Operational HWRF - Performance for 2012 and Priorities for FY2013.

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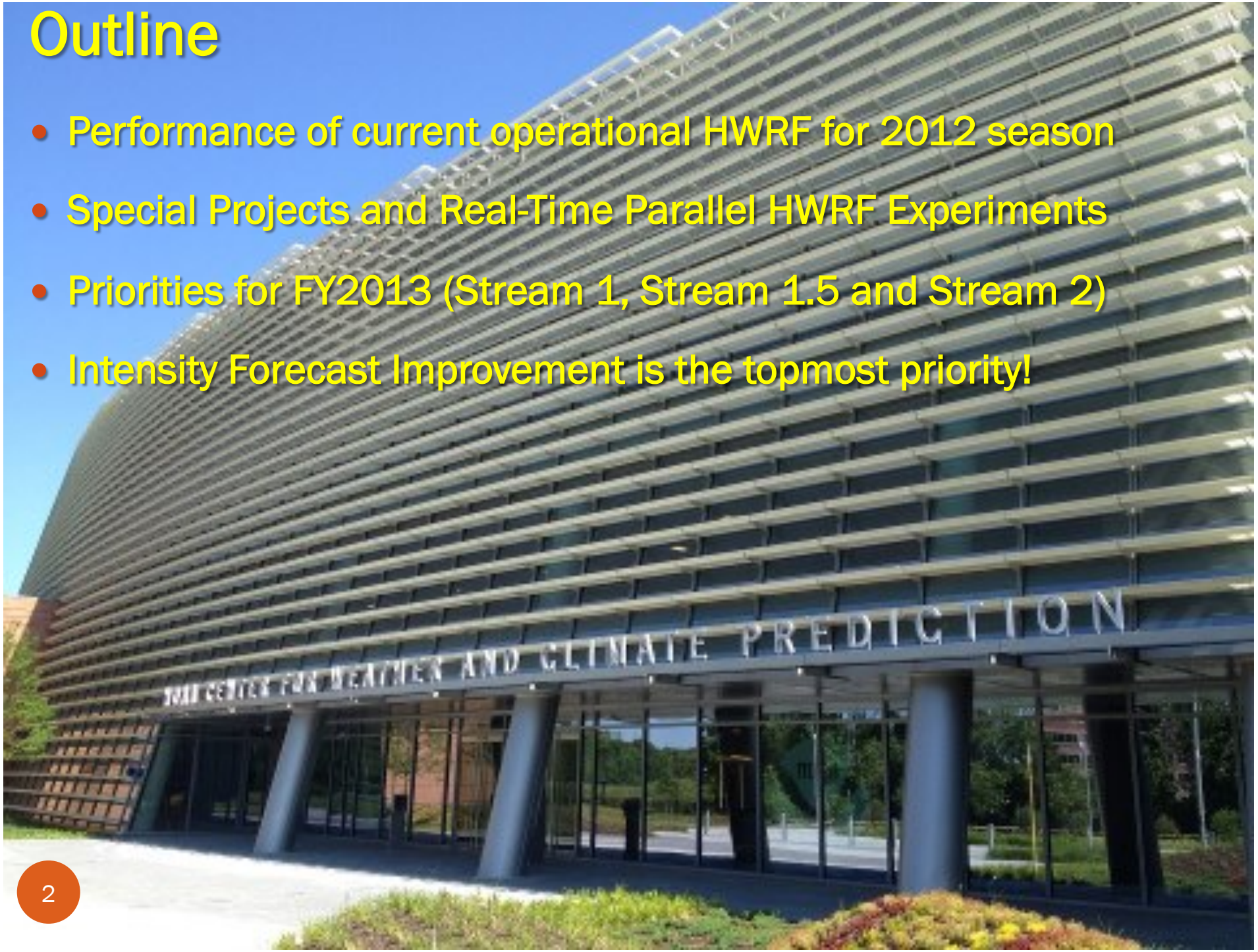
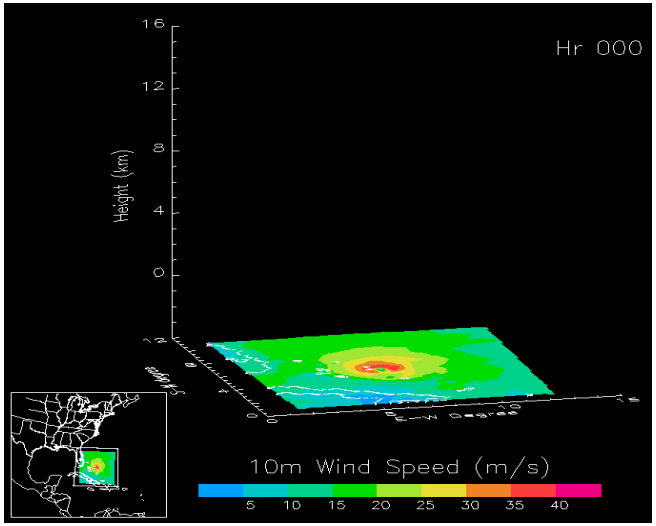
Outline

- Performance of current operational HWRF for 2012 season
- Special Projects and Real-Time Parallel HWRF Experiments
- Priorities for FY2013 (Stream 1, Stream 1.5 and Stream 2)
- Intensity Forecast Improvement is the topmost priority!

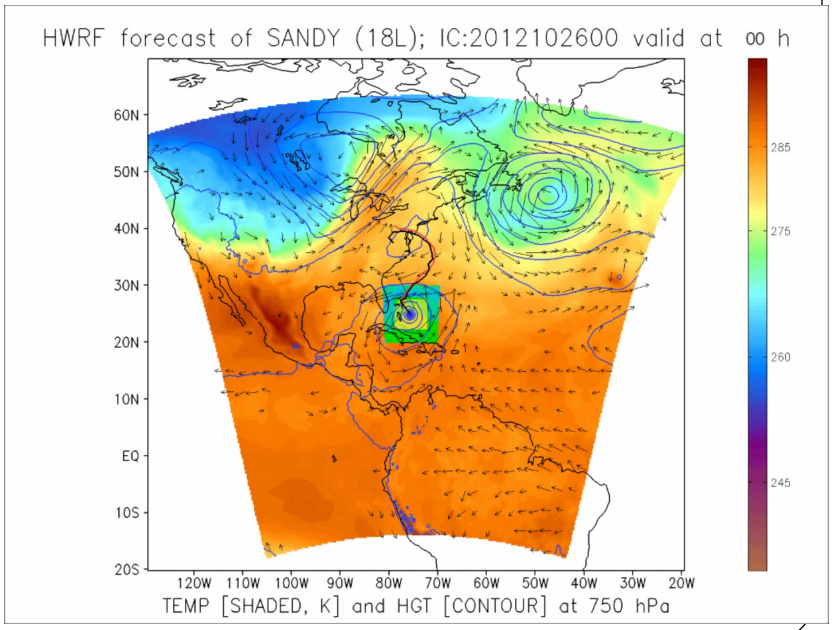


FY2012 High-Resolution Triple-Nested HWRF

- *For the first time, a **high-resolution hurricane model operating at cloud-permitting 3km resolution** 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 for initialization,*
  - ***DTC/NCAR**: code management and repository, MPI profiling*
  - ***ESRL**: Physics sensitivity tests and idealized capability*
  - ***URI**: 1D ocean coupling in East Pac*
  - ***GFDL**: Knowledge sharing, joint T&E*
  - ***NHC**: Diagnostics and evaluation of the HWRF pre-implementation tests and real-time guidance*



Three telescopic domains: 27km: 75x75°; 9km ~11x10° 3km inner-most nest 6x5.5°

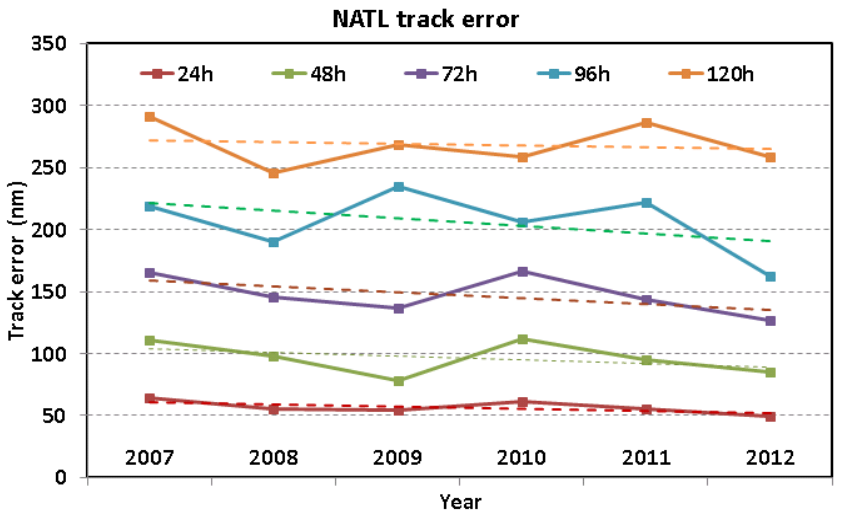


Highlights of 2012 HWRF implementation

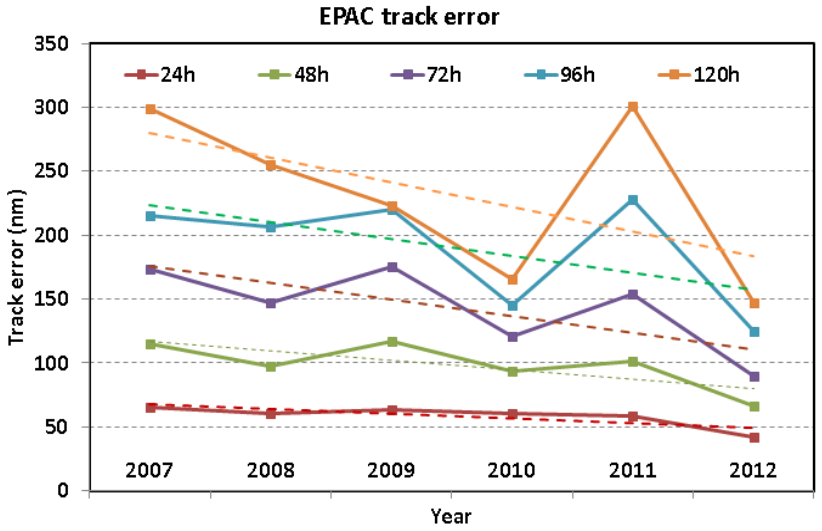
1. **Dynamics**
   - Upgrade WRF to V3.4 and add **I/O servers,** new **mass centroid** based nest movement
   - **Obtain speedup factor of 3.2** in run time from ~265 min. to **~82 min**.) **using 4 nodes** (2011 HWRF used 3 nodes)
   - **Reduced Time step** of model integration 45, 15, 5 sec (54/18 for 2011 HWRF) **and decreased frequency of physics calls 180 sec.** (36 sec. for 2011 HWRF)
   - **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
   - **Upgrade GSI** to version 3.5 which is the latest community version.
3. **Ocean**
   - **Add one dimensional ocean coupling** in Eastern Pacific basin
   - Bug fixes in ocean initialization for Atlantic basin
4. **Physics**
   - **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 vertical mixing **alpha=0.5**
   - Surface physics - use **constant Ch profile** with wind speed consistent with observations

Operational HWRF Progress and Improvement w.r.t 2011

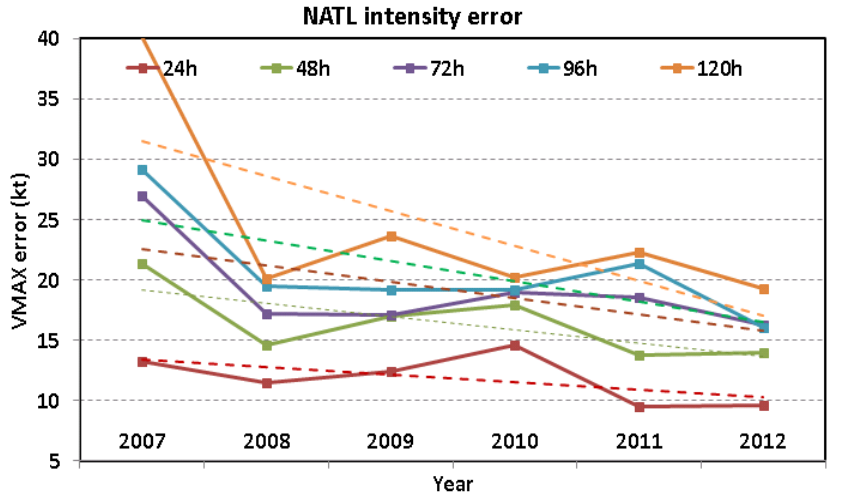
(FY2012 Operational Goals: 10% improvement in track and intensity at all times)



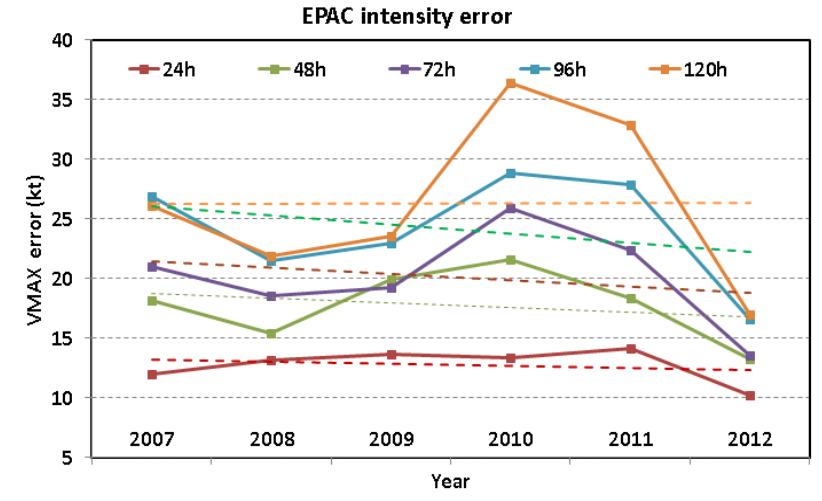
Lead time	12	24	36	48	72	96	120
%improvement	8	10	10	11	11	27	10



Lead time	12	24	36	48	72	96	120
%improvement	15	27	32	33	38	39	49

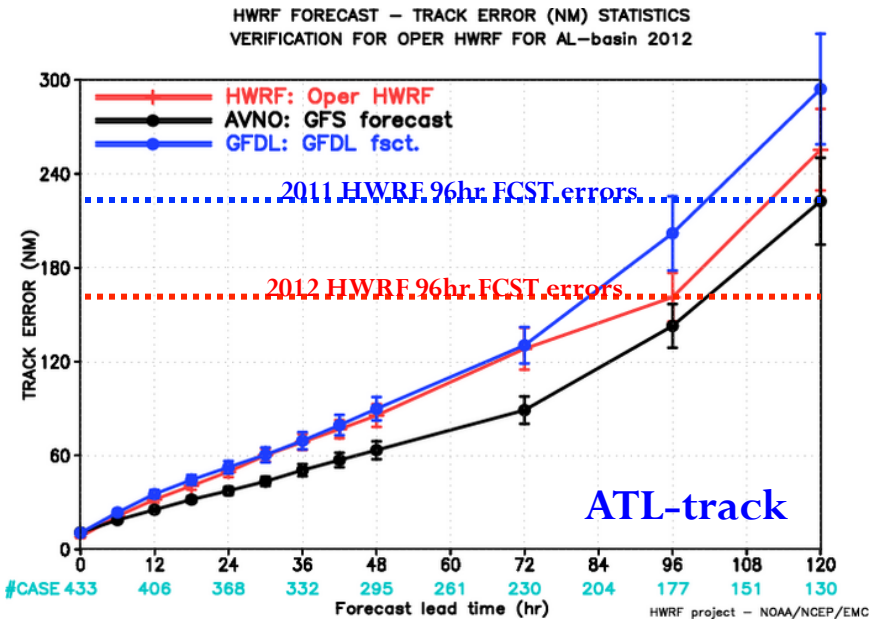


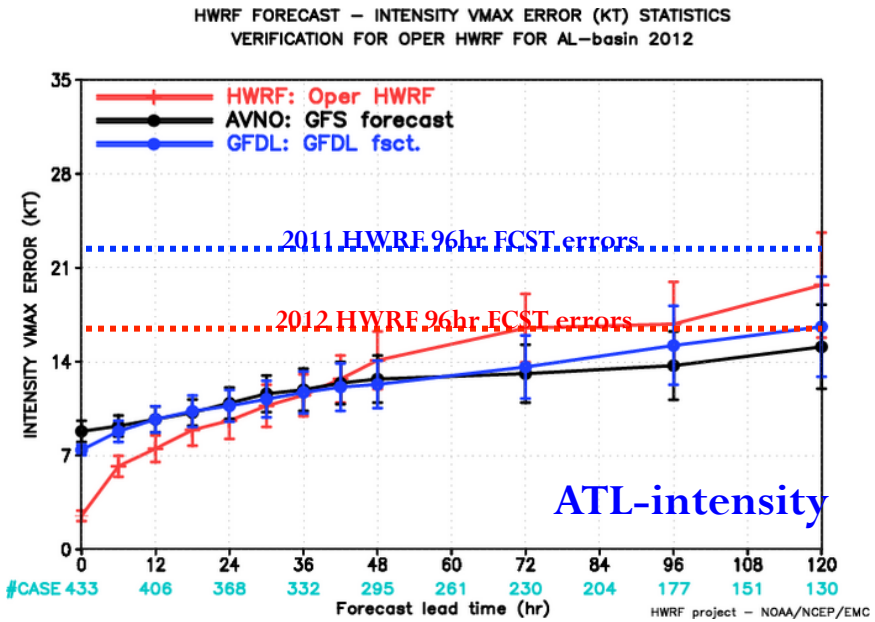
Lead time	12	24	36	48	72	96	120
%improvement	7	-1	-4	0	12	25	13

