Overview of the NCEP Operational HWRF Modeling System

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Outline

- History of Operational HWRF Model Development
- HWRF as a community tropical cyclone modeling system
- Role of academic and research community in HWRF Development Process
- HWRF as a global tropical cyclone modeling system for research and operations
- Performance of the 2015 operational HWRF Model
- Components of the HWRF modeling system
- Ongoing HWRF model developmental efforts for 2016 and beyond

Hurricane WRF (HWRF)

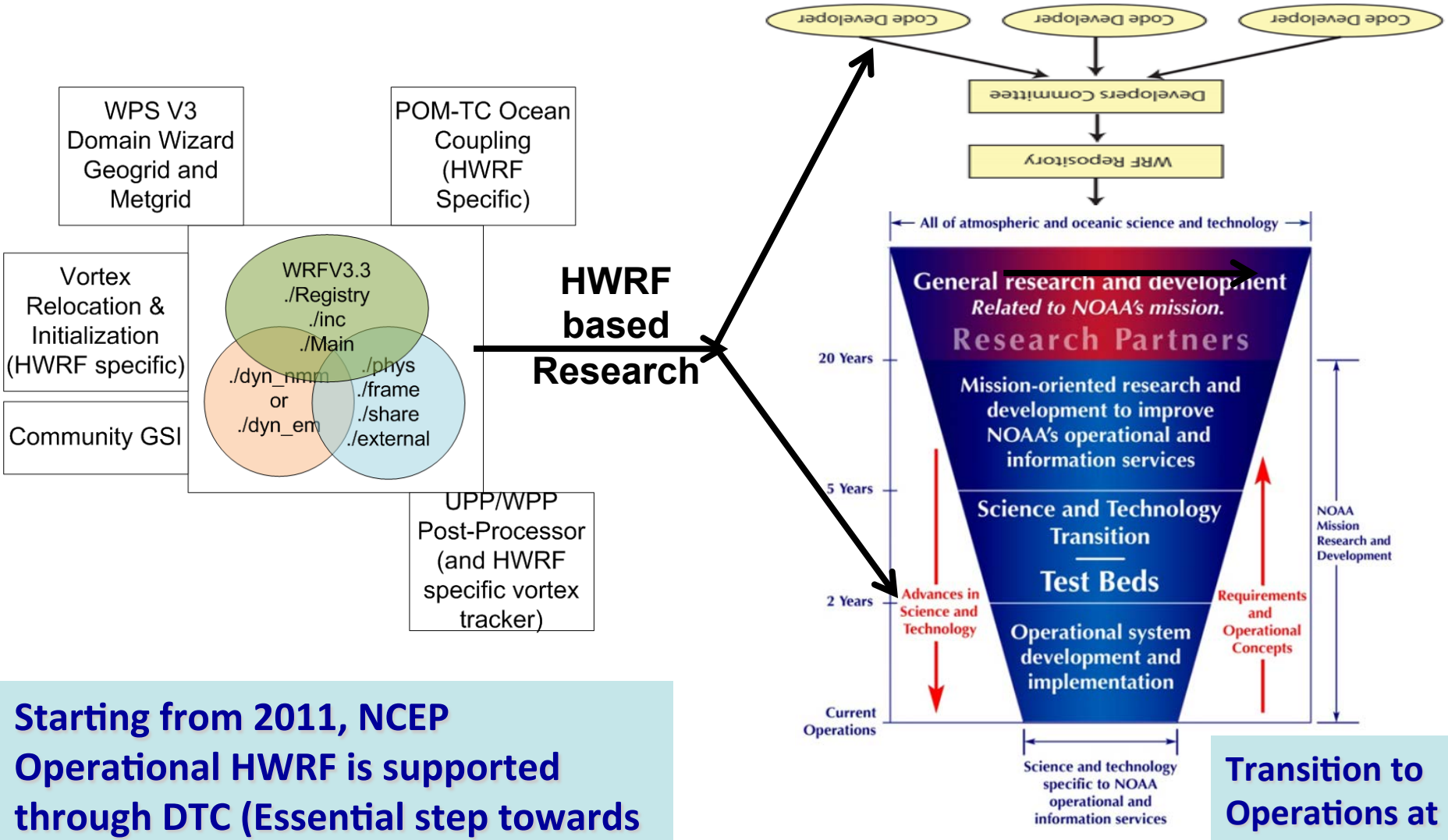
- **The Weather Research and Forecast Modeling System for Hurricanes (HWRF) was designed and developed NCEP/EMC utilizing the community WRF software infrastructure to rapidly advance hurricane forecast skills for operational needs.**

- **HWRF became operational in the year 2007 preceded by extensive testing and evaluation for three hurricane seasons (2004-2006), and has been constantly improved to increase the forecast skill for track, intensity and structure of Atlantic and Eastern Pacific hurricanes.**

- **Starting in 2011, the operational coupled HWRF-POM modeling system became a community tropical cyclone modeling system supported through DTC. The use of same code by research and operations was accomplished through dedicated subversion based code management and community support, facilitating accelerated Operations to Research (O2R) and Research to Operations (R2O).**

- **With the support of NOAA's Hurricane Forecast Improvement Project (HFIP), HWRF has rapidly advanced and evolved as a unique and one of the best tropical cyclone models, catering to both operations and research for all oceanic basins of the world.**

HWRF Upgrade Process



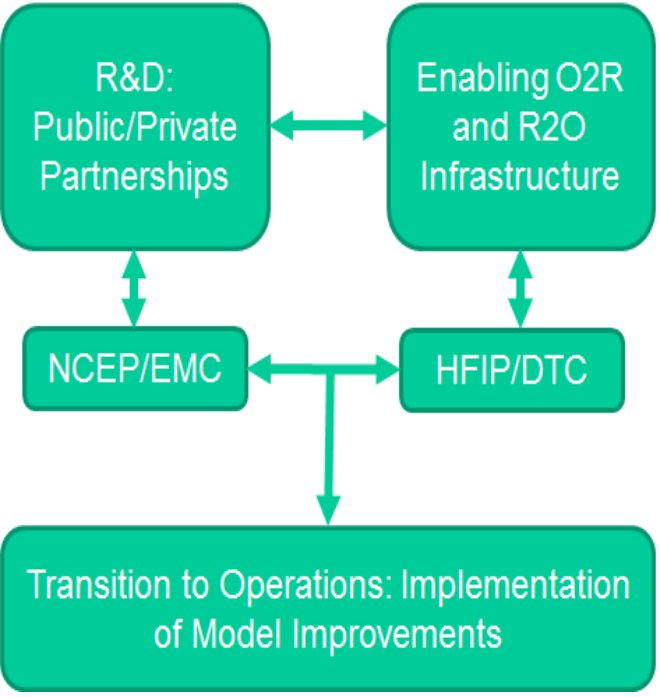
Starting from 2011, NCEP Operational HWRF is supported through DTC (Essential step towards O2R and R2O)

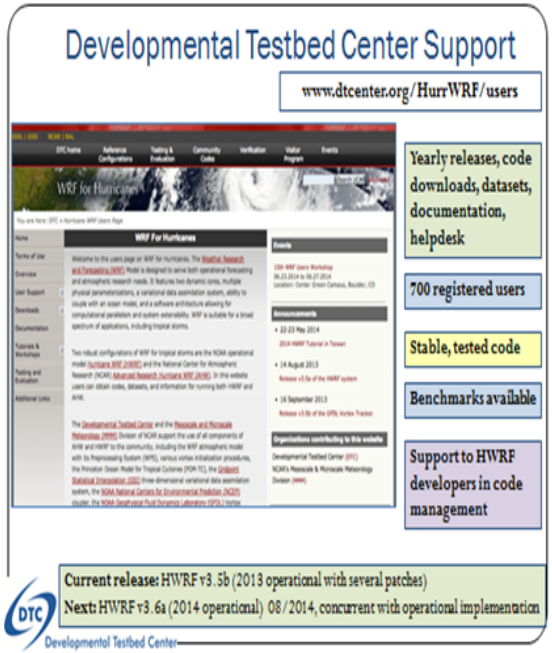
Transition to Operations at NCEP/EMC

Rapid Progress in Hurricane Forecast Improvements

Key to Success: Community Engagement & Accelerated Research to Operations

Operational Hurricane Modeling System Development



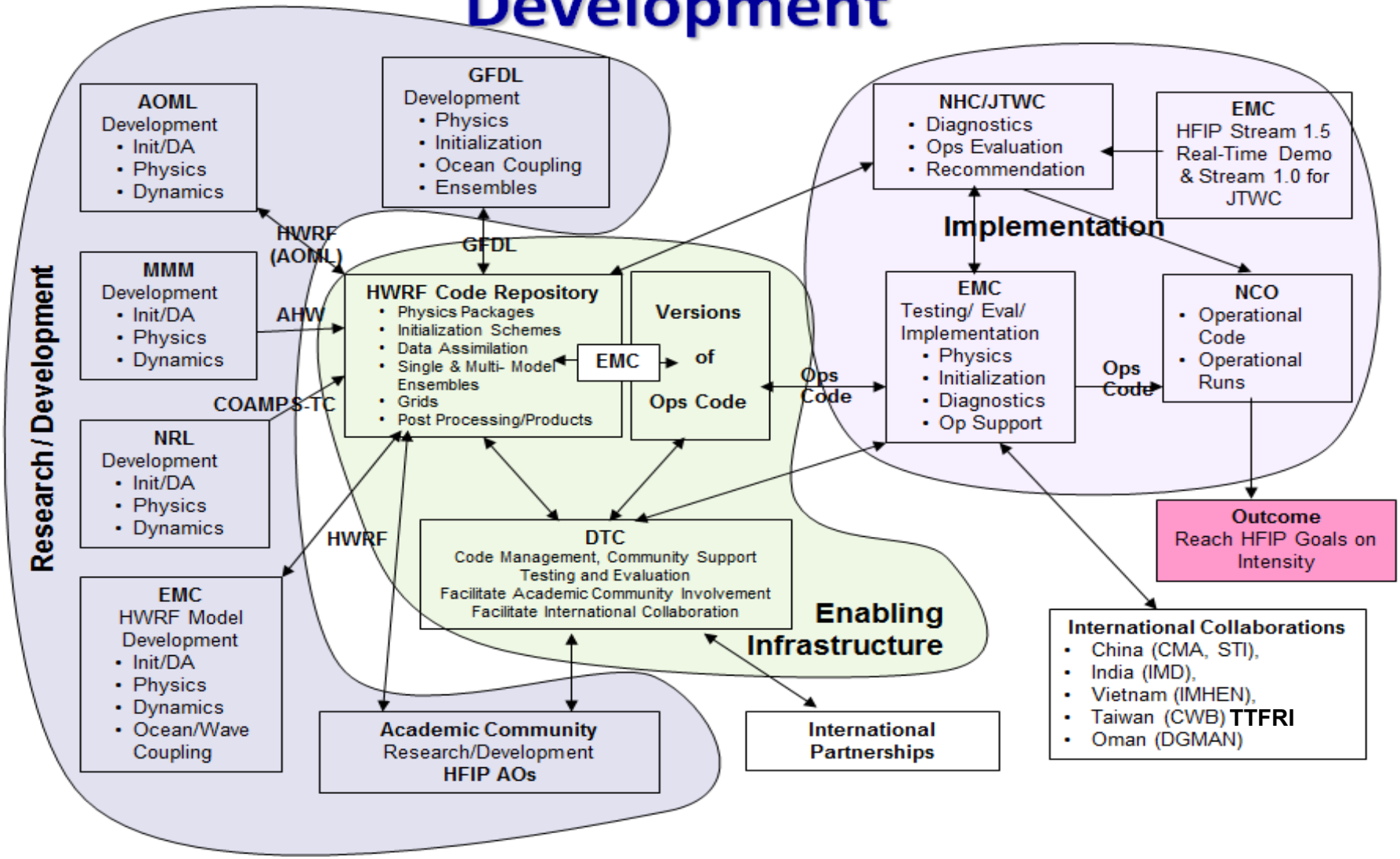


Continue the community modeling approach for accelerated transition of research to operations

