Hurricane WRF: 2017 Operational Implementation and Community Support

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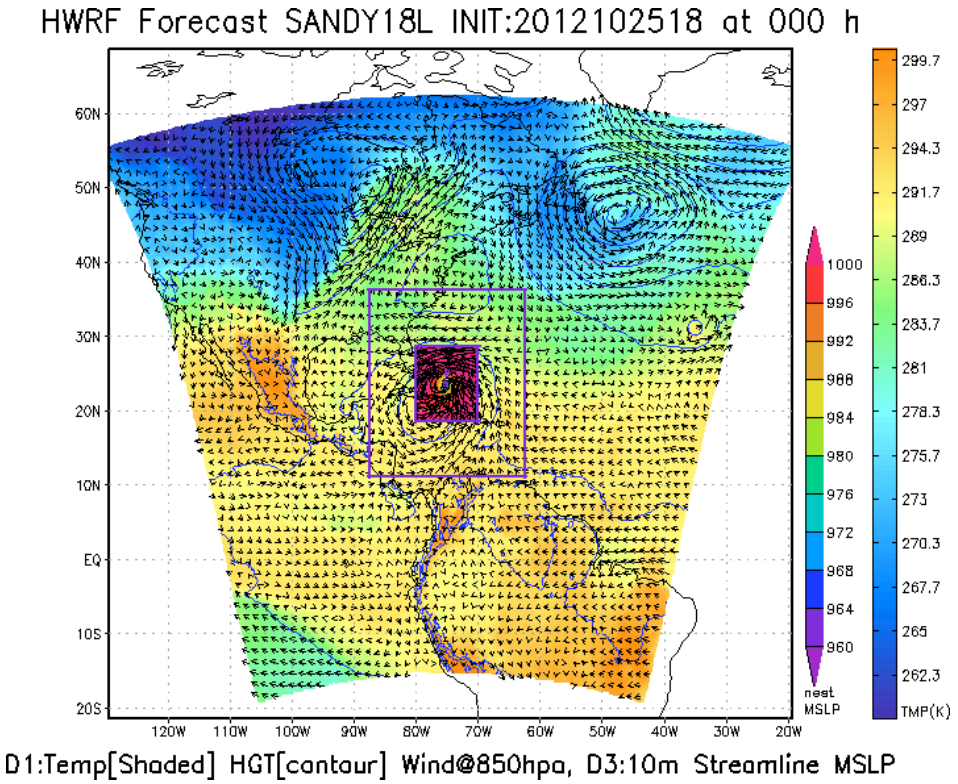
18th WRF Users Workshop, June 12-16, 2017

HWRF Overview

- HWRF is the NCEP operational hurricane model providing model guidance to NHC/JTWC/ CPHC for tropical cyclones (TCs) in all global basins
- HWRF is an air-sea coupled system specialized for hurricane forecasting
  - HWRF-POM(HYCOM)-WW3
- Built within WRF infrastructure and based on WRF-NMM dynamic core
  - Rotated lat-lon projection
  - Arakawa E-grid
  - Hybrid sigma-pressure vertical coordinate
  - Triple nested vortex following domains

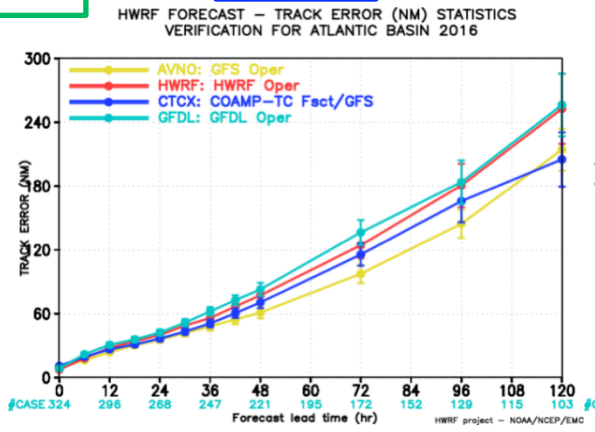


Triple nested (18-6-2km) vortex following domains

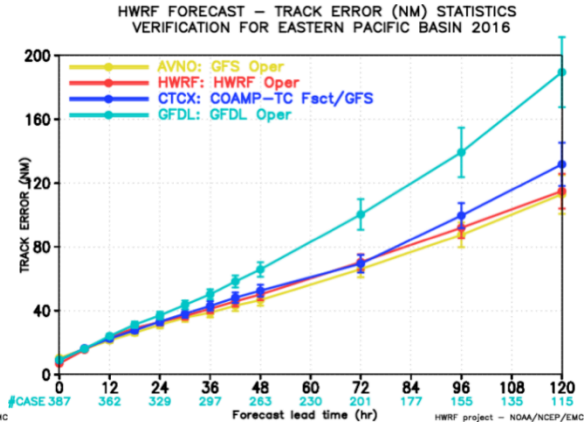
FY2016 HWRF Real-Time Forecast Performance