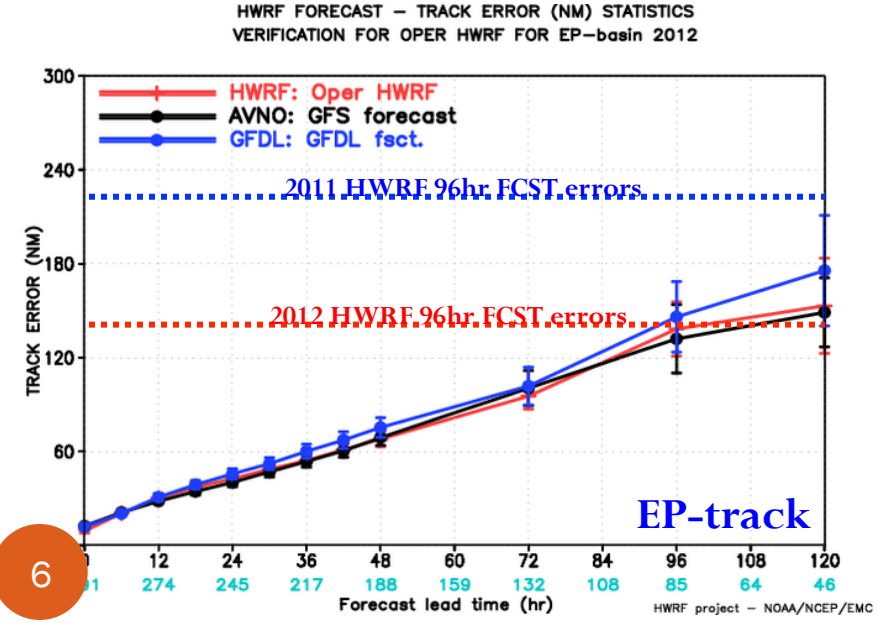


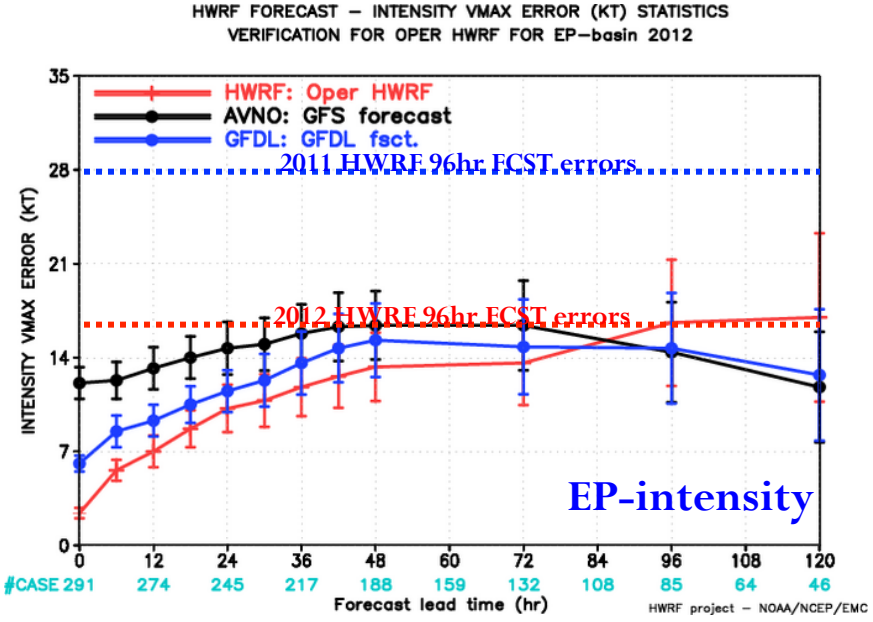
Lead time	12	24	36	48	72	96	120
%improvement	36	28	32	28	39	41	48

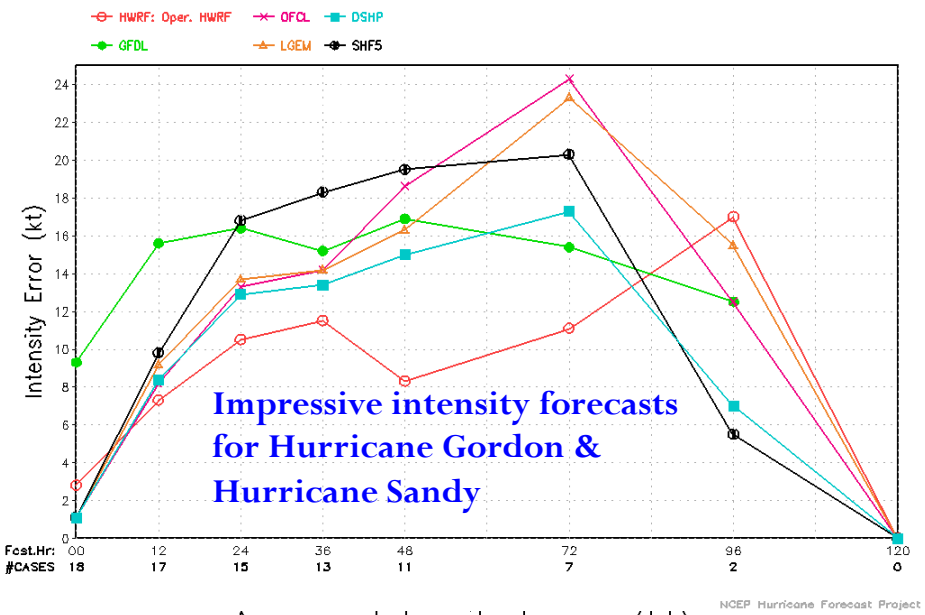
Verification of Operational HWRF for 2012 season

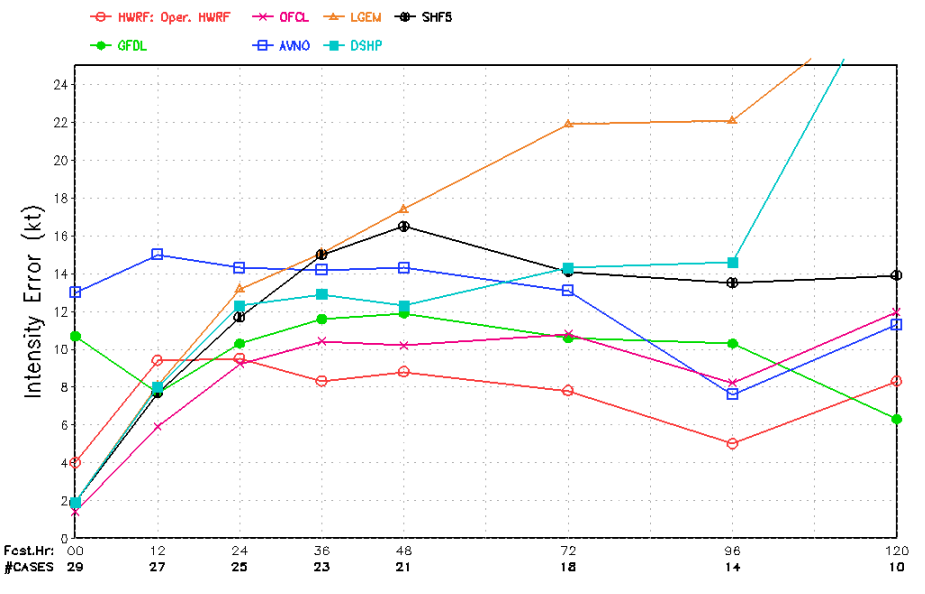


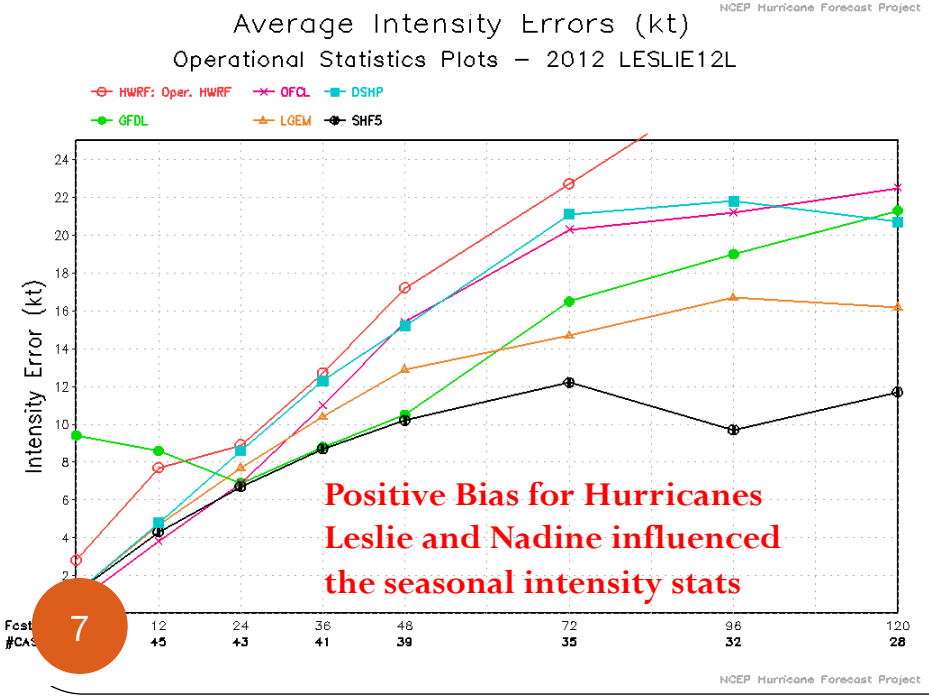


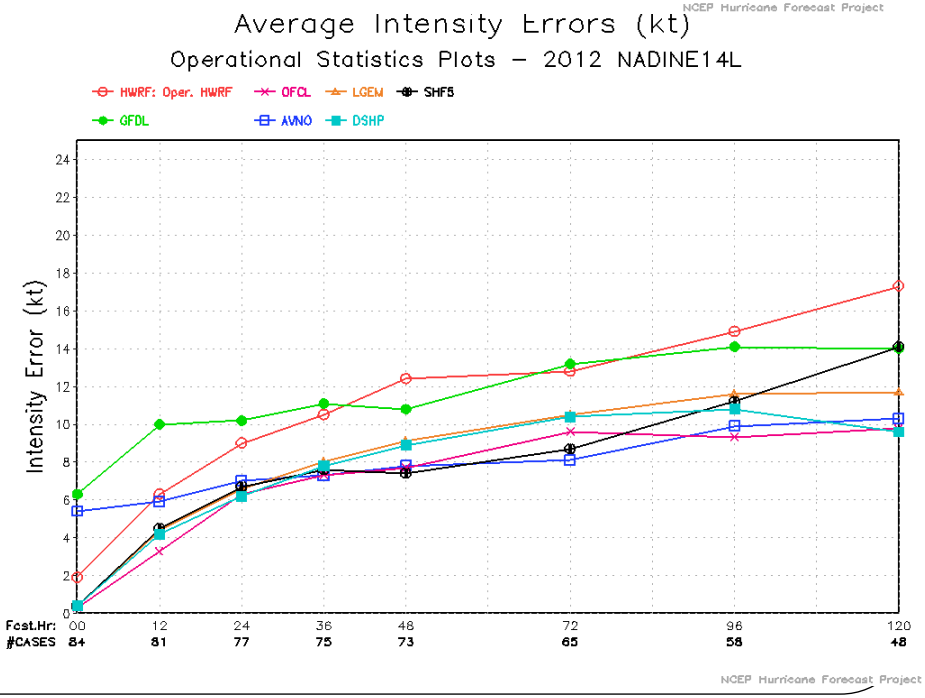


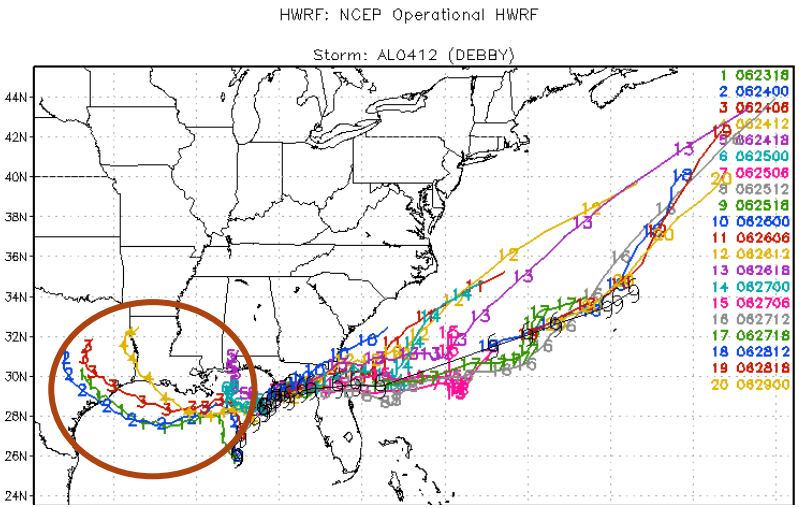


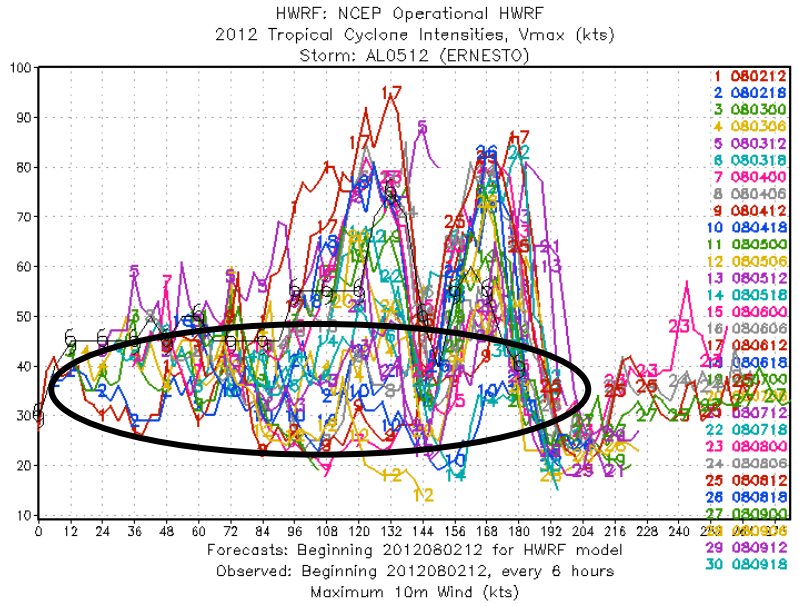

Average Intensity Errors (kt)
Operational Statistics Plots – 2012 GORDON08L
HWRF: Oper. HWRF
OFCL
DSHP
GFDL
LGEM
SHF5
Intensity Error (kt)
Fcst.Hr: 00 12 24 36 48 72 96 120
#CASES 18 17 15 13 11 7 2 0
Impressive intensity forecasts for Hurricane Gordon & Hurricane Sandy
NCEP Hurricane Forecast Project

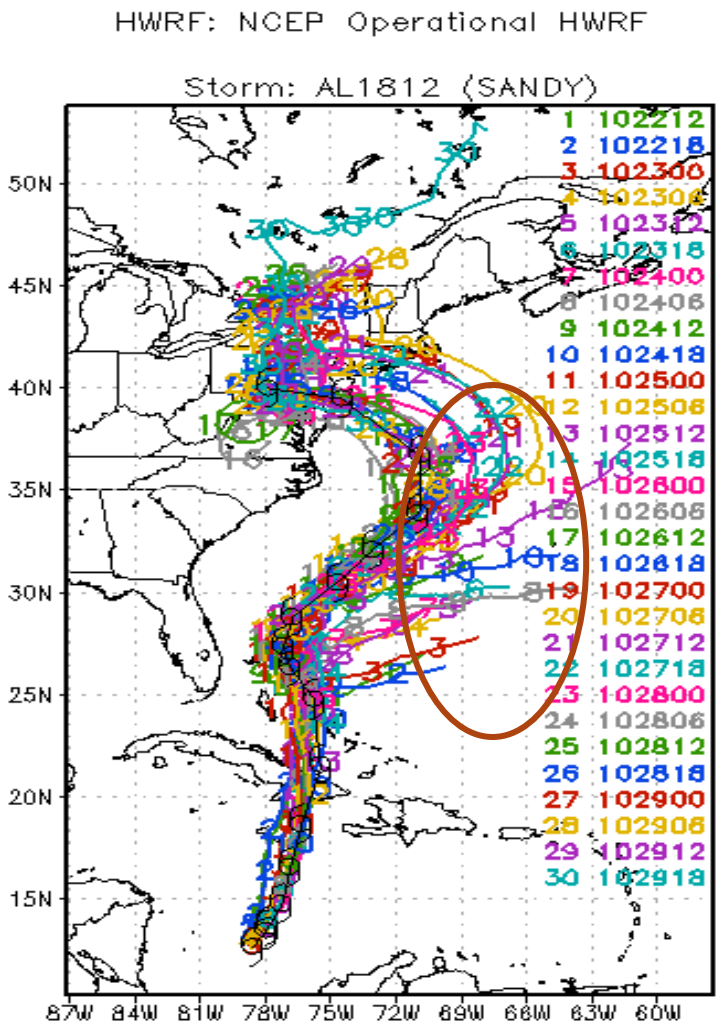

Average Intensity Errors (kt)
Operational Statistics Plots – 2012 SANDY18L
HWRF: Oper. HWRF
OFCL
LGEM
SHF5
GFDL
AVNO
DSHP
Intensity Error (kt)
Fcst.Hr: 00 12 24 36 48 72 96 120
#CASES 29 27 25 23 21 18 14 10
NCEP Hurricane Forecast Project


Average Intensity Errors (kt)
Operational Statistics Plots – 2012 LESLIE12L
HWRF: Oper. HWRF
OFCL
DSHP
GFDL
LGEM
SHF5
Intensity Error (kt)
Positive Bias for Hurricanes Leslie and Nadine influenced the seasonal intensity stats
12 24 36 48 72 96 120
45 43 41 39 35 32 28
NCEP Hurricane Forecast Project


Average Intensity Errors (kt)
Operational Statistics Plots – 2012 NADINE14L
HWRF: Oper. HWRF
OFCL
LGEM
SHF5
GFDL
AVNO
DSHP
Intensity Error (kt)
Fcst.Hr: 00 12 24 36 48 72 96 120
#CASES 84 81 77 75 73 65 58 48
NCEP Hurricane Forecast Project



