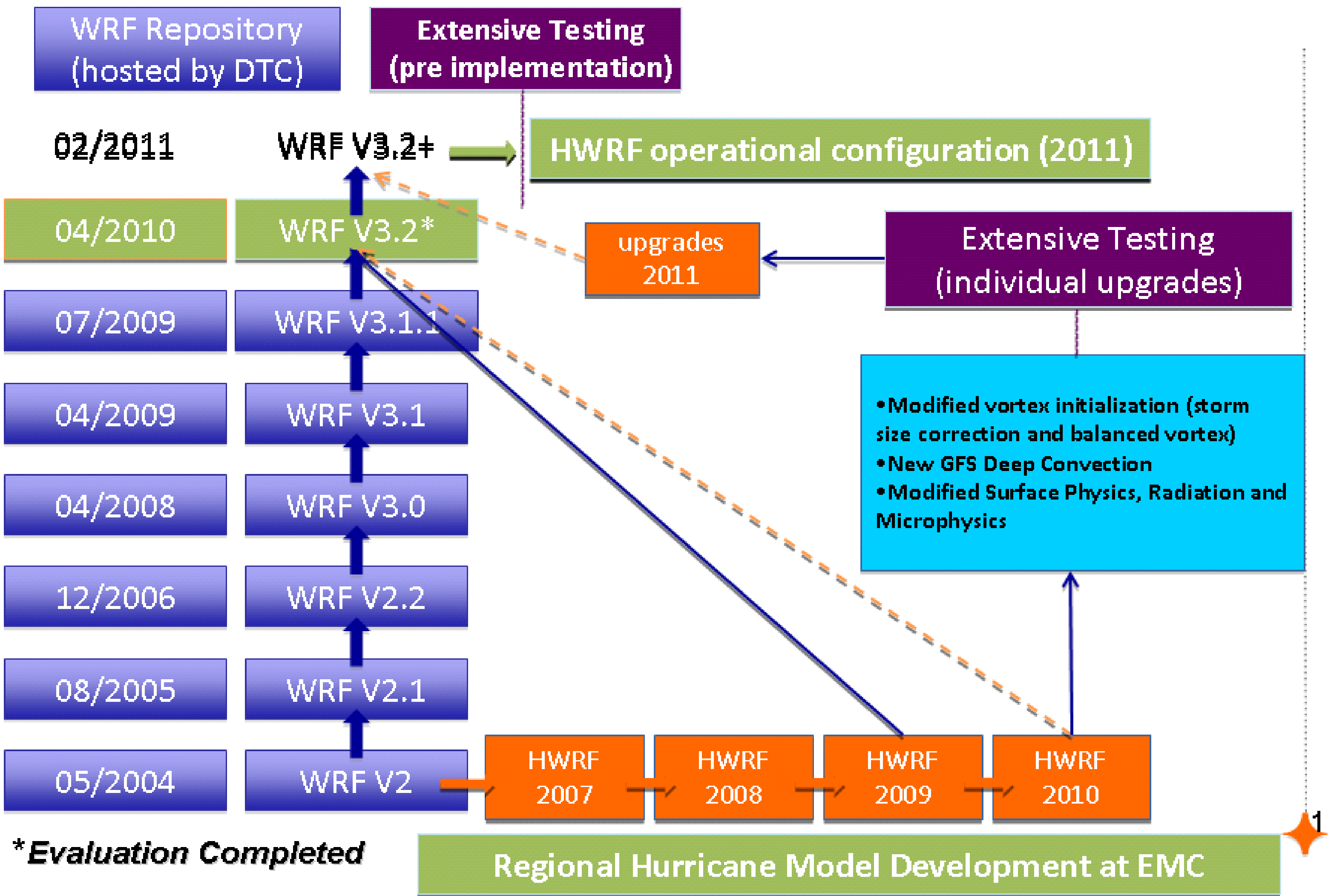
Outline

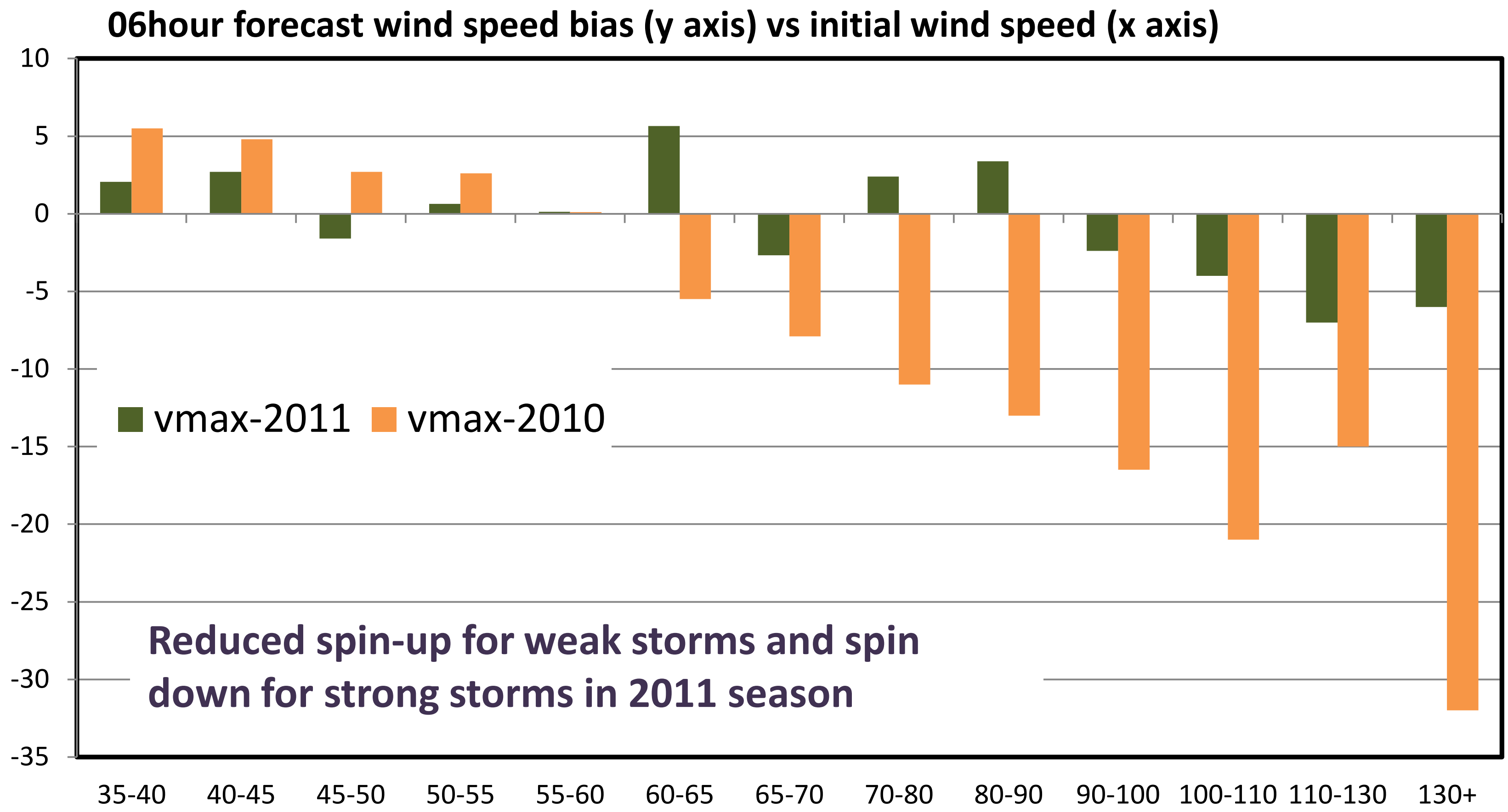
- **Performance of current operational HWRF for 2011 season**
- **Unification of operational and research versions of HWRF in the community modeling framework (EMC/HRD/DTC)**
- **Development and evaluation of high-resolution tripled-nested HWRF through a major collaborative effort (EMC/HRD/GFDL/URI/NHC) - a success story inspired by support from HFIP**
- **Computational and scientific challenges towards implementing high-resolution HWRF at NCEP**
- **Planned FY2012 operational configuration**
- **Future developments 2012 and beyond**

FY2011 HWRF Upgrades

FY2011 Operational HWRF Baseline Configuration



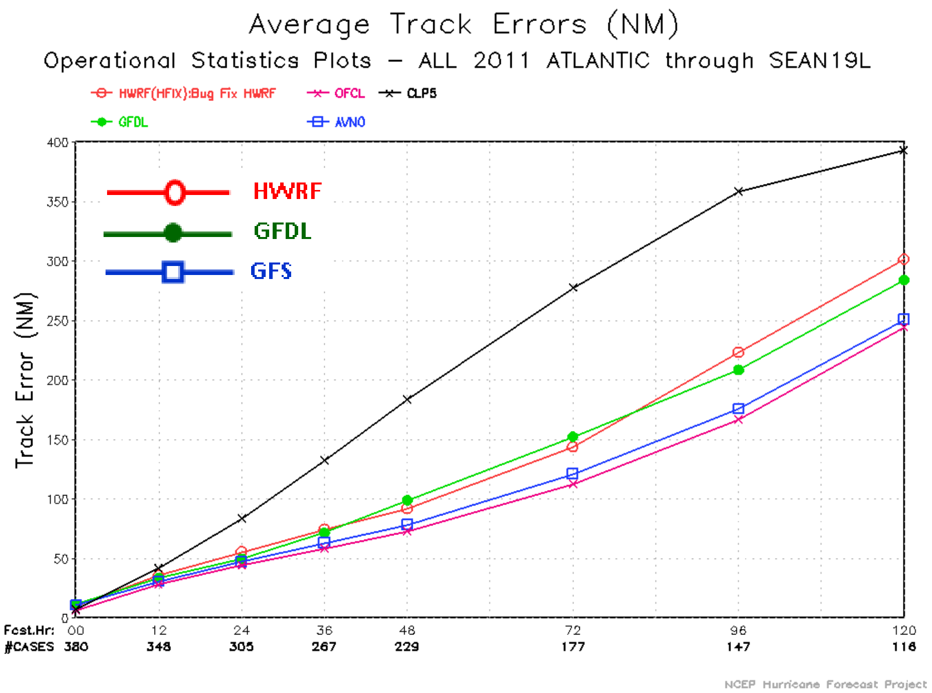
Impact of upgraded vortex initialization scheme in 2011 HWRF

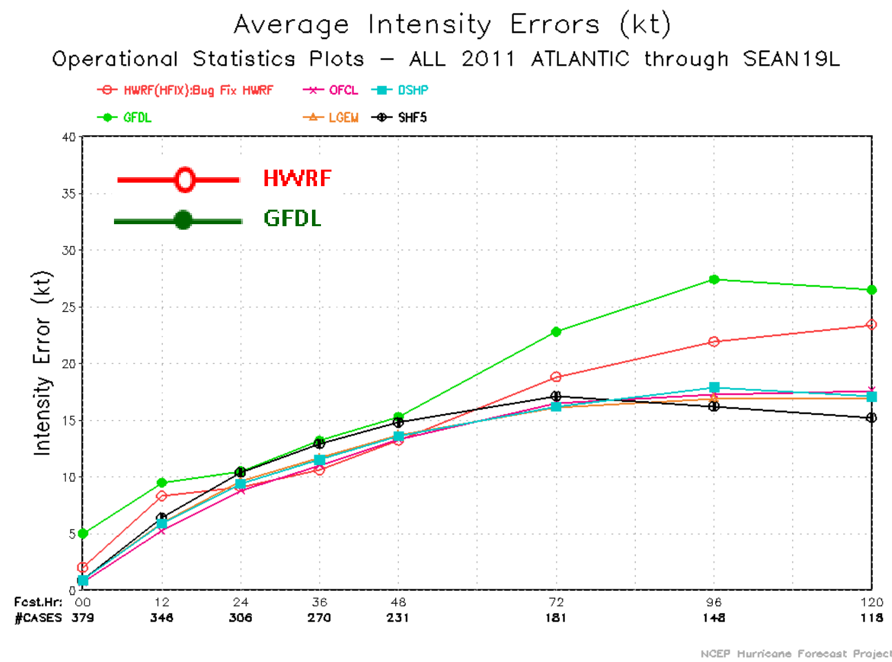


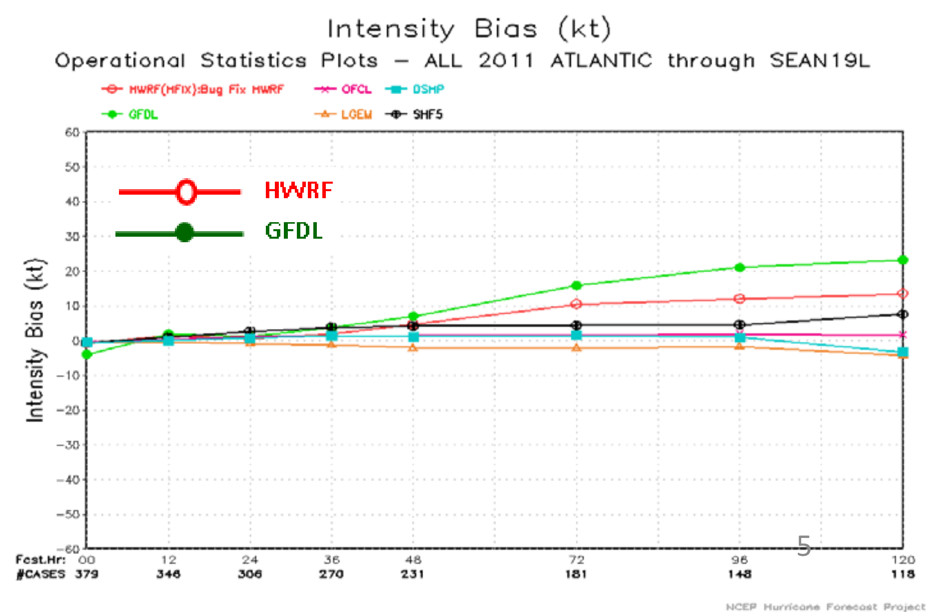
1. Vortex size correction
   - Instead of matching only RMW but also matching outer radii such as ROCI or R34kt
2. Less use of the composite storms for weak storms
   - Preventing the rapid spin-up of weak storms
3. Matching the maximum 10m wind speed but not forcing the minimum SLP
   - With more balanced vortex, rapid spin-down of strong storm is much reduced

*** Modified initialization significantly improved the intensity skill of HWRF model (especially 0-48hr)**

Performance of operational HWRF in 2011 Atlantic Season



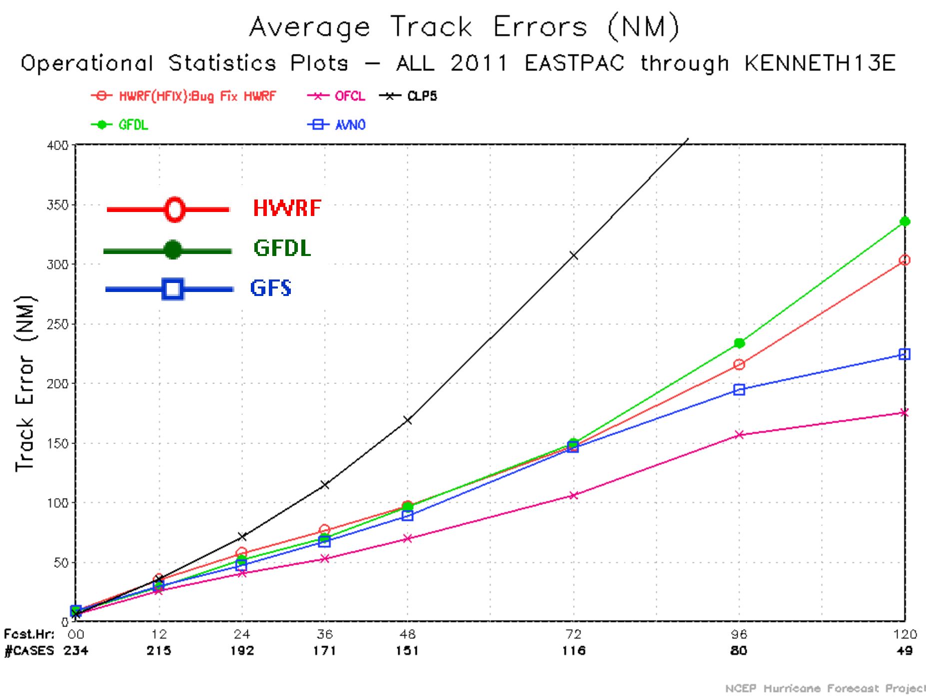


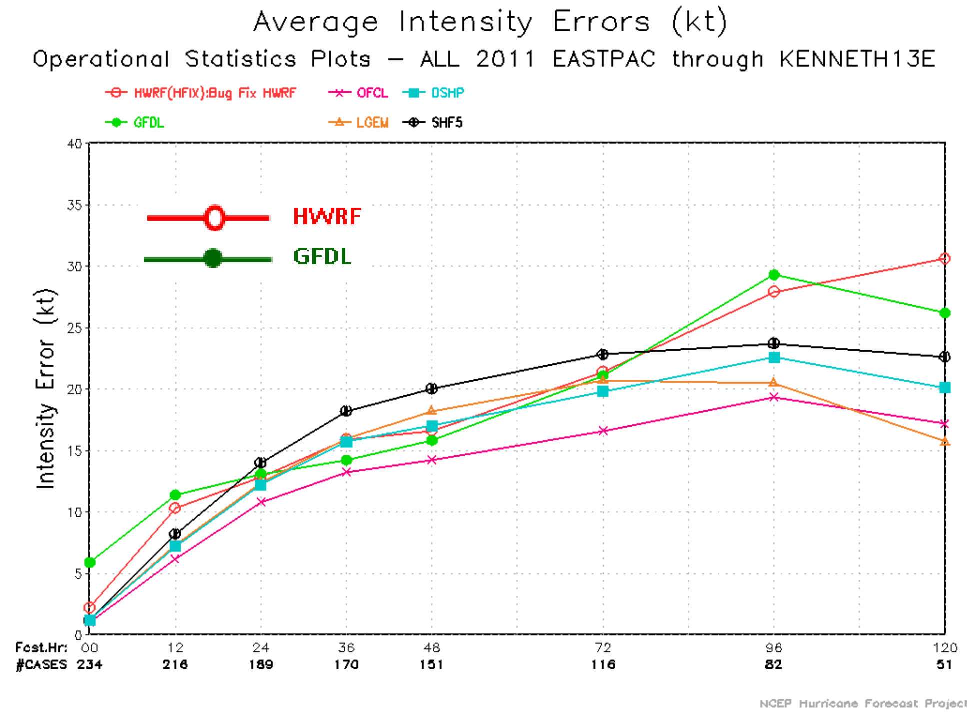


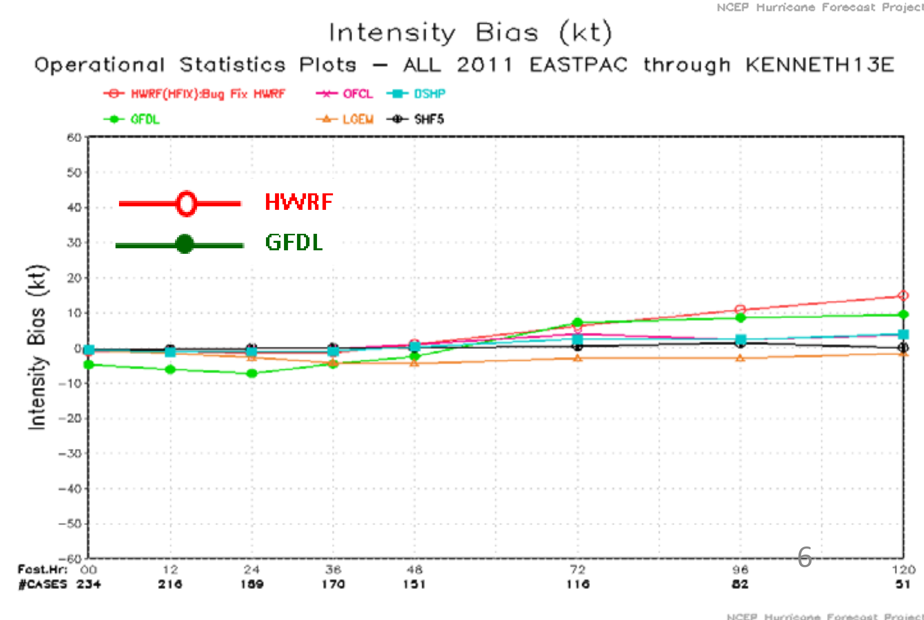
HWRF and GFDL track forecasts less skillful than GFS

HWRF exhibited much improved intensity forecast skill compared to GFDL at all forecast times (10-20% improvement)

Performance of operational HWRF in 2011 Eastern Pacific Season





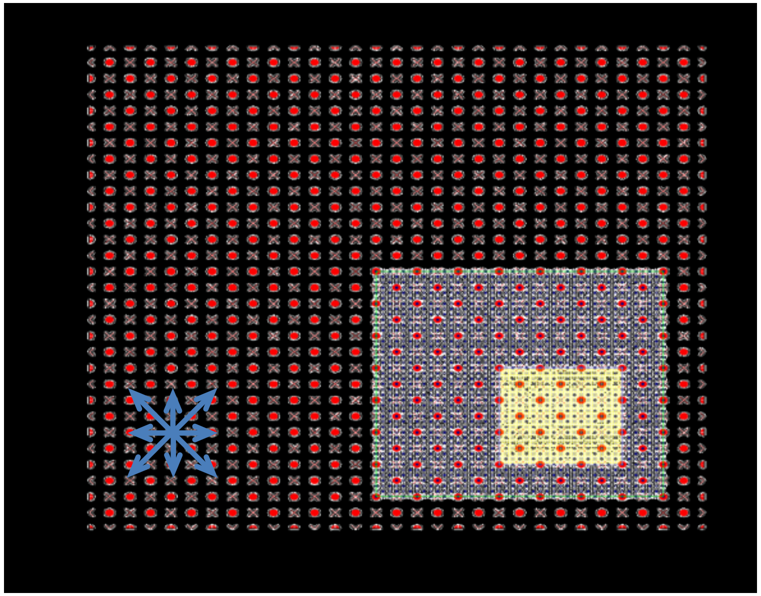


HWRF and GFDL track errors comparable to GFS out to 72-hr fcst.

