NCEP Operational Hurricane Modeling Systems

Verification of 2017 HWRF and HMON Performances

The Hurricane Project Team

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& Several collaborators (extended team members) at NHC, JTWC, HRD/AOML, GFDL, URI, ESRL, DTC, HFIP/JHT PIs and various international agencies

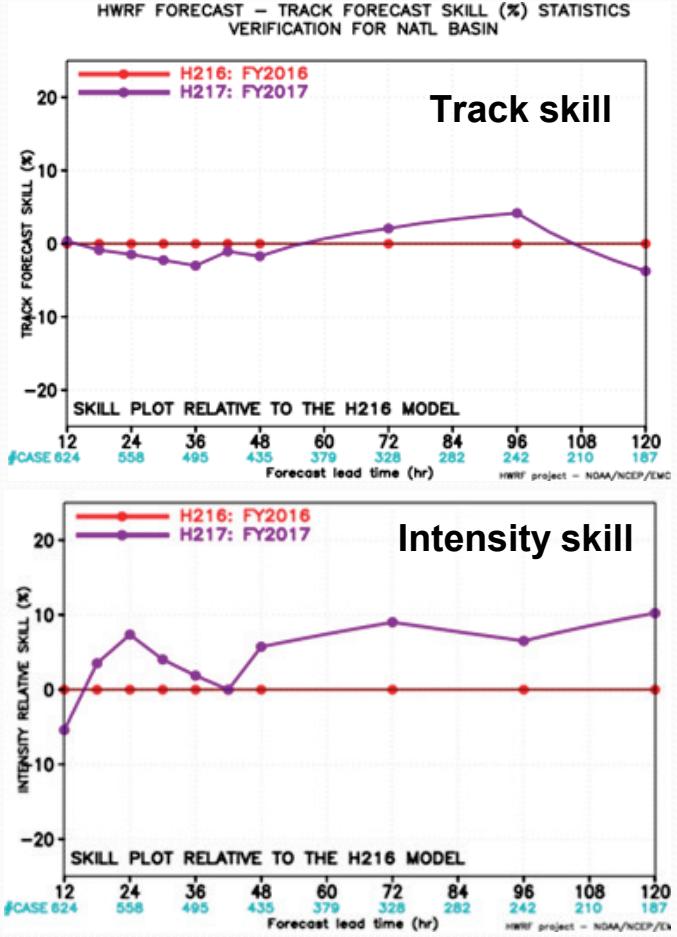
NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

HWRF™ The Hurricane Weather Research And Forecast System

Highlights of FY2017 HWRF Upgrades

- Infrastructure Enhancements
  - Upgrade dynamic core from WRF3.7.1a to WRF3.8.1 (with bug fixes)
  - T&E with 2017 4D-Hybrid GDAS/GFS IC/BC
  - 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
  - GSI code upgrades together with new data sets for DA
  - 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 forecasts for CPAC, in addition to NATL and EPAC
  - Sea surface wave boundary condition from global wave model

H217 performance
for 2014-2016 NATL storms

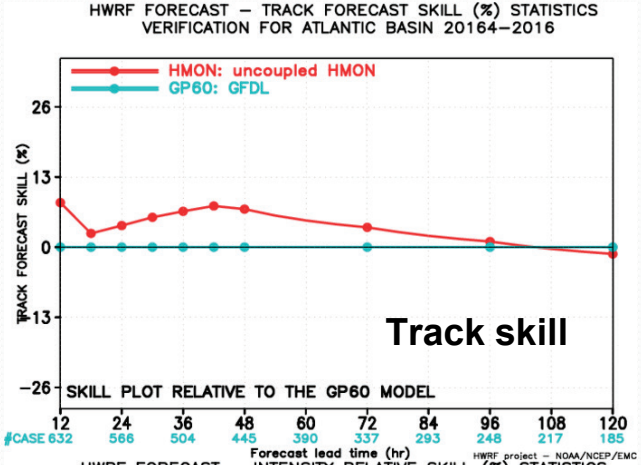


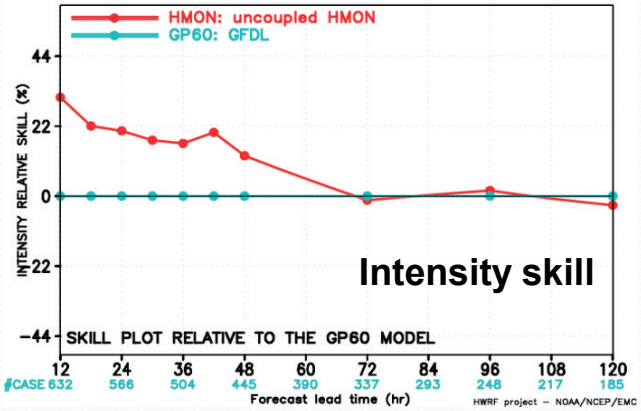
Highlights of FY2017 HMON Implementation

First Year in Operations

- Hurricanes in a Multi-scale Ocean coupled Non-hydrostatic model (HMON,replacing the legacy GFDL hurricane model) provides high-resolution intensity forecast guidance to NHC along with HWRF
- Based on NMMB (Non-hydrostatic Multi-scale Model on a B grid) dynamic core
- Shared infrastructure with unified model development in NEMS. A step closer towards NEMS/FV3 Unified Modeling System for hurricanes
- Much faster, scalable and uses Common Community Physics Package (CCPP) style physics packages
- Development supported by NGGPS, HFIP and HIWPP programs

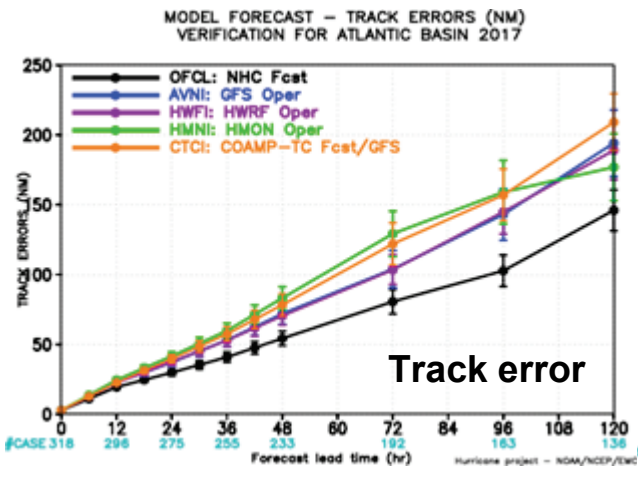
HMON performance
for 2014-2016 NATL storms
Track and intensity skills
relative to GFDL model

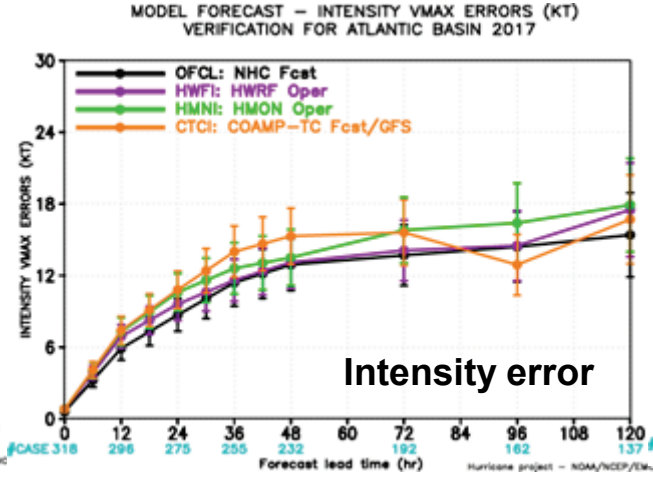


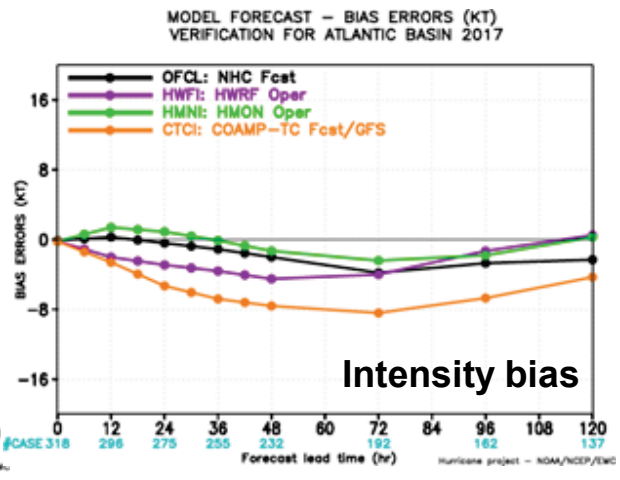


HWRF/HMON in the 2017 North Atlantic Basin

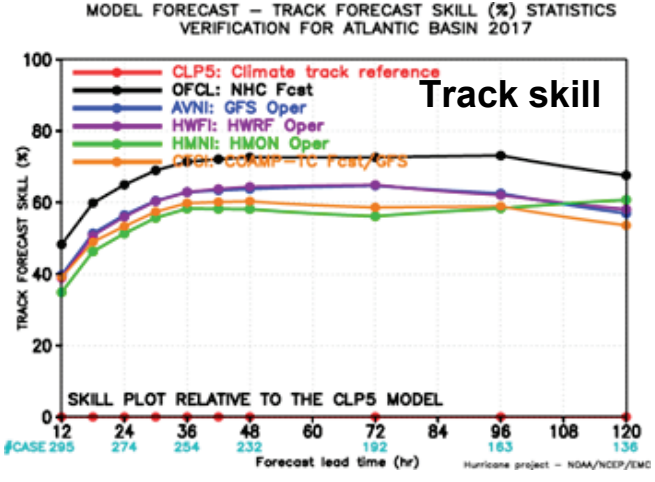
Real-Time Performance (Early Guidance)

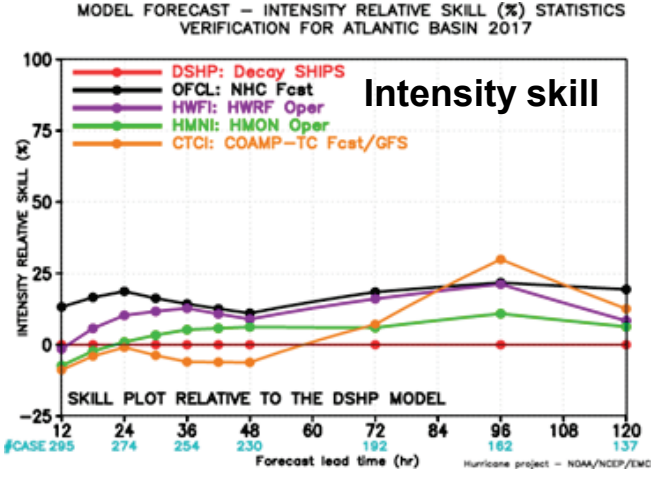






HWRF
HMON
CTCX
GFS
OFCL





HWRF/HMON in the 2017 Eastern Pacific Basin

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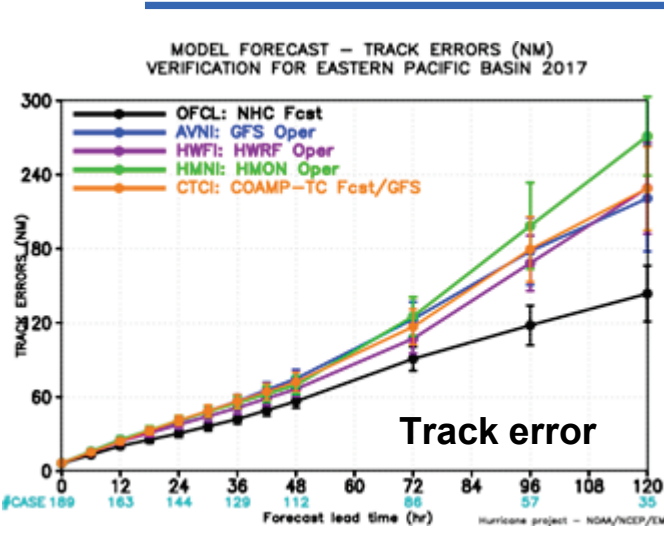
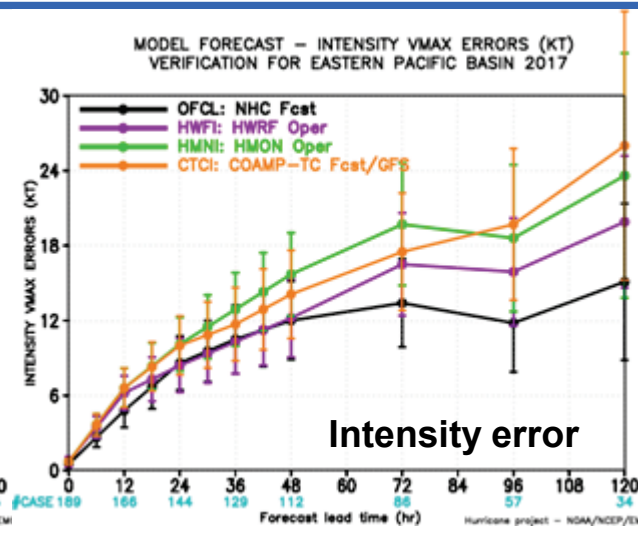
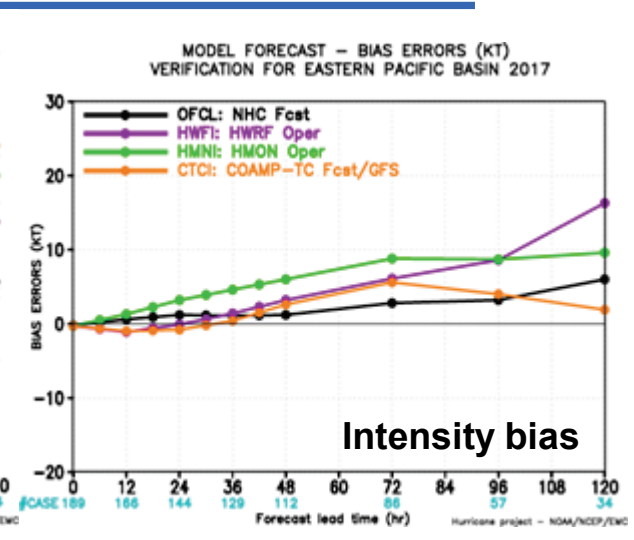
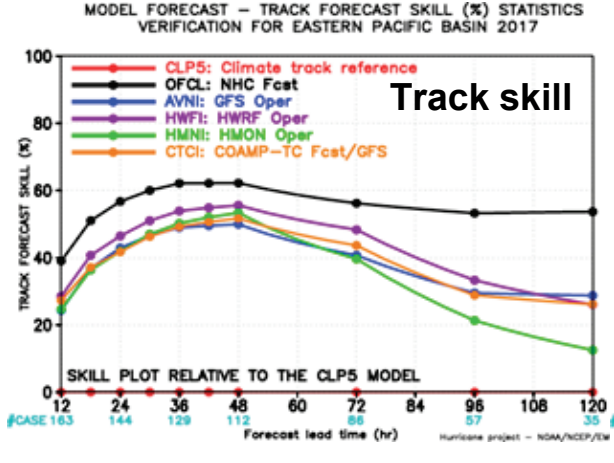
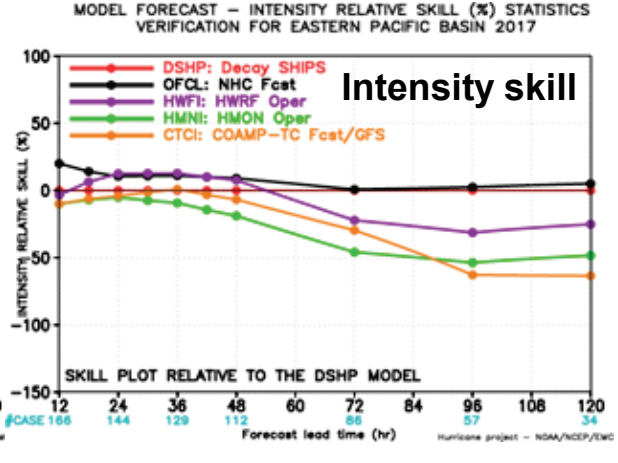