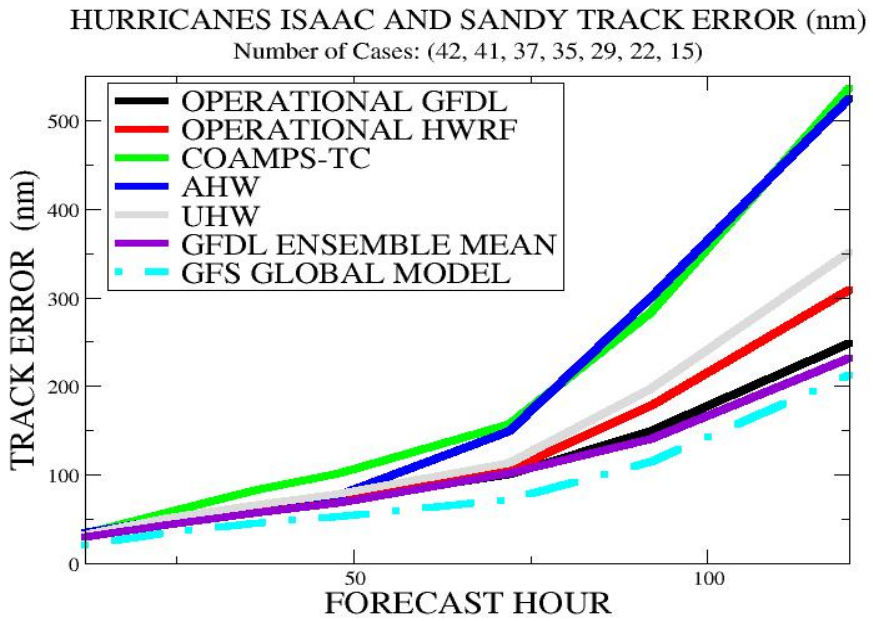


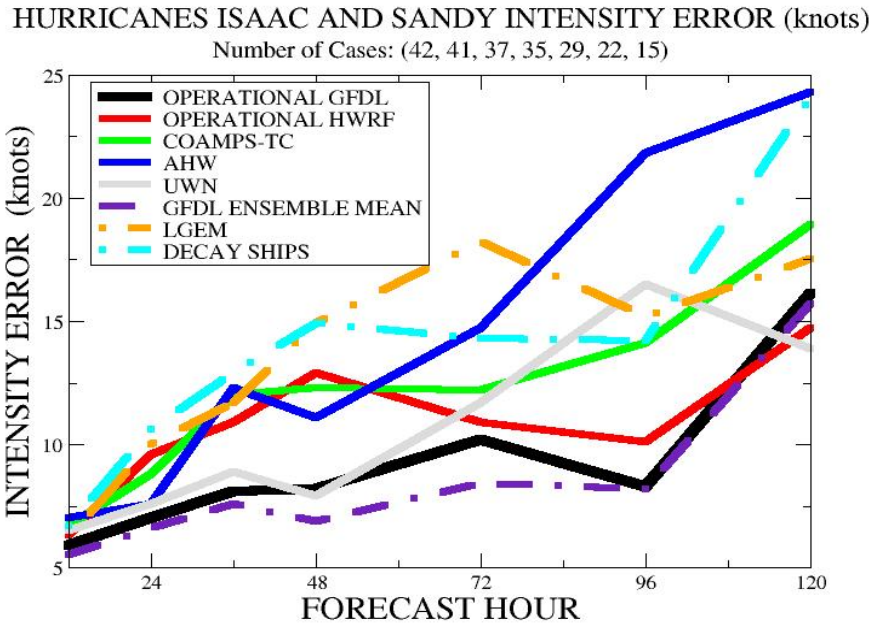


A few outliers for TS Debby & Hurricane Sandy negatively influenced the track statistics

Ernesto was another problematic storm due to nest movement related issues

Verifications for two Major Land-falling events of 2012: HURRICANES ISAAC AND SANDY

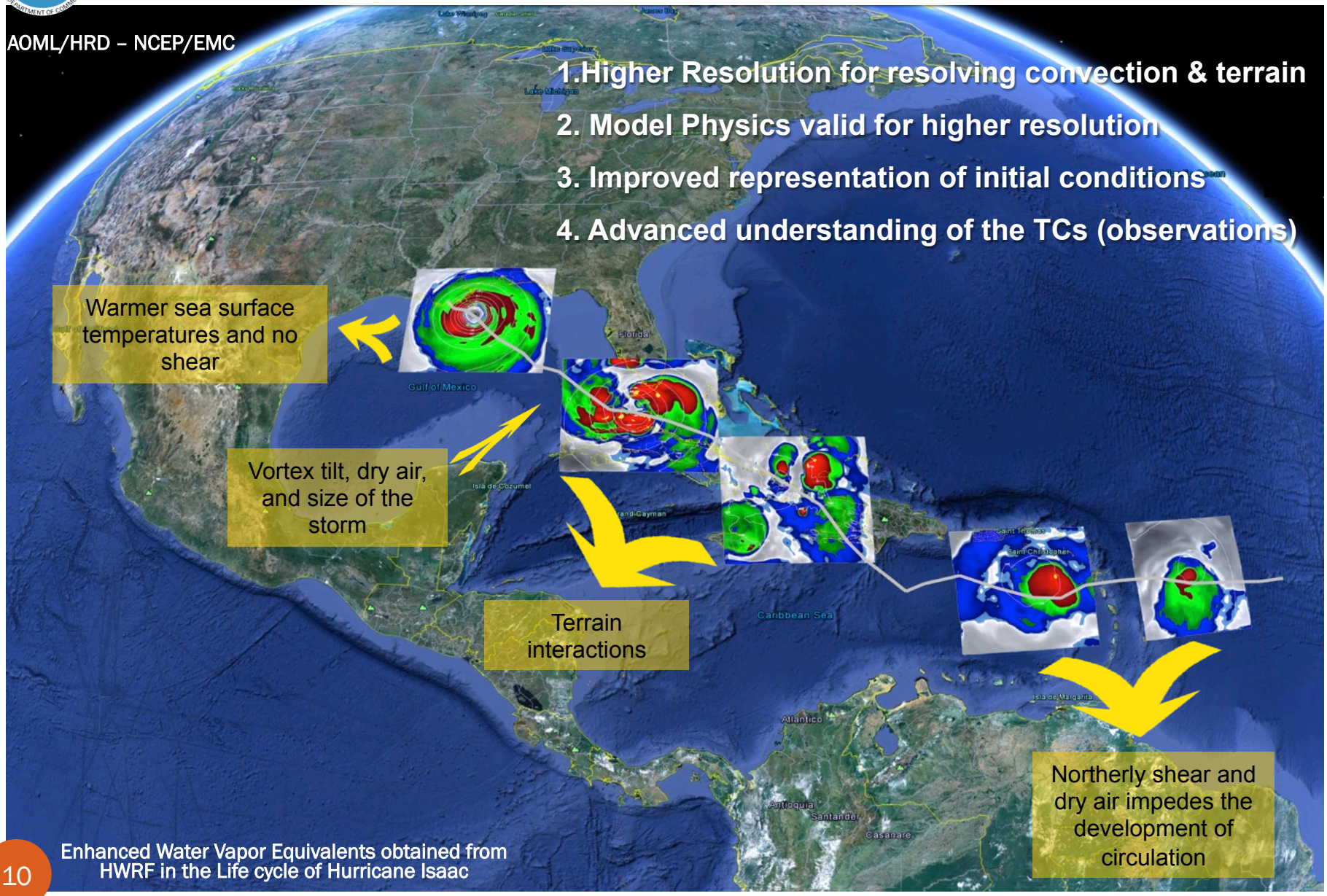




For Track: Operational Models (HWRF & GFDL) performed best overall for both storms. HFIP Regional Models AHW and COAMPS-TC performed very well for Sandy but not for Isaac. GFS is the Best performing Model for both storms. (GFDL Ensemble Mean a close second)

For intensity: Operational models outperformed other dynamical models. (GFDL Ensemble Mean even better).

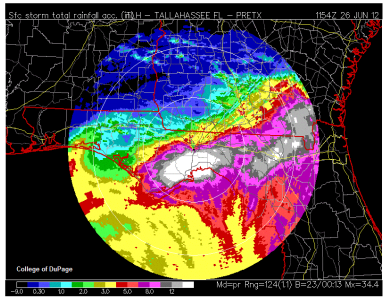
HWRF: Advancing Track and Structure Predictions

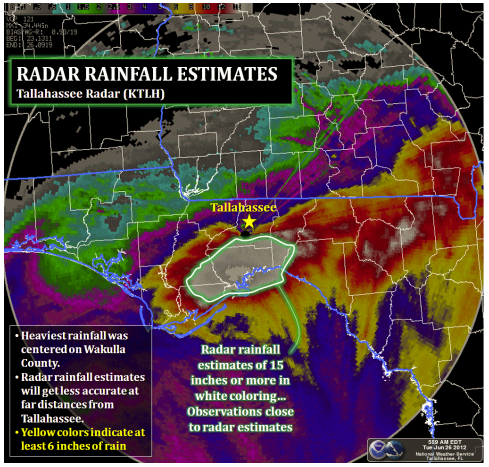


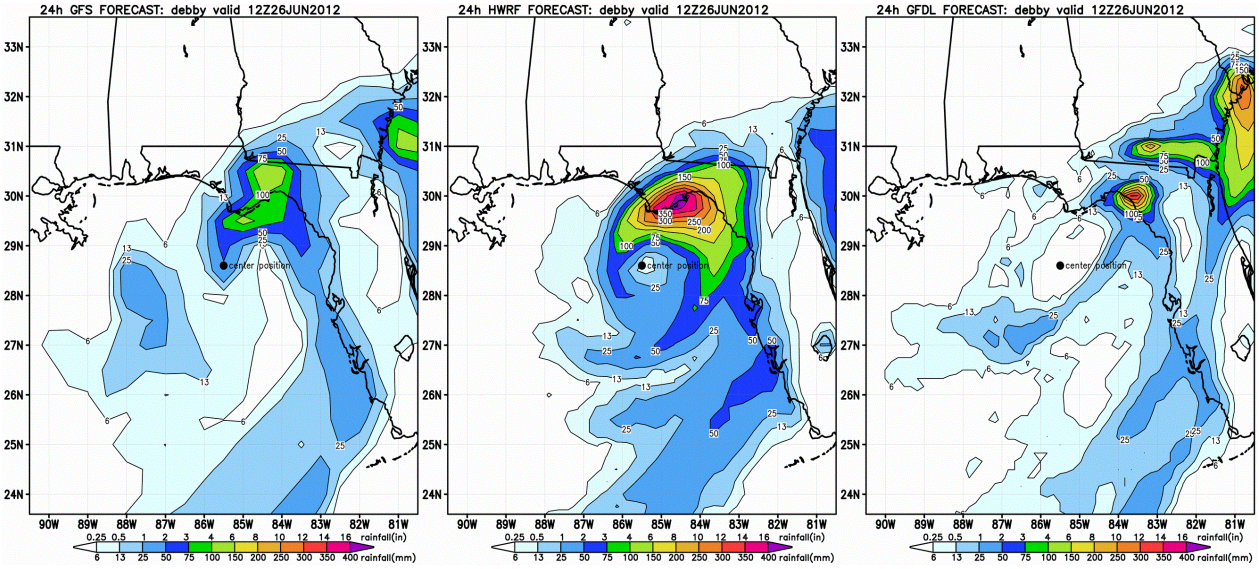
Experimental Real-Time products from HWRF

Supplemental HWRF products than simple track and intensity.
Synthetic Satellite Imagery, High Frequency output and Rainfall products to aid forecast guidance.

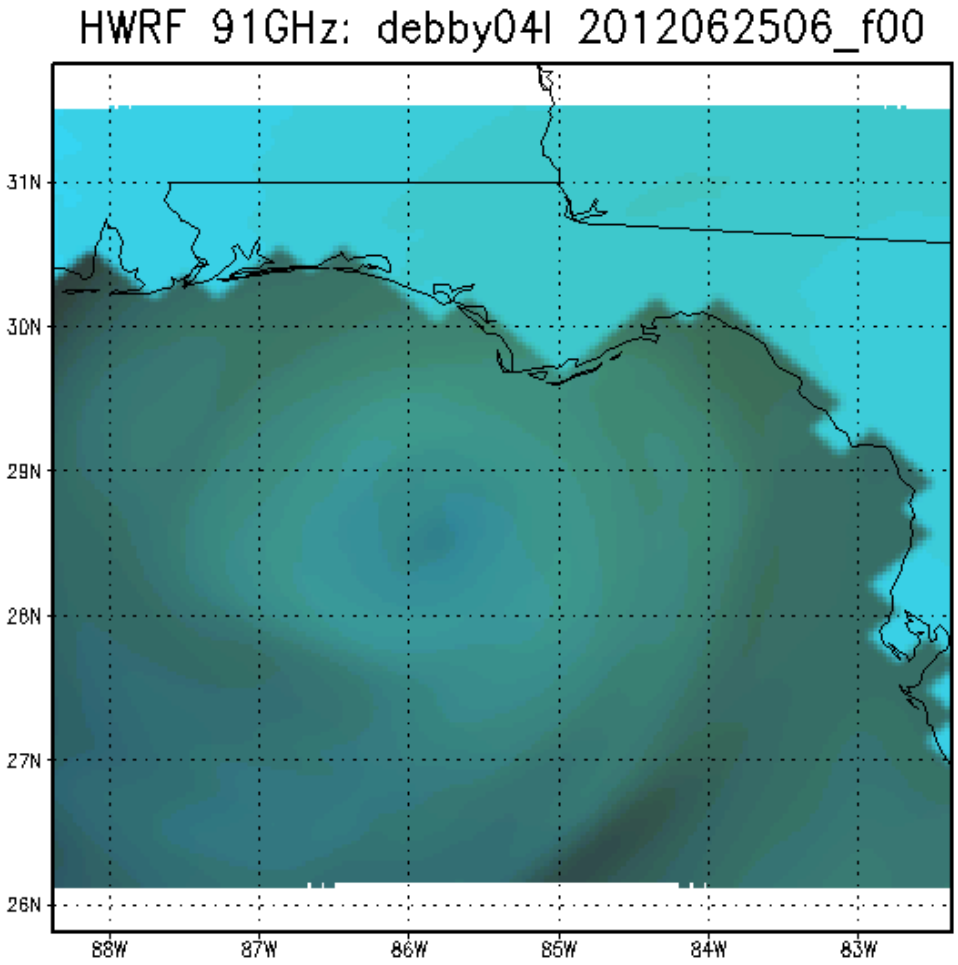
NHC Rainfall Product (below), and verifying radar-estimated rainfall totals (right).



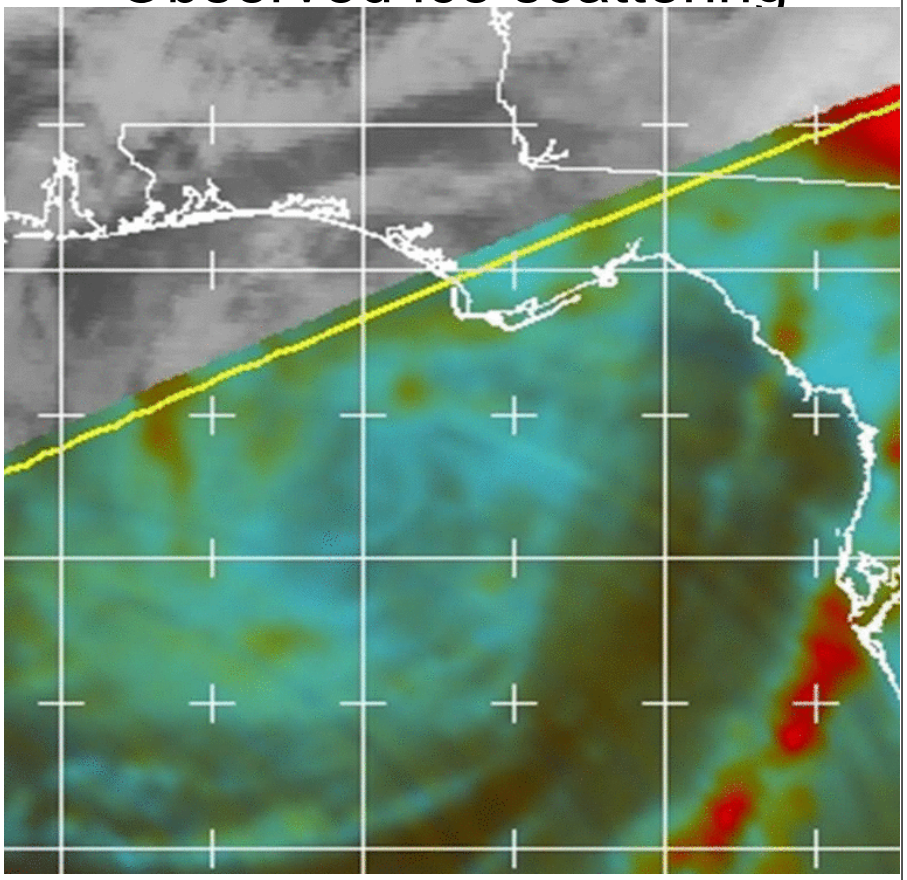


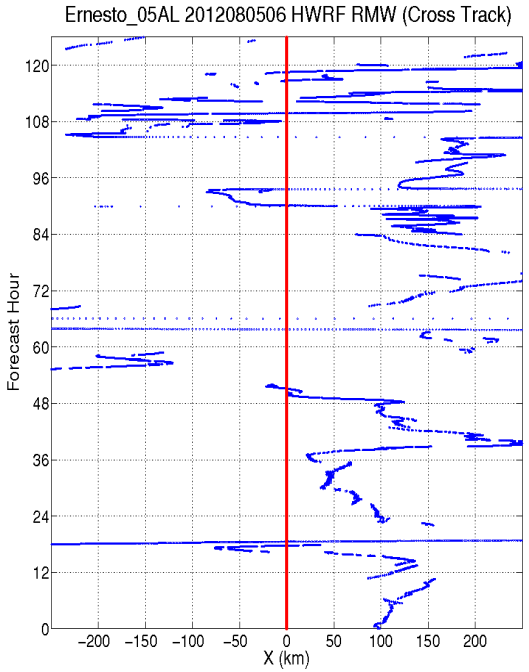


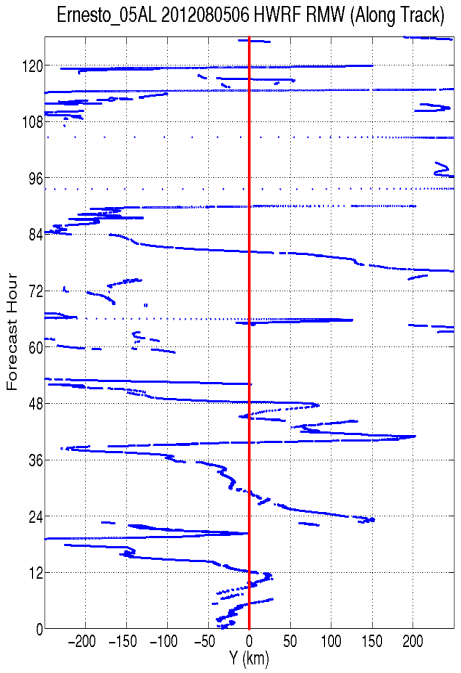
Synthetic Satellite Imagery (SSMI/S) from HWRF