Track

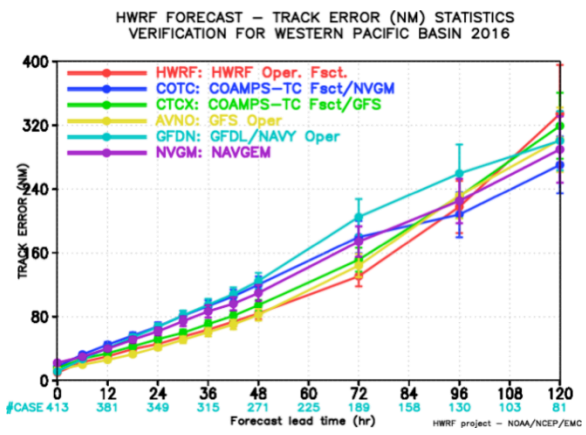
NATL



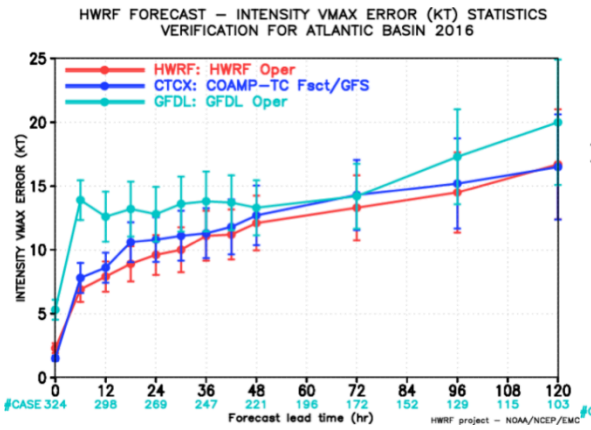
EPAC

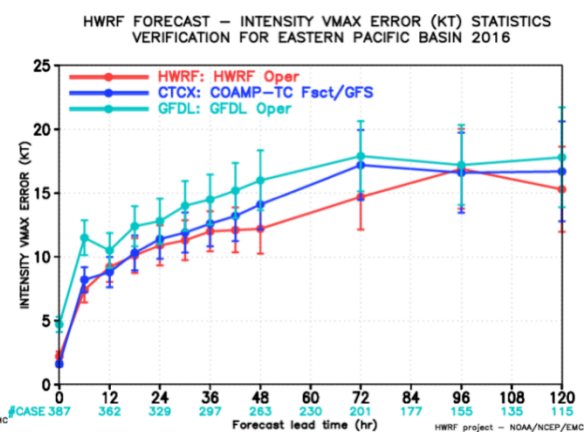


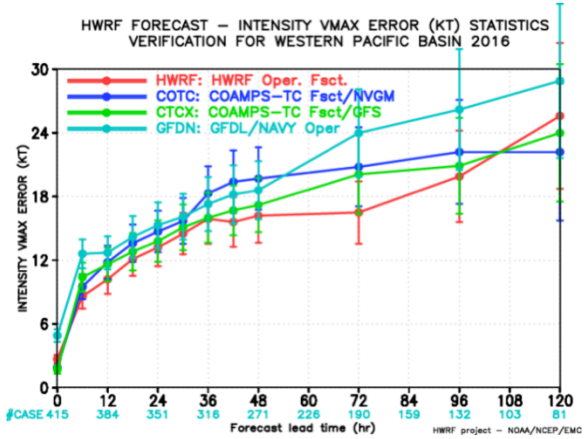
WPAC



Intensity





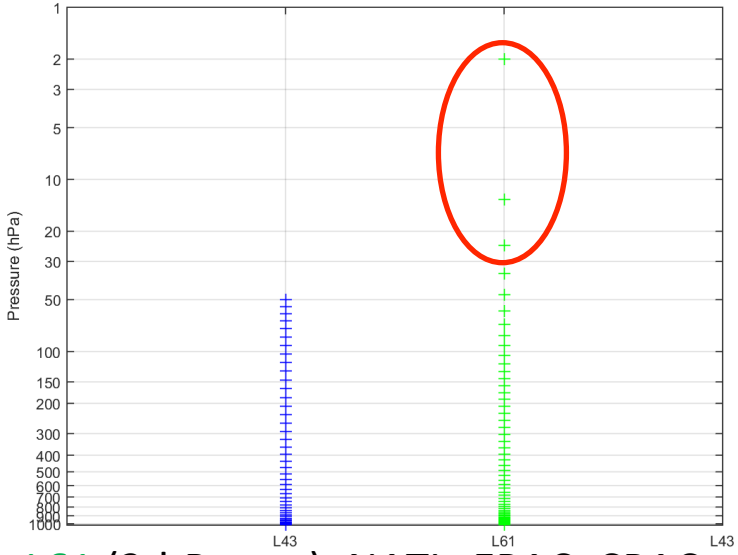


HWRF continues to be the best operational dynamic guidance model for hurricane intensity forecasting

Highlights of 2017 HWRF Upgrades

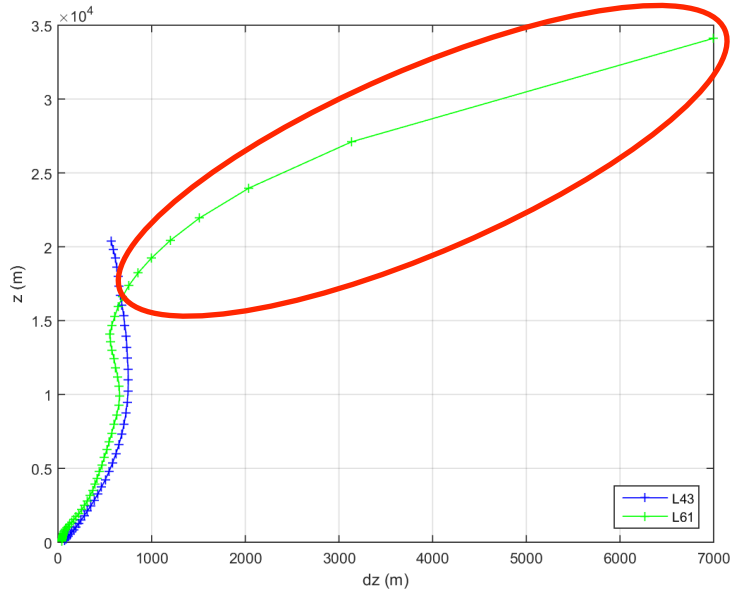
- Infrastructure Enhancements
  - Upgrade dynamic core from WRF3.7.1a to WRF3.8.1 (with bug fixes)
  - T&E with new 2017 4D-Hybrid GDAS/GFS IC/BC
  - Consider storm's meridional movement when determining parent domain center
  - Increase vertical levels to L75 with model top of 10hPa (H216: L61, 2hPa model top)
  - Reduce nested domain size: d02 (265x532), d03 (235 x 472) (H216: 288 x 576)
  - Updated GFDL vortex tracker
- Vortex Initialization/Data Assimilation Improvements
  - Improve vortex initialization (new composite storm vortex)
  - GSI code upgrades together with new data sets for DA (hourly shortwave, clear air water vapor and visible AMV's from GOES, HDOBS flight level data)
  - Fully self-cycled HWRF ensemble hybrid DA for TDR and priority storms
  - Increase the blending threshold of vortex initialization (VI) and GSI analysis (from 50 to 65 kt)
- Physics Advancements
  - Updated scale-aware SAS scheme and Ferrier-Aligo microphysics scheme
  - Updated air-sea momentum and enthalpy exchange coefficients
  - Partial cloudiness modification for RRTMG
- Air-Sea Interaction and Coupling
  - POM RTOFS initialization for CPAC, HYCOM ocean coupling for WPAC, NIO
  - Reduced coupling time step from 9 min to 6 min
  - Increased vertical level for POM from 24 to 41 levels
  - Hurricane sea surface wave forecasts for CPAC, in addition to NATL and EPAC
  - Sea surface wave boundary condition from global wave model