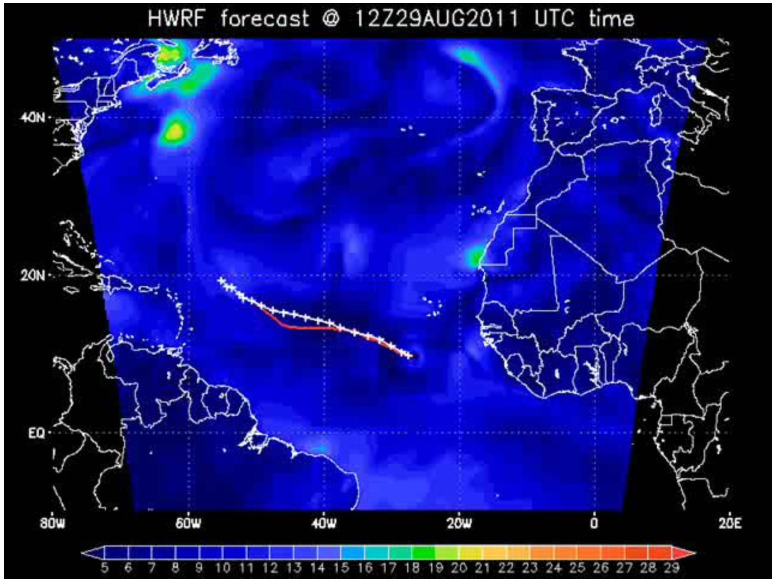
HWRF and GFDL have comparable intensity forecast skill except at 120-hr fcst.

Towards High-Resolution HWRF implementation in FY2012

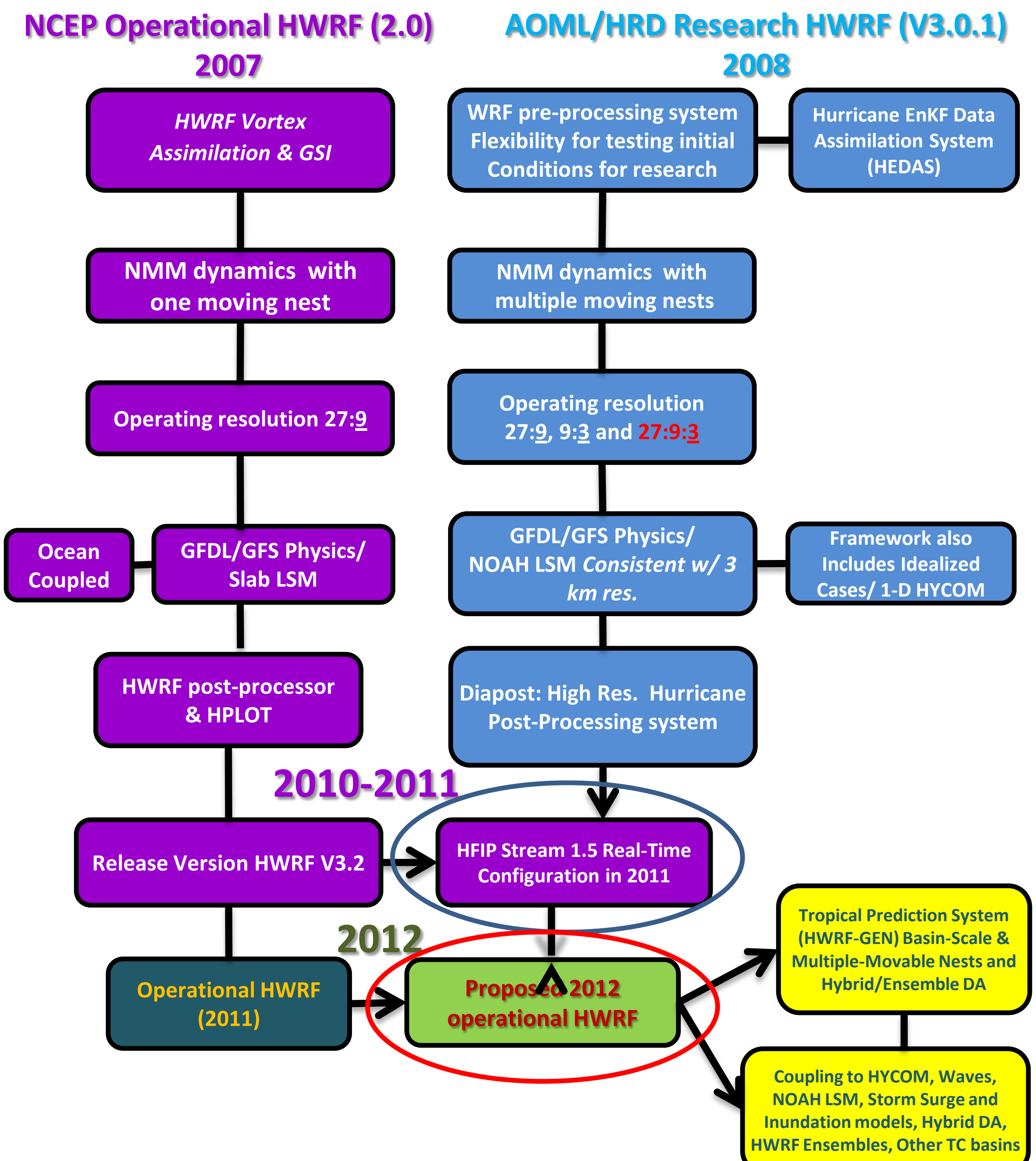
- A major step towards improving intensity forecast skill and address rapid intensity
- Three atmospheric telescoping nested domains:
  - 27km outer domain 75x75 degree
  - 9km intermediate nest ~11x10 degree
  - 3km inner-most nest ~6x5 degree
- New centroid based nest motion algorithm
- Coupled with Princeton Ocean Model (POM) in the Atlantic and Eastern Pacific (1-D)
- Modified HWRF vortex initialization
- Changes to HWRF physics appropriate for 3 km with explicit convection in the third nest
- Upgraded tracker and new high-temporal resolution (every time step) track and intensity product
- New SSMI/S synthetic microwave imagery
- Extensive testing and evaluation starting with Stream 1.5 demo during 2011 season
- Six different configurations evaluated using HFIP computing resources on Jet (~10,000 runs)



• Mass points × Wind points



Integrated developmental path and unified code management

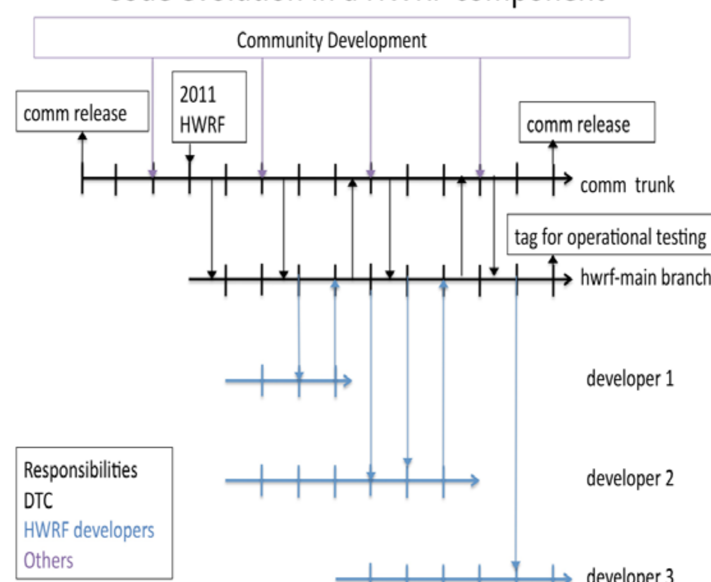


High Resolution Research version of the HWRF system geared to compliment operations

- Improved resolution and improved understanding of forecast at about 3 km resolution
- Incorporate appropriate representation of physical processes in tropics for 3 km resolution based on observations
- Code management and community support through unified repository supported by DTC

DTC Supported Subversion based code management

Code evolution in a HWRF component



Operational Challenges:

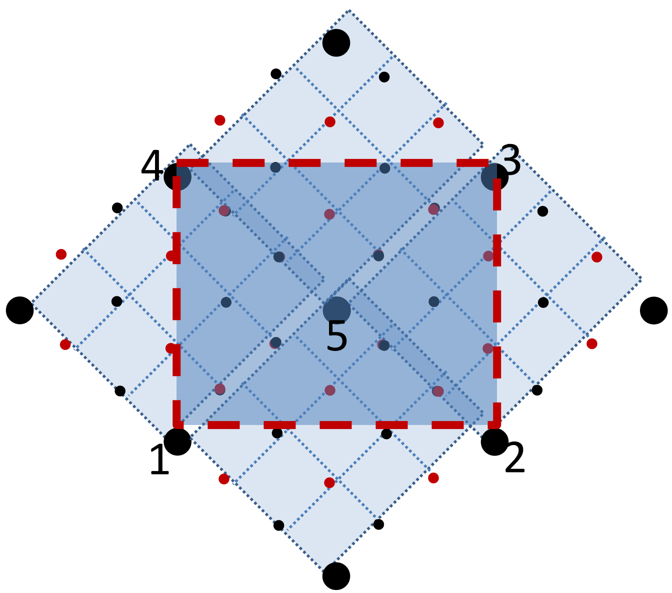
1. Code Optimization for Triple Nested HWRF System

- The bottleneck for the system to be implemented into operation is the run time: it took about 4 hours 15 minutes for 126 hours forecast on NCEP IBM CCS (5 sec. time step at 3 km resolution)
- Several possible ways explored to further reduce the model run time:
  - Extensive profiling of MPI usage – led to changes in NEST_TERRAIN code, *run time reduced by 100 minutes*
  - IO Servers configuration (identical results), *15 minutes;*
  - Adding one more node, *20 minutes;*
  - decreased physics call frequency, *30 minutes;*
  - separate buffering of stdout and stderr; *10 minutes*
- End Result: Triple Nested 3km HWRF system can run in about 80 minutes with four nodes (just 20 minutes more than current 9km operational HWRF)

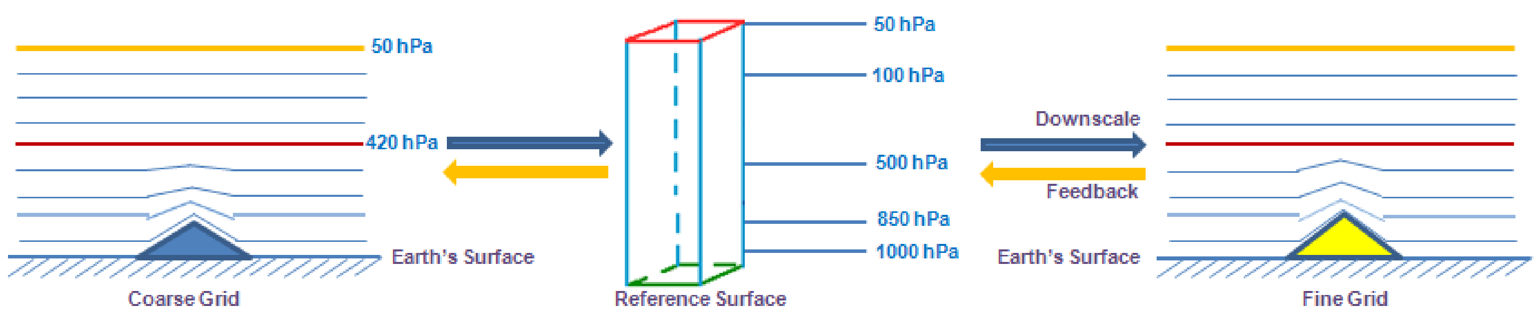
2. Extending Vortex Initialization for triple nested HWRF

- New subroutine for the E-grid to E-grid interpolation
- Changes in 10m wind calculation consistent with model surface physics formulation
- Localized vertical interpolation and improved vertical mass adjustment
- New 30°x30° high-resolution (3 km) analysis domain with improved vortex size and structure correction
- Modified composite storm consistent with high-resolution model configuration
- Separate composite storm for medium and shallow storms
- Upgrade GSI in HWRF to latest community version V3.0

New and improved E-E interpolation algorithm

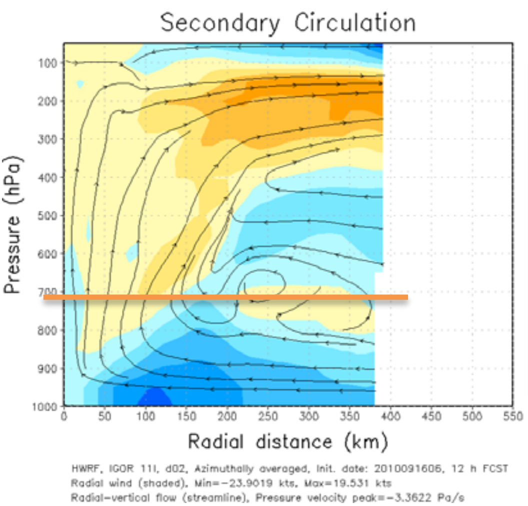


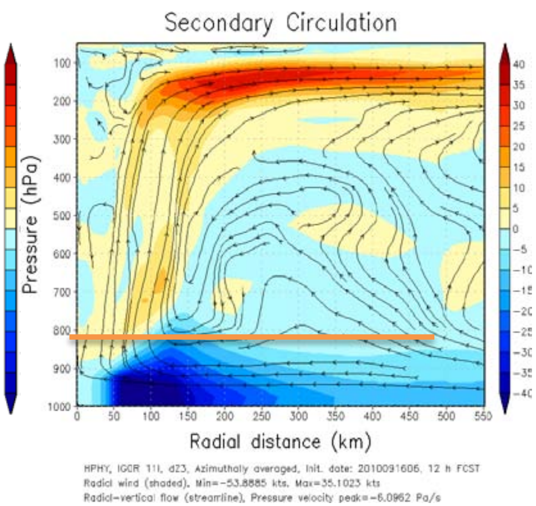
Improved vertical interpolation and mass adjustment

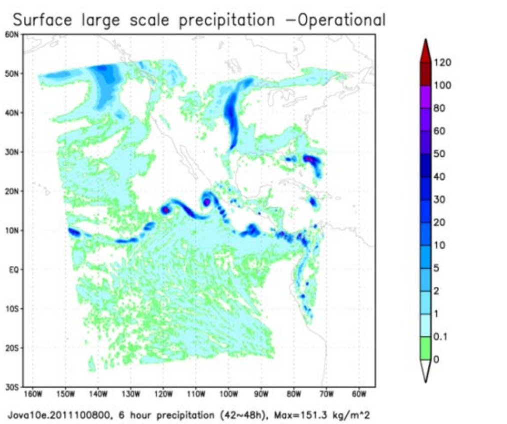


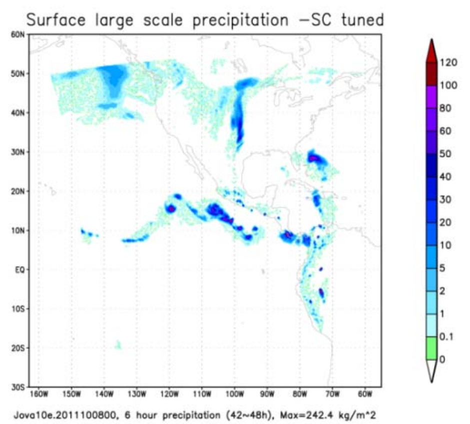
3. Physics upgrades suitable for higher resolution grid

- **Upgrades to GFS PBL - vertical diffusivity reduced by 50%**
- **Surface physics based on HWRF 2010 formulation**
- **Addition of Shallow Convection Parameterization**
- **No CP at 3km resolution**



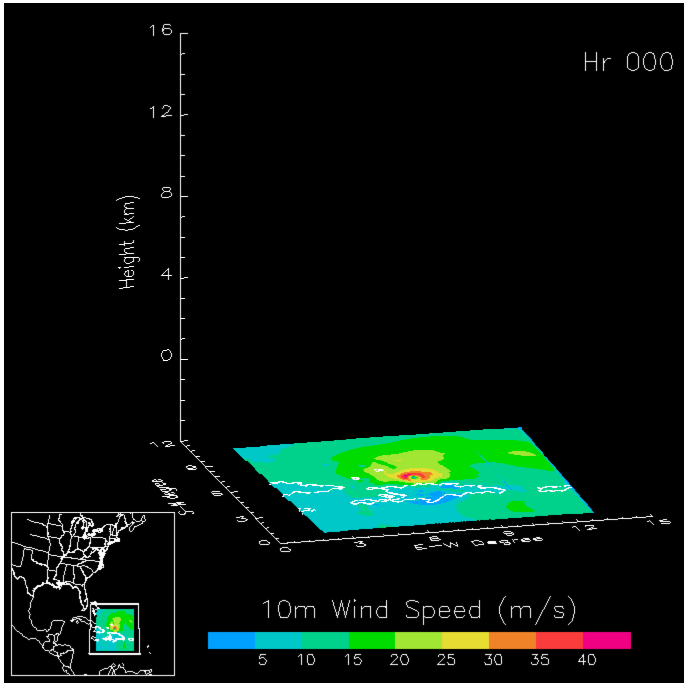






Upgrades to Ferrier Microphysics consistent with higher resolution

- **Increase max allowable ice concentration**
- **Increase NCW from 60 to 250 cm^{-3}**
- **Increase snow fall speeds for ice warmer than 0°C (realistic and consistent with Thomspon scheme)**



