Overview of the NCEP Operational HWRF Modeling System

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HWRF Tutorial, NCWCP, 23-25 January 2018

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

Outline

- **HWRF as a community tropical cyclone modeling system**
- **HWRF as a global tropical cyclone modeling system for research and operations**
- **History of Operational HWRF Model Development**
- **Performance of the 2017 operational HWRF Model**
- **Overview of the tutorial sessions and expected outcomes**

Hurricane WRF (HWRF)

- **The Weather Research and Forecast Modeling System for Hurricanes (HWRF) was designed and developed by NCEP/EMC based on 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).**

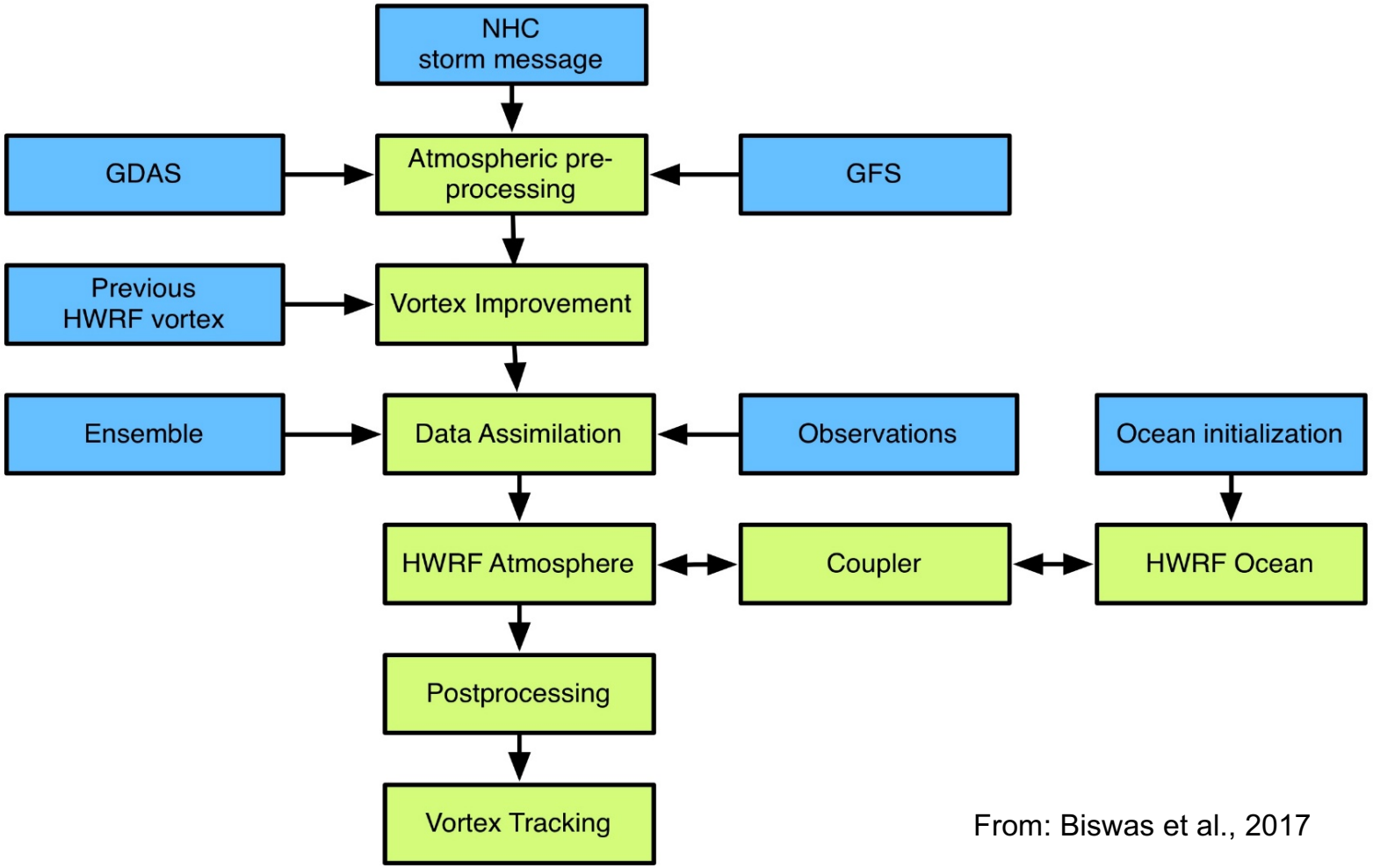
- **With the support of NOAA's Hurricane Forecast Improvement Project (HFIP) and lately from Next Generation Global Prediction System (NGGPS) programs, HWRF has rapidly advanced and evolved as a unique and one of the best tropical cyclone models, catering to both operations and research for all oceanic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

HWRF as a Community Model

HWRF has evolved based on multi-agency efforts supported by HFIP/NGGPS. Some key players include:

- ***EMC****: Computational efficiency, nest motion algorithm, physics improvements, vortex 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****: Ocean initialization and coupling*
- ***GFDL****: Knowledge sharing, joint T&E*
- ***NHC****: Diagnostics and evaluation of the HWRF pre-implementation tests and real-time guidance*

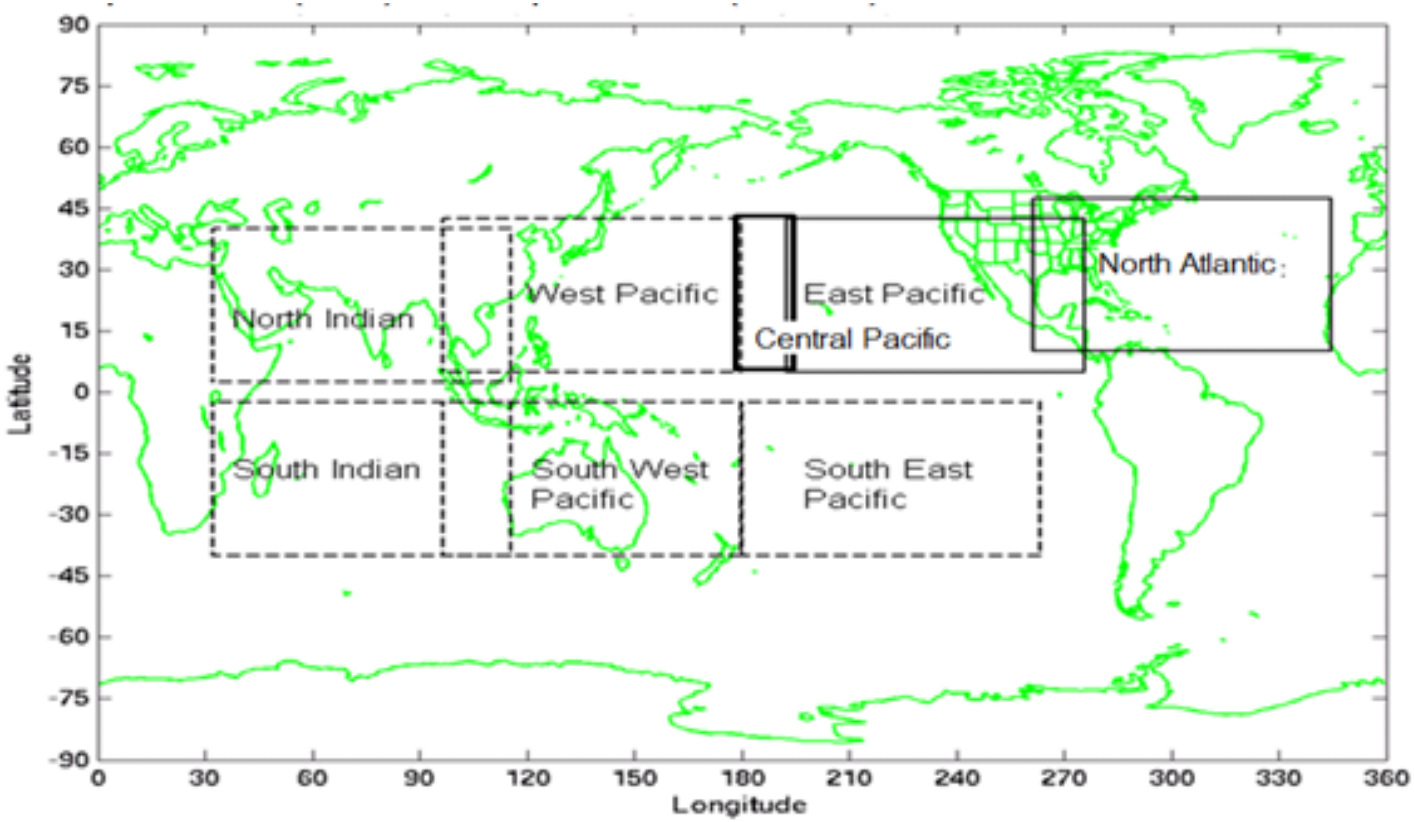
HWRF System
(as configured for the North Atlantic Basin)



From: Biswas et al., 2017

Simplified overview of the HWRF system

Tropical Ocean Basins covered by Operational HWRF



From: Biswas et al., 2017

Solid boxes represent HWRF forecast domains for National Hurricane Center and Central Pacific Hurricane Center areas of responsibility. Dashed boxes are HWRF forecast domains for Joint Typhoon Warning Center areas of responsibility.