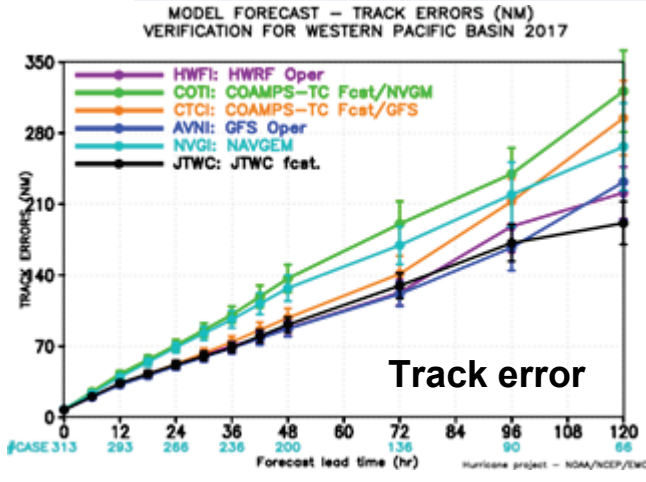
HWRF
HMON
CTCX
GFS
OFCL

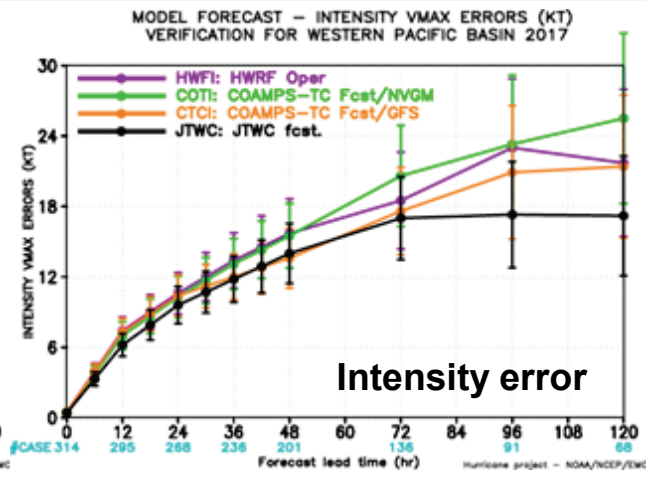


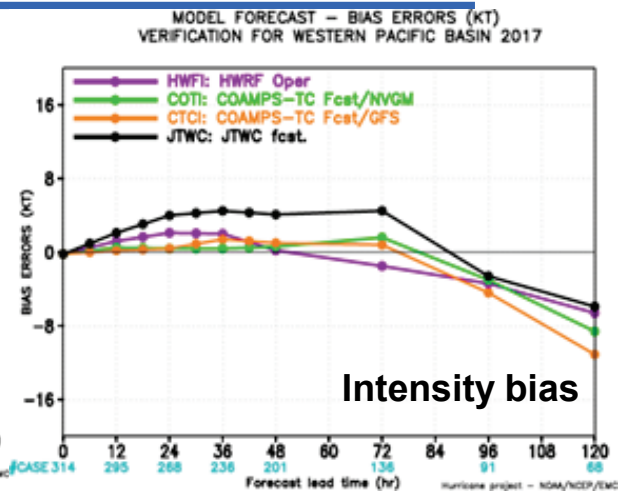


HWRF in the 2017 Western Pacific Basin

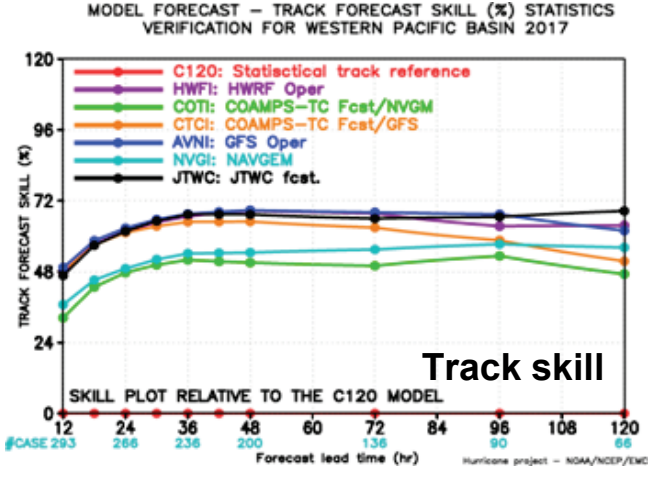
Real-Time Performance (Early Guidance)

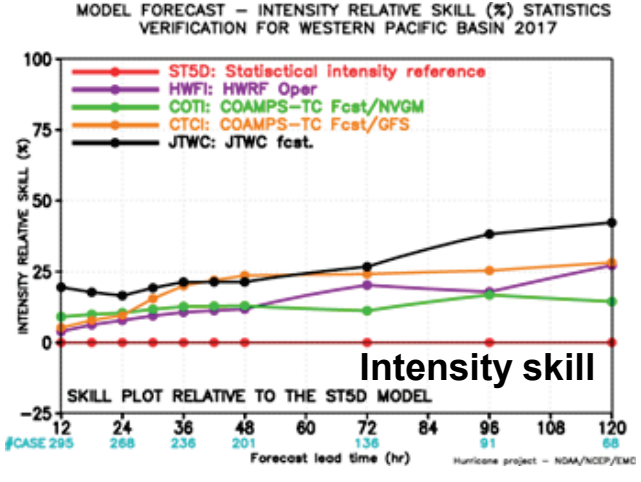






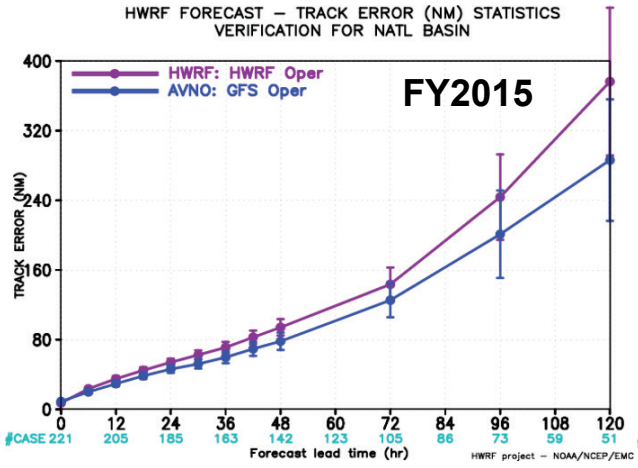
HWRF
COTC
CTCX
GFS
JTWC

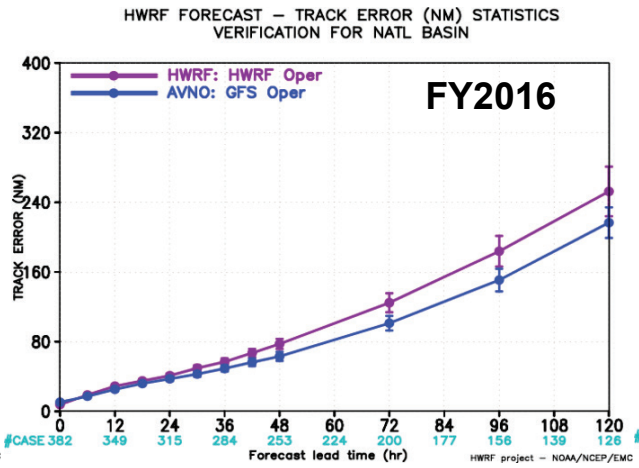


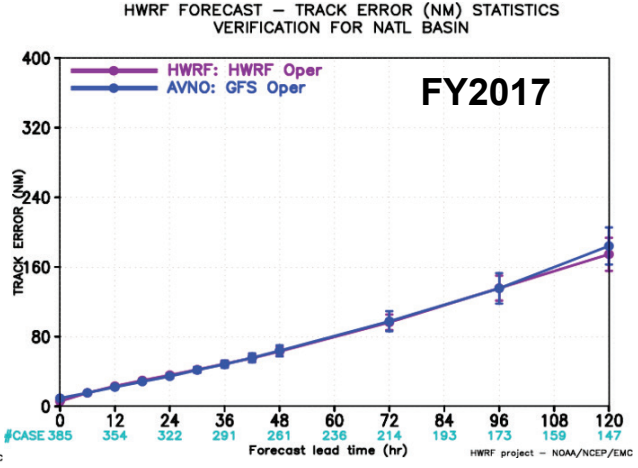


HWRF Track and Size Forecast for NATL Basin

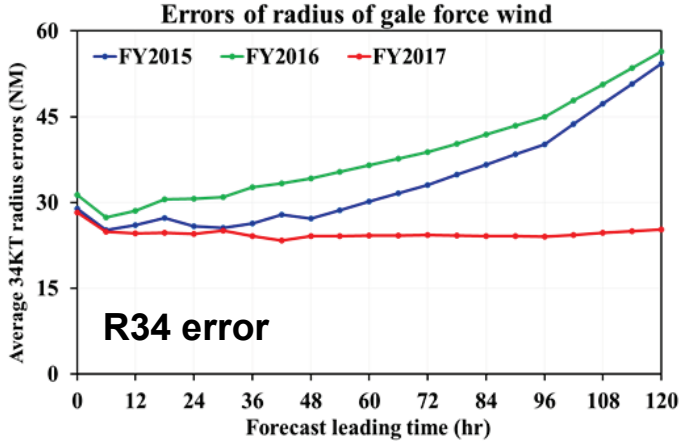
Real-Time Performance for FY2015-2017

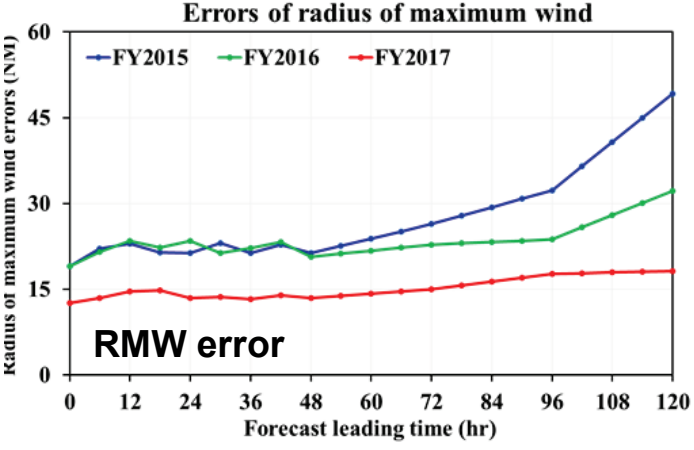






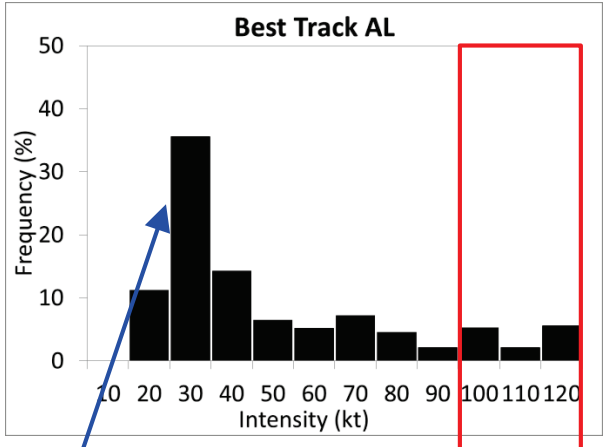
Impressive catch-up in track forecasting and substantial storm size improvement