2010-2011 – Atlantic basin

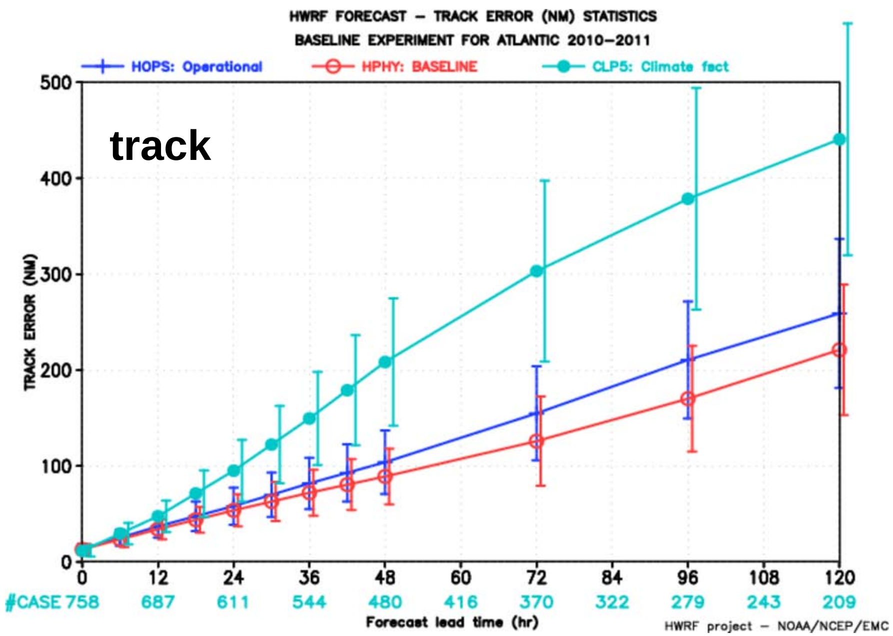


Table 1. Track improvement percentage w.r.t. HOPS (%)

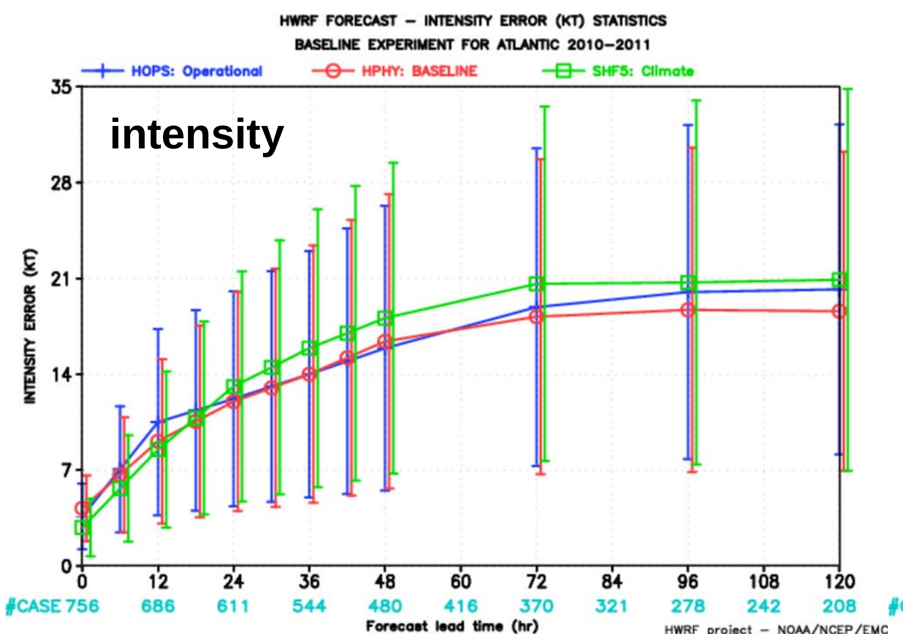
Time/	0	12	24	36	48	72	96	120
HPHY	**4**	**8**	**8**	**12**	**14**	**19**	**19**	**14**

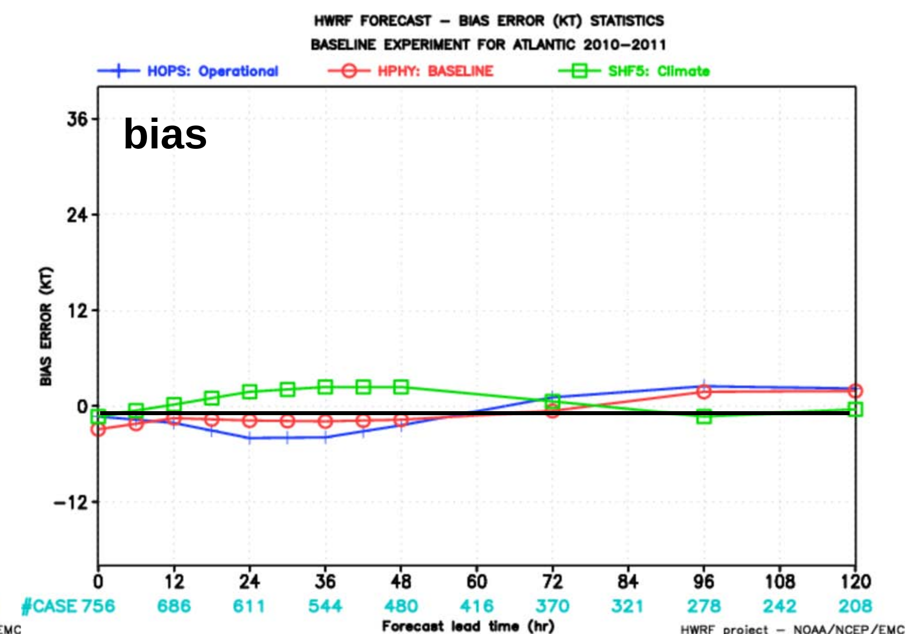
Table 2. Intensity improvement percentage w.r.t. HOPS (%)

Time/ exp	0	12	24	36	48	72	96	120
HPHY	**-5**	**14**	**1**	**0**	**3**	**4**	**7**	**9**

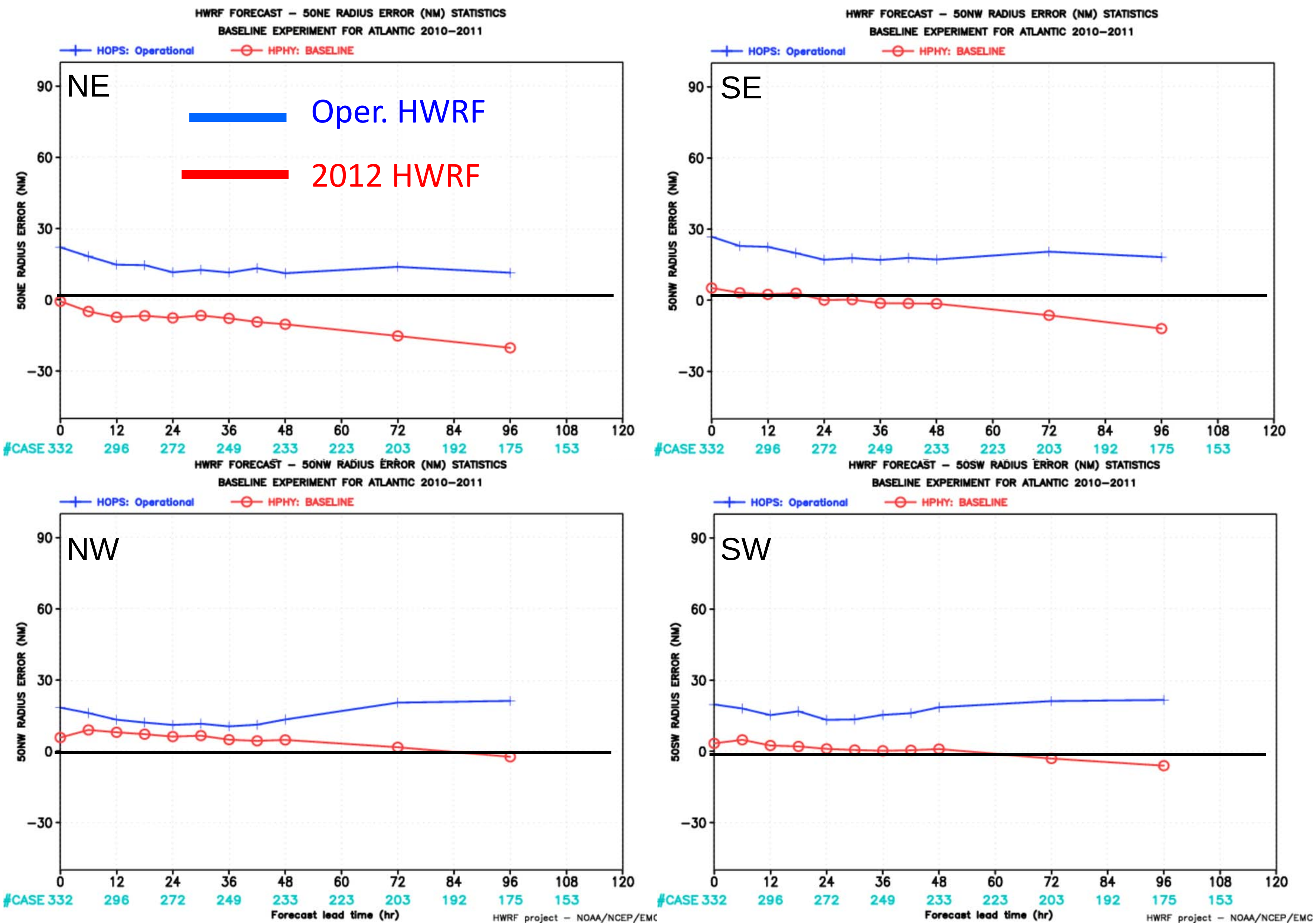
Oper. HWRF

2012 HWRF

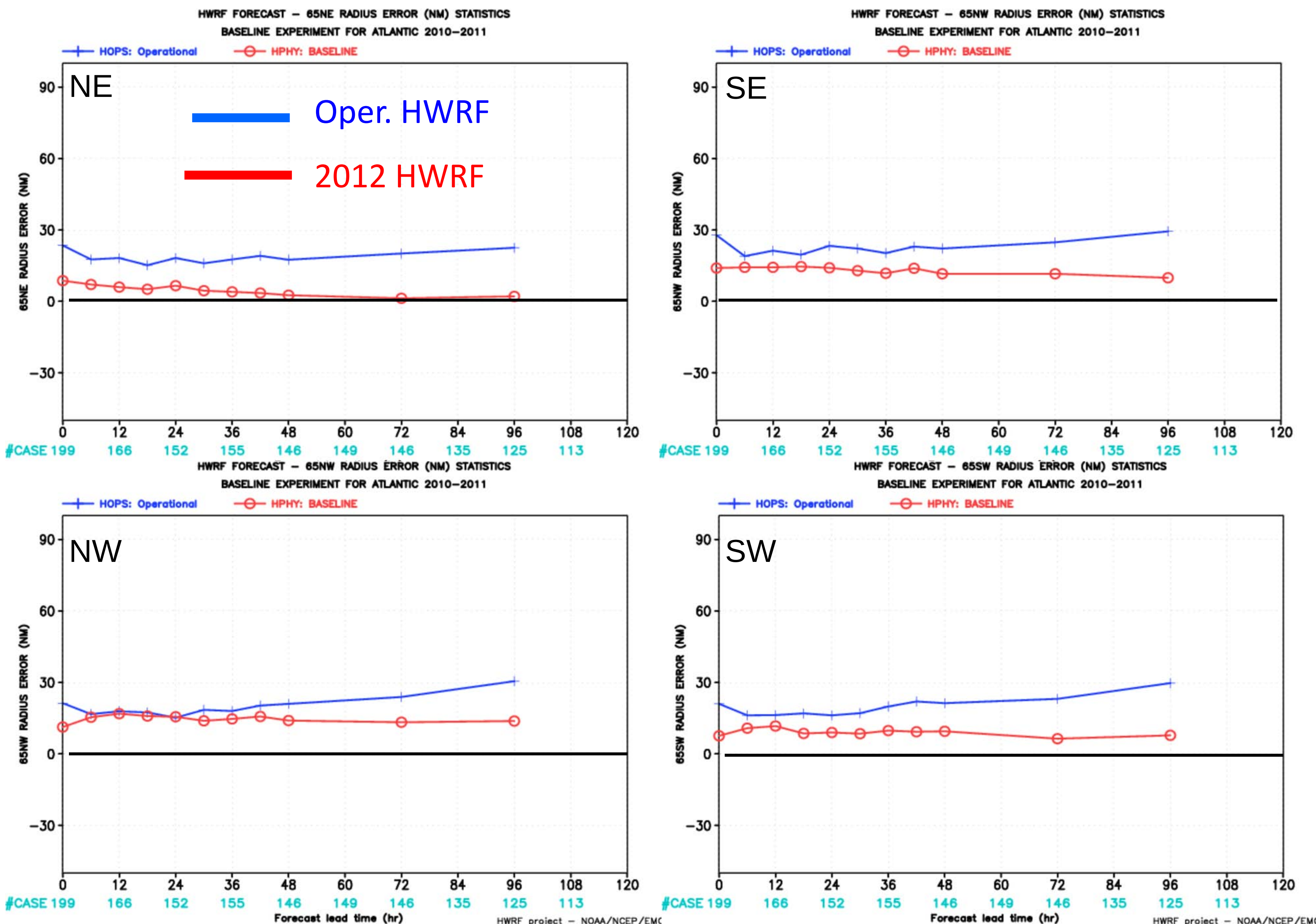




Atlantic: 50-kt Radii verification



Atlantic: 64-kt Radii verification



2010-2011 – Eastern Pacific basin

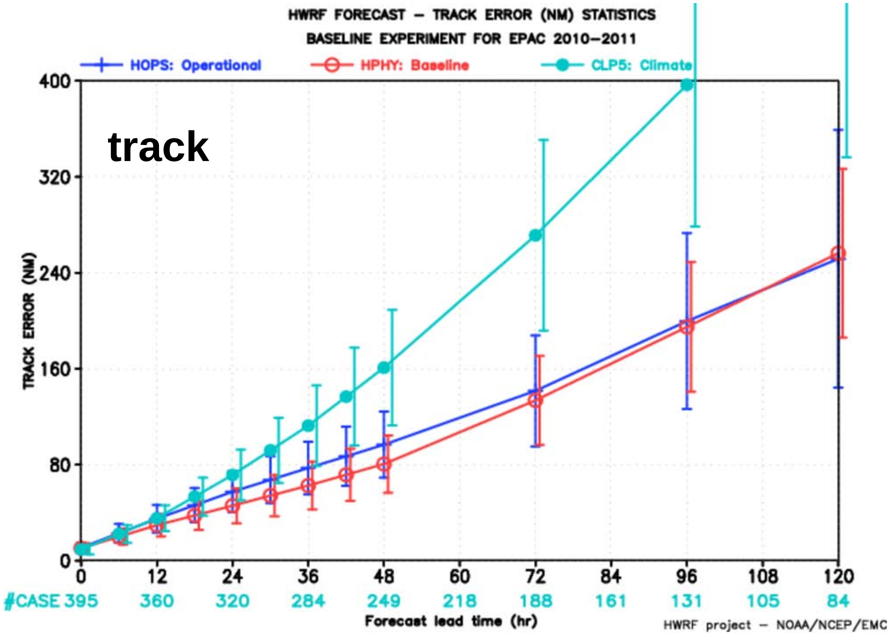


Table 1. Track improvement percentage w.r.t. HOPS (%)

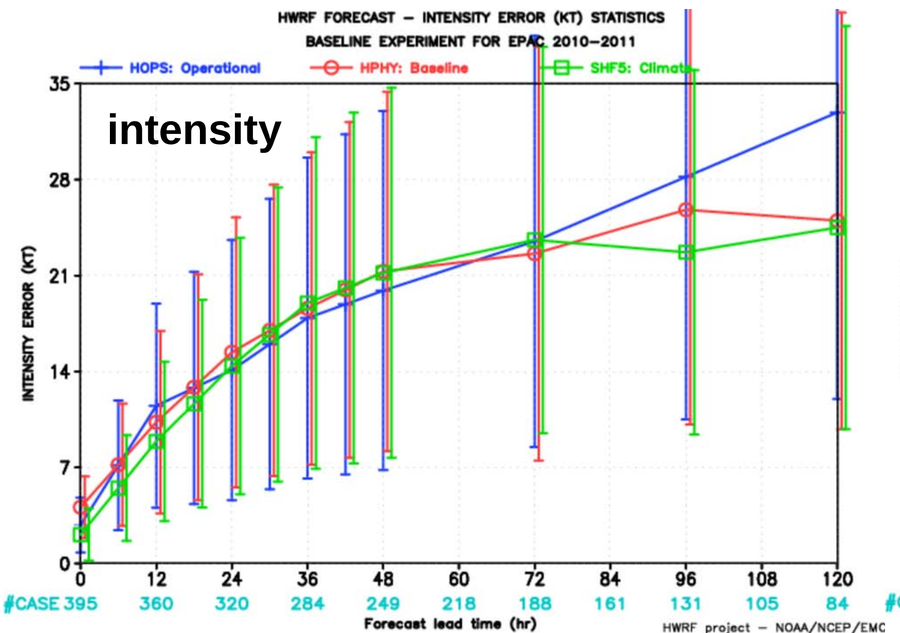
Time/	0	12	24	36	48	72	96	120
HPHY	**3**	**15**	**20**	**18**	**17**	**6**	**3**	**2**

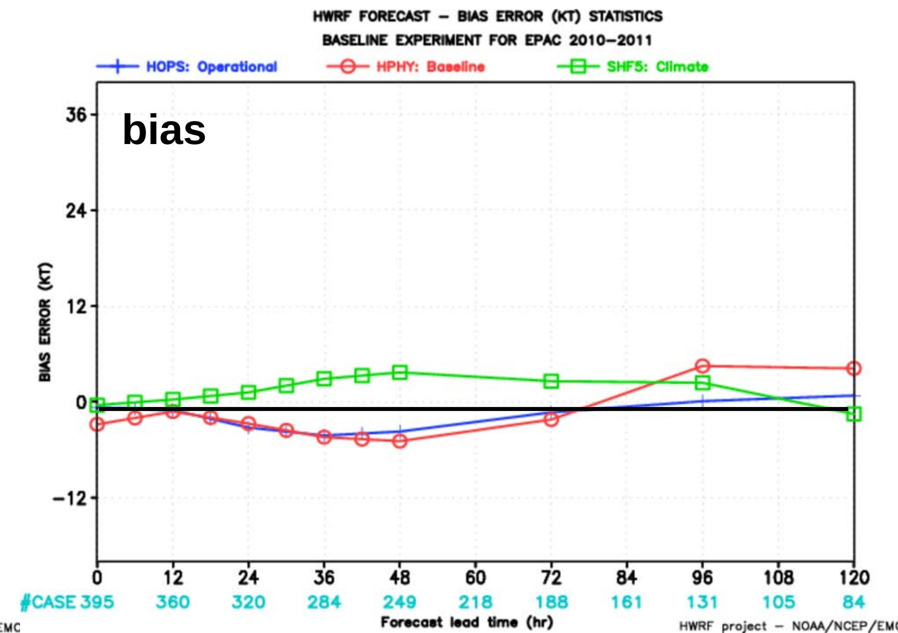
Table 2. Intensity improvement percentage w.r.t. HOPS (%)

Time/ exp	0	12	24	36	48	72	96	120
HB12	**-10**	**10**	**-10**	**-4**	**-8**	**4**	**9**	**22**