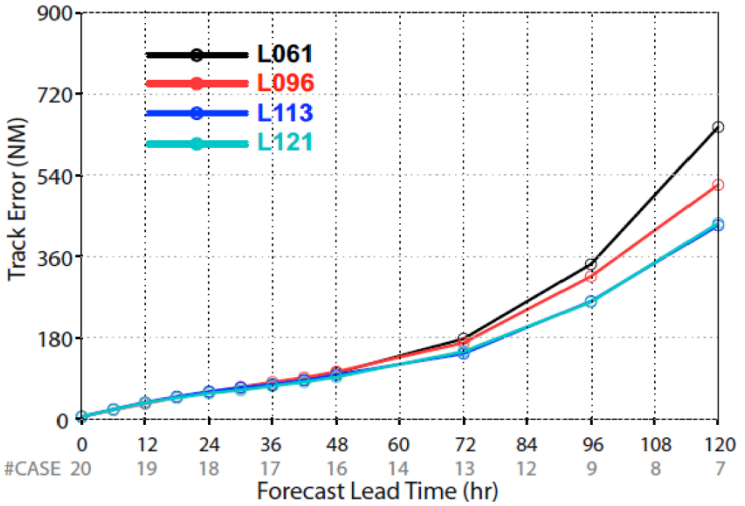
Hurricane Forecast and Model Vertical Resolution



L61 (2-hPa top): NATL, EPAC, CPAC

L43 (50-hPa top): other basins



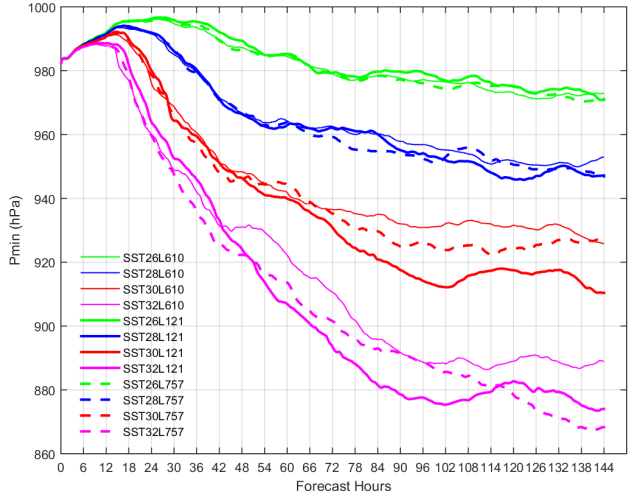


Zhang et al. (2016) showed that the track forecasts of Hurricane Joaquin (2015) were greatly improved by using more vertical levels