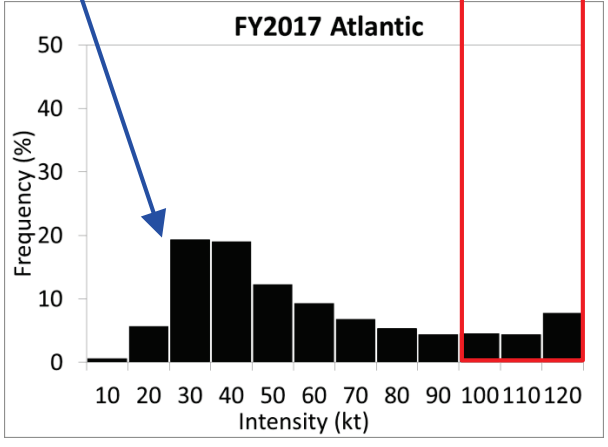


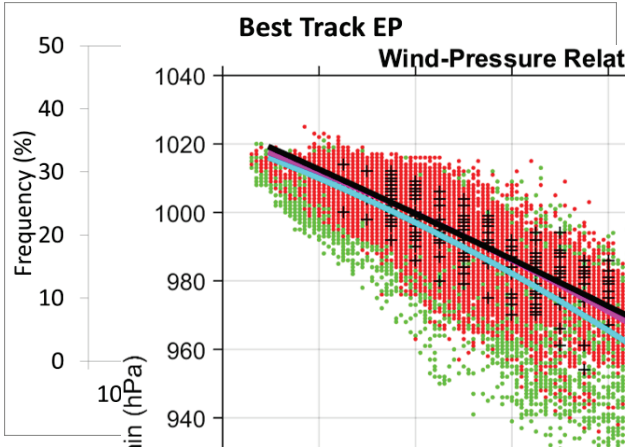


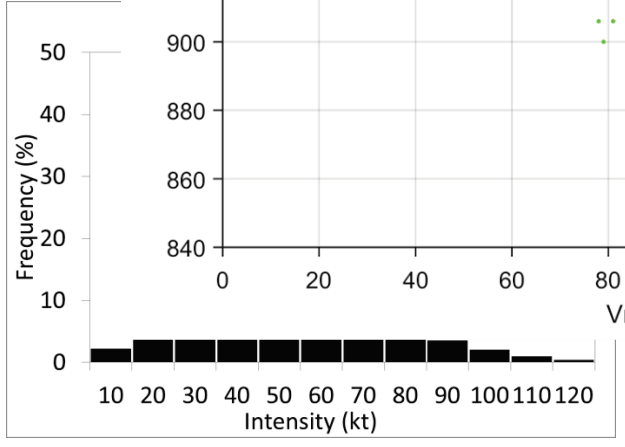
Intensity Distribution and Wind-Pressure Relation

2017 HWRF Real-Time Performance



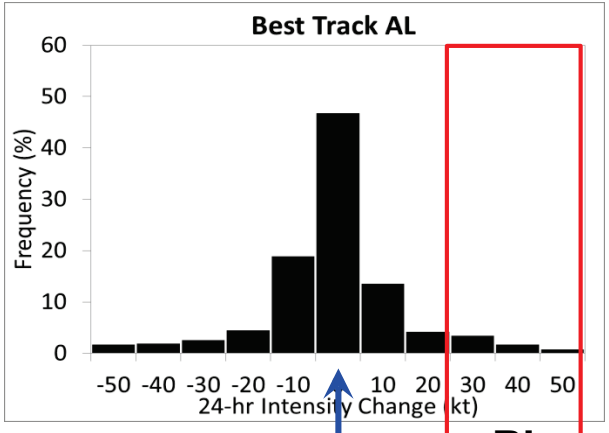


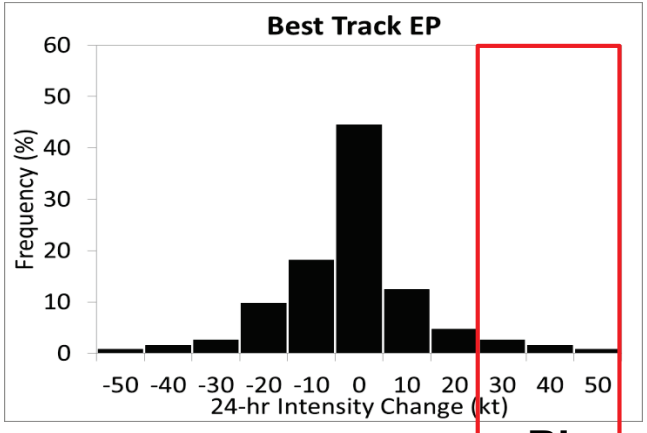


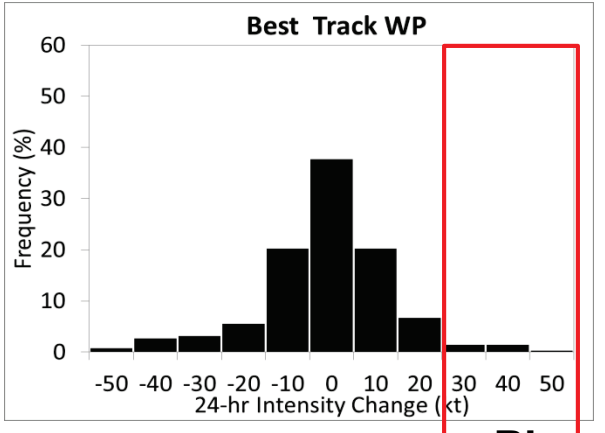


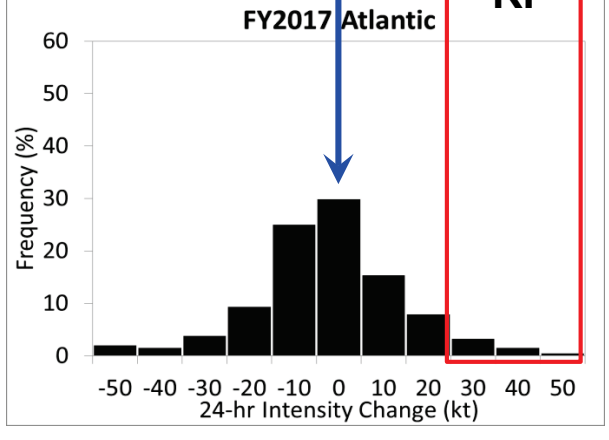
HWRF 24hr Intensity Change Distribution

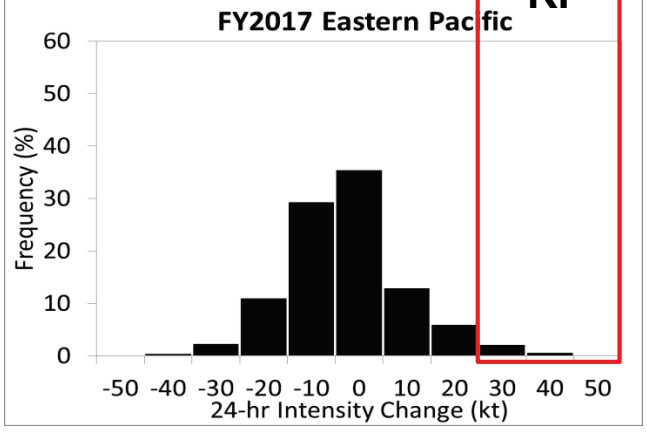
2017 Real-Time Performance

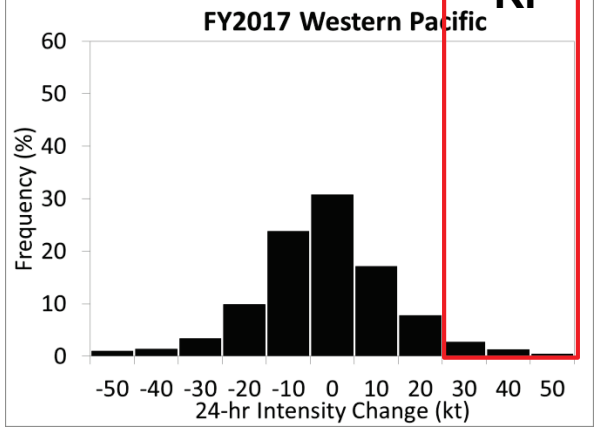








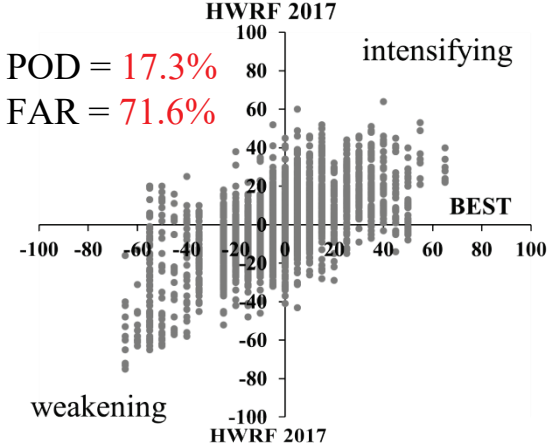




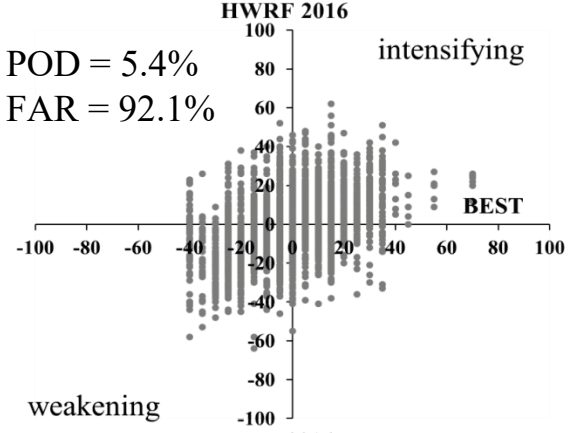
Rapid Intensity Change in NATL/EPAC Basins

POD and FAR for RI

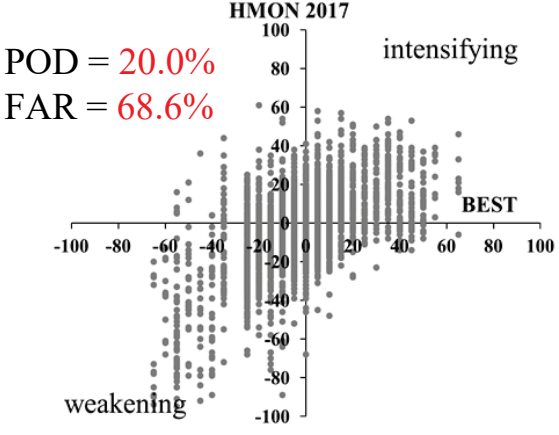
2017 HWRF NATL

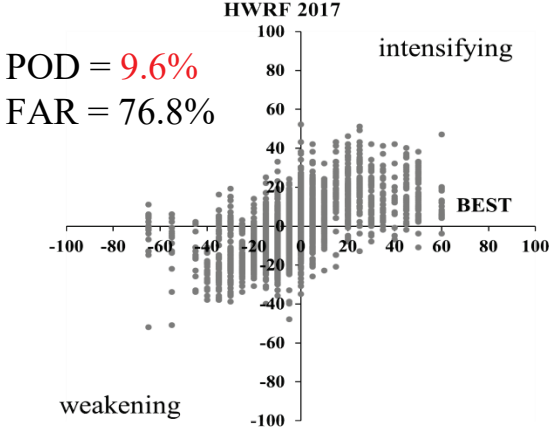


2016 HWRF NATL

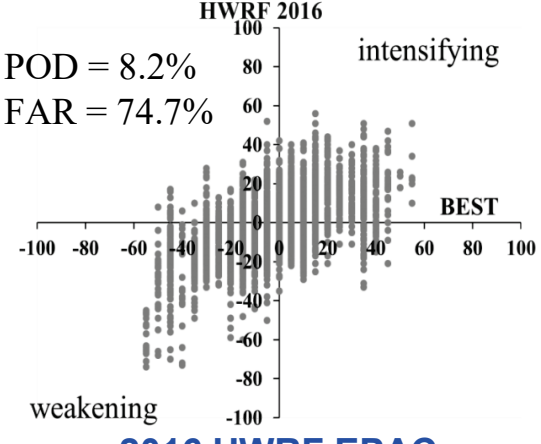


2017 HMON NATL

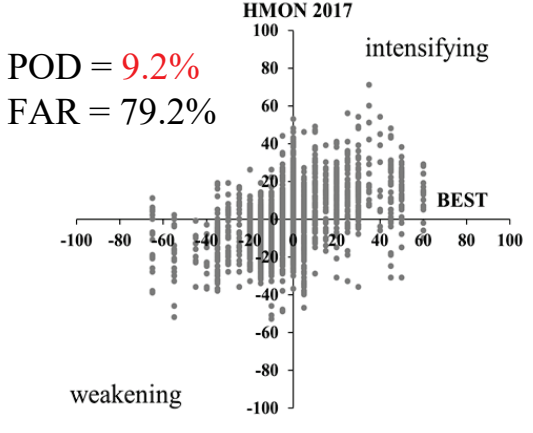




2017 HWRF EPAC



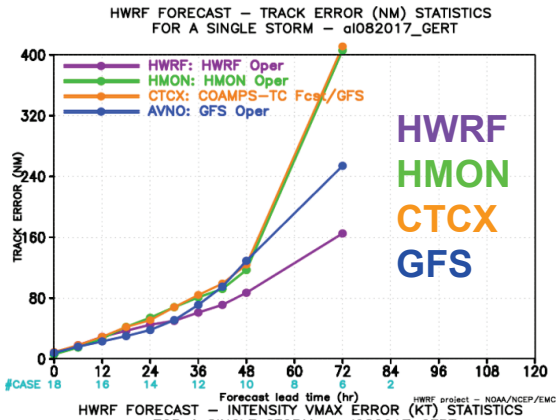
2016 HWRF EPAC

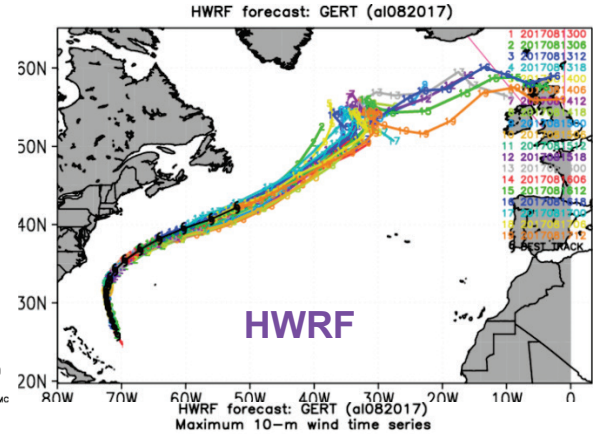


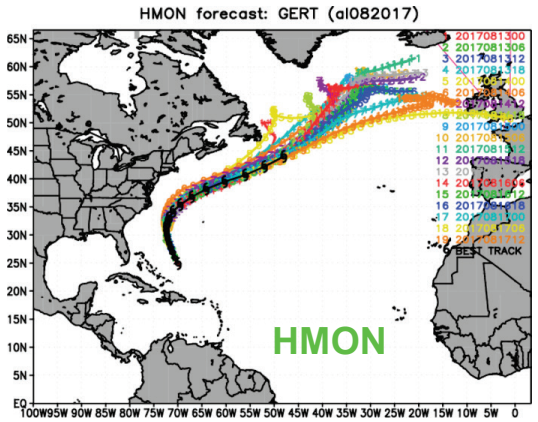
2017 HMON EPAC

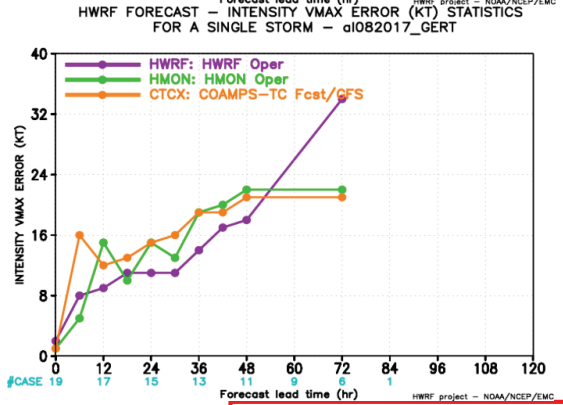
HWRF/HMON Forecast for Hurricane Gert (08L)