International partnerships for accelerated model development & research

Effective and accelerated path for transitioning advanced research into operations

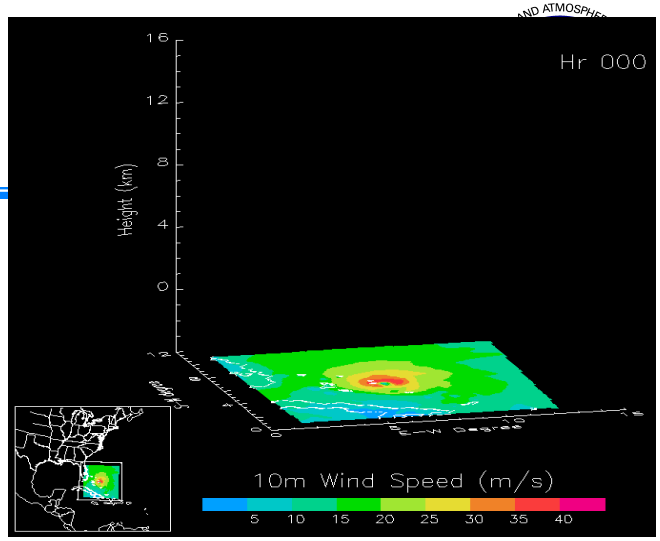
Operational Hurricane Modeling System Development



Evolution of HWRF

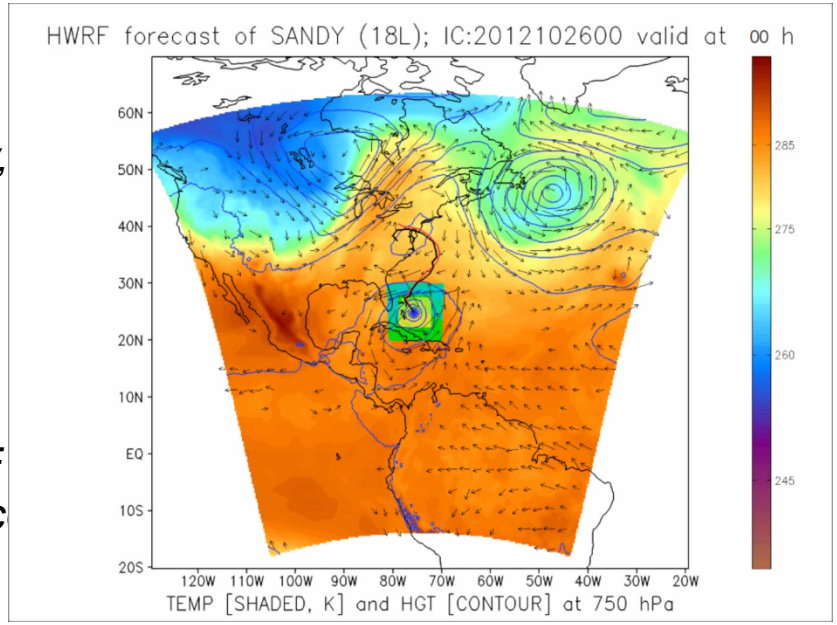
- **Initial implementation in 2007 hurricane season**
  - Model design and development of movable nested grid started in 2002 in collaboration with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) scientists and the University of Rhode Island (URI)
  - Initial HWRF workshop at NSF in 2004
  - 28 different configurations tested individually (each with about 200 simulations) before initial implementation
  - Extensive 3-season (2004-2006) pre-implementation testing of HWRF for all storms in the Atlantic and Eastern Pacific basins
- **Vortex initialization upgrades in 2008**
  - Address intensity bias for weaker systems, modifications to storm balance
- **Infrastructure upgrade and transition to IBM P6 in 2009**
  - Capability enhancements to allow coupling to HyCOM and Wave Watch-III
- **Physics and initialization upgrades in 2010 to improve the forecast skill.**
  - Modified surface physics formulation and use of Gravity Wave Drag parameterization
  - Addition of satellite radiance data assimilation in the hurricane environment

FY2012 High-Resolution Triple-Nested HWRF



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

- ***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 guidanc*



NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

Highlights of FY2013 High-Resolution Triple-Nested HWRF V7.0.0

Infrastructure upgrades:

- Upgrade the **nest tracking algorithm**
- Re-design of **nest-parent interpolations**
- **Increased frequency of physics calls** and **increased size of the third domain**

Physics upgrades:

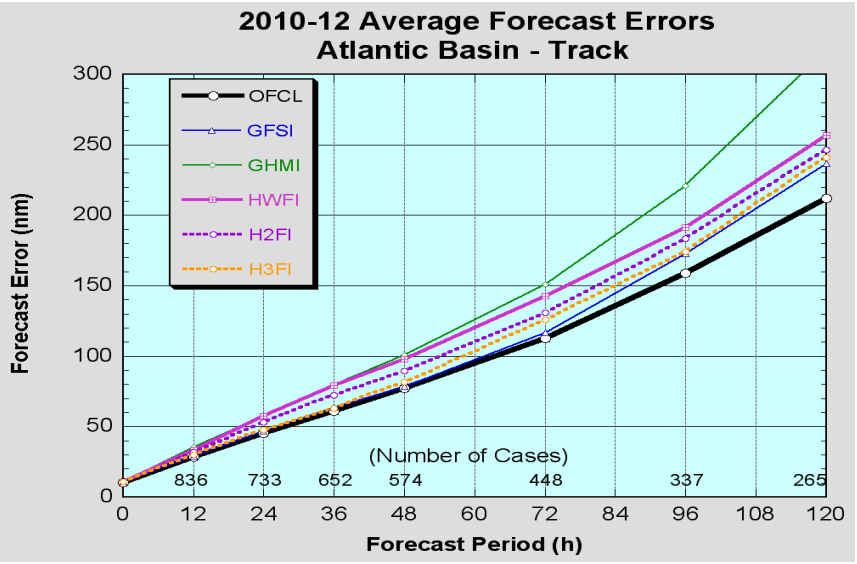
- **Modifications to GFS PBL** and **bug fix for GFDL radiation**

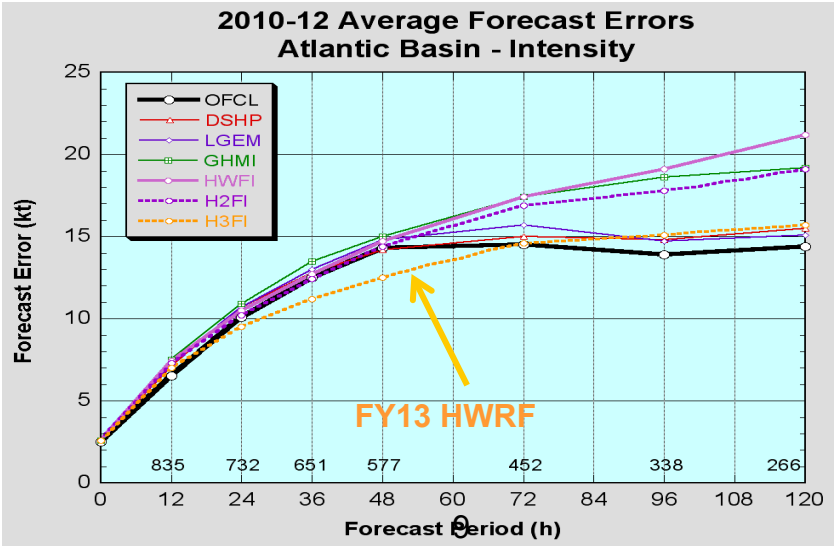
Data Assimilation and Vortex Initialization upgrades:

- **One-way hybrid EnKF-3DVAR data assimilation** and **assimilate real-time inner-core TDR datasets**
- **Improved storm size correction**, **modified filter domain** and **use of GFS vortex** when the storm is weaker than 16 m/s

Extensive evaluation:

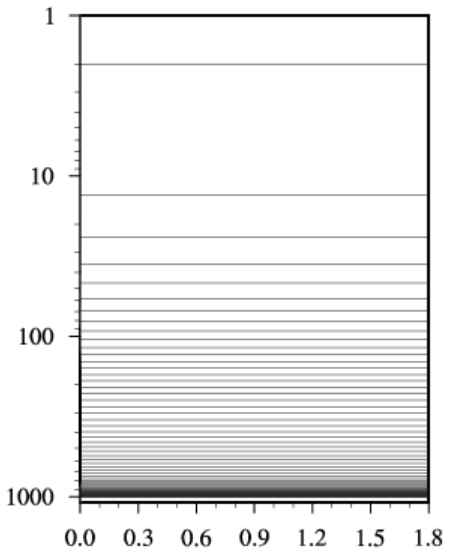
- **Three-season (2010-12) comprehensive evaluation for NATL/EPAC**
- **2012 typhoon season for WPAC**
- **Implemented on July 2, 2013**

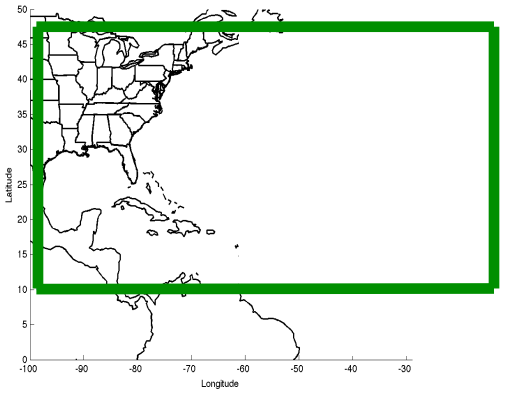




Highlights of FY2014 High-Resolution Triple-Nested HWRF V8.0.0

1. Increase the vertical resolution of atmospheric model to 61 levels with higher model top of 2 hPa, upgrade WRF NMM core to V3.6
2. Upgrade the ocean model (POM) to 1/12° MPI POM with unified trans-Atlantic basin and 3D ocean for Eastern Pacific basin. Upgrade the coupler to run on multiple processors.
3. Further improvements to HWRF vortex initialization scheme and HWRF Data Assimilation System, upgrade GSI to v3.6.
4. Additional operational forecast products from HWRF to include tornado probability forecasts, new variables for downstream applications (hurricane wave model) and 6-minute ATCF output Many bug fixes and enhancements for the vortex tracker, complete GRIB2 output.
5. Rewrite entire HWRF scripts using Python for a unified system





New in 2015 for HWRF in Operations

System & Resolution Enhancements

- *Increase the horizontal resolution of atmospheric model for all domains from 27/9/3 to 18/6/2 km.*

Initialization/Data Assimilation Improvements

- Upgrade Data Assimilation System with hybrid 40-member HWRF-based high-resolution ensembles and GSI system.