HWRF as a Unique Global Tropical Cyclone Model

Developmental Testbed Center Support

www.dtcenter.org/HurrWRF/users

- Yearly releases, code downloads, datasets, documentation, helpdesk
- 700 registered users
- Stable, tested code
- Benchmarks available
- Support to HWRF developers in code management

Current release: HWRF v3.5b (2013 operational with several patches)
Next: HWRF v3.6a (2014 operational) 08/2014, concurrent with operational implementation

Developmental Testbed Center

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

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

NATIONAL HURRICANE CENTER

Japan Meteorological Agency

International partnerships for accelerated model development & research

Operational Real-time forecast guidance for all global tropical cyclones in support of NHC, JTWC and other US interests across the Asia Pacific, North Indian Ocean and Southern Hemisphere ocean basins

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 ocean and waves
- **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

Evolution of HWRF

- **High resolution triple nest implementation in 2012**
  - ***For the first time, a*** **high-resolution hurricane model operating at cloud-permitting 3km resolution** ***implemented into NCEP operational system***

- **HWRF v7.0.0 upgrades in 2013**
  - **Upgrade nest tracking algorithm and nest-parent interpolations**
  - **Increased size of the third domain, physics upgrades (PBL, radiation)**
  - **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**

- **Infrastructure upgrade and transition to Python in 2014**
  - **Increase vertical levels to 61, 1/12 degree MPIPOM with 3D ocean for EPAC**
  - **Additional HWRF products including tornado probability forecasts**

Highlights of FY2015 High-Resolution Triple-Nested HWRF v9.0.0

➢ 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.***

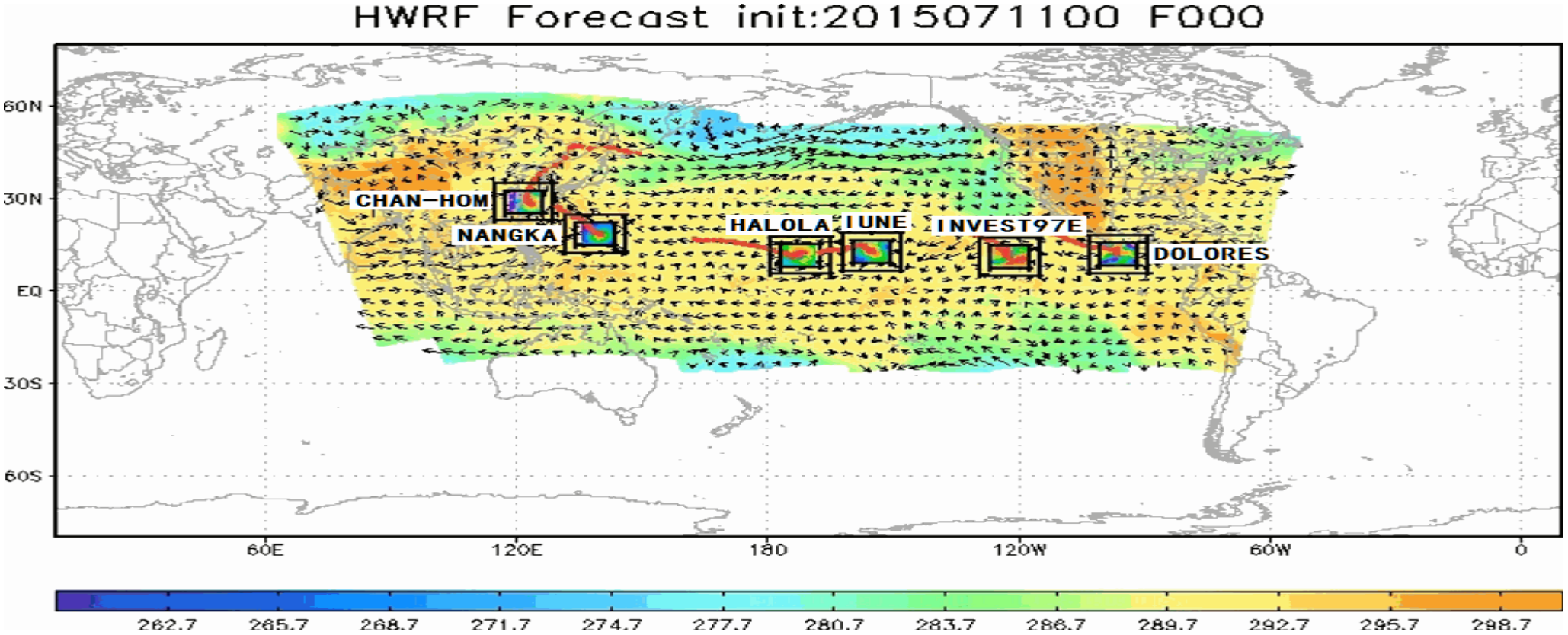
➢ Physics Advancements

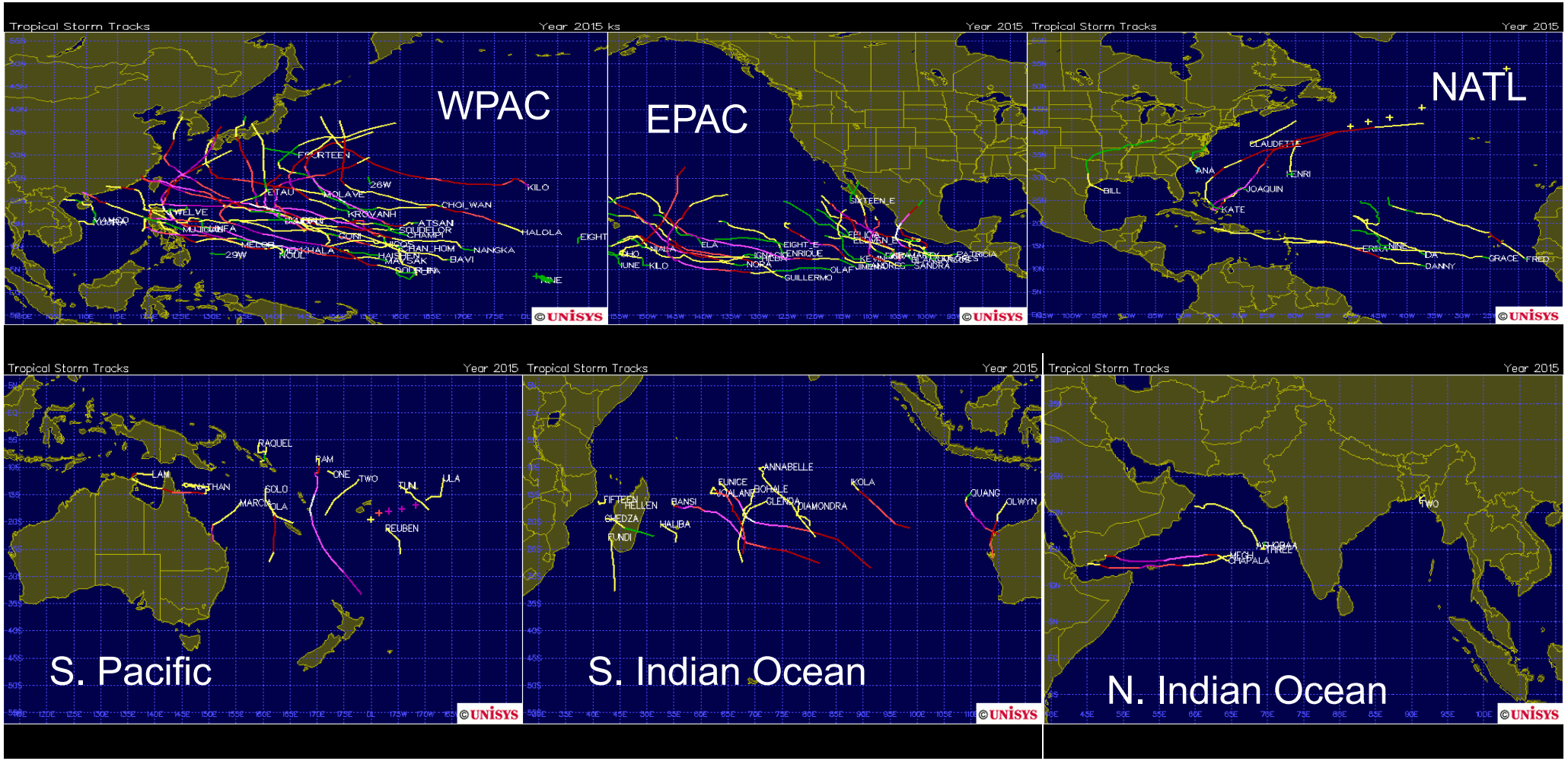
- **Upgrade Micro-physics process (Ferrier-Aligo); replace GFDL radiation with RRTMG scheme including sub-grid scale partial cloudiness; Upgrade surface physics and PBL, replace current GFDL slab model to more advanced NOAH LSM.**

➢ 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**

Real-time Operational Configuration for 2015 HWRF





Global Threat of Tropical Cyclones:
NOAA/NWS areas of interest extend beyond NHC/CPHC AoR
JTWC is responsible for all global TCs

2015 storms:

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

Scope of FY16 HWRF v10.0.0 Upgrades

➢ System & Resolution Enhancements

- T&E with new 2016 4D-Hybrid GDAS/GFS IC/BC
- Upgrade dynamic core from WRF3.6a to WRF3.7.1a (with bug fixes)
- Smaller time step (dt=30 s vs. 38 4/7 s)
- ***Increase the size of nested domains***
- More products: MAG and AWIPS2

➢ Initialization/Data Assimilation Improvements

- GSI upgrades; ***new data sets for GSI (CrIS, SSMI/S, METOP-B changes)***
- ***Turn on Data Assimilation for all storms in East Pacific and use of ROTFS initialization***

➢ Physics Advancements

- Implement ***new GFS PBL*** (2015 version)
- Upgrade to ***new scale-aware SAS convection scheme*** for all domains
- Update momentum and enthalpy exchange coefficients(Cd/Ch)
- Improved vertical wind profile in the surface and boundary layer

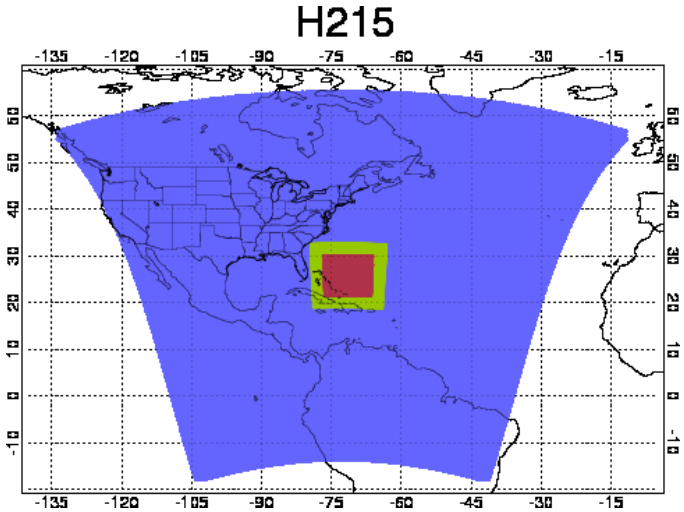
➢ First time in 2016….