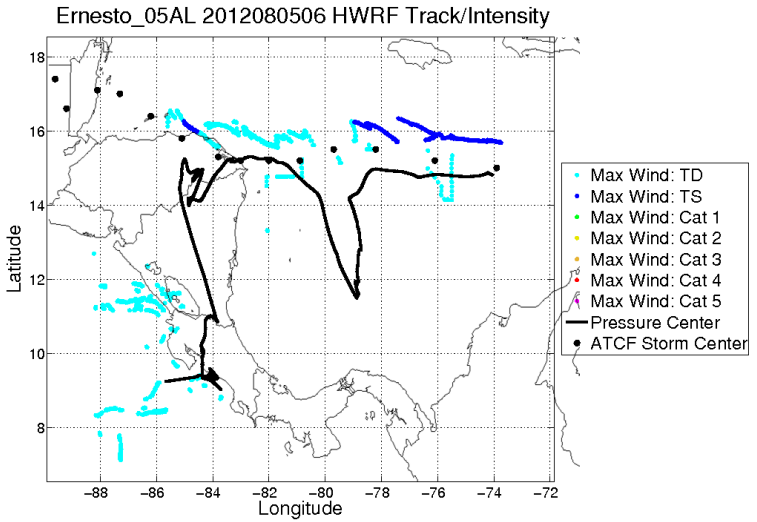


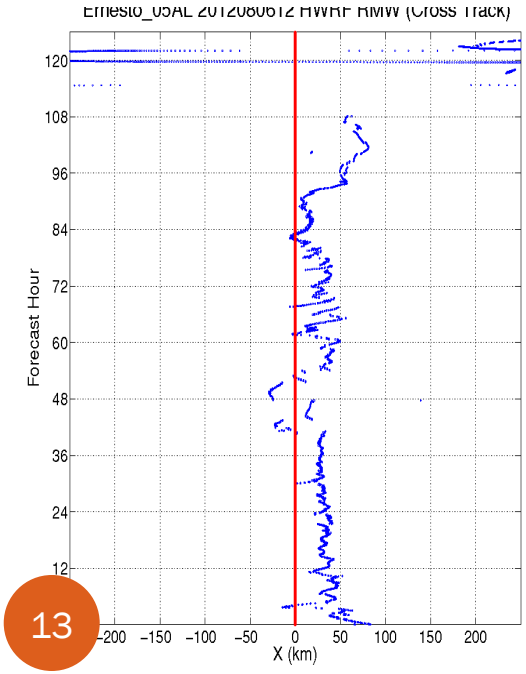
Observed ice scattering

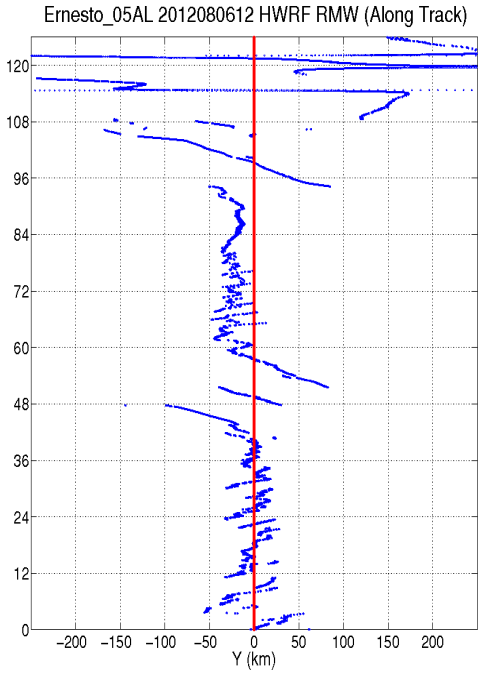




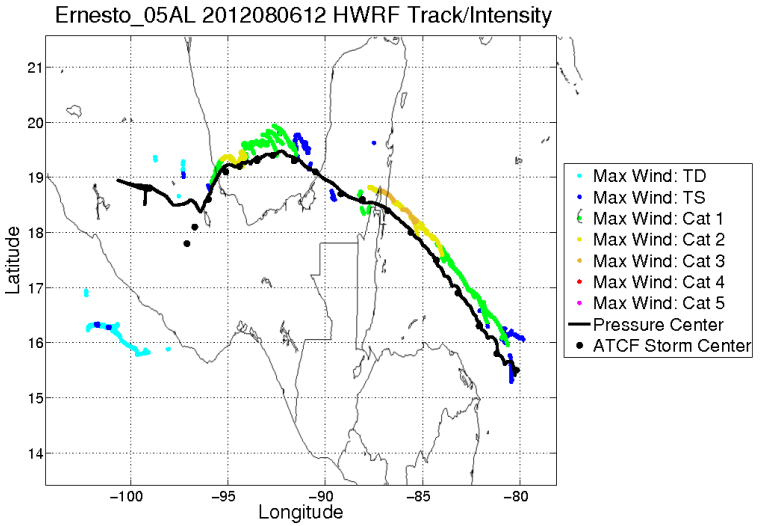








Use of HTCF data to describe time-history of model track, intensity and structure forecasts



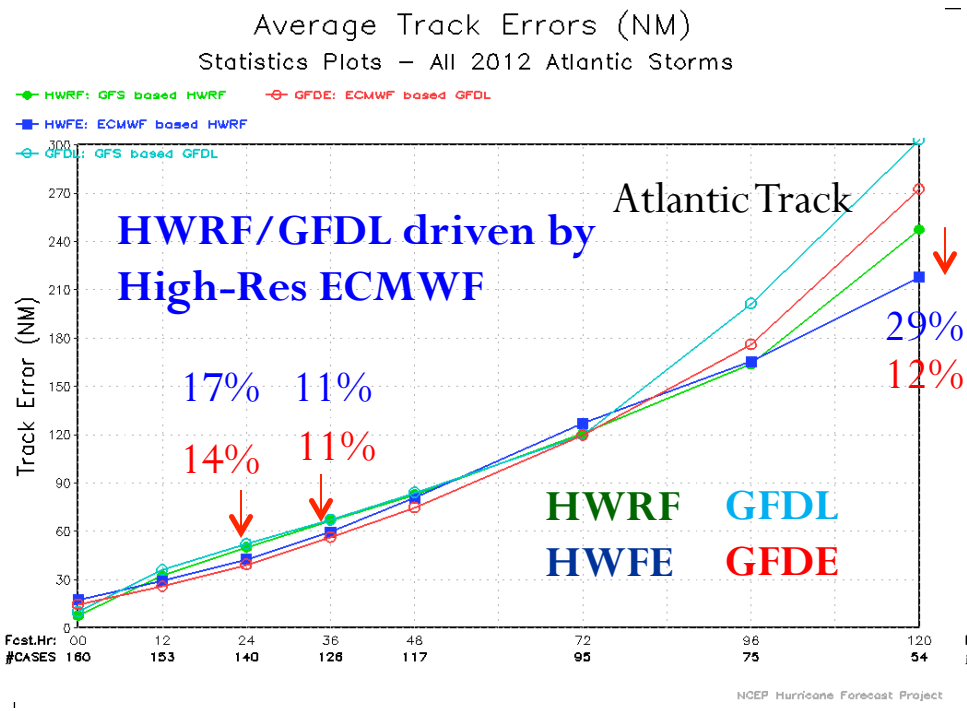
Special HFIP supported Real-Time Projects

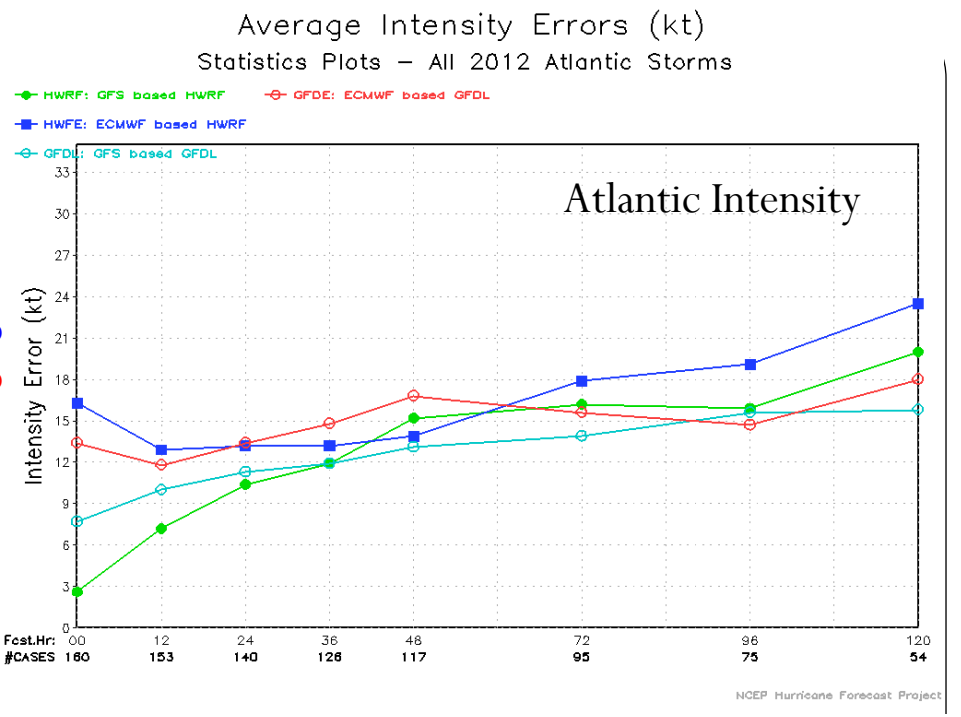
- **ECMWF driven HWRF (requested and facilitated by NHC)**
- **Real-time TDR DA Experiments**
- **Real-time HWRF for Western Pacific (in support of JTWC) and North Indian Ocean (in support of IMD)**
- Alternate physics (MYJ)
- Basin-Scale (hemispheric) HWRF (with multiple moveable domains & Regional Hybrid DA)
- HWRF-HYCOM

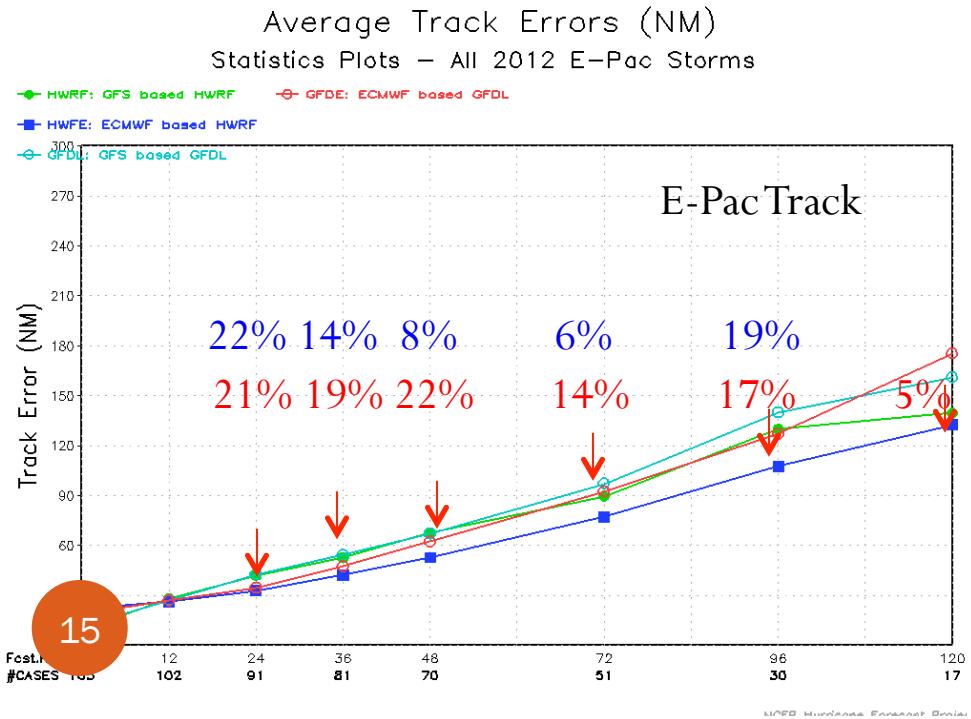
Many of these projects are supported by HFIP and allowed us to expand the Development Phase of operational HWRF for future upgrades.

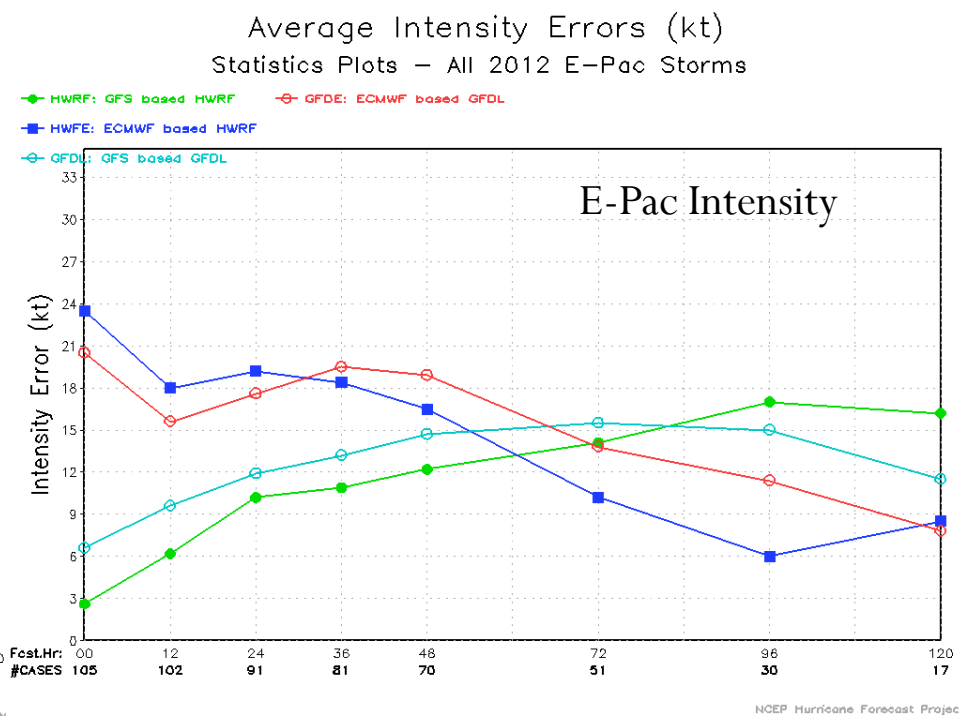
HFIP resources on Jet and NCEP resources on Zeus helped us accomplish these real-time parallel systems.

Cross-platform compliancy through strict code management protocols and subversion based repository (supported by DTC) are pivotal for these efforts.


Average Track Errors (NM)
Statistics Plots – All 2012 Atlantic Storms
HWRF: GFS based HWRF
GFDE: ECMWF based GFDL
HWFE: ECMWF based HWRF
GFDL: GFS based GFDL
Atlantic Track
HWRF/GFDL driven by
High-Res ECMWF
17% 11%
14% 11%
29%
12%
HWRF GFDL
HWFE GFDE
Track Error (NM)
Fcst.Hr: 00 12 24 36 48 72 96 120
#CASES 160 153 140 126 117 95 75 54
NCEP Hurricane Forecast Project

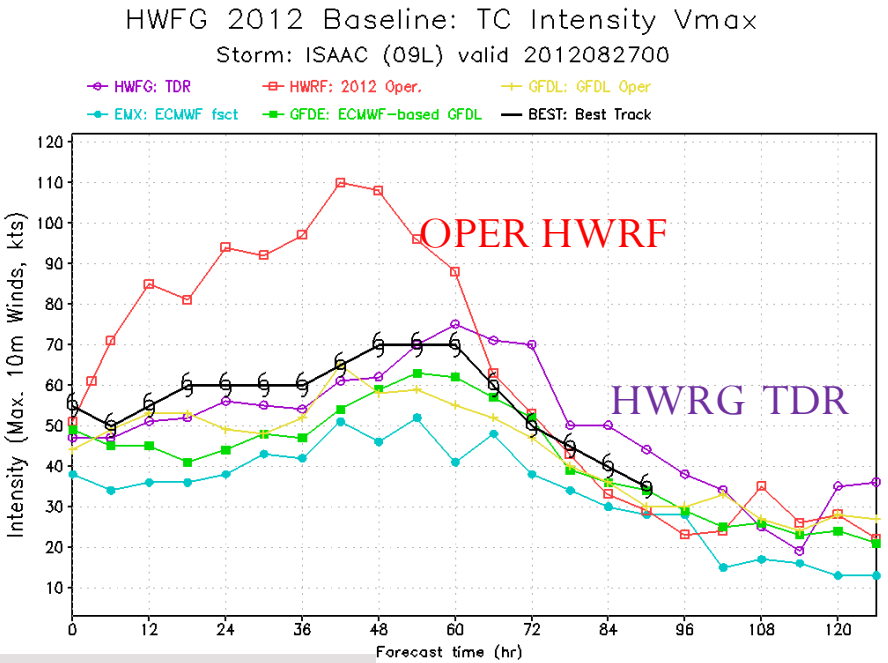

Average Intensity Errors (kt)
Statistics Plots – All 2012 Atlantic Storms
HWRF: GFS based HWRF
GFDE: ECMWF based GFDL
HWFE: ECMWF based HWRF
GFDL: GFS based GFDL
Atlantic Intensity
Intensity Error (kt)
Fcst.Hr: 00 12 24 36 48 72 96 120
#CASES 160 153 140 126 117 95 75 54
NCEP Hurricane Forecast Project


Average Track Errors (NM)
Statistics Plots – All 2012 E-Pac Storms
HWRF: GFS based HWRF
GFDE: ECMWF based GFDL
HWFE: ECMWF based HWRF
GFDL: GFS based GFDL
E-Pac Track
22% 14% 8% 6% 19%
21% 19% 22% 14% 17% 5%
Track Error (NM)
#CASES 102 91 81 70 51 30 17