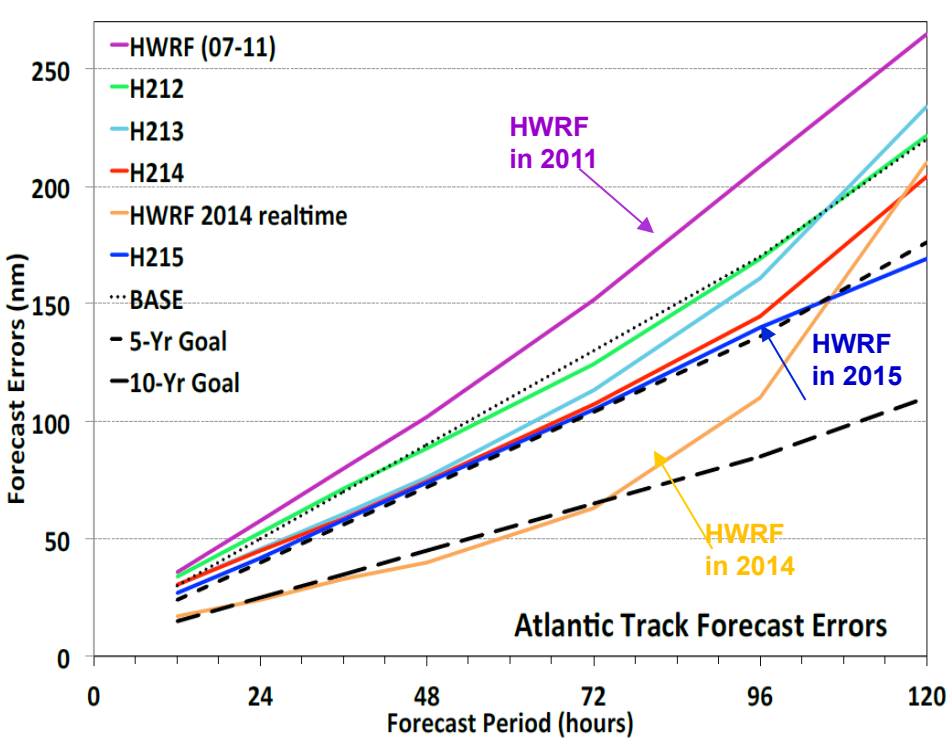
Physics Advancements

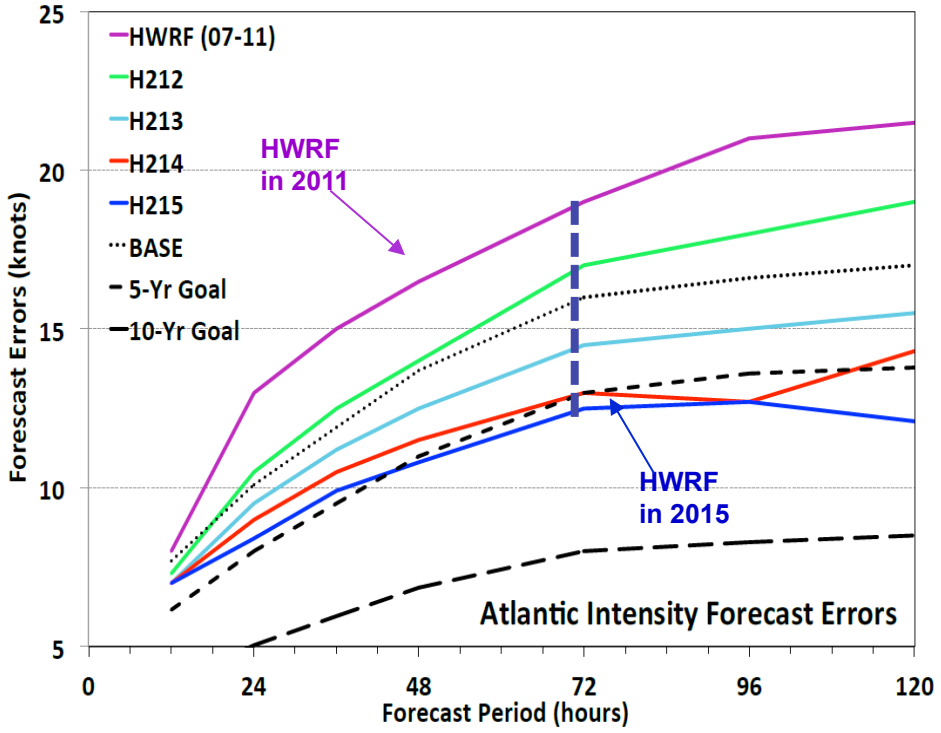
- Upgrade Micro-physics process (**Ferrier-Aligo**); replace GFDL radiation with **RRTMG scheme including sub-grid scale partial cloudiness**; Upgrade surface physics and PBL, replace current GFDL slab model to more advanced **NOAH LSM**.

First time in 2015….

- *Self cycled HWRF ensembles based warm start for TDR DA*
- *Expand HWRF capabilities to all global (including WP/SH/IO) basins through 7-storm capability in operations to run year long*

Significant improvements in Atlantic Track & Intensity Forecasts



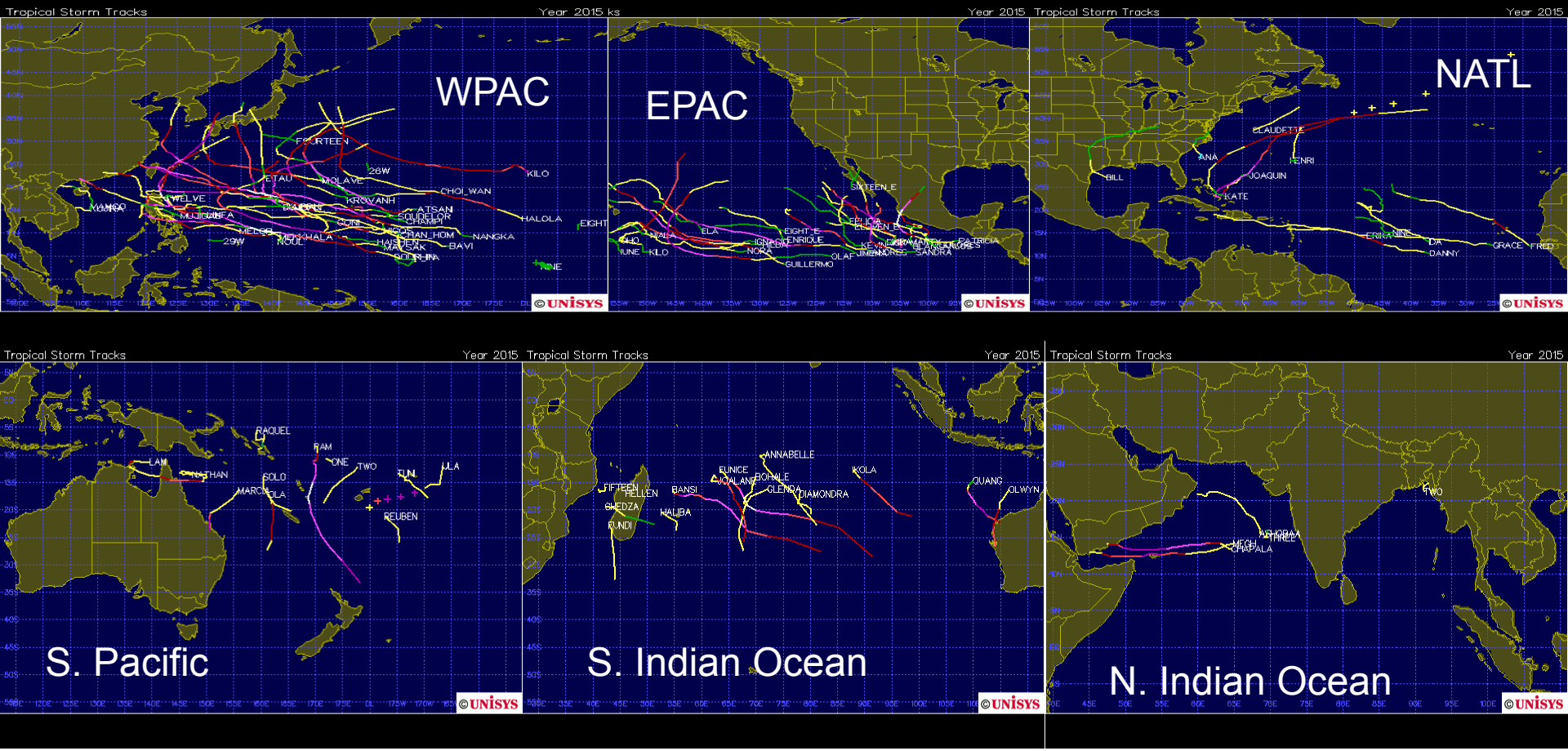


Improvements of the order of 10-15% each year since 2012

What it takes to improve the models and reduce forecast errors???

- **Physics**
- **Data Assimilation**
- **& Higher Resolution**

Targeted research and development in all areas of hurricane modeling



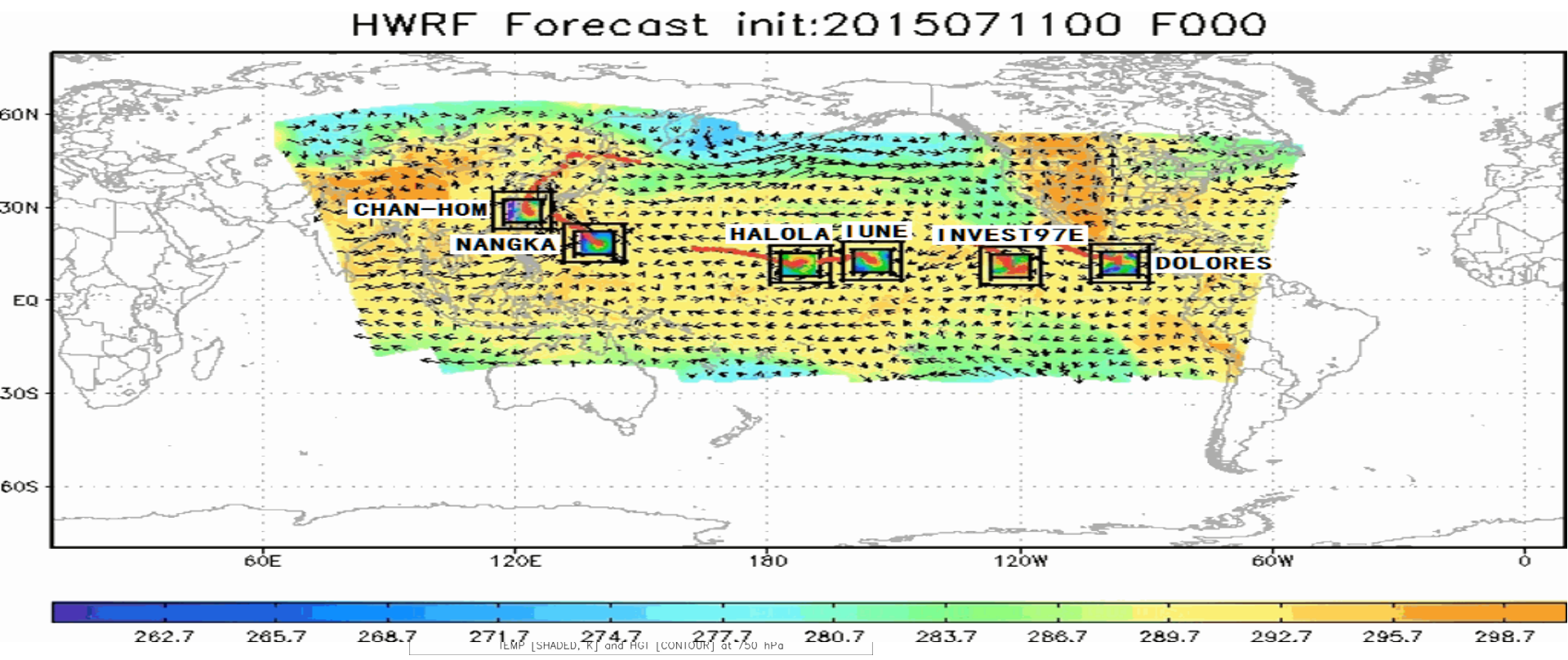
Global Threat of Tropical Cyclones:

NOAA/NWS areas of interest extend beyond NHC/CPHC AoR

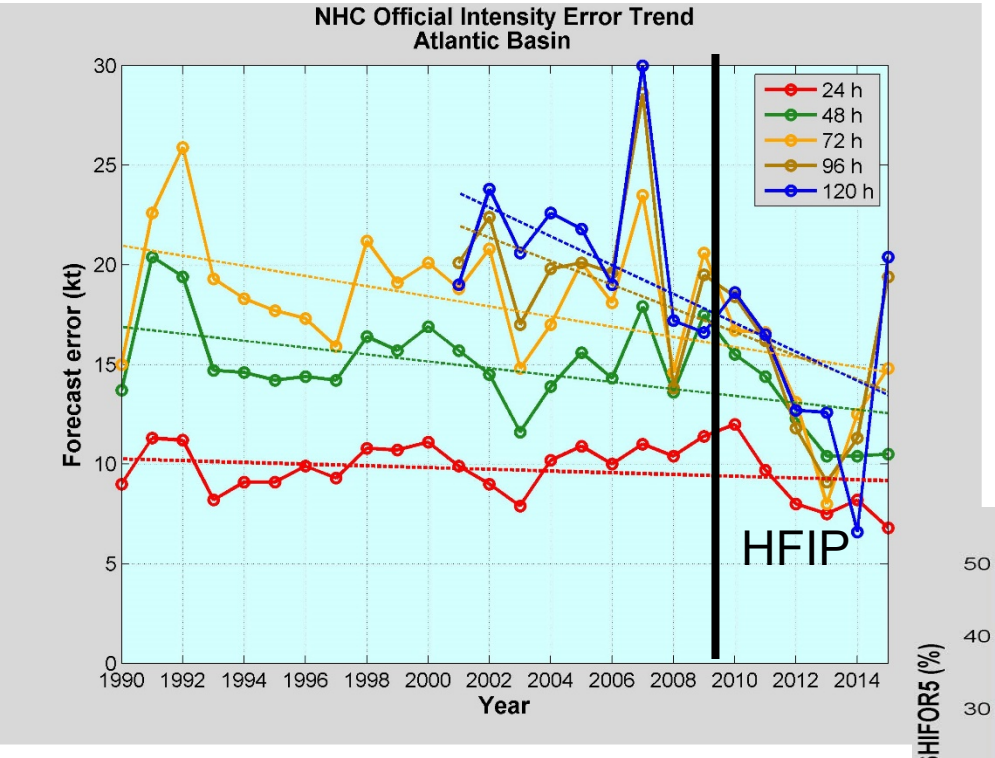
JTWC is responsible for all global TCs

N. Atlantic:	12 storms
E. Pacific:	22 storms
C. Pacific:	9 storms
W. Pacific:	33 storms
S. Pacific:	13 storms
S. IO:	17 storms
N. IO:	5 storms

Real-time Operational Configuration for 2015 HWRF

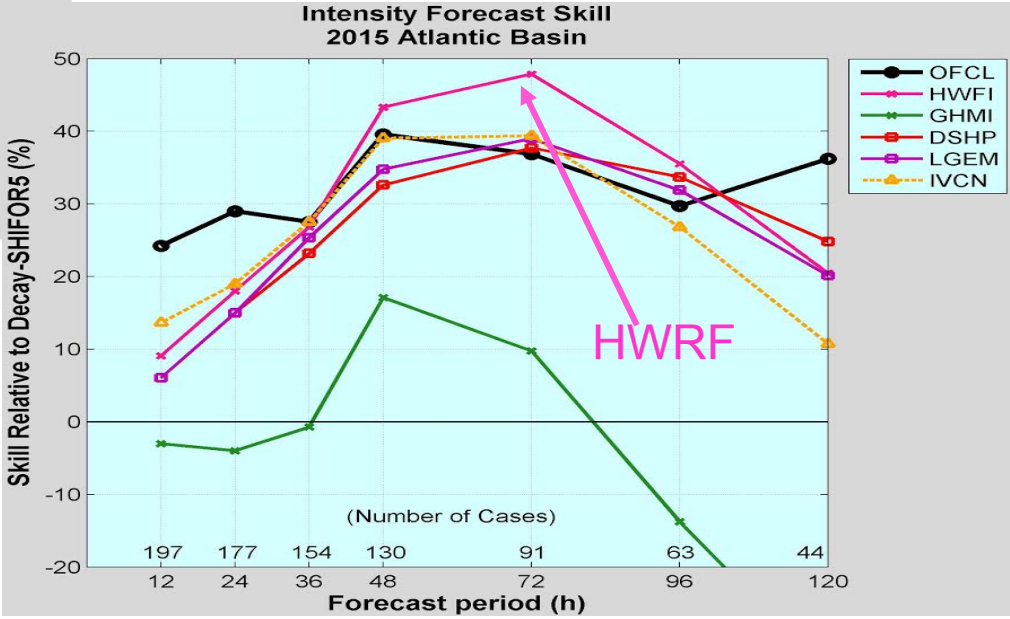


Highlights for 2015: Intensity forecast improvements realized in real-time from operational HWRF



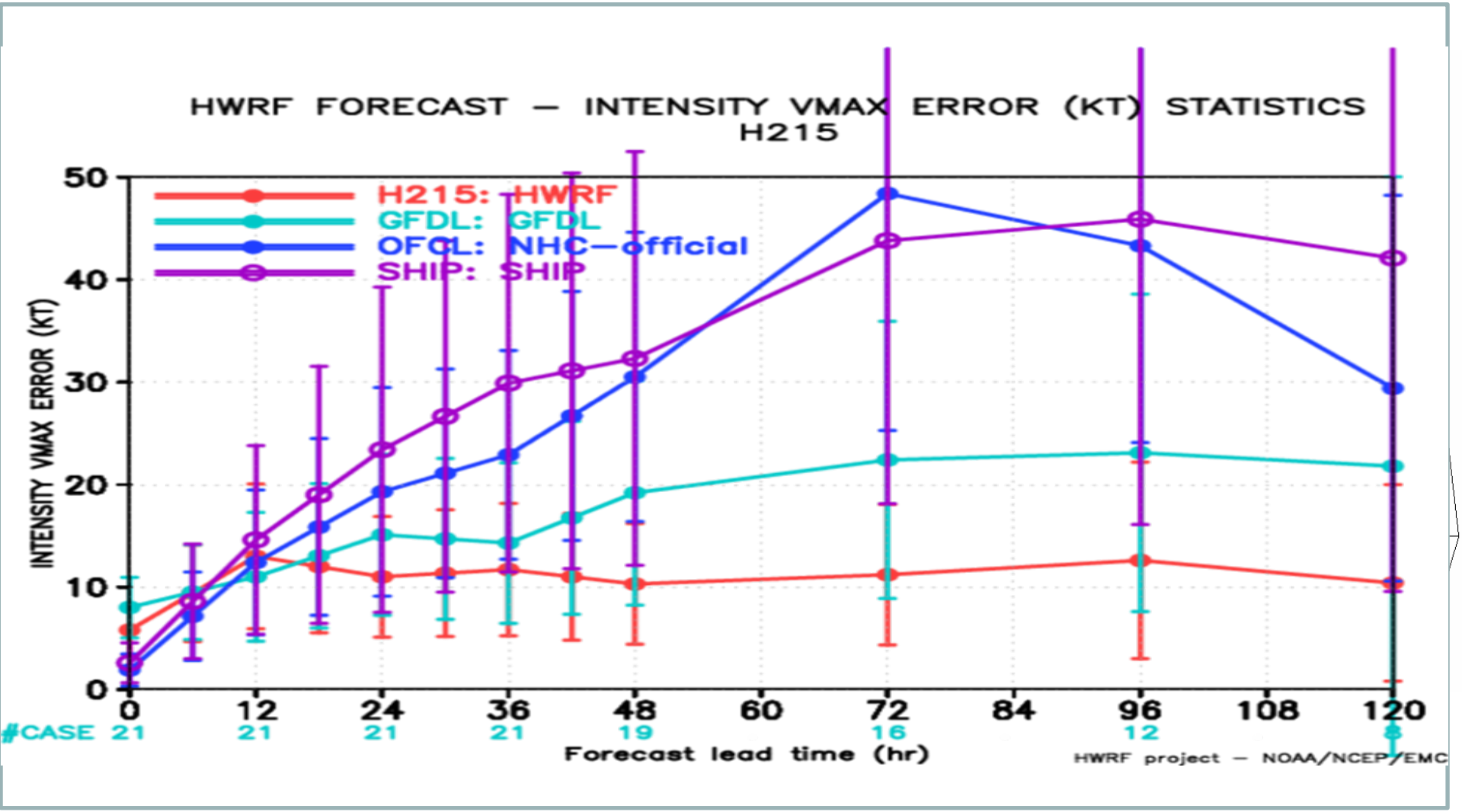
Long term trends show slow improvement in intensity forecasts.

HWRF intensity forecast skill highest among other model guidance for 2015



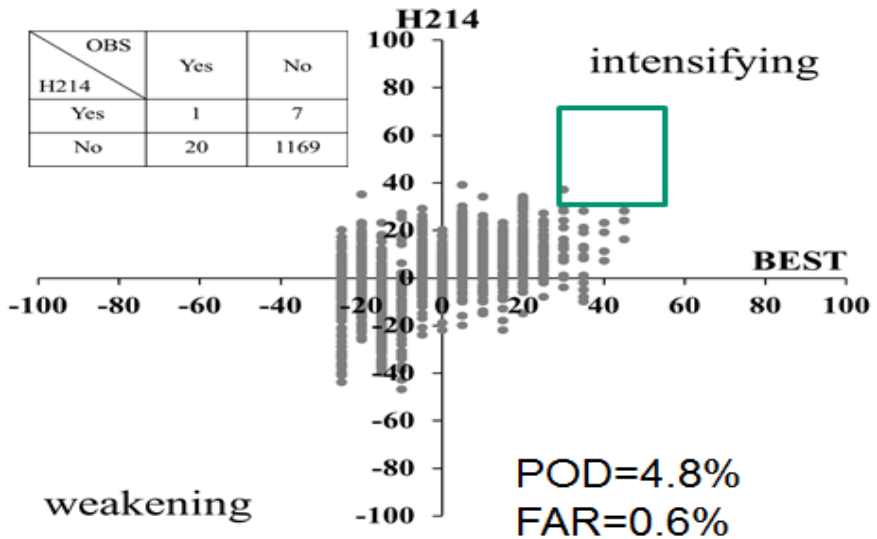
Courtesy: James Franklin & Eric Blake, NHC

Have the models improved in the past decade?