Thin line: L61

Thick line: L121

Dashed: L75



26 degC

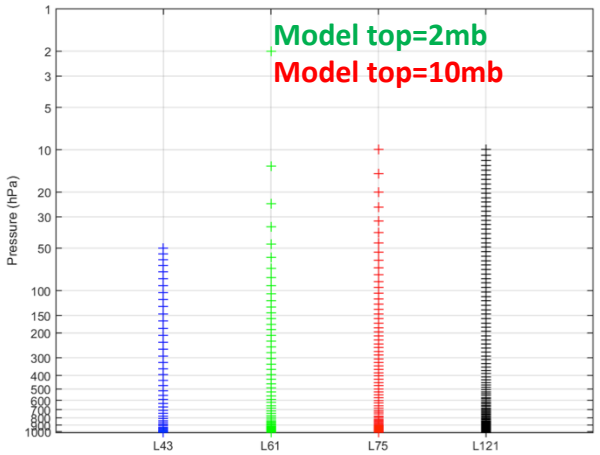
28 degC

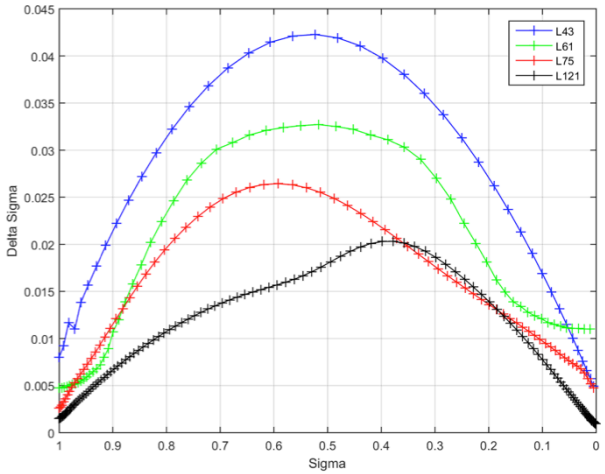
30 degC

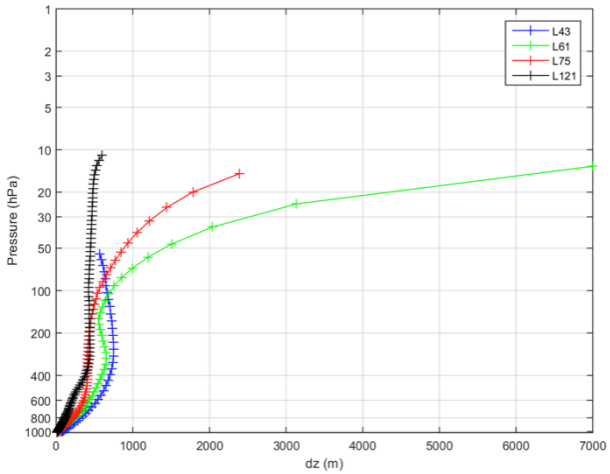
32 degC

Idealized HWRF TC simulations with different vertical levels and different SSTs

Increased Vertical Resolution and Adjusted Nested Domain Sizes

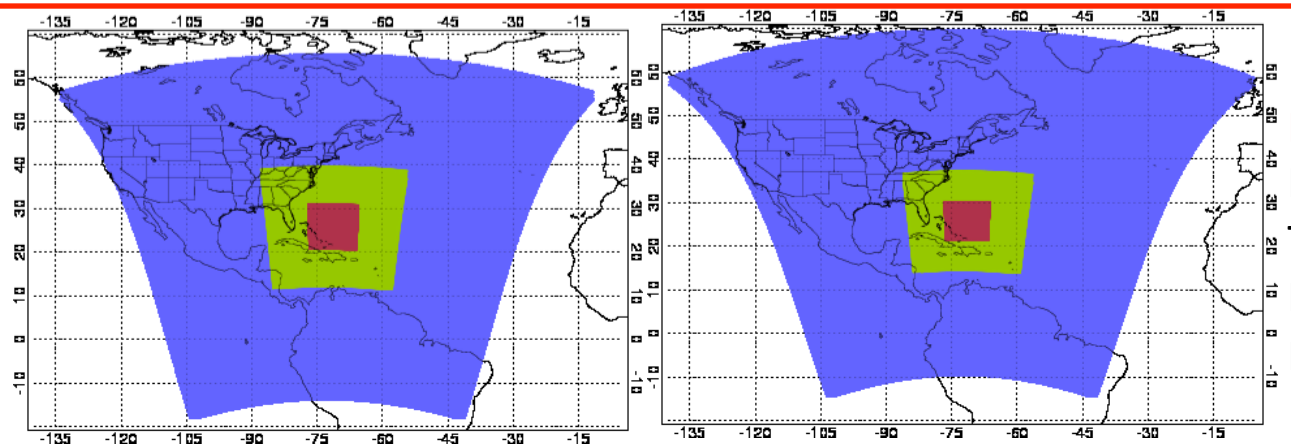






Increase from 61 to 75 vertical levels with model top changing from 2 hPa to 10 hPa and adjusted nested domain sizes

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)

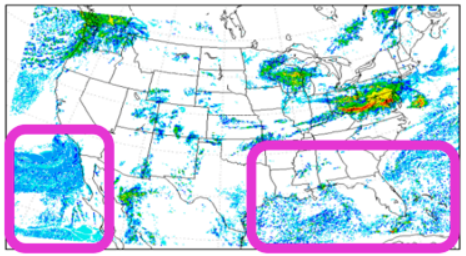
High reflectivity bias at anvil

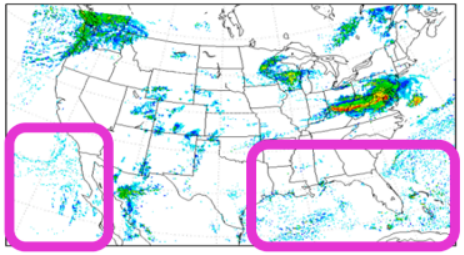
Increased largest possible number concentration of snow

Lack of stratiform precipitation

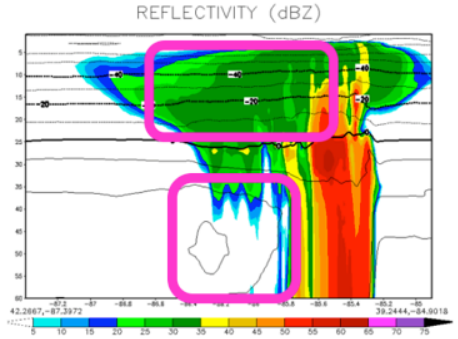
Constant rain drop size during rain evaporation (reduces evaporation)

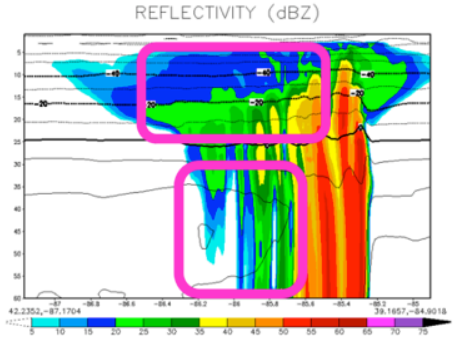
Old | New





12Z 23 June 2016





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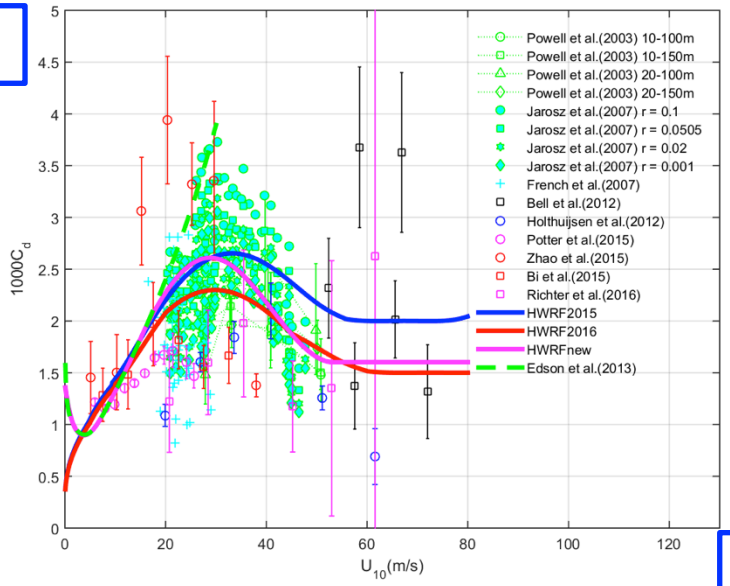
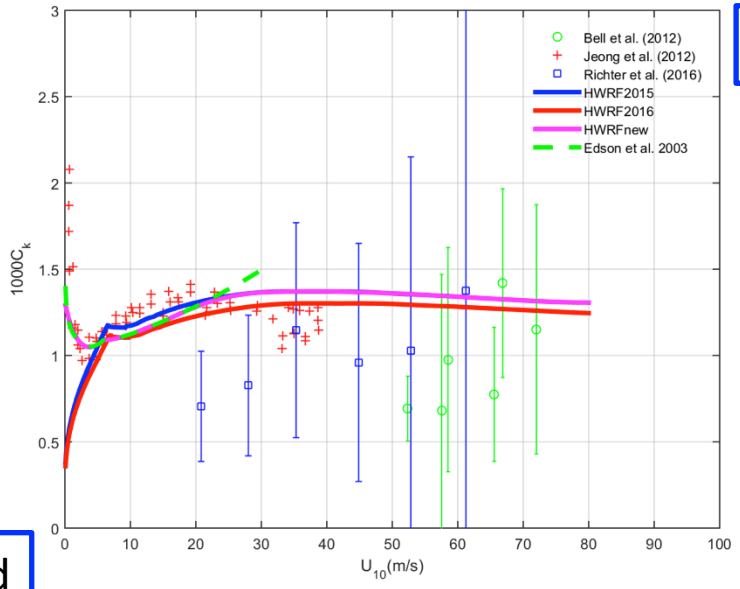
Update to the latest microphysics scheme used in the 2017 NCEP NAM model

