FY2012 Implementation of High-Resolution 3km Triple-Nested HWRF System

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Priorities for the FY12 HWRF Implementation

- **WRF NMM core and infrastructure:**
  - **Upgrade NMM Core for HWRF from V3.2 to V3.4+**
  - **Upgrade WPS , GSI and HWRF-POST to corresponding community versions**
- **Vertical Structure Implementation of HWRFV6.0.0**
- **Focus areas for FY12 Implementation:**

  a) Increase model resolution to 3 km near the hurricane core
    - **Introduction of storm following third nest in 27/9/3 framework**
    - **Reduce time step from 54/18/6 to 45/15/5 sec.**
    - **Increase the computational efficiency to fit into operational window**
    - **Re-design Vortex Initialization Procedure (applicable for 3km resolution)**
    - **Improved interpolation algorithms, composite storm structure and initial storm size**

  b) Improve track, intensity and structure forecast skills and w-p relationship
    - **Explicit convection in 3km domain**
    - **New GFS Shallow Convection**
    - **Surface fluxes based on 2010 HWRF implementation (based on observations)**
    - **Modified GFS PBL with observations based vertical diffusivity coefficients**
    - **1-D POM coupling for the Eastern Pacific basin**
    - **Improved Microphysics and SAS**
- **Conduct scientific testing and evaluation of all 2010 and 2011 ATL and EP storms**
- **Use of FY2012 Hybrid GSI/GFS retrospectives for 2011 hurricane season (including reruns)**

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**
- **This 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, Stream 1.5 and 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*
- **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 coupling in East-Pac, improved physics & vortex initialization**
- **Upgraded tracker and new high-temporal resolution (every time step) track and intensity product (htcf) and new SSMI/S synthetic microwave imagery**

2012 HWRF Model Upgrades

1. **Dynamics**
   - **modified several components of the model codes** and add **I/O servers** and redirect the standard output through log-buffering to speedup model run time in order to fit within the operational time window (**speedup factor of 3.2** in run time from ~265 min. to **~82 min**.) and **using 4 nodes** (oper. HWRF uses 3 nodes)
   - **Reduced Time step** of model integration 45, 15, 5 sec (oper. HWRF uses 54,18 sec)
   - **Fix a bug** in mask inside the leading edge of a nest domain
2. **Initialization and GSI**
   - Build the **vortex initialization at 3km resolution** with more accurate interpolation algorithms and composite storm structure consistent with 3km HWRF
   - **Upgrade GSI** to version 3.5 which is the latest community version. Optimize (reduce) the impact of prepbufr data in a storm environment.
3. **Ocean**
   - **Add one dimensional ocean coupling** in Eastern Pacific basin
   - Bug fixes in ocean initialization for Atlantic basin
4. **Physics**
   - Add **GFS shallow convection** scheme with slight tuning (no precip. from SC when cloud is less than 50mbs thick and SC top is below PBL top)
   - Modify **several microphysical parameters** to more realistic values (NLImax, NCW and snow fall speed)
   - PBL: Change **critical Richardson number** from 0.5 to 0.25, and **alpha=0.5** from 1
   - Use the **constant Ch profile** with wind speed consistent with observations

2012 Triple-Nested HWRF pre-implementation Test Plan

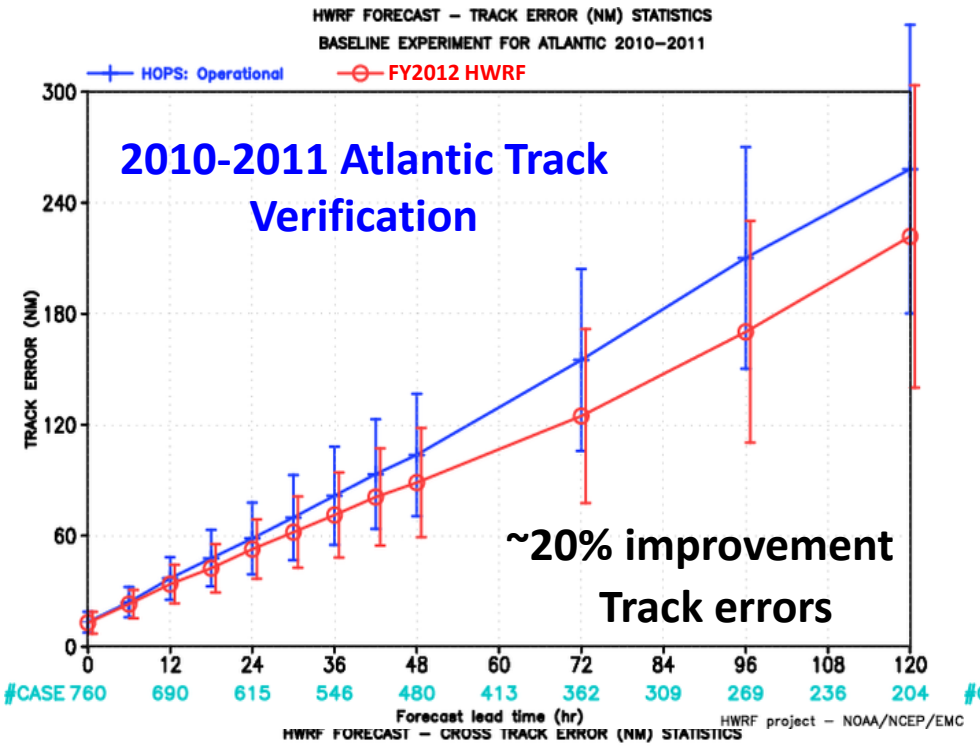
EXP	Description	Comments	Platform/# of cases
HBSE	Baseline: with the stripe bug fix (a=0.5, coac=0.75, 3.0, 4.0)	Unstable due to 54 sec. time step. Noise in several fields especially at higher latitudes. Not a viable configuration for operations. Operational GFS.	Jet, All 2010-11 ATL & EP, 1265
HPHY	HBSE + S.C. + MP tune (dt=45s, no sas in d03)	Revised HBSE configuration with 45 sec. time step. Numerically stable with no noticeable noise. Shallow convection and microphysics tuning included. Explicit convection in d03. Operational GFS.	Jet, All 2010-11 ATL & EP, 1265
HOCN	HPHY + new ocean	1-D coupling for East-Pac storms, Operational GFS.	Jet, All 2010-11 EP, 418
HGSI	HPHY + GSI	Reduced impact of observations (prepbufr) in HWRF-GSI. Operational GFS.	CCS, Majority of 2010-11 ATL, 400
H12J	HPHY+HOCN+HGSI for 2010, w/Hybrid GFS* for 2011	For 2011 season, use hybrid GFS reruns (pre13r) for the period from Aug. 20 to Oct. 11, 2011. Use pre13h for rest of the season. Operational GFS for 2010 season.	Jet, All 2010-11 ATL & EP, 1265
H212	**HPHY+HOCN+HGSI for 2010, w/Hybrid GFS* for 2011**	**For 2011 season, use hybrid GFS reruns (pre13r) for the period from Aug. 20 to Oct. 11, 2011. Use pre13h for rest of the season. Operational GFS for 2010 season.**	**CCS, All 2010-11 ATL & EP, 1265**

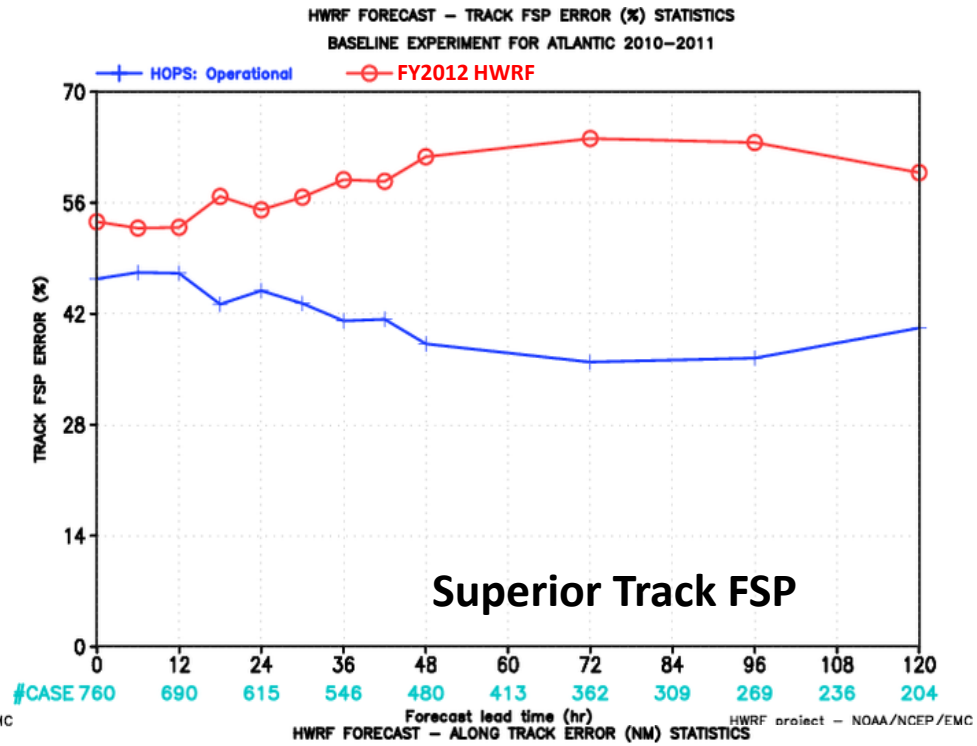
Not shown here: HSHAL (HBSE+Shallow Convection) – All 2010 ATL (Jet, 446), HBSE2 (Modified initialization): All 2011 ATL (Jet, 401), HPRD (Oper. HWRF w/new GFS): All 2011 ATL+EP (CCS, 664), H3GP: Stream 1.5, All 2011 ATL+EP (Jet, 800)

Unprecedented T&E of about 10 different configurations, more than 8000 simulations from 64 storms on Jet & CCS, thanks to support from HFIP PO for Jet usage, and from NCO for "devmax" usage on CCS

Performance of H212 compared to operational HWRF (HOPS)
(2010-2011* seasons)

*Final Retrospective runs for 2011 hurricane season are based on FY12 Hybrid GSI/GFS IC/BC (including reruns for the period from Aug.20-Oct.11 2011.


HWRF FORECAST – TRACK ERROR (NM) STATISTICS
BASELINE EXPERIMENT FOR ATLANTIC 2010–2011
HOPS: Operational
FY2012 HWRF
2010-2011 Atlantic Track Verification
~20% improvement Track errors
TRACK ERROR (NM)
Forecast lead time (hr)
#CASE 760 690 615 546 480 413 362 309 269 236 204
HWRF project – NOAA/NCEP/EMC


HWRF FORECAST – TRACK FSP ERROR (%) STATISTICS
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FY2012 HWRF
Superior Track FSP
TRACK FSP ERROR (%)
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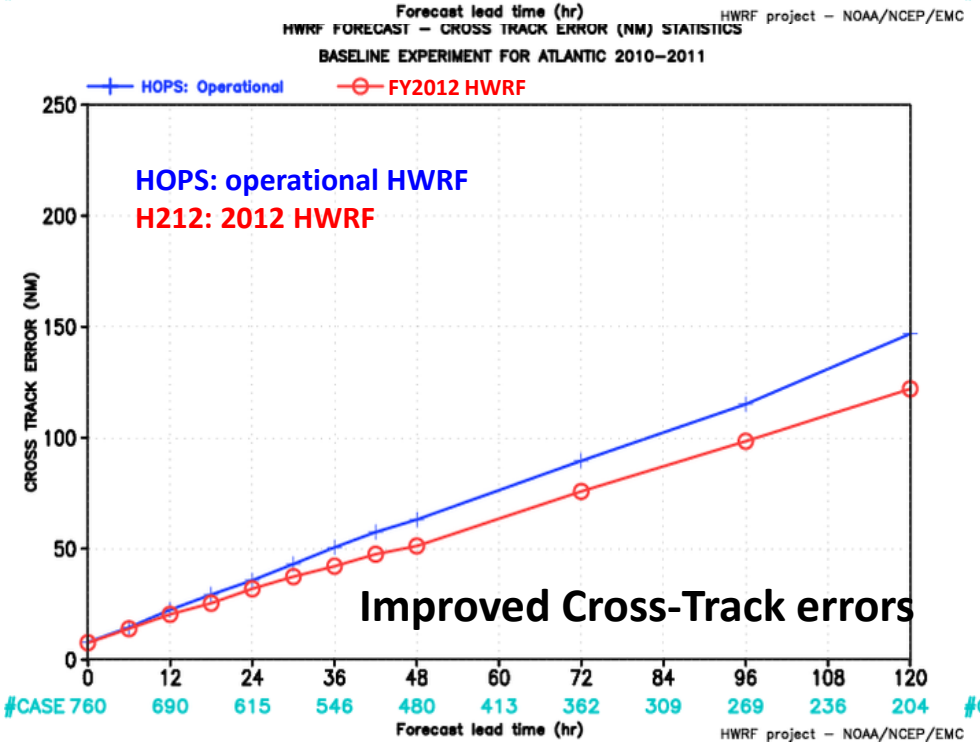
HWRF FORECAST – CROSS TRACK ERROR (NM) STATISTICS
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H212: 2012 HWRF
Improved Cross-Track errors
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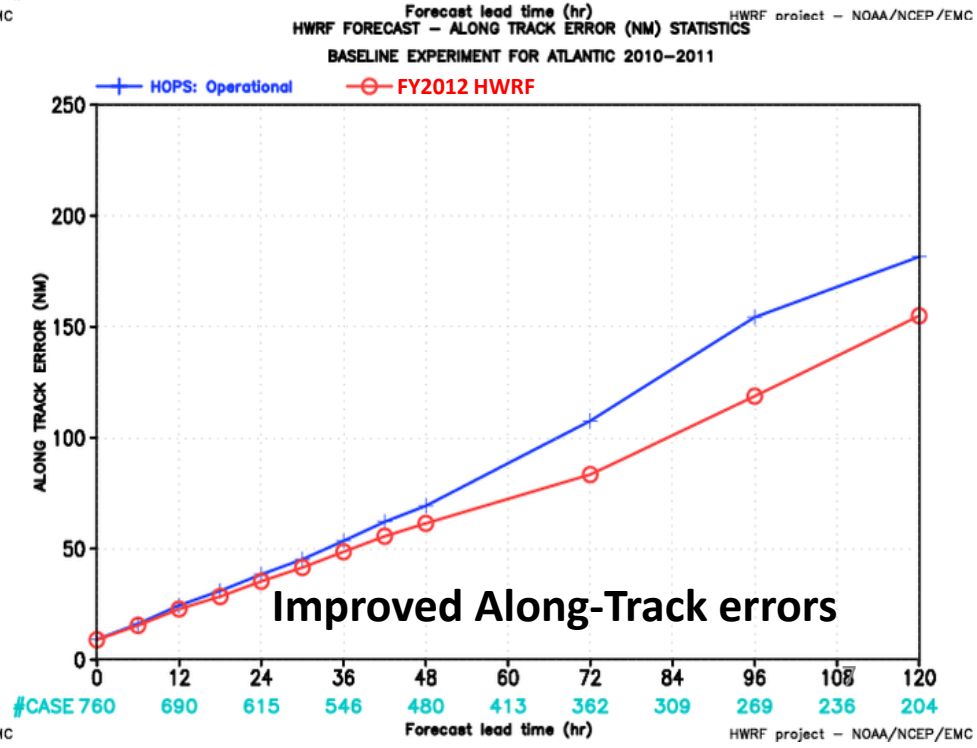
HWRF FORECAST – ALONG TRACK ERROR (NM) STATISTICS
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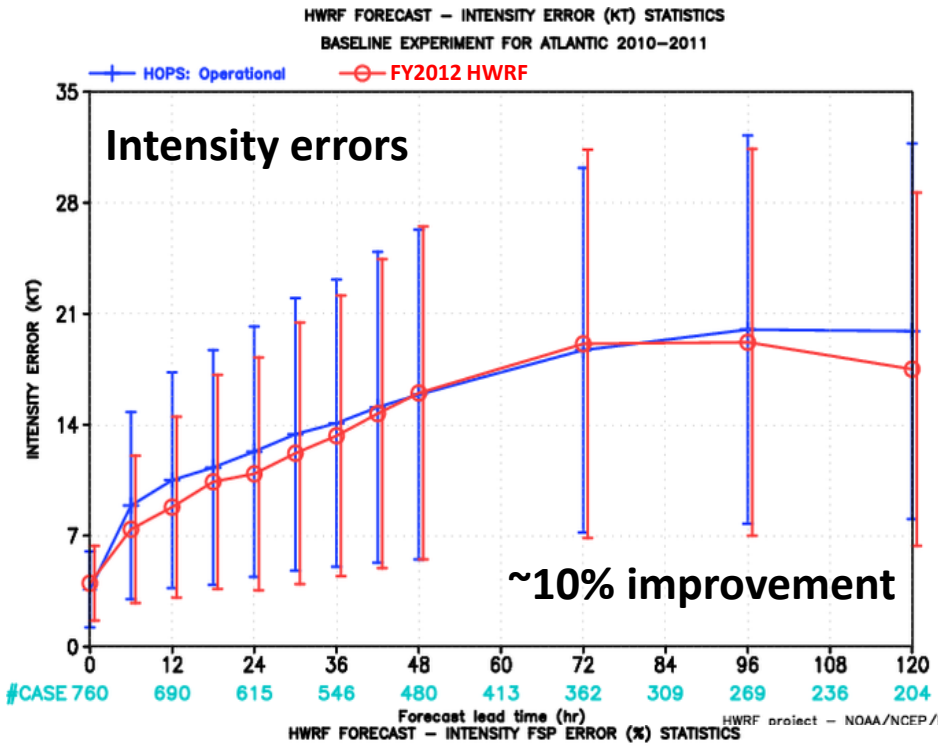
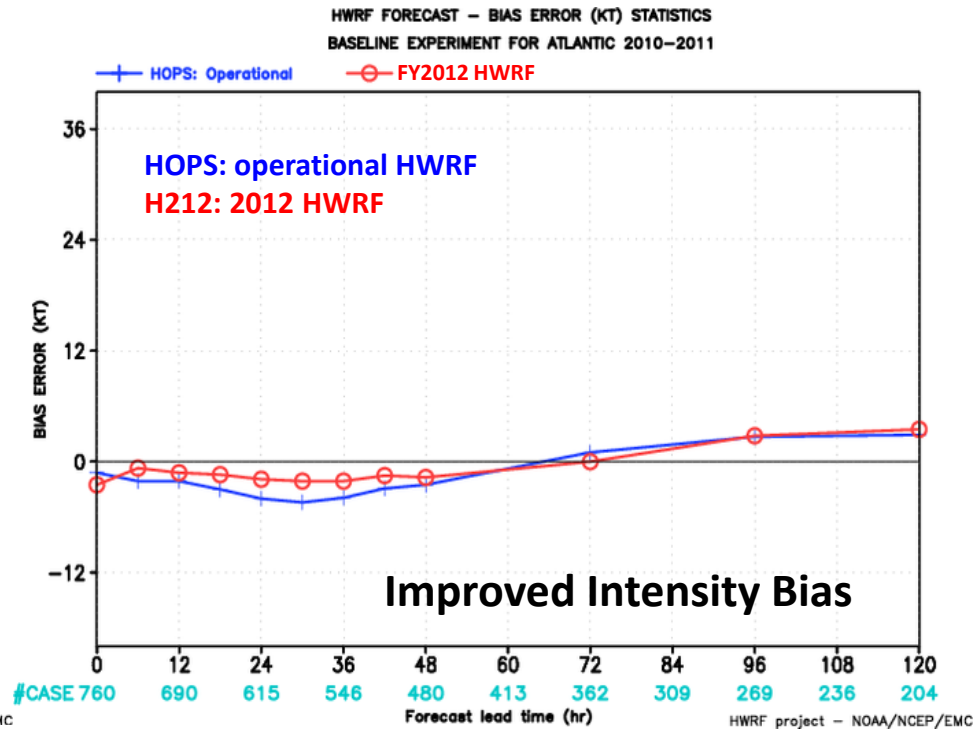
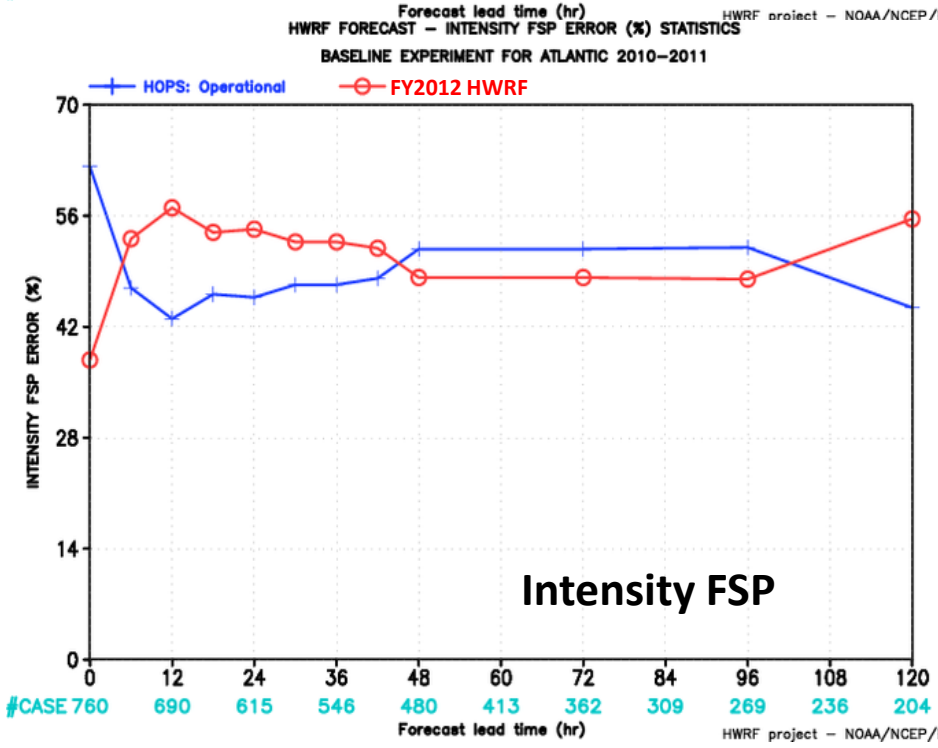
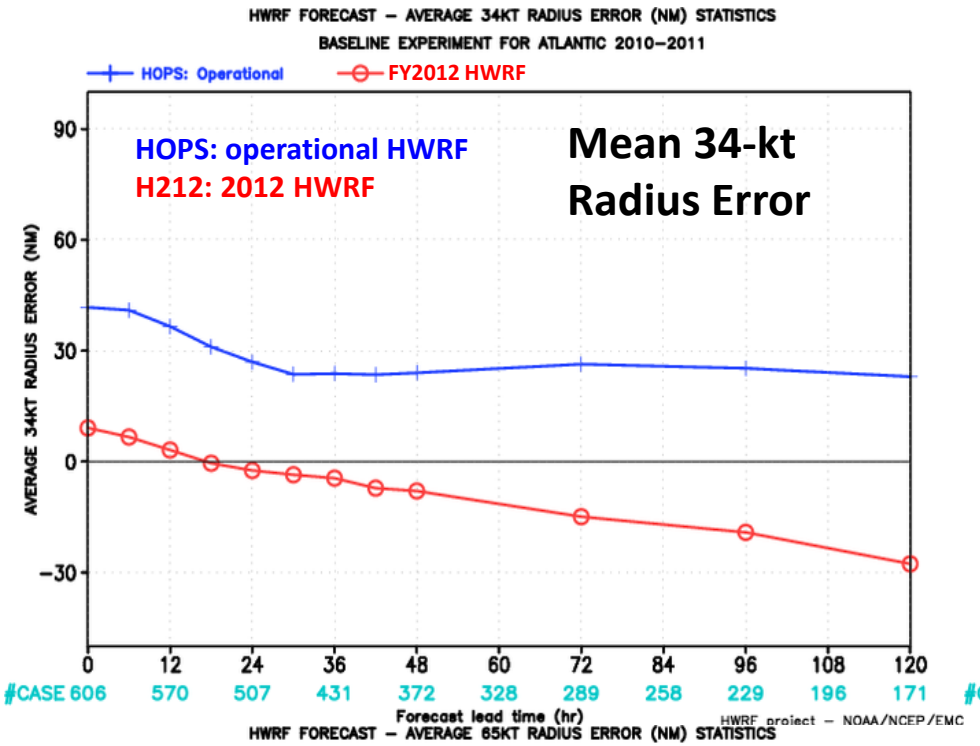
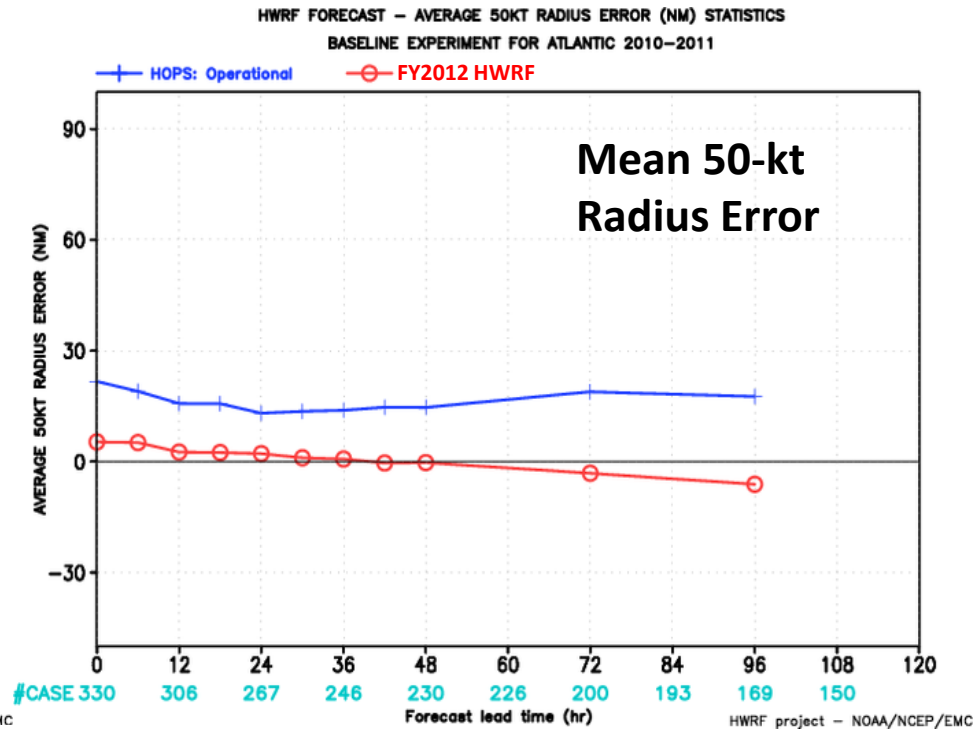