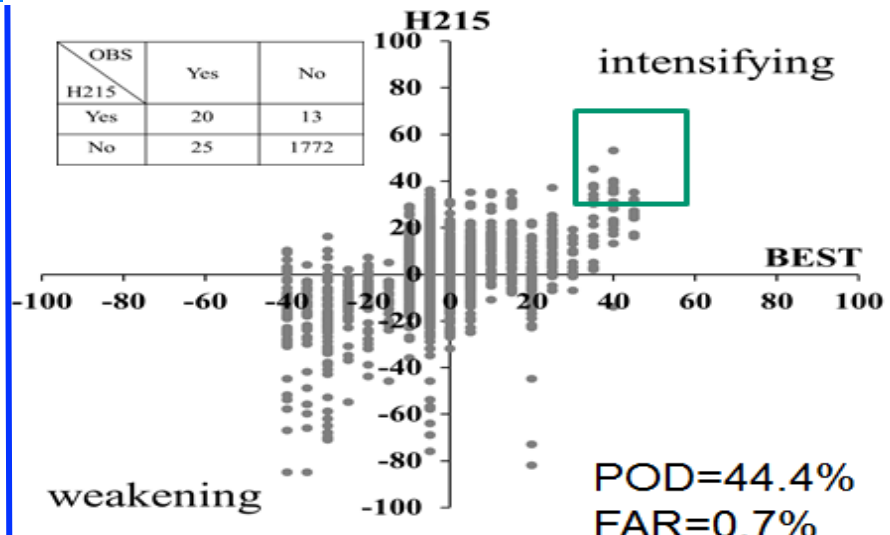
Challenges in RI Forecasts: North Atlantic and Eastern Pacific Basins

OBS / H214	Yes	No
Yes	1	7
No	20	1169



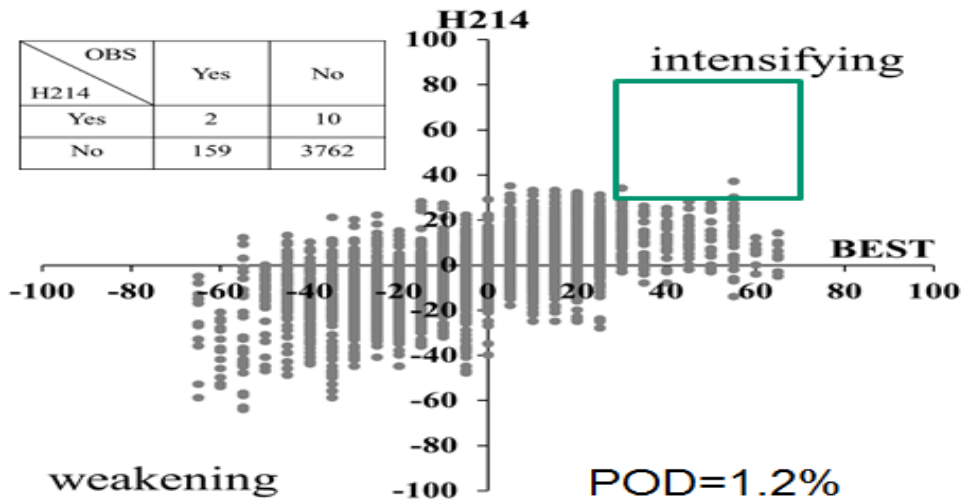
POD=4.8%
FAR=0.6%

OBS / H215	Yes	No
Yes	20	13
No	25	1772



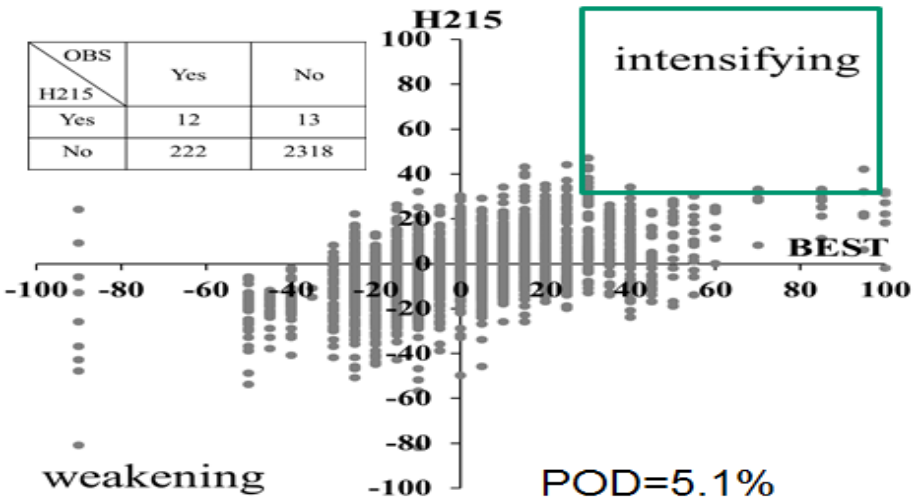
POD=44.4%
FAR=0.7%

OBS / H214	Yes	No
Yes	2	10
No	159	3762



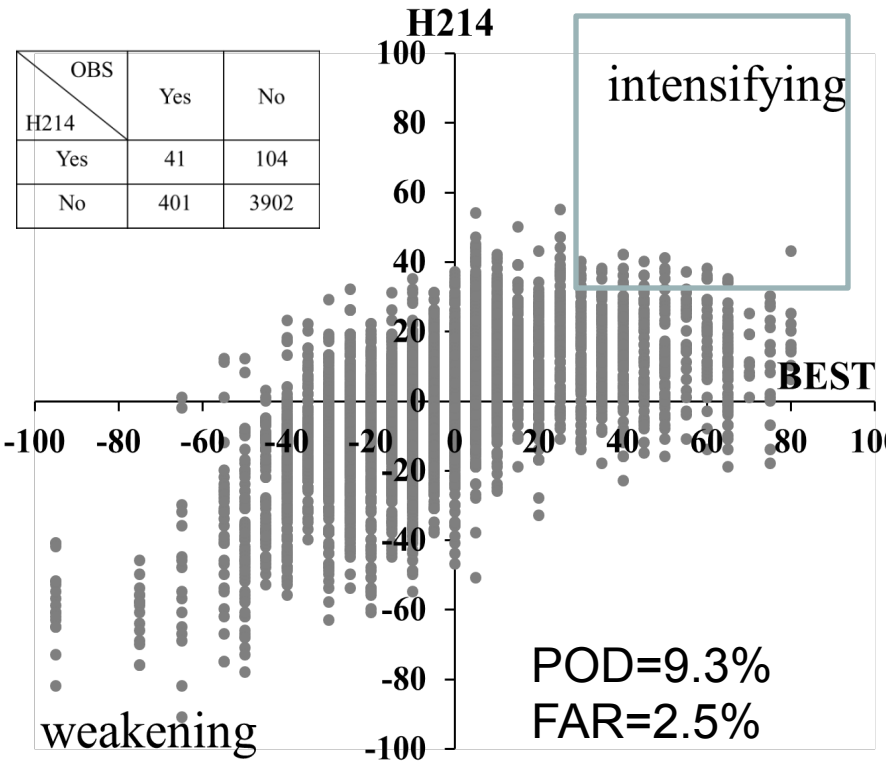
POD=1.2%
FAR=0.26%

OBS / H215	Yes	No
Yes	12	13
No	222	2318

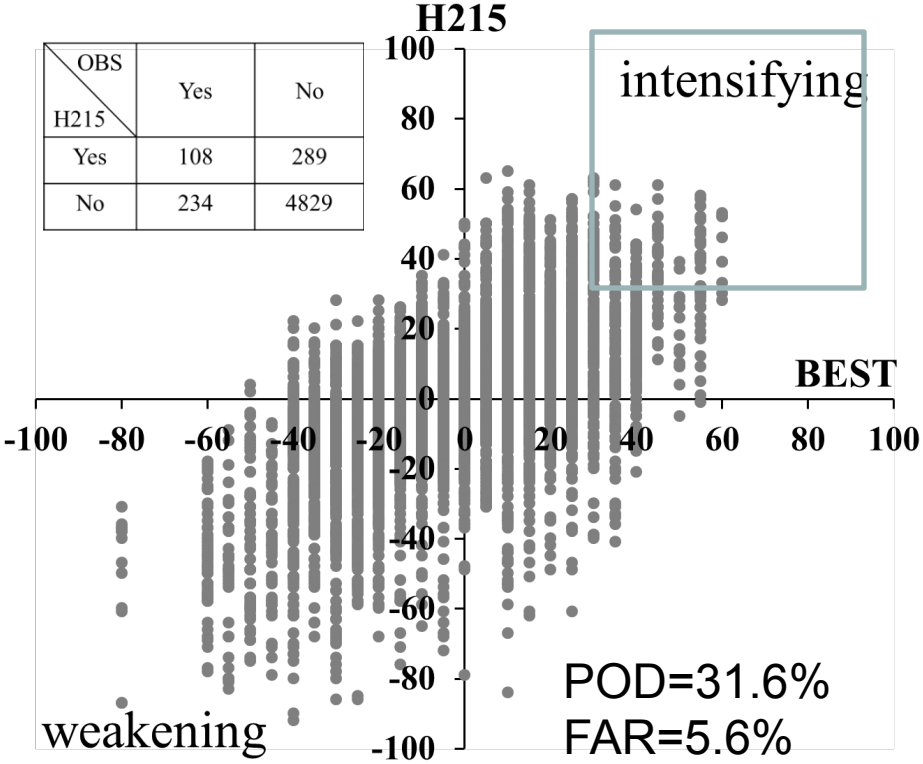


POD=5.1%
FAR=0.55%

RI Improvements in the Western Pacific Basin



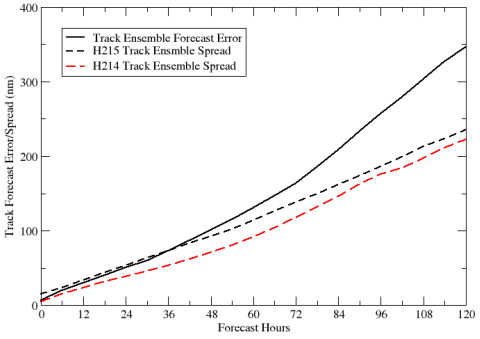
OBS / H214	Yes	No
Yes	41	104
No	401	3902

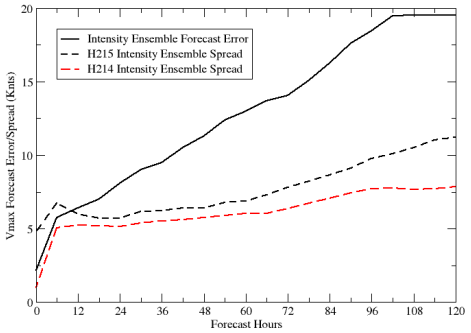


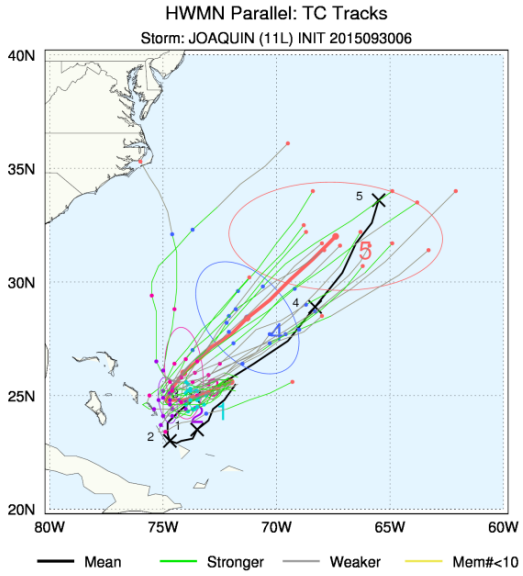
OBS / H215	Yes	No
Yes	108	289
No	234	4829

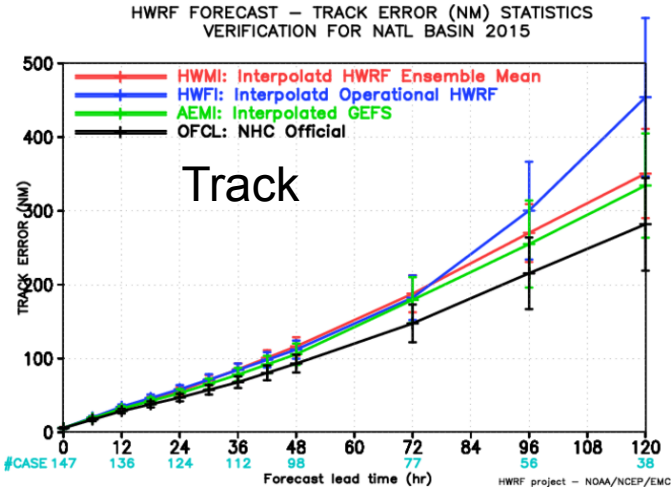
HFIP Experimental Regional Ensemble Prediction System in 2015