Adjustments of Air-Sea Exchange Coefficients

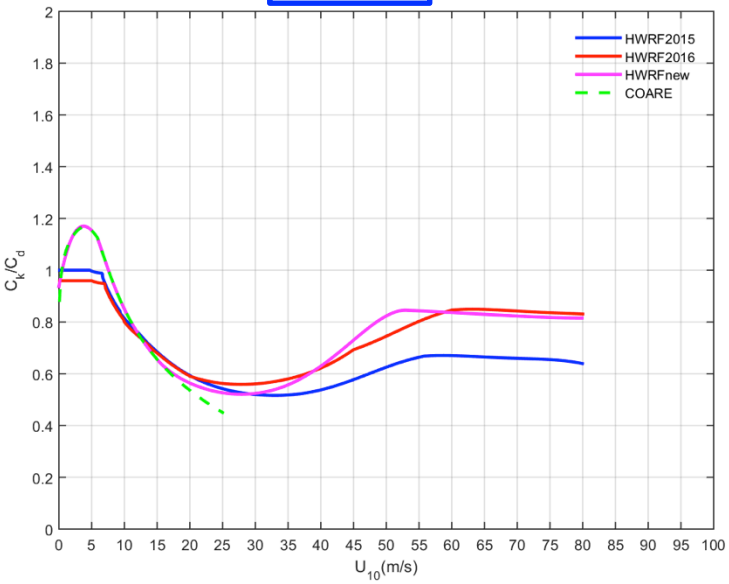
Cd



Ck



Ck/Cd



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

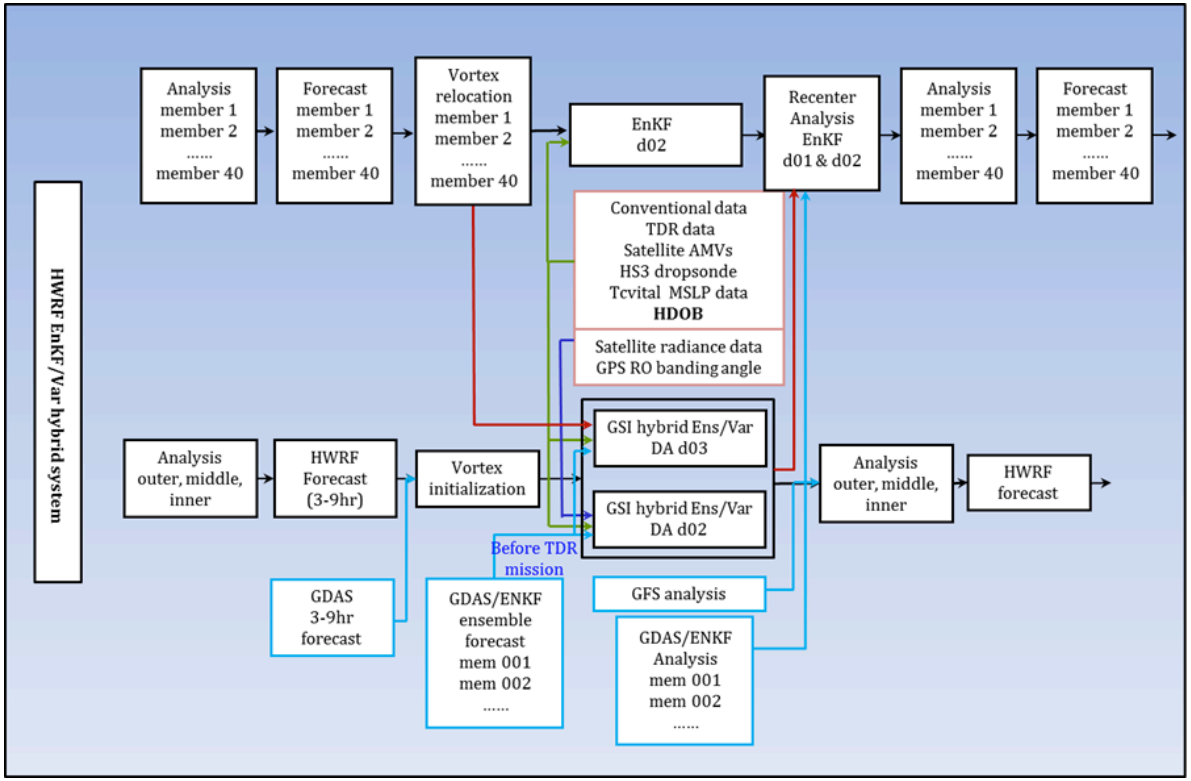
Low to moderate winds:
Using COARE algorithm
High winds:
Fitting to observed Cd

Emanuel's MPI theory:

$$V\downarrow max\uparrow 2 \propto Ck/Cd \times Ts-To/Ts \times (k\downarrow 0\uparrow * - k\downarrow a)$$

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
  - HDOB flight-level data
  - Hourly shortwave, clear air water vapor and visible AMVs from GOES
  - Flag Global Hawk dropsonde u/v observations in the inner-core area
- Fully self-cycled EnKF ensemble hybrid DA system for TDR/priority storm