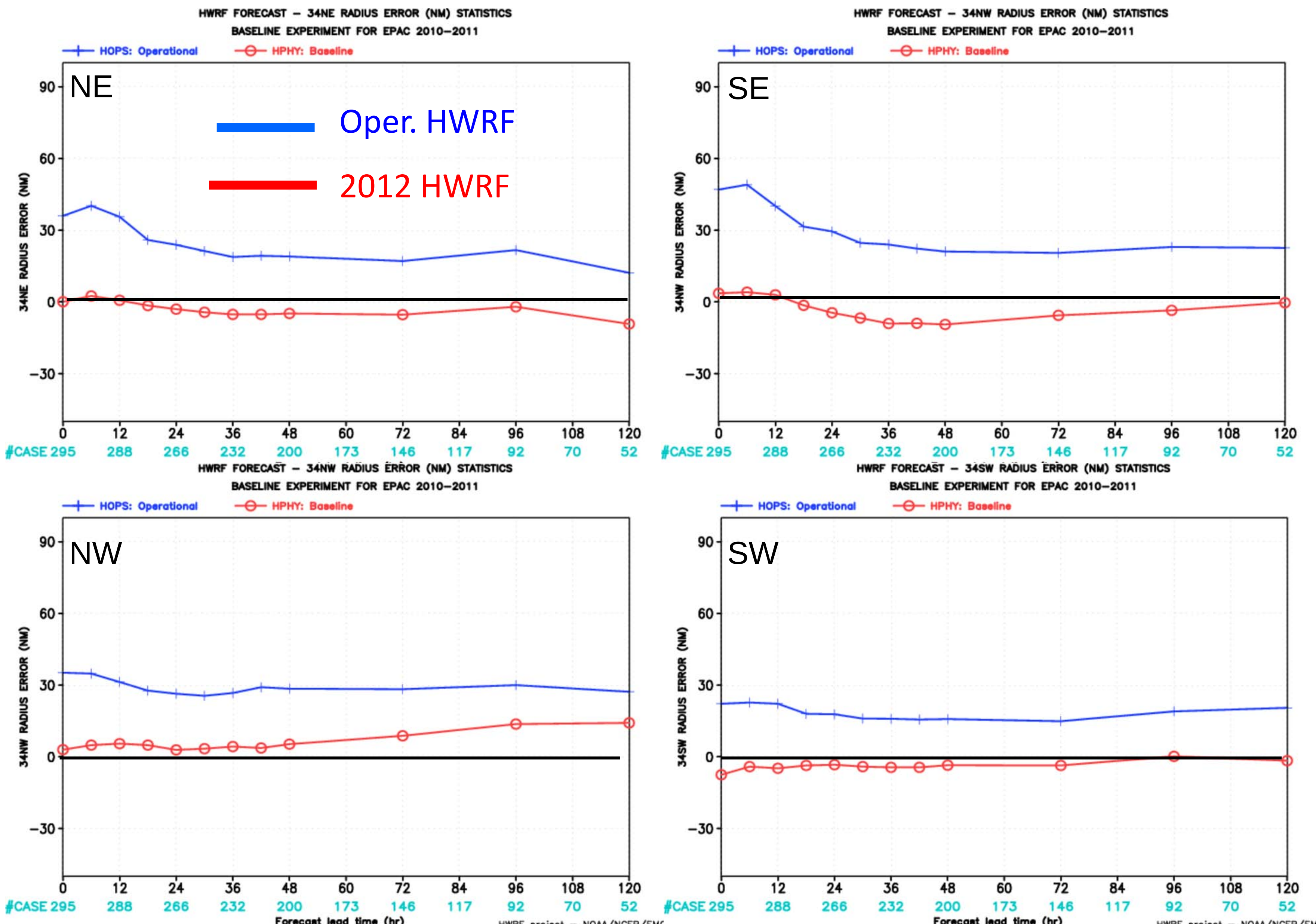
Oper. HWRF

2012 HWRF

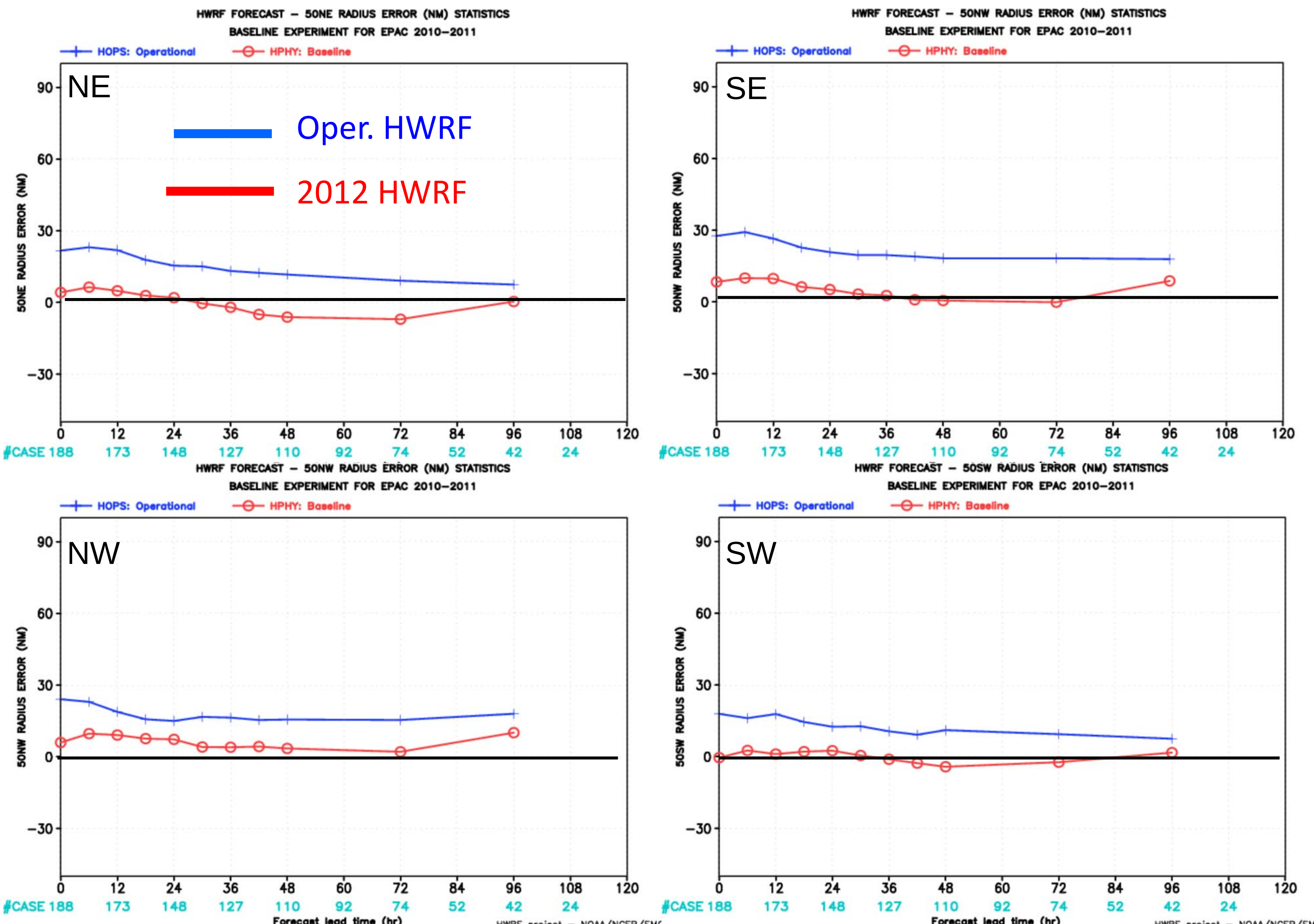




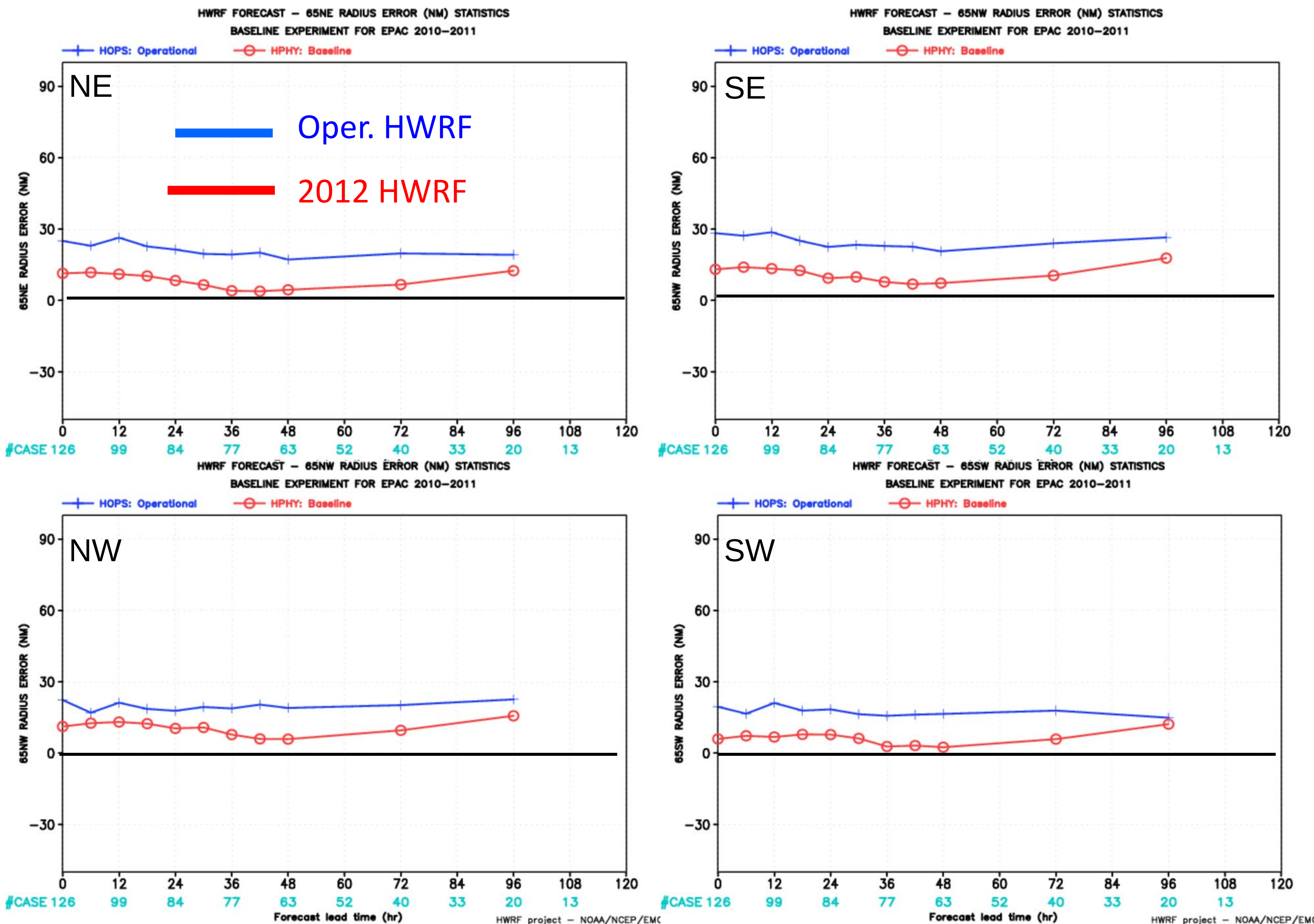
EPAC: 34-kt verification



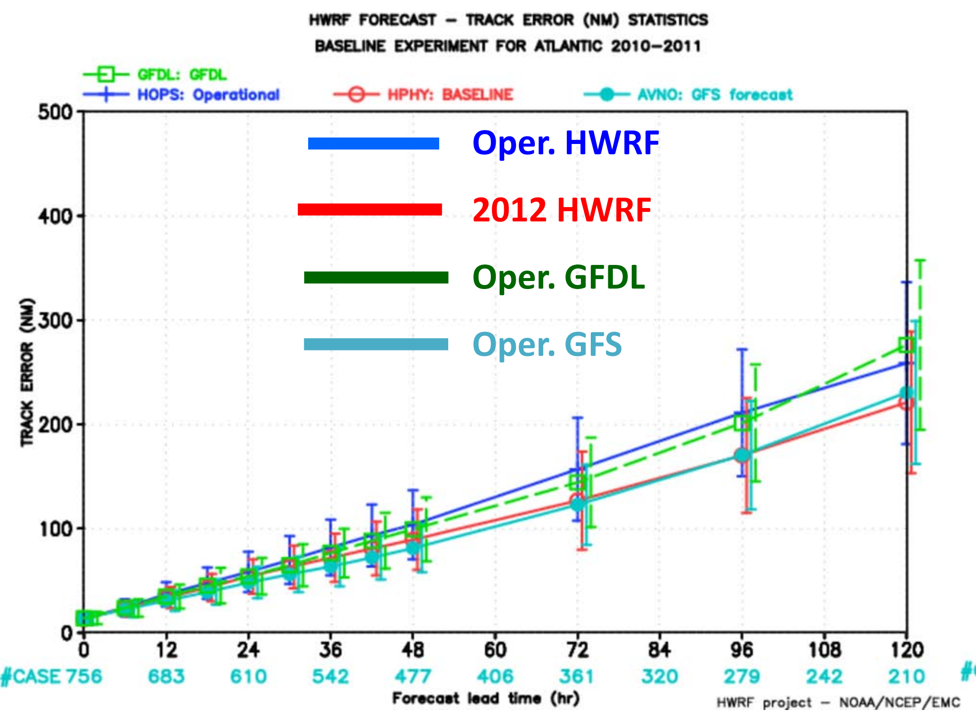
EPAC: 50-kt verification



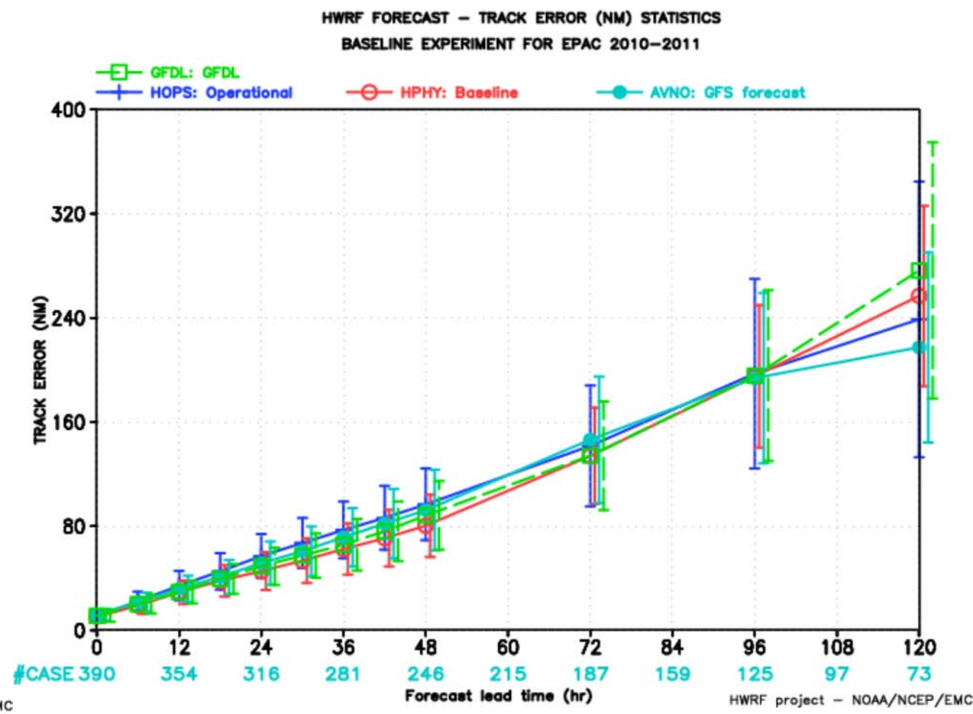
EPAC: 64-kt verification



Atlantic basin



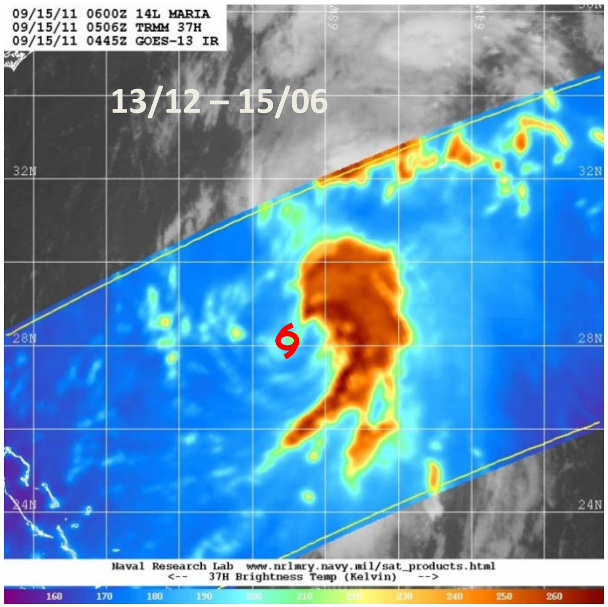
EPAC basin



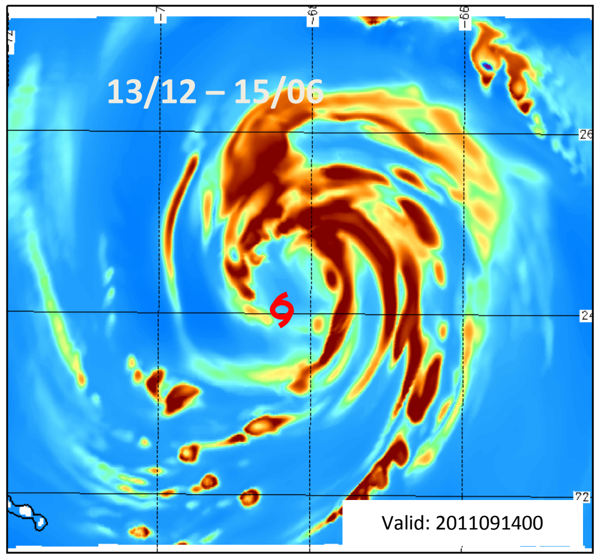
3km HWRF Track Forecast Skill Comparable to Operational GFS for 2010-2011 seasons

New experimental products from operational HWRF

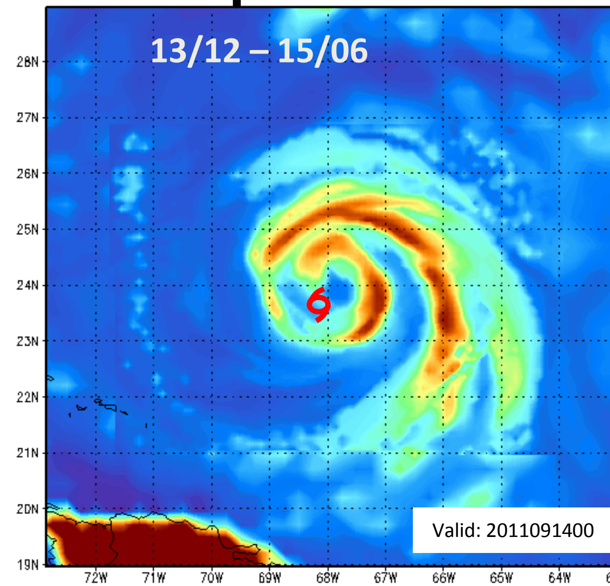
- **Synthetic satellite imagery using a uniform RTM:**
  - GOES-13 and GOES-11 Channel 2,3,4,6
  - Microwave 37 GHz and 85 GHz Vertical and Horizontal Polarization (replace AMSRE with SSM/I F17/F18/F20)



Simulated 3 km



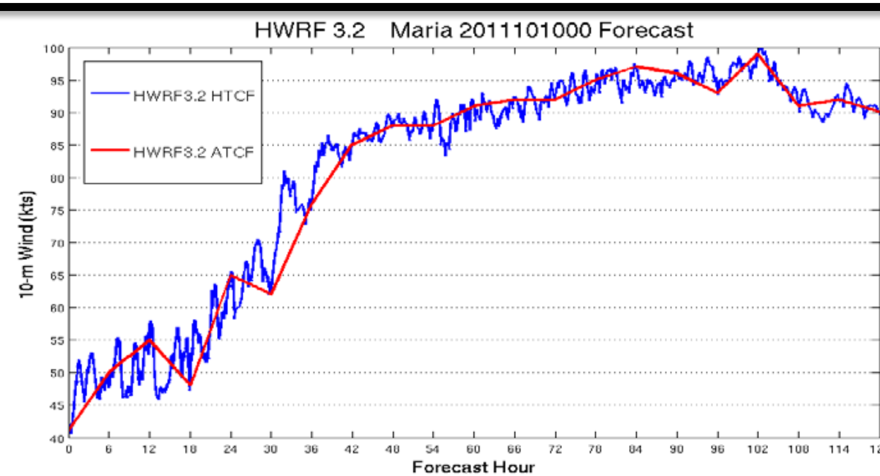
Simulated 9 km operational

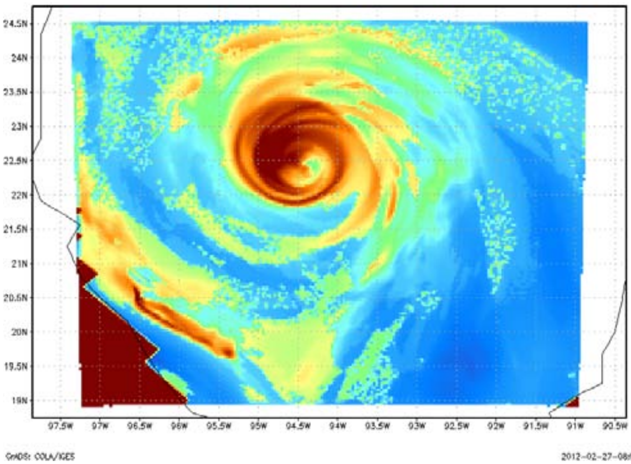


High Temporal Resolution HWRF ATCF-style output at every time step (5 seconds) at 3km resolution

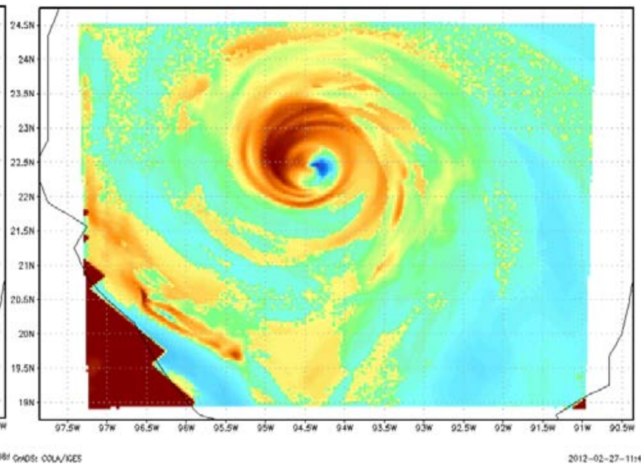
Are 6-hr outputs representative of the actual model forecast?