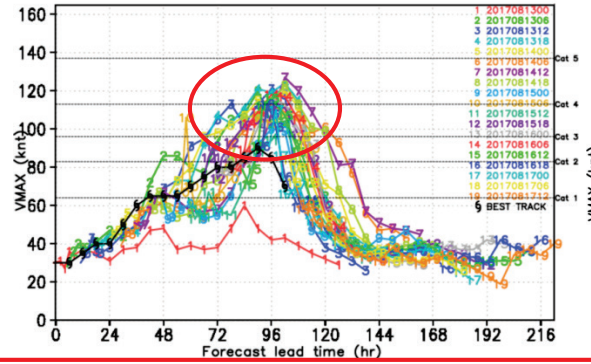
Track and intensity errors and composites

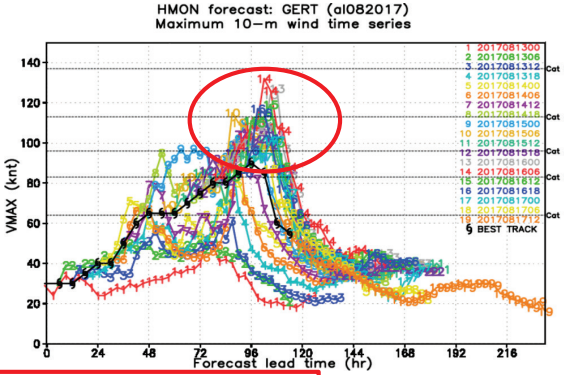








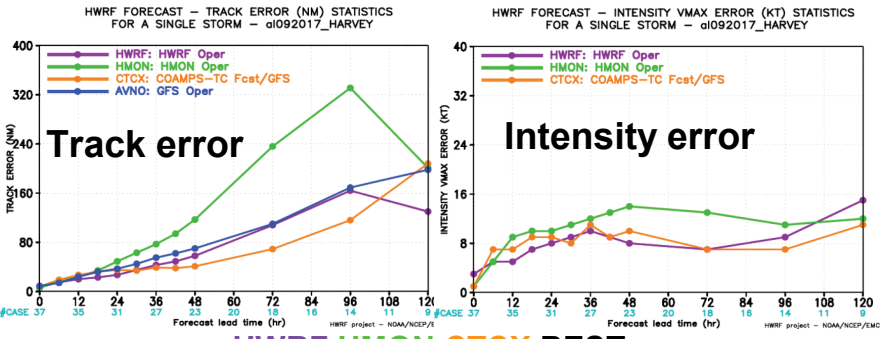


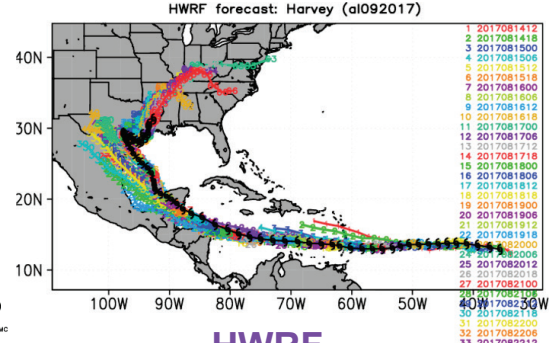


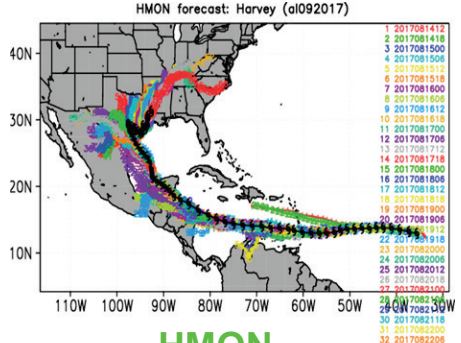
Large over-intensification for Hurricane Gert for both HWRF and HMON

- Interaction with large-scale environment (VWS, etc)
- Positive bias from GFS NSST
- Southward track bias for HWRF

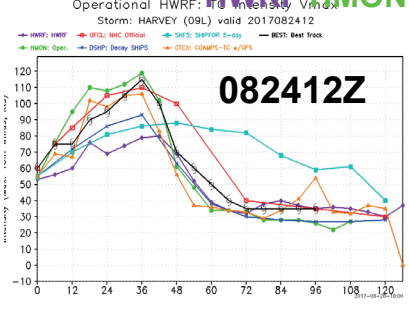
HWRF/HMON Forecast for Hurricane Harvey (09L)

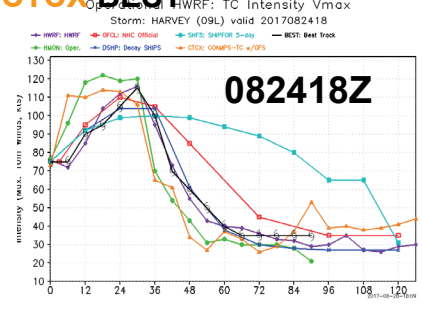


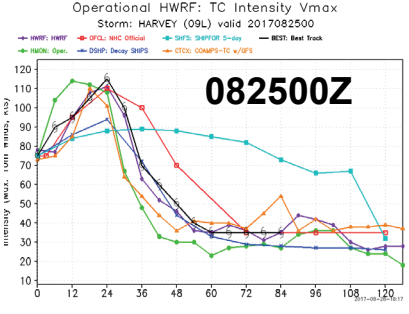


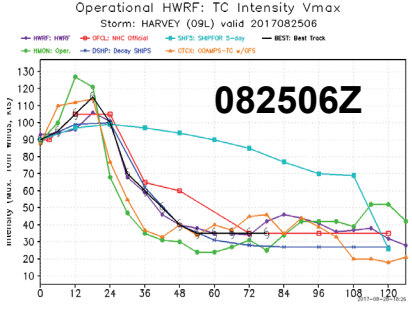


HWRF HMON CTCX BEST

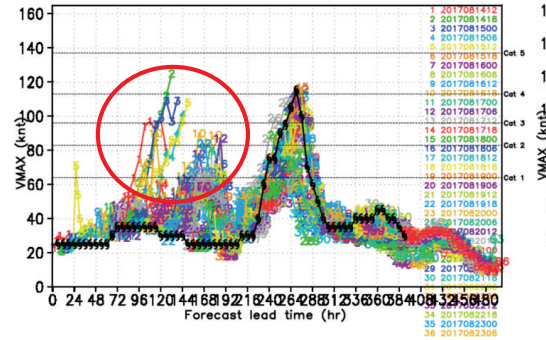




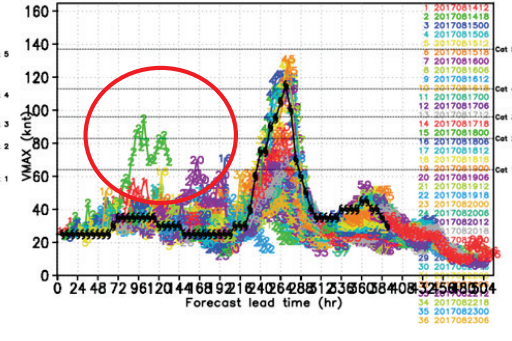




HWRF

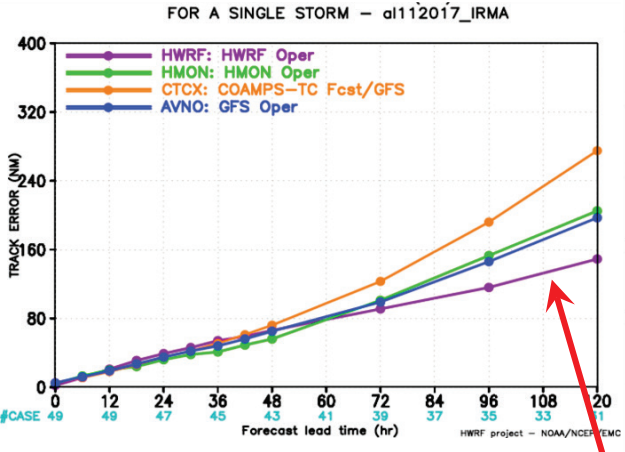


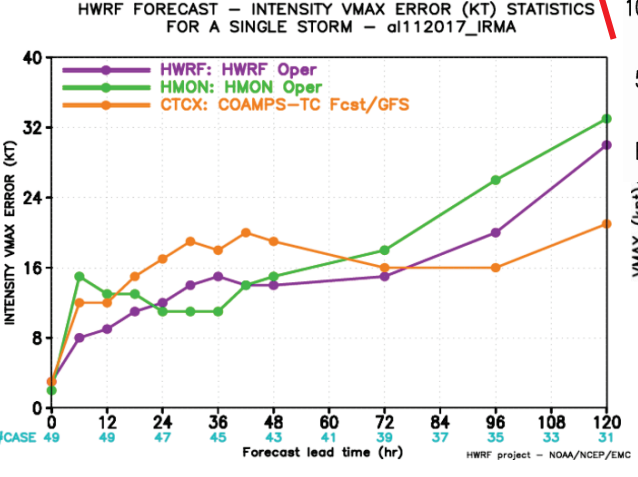
HMON

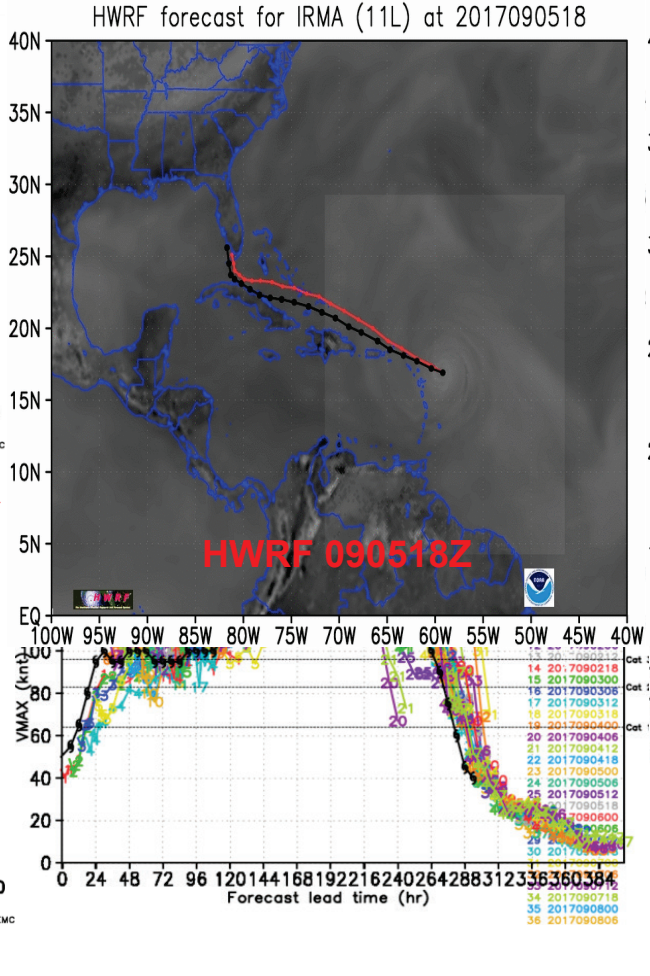


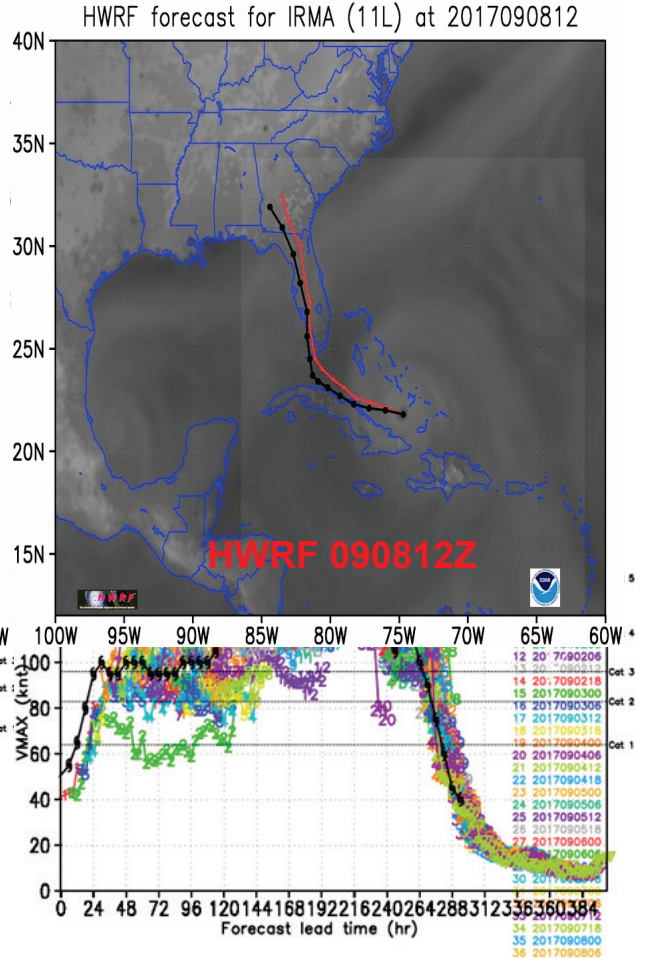
HWRF's track forecast is better than GFS and HMON
Both model have good intensity forecast for strong cycles
HWRF had some more over-intensification invest cycles than HMON