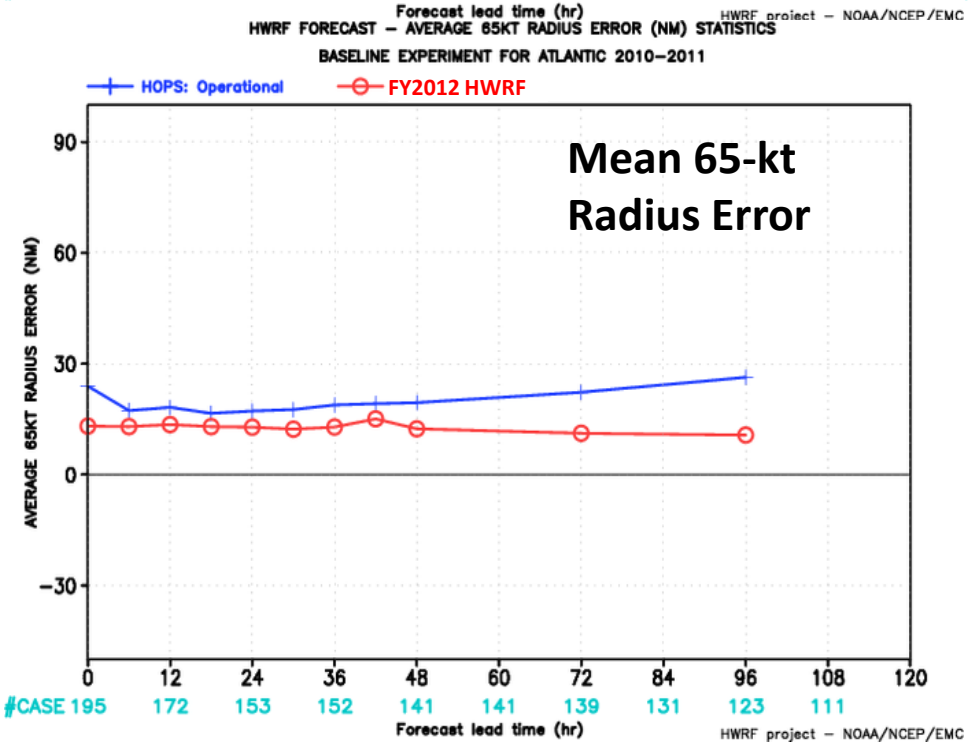




2010-2011 Atlantic Intensity Verification

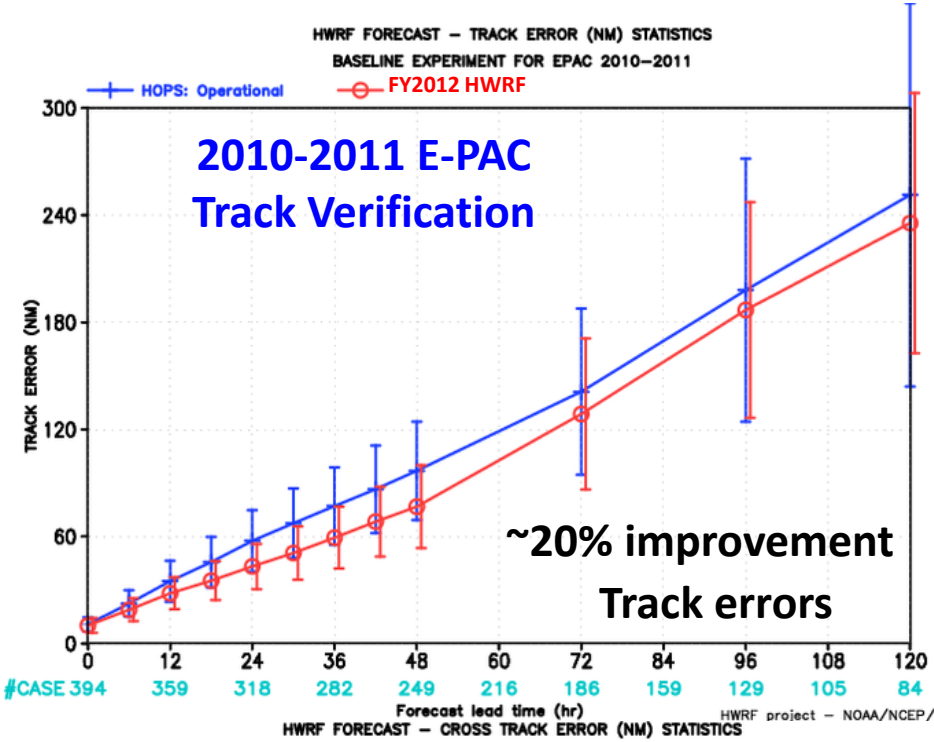






2010-2011 Atlantic Radii Verification

Significant improvements in storm size and structure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FY2012 HWRF
2010-2011 E-PAC
Track Verification
~20% improvement
Track errors
TRACK ERROR (NM)
Forecast lead time (hr)
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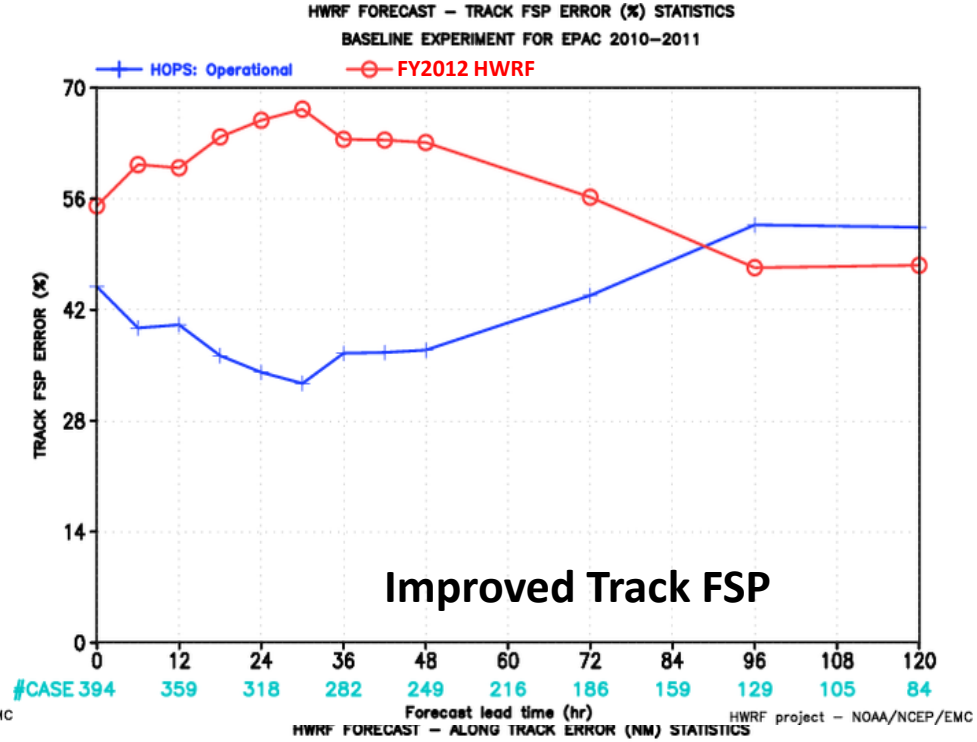
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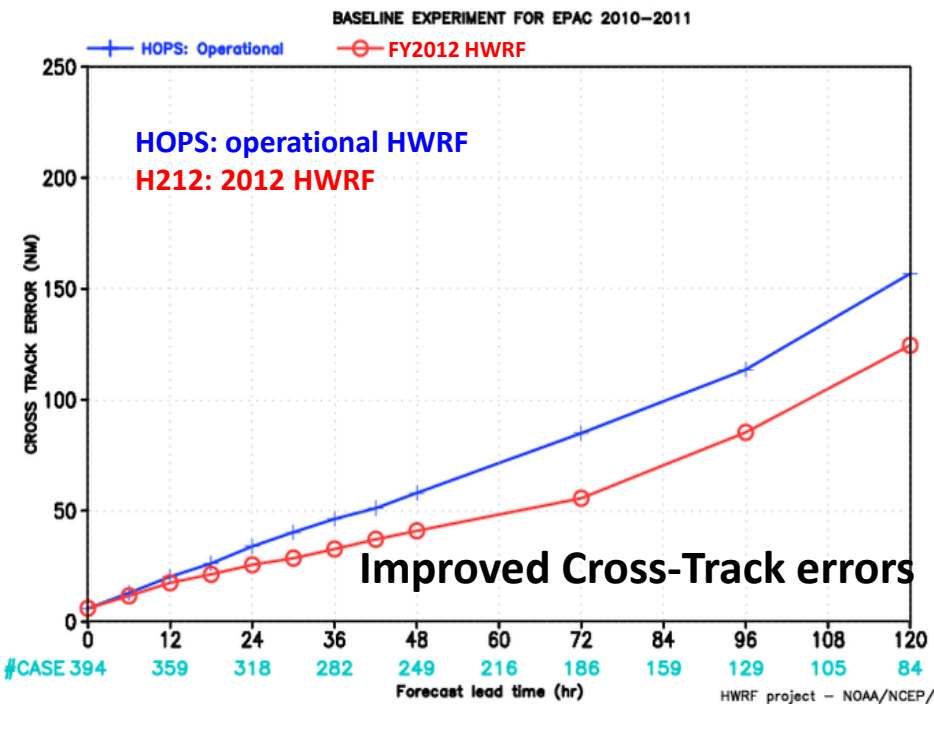
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H212: 2012 HWRF
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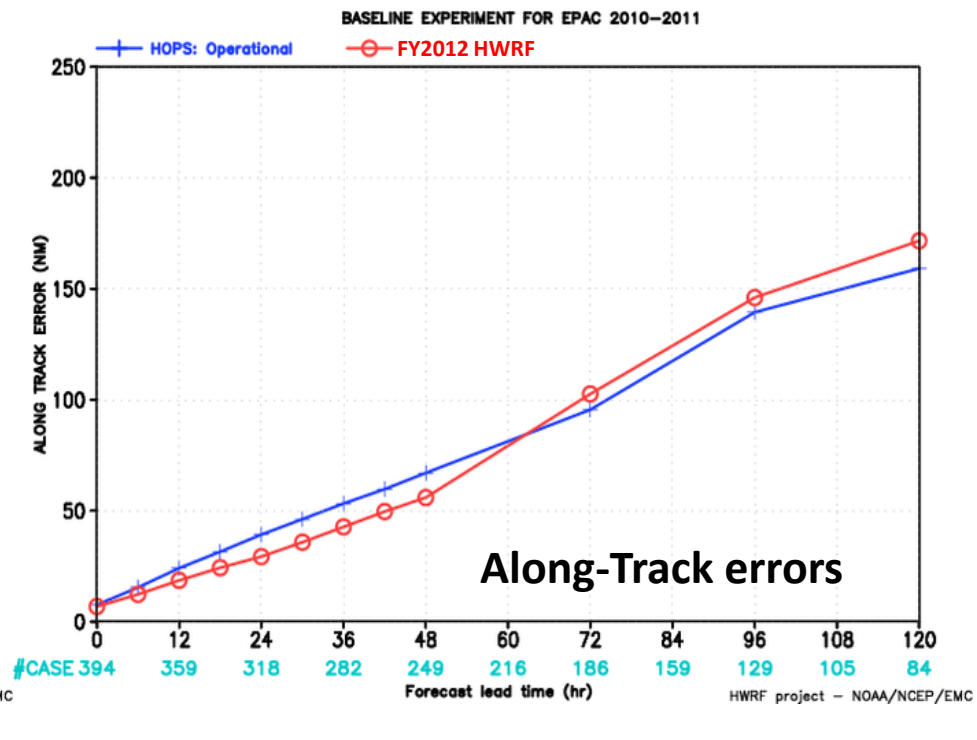
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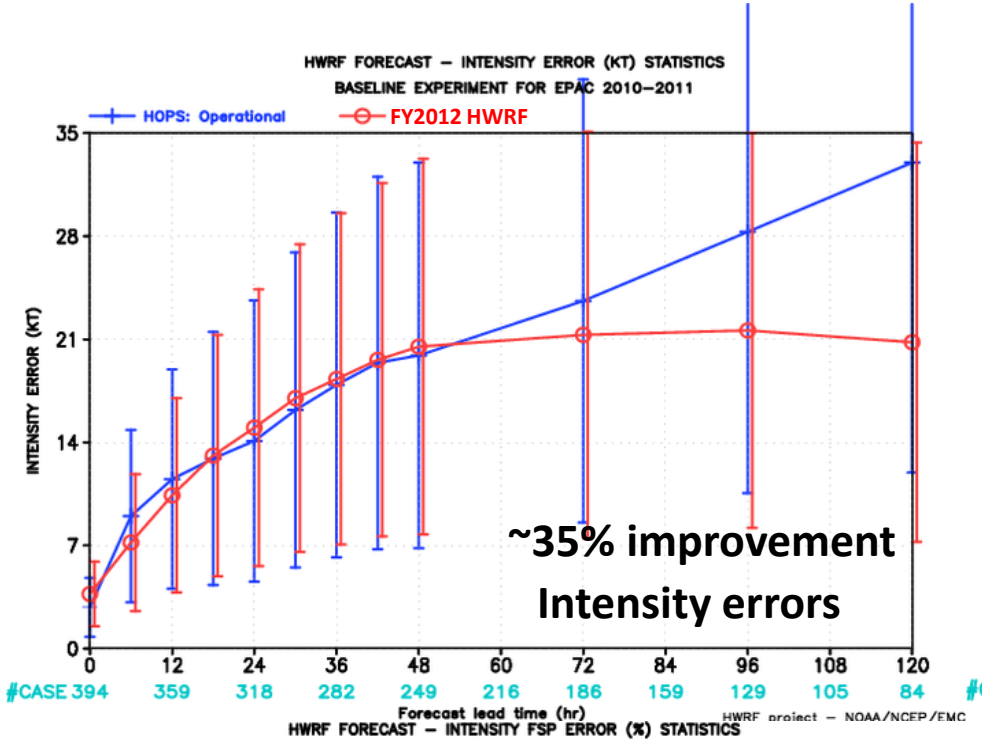
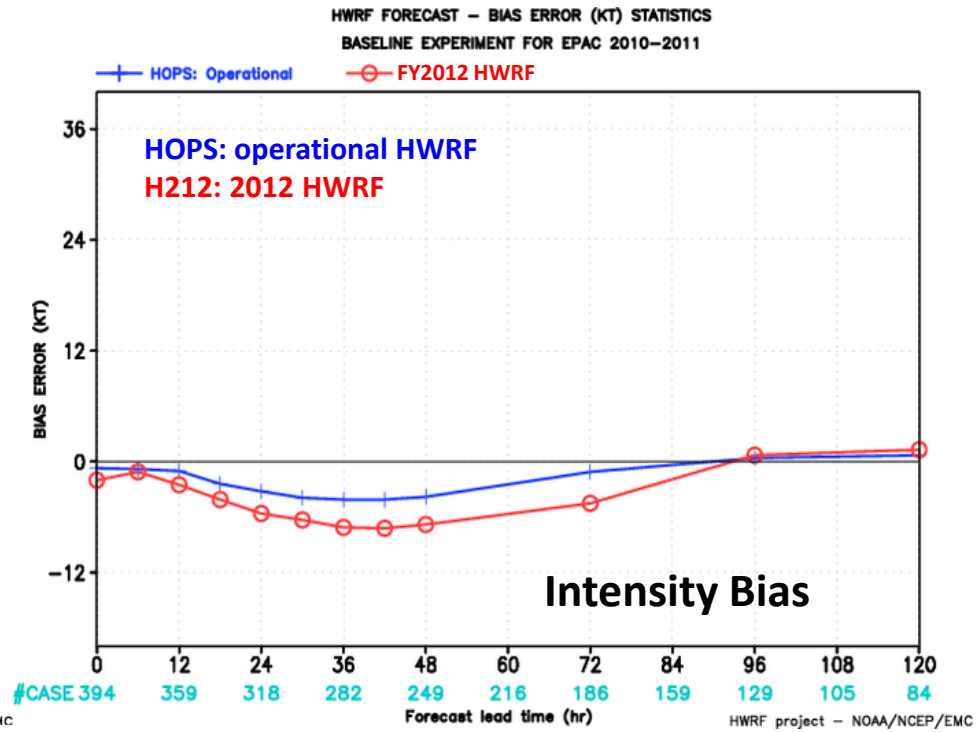
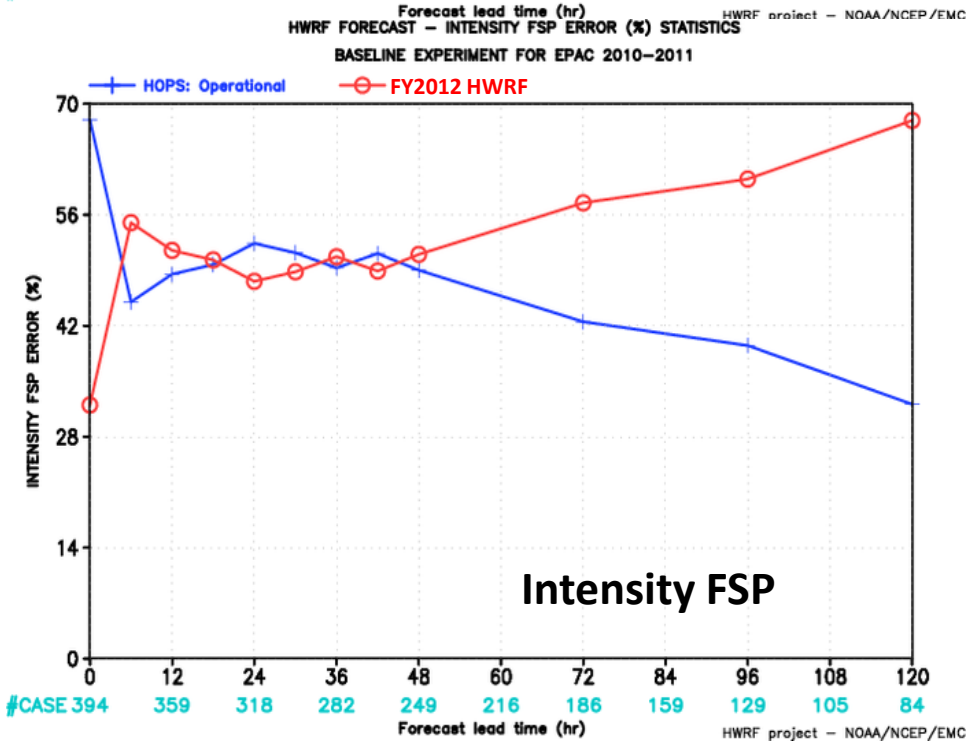
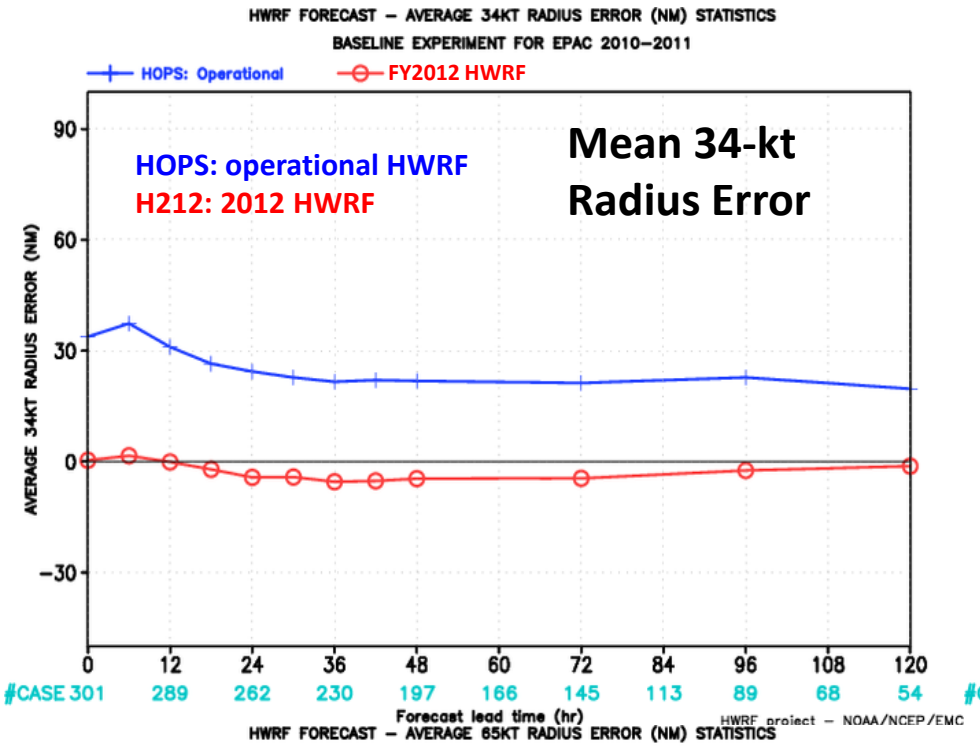
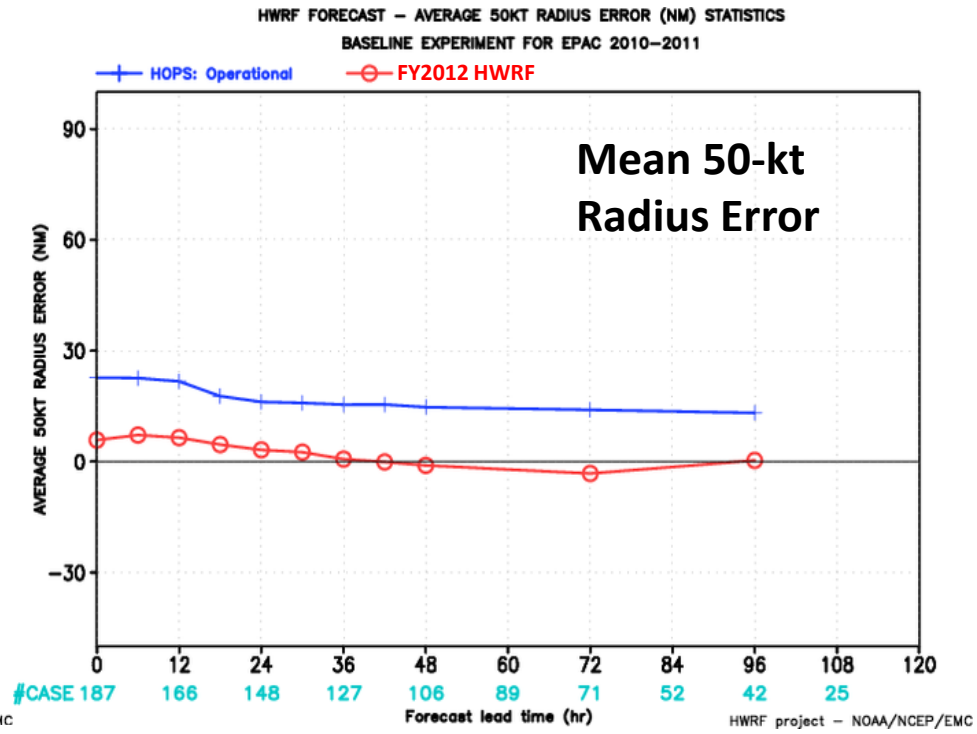