What is happening during development and RI within the model?

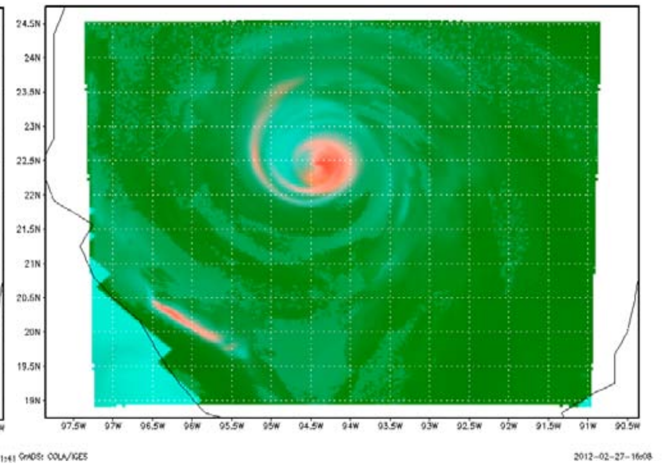




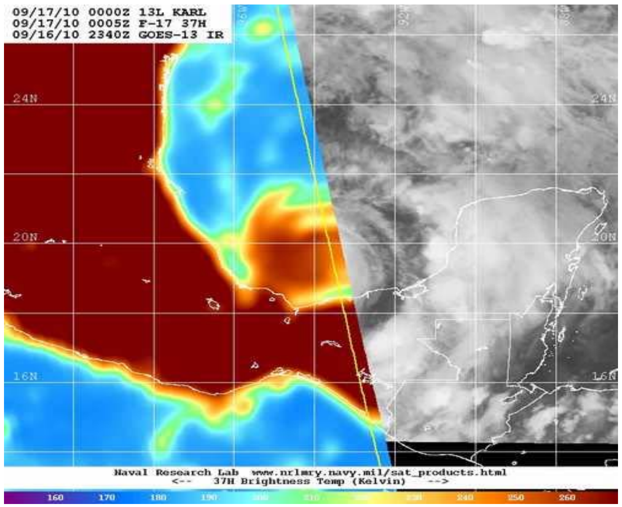
SSMI/S 37 GHz-H

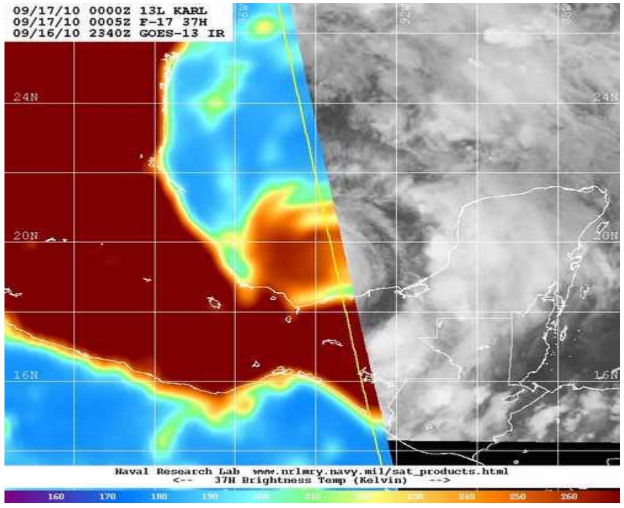


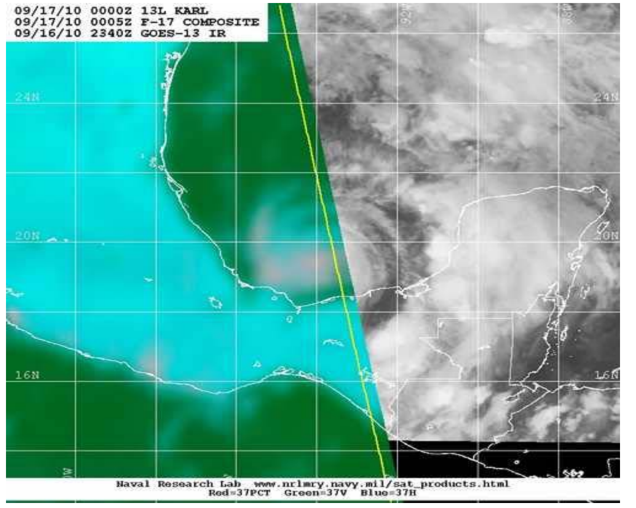
SSMI/S 37 GHz-V



SSMI/S 37 GHz-Color Composite

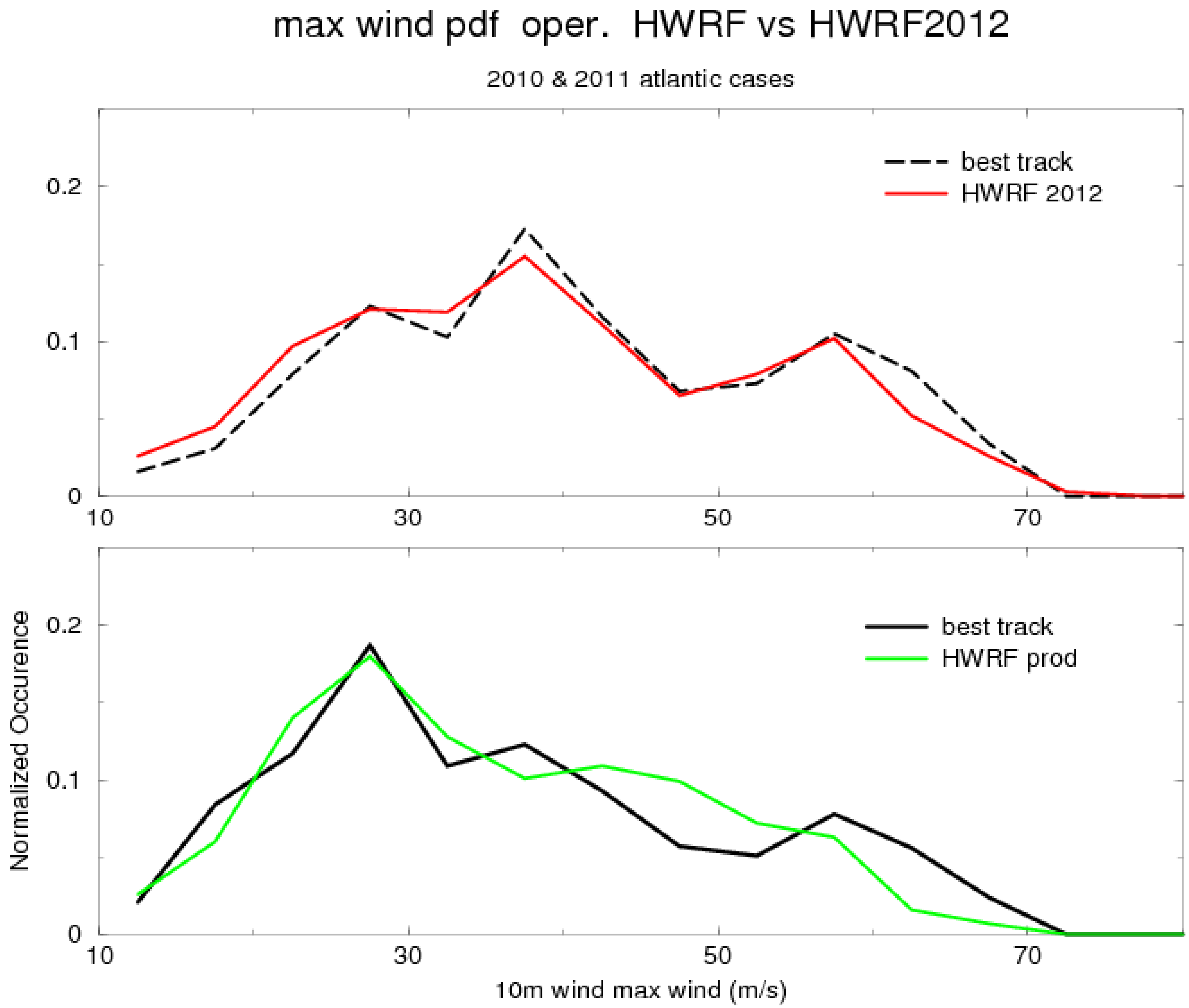






HWRF Generated SSM/I S Microwave Imagery (new operational product)

-- Courtesy: Dave Zelinsky, NHC

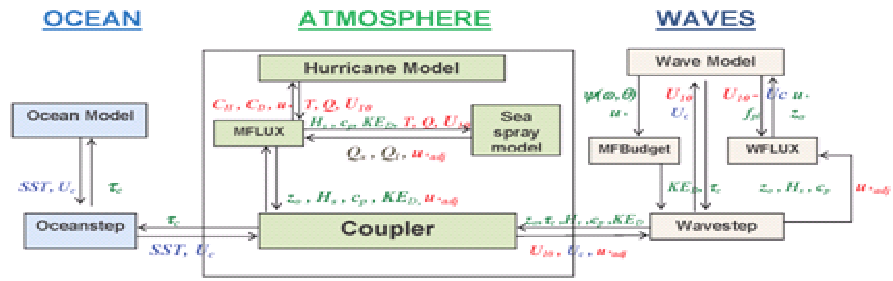


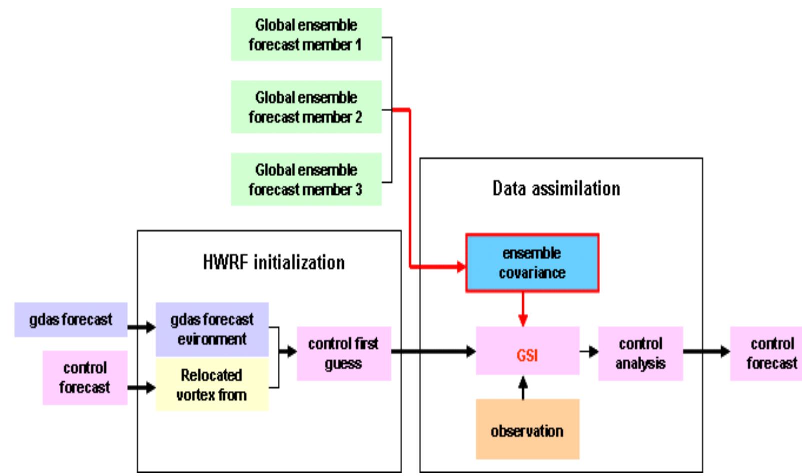
max wind pdf oper. HWRF vs HWRF2012
2010 & 2011 atlantic cases
best track
HWRF 2012
0.2
0.1
0
10
30
50
70
best track
HWRF prod
Normalized Occurence
0.2
0.1
0
10
30
50
70
10m wind max wind (m/s)

FY2012 and beyond…

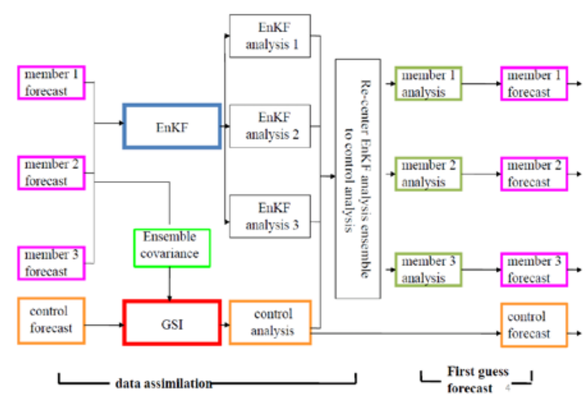
- HWRF Model (EMC, HRD)
  - Multiple moving nests within a basin scale domain
  - Improved multi-scale interactions
- HWRF Physics (URI, GFDL, ESRL,HRD)
  - Surface fluxes, sea spray and wave coupling
  - Physics for high-resolution (convection, micro physics, PBL, LSM)
- HWRF Diagnostics (HFIP, EMC, NHC, FSU, CIRA, HRD, UMBC/UMD)
  - Hurricane model diagnostics, evaluation and verification
  - Develop a common and comprehensive diagnostics framework and tools to integrate model output with available observations for verification
  - Enhanced real-time product display and navigation
- HWRF Ensembles
  - Large Scale Flow, Structure and Physics Perturbations;
  - EnKF based perturbations in support of DA
- Hybrid EnKF-GSI Data Assimilation for HWRF
  - Real-time transmission of the P3 TDR data flow from aircraft to NCO/TOC/AOC and assimilation using advanced GSI and improved vortex initialization (model consistent 3-D balanced vortex)
  - Ensemble data assimilation - hybrid EnKF (Planned Demo for 2012 hurricane season (HFIP Stream 2))
  - Improved use of satellite radiance datasets, Model vertical levels and top consistent with NAM

Three-way Atmosphere-Ocean-Wave Coupled System



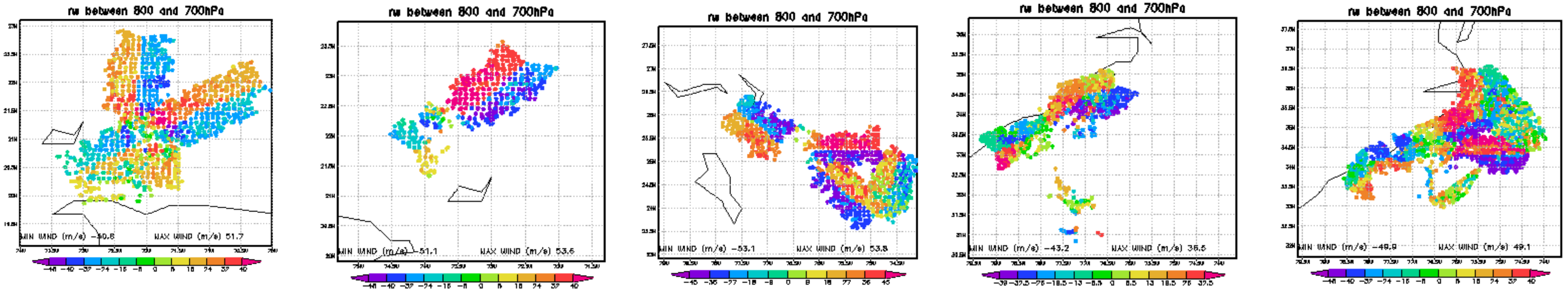


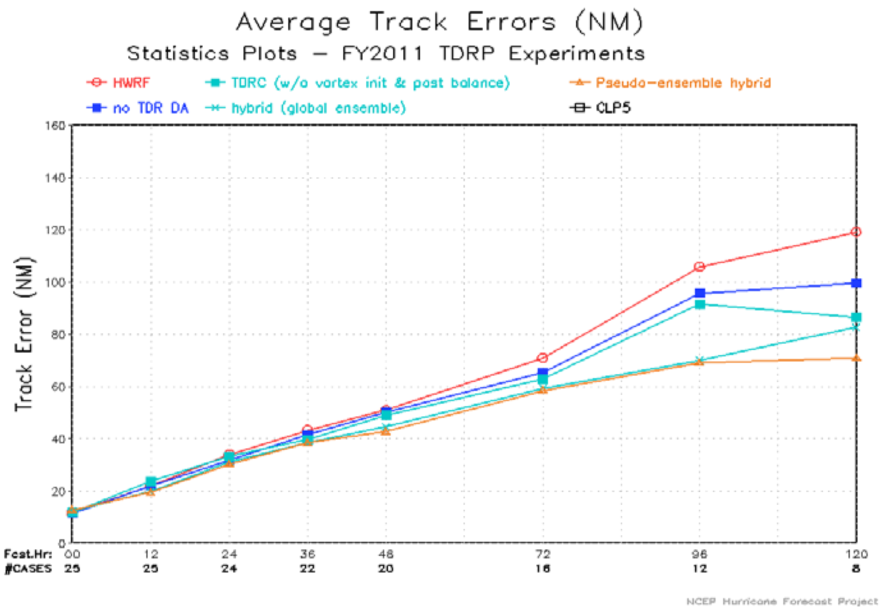
Hybrid EnKF-GSI DA system: 2 way coupling