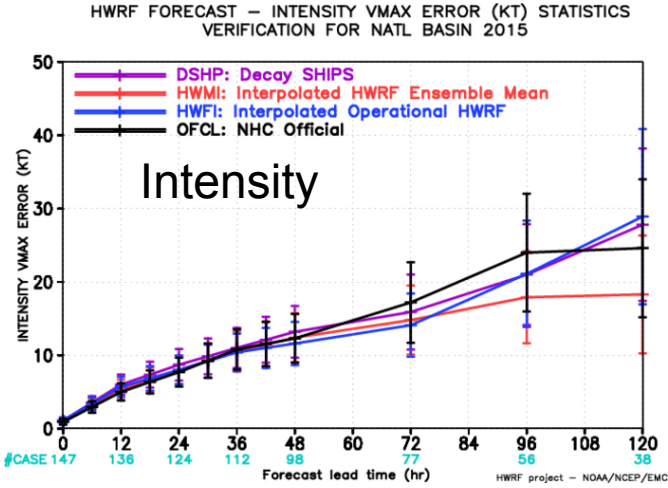
High-Resolution HWRF based Ensembles for Hurricane Forecasts at NATL
Advanced probabilistic guidance with representation of forecast uncertainty











- ***20-member 3km HWRF ensembles driven by GEFS for IC/BC and stochastic convective and PBL perturbations***
- ***High-resolution probabilistic products provide forecast uncertainty in track, intensity, structure (size) and rainfall, along with ensemble mean products***

HWRF as an operational forecast guidance tool for all global TC basins

- Starting in 2012, EMC HWRF team has been experimenting real-time forecasts for the WPAC basin, using NCEP Operational HWRF system, thanks to the support from NOAA's Hurricane Forecast Improvement Project (HFIP).
- ~ 85-90% reliability in delivering forecast products to JTWC was accomplished using dedicated resources (three sets of infinite reservations) on HFIP machines in Boulder. **Continued delivering**

HWRF as a unique tropical cyclone model with global coverage

Run in real-time for all global tropical cyclones in support of NHC, JTWC and other international operational agencies across the Asia Pacific and North Indian Ocean regions

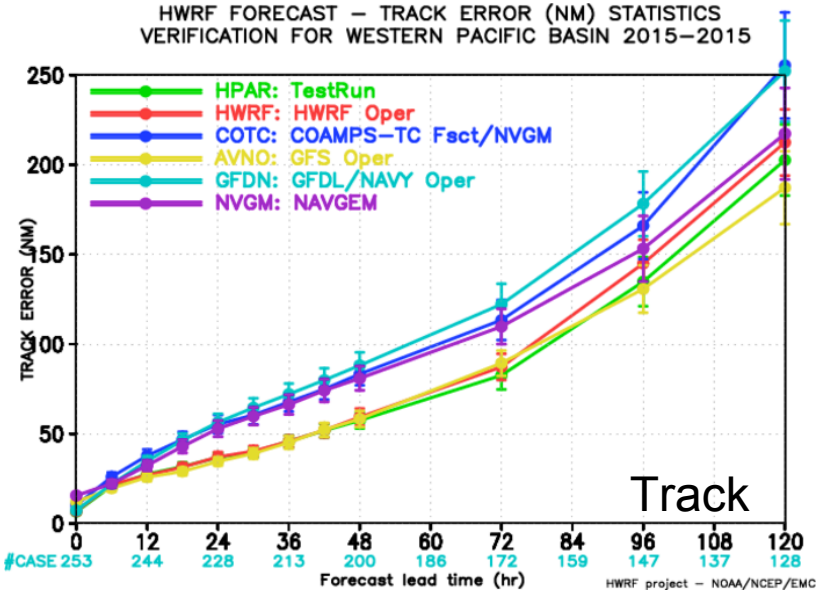
model continues to perform very well, especially for intensity, where it outperformed other mesoscale models out to 72 hrs and was especially useful during the frequent rapid intensification events that occurred in the Western North Pacific this year"

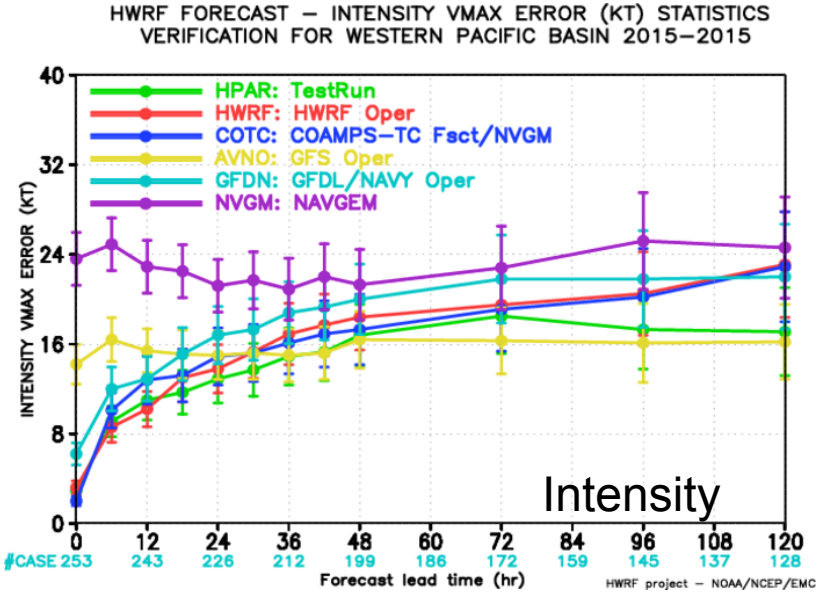
--Bob Falvey, Director, JTWC

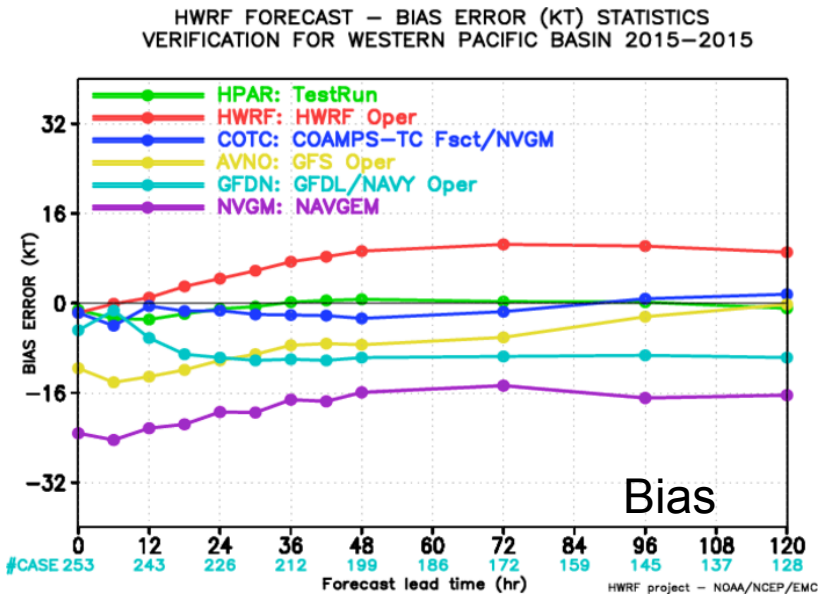
- ***A preliminary analysis of the performance of various models indicate that the performance of NCEP HWRF model was very good. It was a very useful product in terms of track, intensity and landfall forecast guidance as well as rainfall. Its performance was better that that of IMD HWRF.***

-- Dr. Mohapatra, Director, Cyclone Warning Division, IMD, India

Forecast verification for WPAC with ocean coupling





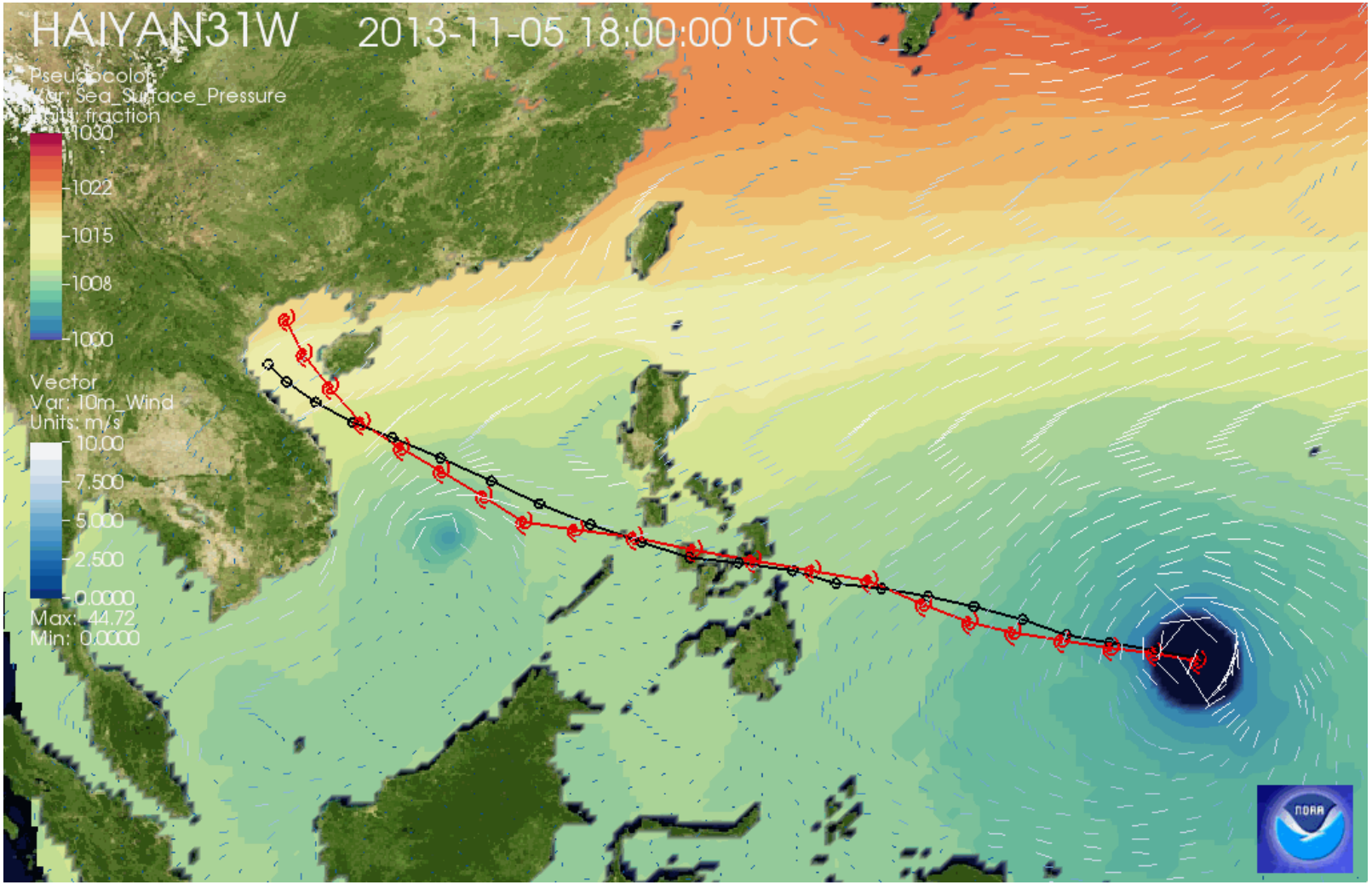


HWRF: Operational HWRF for WPAC without ocean coupling

HPAR: HWRF for WPAC with ocean coupling

Chan-Hom 09W
Nangka 11W
Soudelor 13W
Goni 16W
Etau 18W
Dujuan 21W
Mujigae 22W
Koppu 24W