HWRF/HMON Forecast for Hurricane Irma (11L)

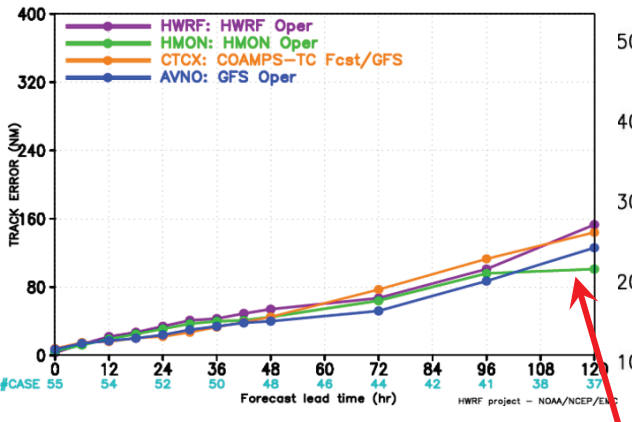


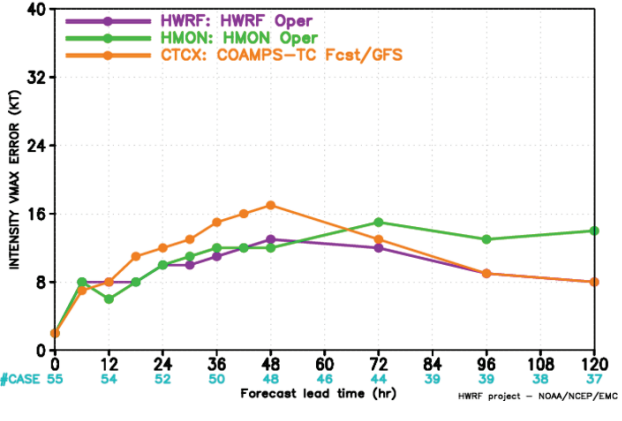


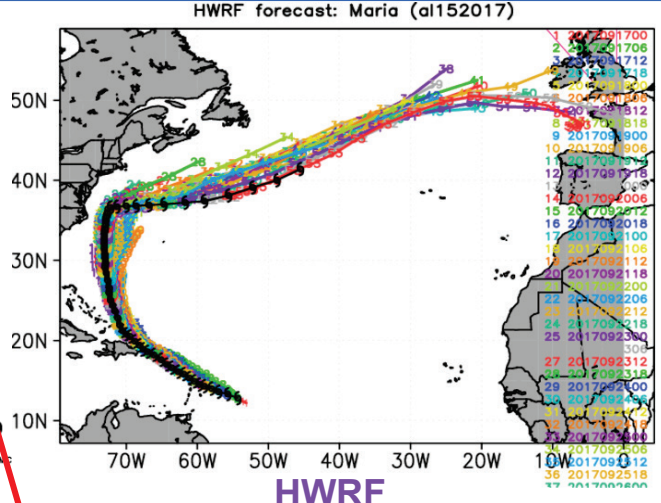




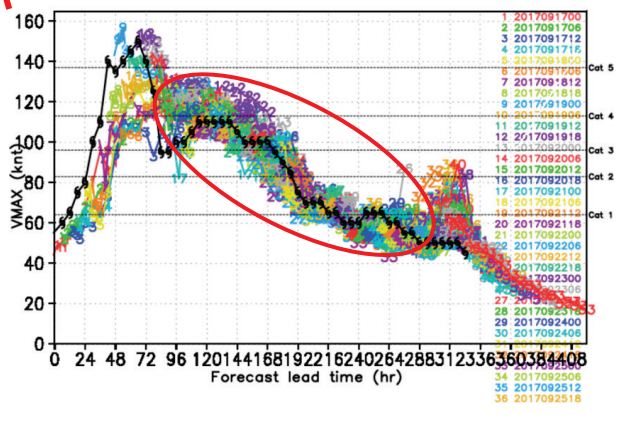
HWRF/HMON Forecast for Hurricane Maria (15L)

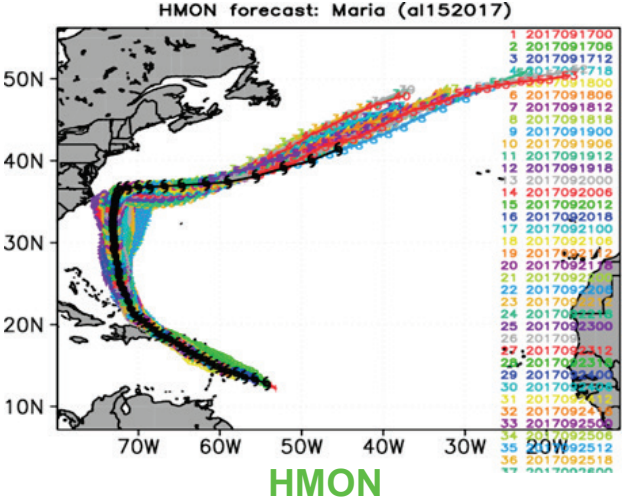




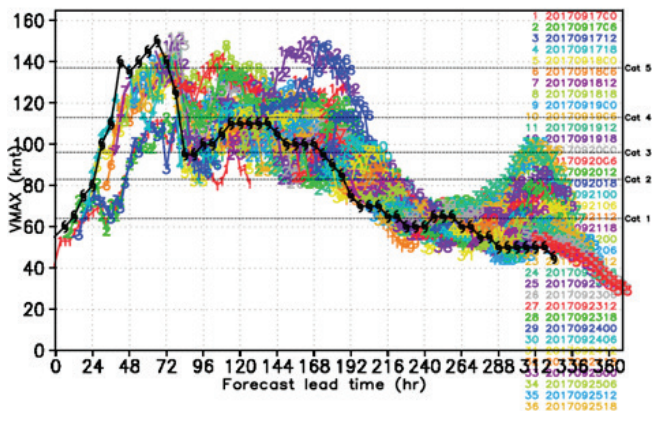


HWRF





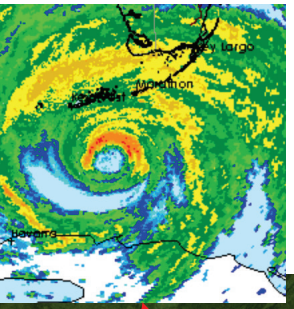
HMON



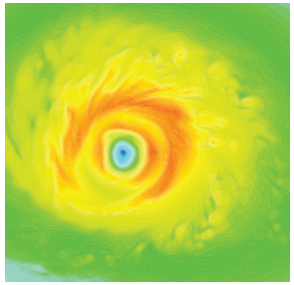
HWRF/HMON Forecast for Concentric Eyewalls

Hurricane Irma (11L)

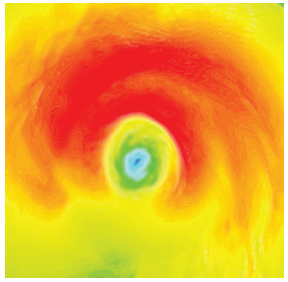
09/10 09Z



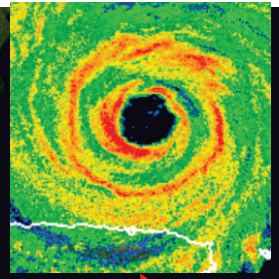
09/09 06Z f18



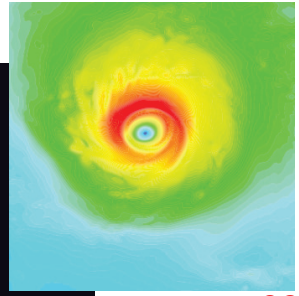
09/08 12Z f15



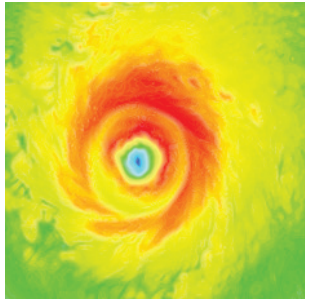
09/07 00Z



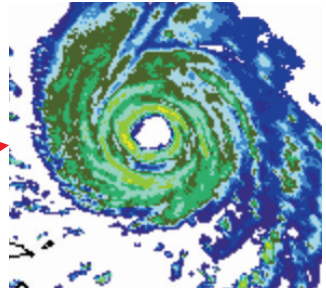
09/05 12Z f42



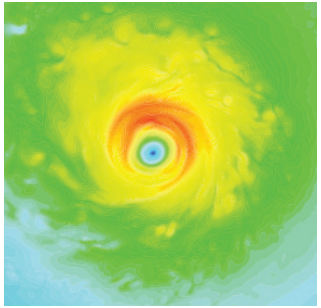
09/04 18Z f63



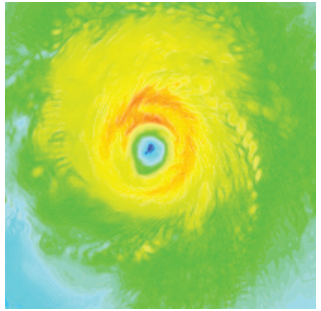
09/05 12Z



09/02 18Z f63

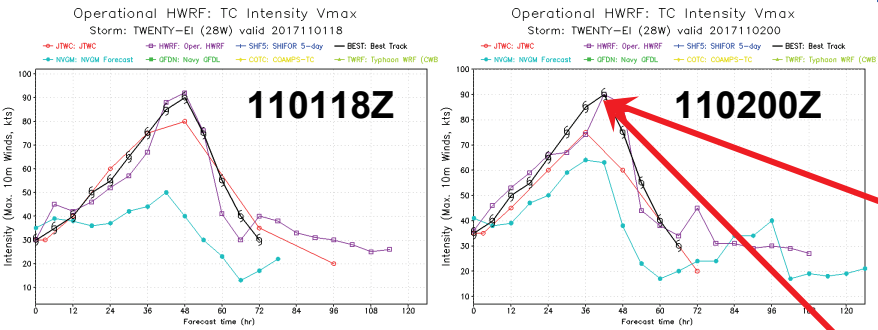


09/02 12Z f69

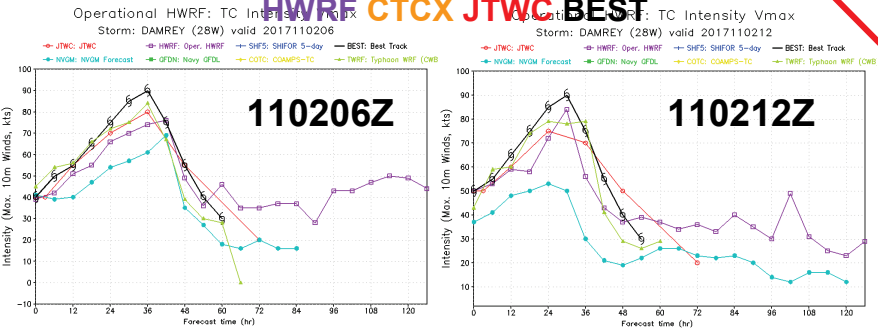


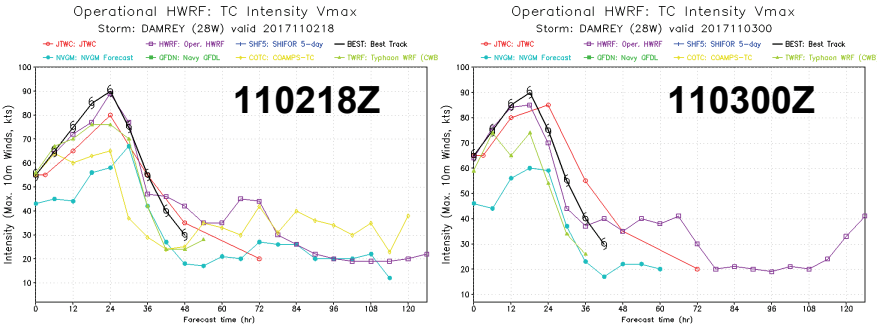
- Evidence of secondary eyewalls in **93%** (**95%**) of the **HWRF** (**HMON**) cycles initialized between: 08/30 12Z to 09/09 06Z
- **18%** (**58%**) of the **HWRF** (**HMON**) cycles developed secondary eyewalls more than once

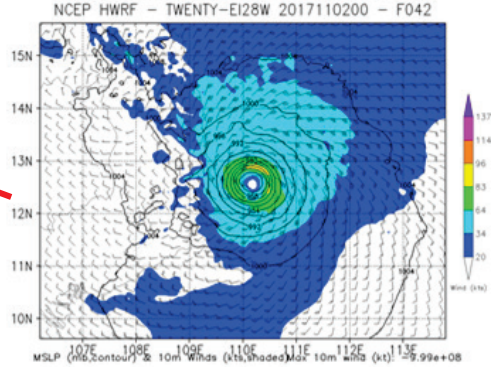
HWRF Forecast for Typhoon Damrey (28W)

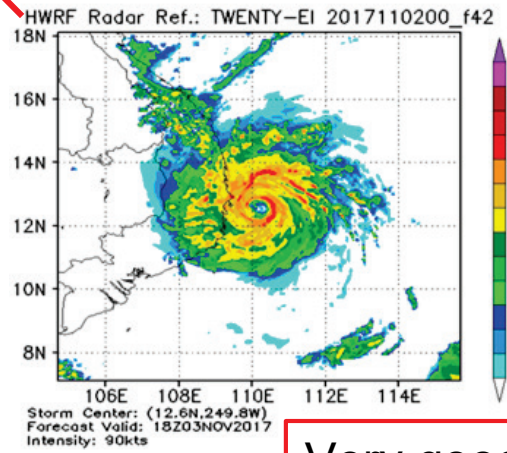


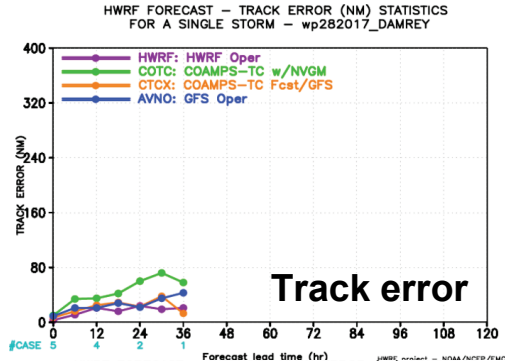
HWRF CTCX JTWC BEST

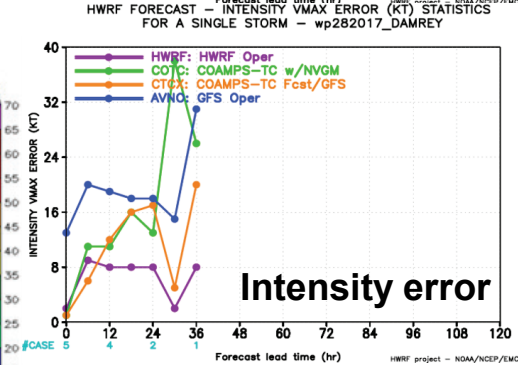












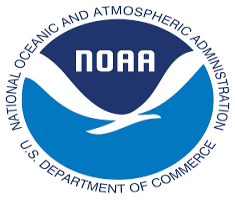
Very good track forecast
Phenomenal intensity forecast