- Implementation on WCOSS Cray
- Ocean coupling for CPAC, WPAC and NIO (all NH basins)
- One-way coupling to wave model (Hurricane Wave Model)
- Use of dev-ecflow for accelerated T2O

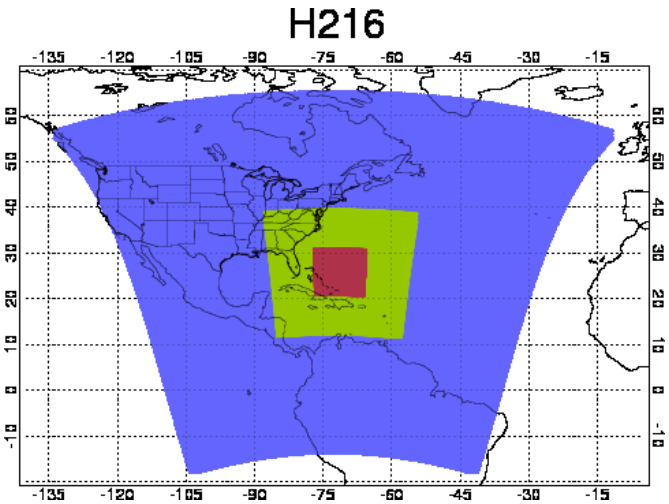
Highlights of FY2017 HWRF v11.0.0 Upgrades

- **Infrastructure Enhancements**
  - Upgrade dynamic core from WRF3.7.1a to WRF3.8.1 (with bug fixes)
  - ***75 vertical levels with model top of 10hPa with smaller nested domains***
  - New vortex tracker (Tim Marchok, GFDL
- **Vortex Initialization and DA Improvements**
  - Improved vortex initialization with new composite vortex
  - Increased blending threshold for VI and GSI analysis (from 50 to 65 Kt)
  - ***Assimilate HDOBS observations***
  - ***Fully cycled HWRF ensemble hybrid DA for TDR and priority storms***
- **Physics Advancements**
  - Updated Ferrier-Aligo microphysics and scale-aware SAS schemes
  - Updated momentum and enthalpy exchange coefficients (Cd/Ch)
  - Partial cloudiness modification for RRTMG (DTC)
- **Air-Sea Interaction and Coupling**
  - Reduced coupling time step from 9 min to 6 min
  - ***Increased vertical level for POM from 24 to 40 levels***
  - POM RTOFS initialization for CPAC, in addition to EPAC
  - ***HYCOM ocean coupling for WPAC/NIO***
  - ***Hurricane wave model (multi_2) is decommissioned***

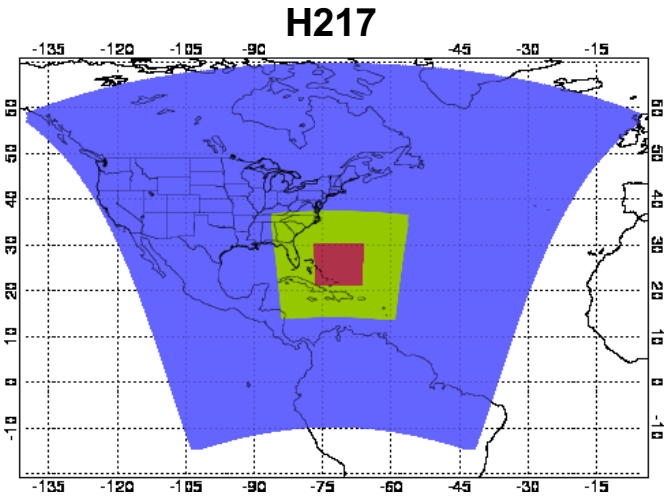
Adjusted HWRF Domain Sizes for H217 with higher vertical resolution



d02:	142 x 274
d03:	265 x 472
Levels:	61
Top:	2 mbar



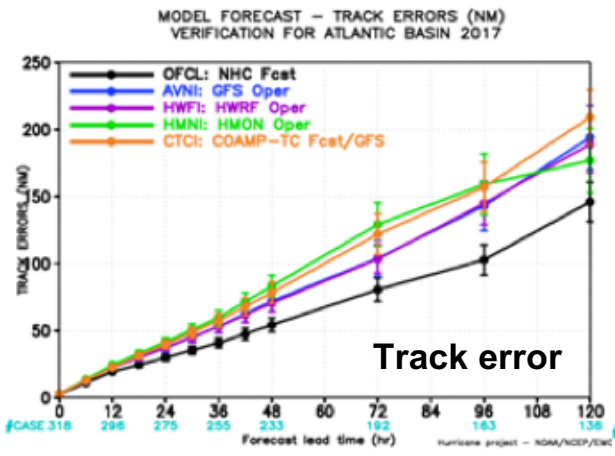
d02:	288 x 576
d03:	288 x 576
Levels:	61
Top:	2 mbar

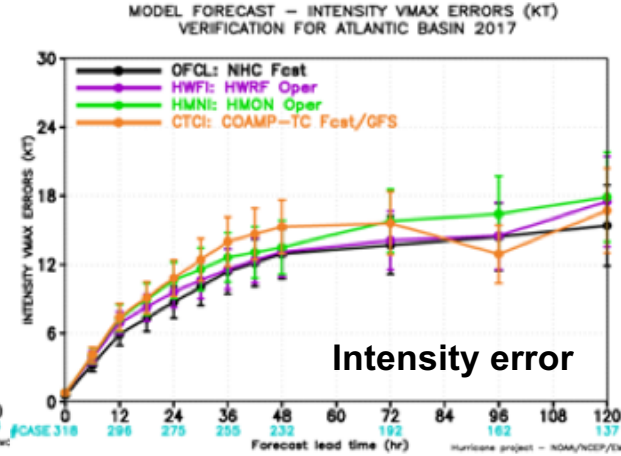


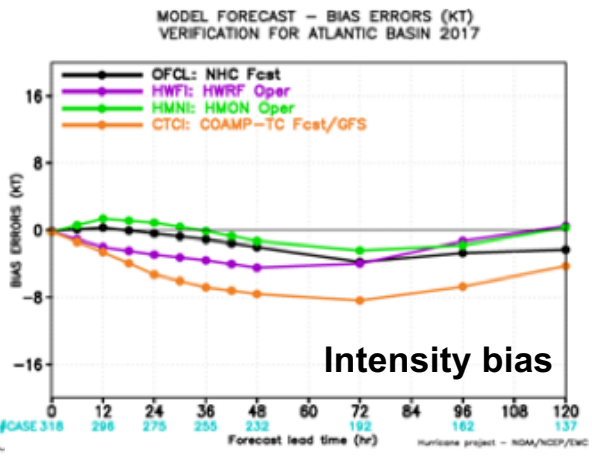
d02:	265 x 532
d03:	235 x 472
Levels:	75
Top:	10 mbar

HWRF/HMON in the 2017 North Atlantic Basin

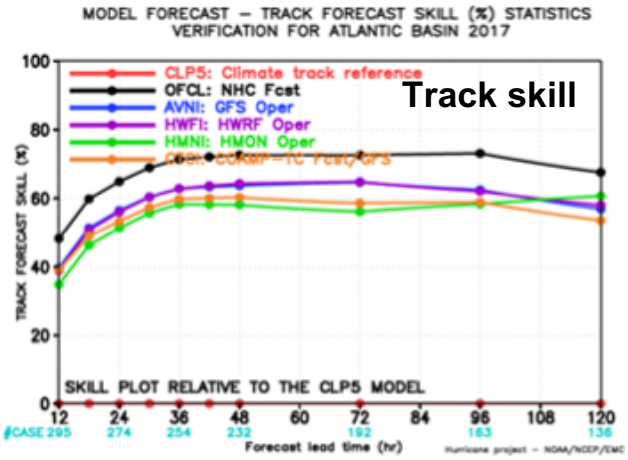
Real-Time Performance (Early Guidance)