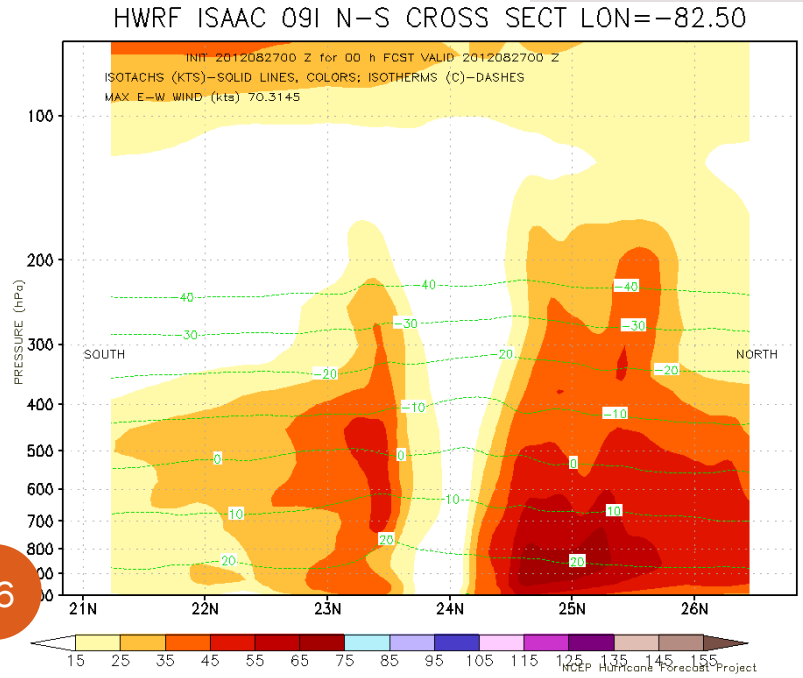

Average Intensity Errors (kt)
Statistics Plots – All 2012 E-Pac Storms
HWRF: GFS based HWRF
GFDE: ECMWF based GFDL
HWFE: ECMWF based HWRF
GFDL: GFS based GFDL
E-Pac Intensity
Intensity Error (kt)
Fcst.Hr: 00 12 24 36 48 72 96 120
#CASES 105 102 91 81 70 51 30 17
NCEP Hurricane Forecast Projec

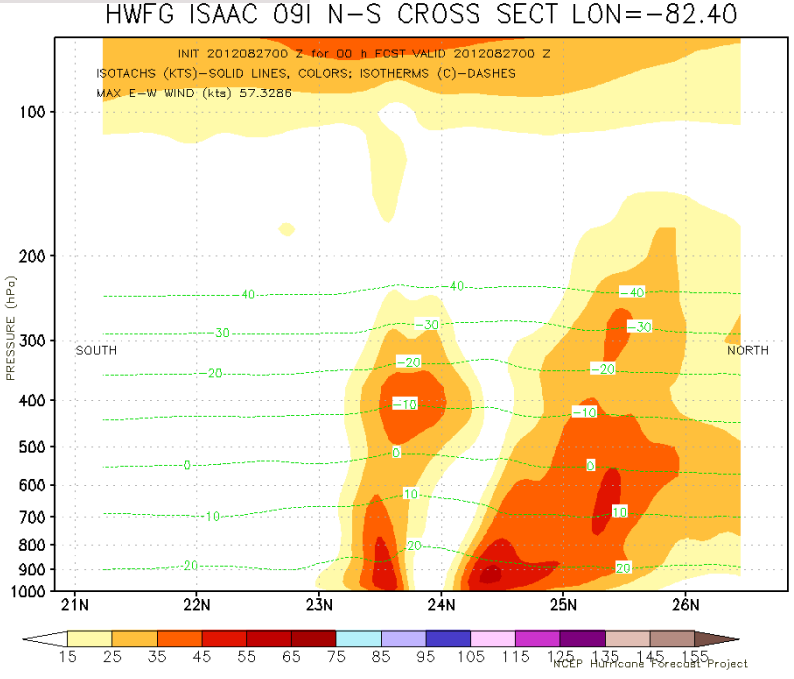
Inner Core P3 TDR data assimilation (includes one-way hybrid GSI for HWRF using GFS ensembles)

Impact of TDR data assimilation to hurricane intensity forecast

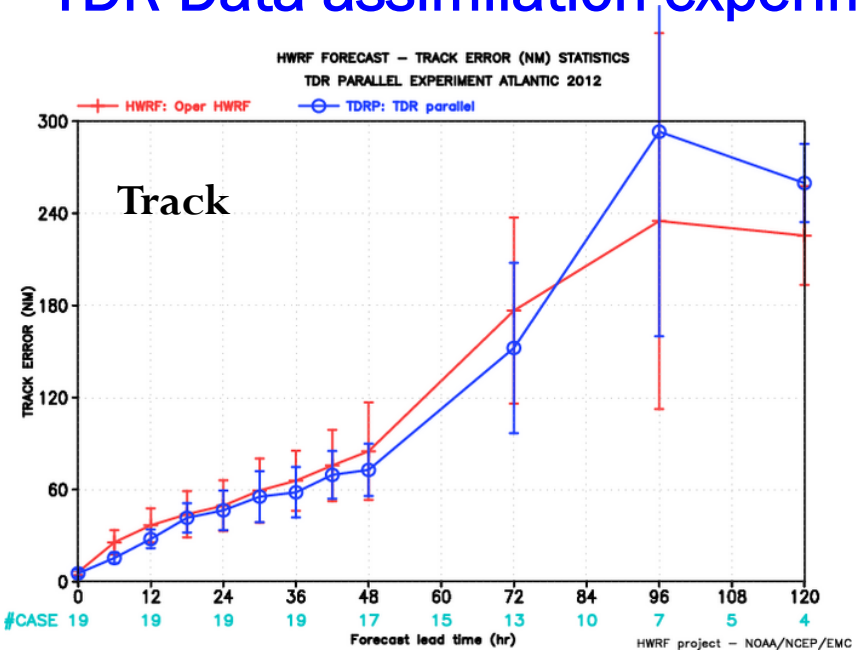


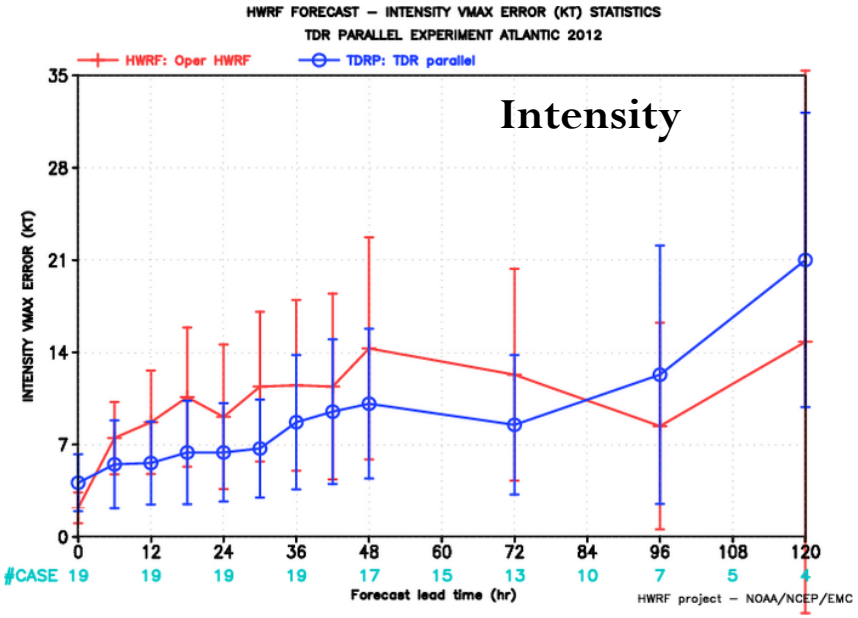
Cross section at initial time





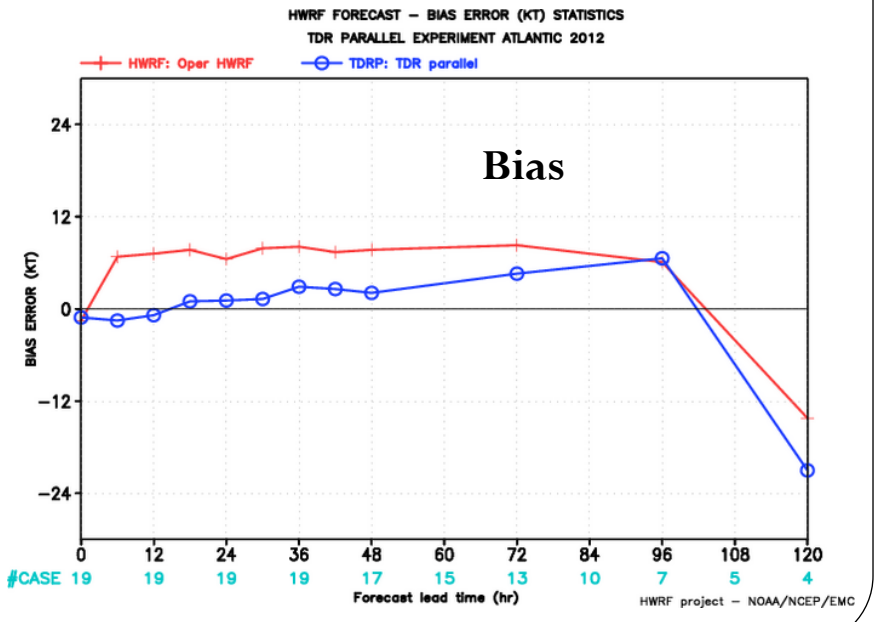
TDR Data assimilation experiment - Atlantic 2012





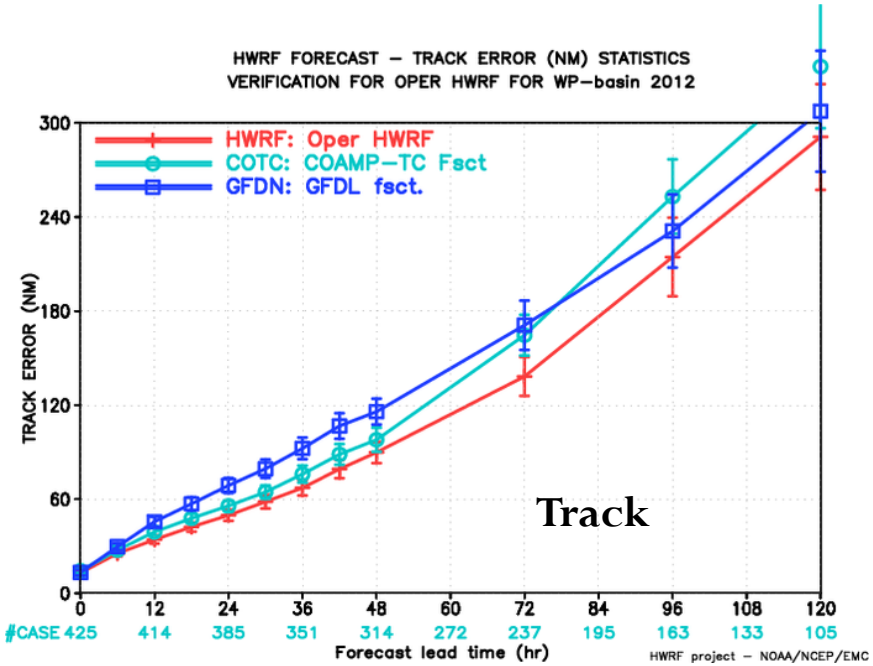
Assimilation of TDR data provided significant positive impact on intensity forecasts (20-30% improvement through 72-hrs), without degrading track forecast skill.

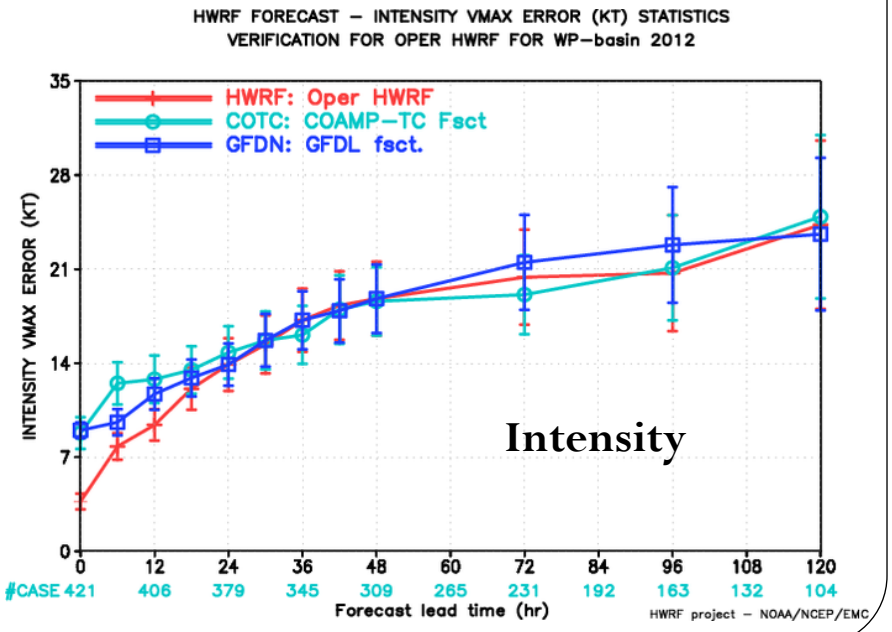
Hybrid DA framework (currently one-way) allows for assimilation of flight level, dropsonde and all-sky satellite radiance data, and fits into operational resources



Operational HWRF for Western-Pacific Basin

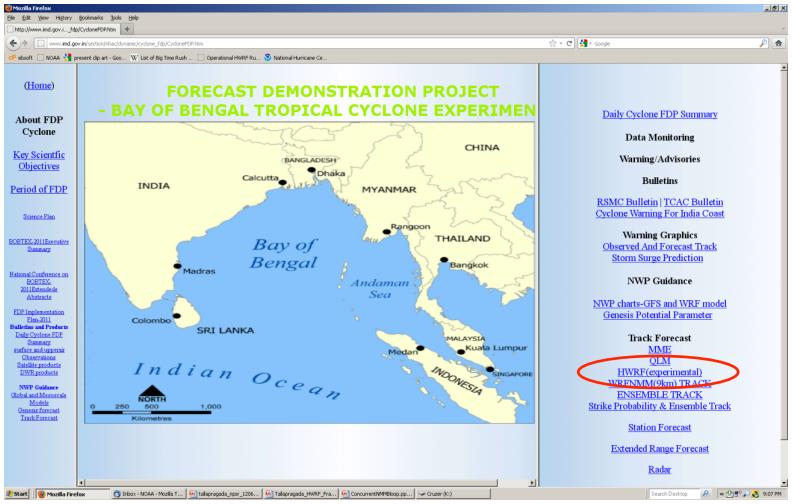
- For the first time, Real-Time forecast guidance from NCEP Operational HWRF is made available for JTWC for all Western Pacific storms starting with Sanvu (03W) from May 21, 2012.
- Operational HWRF configuration for Western Pacific includes modified vortex initialization and no ocean coupling (atmosphere only).
- All operational products, including synthetic satellite imagery, high-frequency track & intensity forecasts, and additional special graphics requested by JTWC are provided through HWRF website: http:// www.emc.ncep.noaa.gov/HWRF/WestPacific/
- The model setup and real-time delivery of products are accomplished using HFIP supported resources on Jet (dedicated reservations) and sophisticated automation tools developed by the HWRF team. ~80% on-time delivery of products for use by JTWC.
  - Results have been quite encouraging: HWRF track errors better than COAMPS-TC and GFDN
  - HWRF intensity errors comparable to COAMPS-TC and GFDN
  - GFDN and COAMPS-TC use NOGAPS while HWRF uses GFS for IC & BC