Summary and Concluding Remarks for HWRF

- HWRF track forecast skill is substantially improved comparing to FY2015-2016 HWRF performance for NATL, showing as good as or similar to GFS track forecast skill
- FY2017 HWRF continues to provide very good intensity model guidance (close to OFCL intensity forecast guidance for NATL storms), with improved performance for rapid intensity change forecasting
- Improvement of simulations of storm size and structure, with substantially reduced storm size errors and good evidence of modeling concentric eyewalls and eyewall replacement cycles
- Although much improved comparing to FY2016 HWRF, there were still some over-intensification invest cycles and negative intensity bias for very strong storms

Summary and Concluding Remarks for HMON

- First year into operations replacing the legacy GFDL hurricane model
- Comparable (with slightly reduced skills) track and intensity forecasts to HWRF forecasts, whereas using much less computation resources (26 nodes vs 63 nodes in operations)
- For individual storms/forecast cycles, HMON and HWRF provided mixed track and intensity forecast skills
- Overall slightly better POD for RI forecast than HWRF for 2017 NATL storms
- HMON's wind-pressure relation not well aligned with best track data
- Currently no ocean coupling for NATL storms
- Currently no inner-core data assimilation



GFDL Geophysical Fluid Dynamics Laboratory

DTC

THE UNIVERSITY OF RHODE ISLAND

AOML

NOAA ESRL GSD

NCAR

HFIP NCEP

Noaa HURRICANE FORECAST IMPROVEMENT PROJECT

Thank you!

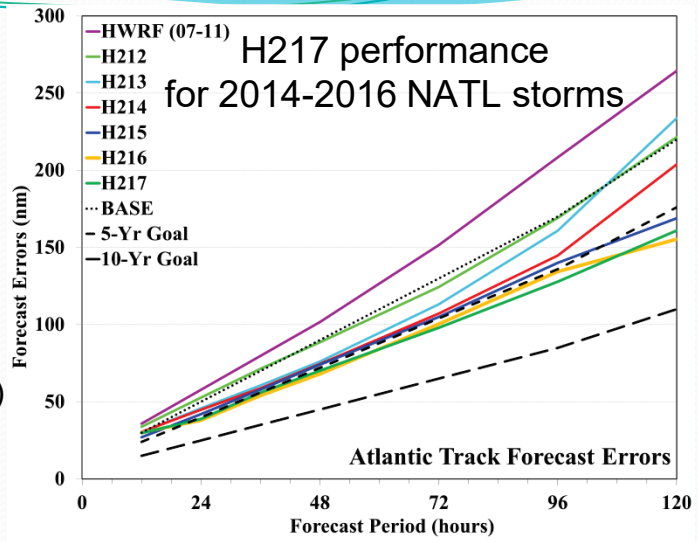
Real-time NCEP operational model guidance for all global TCs

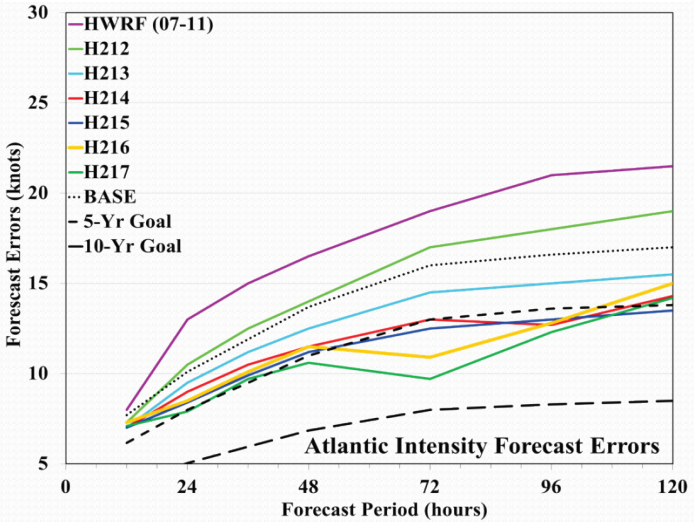
HWRF: http://www.emc.ncep.noaa.gov/HWRF

HMON: http://www.emc.ncep.noaa.gov/gc_wmb/vxt/HMON

Highlights of FY17 HWRF Upgrades

- Infrastructure Enhancements
  - Upgrade dynamic core from WRF3.7.1a to WRF3.8.1 (with bug fixes)
  - T&E with 2017 4D-Hybrid GDAS/GFS IC/BC
  - 75 vertical levels with model top of 10hPa with smaller nested domains
  - New vortex tracker (Tim Marchok, GFDL)
- Initialization and DA Improvements
  - Improved vortex initialization with new composite vortex
  - GSI code upgrades together with new data sets for DA
  - 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 forecasts for CPAC, in addition to NATL and EPAC
  - Sea surface wave boundary condition from global wave model

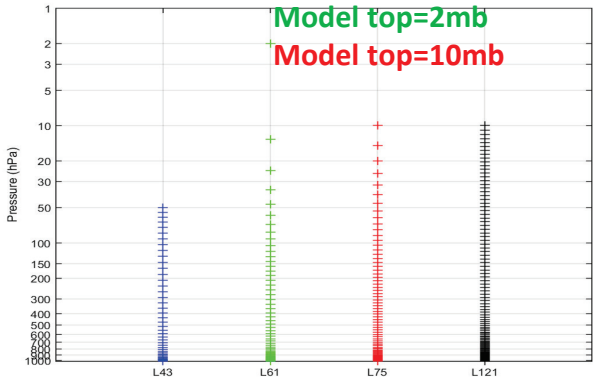


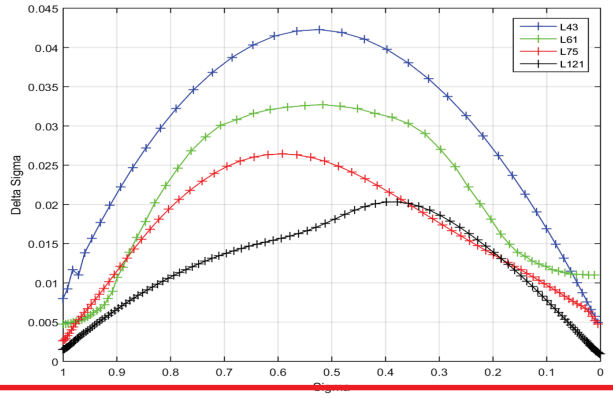


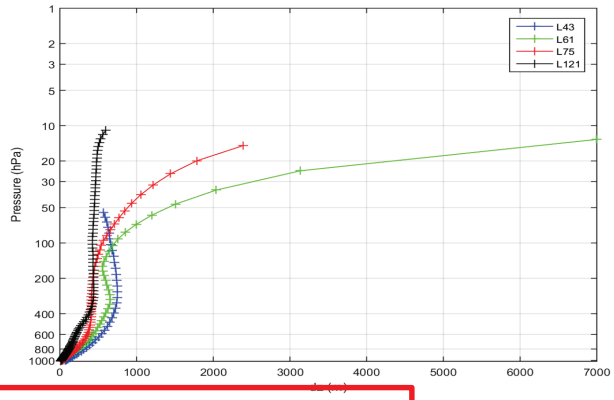
FY2017 HWRF/HMON Configuration

	HWRF	HMON
Dynamic core	Non-hydrostatic, NMM-E	Non-hydrostatic, NMM-B
Nesting	18/6/2 km; 75°/25°/8.3°; 75 vertical levels Full two-way moving	18/6/2 km; 75°/12°/8°; 43 vertical levels Full two-way moving
Data Assimilation and Initialization	Vortex relocation & adjustment Self-cycled hybrid EnKF-GSI with inner core DA (TDR)	Vortex relocation & adjustment
Physics	Updated surface (GFDL), GFS-EDMF PBL, Scale-aware SAS, NOAH LSM, RRTM, Ferrier	Surface (GFDL), GFS PBL (2015), SAS, NOAH LSM, RRTM, Ferrier
Coupling	MPIPOM/HYCOM, RTOFS/GDEM, WaveWatch-III	HYCOM, RTOFS/NCODA, No waves
Post-processing	NHC interpolation method Updated GFDL tracker	NHC interpolation method GFDL tracker
NEMS/NUOPC	No	Yes with moving nests
Computation cost for forecast job	63 nodes in 95 mins	26 nodes in 95 mins

HWRF Vertical Levels and Domain Nesting

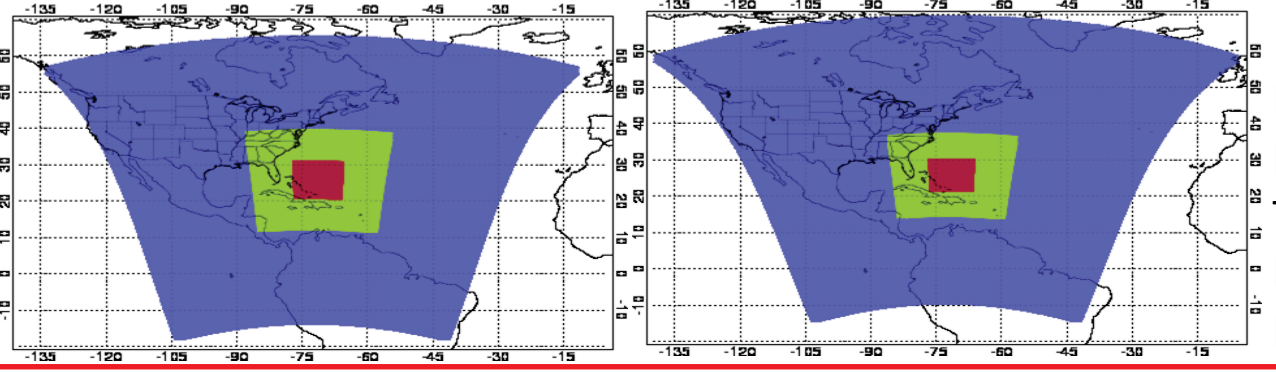






Increase from 61 to 75 vertical levels with model top changing from 2 hPa to 10 hPa and adjusted nested domain sizes

FY2016 HWRF
Levels: 61
Top: 2 hPa
D02: 288x576
D03: 288x576



FY2017 HWRF
Levels: 75
Top: 10 hPa
D02: 265 x 532
D03: 235 x 472

Consider storm's meridional movement when choosing domain center

Updated Scale-Aware SAS scheme

- Updates of the scale awareness:
  - Cloud base mass flux reduction by clouds being advected before they complete their turnover time
  - For dx<8km, the cloud base mass flux is proportional to the mean updraft velocity and not by the Arakawa-Schubert quasi-equilibrium
  - Shallow convection cloud base mass flux is now a function of the cumulus updraft velocity averaged over the whole cloud depth
- Reduced the decreasing rate of rain conversion rate with decreasing air temperature above the freezing level
- Entrainment enhancement in dry environment
- Precipitating shallow convection to reduce too many low clouds
- Separation criteria between deep and shallow is changed to 200 hPa (previously 150 hPa) for cumulus depth

Update to the latest SAS scheme used in NCEP 2017 GFS

Ferrier-Aligo Microphysics Changes

Problem / Solution

High reflectivity bias in PBL clouds

Added a drizzle parameterization (allows smaller/more numerous drops)

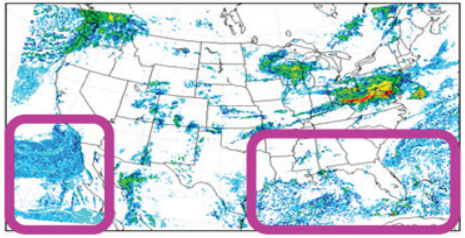
High reflectivity bias at anvil

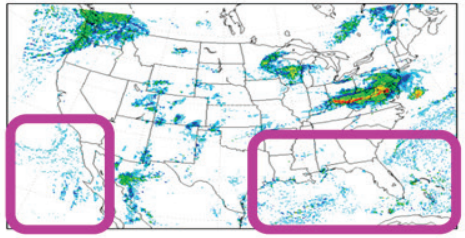
Increased largest possible number concentration of snow

Lack of stratiform precipitation

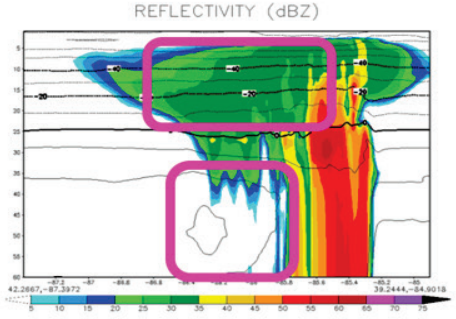
Constant rain drop size during rain evaporation (reduces evaporation)