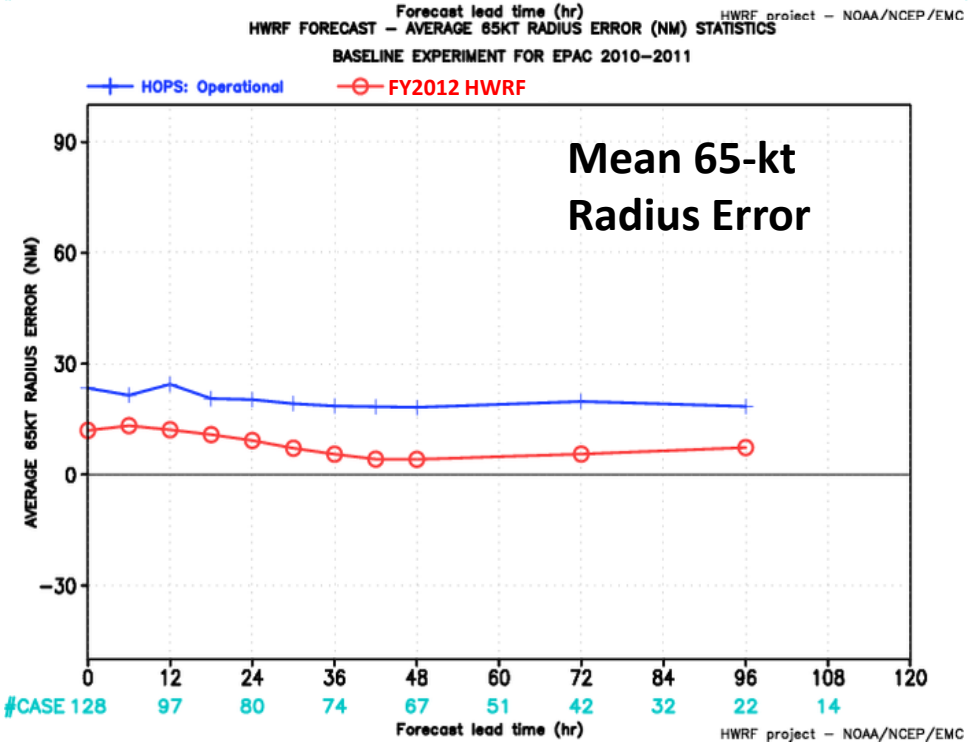




2010-2011 E-PAC
Intensity Verification

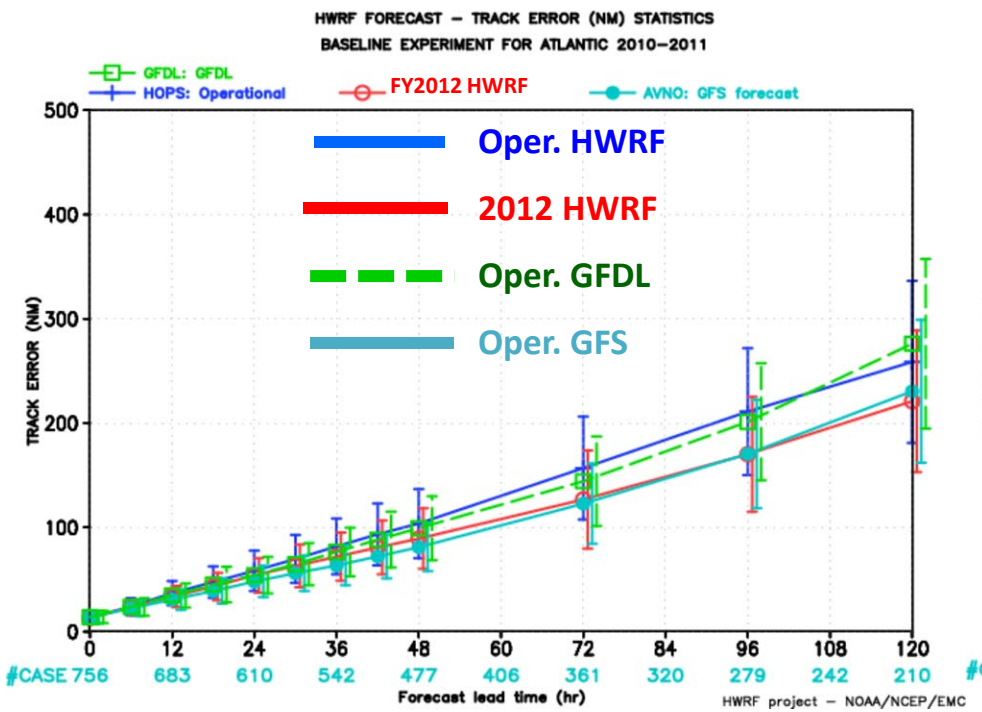




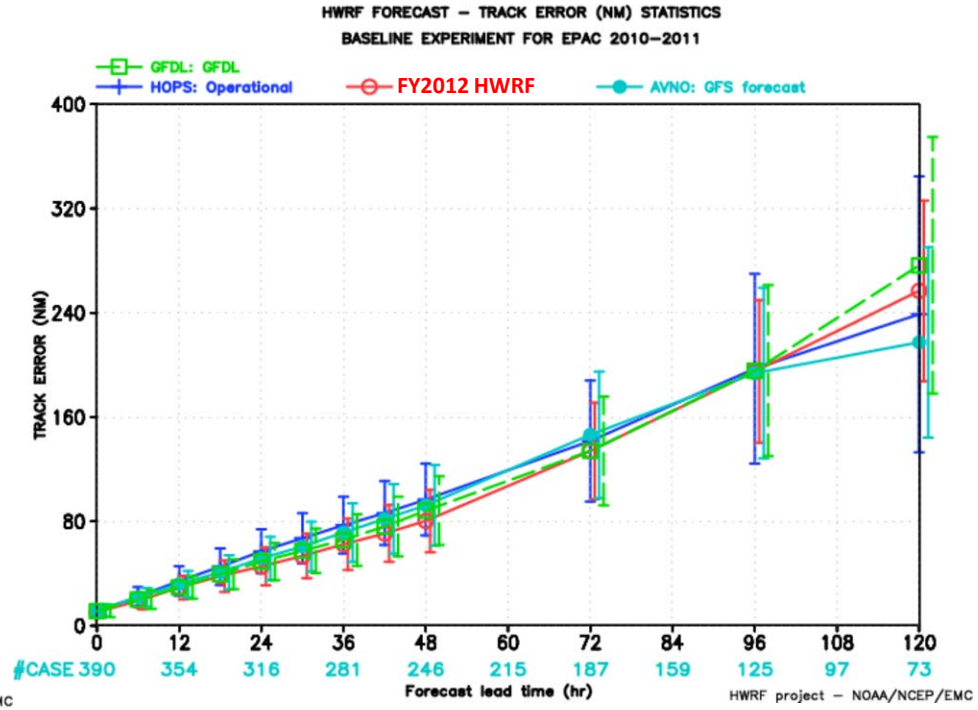


2010-2011 E-PAC
Radii Verification

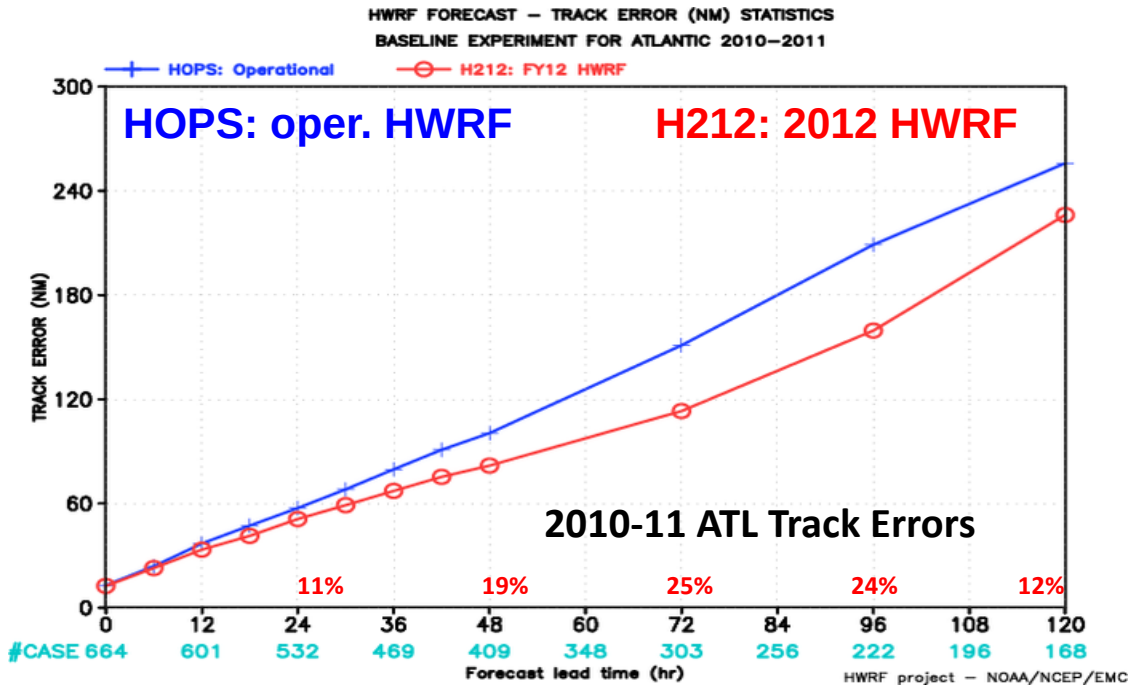
Atlantic basin

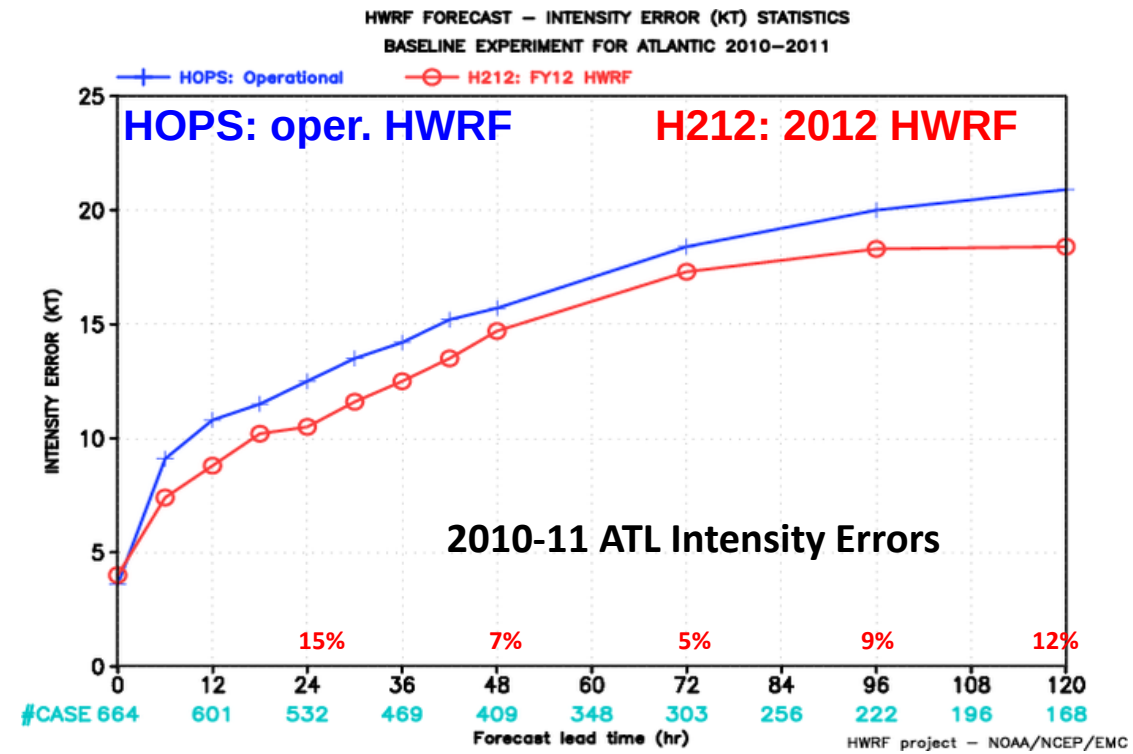


EPAC basin



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



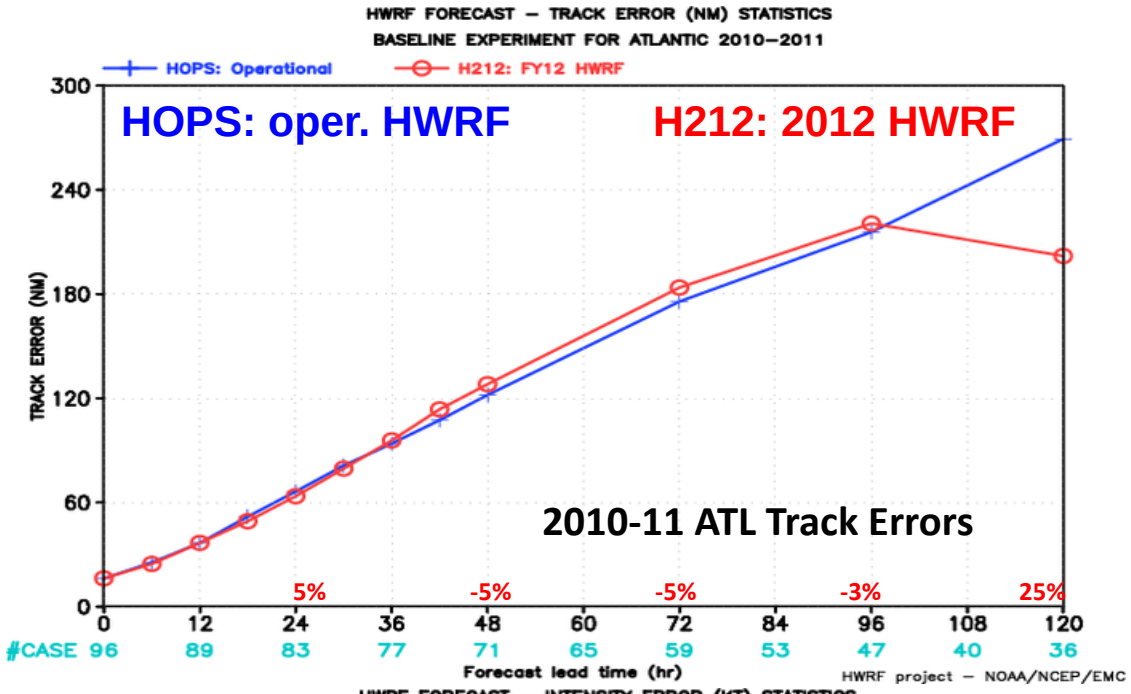


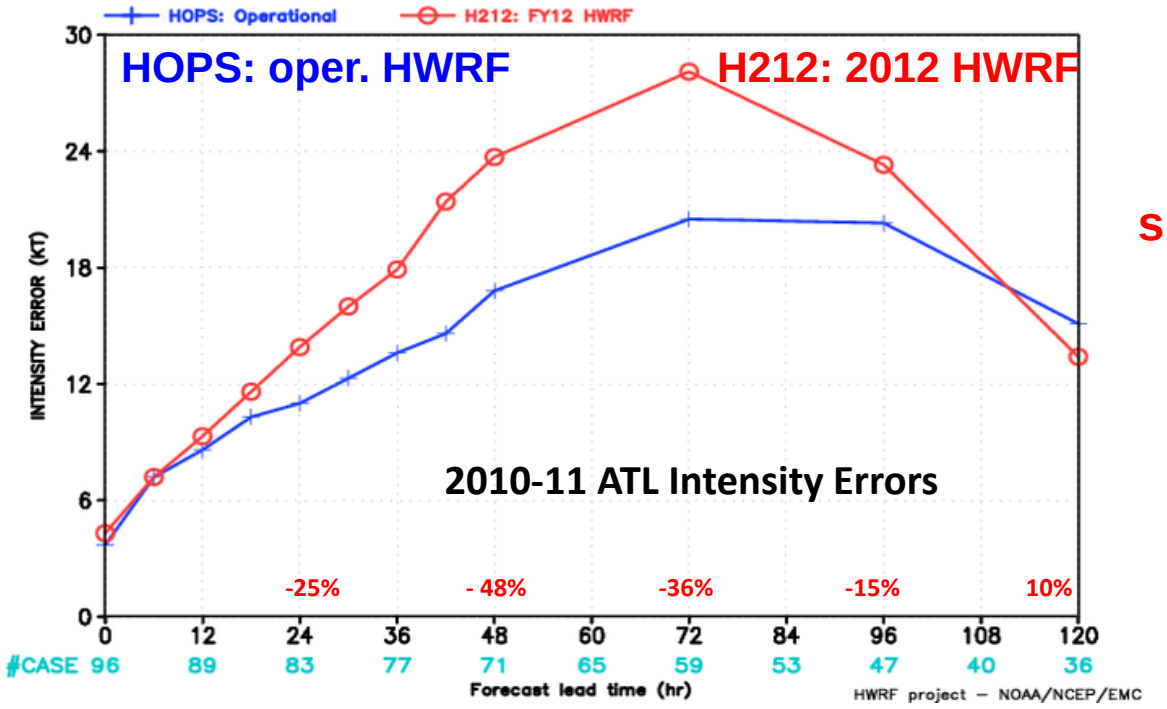
87% of total retrospective runs from 2010-2011 seasons show 10-25% reduction in track errors and 5-15% reduction in intensity errors

37 Storms

2010: Alex, Two, Bonnie, Colin, Five, Danielle, Earl, Fiona, Gaston, Hermine, Igor, Karl, Matthew, Nicole, Otto, Paul Richard, Shary, Tomas

2011: Arlene, Bret, Cindy, Don, Emily, Franklin, Gert, Harvey, Irene, Ten, Lee, Katia, Maria, Nate, Philippe, Rina, Sean