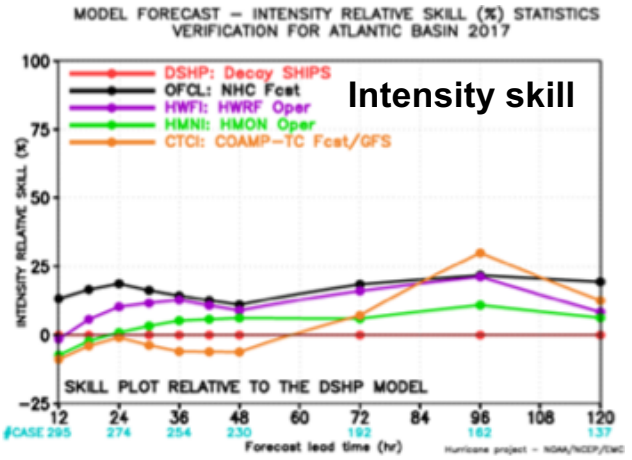




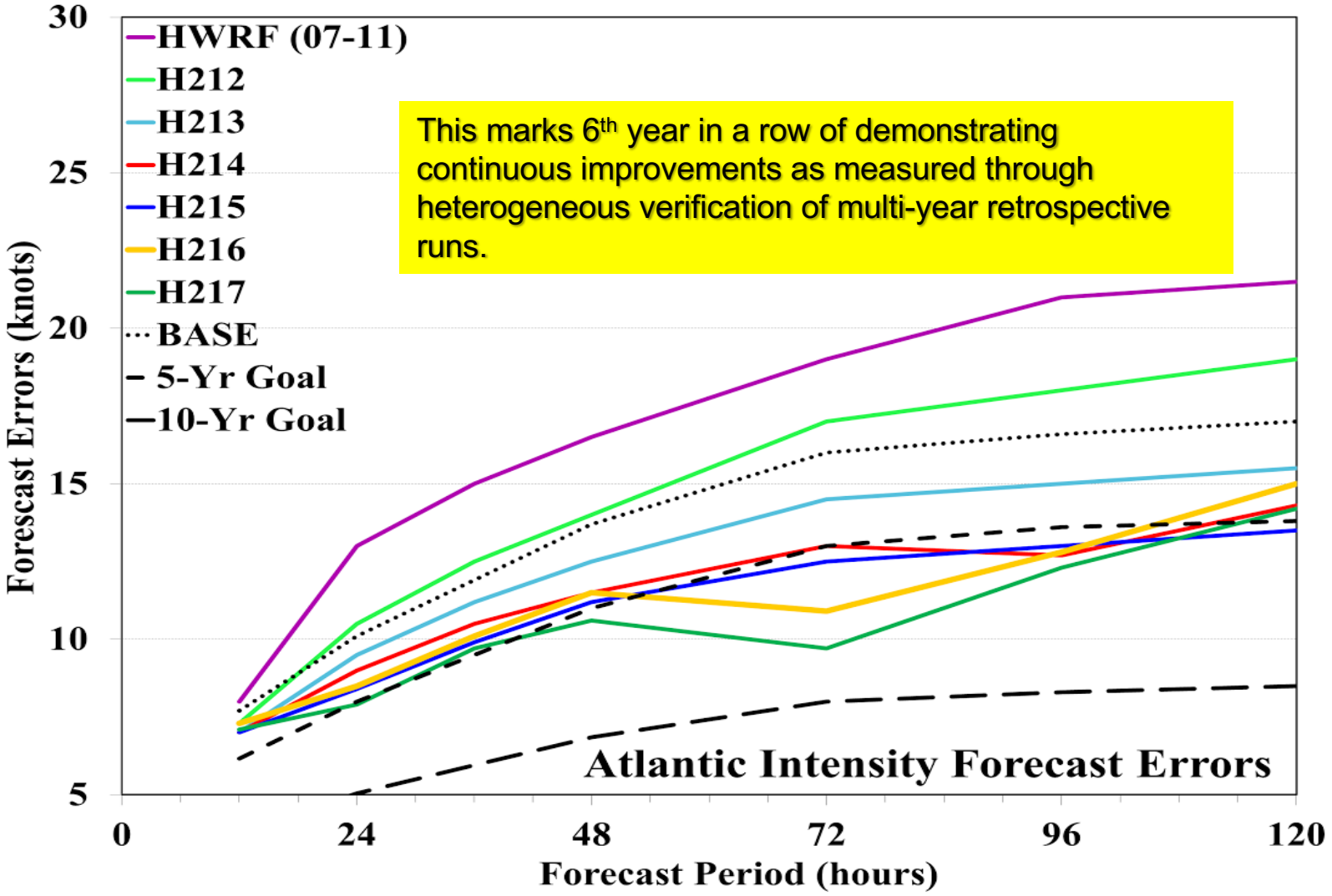


HWRF
HMON
CTCX
GFS
OFCL



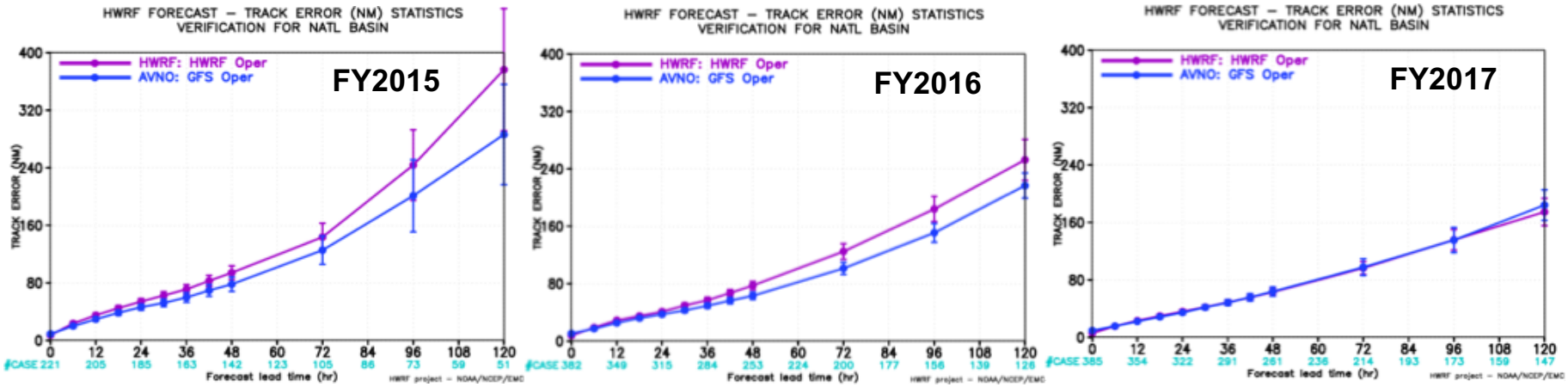


2017 HWRF: Continuing the trend of incremental but substantial improvements in NATL intensity forecasts

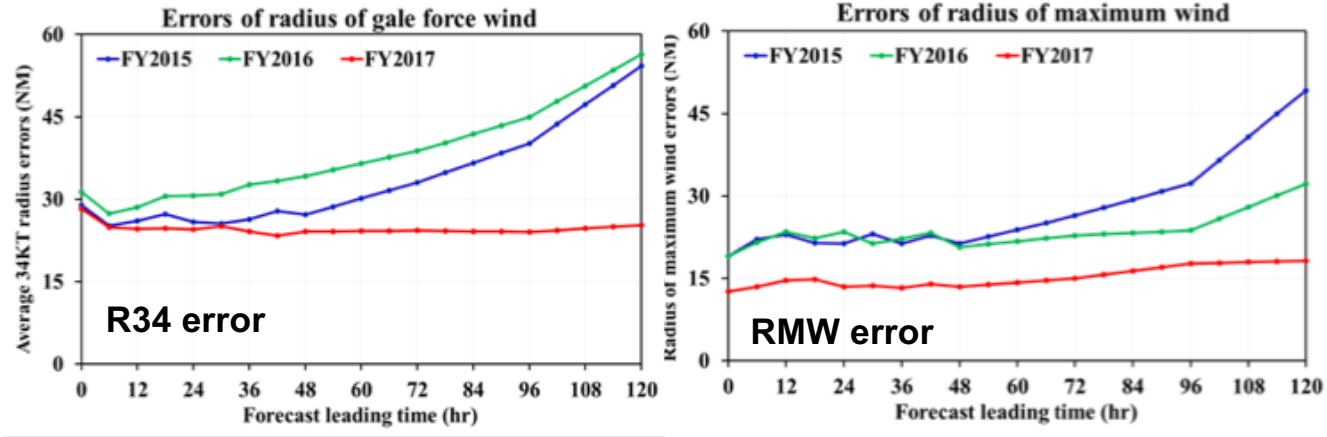


HWRF Track and Size Forecast for NATL Basin

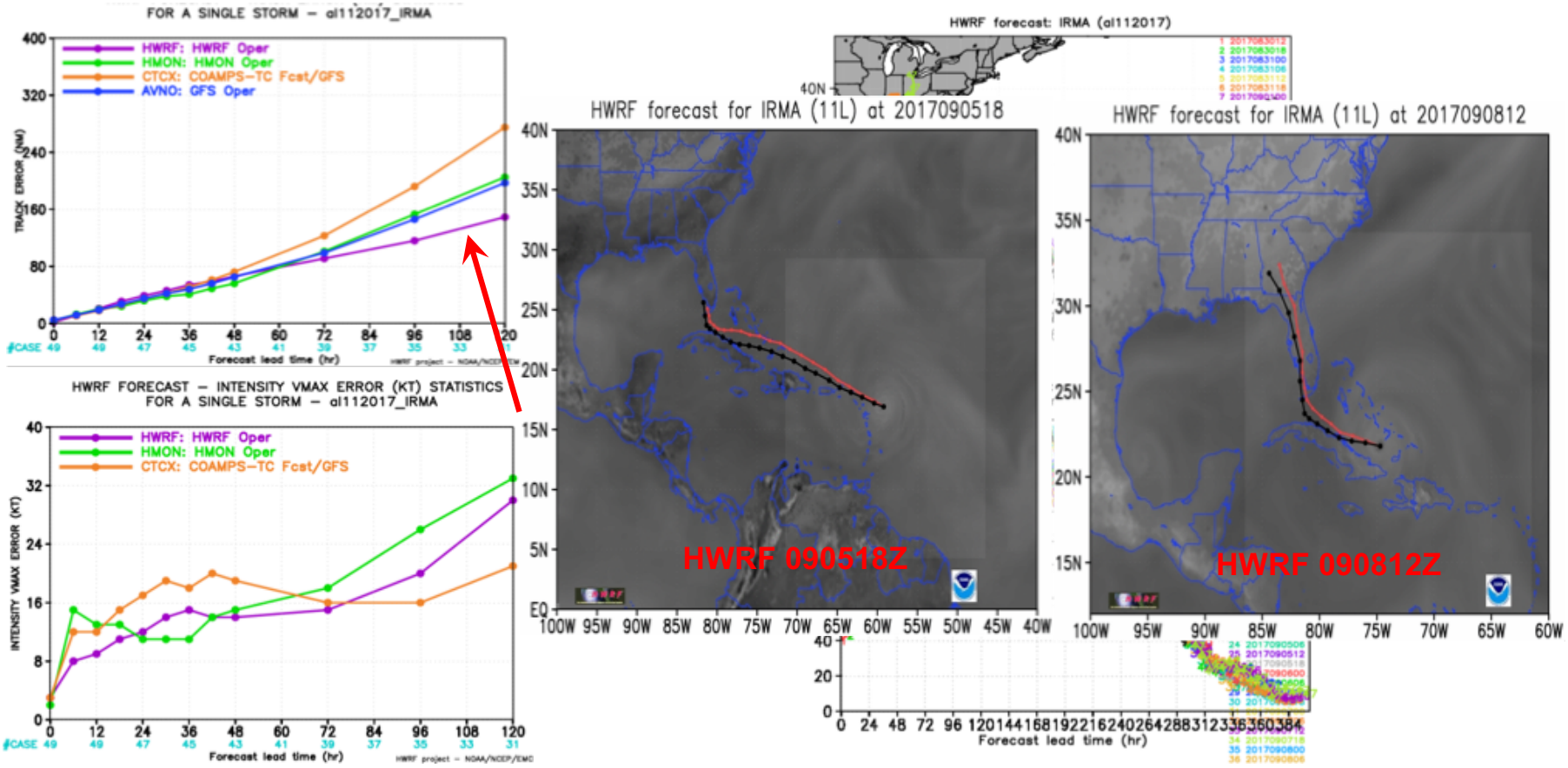
Real-Time Performance for FY2015-2017



Impressive catch-up in track forecasting and substantial storm size improvement