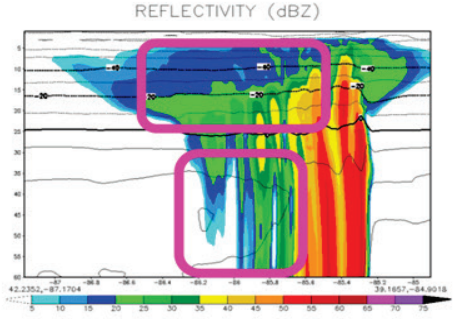
Old | New





12Z 23 June 2016



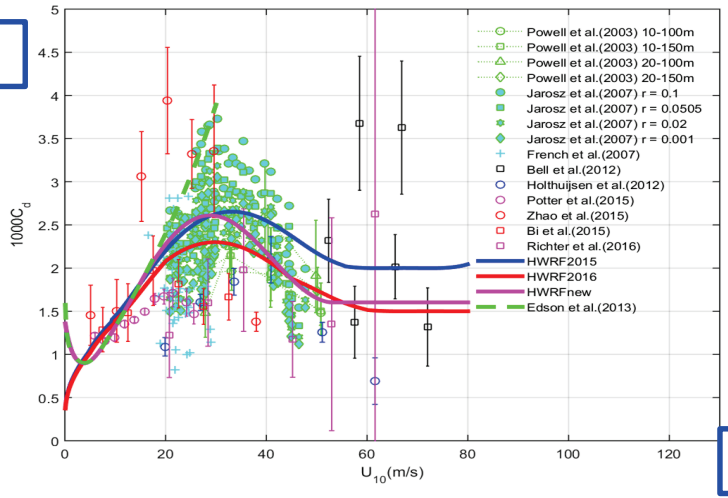


21Z 29 June 2012

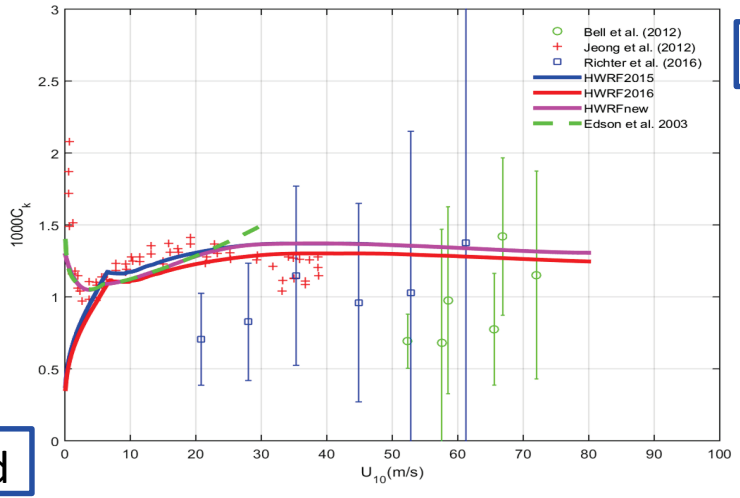
Update to the latest microphysics scheme used in the 2017 NCEP NAM model

Adjustments of Air-Sea Exchange Coefficients

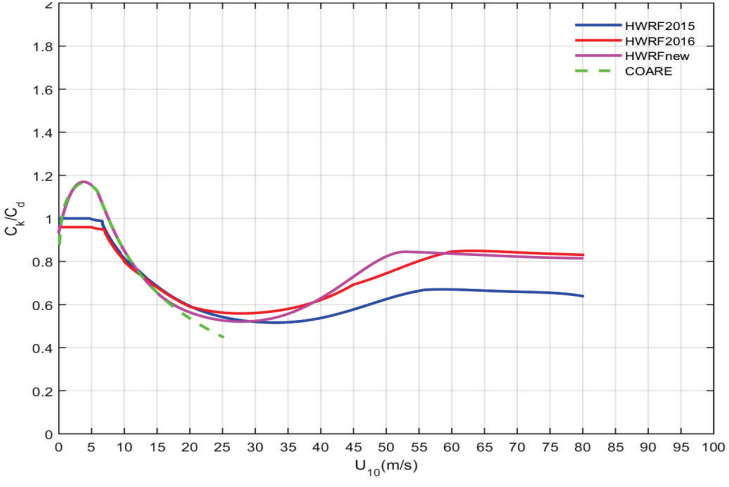
Cd



Ck



Ck/Cd



Magenta: FY2017 HWRF
Red: FY2016 HWRF
Blue: FY2015 HWRF

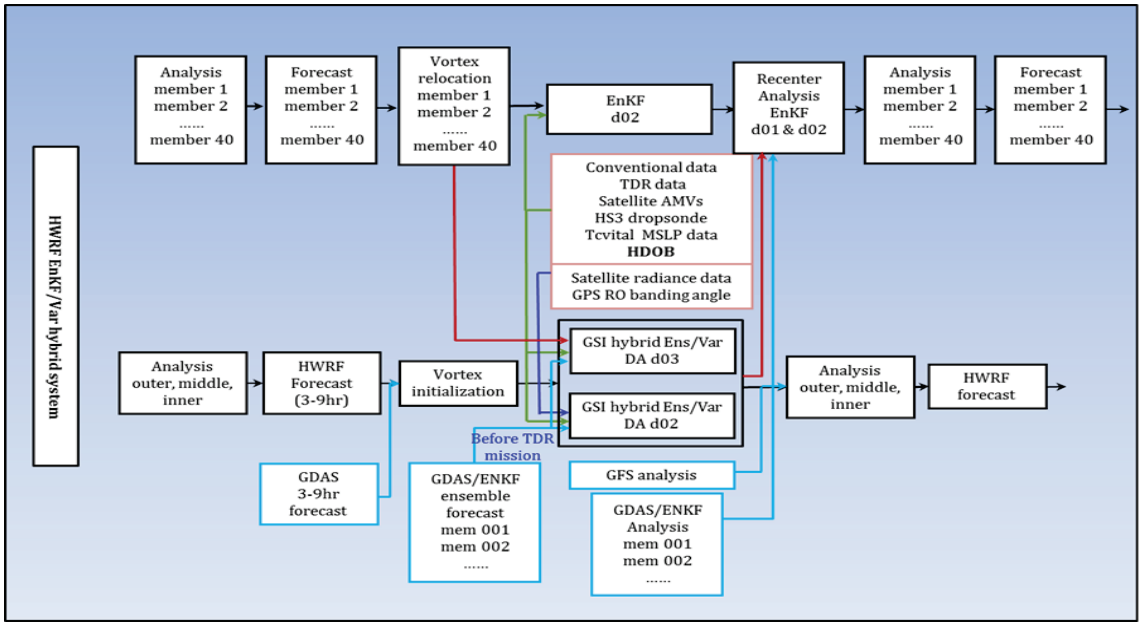
Low to moderate winds:
Using COARE algorithm
High winds:
Fitting to observed Cd

Emanuel's MPI theory:

$$V_{max}^2 \propto \frac{Ck}{Cd} \times \frac{Ts - To}{Ts} \times (k_0^* - k_a)$$

FY2017 HWRF DA Upgrades

- GSI code upgrades (align with EMC GSI)
- Increase the blending threshold of VI and GSI analysis (from 50 to 65 kt)
- New data to be assimilated and other data usage changes
  - HDOBS flight-level data
  - Hourly shortwave, clear air water vapor and visible AMVs from GOES
- Fully self-cycled EnKF ensemble hybrid DA system for TDR/priority storm



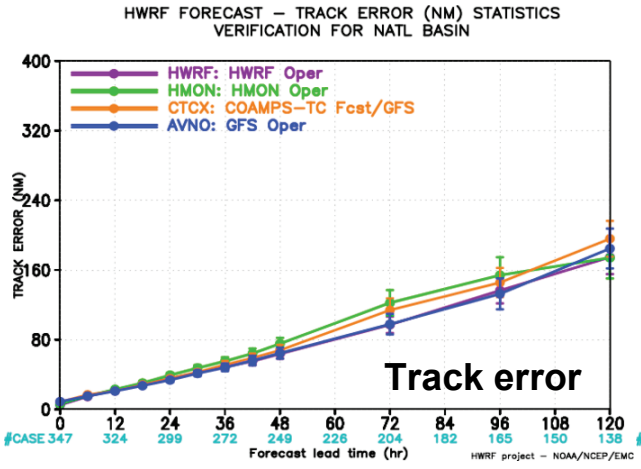
FY2017 HWRF Configurations for Different TC Basins

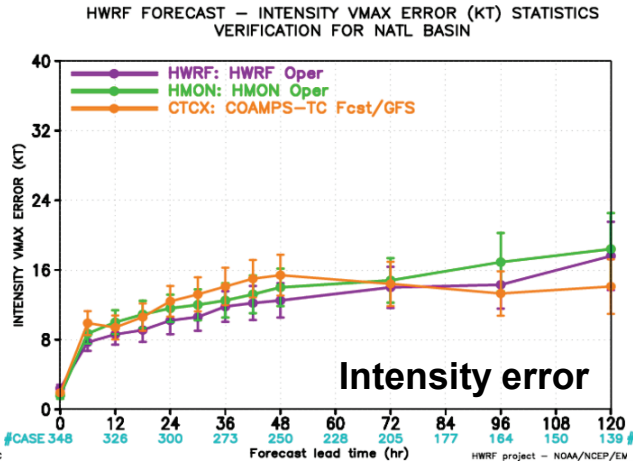
Basin	Ocean Coupling	Wave Coupling	DA	Ensemble DA	Vertical	Top
NATL	POM GDEM/GFSSST	WW3 1-way	Always	TDR/priority storm	75 level	10 mb
EPAC	POM RTOFS	WW3 1-way	Always	TDR/priority storm	75 level	10 mb
CPAC	POM RTOFS	WW3 1-way	None	None	75 level	10 mb
WPAC	HYCOM	None	None	None	61 level	10 mb
NIO	HYCOM	None	None	None	61 level	10 mb
SIO	None	None	None	None	43 level	50 mb
SPAC	None	None	None	None	43 level	50 mb

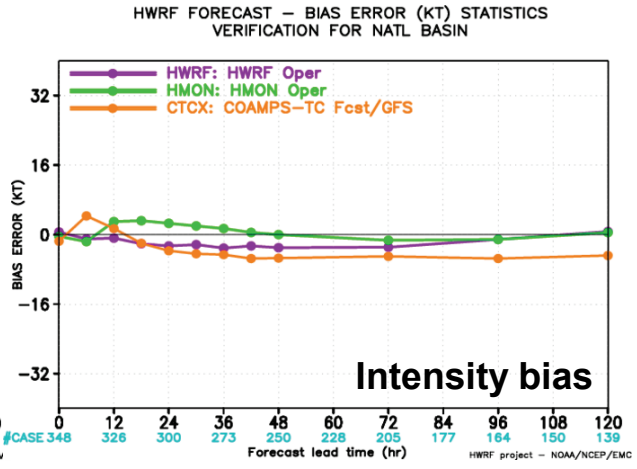
- EnKF self-cycled DA system for one TDR or priority storm
- 75 vertical levels with 10-hPa top for NATL/EPAC/CPAC
- 61 vertical levels with 10-hPa top for WPAC/NIO
- Enable ocean coupling for all NH basins (POM for NATL, EPAC and CPAC, HYCOM for WPAC and NIO)
- Utilize daily RTOFS (instead of GDEM climatology) data for POM initialization for CPAC basin
- One-way coupling to wave model for NATL, EPAC, and CPAC to replace the NCEP standard-alone hurricane wave model (multi_2)

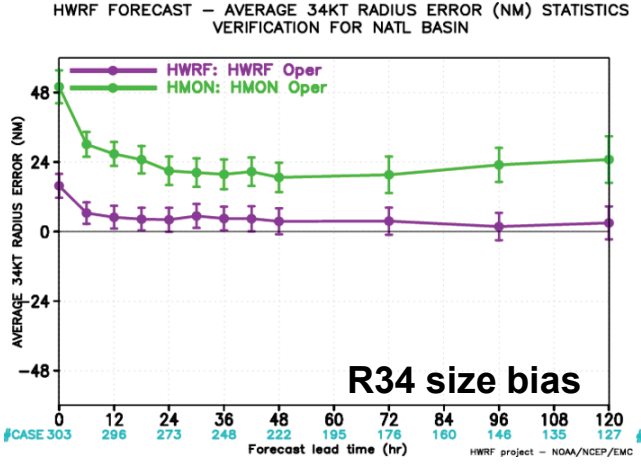
HWRF/HMON in the 2017 North Atlantic Basin

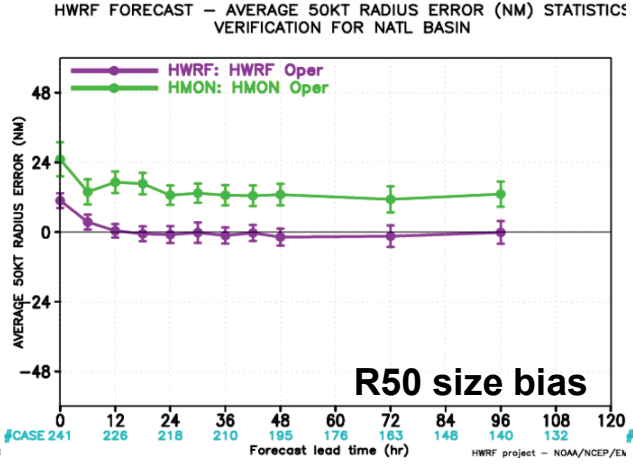
Real-Time Performance (Late Guidance)