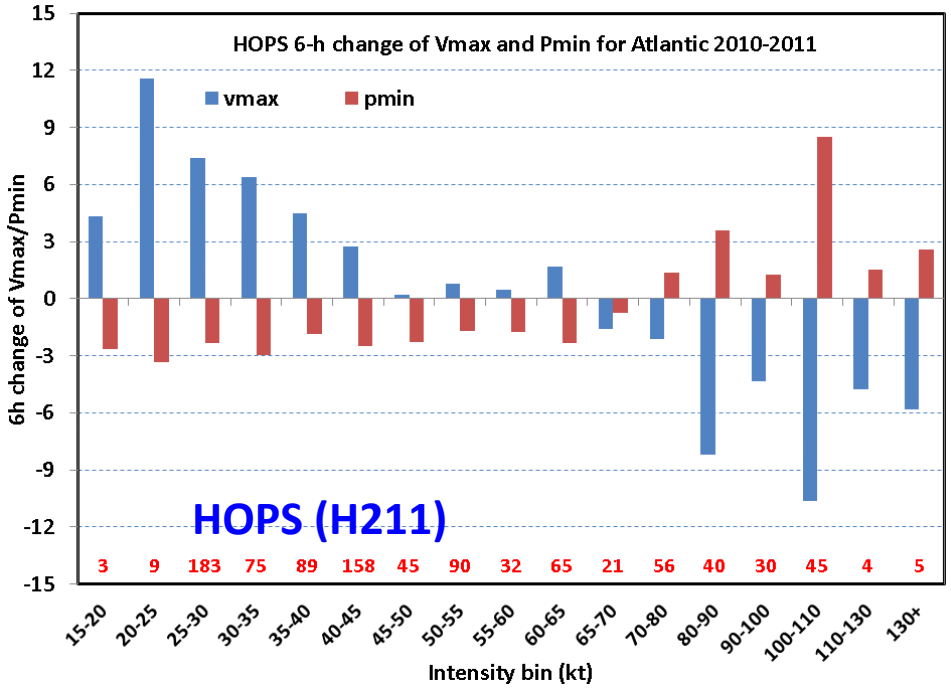


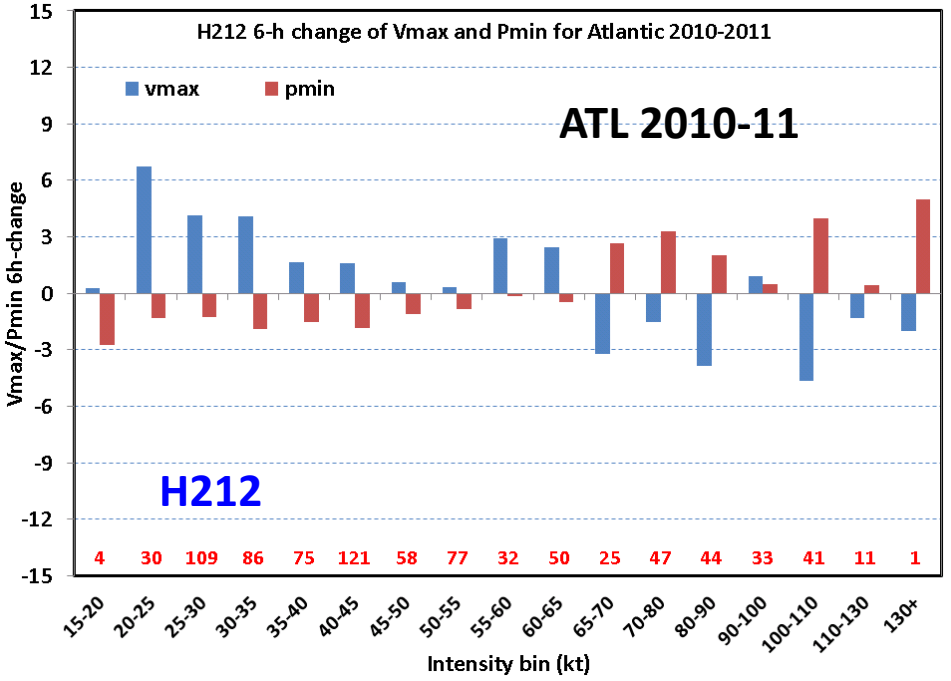
Three storms (Julia and Lisa from 2010 and Ophelia from 2011) are the outliers

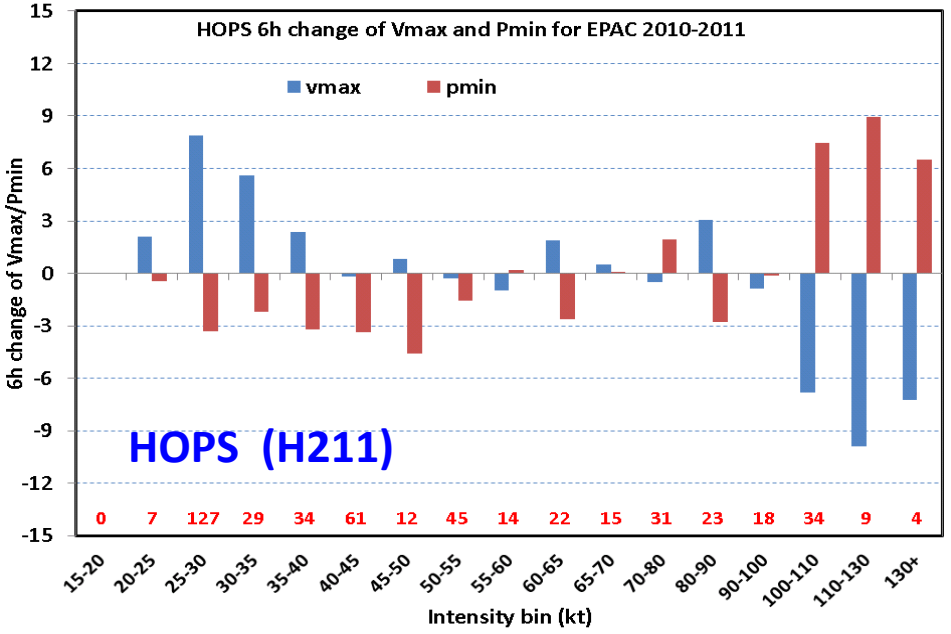
Track errors were comparable (25% improvement at day-5)

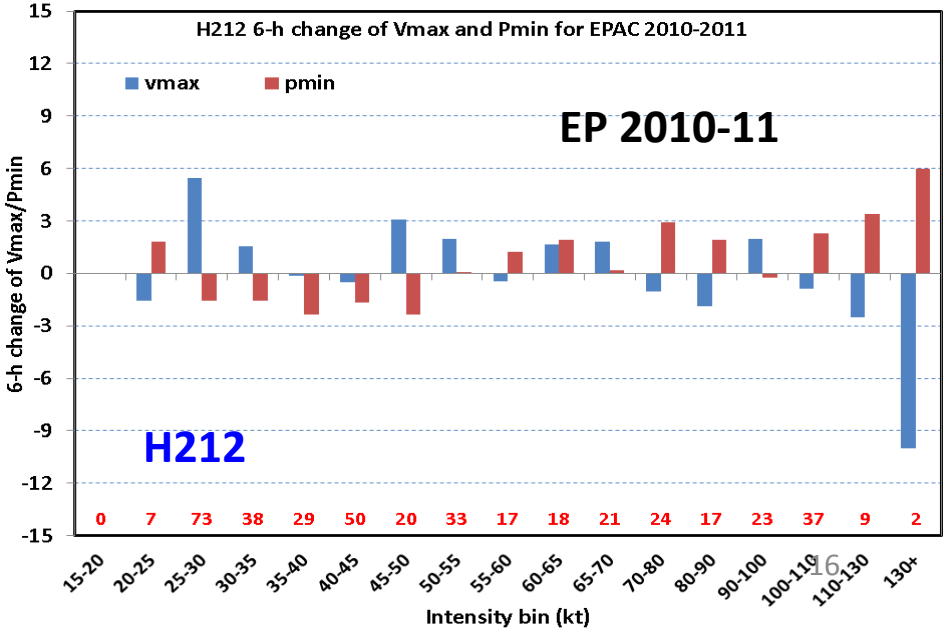
intensity errors showed improvement at day-5 but significant loss of skill at days 2-4

HOPS vs. H212 6-h intensity change

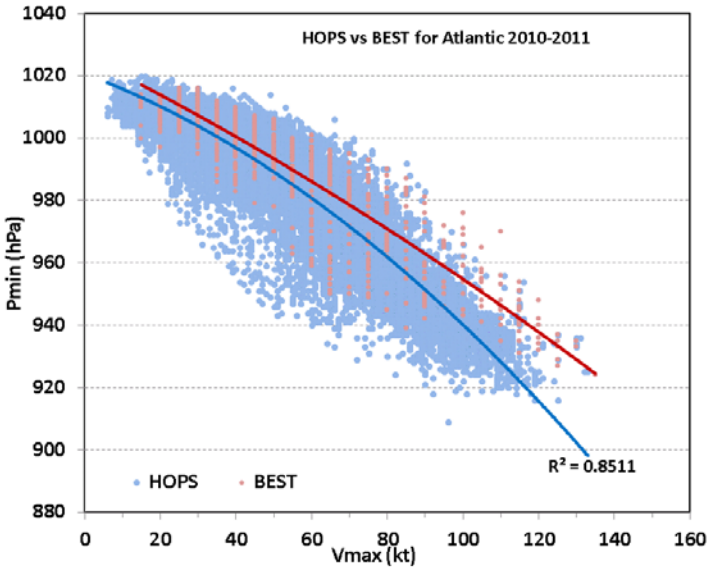




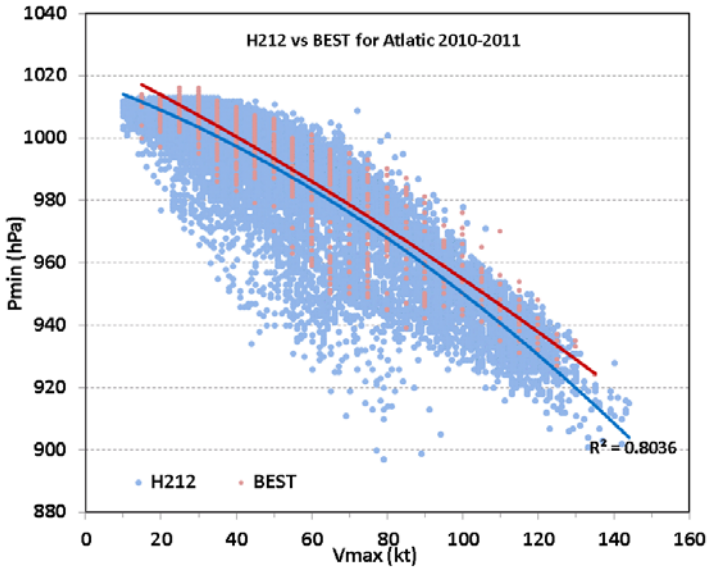


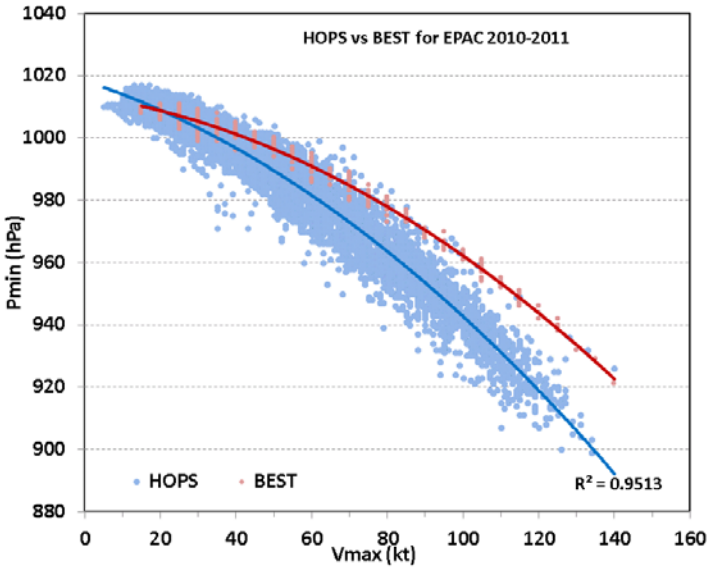


HOPS vs. H212 P-W relationship

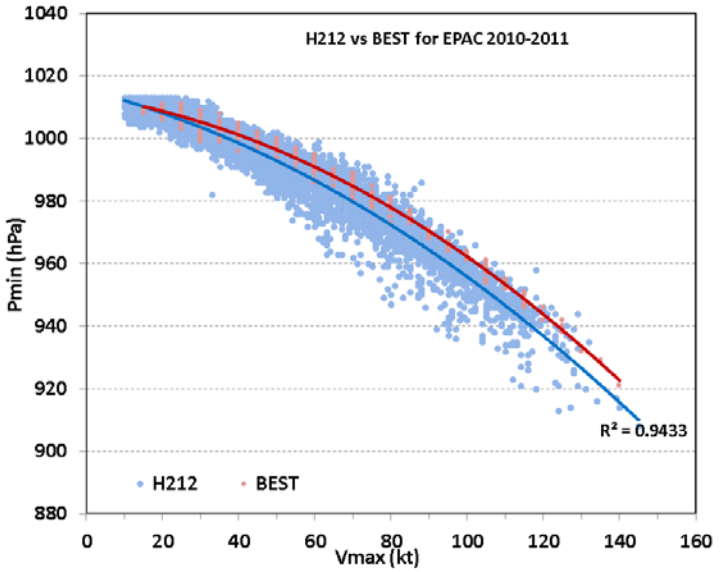


ATLANTIC

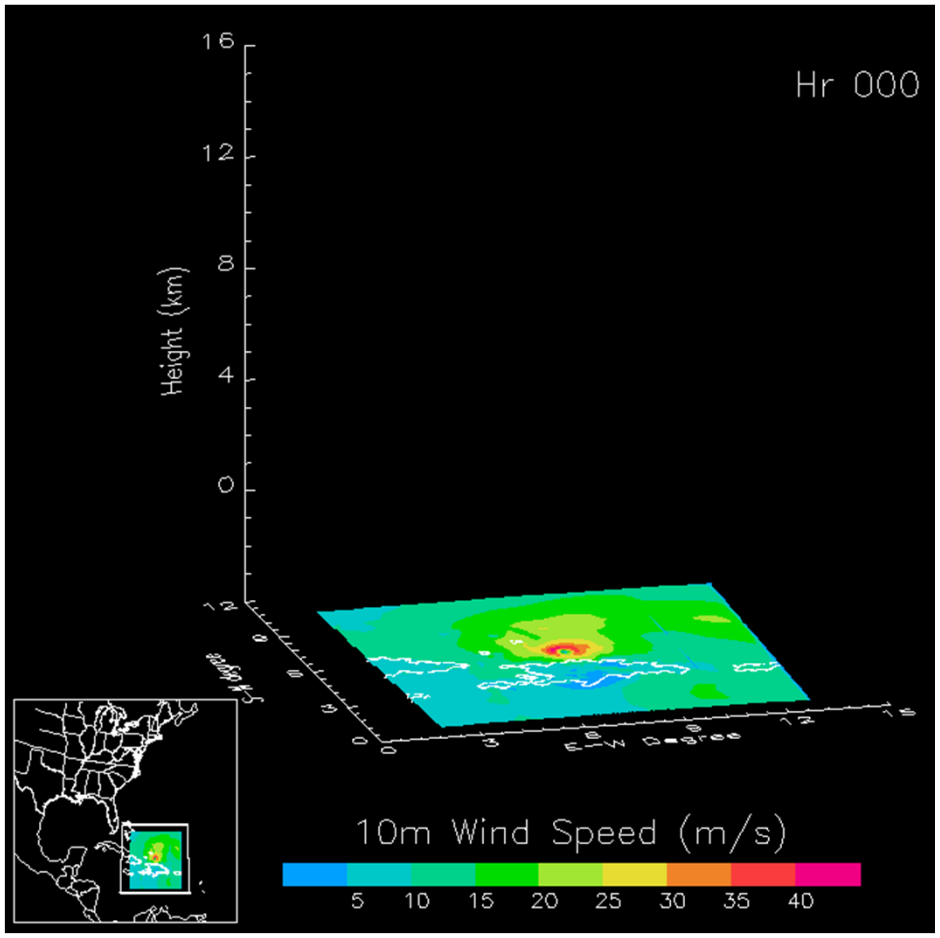




E-PAC

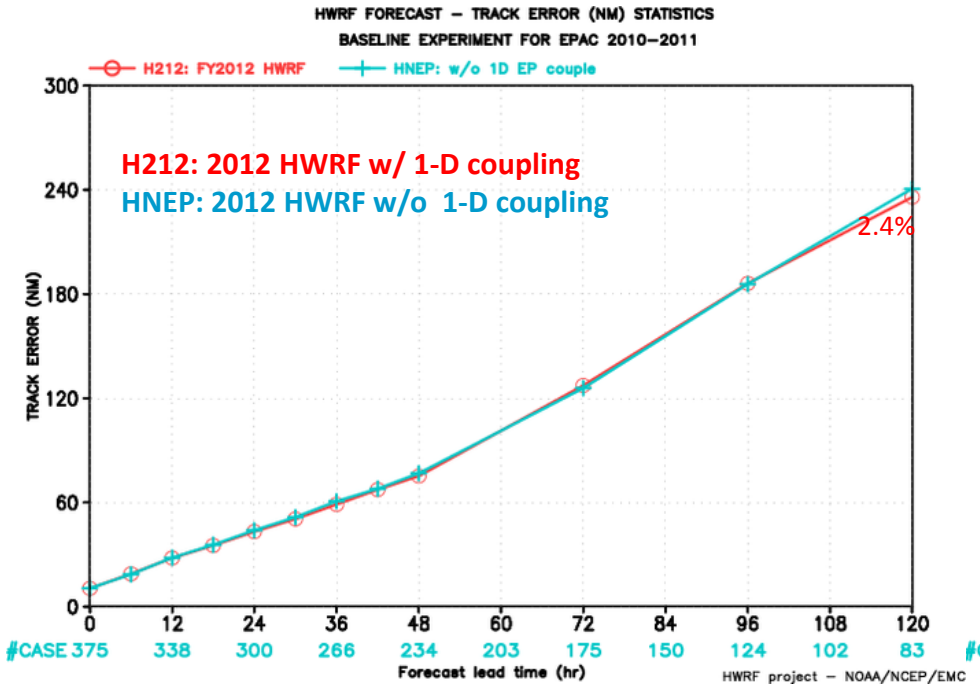


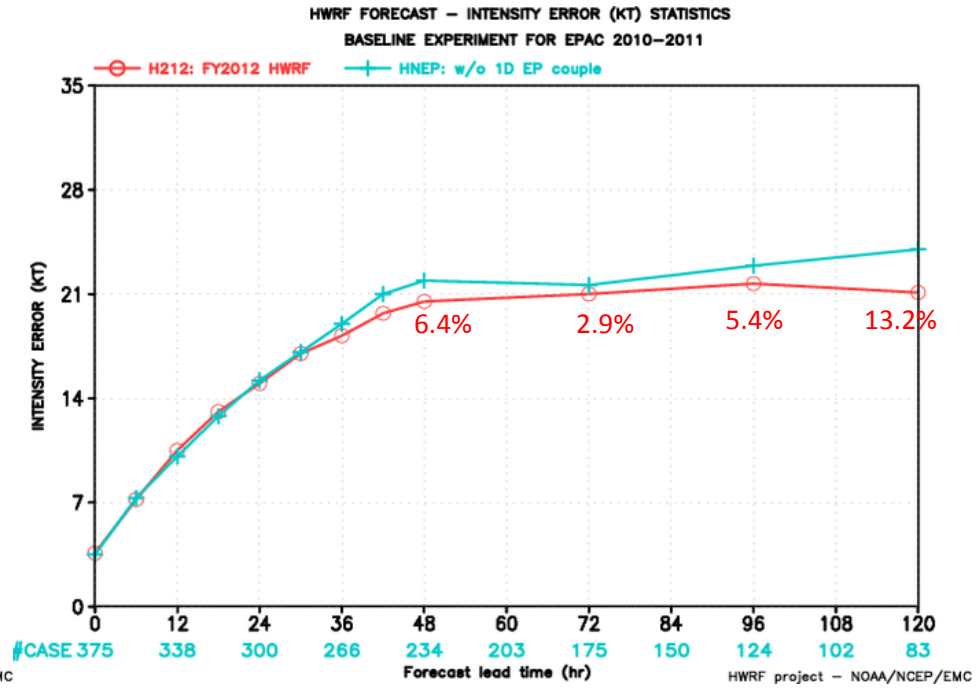
Impact of Physics and Resolution Upgrades