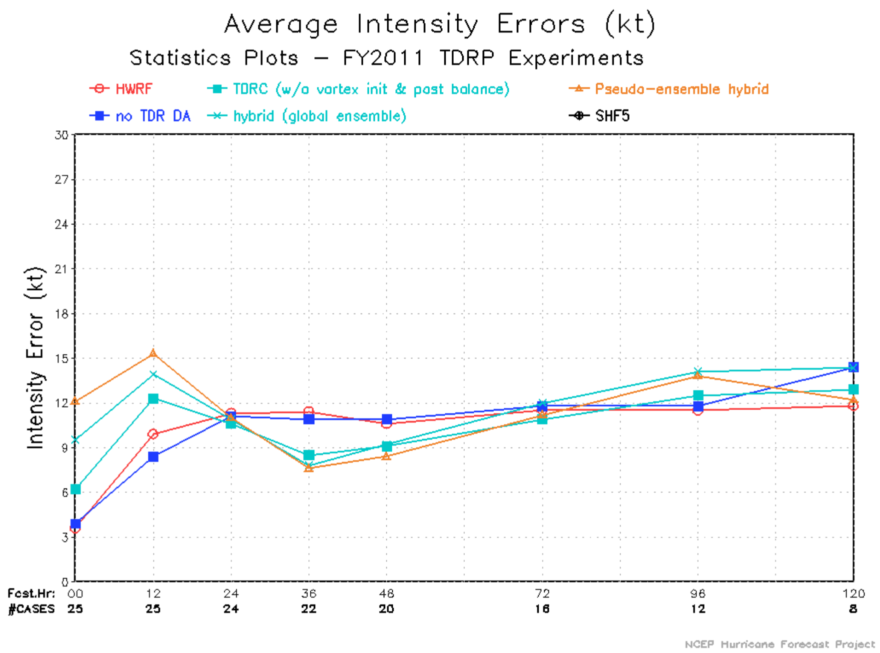


Real-Time TDR radial velocity data assimilated in inner analysis domain

2011.08.24 00Z 2011.08.24 12Z 2011.08.25 12Z 2011.08.27 00Z 2011.08.27 12Z





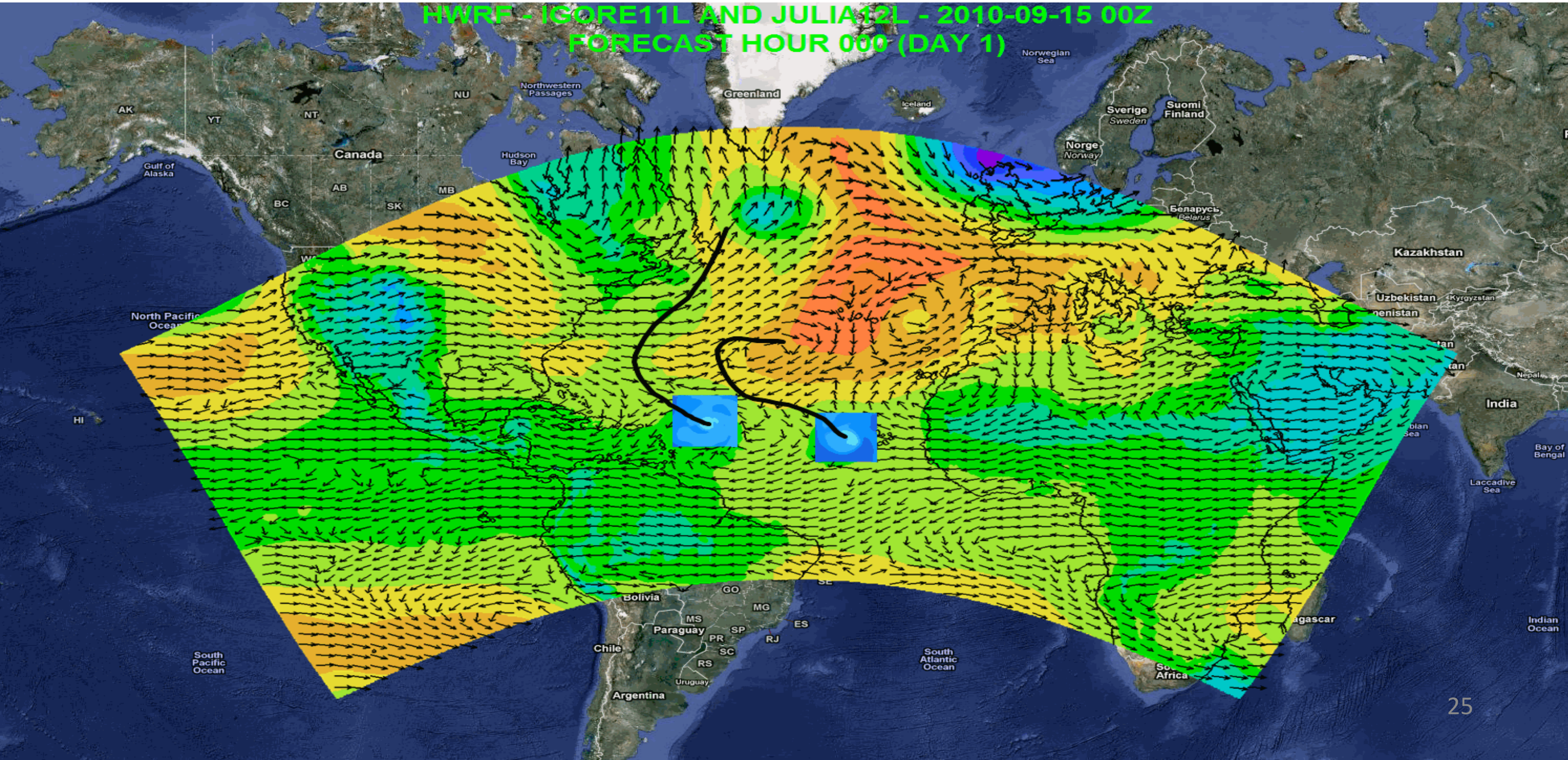


Positive improvements in track and intensity forecast skill using TDR data

HWRF Domain With Multiple Moving Nests

- Basin scale domain
- 7 days forecast
- SDA and cycling

- Regional ensembles/products
- Daily Tropical Outlook/genesis
- Computational Efficiency (27:9;about 2 h; 168 CPUs)



Advancing the HWRF System FY2012 & Beyond

	2012	2013	2014*	2015*	2016*
Resolution/ Infrastructure	Triple nested HWRF (27/9/3 km)	Increased vertical resolution, higher model top	community R2O efforts (HFIP)	Upgrades to WRF infrastructure, Multiple moving domains, NEMS/ESMF/NMM-B, Other oceanic basins	
Physics	PBL, Shallow Convection & Microphysics	Microphysics, Radiation, Surface Physics, Coupling to Waves and Land Surface, Physics for high-resolution			
DA/ Vortex Initialization	Storm size correction, dynamic mass-wind consistency	Inner core DA (Doppler Radar, satellite)	Hybrid-EnKF DA, advanced vortex relocation procedure, improved GSI		
Ocean	HYCOM Coupling	Improved ocean data assimilation, physics and resolution, unified coupled system for ATL & EPAC			
Waves	One-way Wave Coupling		Two-way wave coupling, multi-grid surf zone physics, effects of sea spray		
Diagnostics and Product Development		HWRF Ensembles, Coupling to Hydrological/ Surge/ Inundation models, diagnostics, product development			

Ongoing Work	2012 upgrades	Planned developments	*Computer upgrade

Real-time and pre-implementation T&E HWRF products:

http://www.emc.ncep.noaa.gov/gc_wmb/vxt/index.html

Thanks for your attention

Questions?

Acknowledgements:

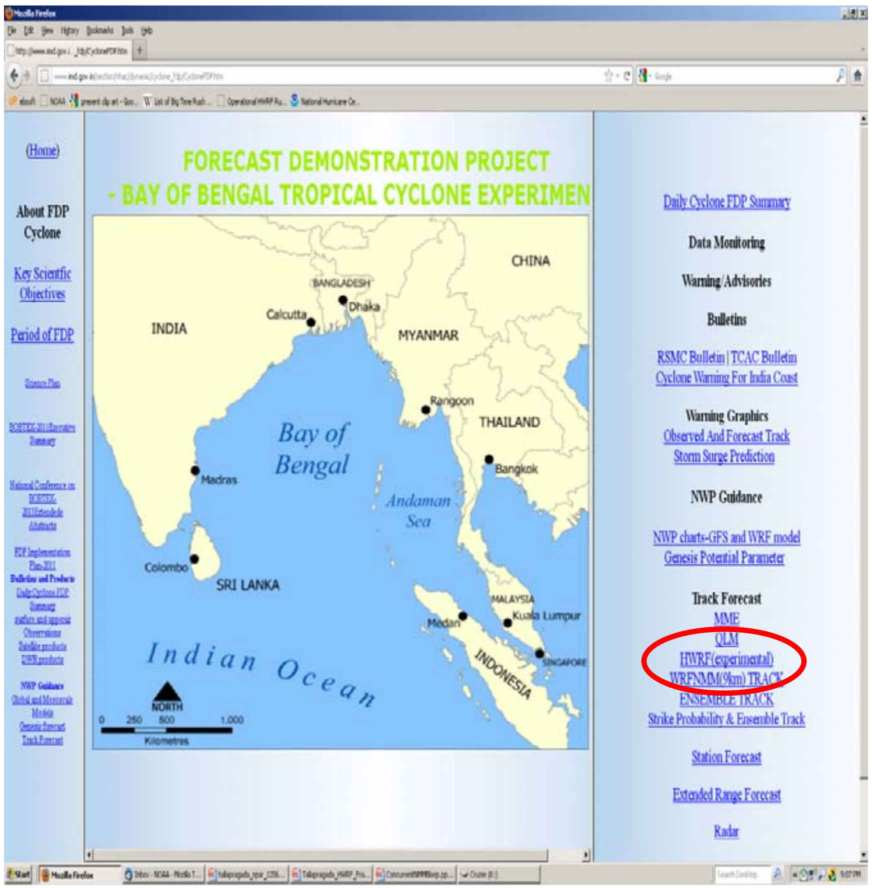
HWRF team at EMC, HRD and NHC

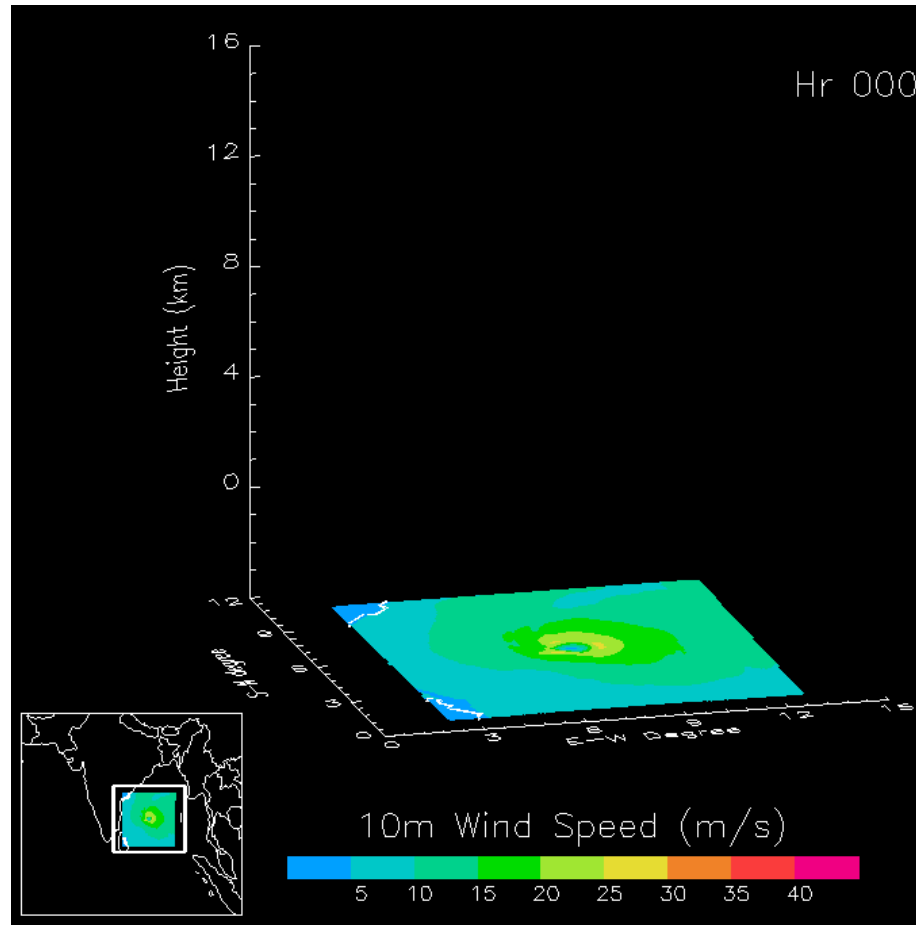
EMC and HFIP Management

Collaborations with NHC, DTC, HRD, GFDL, URI, CIRA and other HFIP partners

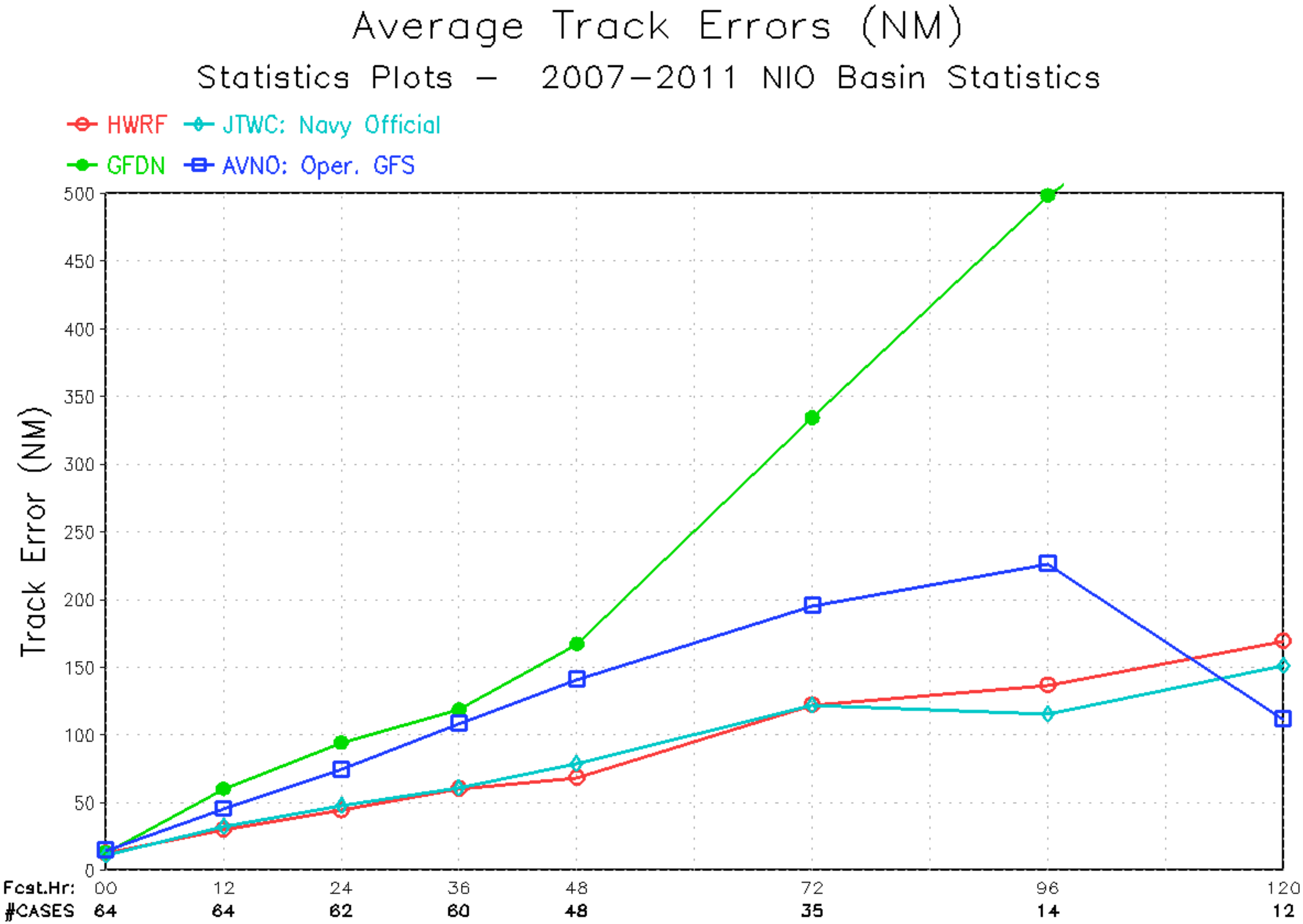
Expanding the scope and applications of HWRF for world oceanic basins

Operational implementation of HWRF in India
http://www.imd.gov.in/section/nhac/dynamic/cyclone_fdp/CycloneFDP.htm