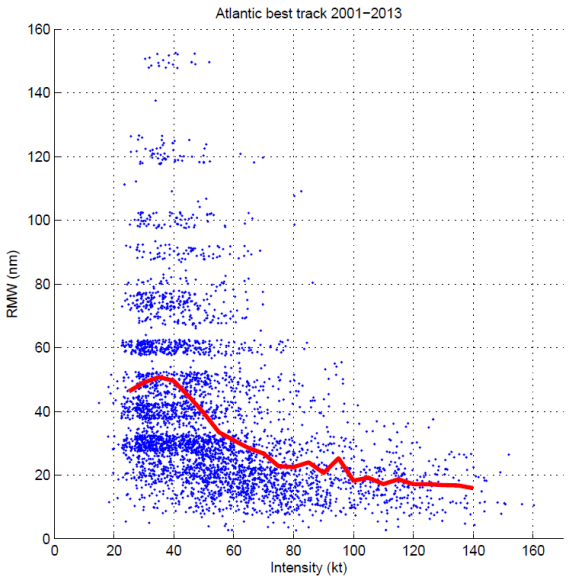
Track forecast of Typhoon Haiyan



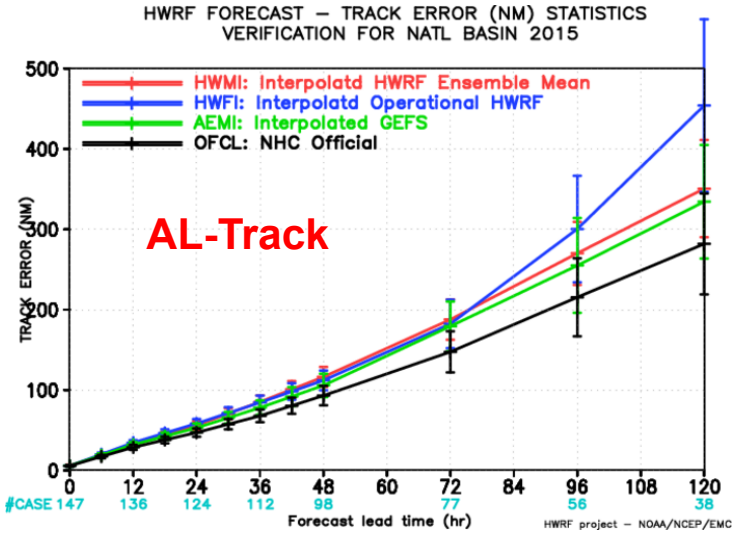
20-member HWRF Ensembles

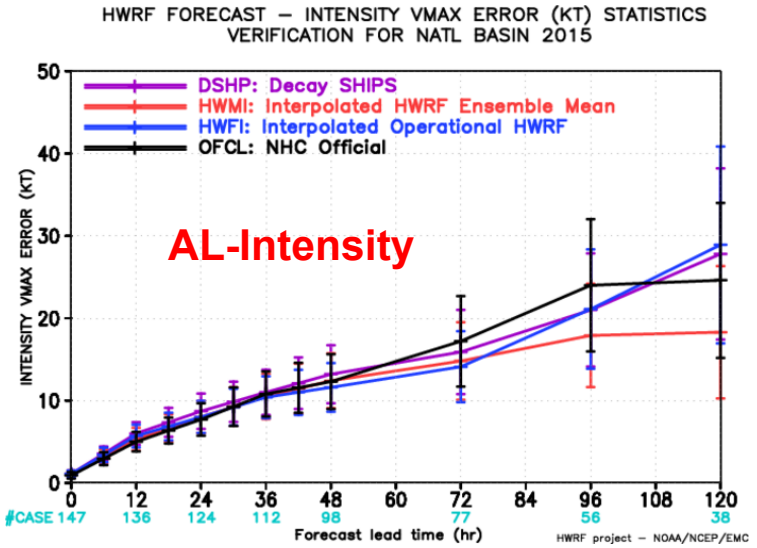
- Use 2015 operational deterministic HWRF model except for
  - Less vertical resolution: L43 vs. L61;
  - Smaller D02, D03 domains, same as H213;
  - No GSI due to lack of GDAS data;
- IC/BC Perturbations (large scale): 20 member GEFS.

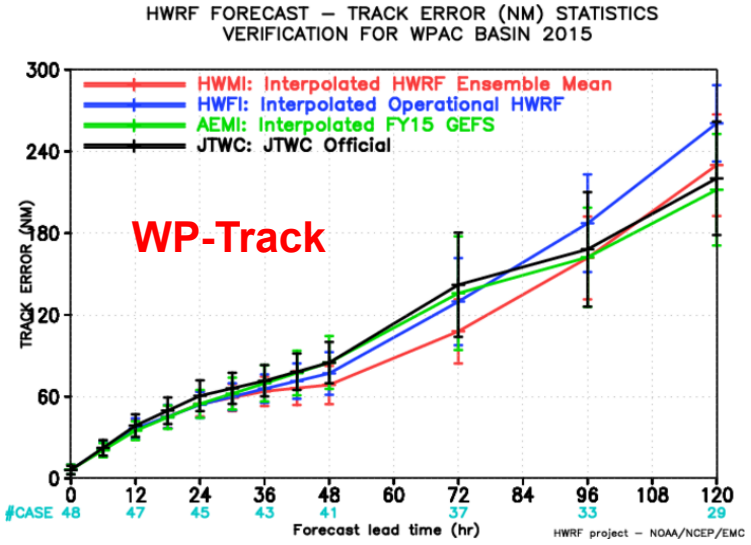
- Model Physics Perturbations (vortex scale):
  - Stochastic Convective Trigger in SAS: -50hPa to + 50hPa white noise ;
  - Stochastic boundary layer height perturbations in PBL scheme, -20% to +20%;
  - Stochastic Cd Perturbations;
  - Stochastic initial wind speed and position perturbations considering best track uncertainty (Ryan Torn).