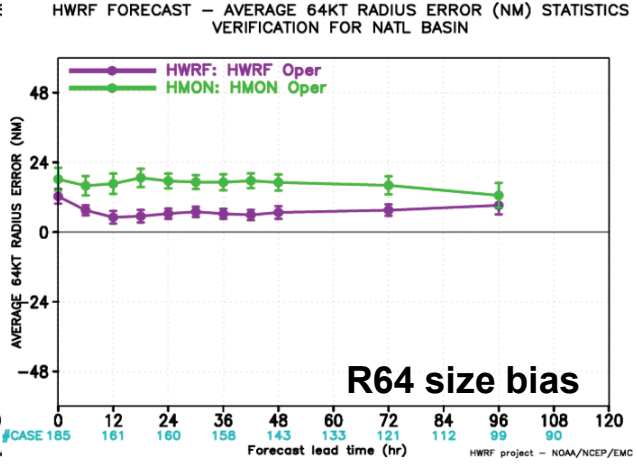






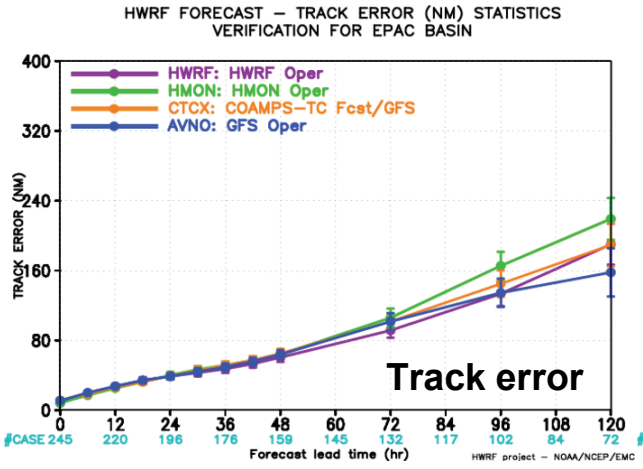


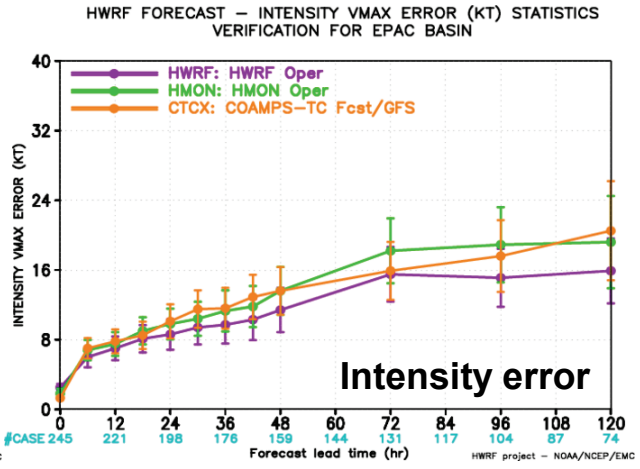


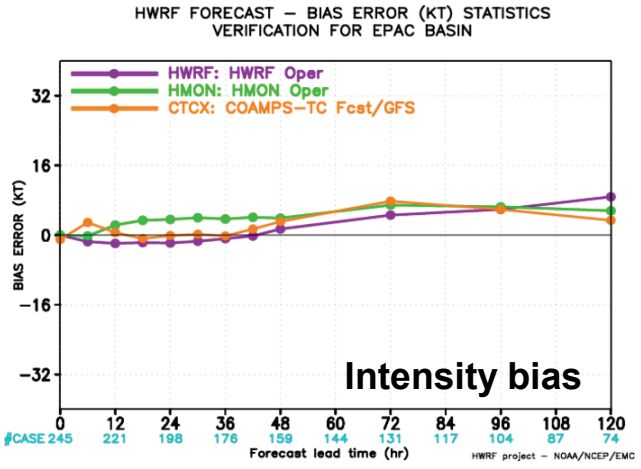


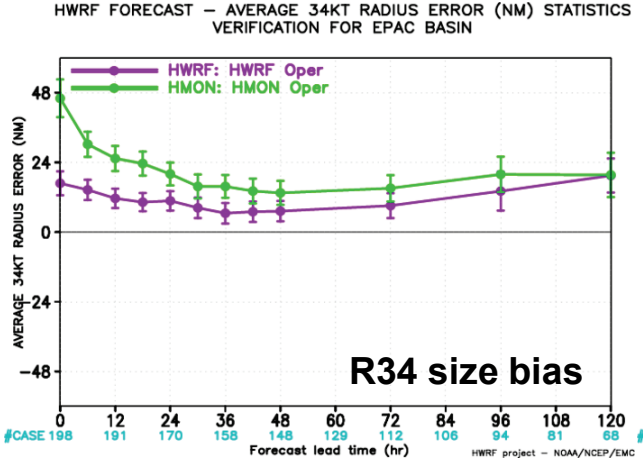
HWRF/HMON in the 2017 Eastern Pacific Basin

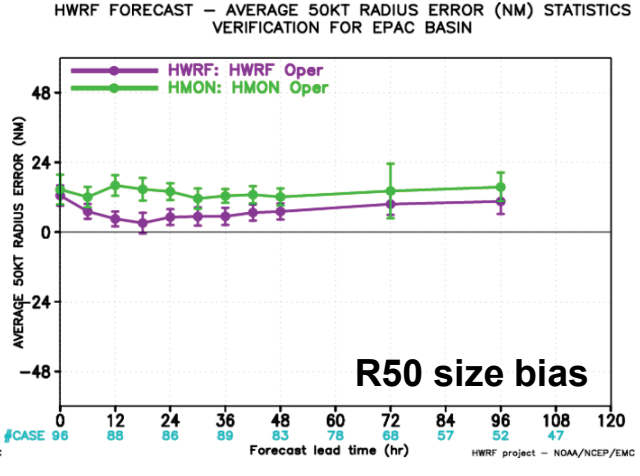
Real-Time Performance (Late Guidance)

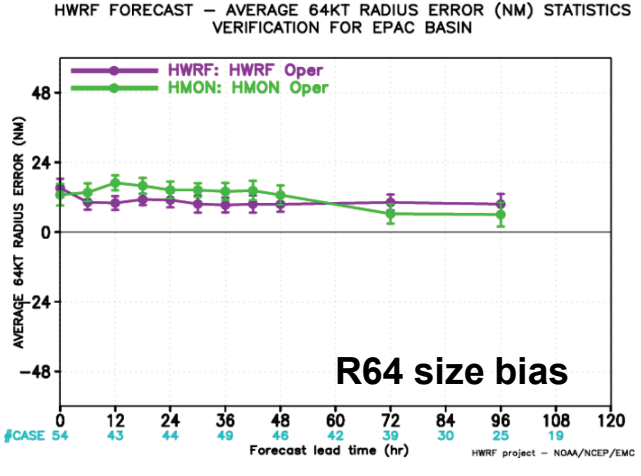






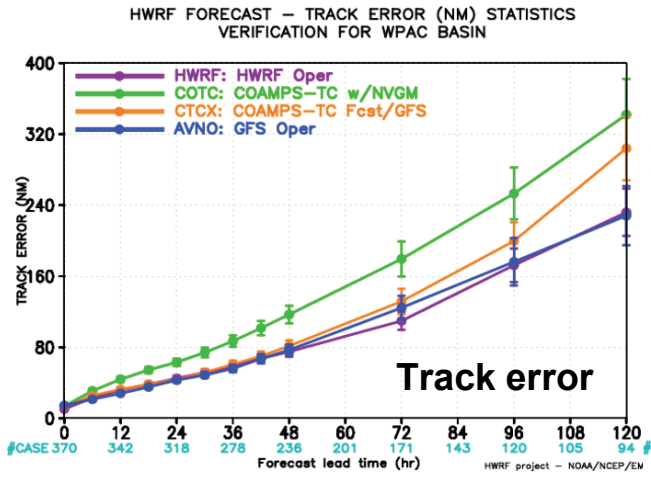


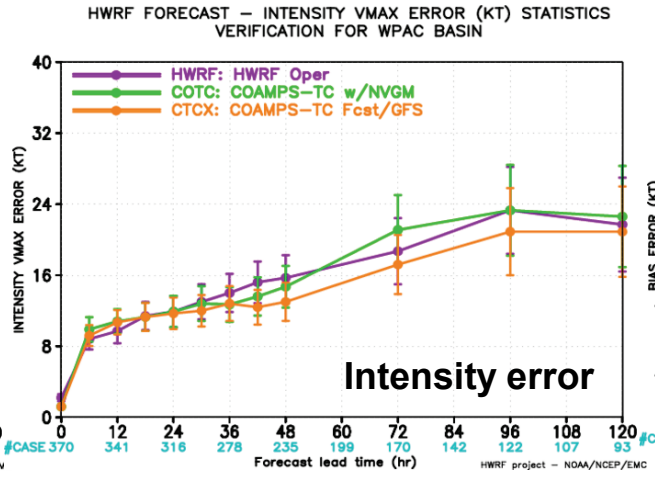


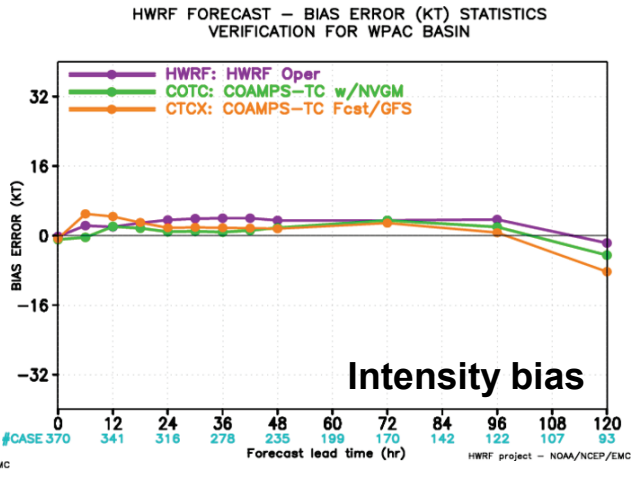


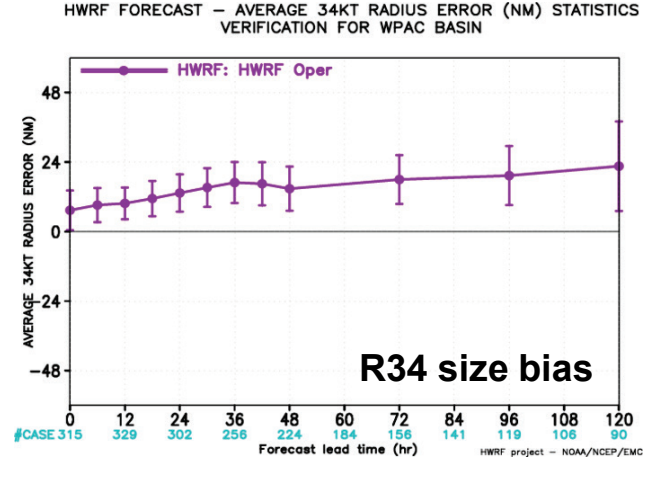
HWRF in the 2017 Western Pacific Basin

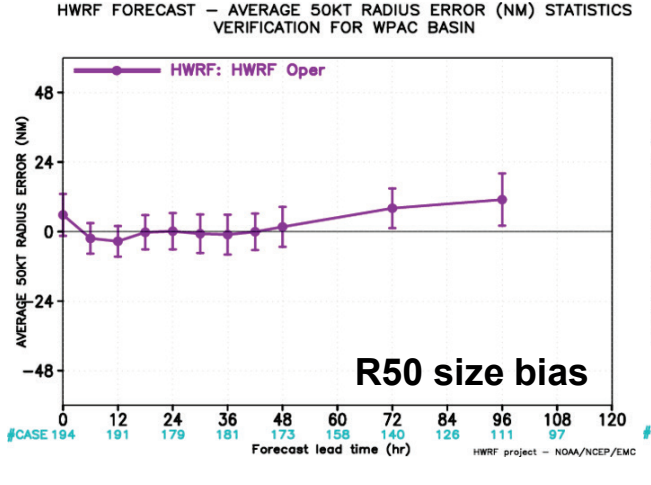
Real-Time Performance (Late Guidance)

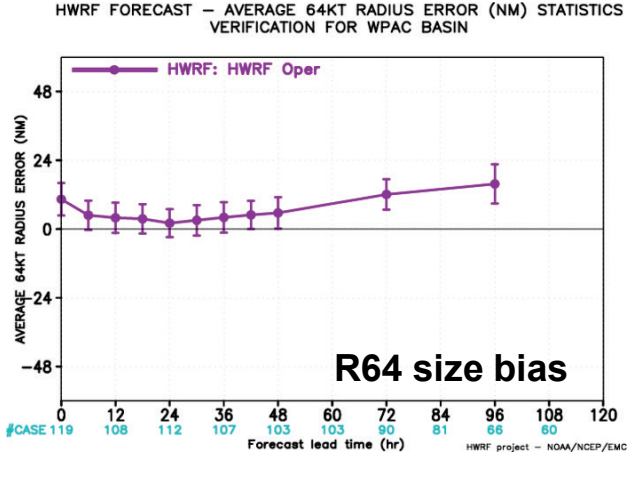








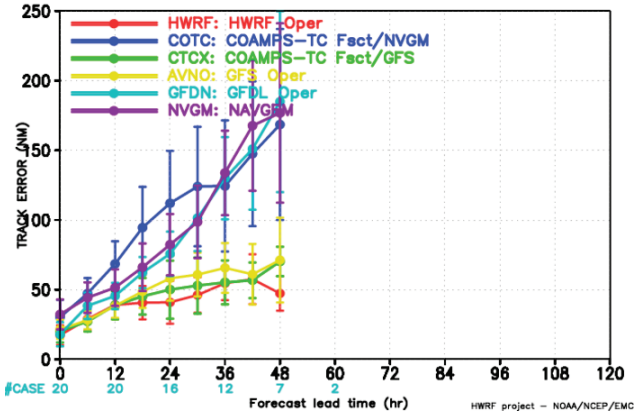


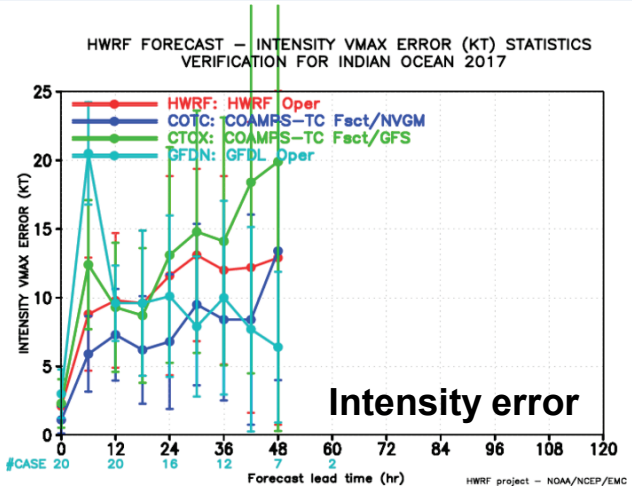


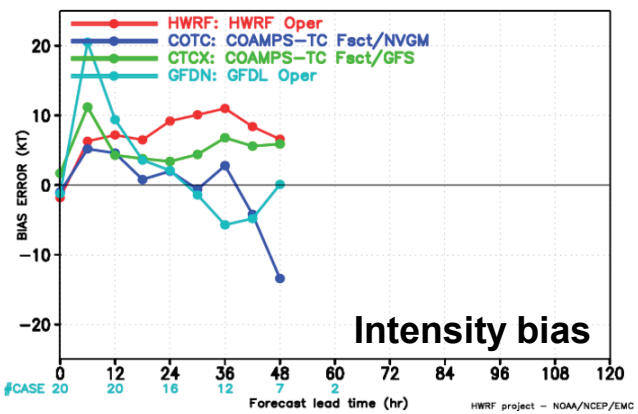
HWRF in the 2017 NIO and SH Basins

Real-Time Performance (Late Guidance)

NIO







SH