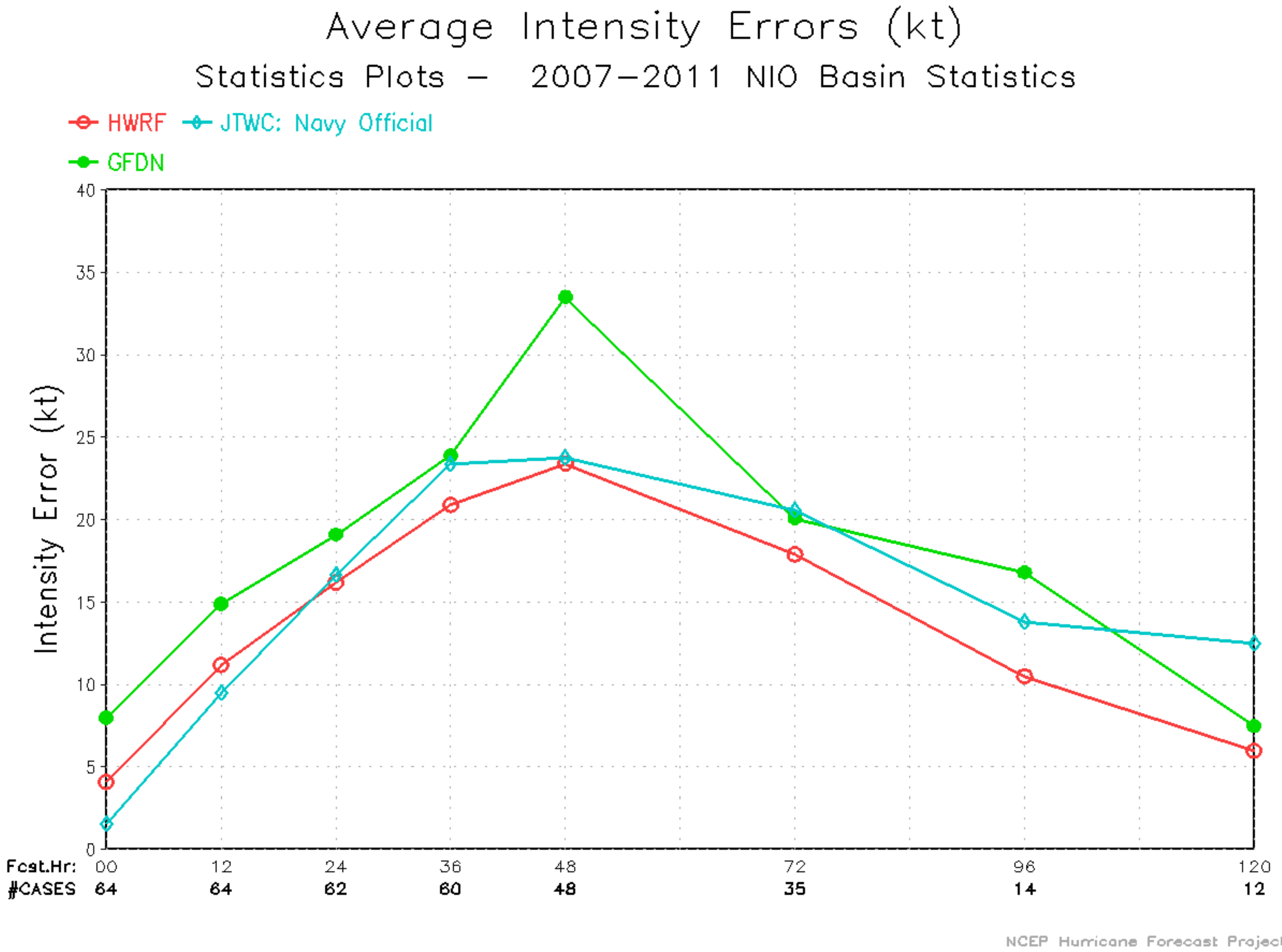


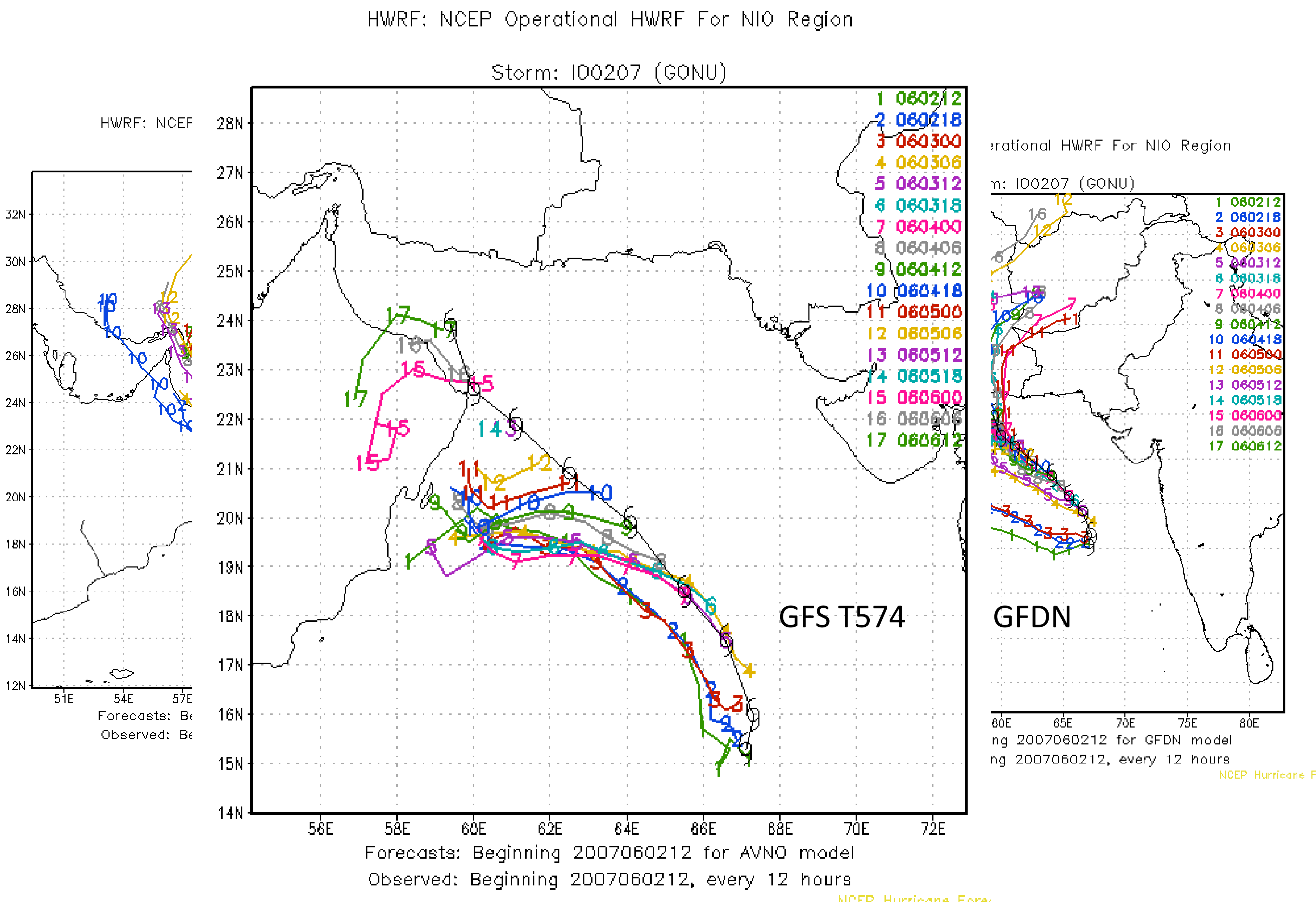


Benchmarking HWRF for Tropical Cyclones in the North Indian Ocean region

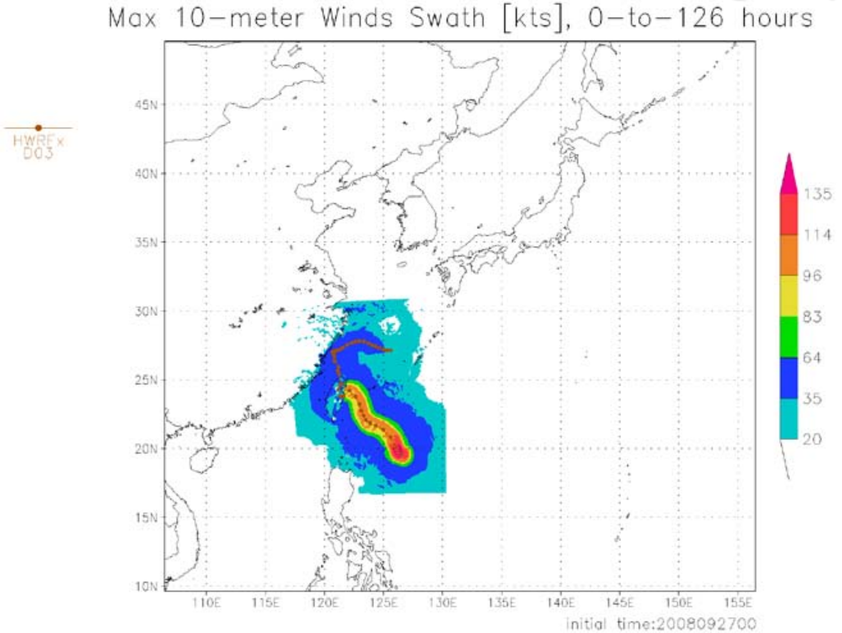


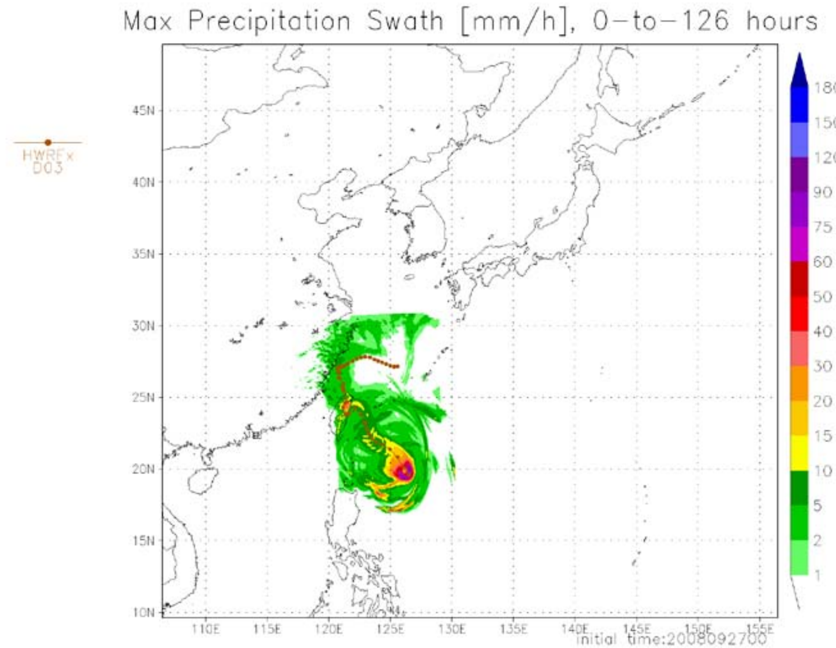
Benchmarking HWRF for Tropical Cyclones in the North Indian Ocean region

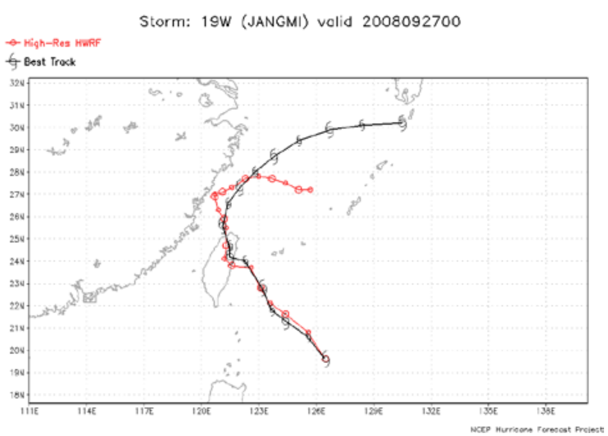


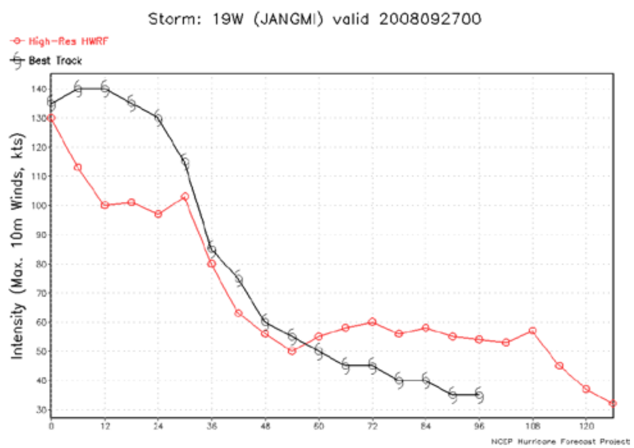

HWRF: NCEP Operational HWRF For NIO Region
Storm: IO0207 (GONU)
1 060212
2 060218
3 060300
4 060306
5 060312
6 060318
7 060400
8 060406
9 060412
10 060418
11 060500
12 060506
13 060512
14 060518
15 060600
16 060606
17 060612
Forecasts: Beginning 2007060212 for AVNO model
Observed: Beginning 2007060212, every 12 hours
NCEP Hurricane Fore
GFS T574
GFDN
erational HWRF For NIO Region
n: IO0207 (GONU)
ng 2007060212 for GFDN model
ng 2007060212, every 12 hours
HWRF: NCEF
Forecasts: Be
Observed: Be

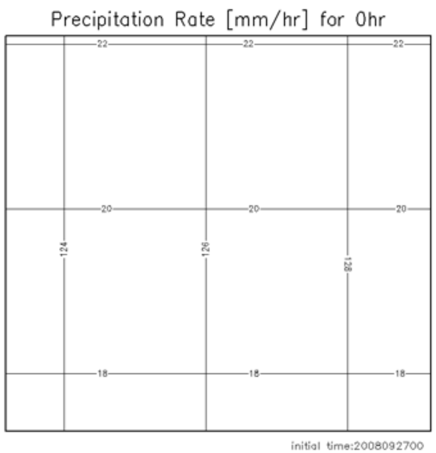
HWRF Forecasts for Western Pacific Typhoons
Jangmi (19W), IC 2008092700



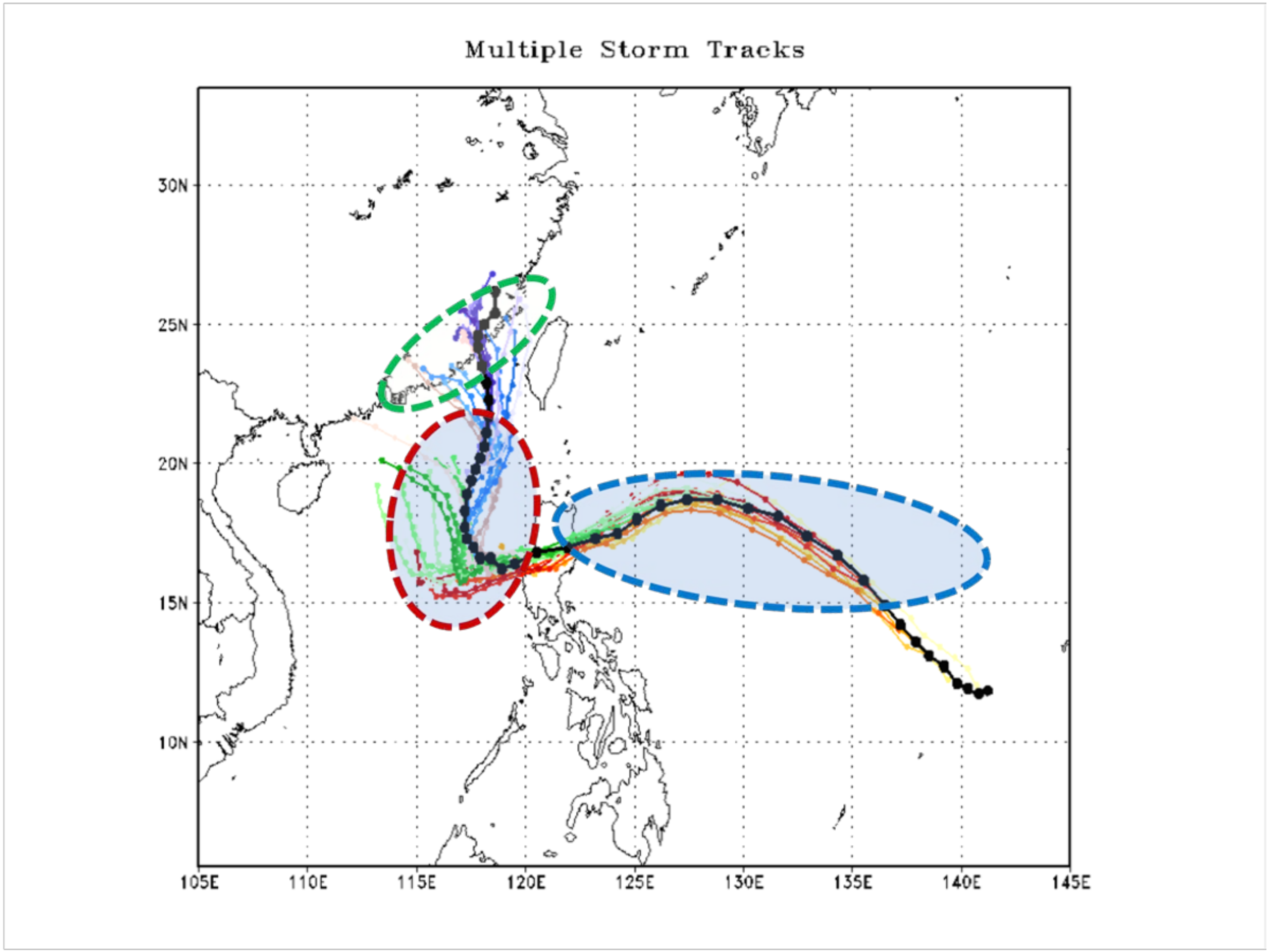




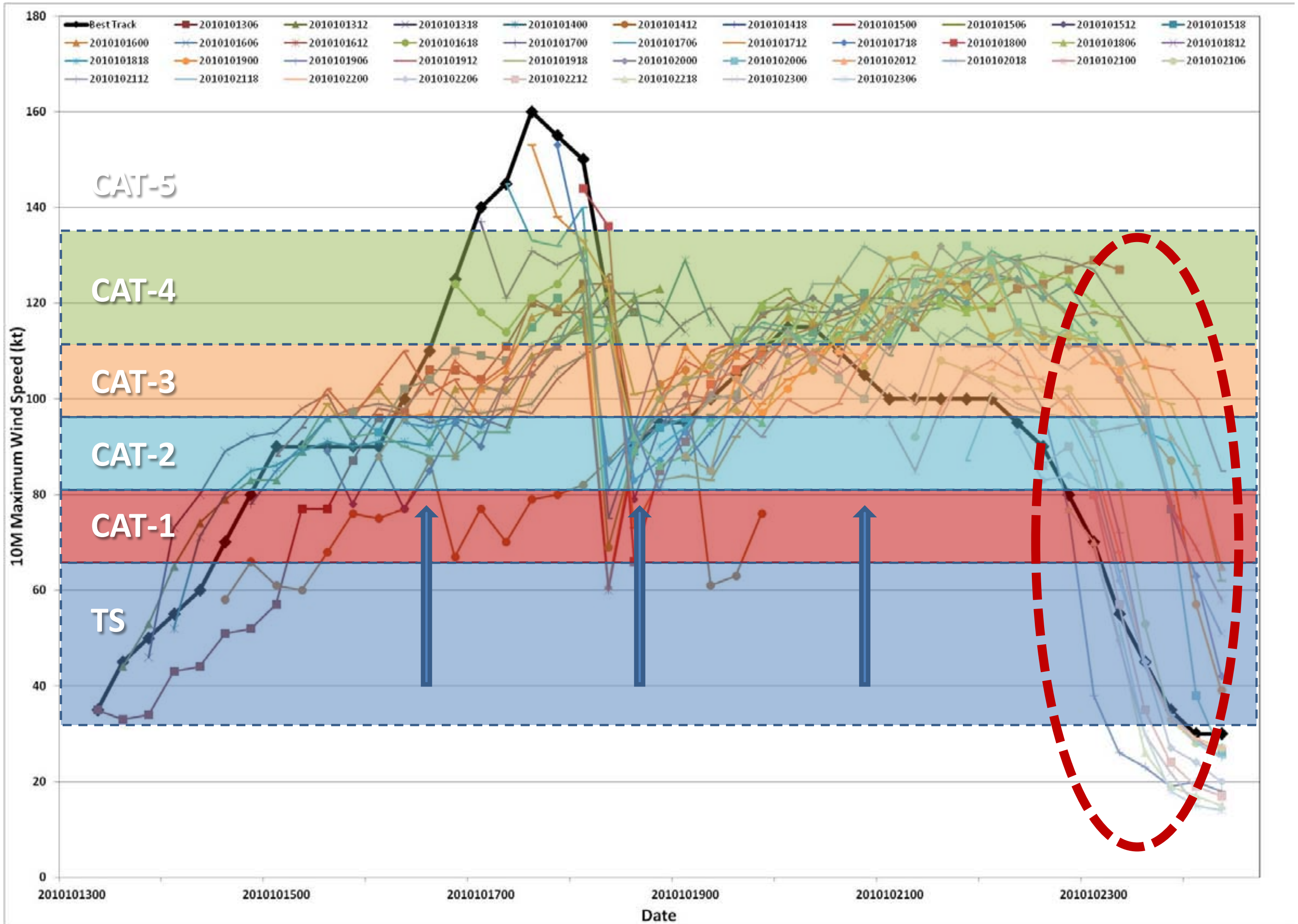




Typhoon Megi

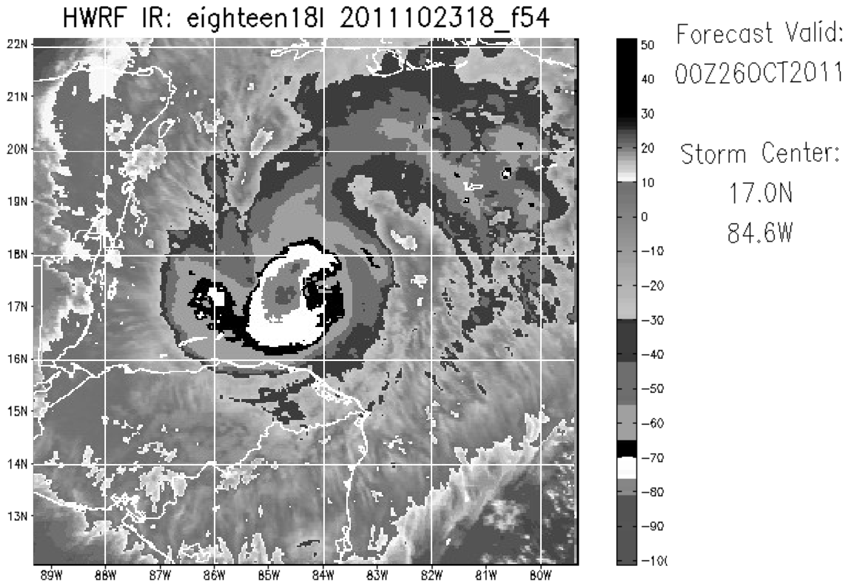


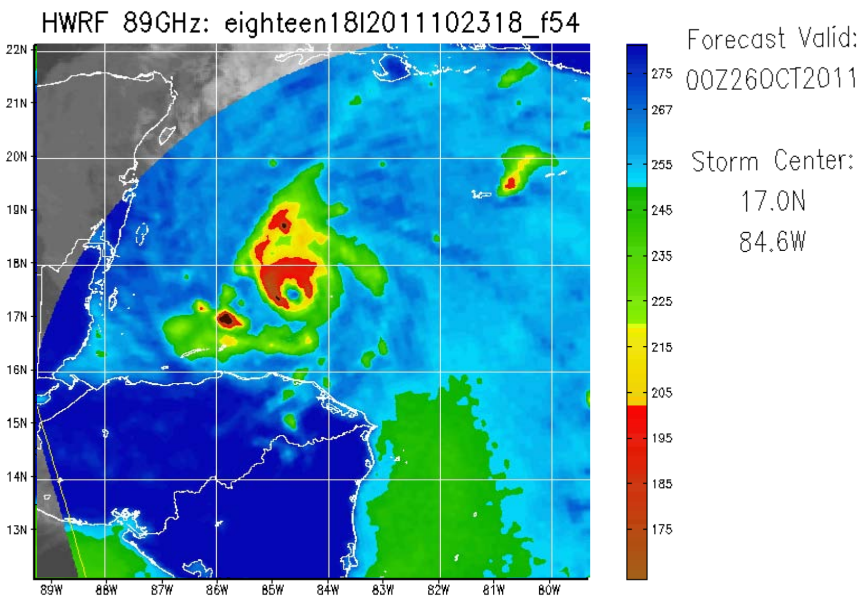
Typhoon Megi

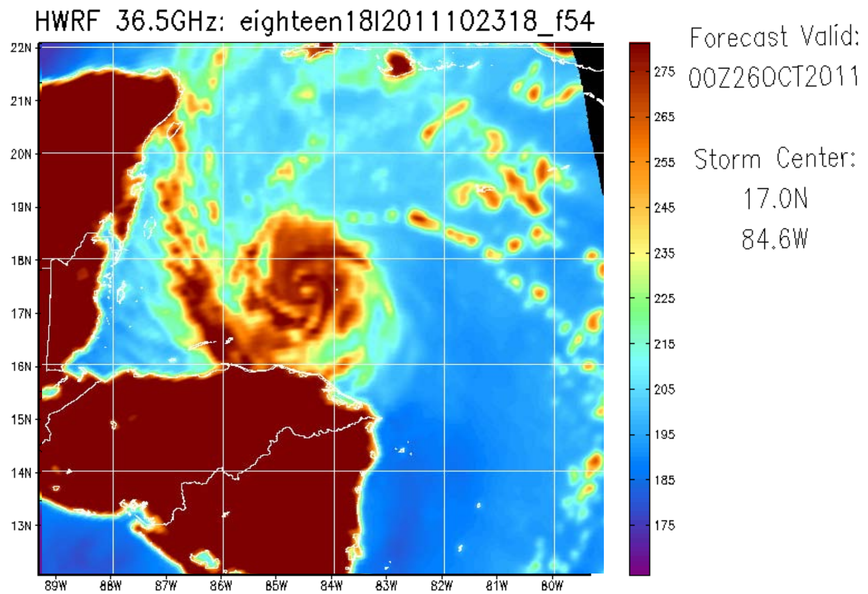


Simulated Satellite Model Forecasts

- Forecast Verification
  - Structure
    - IR (Dvorak)
    - Microwave
  - Microphysics
    - Satellite images dependent on modeled hydrometeors
- Operations
  - Composite images to allow forecast to easily compare model forecast with real storm