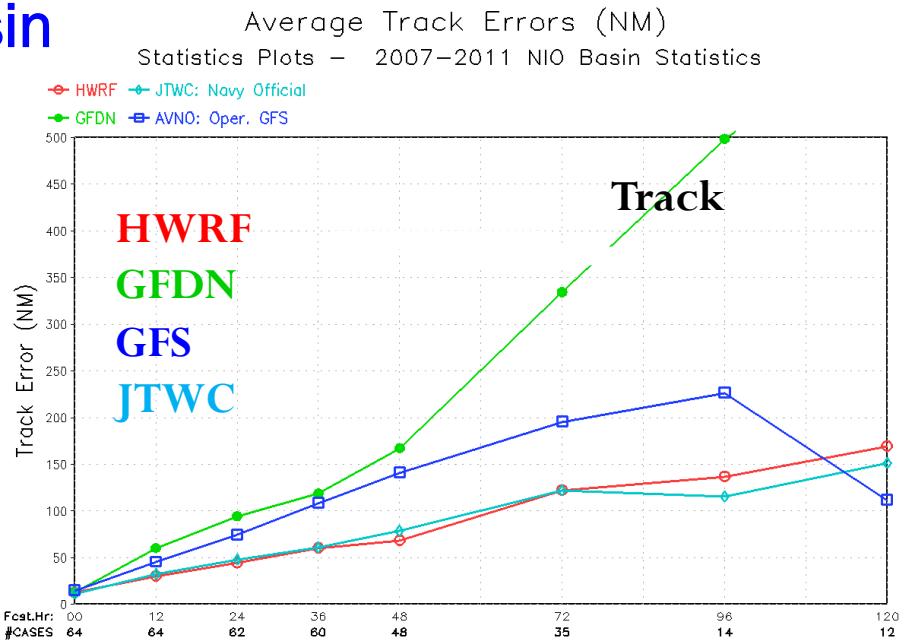


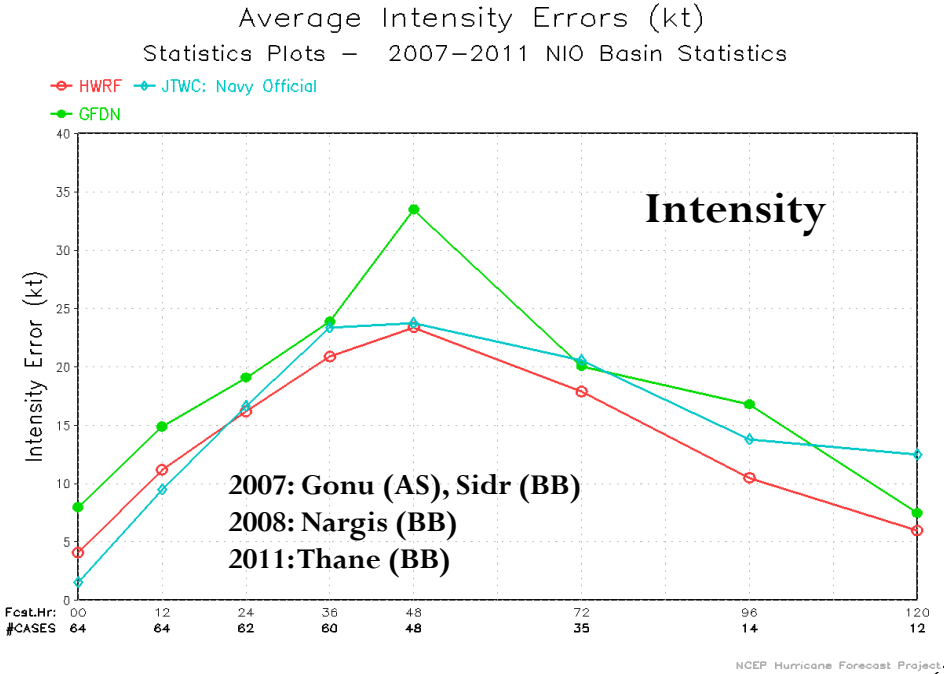
HWRF for North Indian Ocean Basin

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



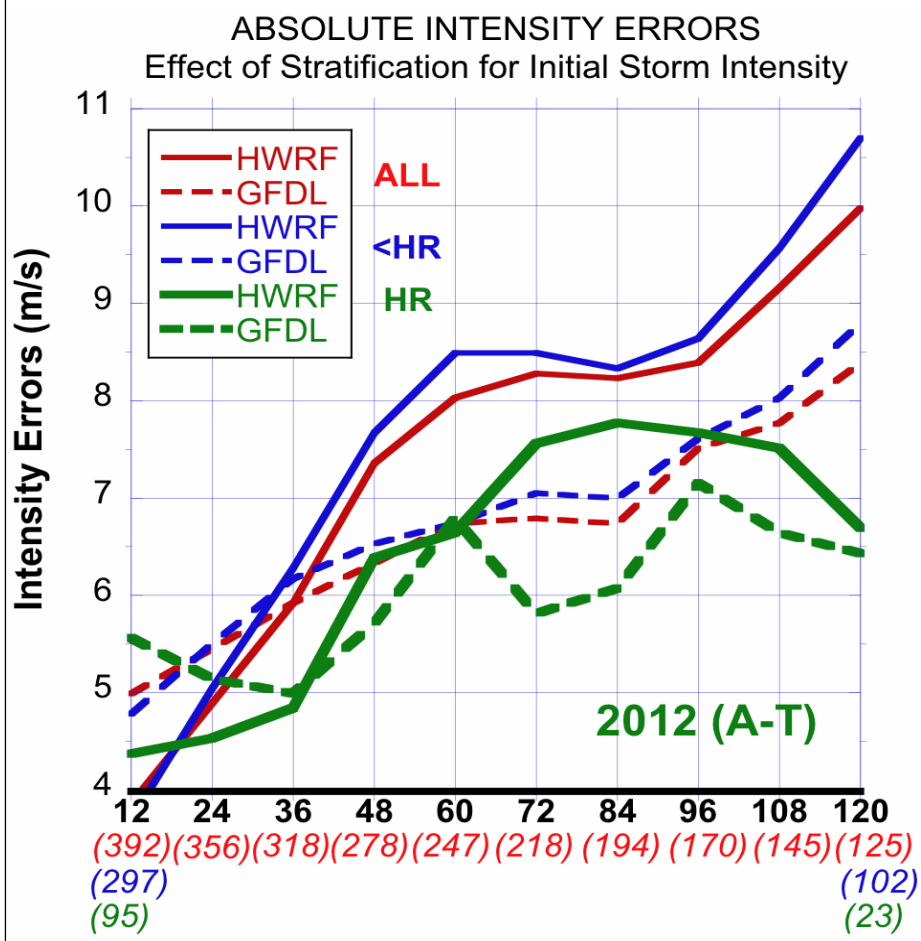
- Technology transfer of HWRF to IMD in June 2011 (NOAA-MoES MoU/IA)
- 7-day workshop and tutorial on HWRF at Bhubaneshwar, India in July 2012 (sponsored by IUSSTF/MoES)
- HWRF Team provided Real-Time guidance to all tropical cyclones for 2012 season using 27/9/3 uncoupled configuration
- Products available from EMC HWRF Website at: http://www.emc.ncep.noaa.gov/gc_wmb/vxt/PARA/Zhan





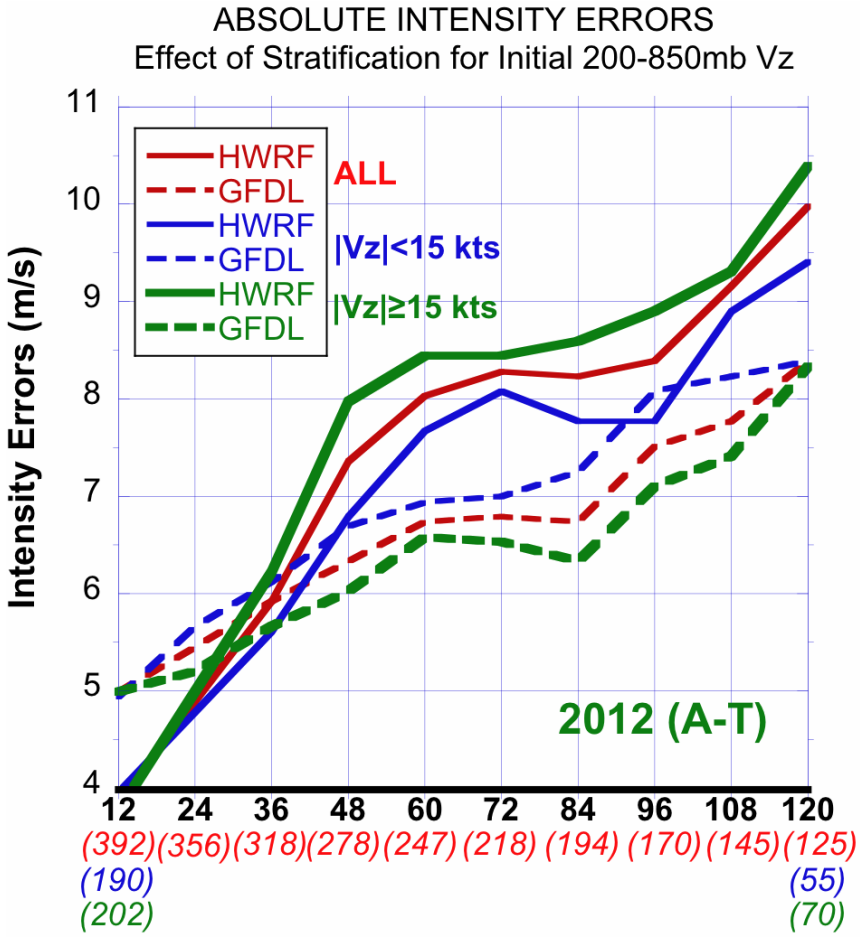
What's wrong with intensity forecasts?

Errors Stratified by Initial Storm Intensity



All Cases/Initially <Hurricane/Initially Hurricane

Errors Stratified by Initial Vertical Shear



All Cases / |Vz|<15 kts / |Vz|≥15 kts

Weak and sheared storms mostly contribute to HWRF intensity error

NHC's Wish List for 2013

- Improved regional hurricane model guidance for intensity; request continued EMC participation and support of HFIP model development activities
- Assimilation of inner-core aircraft data (Tail Doppler, flight-level, dropsonde winds) in the HWRF initialization

Priorities for Operational HWRF for 2013 hurricane season

NHC's Wish List for 2013:

Improved regional hurricane model guidance for intensity; request continued EMC participation and support of HFIP model development activities

Assimilation of inner-core aircraft data (Tail Doppler, flight-level, dropsonde winds) in the HWRF initialization

- **WCOSS Transition and Timelines**
- **Pre-Implementation T&E**
- **Operational Implementation Plans**
- **HFIP supported real-time efforts**

Transition to WCOSS and Timelines

- Entire production suite from CCS (IBM-P6) to WCOSS is expected to be completed by August 31, 2013 – which means current CCS will continue delivering operational products during early part of the hurricane season. **No scientific changes are allowed during the transition process (including bug fixes, except for those that will break the operational system due to compiler/OS/machine differences).** Initial implementation of HWRF on WCOSS will use the same 2012 operational configuration.
- **EMC HWRF Team will proceed with annual upgrade process and will work with NHC to make alternate arrangements FY2013 HWRF implementation and real-time product delivery (parallel feed from WCOSS with Jet as backup)**

2013 HWRF pre-implementation test plan

	Baseline (H130)	Physics upgrades					Combined (H213)
		PBL2 (H131)	Meso-SAS (H132)	RRTMG (H133)	MP (H134)	Ocean (H135)	
Description	Revised init/GSI New nest parent interpolations Radiation bug fix Revised nest movement Increased frequency of Physics calls	Variable Ric	Meso SAS	Radiation	2 way interaction of MP species	Removal of flux truncation MPI-POM?	Baseline+ physics
Cases	Whole 2012 storms	Priority / All 2012 cases	Priority / All 2012 cases	Priority /All 2012 cases	Priority /All 2012 cases	Priority /All 2012 cases	2010+2011+ 2012 all storms
Due date	Jan. 15	Jan. 15/ Feb. 15	Jan. 15/ Feb. 15	Jan. 15/ Feb. 15	Jan. 15/ Feb. 15	Jan. 15/ Feb. 15	April 15
Platform	Jet/Zeus/WCOSS*	Jet	Jet	Zeus	Zeus	Jet	Jet/WCOSS*

Improved intensity forecast skill is the highest priority for 2013 implementation

Additional testing for Western Pacific Storms based on final H213 configuration

New Baseline* for 2013 HWRF

- **Define the baseline configuration (H130) (individual components tested for all 2012 storms):**
- Revised vortex initialization scheme
- Infrastructure changes with new nest-parent interpolation
- Revised nest-motion algorithm based on PDYN from d01/d02 and increased frequency of physics calls
- Revised GSI (one-way hybrid, with TDR and flight level DA capability) with modified vortex initialization procedure
- *** Performance of the baseline configuration should be equal or better than the operational HWRF**

Physics Upgrades*

- **Physics upgrades on top of the baseline configuration, Two-stage testing; idealized and real cases**
- Revised PBL scheme with various critical Richardson number approach **H131**
- Meso SAS: **H132**
- RRTMG radiation scheme: **H133**
- Microphysics feedback: **H134**
- Removal of flux truncation and 3-D ocean for Eastern Pacific basin: **H135**
- Evaluation of results, Model diagnostics, web-based graphics and extended verification based on HFIP ADD efforts
- ***Goal is to accomplish at least 20% improvement in intensity forecast skill from the combination of new baseline and physics upgrades**

New Interpolation

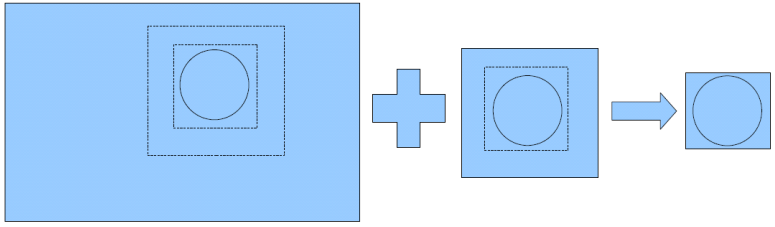
OLD METHOD	NEW METHOD
Two-step spline Expensive, introduces artificial structure	**Single-step linear interpolation** More accurate, faster.
Only supports bulk (Ferrier) microphysics Zero condensate advected from boundary. Method too expensive to allow MP. interp.	**Supports any microphysics scheme** Faster interp allows two-way interaction of mass and number concentration.
Extra memory usage & communication Two additional 3D arrays for every interpolated variable.	**Less memory and communication** No extra 3D arrays. Framework improvements allow less communication.
Downscale-only mass adjustments Framework limitations prevent mass adjustments during upscale interp.	**Mass adjustment also in upscale dir.** Framework improvements allow both upscale and downscale mass adjustments.
Numerous minor bugs Many minor bugs in both upscale and downscale directions.	**Many minor bug fixes** Many fixes to minor bugs in upscale and downscale interp. directions.

New Nest-Parent Interpolation method in WRF-NMM is computationally advantageous (accurate and faster) and allows us to experiment with more sophisticated microphysics schemes and 100% feedback from nest to parent

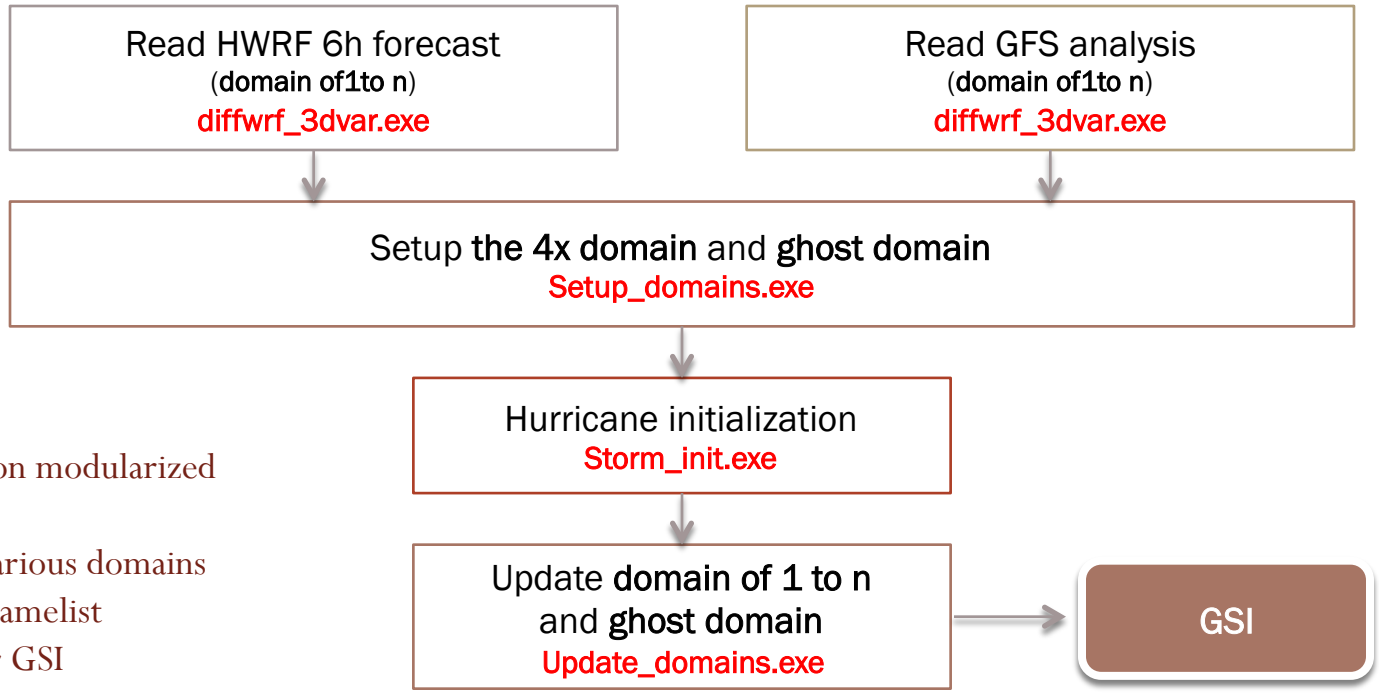
New nest movement algorithm is designed to prevent the nest loosing the storm (especially in the presence of topography or another large-scale system) and to have the nest centered over the storm more accurately. This is a significant improvement over centroid based methods.

New Nest Motion Algorithm Dynamic Pressure Minimum

- Mean sea level dynamic pressure:
  - $q=P_{MSLP} + v^2\rho_{MSLP}/2$
  - Less noisy than P_{MSLP}
- Average 27km and 9km q (even less noisy!)
- 3km domain searches for minimum value.