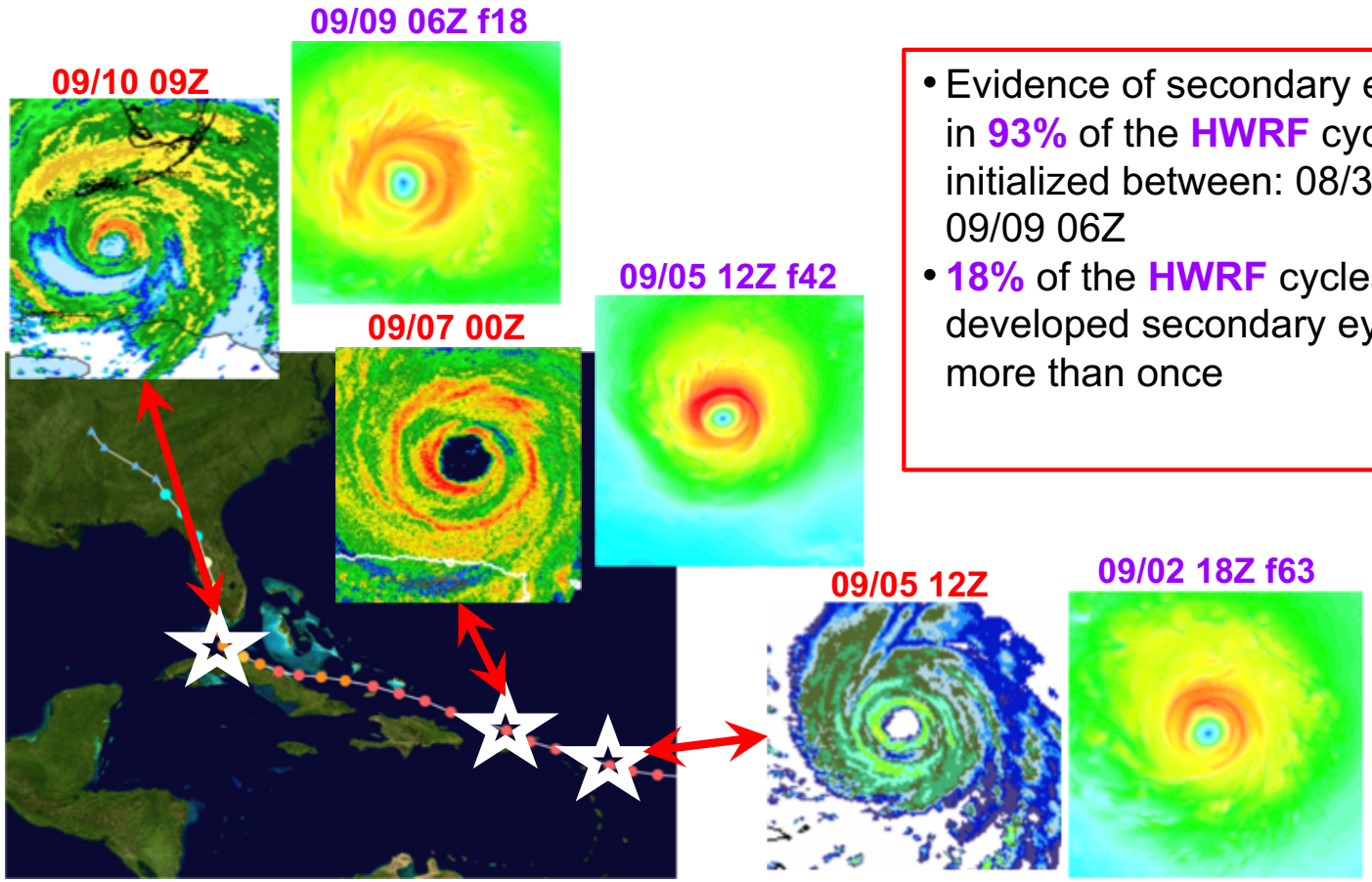


HWRF Forecasts for Hurricane Irma (11L)



HWRF Forecast for Concentric Eyewalls

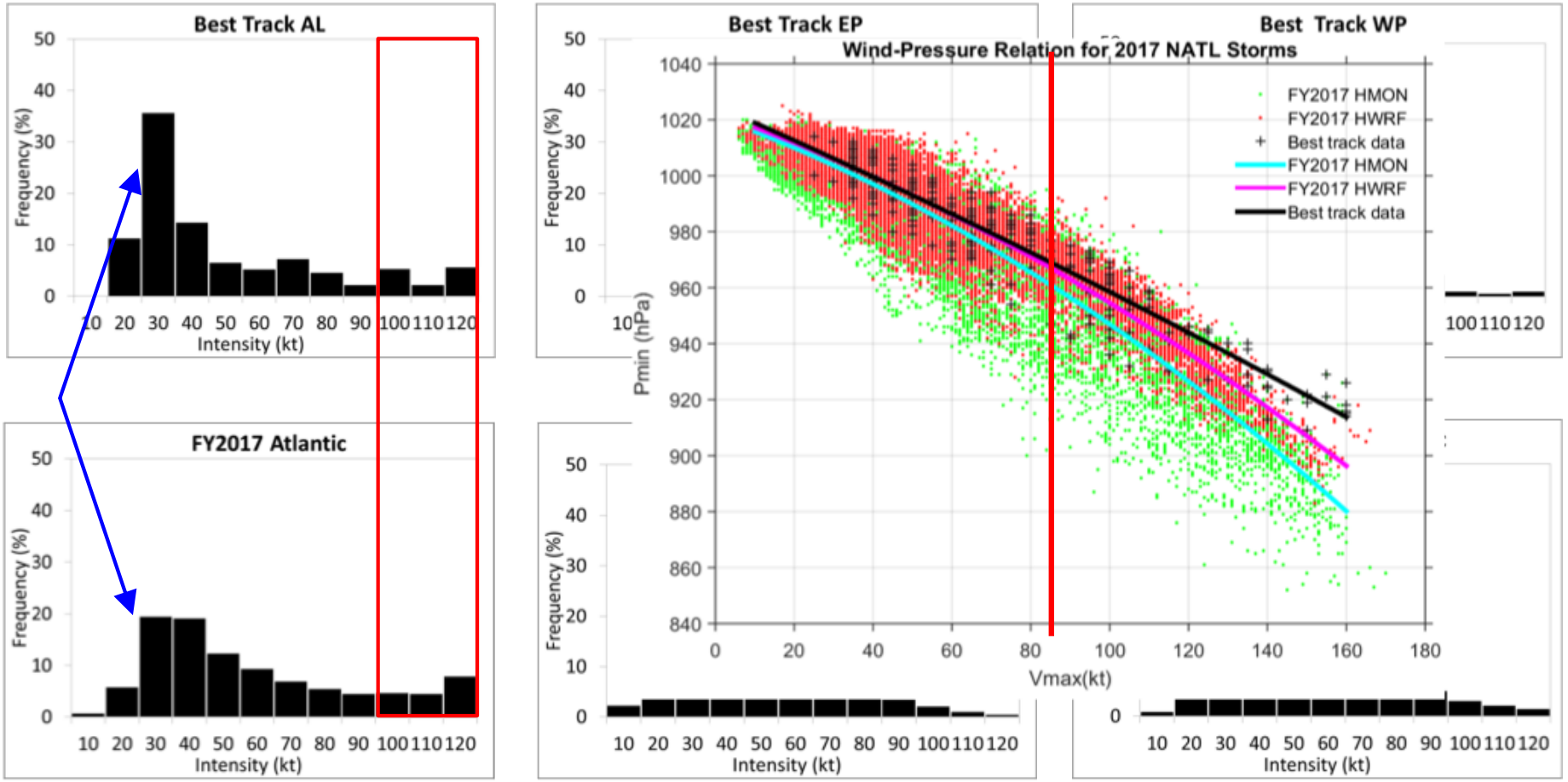
Hurricane Irma (11L)



- Evidence of secondary eyewalls in **93%** of the **HWRF** cycles initialized between: 08/30 12Z to 09/09 06Z
- **18%** of the **HWRF** cycles developed secondary eyewalls more than once

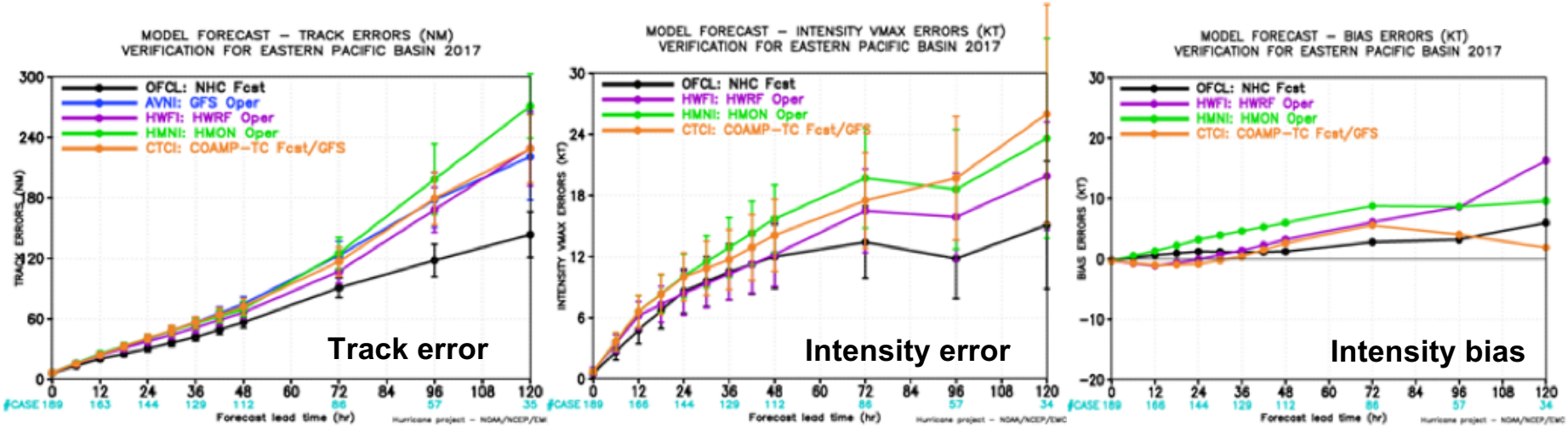
Intensity Distribution & Wind-Pressure Relation