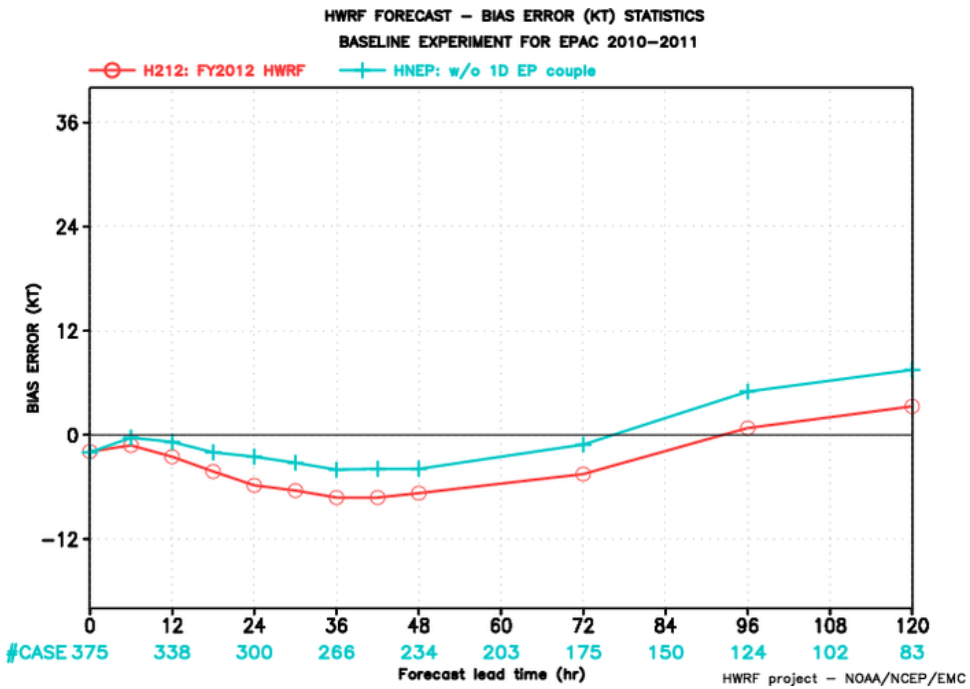


Surface of 10^{-5} kg/kg Total Condensate

Irene 2011082318

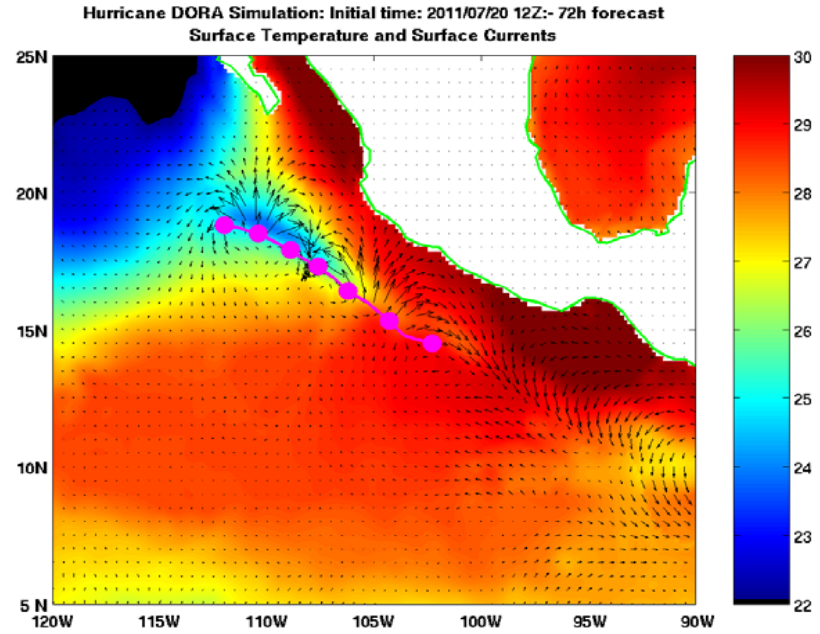




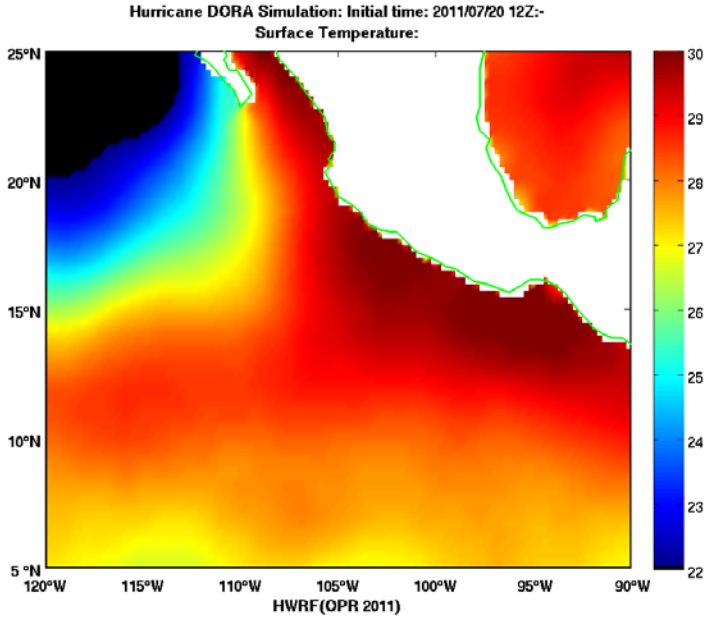


Impact of 1-D Ocean Coupling
E-Pac Storms 2010-2011

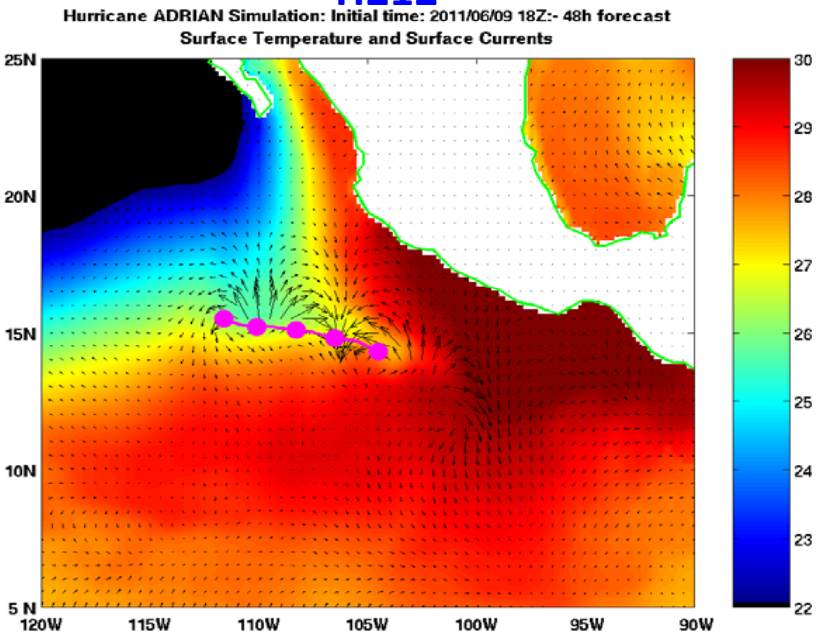
Impact of 1-D Ocean Coupling for E-Pac Storms



Hurricane Dora

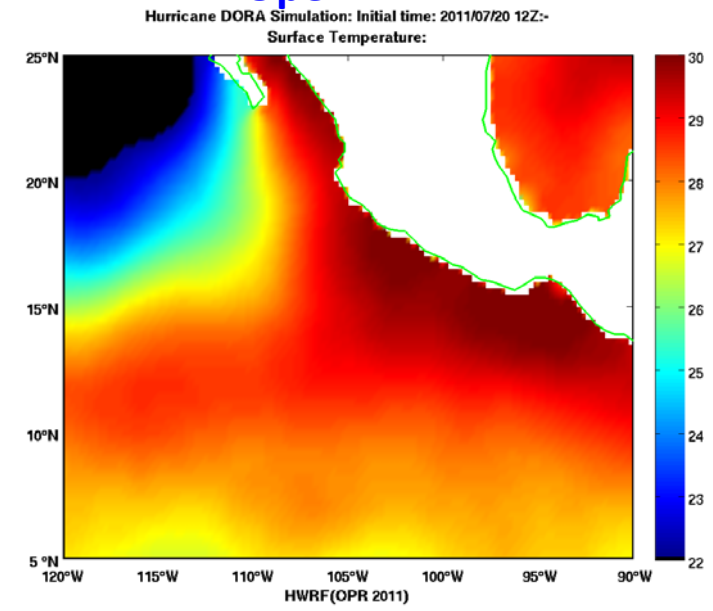


H212



Hurricane Adrian

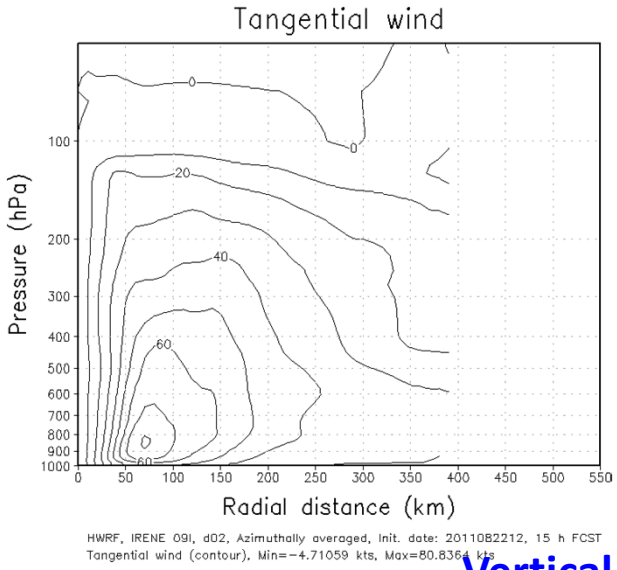
Oper. HWRF

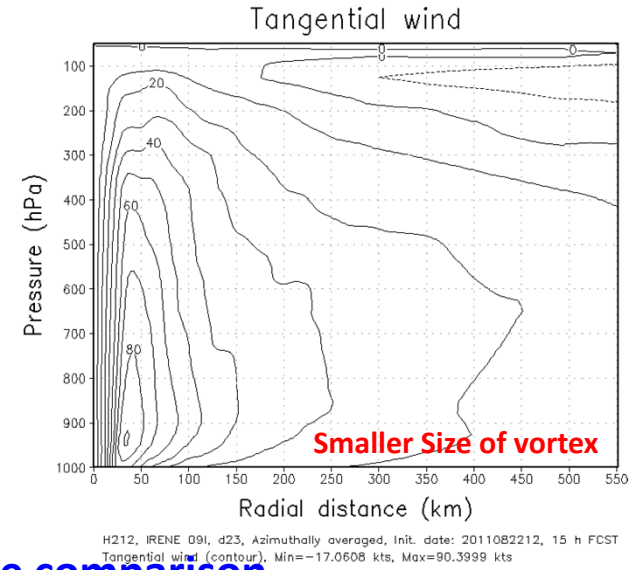


Advanced Vortex Scale Diagnostics

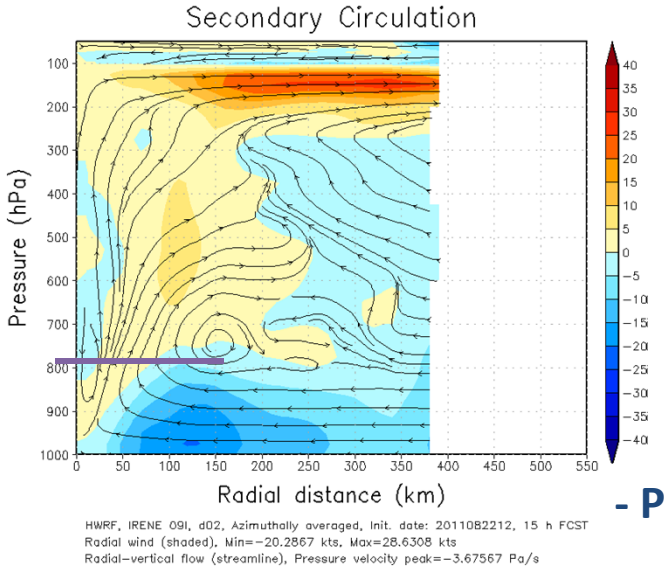
HOPS **H212**

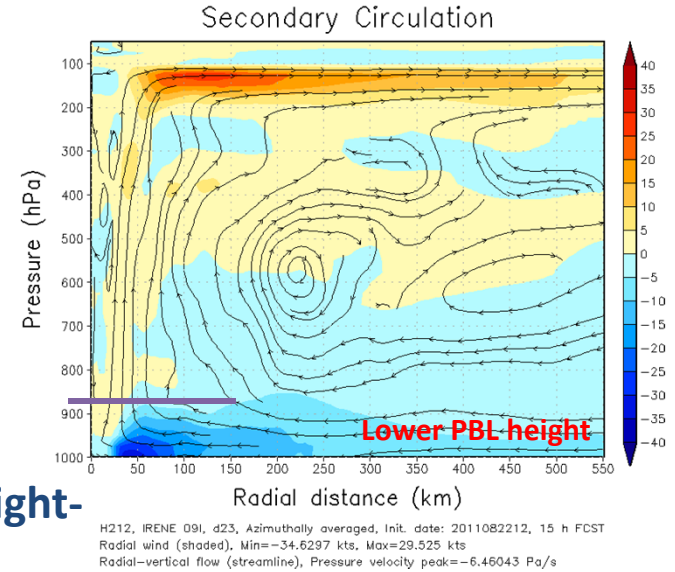
- Wind structure -





Vertical structure comparison
(Irene09L.2011082212 15h forecast)



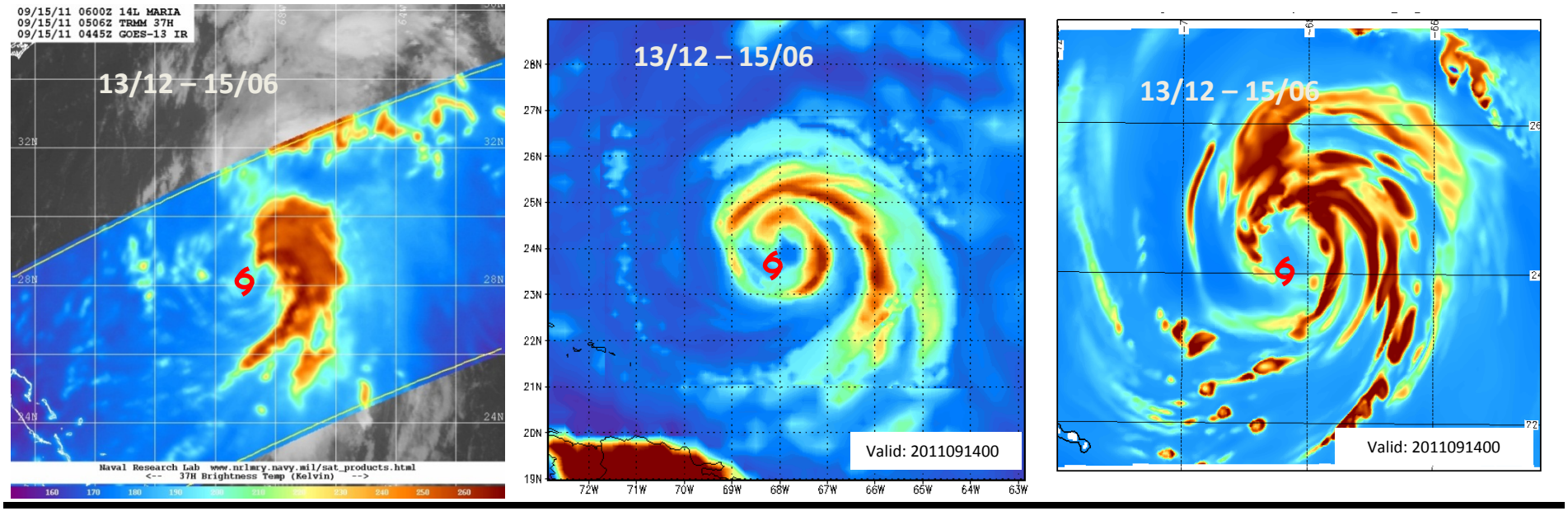


- PBL height-

New experimental products from operational HWRF

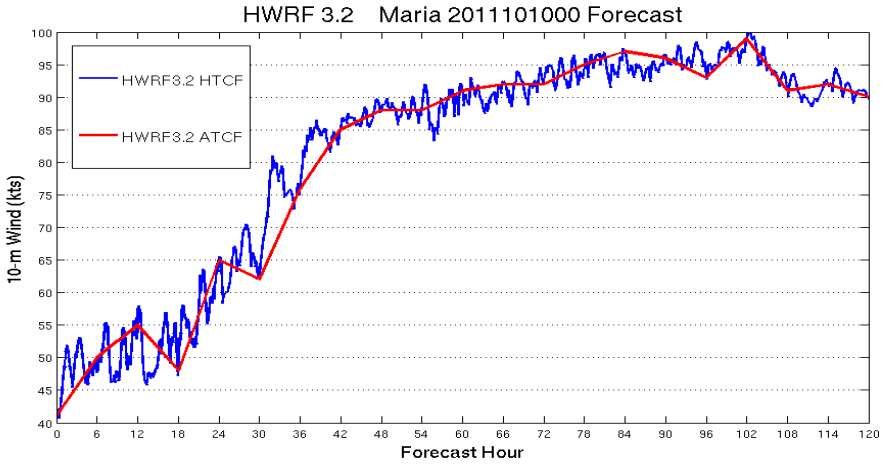
- **Synthetic satellite imagery using a uniform RTM:**
  - GOES-13 and GOES-11 Channel 2,3,4,6
  - SSM/I Microwave 37 GHz and 85 GHz V&H

Observed | **Simulated 9 km HOPS** | **Simulated 3 km HWRF**

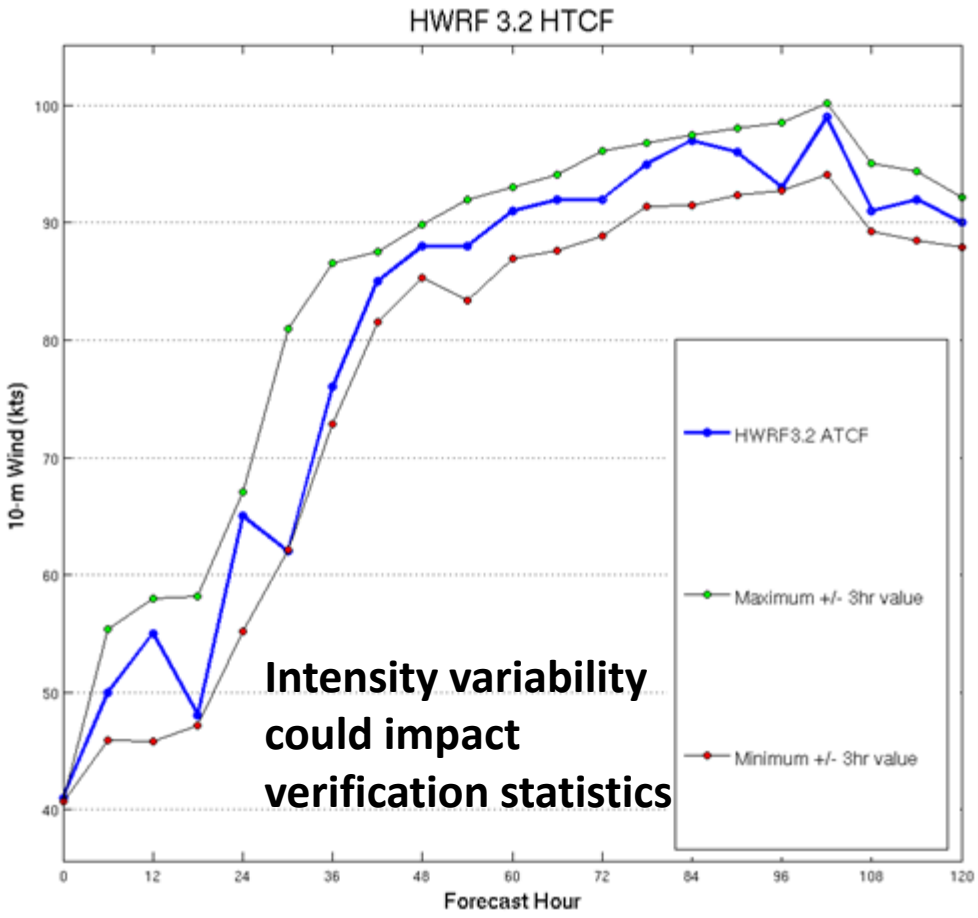


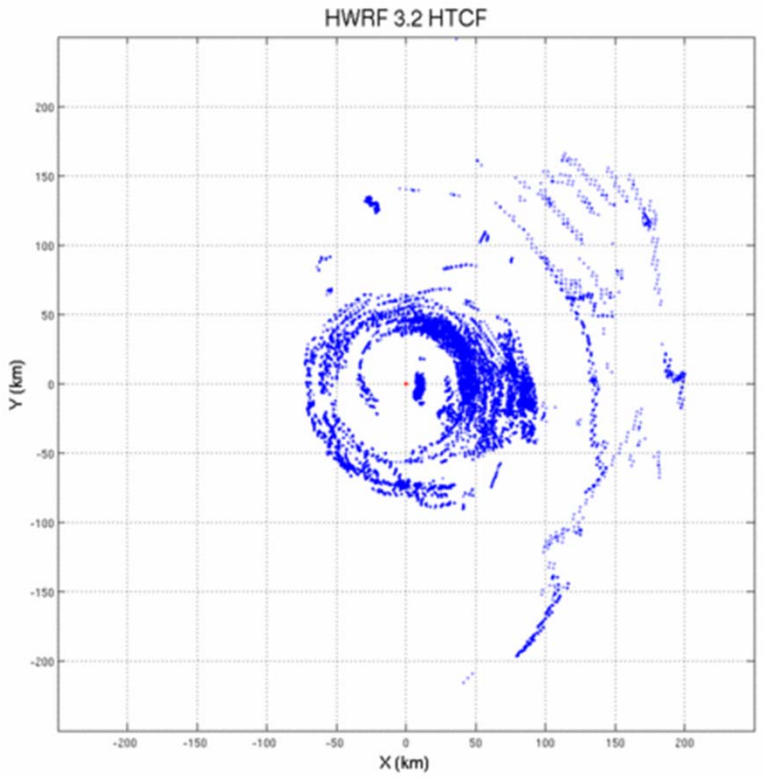
High Temporal Resolution HWRF ATCF-style output at every time step (5 seconds) at 3km resolution

Are 6-hr outputs representative of the actual model forecast? What is happening during development and RI within the model?