New Vortex Initialization procedure (total number of domains = n)

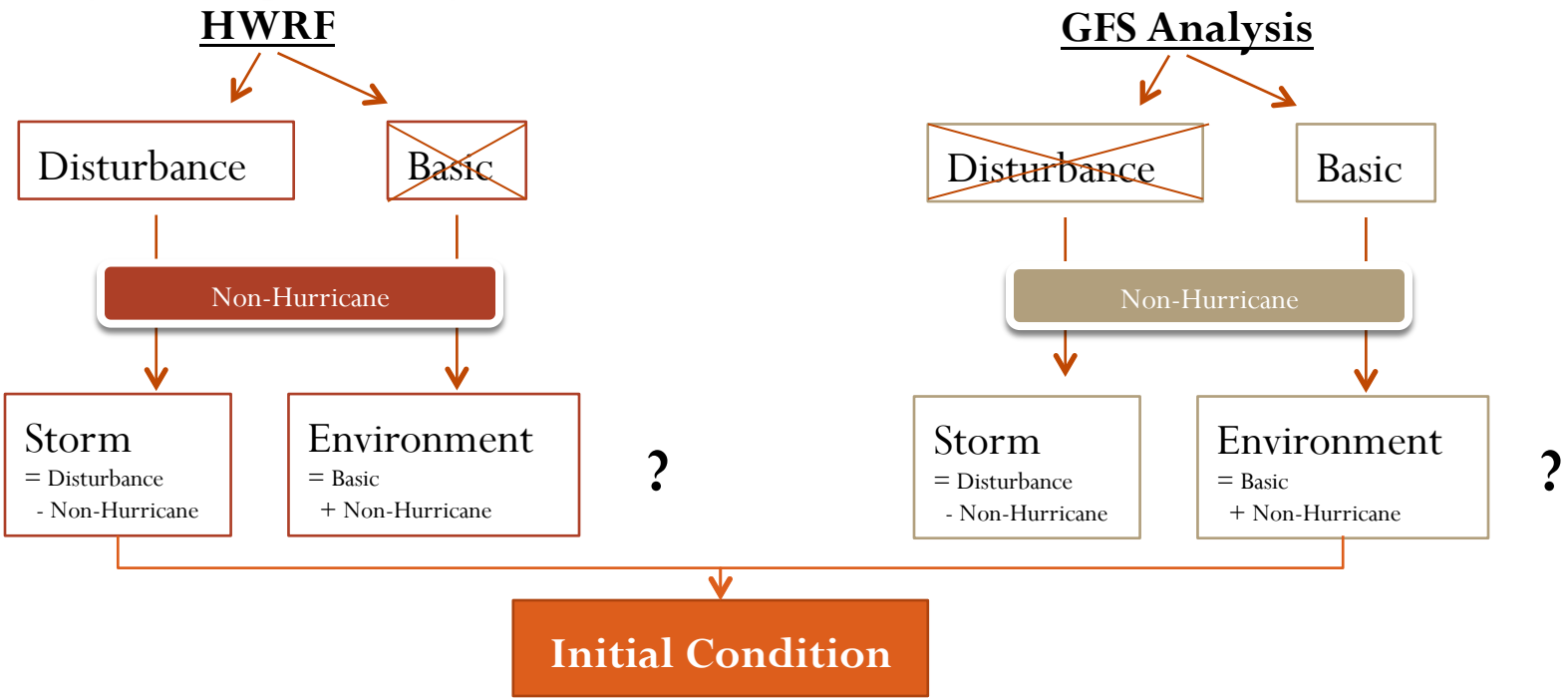


Vortex initialization modularized
: Simple structure
: Flexible about various domains
: Control with a namelist
: Variable table for GSI

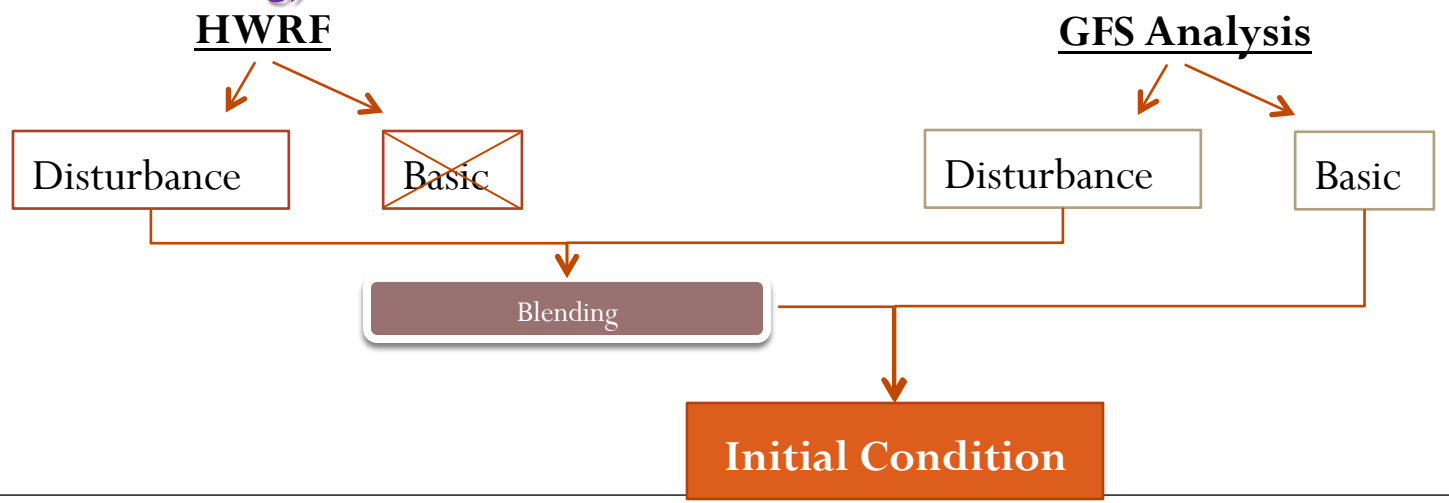
2. Scientific difference from the operational HWRF)

Scientific difference	New TC Initialization
Size correction	Taking the intensity into account before size calculation Pressure recalculation after the wind structure correction
Intensity correction	Tangential wind adjustment after the geopotential correction
Moisture adjustment	Temperature and moisture calculation from the virtual temperature and humidity
Storm blending	Blending two disturbance fields (Outer area: GFS, Inner core: HWRF)

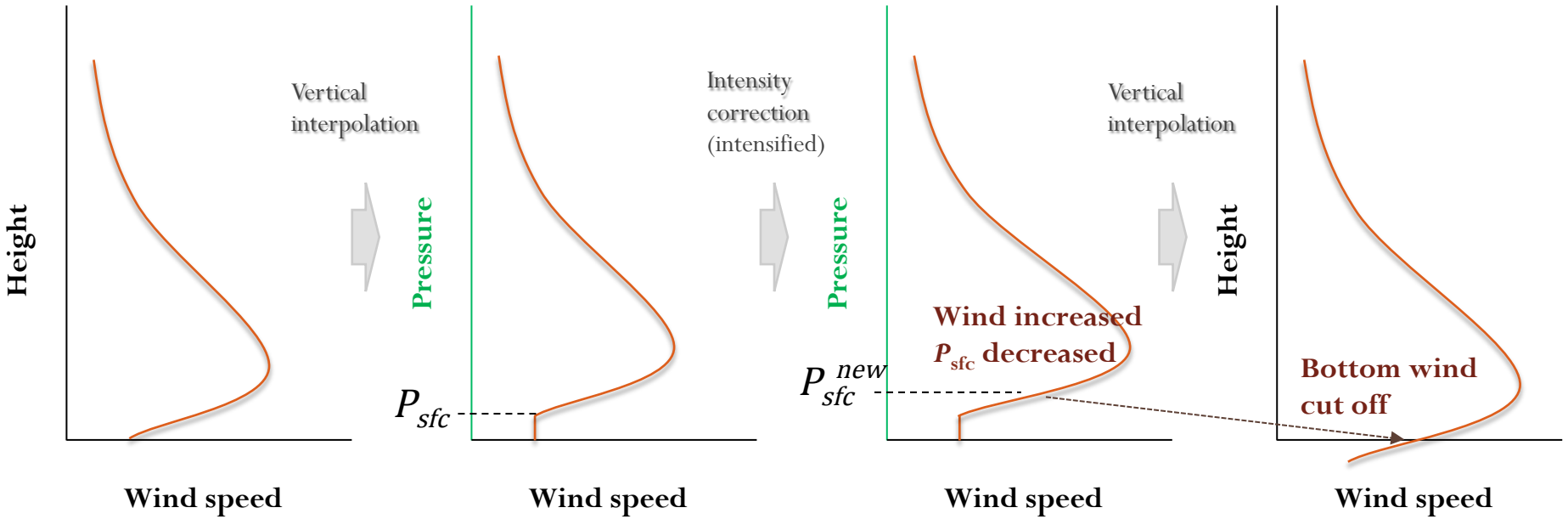
Operational (Vortex replacement)



New (vortex blending)



Problem of the intensity correction on pressure coordinates

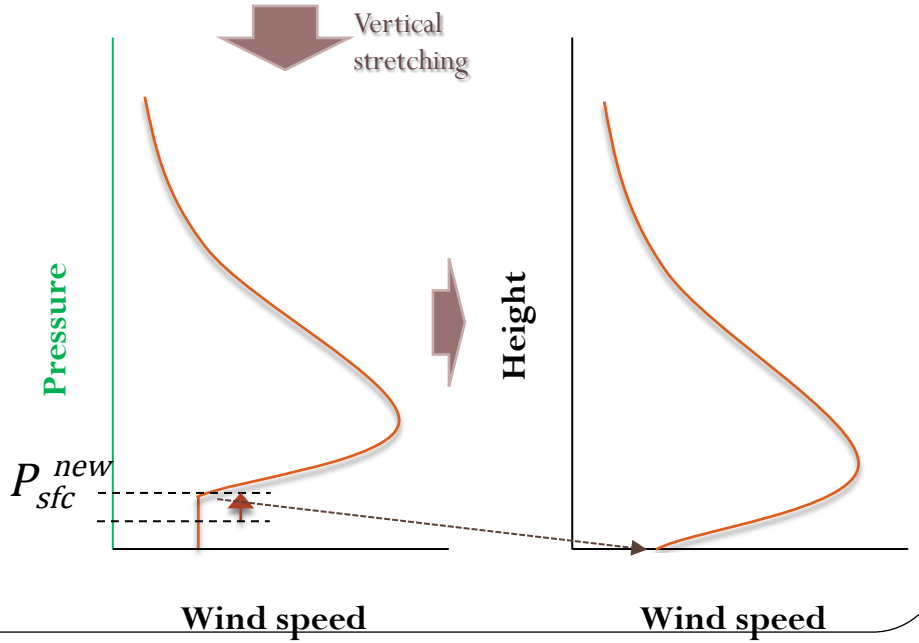


Solution: Vertical stretching

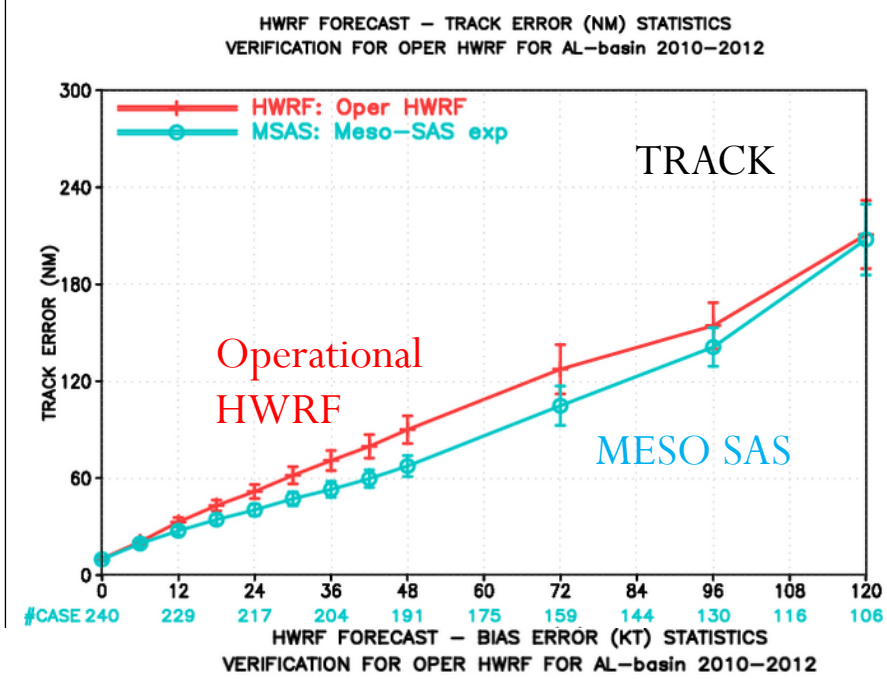
- Wind at p_{sfc} is relocated to p_{sfc}^{new}
- When wind increases → Stretched up
- When wind decreases → Stretched down

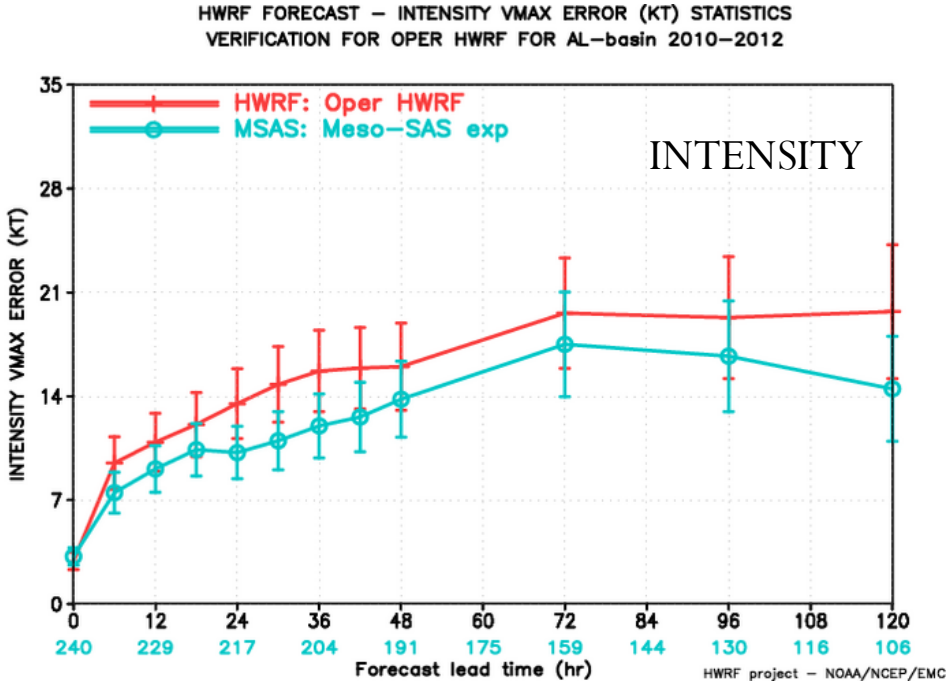
Additional benefit of the stretching

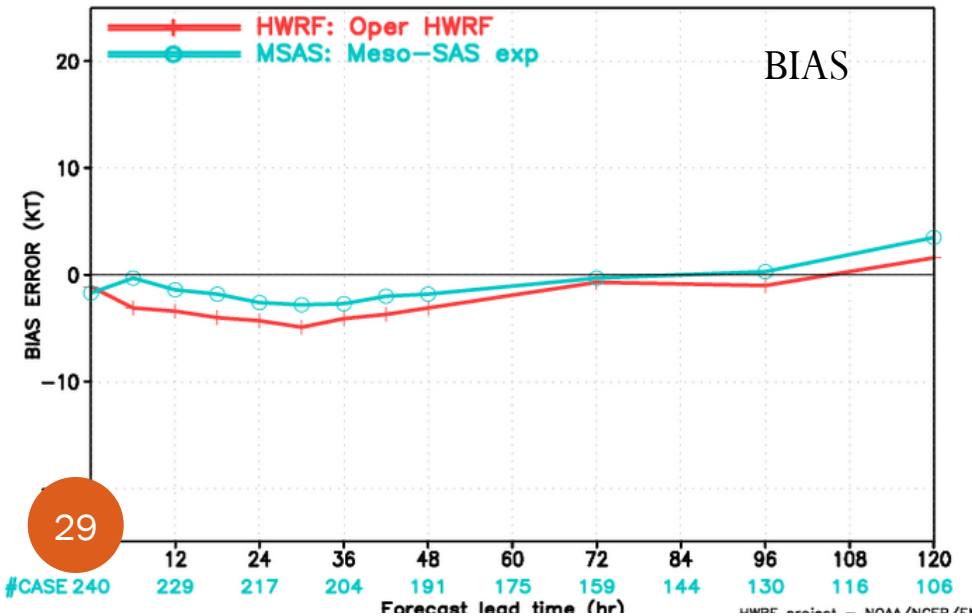
- If the first guess intensity is weaker than the observation, during the initialization, Warm core height rises as well as wind increases
  : Favorable to the storm intensification



Convective Parameterization for high-resolution grids (Meso-SAS)







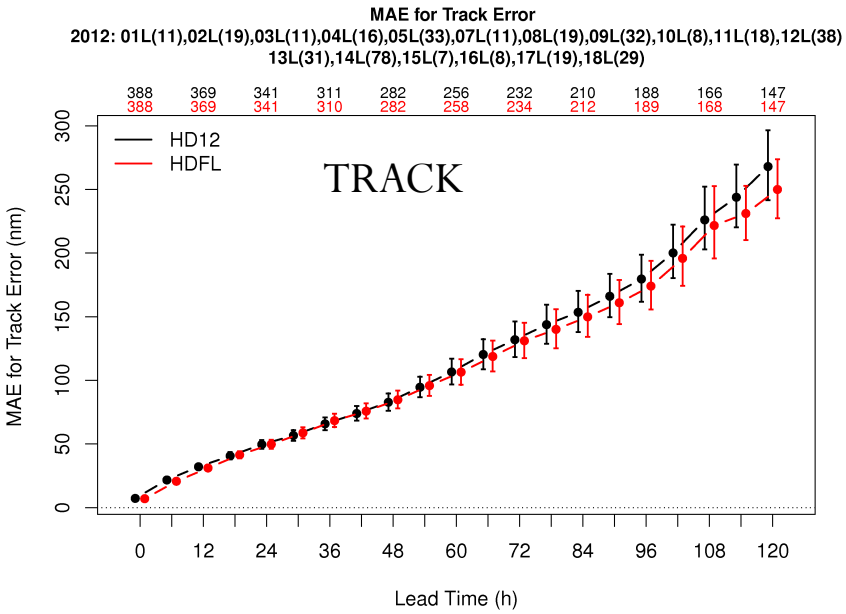
Operational SAS scheme is not designed for high-resolution models:

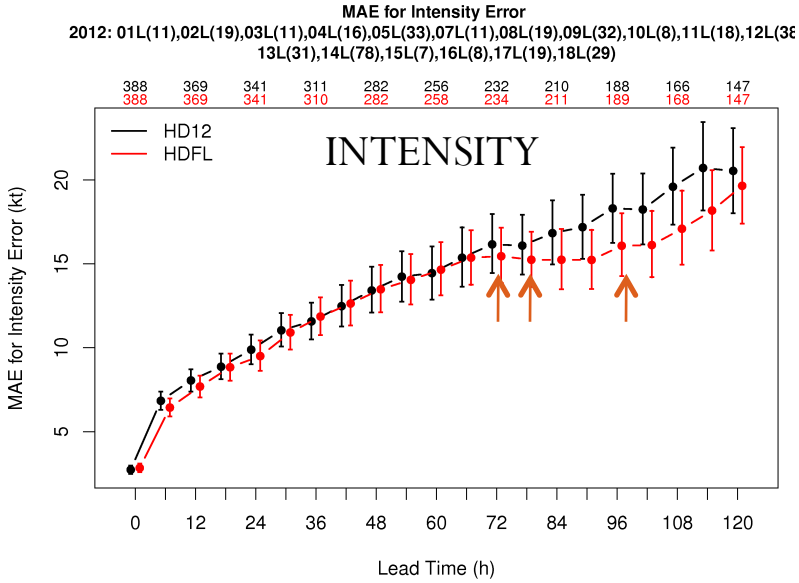
Basic assumption: updraft area is very small compared to the model grid size – which begins to break down at resolution <10 km.