2017 HWRF Real-Time Performance



HWRF/HMON in the 2017 Eastern Pacific Basin

Real-Time Performance (Early Guidance)



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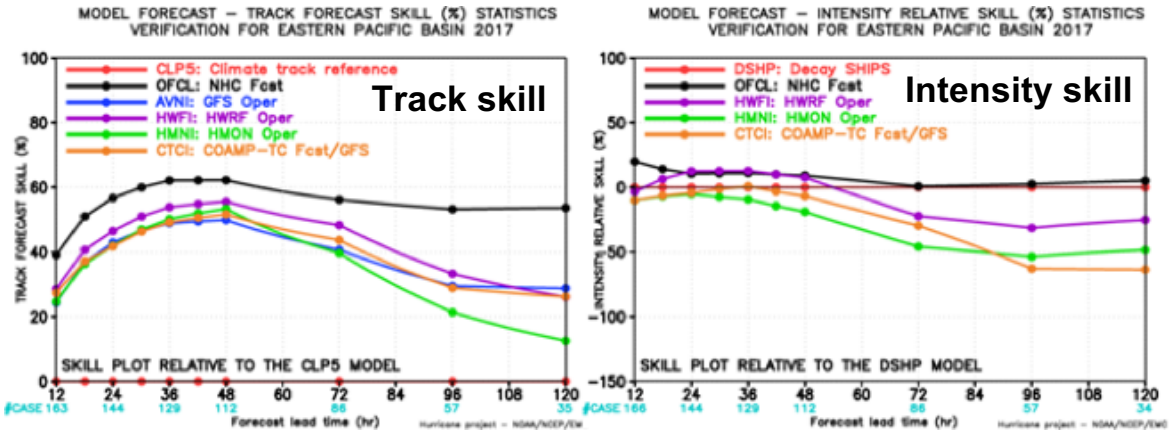
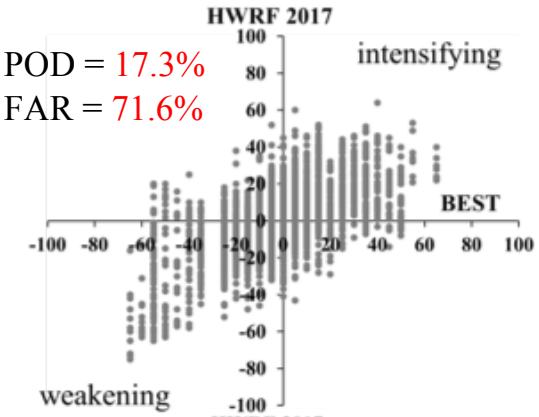


Challenges in RI Forecasts: North Atlantic and Eastern Pacific Basins

POD and FAR for RI

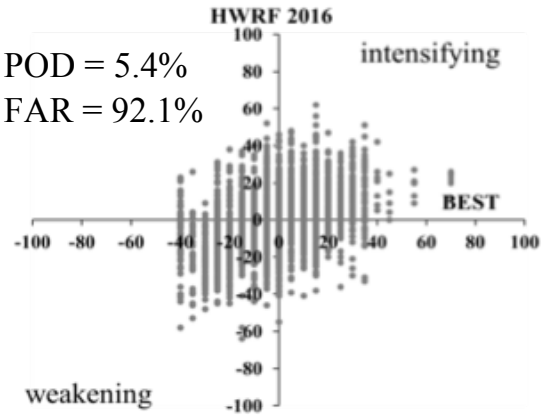
2017 HWRF NATL

POD = 17.3%
FAR = 71.6%



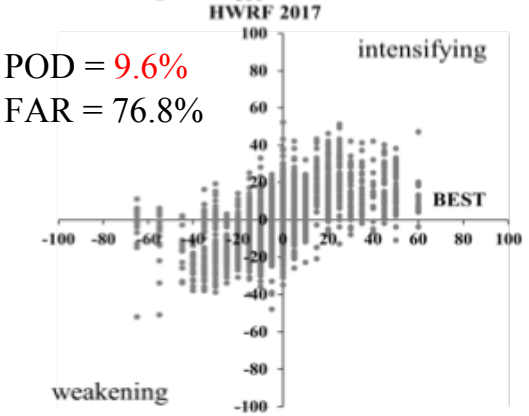
2016 HWRF NATL

POD = 5.4%
FAR = 92.1%



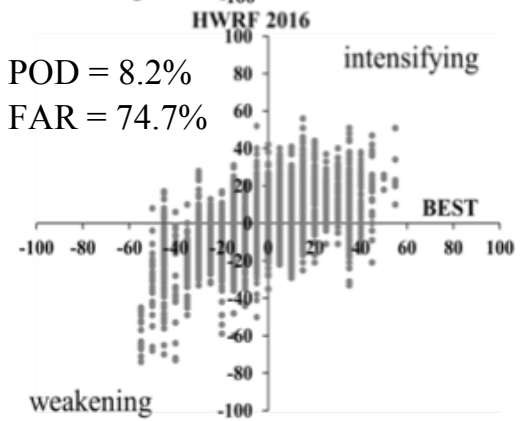
2017 HWRF EPAC

POD = 9.6%
FAR = 76.8%



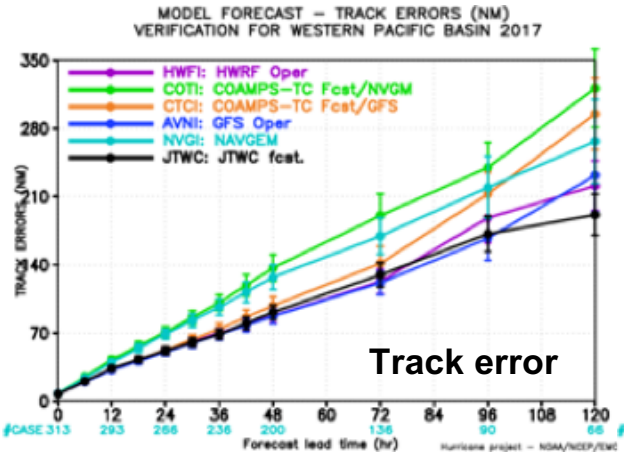
2016 HWRF EPAC

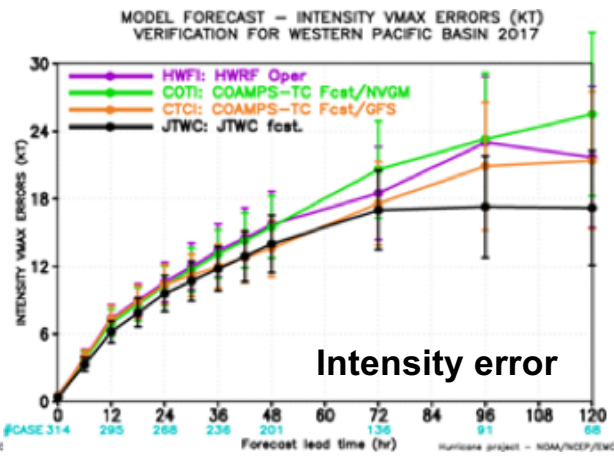
POD = 8.2%
FAR = 74.7%

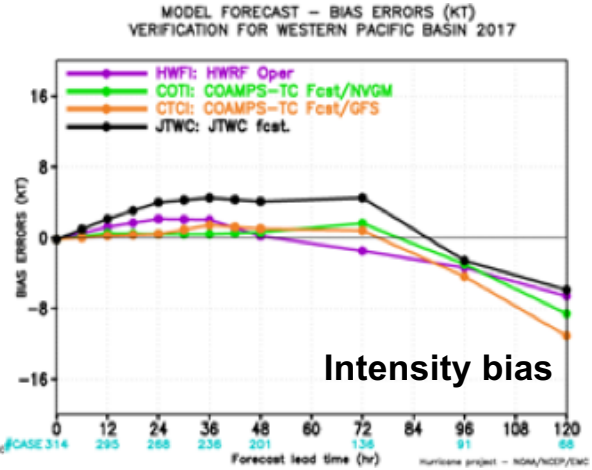


HWRF in the 2017 Western Pacific Basin

Real-Time Performance (Early Guidance)