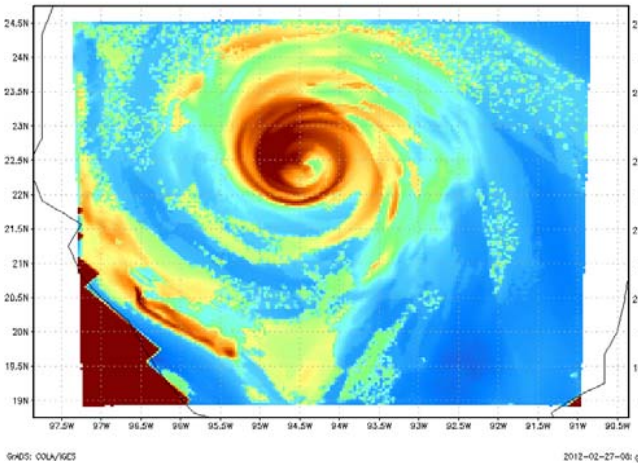


High Temporal Resolution Model Output

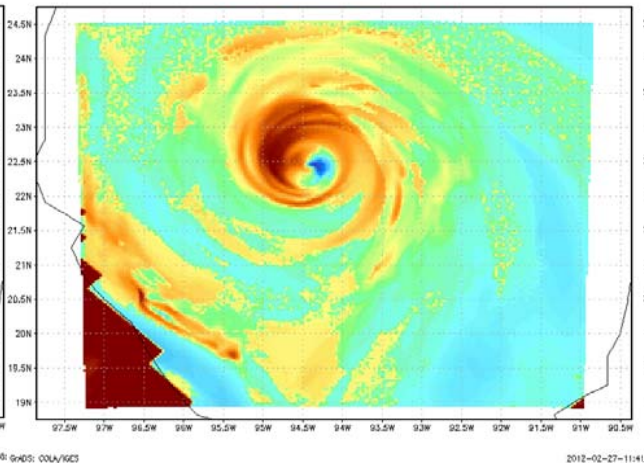




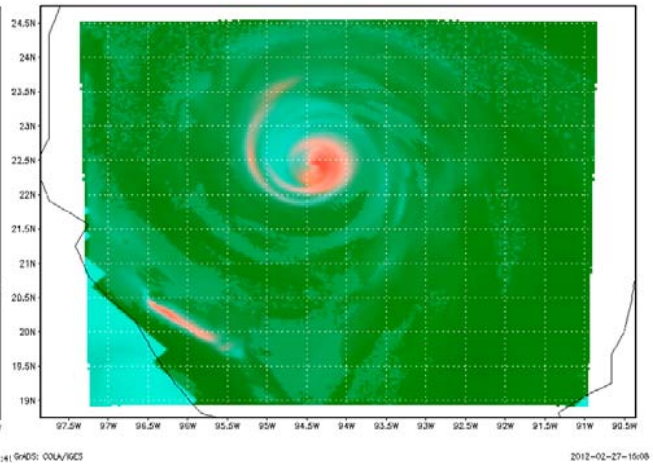
Evaluation of High-resolution structure now possible



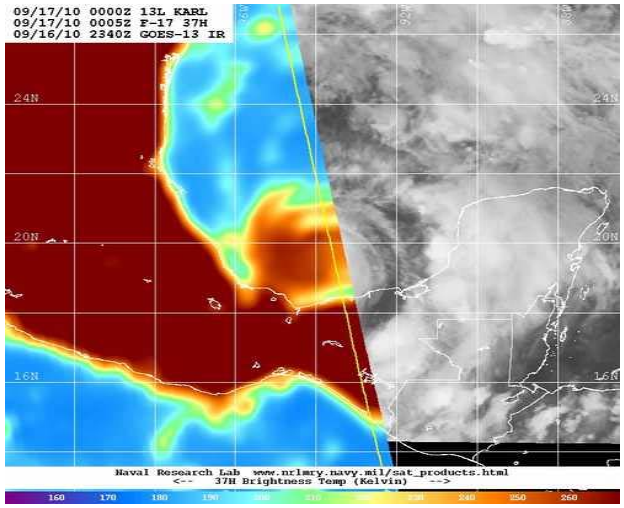
SSMI/S 37 GHz-H

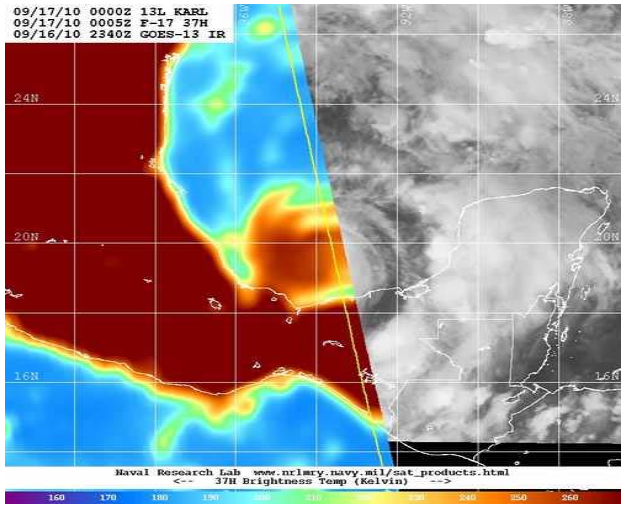


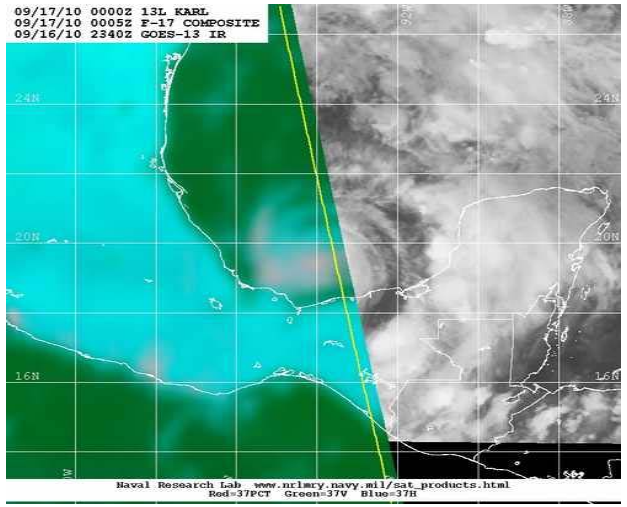
SSMI/S 37 GHz-V



SSMI/S 37 GHz-Color Composite



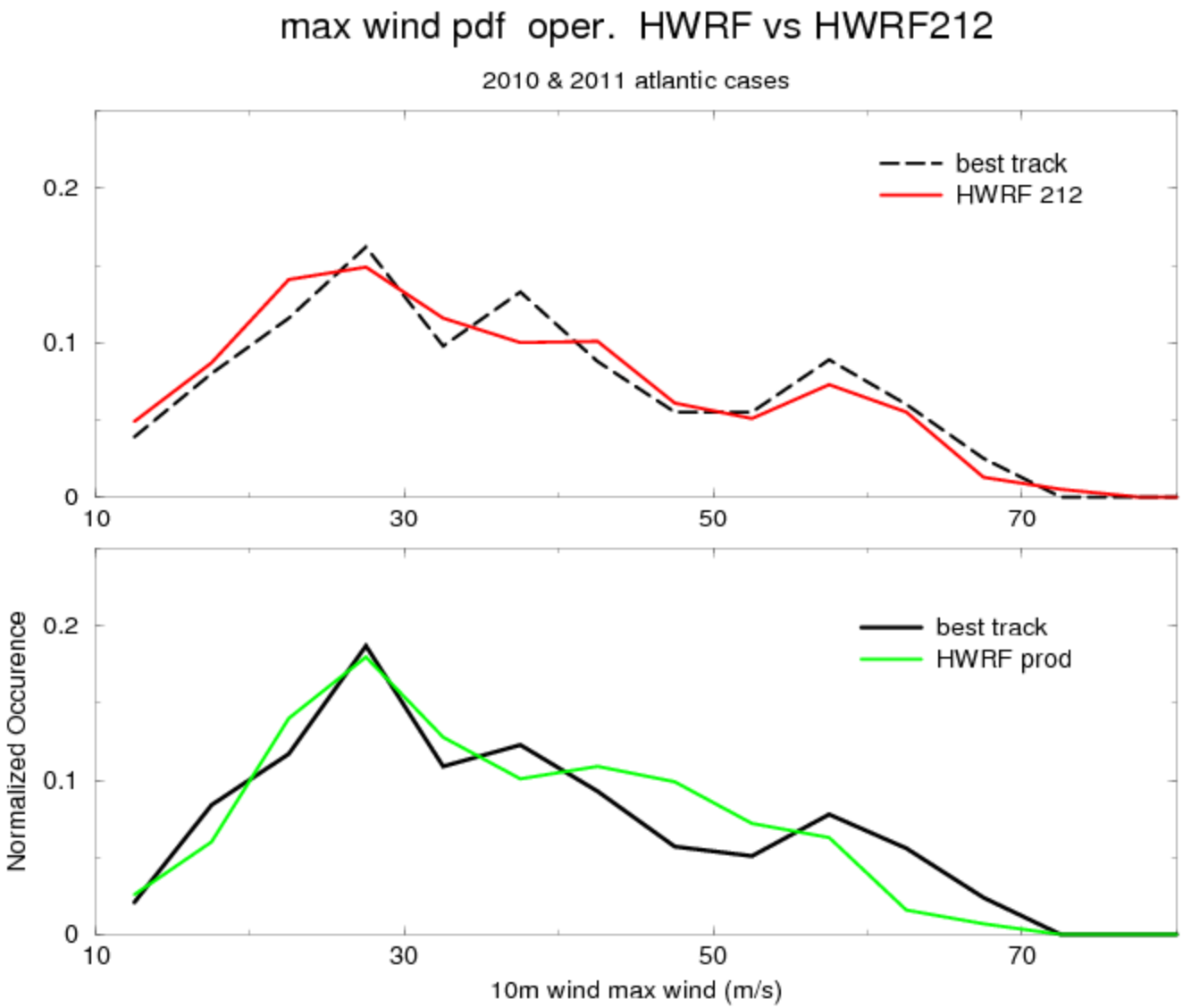




HWRF Generated SSM/I S Microwave Imagery (new operational product)

-- Courtesy: Dave Zelinsky, NHC

Maximum wind PDF

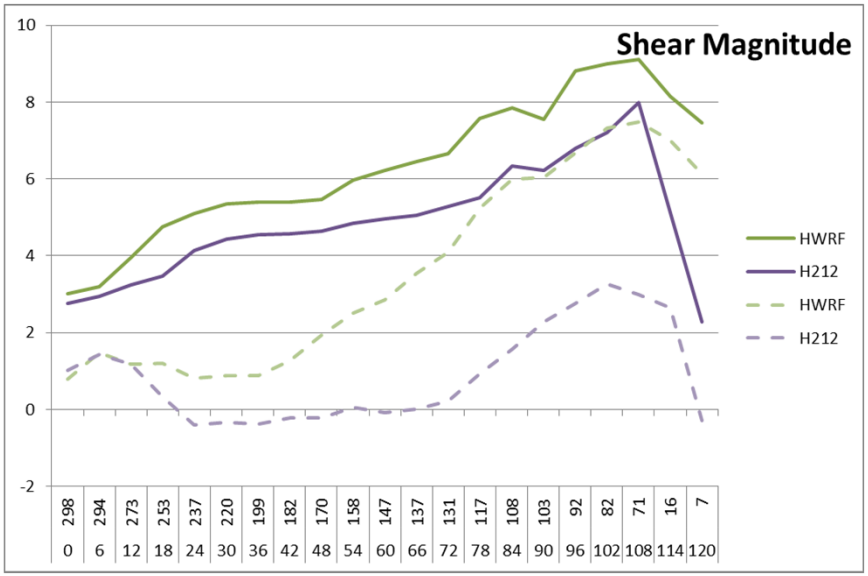


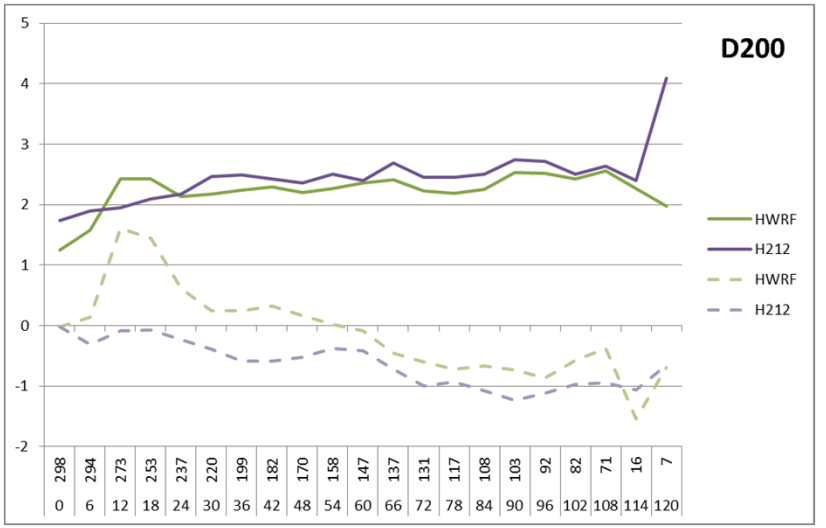
Extended HWRF Verification

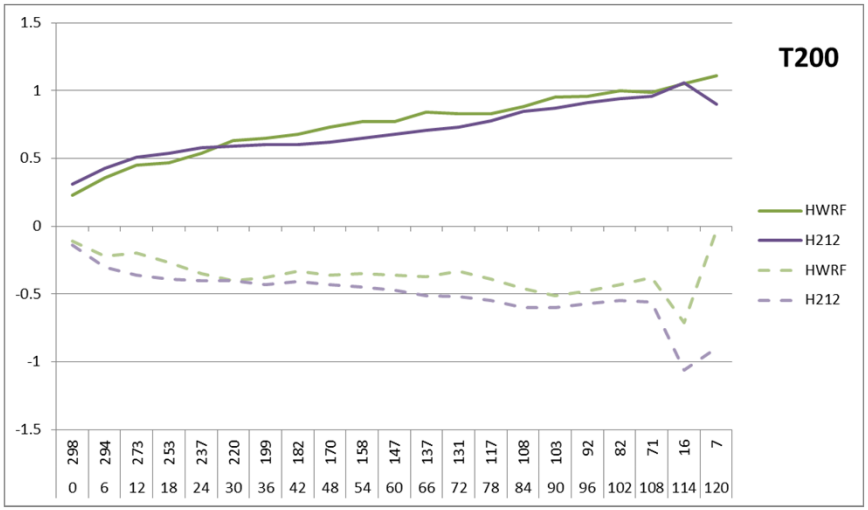
- Storm environmental variables
  - Verify parameters identified in SHIPS model to have correlation with intensity changes
  - 200-850 hPa vertical shear (0-500 km radius)
  - 200 hPa divergence (0-1000 km radius)
  - Mid-level relative humidity (700-500 hPa, 200-800 km radius)
  - 200 hPa temperature (200-800 km radius)

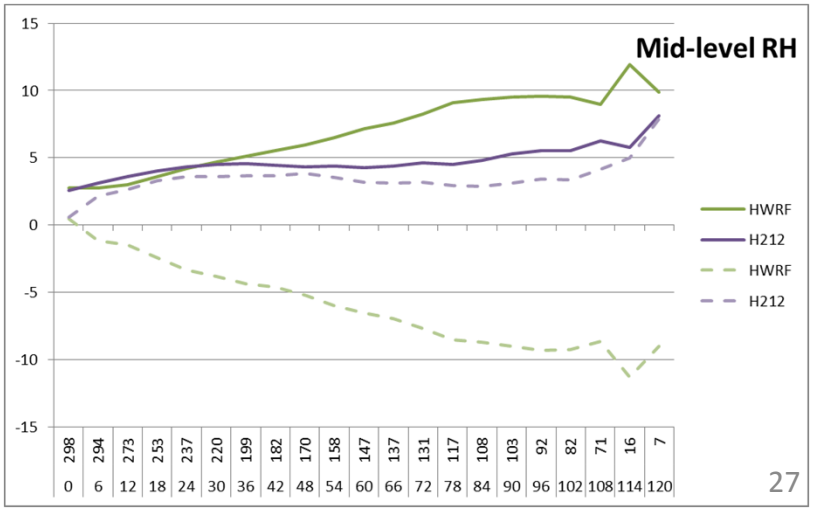
- Cloud top IR brightness temperatures
  - Compare synthetic GOES imagery from HWRF to real GOES data
  - GOES channel 3 (water vapor) and 4 (window channel)
  - Mean absolute error, bias, brightness temperature histograms

Comparison of Operational HWRF and H212 for 2010-2011 Atlantic Cases

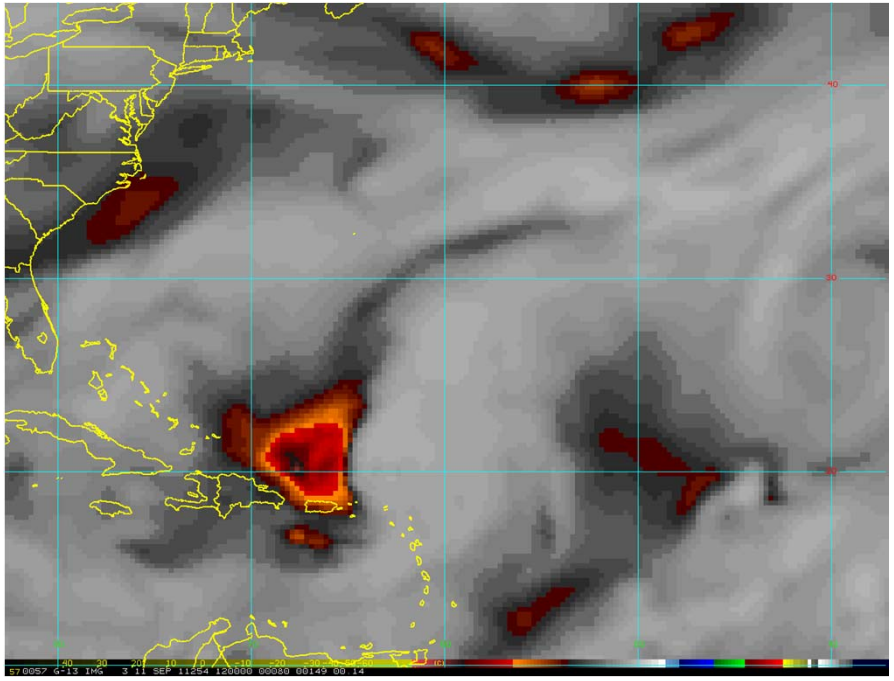




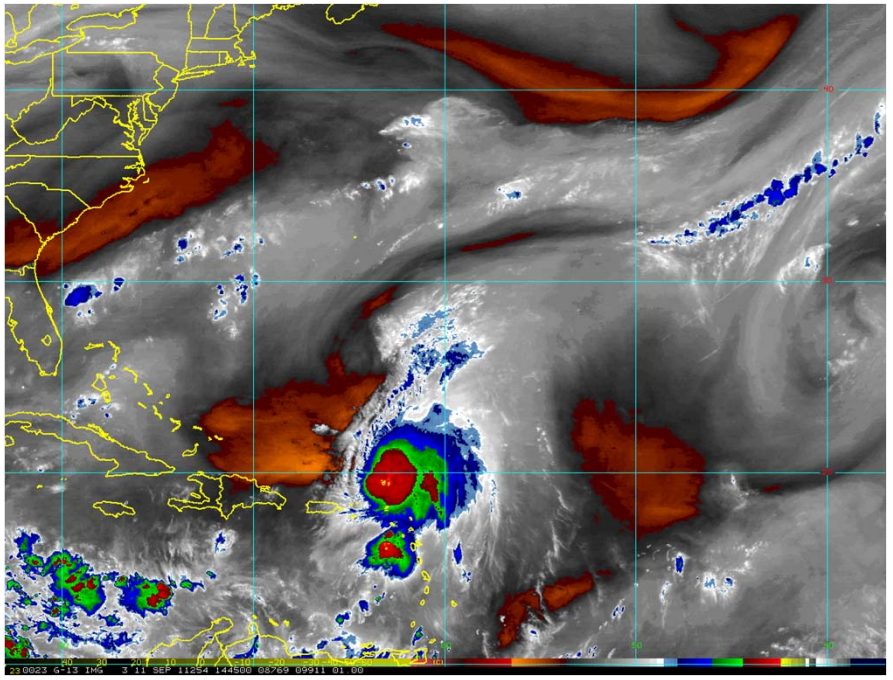




IR Channel 3 Example for Operational HWRF Maria forecast

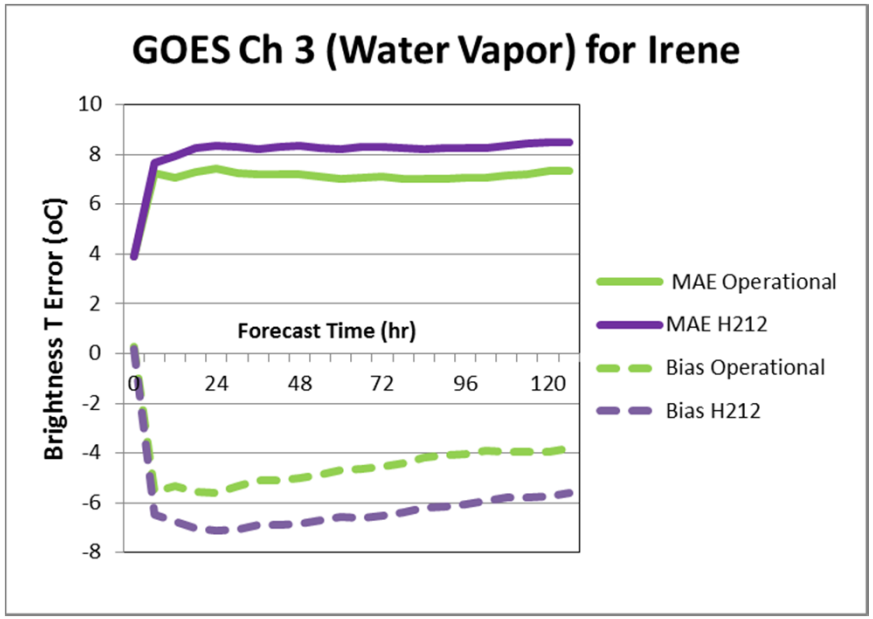


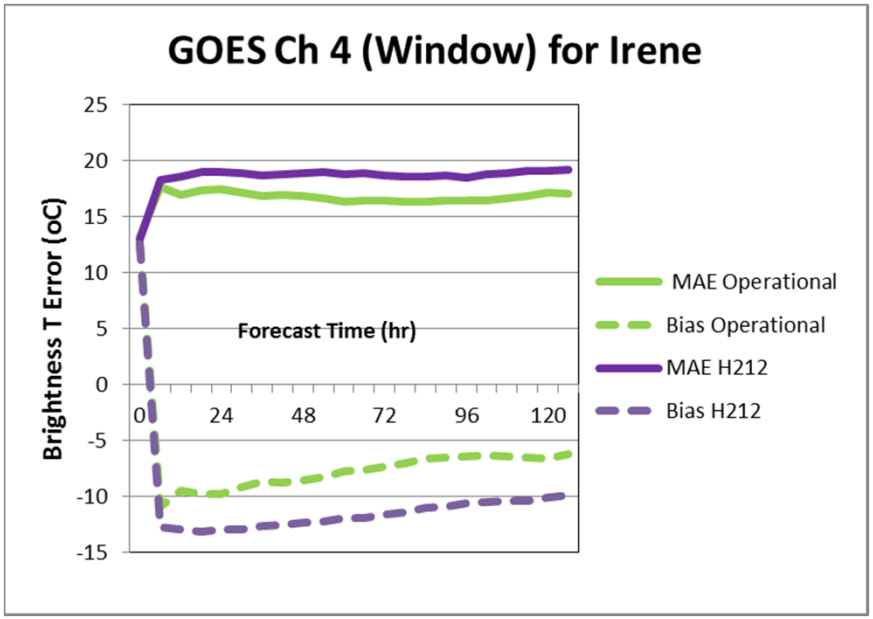
Synthetic



Real

Validation of GOES Ch3 and Ch4 for Hurricane Irene Forecasts





Note: Higher resolution of HWRFGOES data for H212 (0.1 deg) than operational (0.25 deg) may partially explain colder H212 bias

Summary

- Track forecast skills of H212 improved significantly over both 2011/2010 seasons on **Atlantic basin** with about **20-25% improvement** against HOPS
- Track forecast skills of H212 of **Eastern Pacific basin** also improved maximum **25%** over the HOPS in 2011 season, but **little degradation at day 4 and 5 in 2010 season** mainly due to Hurricane Frank
- **Intensity forecast** improvement is not as impressive as track improvement, but show **overall improvement**. The biggest improvement of intensity is 2011 EP basin with over 40% to HOPS. However, **significant improvements in intensity bias** is noted for both Atlantic and Eastern Pacific, for both 2010-2011 seasons.
- On top of track and intensity skill, **the storm size and structure** of H212 improve as well, in terms of radii verification and evaluation of PBL height
- The problem of **wind-pressure relationship** in high wind speed regime also significantly improved in H212
- **With high resolution and improved physics, we are laying foundation for improved intensity predictions through improved storm structure.**