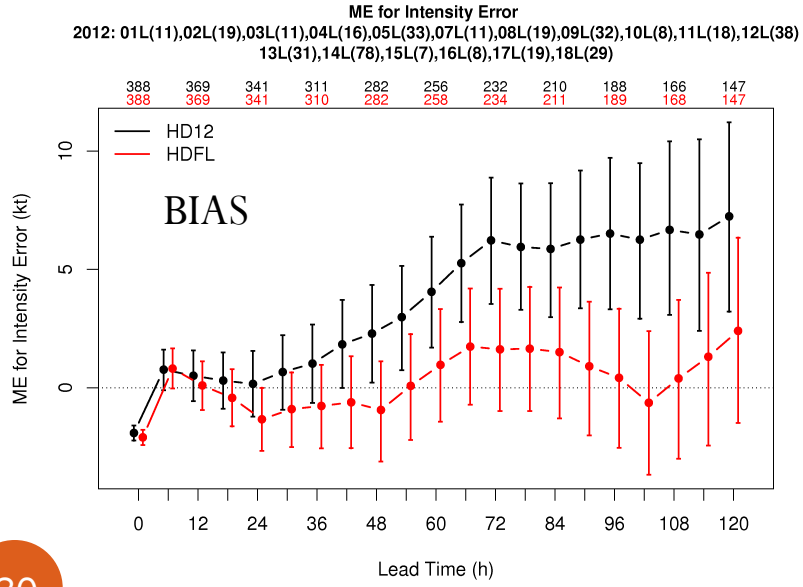
At 0.5-10km model resolution, use of explicit MP scheme is still problematic (vertical motion may not be large enough) and creates grid-point storms

Hua-Lu Pan re-derived the SAS scheme by removing the assumption that the updraft area be small, and make it possible to form the meso-SAS scheme which can be used in high resolution models.

Ocean upgrades: Removal of heat & momentum flux truncation







- DTC has completed the runs of control and flux experiment for entire 2012 season
- Overall the impact of the change in fluxes seem beneficial
- Will be included in 2013 GFDL upgrades as well.

HFIP Stream 1.5/ Stream 2.0 efforts

- **Physics driven HWRF ensembles ----- Stream 1.5**
- **Suite of High-resolution Physics ----- Stream 1.5**
- **HWRF-MPIPOM (including 3D ocean for Eastern Pacific) ----- Stream 1.5**
- **FY2013 HWRF for Western Pacific and Indian Ocean basins ----- Stream 1.5***
- **Basin-scale HWRF with regional hybrid-DA ----- Stream 2.0**
- **Basin-Scale HWRF with multiple moveable domains ----- Stream 2.0**
- **Three-way coupled HWRF-POM-WWIII system ----- Stream 2.0**
- **Continued evaluation of HWRF-HYCOM coupled system ----- Stream 2.0**

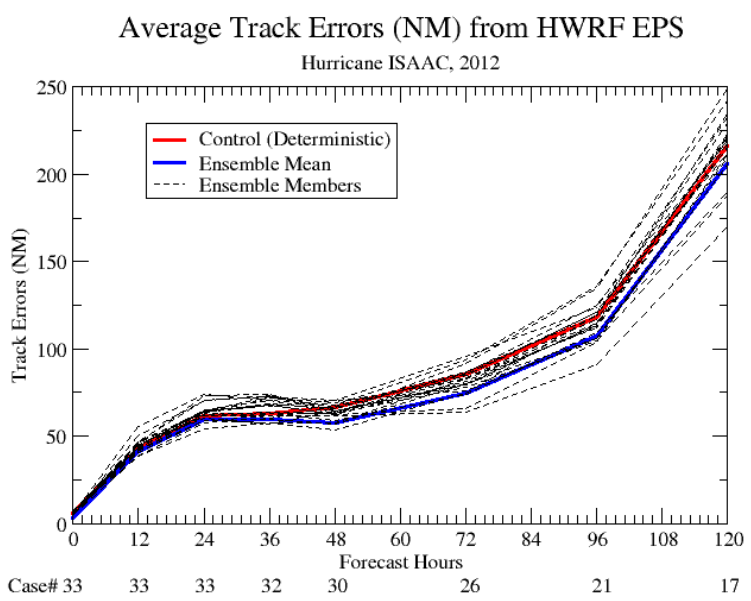
Ensemble Prediction System for HWRF – HFIP Stream 1.5

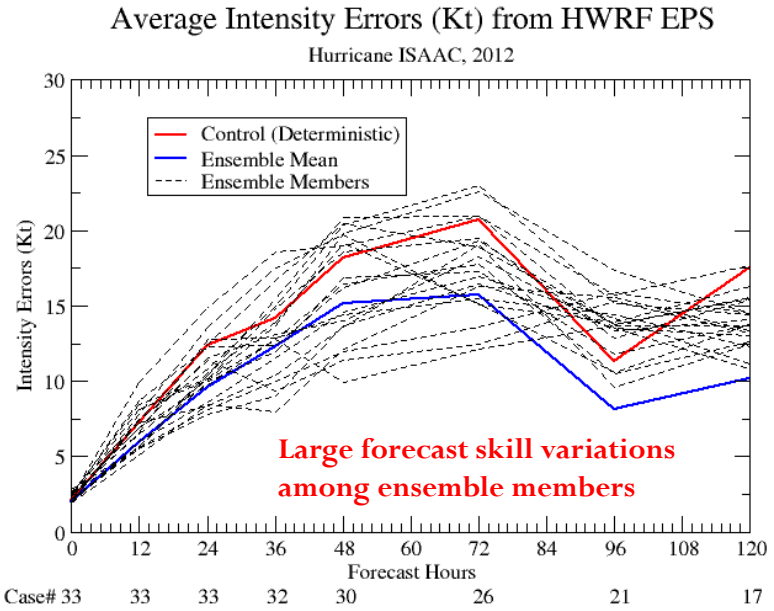
1. **IC/BC Perturbations**
   - **Large scale flow based, either from GEFS/ETR or GEFS/EnKF;**
   - **Initialize the HWRF system from Global EPS-based fields as IC and BC;**
   - **Reduce uncertainties in model IC/BC in the large scale flows.**

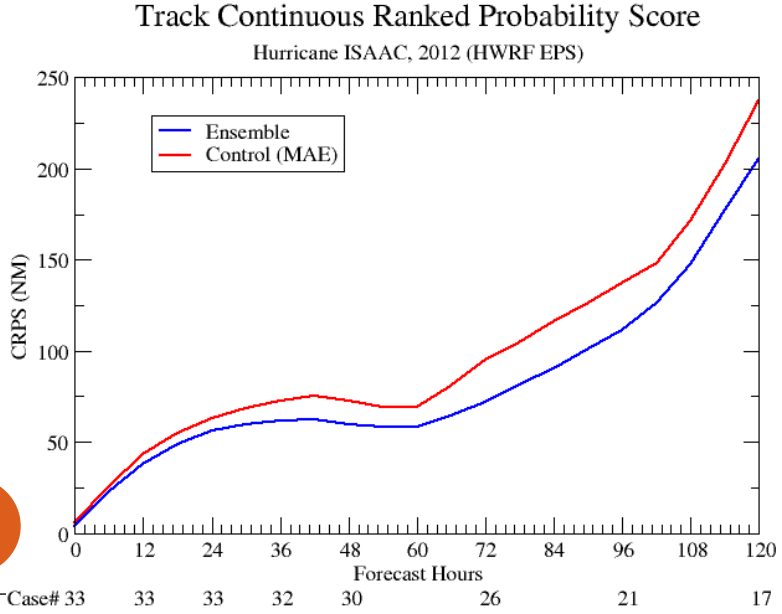
2. **Model Physics Perturbations**
   - **Physics –based method;**
   - **Stochastic Perturbed Parameterization Tendencies (SPPT);**
   - **Perturbing the convective trigger in the current SAS scheme to generate ensembles;**

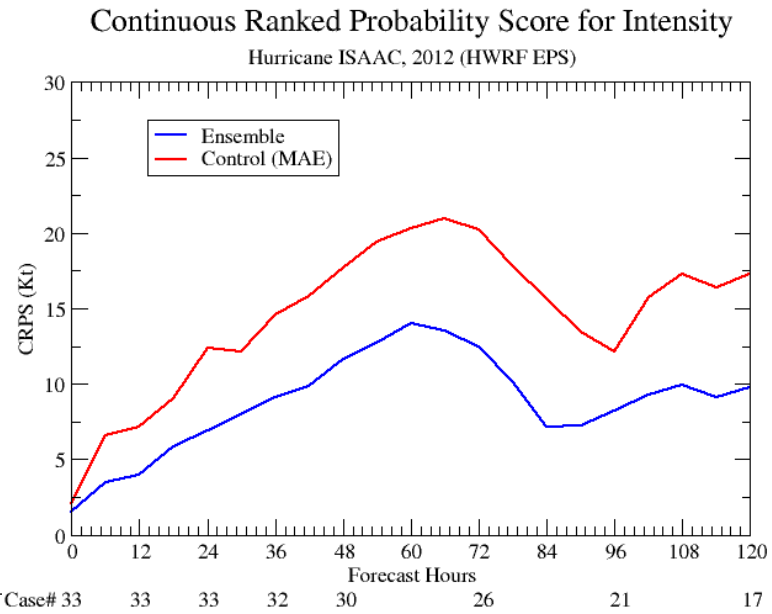
3. **10-20 ensemble members will be generated by combining the above two perturbations.**

20 member ensemble by perturbing convective trigger in SAS



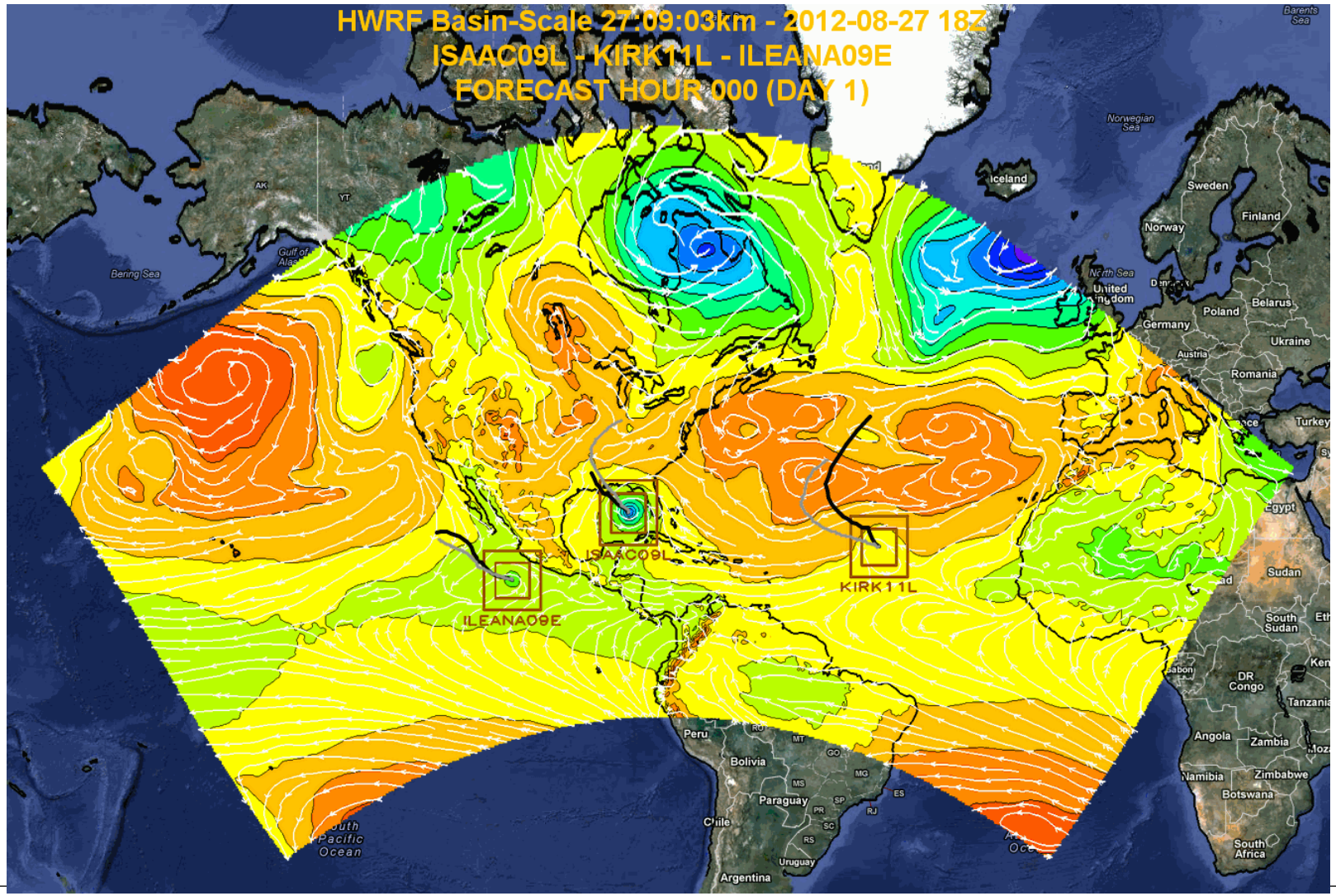






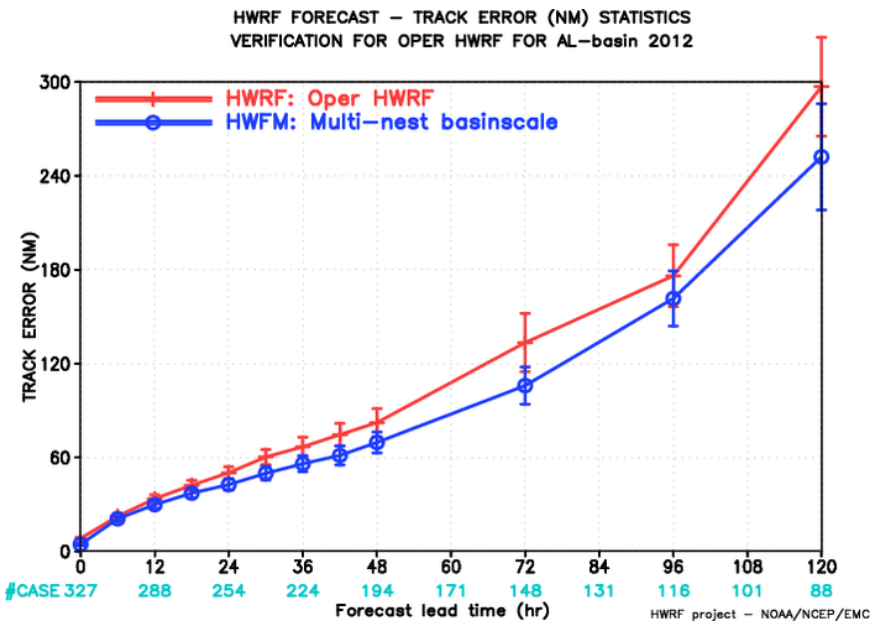
Advancements to Operational HWRF – Basin Scale Configuration with multiple moveable nests (Stream 2.0)

Isaac-Ileana-Kirk real-time forecast

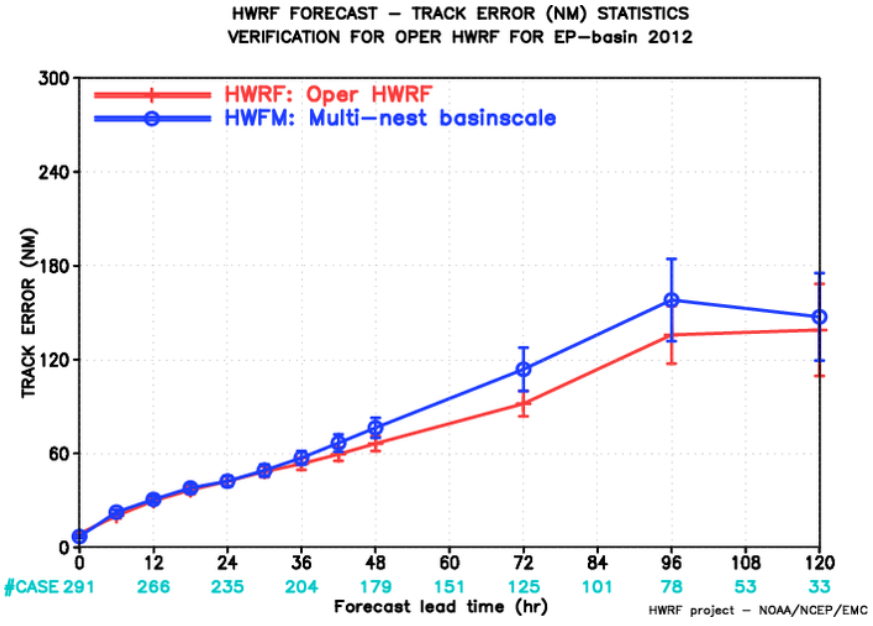


Basin Scale Multi-domain HWRF performance (2012)

Atlantic Track error



Eastern Pacific Track error



Improved track forecast skill in the Atlantic from Basin-Scale HWRF

- Regional EnKF-GSI based data assimilation system is actively being developed for the basin-scale HWRF through support from HFIP with a possible 2014 implementation (EMC/ESRL/OU/DTC collaboration)
- Computational efficiency of basin-scale HWRF with multiple moveable domains is a challenging task and is explored by EMC/AOML

Advancing the HWRF System FY2013 & Beyond

	2013	2014*	2015*	2016*	2017*
Resolution/ Infrastructure	New Nest-Parent Interpolations; expanded domain size & new nest movement algorithm	Increased vertical resolution with higher model top	community R2O efforts (HFIP), Multiple moving domains	Upgrades to infrastructure - NEMS/ ESMF/NMM-B, Other oceanic basins, HWRF Ensembles, Global to local scale modeling for hurricanes	
Physics	Meso-SAS, Modified PBL, Improved microphysics & Radiation	Microphysics, Radiation, Surface Physics, Coupling to Waves and Land Surface, Physics for high-resolution			
DA/ Vortex Initialization	Modified vortex initialization and One-Way Hybrid with inner-core TDR and flight level DA	Inner core DA (TDR, satellite), cloudy radiance assimilation Two-Way regional Hybrid DA HWRF Ensembles		Hybrid-EnKF DA, advanced vortex relocation procedure, improved GSI/ Hybrid techniques, DA for moving nests	
Ocean	3-D ocean for Eastern Pacific & removal of flux truncation	Improved ocean data assimilation, physics and resolution, unified coupled system for ATL & EPAC			
	HWRF-HYCOM for all oceanic basins (driven by Global RTOFS)				
Waves	Atmosphere-Ocean-Wave Coupling		Multi-grid surf zone physics, effects of sea spray		
Diagnostics and Product Development	HWRF Ensemble based products, Coupling to Hydrological/ Surge/ Inundation models, advanced model diagnostics based on observations, improved product development				

2013 upgrades

Planned/ongoing developments

*Resource permitting

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/AOML, PSD/ESRL, GFDL, URI, UMD, FSU, CIRA and other HFIP partners