HWRF
COTC
CTCX
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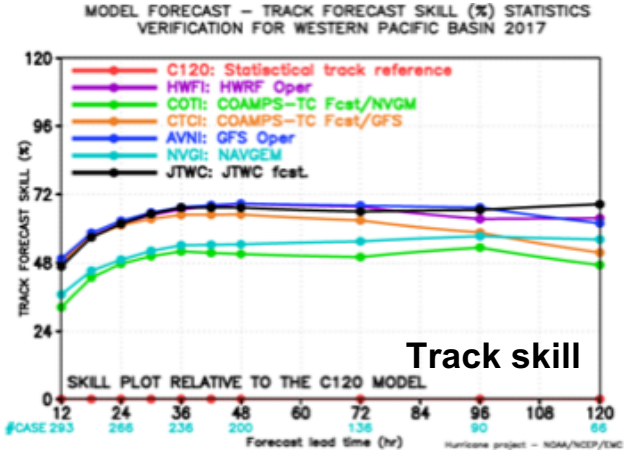
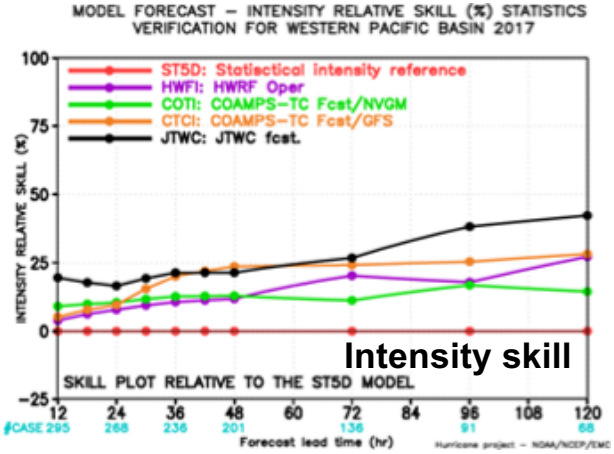
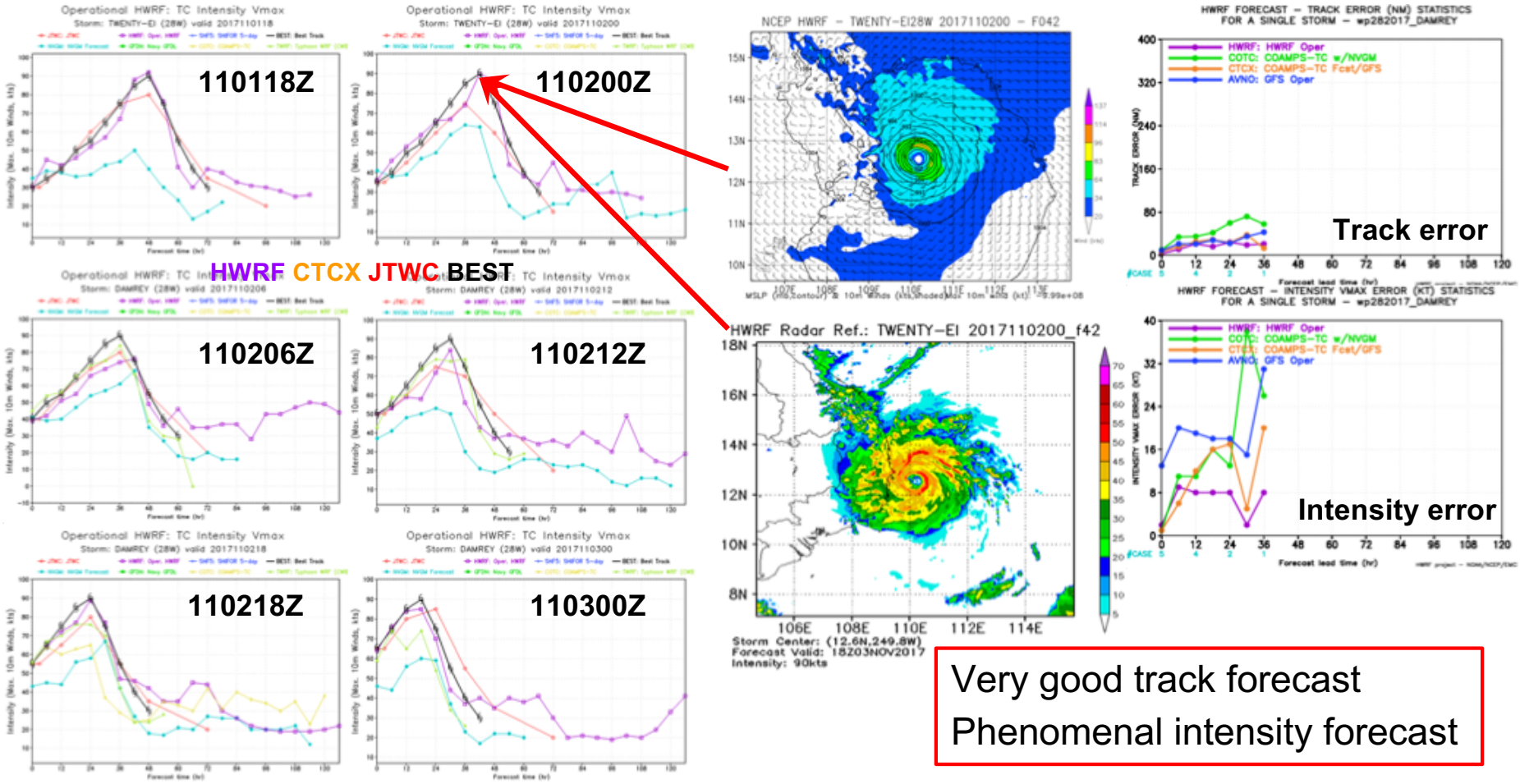


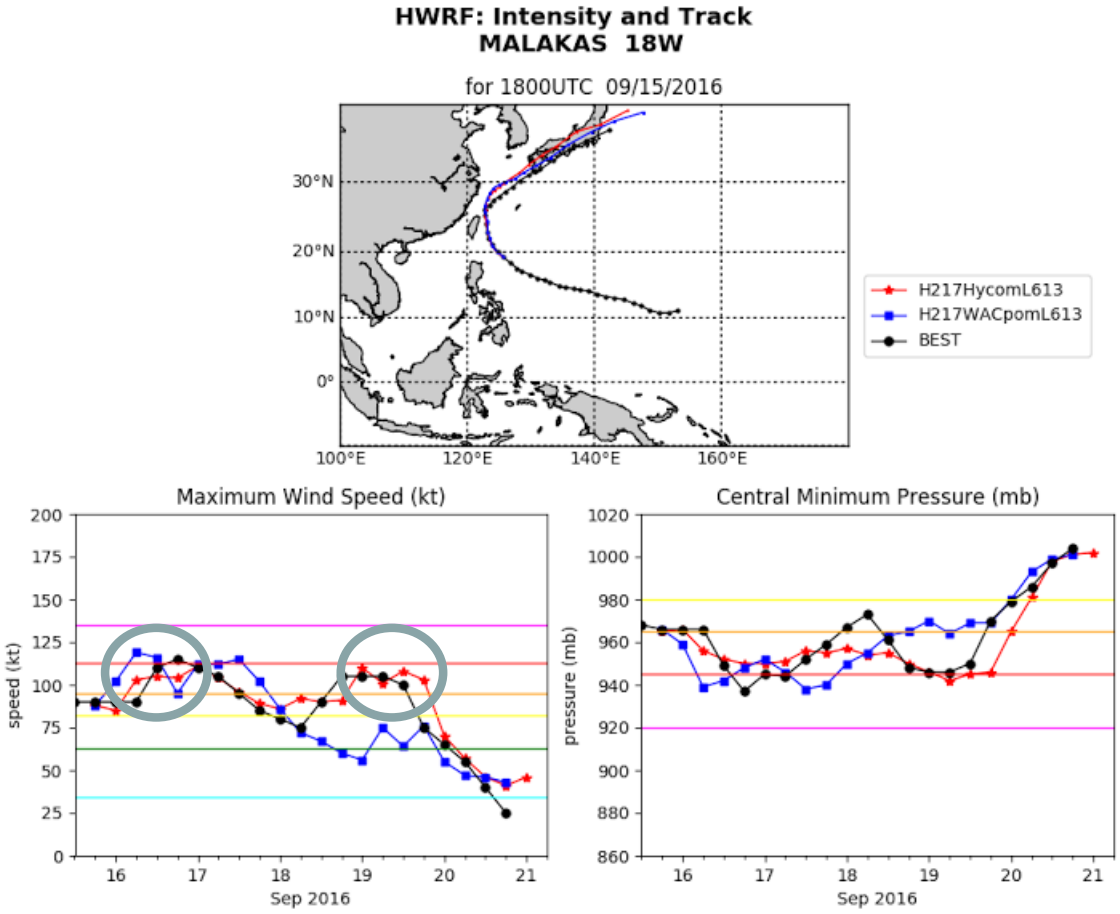


HWRF Forecast for Typhoon Damrey (28W)

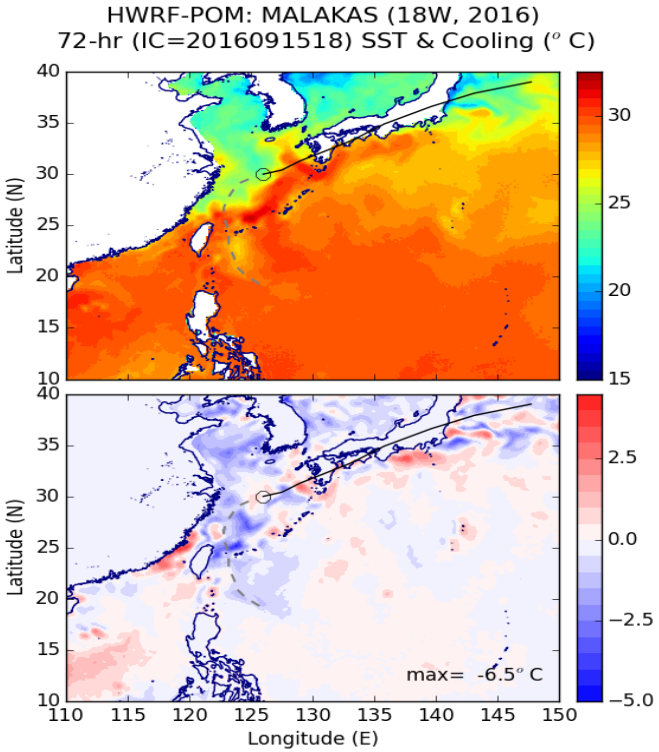


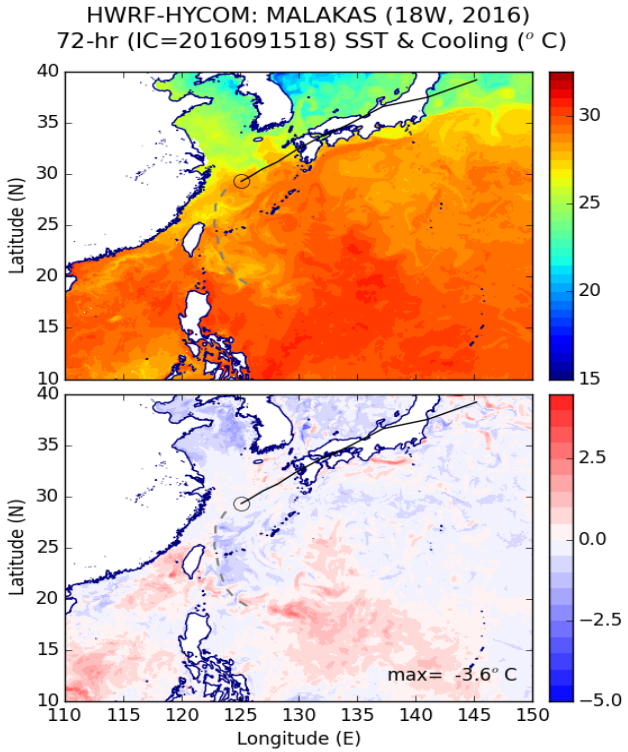
Very good track forecast
Phenomenal intensity forecast

Impact of using HYCOM in H217 for WPAC storms



Impact of using HYCOM in H217 for WPAC storms





SST (top panel) and SST change (bottom panel) for Malakas, where the 2nd intensification took place before it made landfall in Japan. POM overpredicted reduction in SST's (left panel) and hence failed to intensify the storm because of relatively cold water on the shelf (< 26°C), unlike HYCOM (right panel) which has a better SST representation.