Evaluation and Recommendations from NHC & EMC

- **All HWRF FY2012 T&E was conducted in close collaboration with NHC with weekly updates.**
- **Evaluation and Recommendation from Richard Pasch, Senior Hurricane Specialist at NHC:**
- ***The National Hurricane Center approves of the upgrades to the HWRF Model proposed for the 2012 hurricane season. A major accomplishment was the development of a third nest, at 3 km resolution, to cover the inner core and most of surrounding circulation of the storm. This would make the HWRF model the highest resolution hurricane model ever implemented for operations in the National Weather Service. Other changes to the model include a bug fix to the nesting scheme, the inclusion of ocean coupling in the eastern North Pacific, upgrades to models physics such as shallow convection and improvements to the planetary boundary layer formulation. Reruns of the model on a large number of tropical cyclone cases from the 2010 and 2011 Atlantic and east Pacific hurricane seasons generally show significant improvements to track and storm size forecasts. Some reductions in intensity forecast errors were noted, with a significant reduction of a high bias for weak storms.***
- ***Based on these results, we recommend implementation of this new version of the HWRF model for the 2012 season.***
- **EMC Director approved implementation of suggested upgrades/ enhancements to operational HWRF system for the 2012 hurricane season**

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

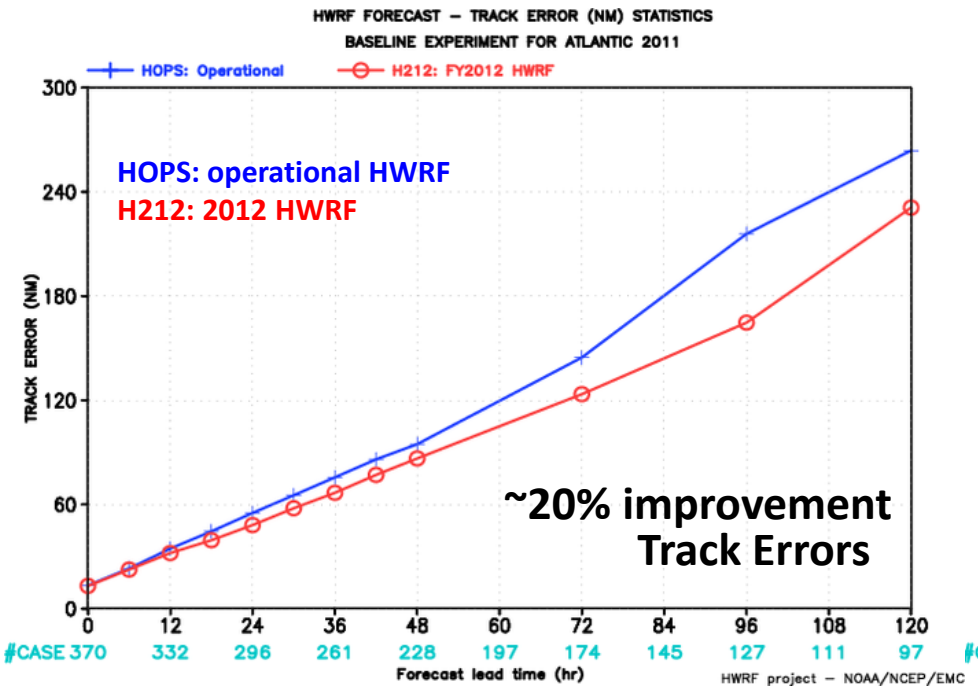
EMC and HFIP Management

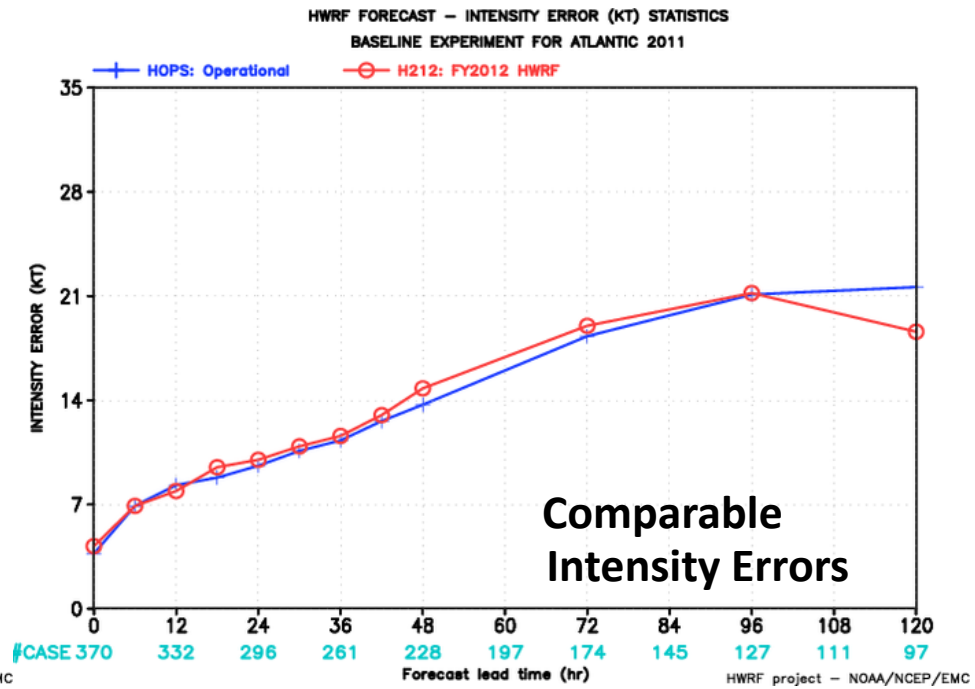
Collaborations with NHC, DTC, HRD, GFDL, URI, CIRA and other HFIP partners

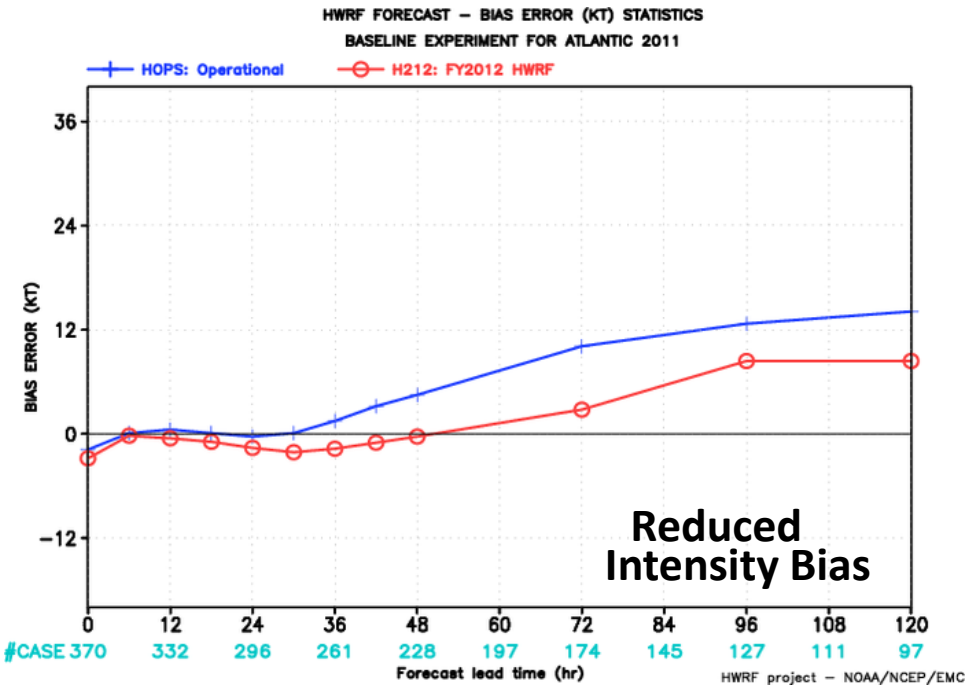
Supplemental Material

- Composite Track Plots:
  - http://www.emc.ncep.noaa.gov/HWRF/weeklies/MAR12/h212_composite_tracks.pptx
- Composite Intensity Plots:
  - http://www.emc.ncep.noaa.gov/HWRF/weeklies/MAR12/h212_composite_intensity.pptx
- Stats for individual storms:
  - http://www.emc.ncep.noaa.gov/HWRF/weeklies/MAR12/h212_individual_stats.pptx
- Additional diagnostics:
  - Ryan Torn/Vijay: Extended evaluation of H212 track, intensity and structure
  - Mark DeMaria/Janna O'Connor: SHIPS based diagnostics (large-scale) and GOES BT verification
  - Jonathan Vigh/Chanh Kieu: Environmental and vortex scale diagnostics based on VDMs
  - Stan Goldenberg/Young Kwon: Stratification of storms based on initial intensity
  - Dave Zelinsky/Wallace Hogsett: RI verification, Diagnostics of Microwave imagery

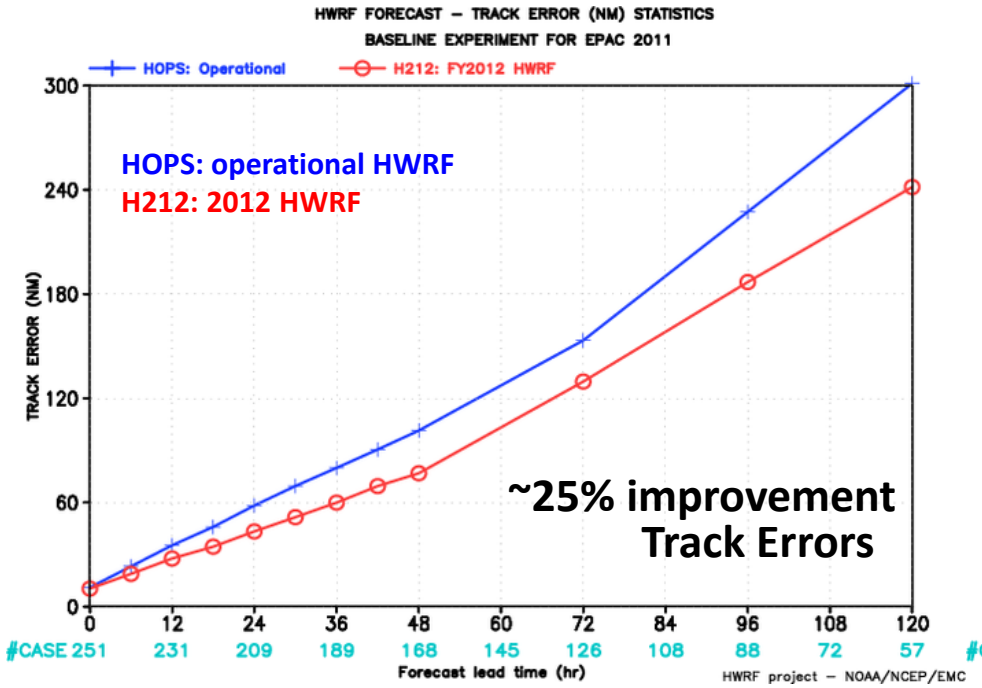
Performance of H212 for Individual Hurricane Seasons

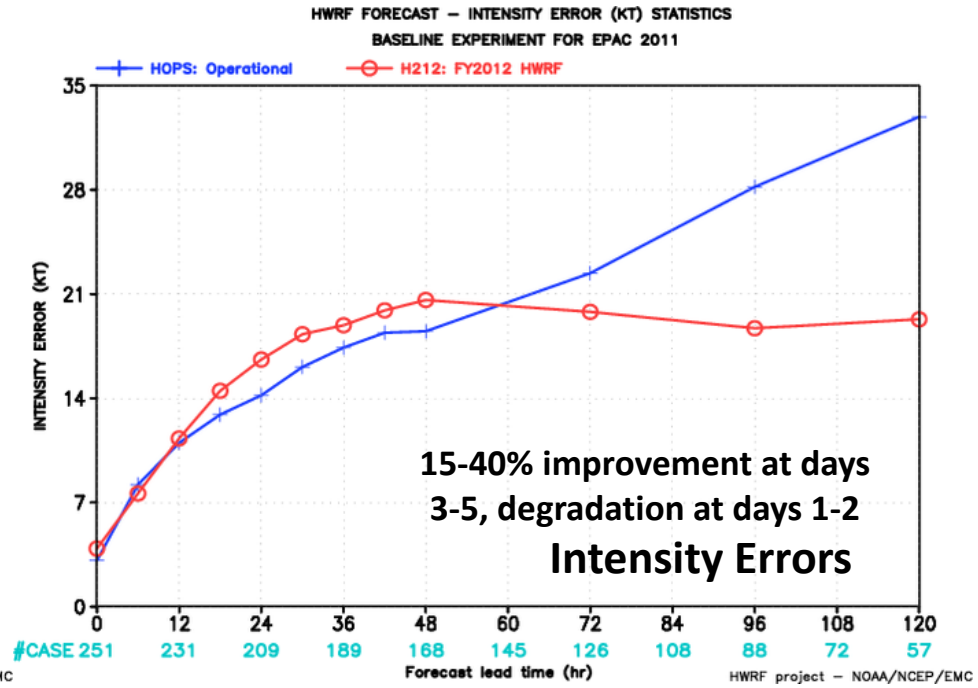


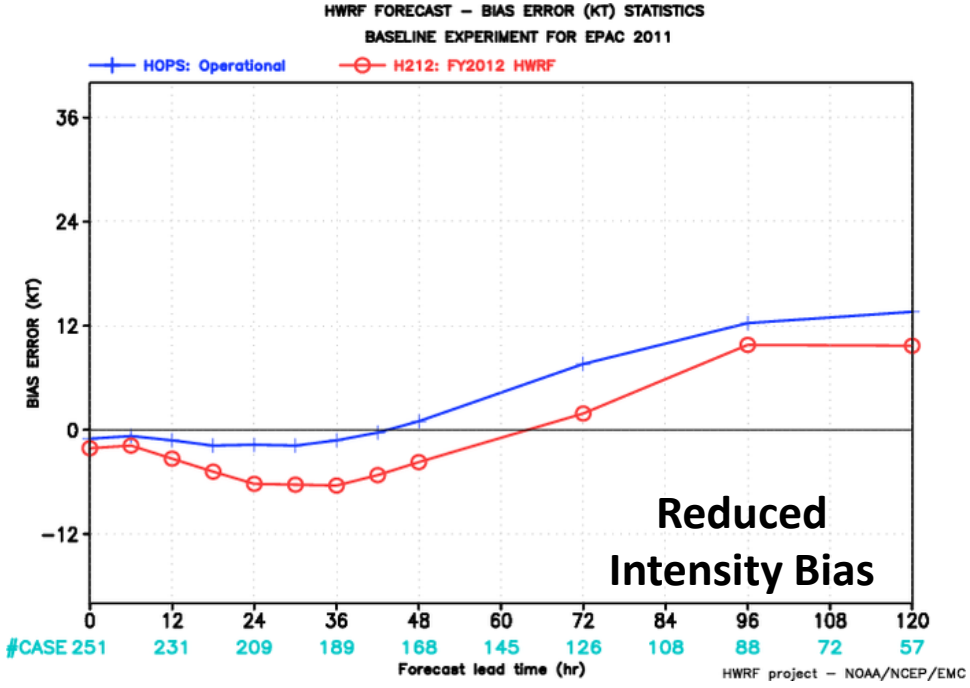




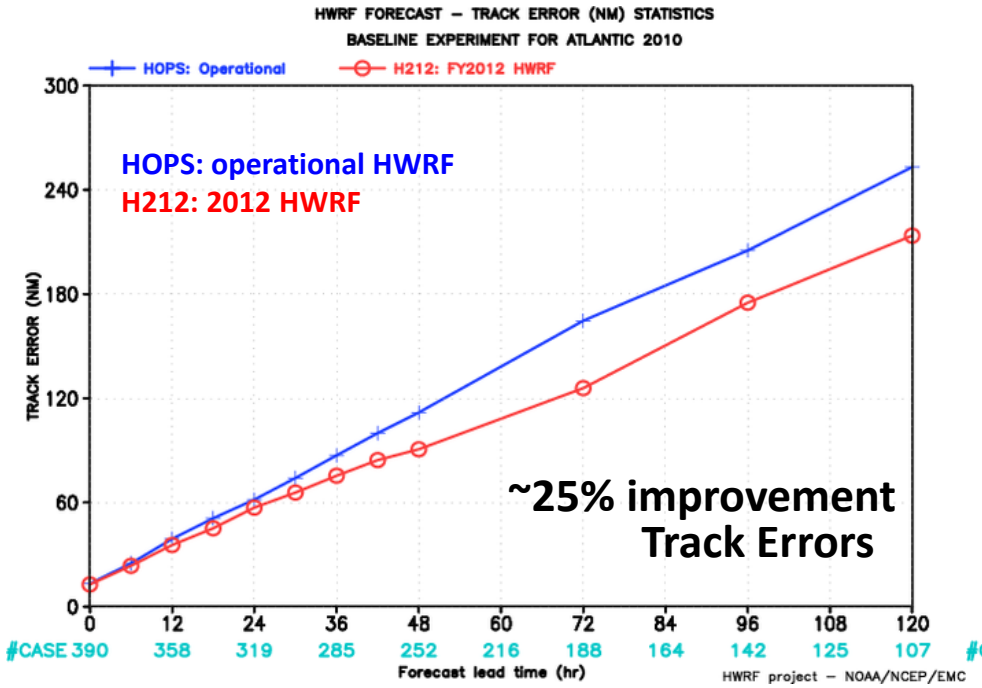
2011 Atlantic using
FY2012 Hybrid GSI/GFS