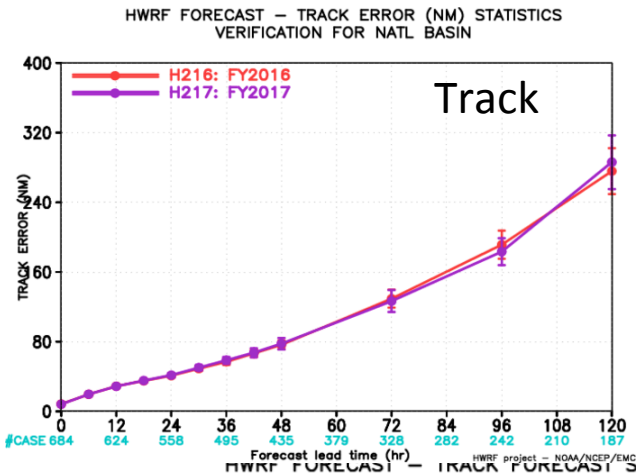


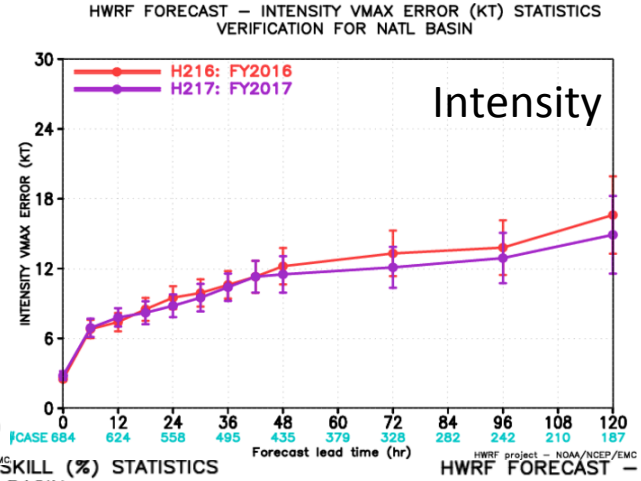
FY2017 HWRF Configurations for Different TC Basins

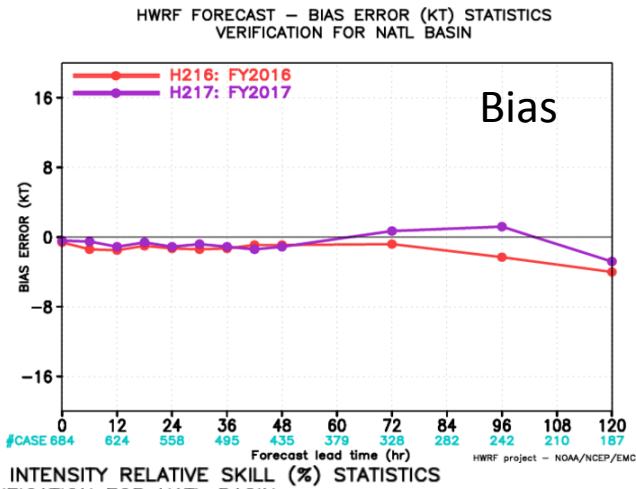
Basin	Ocean Cpling	Wave Cpling	Data Assimilation	Ensemble DA	Vertical	Top
NATL	POM GDEM/ GFSSST	WW3 1-way	Always	TDR/priority storm	75 level	10 mb
EPAC	POM RTOFS	WW3 1-way	Always	TDR/priority storm	75 level	10 mb
CPAC	POM RTOFS	WW3 1-way	None	None	75 level	10 mb
WPAC	HYCOM	None	None	None	61 level	10 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

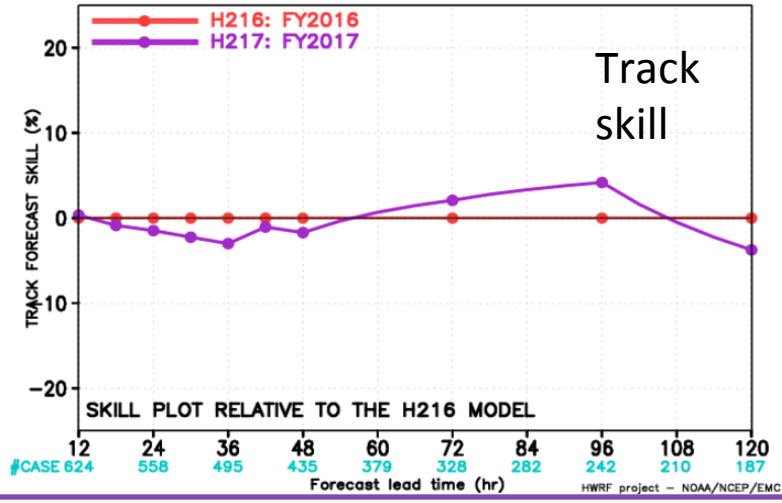
- EnKF self-cycled DA system for one TDR or priority storm
- 75 vertical levels with 10-hPa top for NATL/EPAC/CPAC
- 61 vertical levels with 10-hPa top for WPAC/NIO
- Enable ocean coupling for all NH basins (POM for NATL, EPAC and CPAC, HYCOM for WPAC and NIO)
- Utilize daily RTOFS (instead of GDEM climatology) 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)

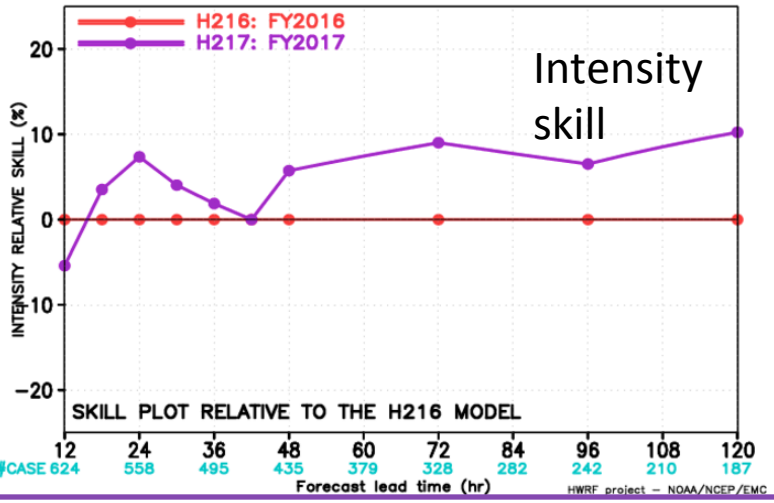
Evaluation of 2017 HWRF for NATL (2014-2016 storms)