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

- Starting in 2012, EMC HWRF team has been experimenting with 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

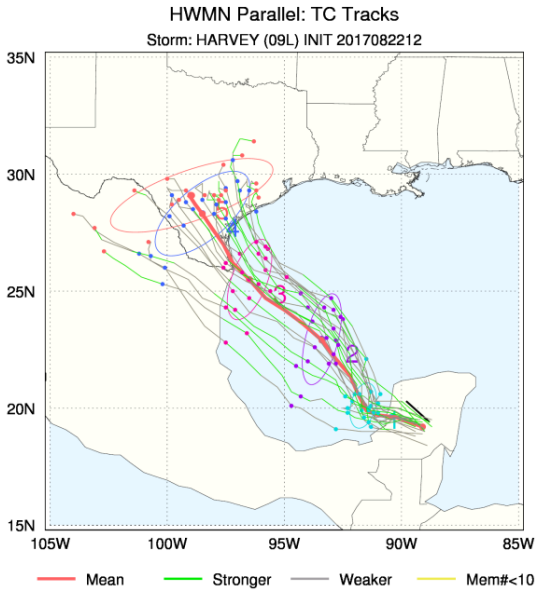
model continues to perform very well, especially for intensity, where it outperformed other mesoscale models out to 72 hrs and was especially useful during the frequent rapid intensification events that occurred in the Western North Pacific this year"

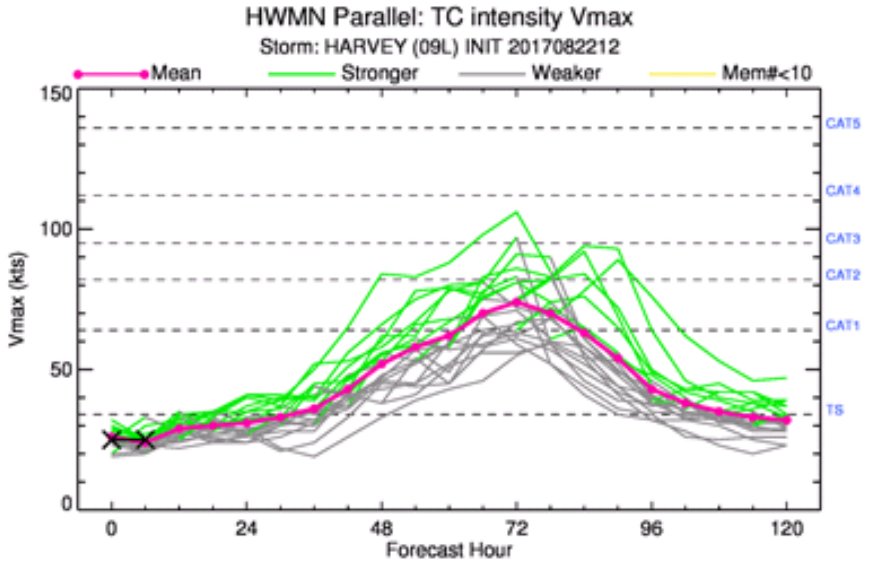
--Bob Falvey, Director, JTWC

- ***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

HFIP Experimental Regional Real time Multi-Model Ensemble Prediction System in 2017





HWMN: HWRF, 20 ensemble members
HMMN: HMON, 11 ensemble members
CTMN: COAMPS-TC, 10 ensemble members

- ***Total 41 ensemble members, simple average to provide multi-model ensemble track/intensity forecasts***
- ***High-resolution probabilistic products provide forecast uncertainty in track, intensity, structure (size) and rainfall, along with ensemble mean products***

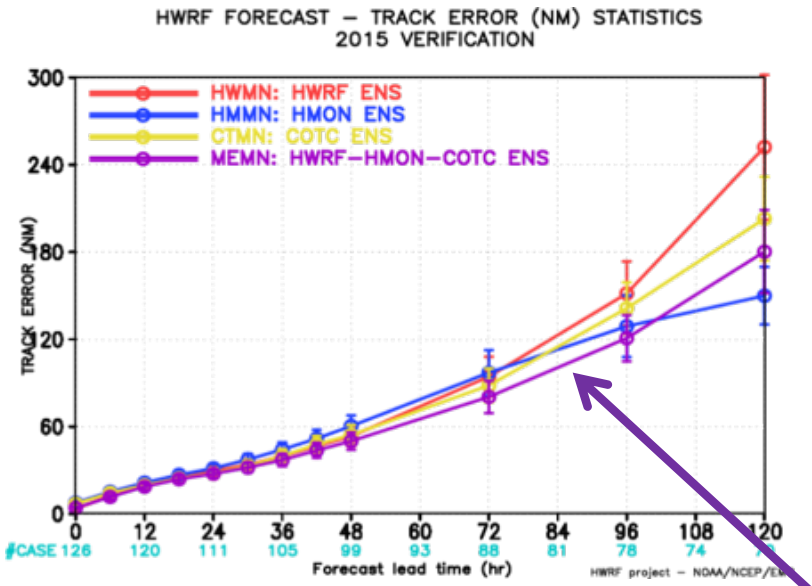
HFIP Experimental Regional Real time Multi-Model Ensemble Prediction System in 2017

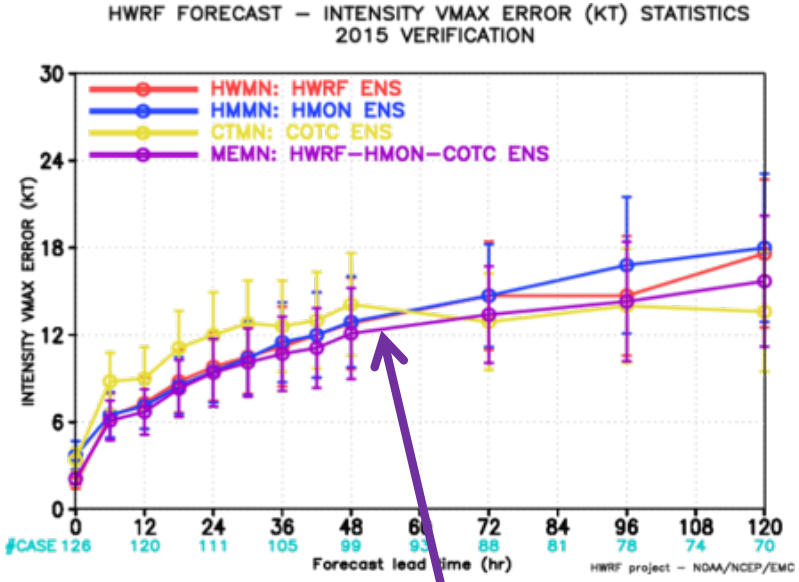
- Use 2017 operational deterministic HWRF model except for
  - Less horizontal resolution: 27/9/3km vs. 18/6/2km
  - Less vertical resolution: L43 vs. L75;
  - No GSI due to lack of GDAS data

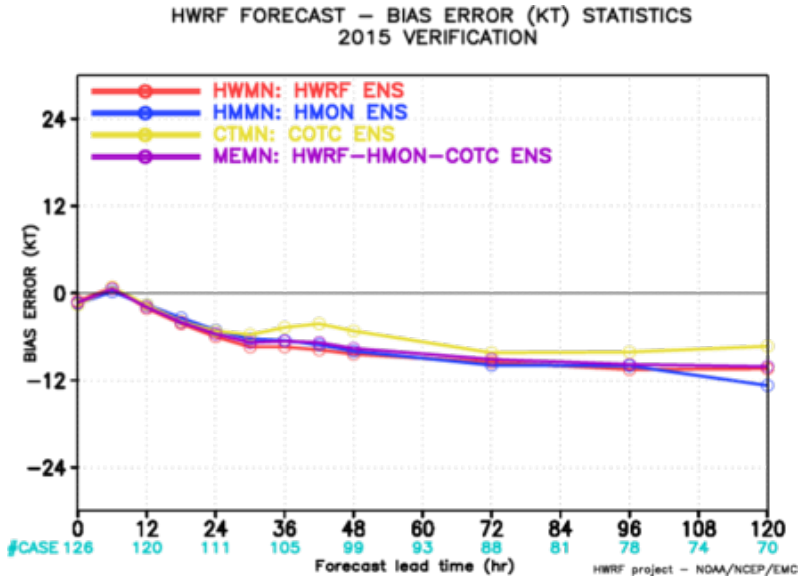
- IC/BC Perturbations (large scale): 20 member GEFS.

- Model Physics Perturbations (vortex scale):
  - Stochastic Convective Trigger Perturbations in SAS: -50hPa to + 50hPa white noise ;
  - Stochastic boundary layer height perturbations in PBL scheme, -20% to +20%;
  - Stochastic Cd perturbation;
  - Stochastic initial wind speed and position (TCVital) perturbations considering best track uncertainty;
  - Bug fixes to better represent the model physics uncertainties

HFIP Experimental Regional Real time Multi-Model Ensemble Prediction System in 2017







Ensemble mean

Overview of the HWRF Modeling System

- Regional-scale, moving nest, Ocean-Atmosphere-Wave 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, self-cycled since 2017)
- Physical parameterization schemes designed and tested for tropical cyclones
- Ocean coupled modeling system using an advanced NCEP coupler.

2018 Tutorial of the HWRF Modeling system

- (Day 1) WRF Model (NMM dynamical core)
- *Ocean Initialization, Ocean Model (MPIPOM-TC)*
- *HWRF Nesting*
- HWRF Physics
- HWRF Initialization, Vortex Initialization
- Mechanics of Running HWRF
- *(Day 2) Introduction to GSI*
- *Hybrid EnKF-3DVAR regional data assimilation system based on community GSI*
- *NCEP Coupler*
- *HYCOM coupling (Enrichment)*
- Post-Processing Program (UPP)
- GFDL Vortex tracker
- Python scripting structure
- HWRF Multi-storm system (Enrichment)
- Alternate HWRF Configurations
- (Day 3) HWRF Idealized configuration
- HWRF based EPS (Enrichment)
- TC Forecast Verification (Enrichment)
- Future of HWRF and operational Hurricane Modeling at NCEP

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)
- Basin-scale HWRF with multiple moveable nests has also been integrated into the HWRF community modeling system

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 daily 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

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

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

Thanks!

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