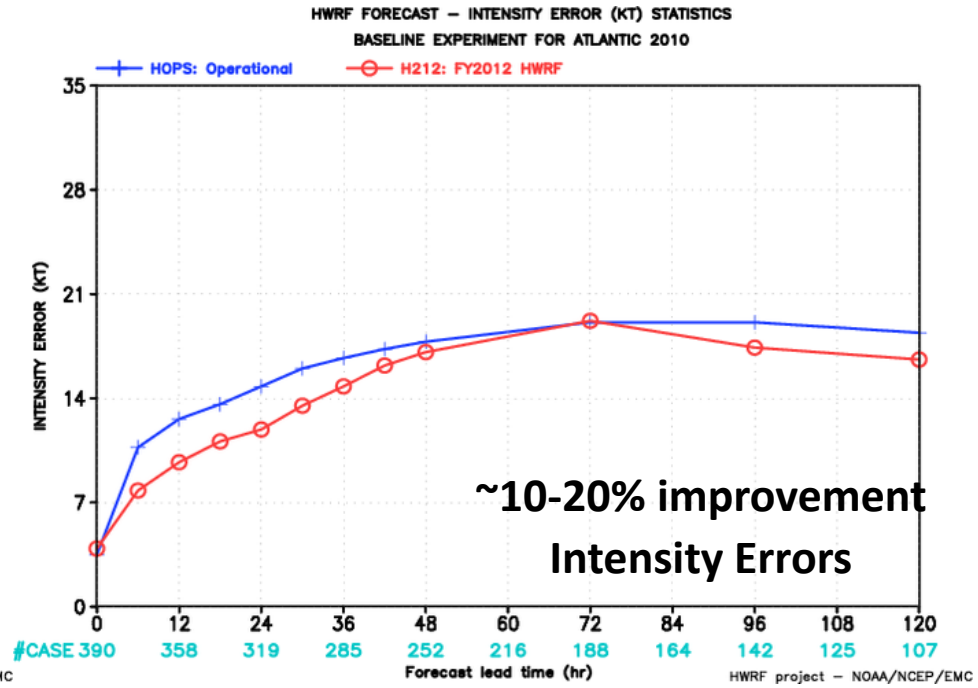


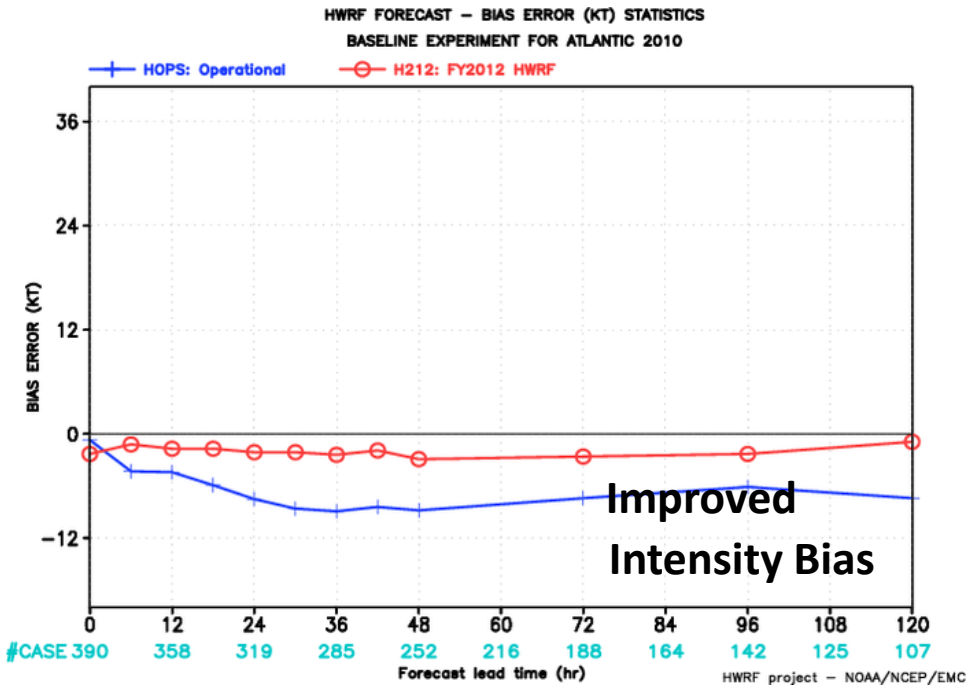




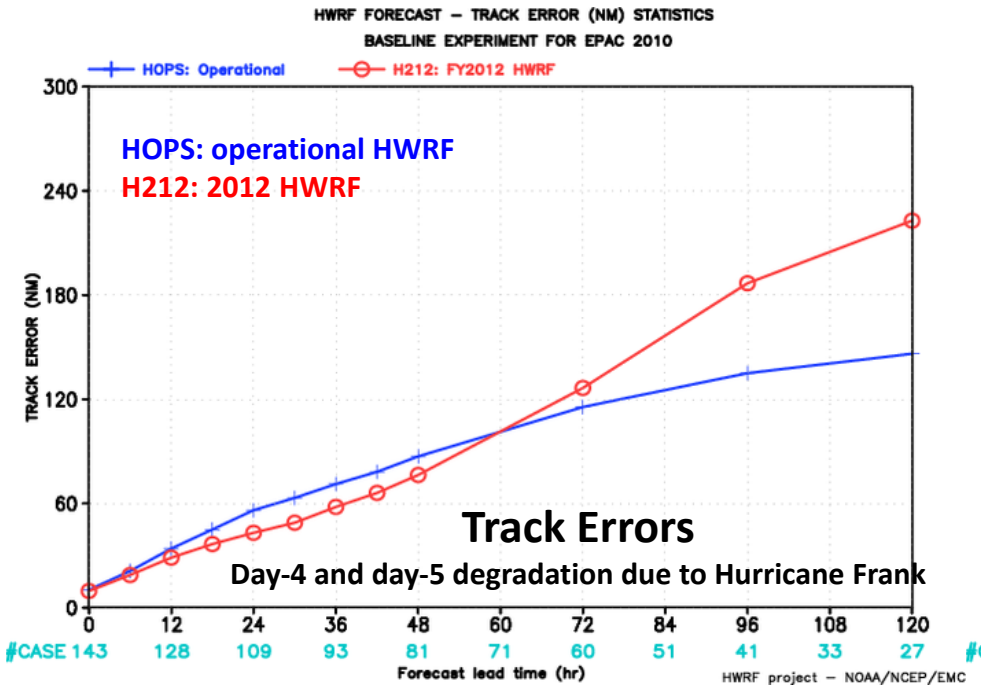
2011 E-Pac using
FY2012 Hybrid GSI/GFS

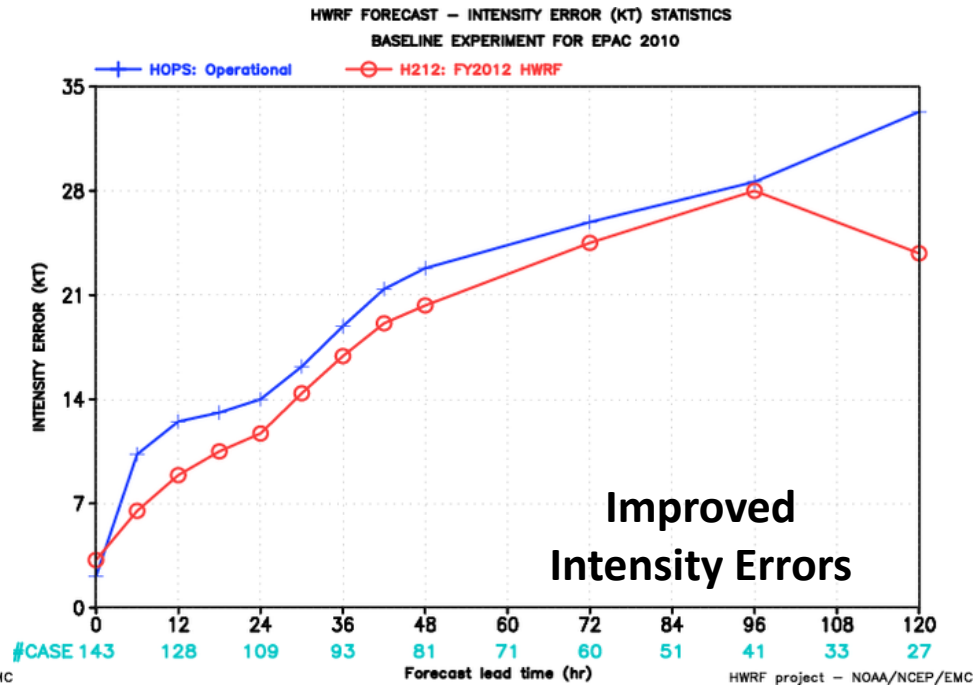


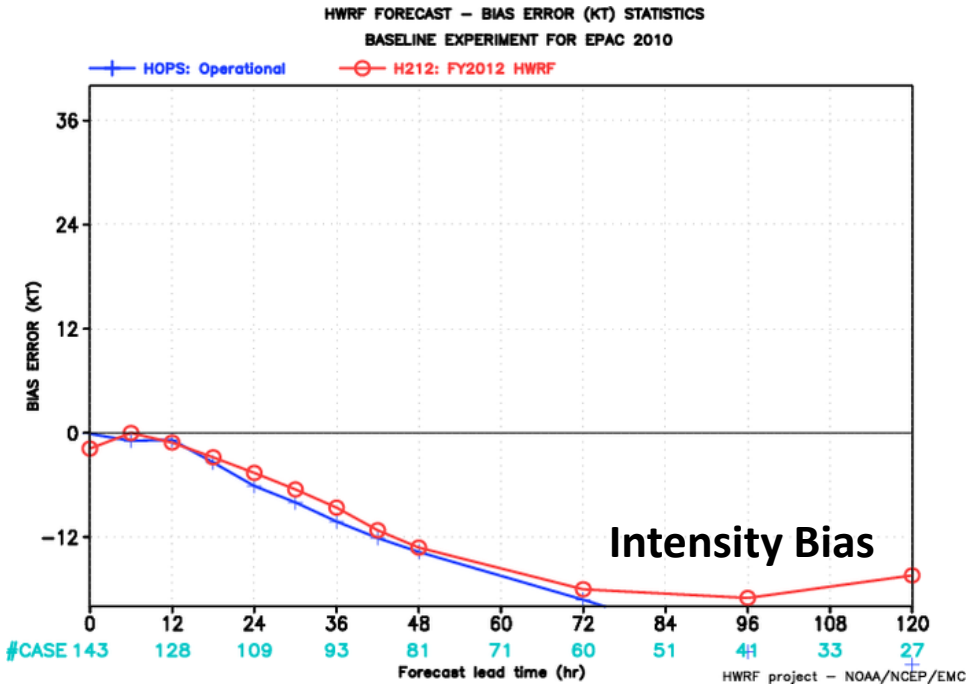




2010 Atlantic using operational GFS

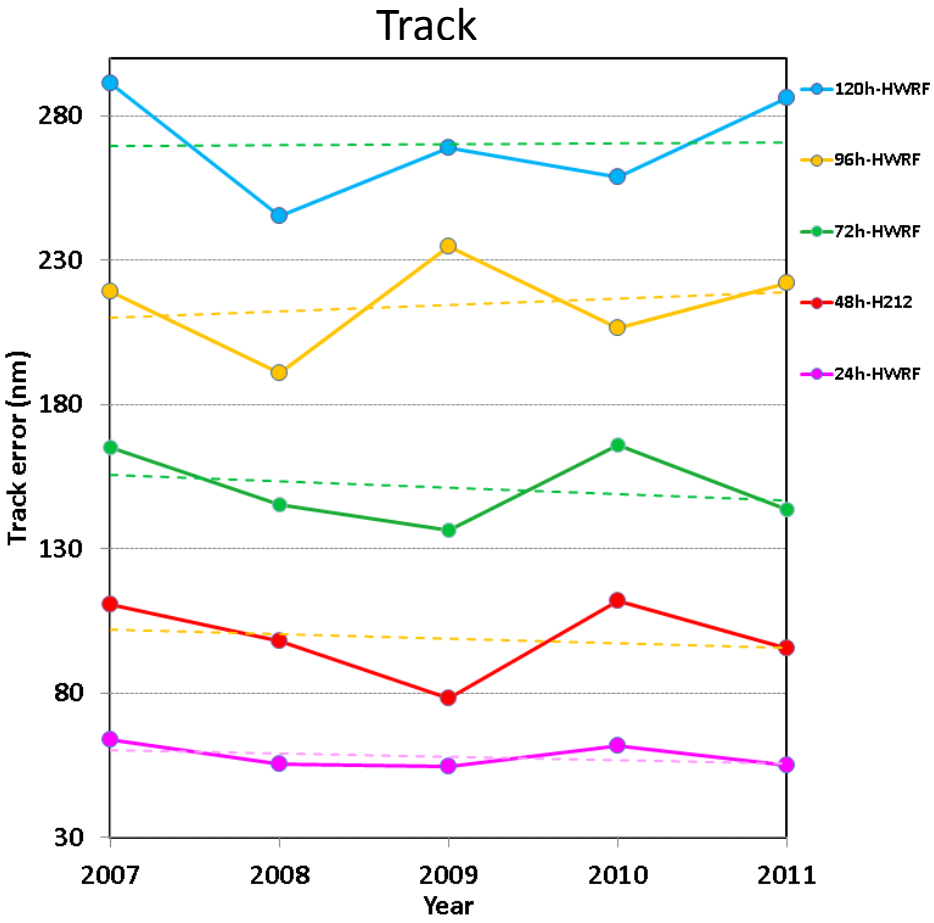


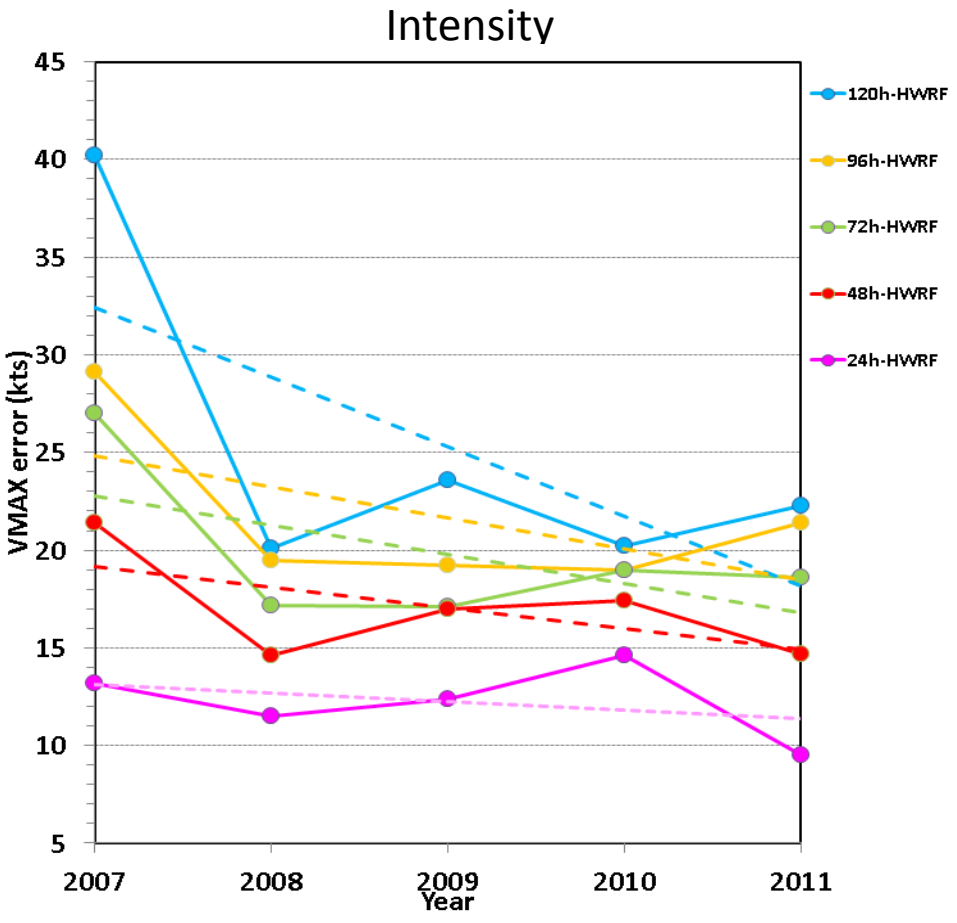




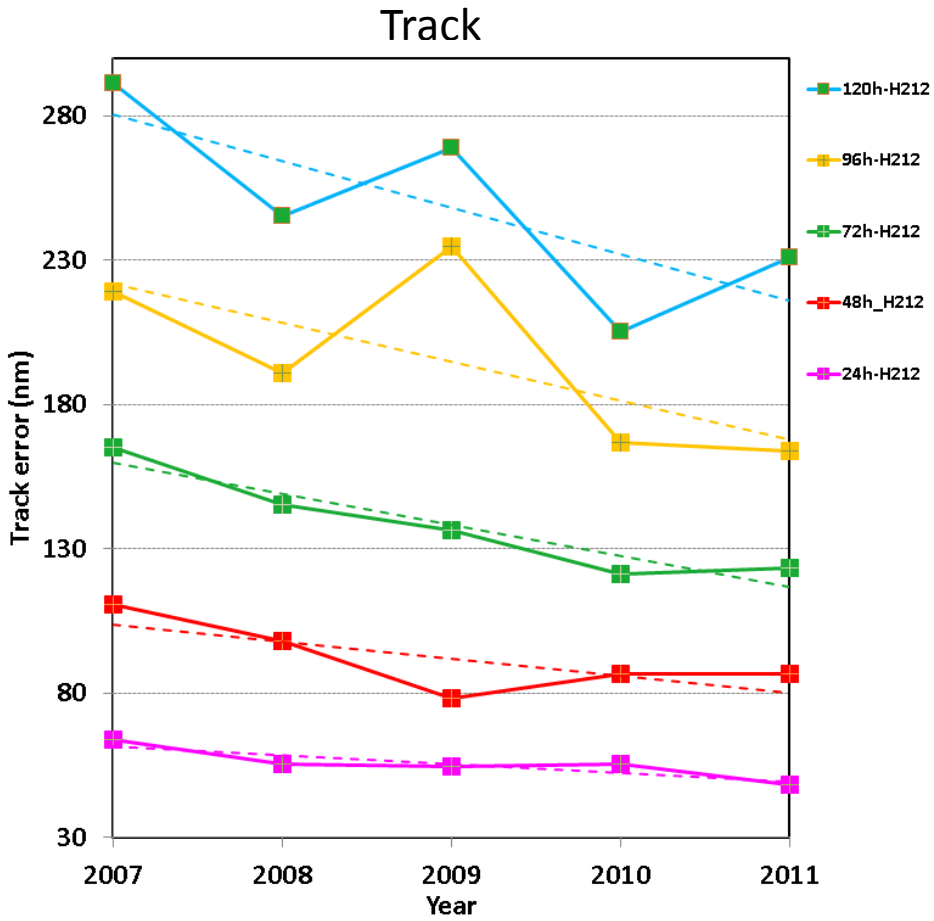
2010 E-Pac using operational GFS

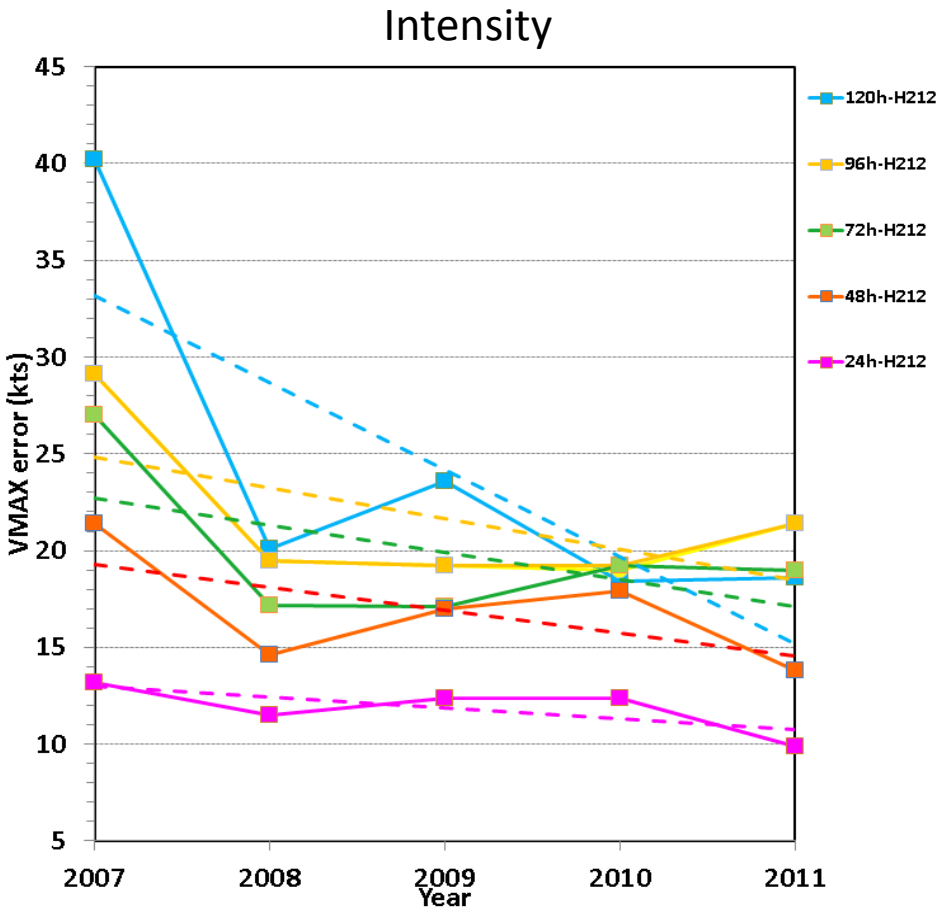
Atlantic basin 2007-2011: HWRF



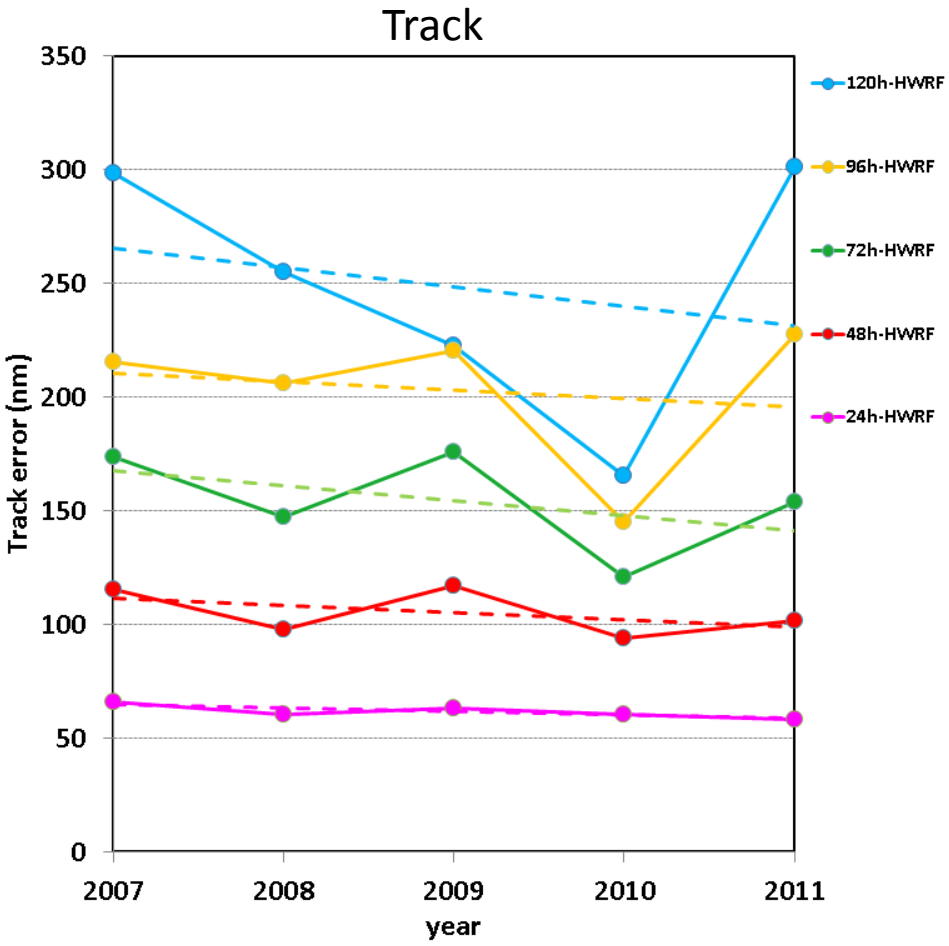


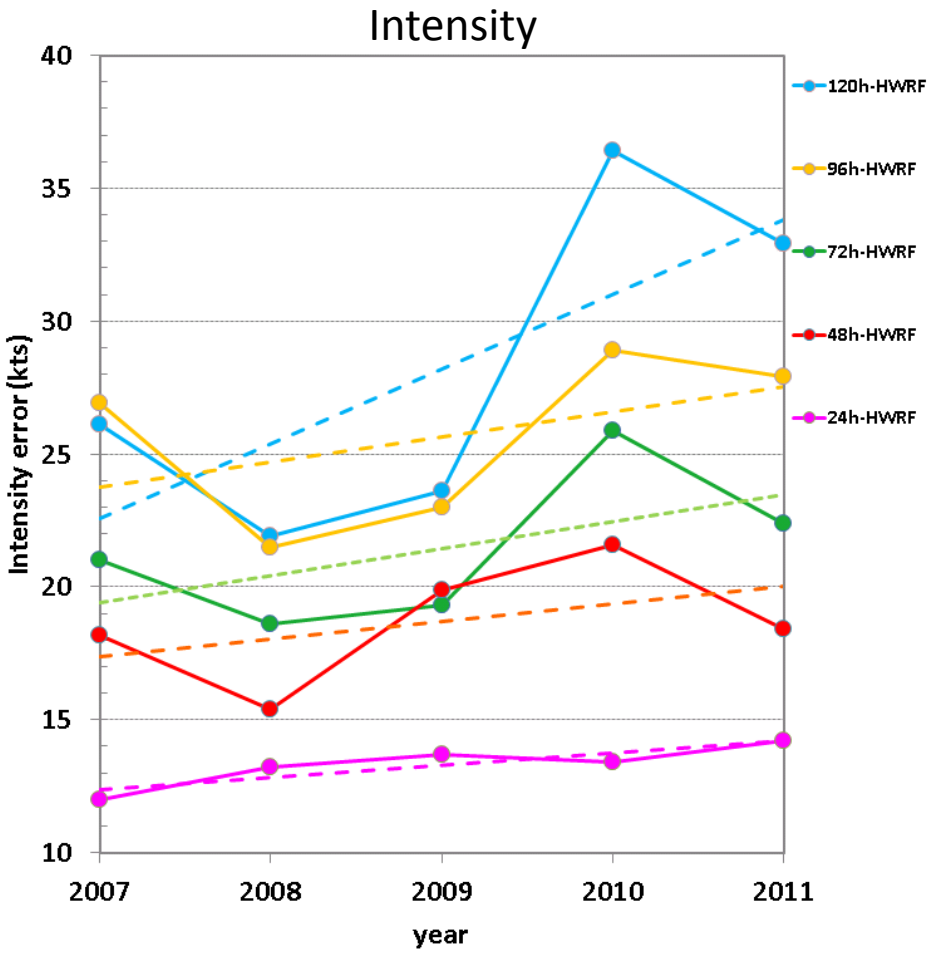
Atlantic basin 2007-2011: H212





EPAC basin 2007-2011: HWRF





EPAC basin 2007-2011: H212