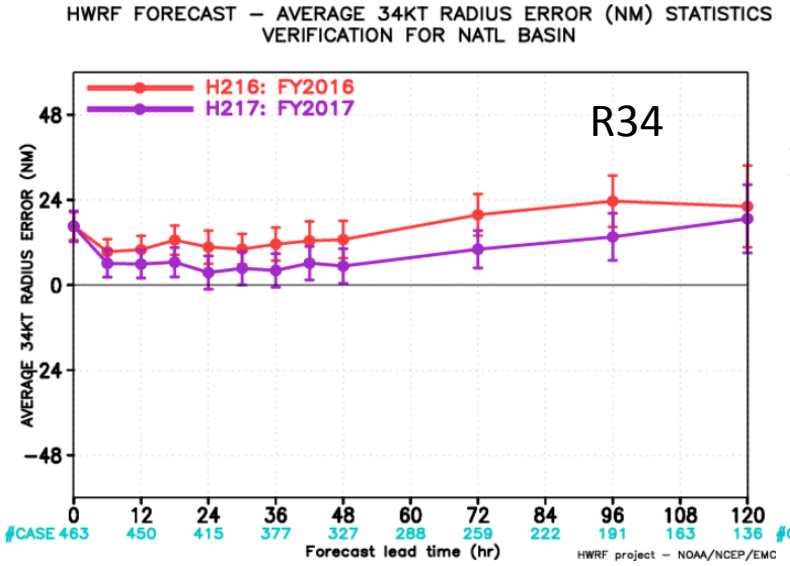


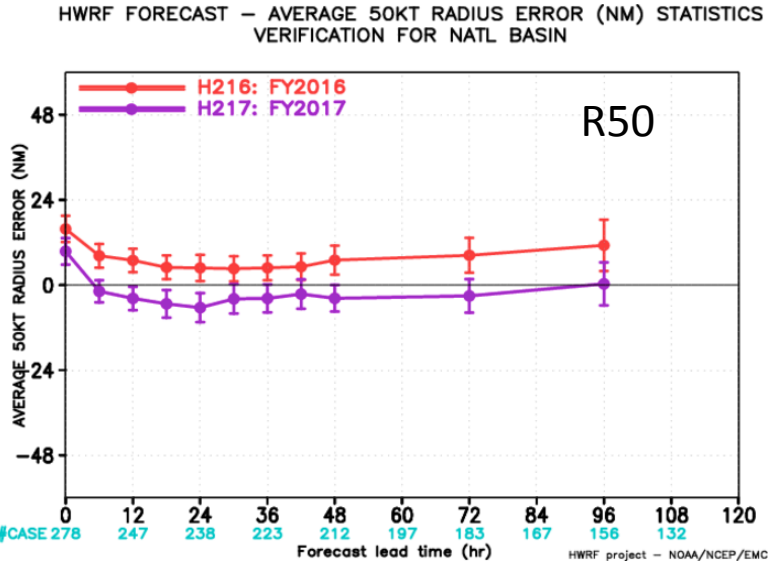


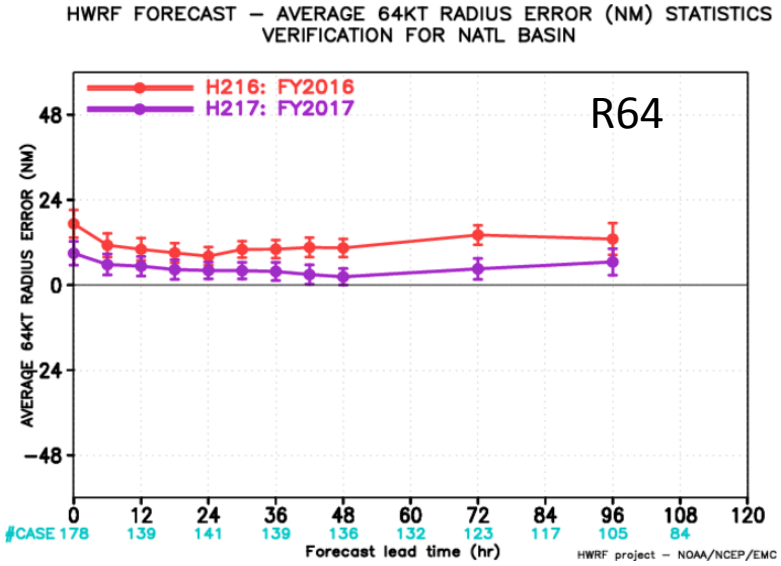


- Track forecast: Mostly neutral with improvement for lead times from 60-108 hr
- Intensity forecast: Improved at almost all lead times, around 10% at days 3-5
- Intensity bias: Lower bias compared with H216

Evaluation of 2017 HWRF for NATL (Storm size errors)