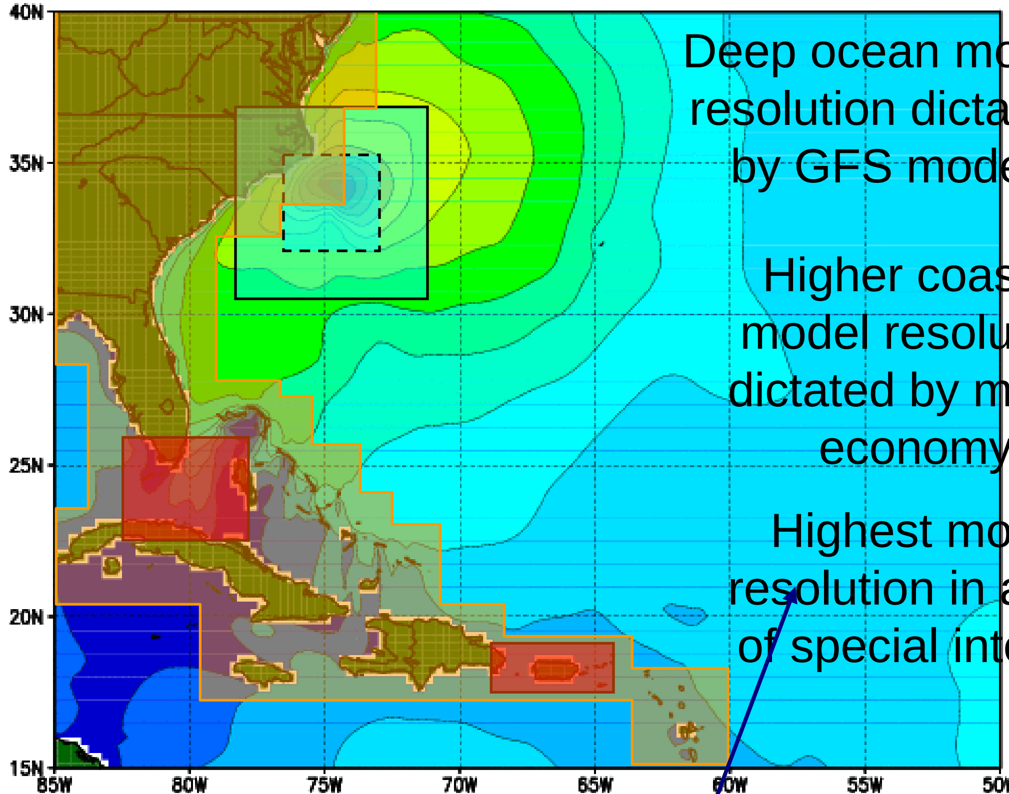




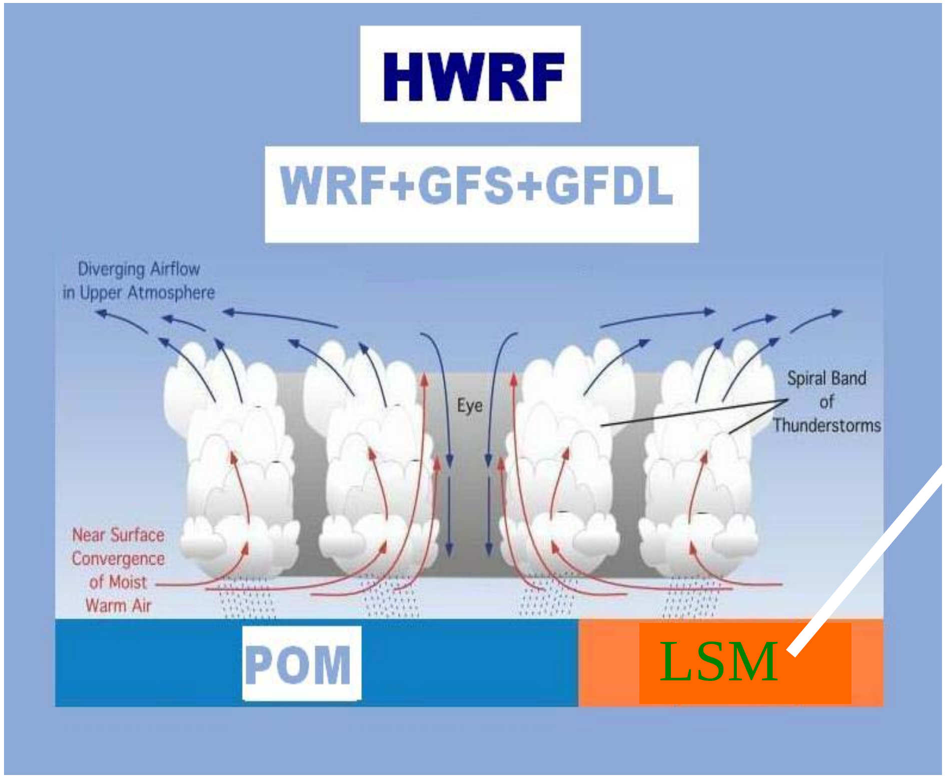


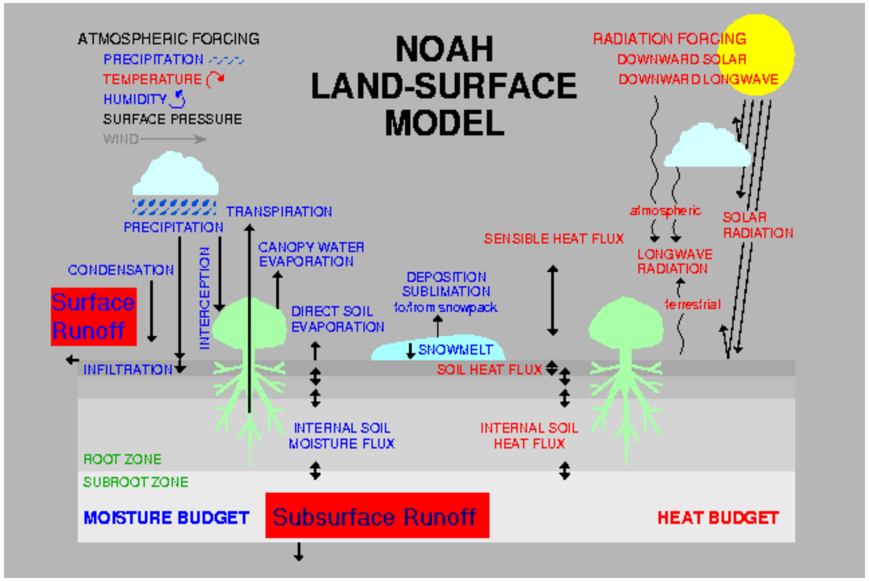
Coupling to Wave-Watch III

- NOAA/NCEP in-house wave model, based on WAM.
- Operational global and (nested) regional model.
- Specialized Atlantic and Pacific hurricane wave models with blended winds from GFS and GFDL model.
- WAVEWATCH III will be coupled to HWRF

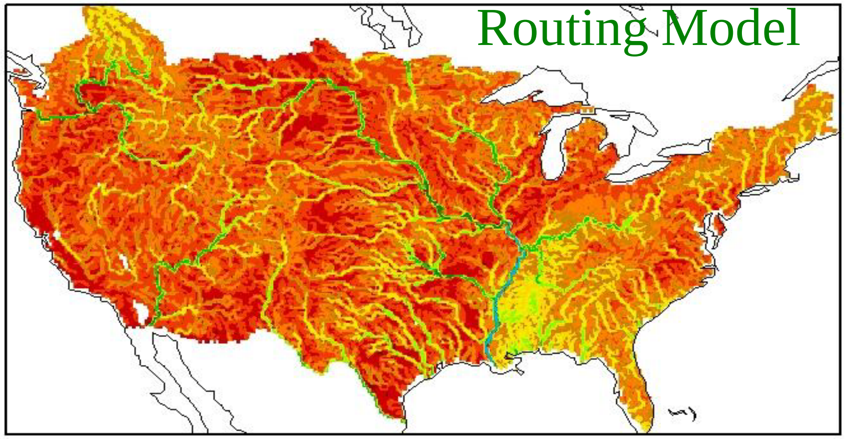


Coupling to Land Surface Model





www.emc.ncep.noaa.gov/HWRF



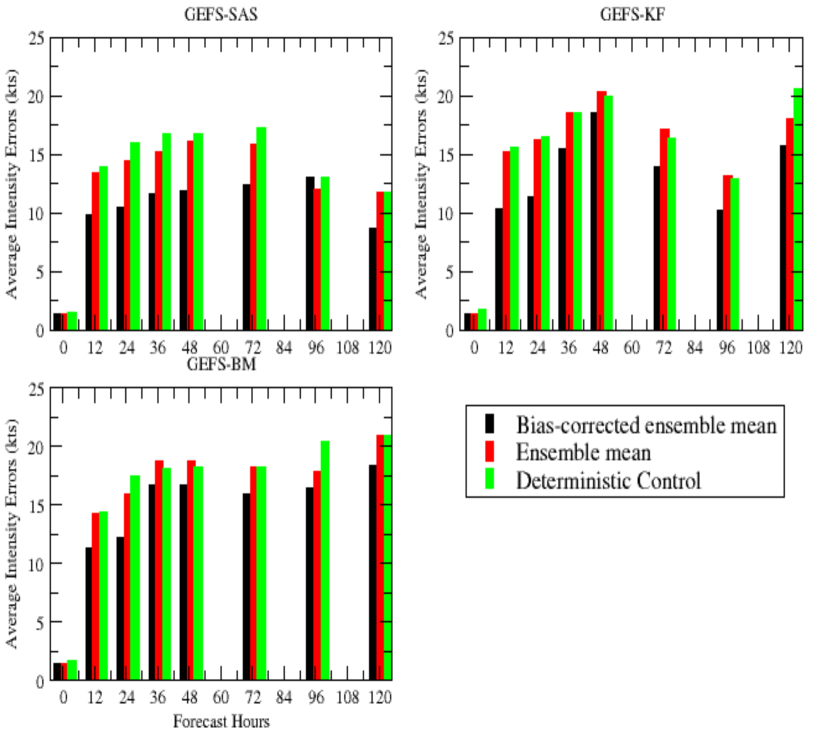
Driving Forcing: Surface runoff and baseflow

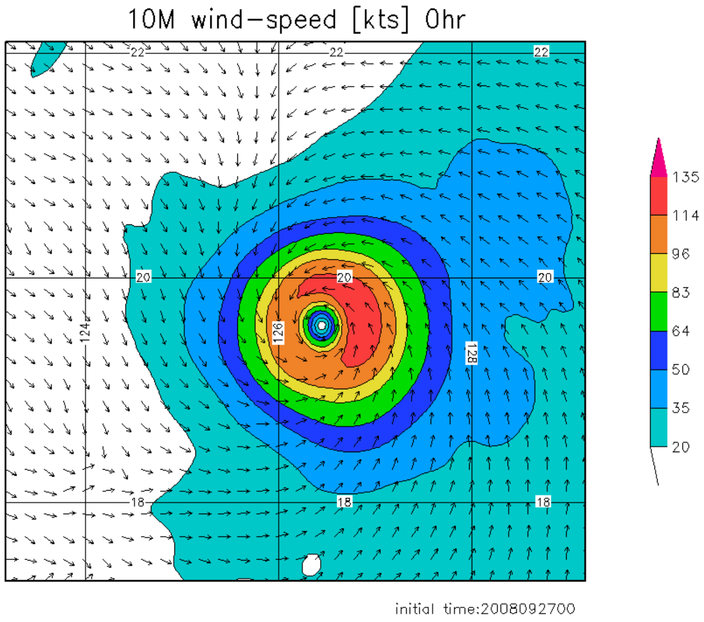
Coupling to HYCOM

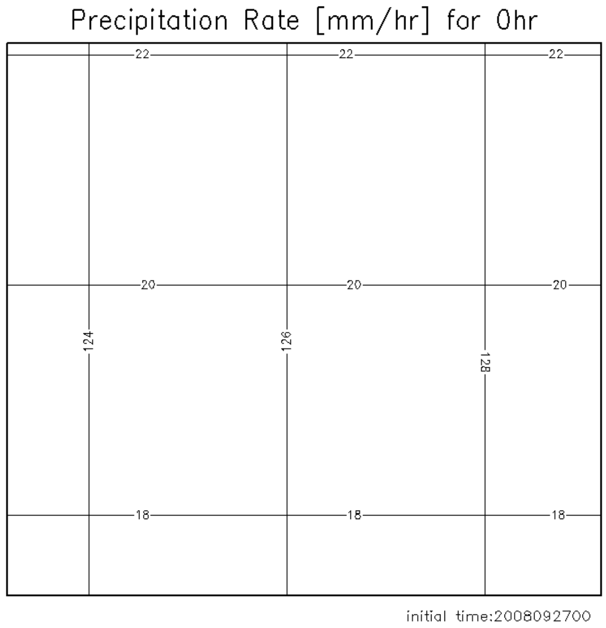
- New paradigm proposed by MMAB:
  - First assure that you have the most realistic ocean possible in a coupled HYCOM-HWRF system.
    - Use frozen HWRF and frozen RTOFS-Global (IC/BC).
    - Develop best possible coupled RTOFS nest.
      - Make GFS and HWRF fluxes compatible.
      - Add data assimilation to nested domain.
      - Validate and retune HYCOM using global TC data.
  - Then tune / modify HWRF for use with this ocean representation (optimizing track and intensity).
    Adjust fluxes / HYCOM tuning as needed while incrementally working on HWRF.
- Assuming that HWRF may fill present resources with third nest, no room for HYCOM in ops until 2014/15.
- 2012: MMAB sets up best possible RTOFS-HWRF.
    - Frozen HWRF, with bias correction in coupler.
    - Based on RTOFS-Global (not Atlantic).
    - Including data ocean data assimilation.
    - Focus on "global" ocean validation.
- 2013/2014:
  - Optimize HWRF for HYCOM.
    - Optimize HWRF for track and intensity, while
    - Assuring that ocean retains best behavior.
  - Possible addition of wave model to test system.
- 2015: Tentative implementation.

HWRF ensembles

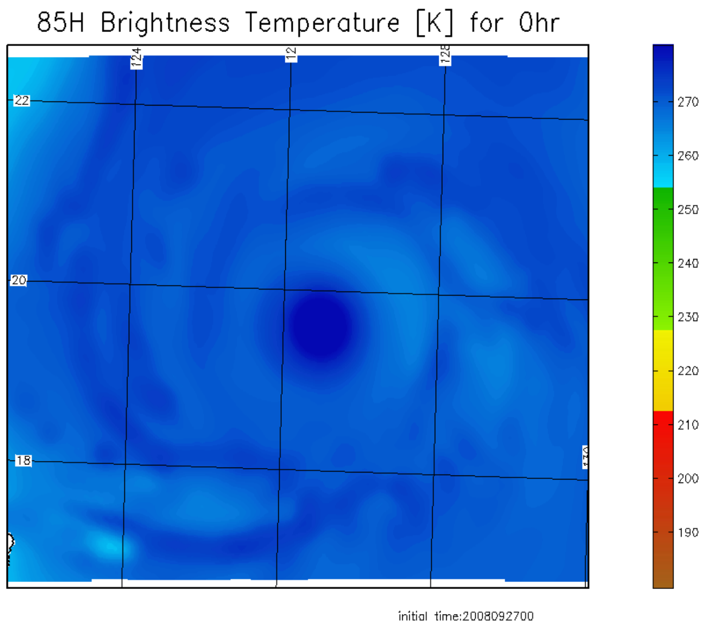
- ➢ Mainly focused on better estimation of hurricane intensity forecasts from EPS.
- ➢ **Single model, multi-initial condition ensembles**.
  1) GEFS-based HWRF ensembles with three cumulus convection schemes: Simplified Arakawa-Schubert (SAS), Kain-Fritsh (KF), and Batts-Miller (BM); Each includes 21 members.
  2) Error distribution-based model bias correction method was developed.
  3) Intensity forecast skills are greatly improved by the bias correction method, compared to simple ensemble average method (See Figure).
- ➢ **Multi-model, multi-physics ensembles**.
  1) Ensemble members include GFDL, high resolution (27-9-3) HWRF, HWRF with various cumulus convection schemes, PBL schemes;
  2) Mode analysis was developed using PDF kernel density estimation method
  3) Results showed that the intensity forecast skills are further improved by using mode analysis, compared to the arithmetic ensemble mean.

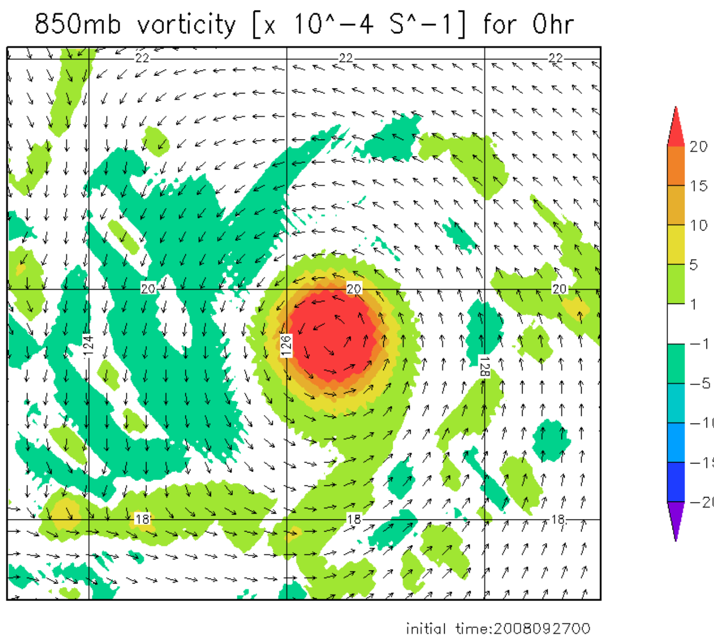






HWRF Forecasts for Typhoon Jangmi (19W), IC 2008092700





SUMMARY

There has been lot of progress advancing the hurricane modeling capabilities at EMC, thanks to active collaboration between research and operations.

Improving intensity/structure forecasts are orders of magnitude more difficult than was for track forecasts.

Requires substantial effort between research and operational hurricane communities

With improved track, intensity and structure, it is possible to provide improved guidance on rainfall, storm surge, flooding and inundation.