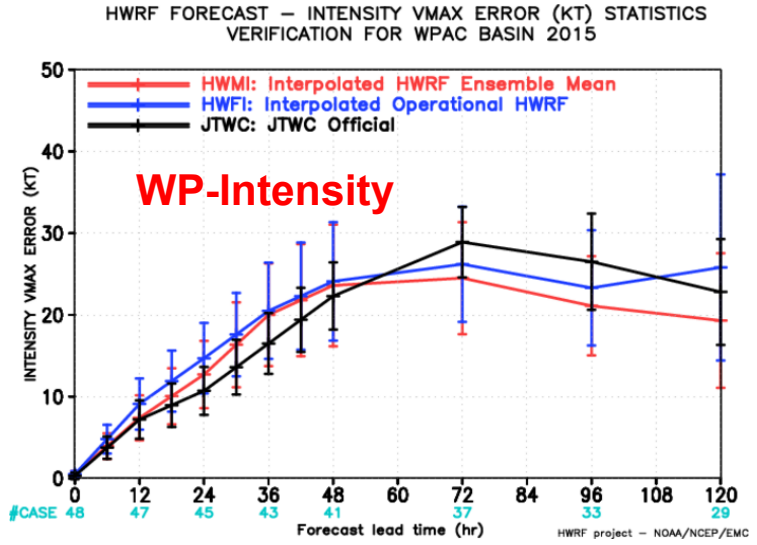


Real-Time HWRF Ensemble Prediction System Verifications for 2015 Storms

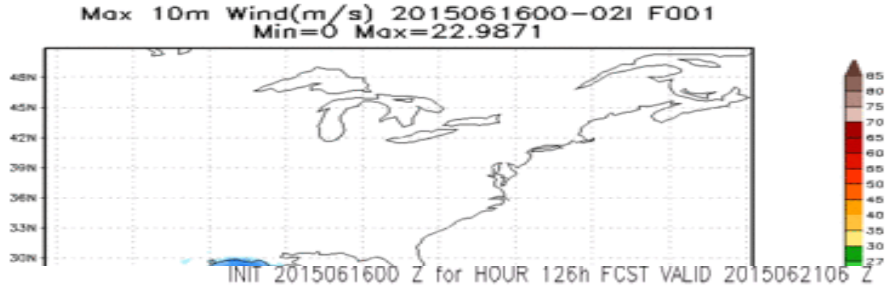


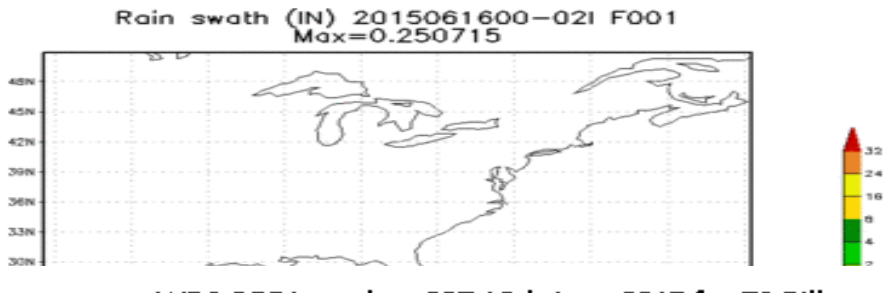




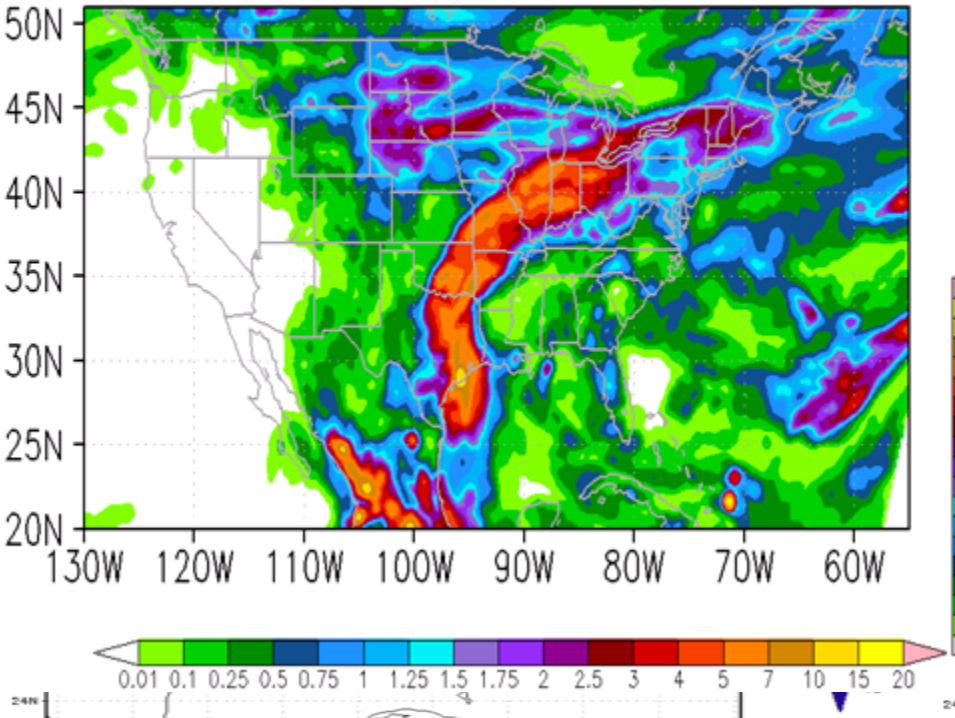


New Products from 2015 HWRF

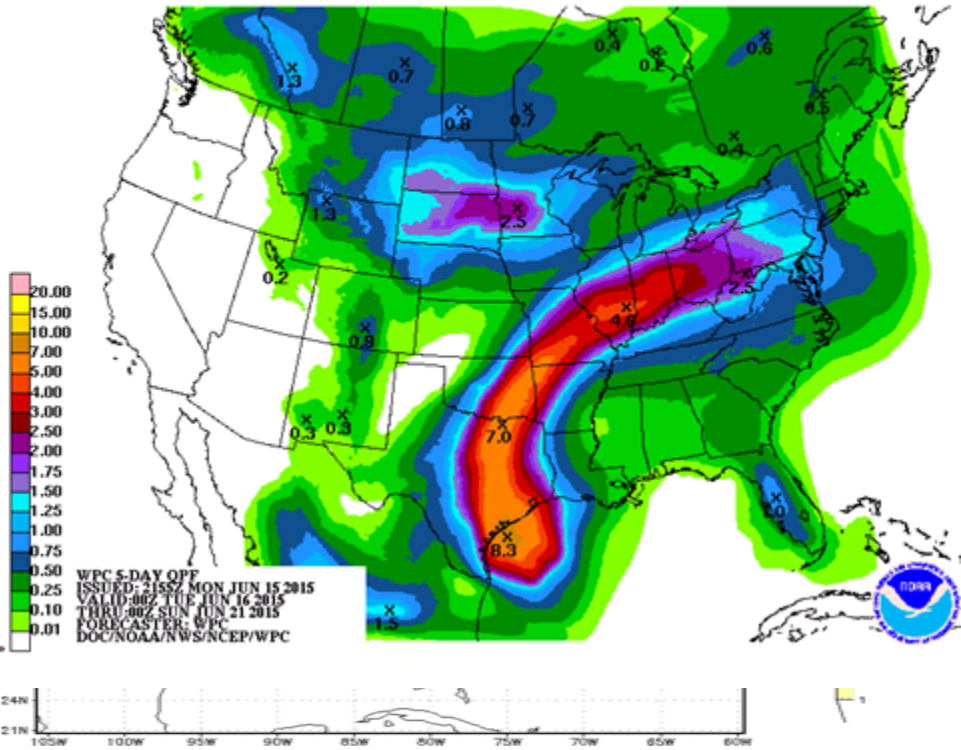




HWRF TOTAL RAINFALL(IN) STORM



WPC QPF Issued on 00Z 16th June 2015 for TS Bill



Overview of the HWRF Modeling System

- Regional-scale, moving nest, Ocean-Atmosphere coupled modeling system specially designed to advance hurricane forecasts.
- Non-hydrostatic system of equations within the WRF modeling infrastructure and framework
  - rotated latitude-longitude, Arakawa E-grid
  - vertical pressure hybrid (sigma-P) coordinate.
- NMM dynamics modified for inclusion of
  - movable nested grids, coupling to ocean model (MPIPOM-TC/HYCOM)
- HWRF vortex initialization includes
  - vortex relocation, correction to winds, MSLP, temperature and moisture in the hurricane region
  - adjustment to actual storm size and intensity
  - assimilation of conventional observations and clear-sky radiance datasets using community GSI (one-way hybrid EnKF-3DVAR data assimilation since 2013)
- Physical parameterization schemes designed and tested for tropical cyclones
- Ocean coupled modeling system using an advanced NCEP coupler.

Tutorial aspects of the HWRF Modeling system

- **HWRF Pre-processing System (WPS and prep-hybrid)**
  - Domain Specification and grid selection
  - Choice of using GFS/GDAS analysis/forecast data in grib format or spectral coefficients (HWRF specific, prep-hybrid utility)
- **WRF Model (HWRF dynamical core and HWRF Physics)**
  - Initialization programs for real (real.exe – same as NMM dynamical core)
  - Numerical integration program (wrf.exe)
- **HWRF Vortex Initialization Software**
- ***One-way hybrid EnKF-3DVAR regional data assimilation system based on community GSI****
- ***Ocean Initialization, Ocean Model (MPIPOM-TC) for Atlantic and Eastern Pacific basins****
- ***NCEP Coupler****
- **Post-Processing Program (UPP)**
- **GFDL Vortex tracker**
- **Advanced applications of HWRF modeling system to include:**
  - Idealized hurricane simulation capability
  - Advanced physics options
  - Multiple moveable nests (not currently supported)
  - Downstream applications (not currently supported)

Expanded capabilities for operational HWRF

- Starting with 2013 HWRF release, idealized hurricane simulation capability is included in the distributed code.
- A great research tool for testing the sensitivity of model forecasts to various forcings in an idealized framework.
- HWRF now can be run in any tropical oceanic basin in all global oceanic basins;
- HWRF can also be designed with a three-way ocean-wave-atmosphere coupled system (not currently supported, FY16 upgrade)
- Basin-scale HWRF with multiple moveable nests is currently being integrated into the HWRF community modeling system, and will be included in 2015 release version (not currently supported).

Applications of HWRF model

- Apart from canned cases for tutorial purpose, atmospheric HWRF (stand-alone) can be run for any storm in all tropical oceanic basins with GFS (or any global model) initial and boundary conditions.
- Coupled model can be run for any storm in the world.
- Idealized HWRF can be set to run using standard sounding for tropical cyclones.
- High resolution NWP model with static nests;
- There are unlimited applications that can be designed for HWRF model. NOAA HFIP, DTC, NCEP, NESDIS, AOML, ESRL and various other agencies provide opportunities to work on HWRF model for further improvements to the operational modeling system.
- Various international operational and research centers have adopted HWRF for tropical cyclone forecast applications, opening new opportunities for expanding the outreach and utility of HWRF model

What to expect from practical hands-on sessions

Students will learn

- How to obtain and compile the HWRF software
- How to initialize HWRF model, WPS and vortex initialization
- How to configure and run HWRF modeling system (cold start as well as cycling)
- How to post-process HWRF model output
- How to generate track forecast files

What's New for 2016?

	Model upgrades	Physics and DA upgrades				Combined
	Baseline (H160)	**New GFS PBL (H161)**	**Advecting species Microphysics (H162)**	**Three-way coupling (H163)**	**Data Assimilation***	**H216**
Descriptions	1. WRF-NMM V3.7.1a dynamic core with retention of non-hydrostatic status during the nest movement; 2. Smaller time step 3. New GFS upgrade	1. Eddy Diffusivity Mass-Flux Scheme w/ alpha in storm region 2. Scale-aware convection schemes	Choice of Ferrier-Aligo (Multi-specie advection) scheme or Thompson scheme	Three-way HWRF-MPIPOM-WaveWatch-III coupled system for AL	Hybrid GSI/ HWRF-EPS based DA	Baseline + EDMF +newMP+3-Coupling +DA
Cases	Four-season 2013-2015 simulations in ATL/ EPAC, cases (~2000)	Priority cases (TBD)	Priority cases (TBD)	Priority cases (TBD)	Only Aircraft DA cases for 2013-2015	Four-season 2013-2015 retrospectives ~2000 simulations in ATL/ EPAC
Platform	WCOSS	Zeus	Jet	Jet/Zeus	Jet	Jet/WCOSS/Zeus

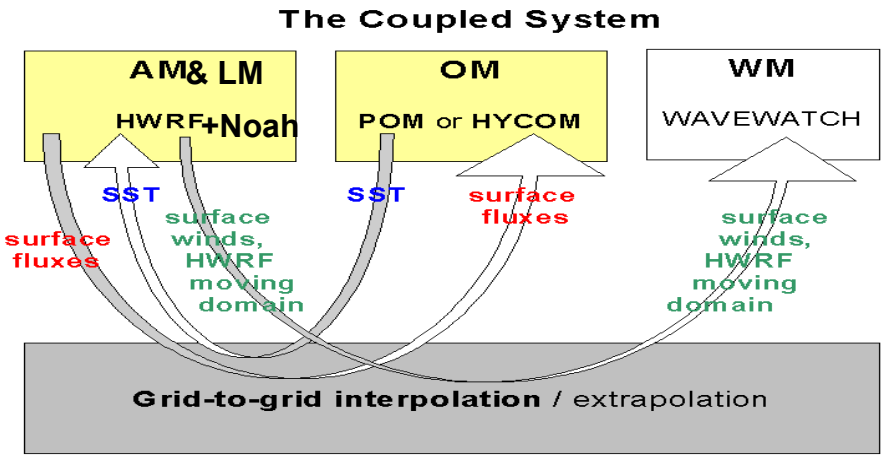
Public Release for 2016 HWRF scheduled for August 2016

HWRF as a Community Global Tropical Cyclone Forecast Model for operations and research

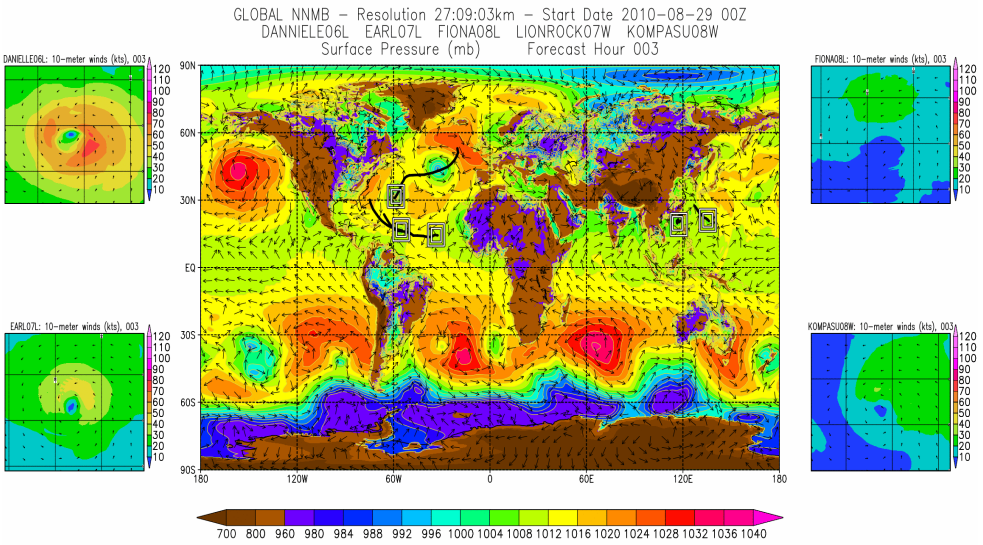
- **HWRF in China:** 1.Experimental implementation at STI in 2013; at CMA in 2014. *NOAA/CMA 18th JWG included collaboration on HWRF in Dec. 2013; 2.* Experiment with HWRF-HYCOM for 2015 season; 3. HWRF Tutorial, December 2015 in Nanjing; Nov. 30-Dec. 3
- **HWRF in Vietnam**: Experimental implementation in 2014
- **HWRF in India:** upgraded HWRF to run operationally at 3km resolution (2014 version)---- April 2015
- **HWRF in Taiwan:** upgraded their operational HWRF to 2015 version – part of multi-model ensemble for typhoon related rainfall and flood predictions --- June 2015; HWRF tutorial at Taipei, Taiwan in May 2014;
- **HWRF in South Korea:** experiment with HWRF for 2015 season --- August - December 2015
- **HWRF in Japan:** Operational HWRF products will be included in WMO-TCEFP led by JMA/RSMC Tokyo
- **APEC Typhoon Committee** Member Economies to benefit from NCEP's real-time operational HWRF forecast guidance
- **HWRF in Oman:** upgraded their operational HWRF (two versions - static domain over Oman and TC following) to latest 2015 version run at 3km resolution --- November 2015

Long-Term Plans for Hurricane Modeling at NCEP

2016	2017	2018	2019	2020
GFDL ——— **HNMMB**		**10-member HWRF/ HNMMB Ensembles**	NEMS Global Nests (NGGPS)	
HWRF Operational Model Continues Followed by Ensembles				
Basin-Scale HWRF/NMMB———Tropical NMMB Domain				
Hurricane Models take over Hurricane Wave Forecasts				



(additional **WM? AM** and **WM? OM** communications in progress)



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

http://www.emc.ncep.noaa.gov/HWRF

Thanks for your attention

Questions?

Acknowledgements:

HWRF team at EMC

EMC, DTC and HFIP Management

Collaborations with national and international operational and research agencies and academia