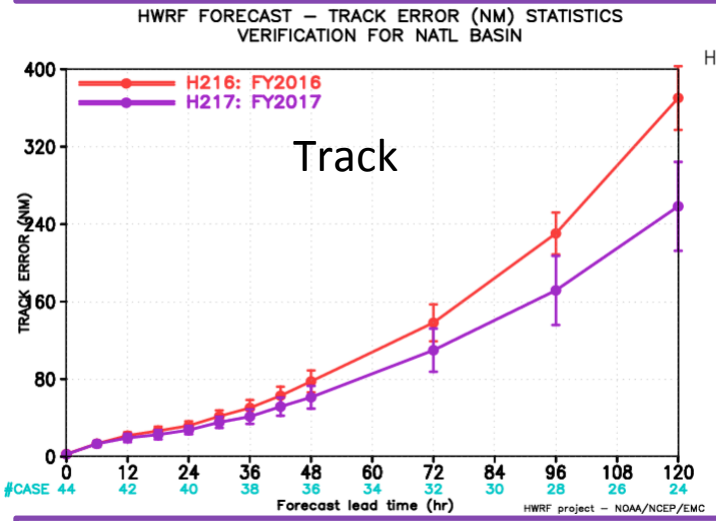


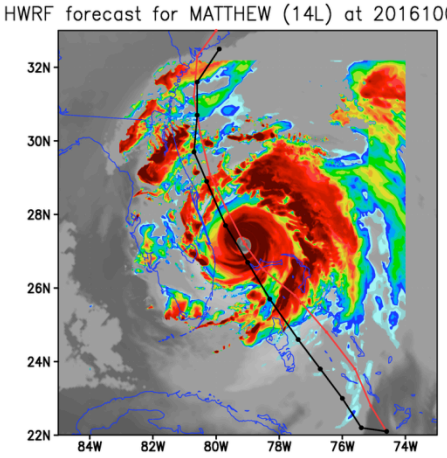


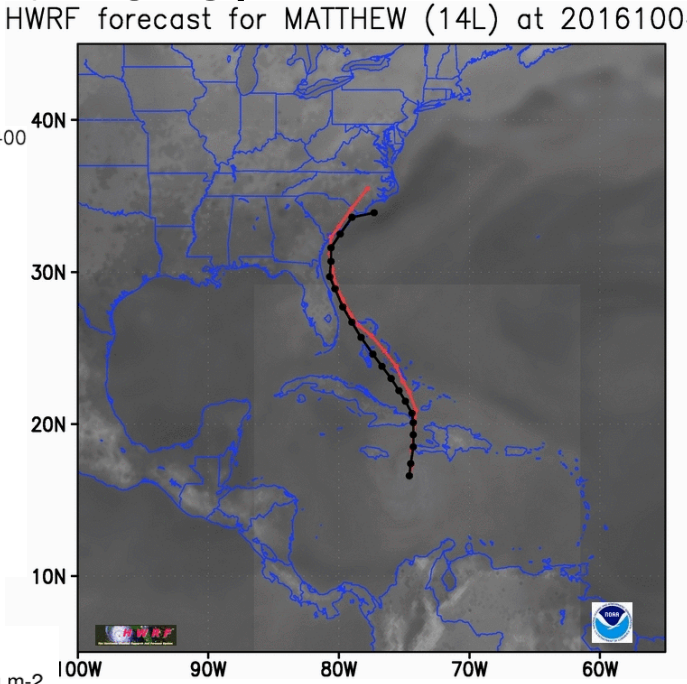
Storm size errors were significantly reduced in H217 for all lead times and for all radii (r34, 50 and 64 kts).

Evaluation of 2017 HWRF for NATL (Hurricane Matthew 14L2016)

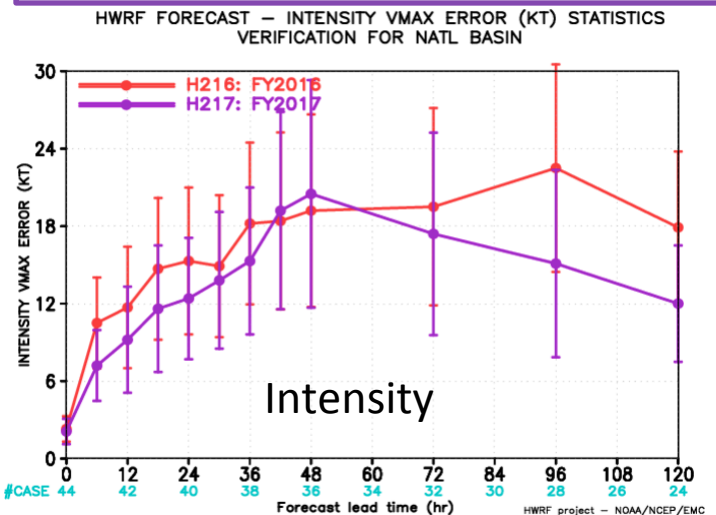
Significantly improved track forecast

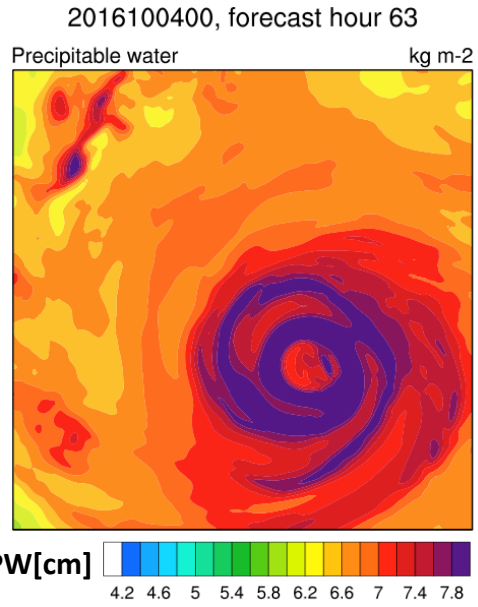


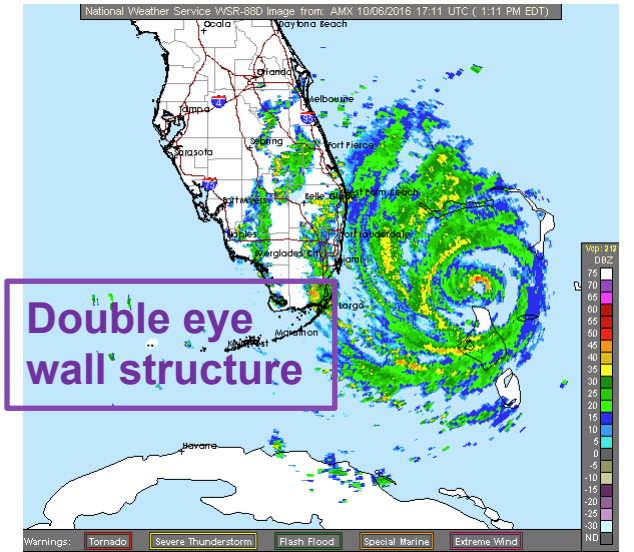




Substantially reduced intensity errors except at day 2

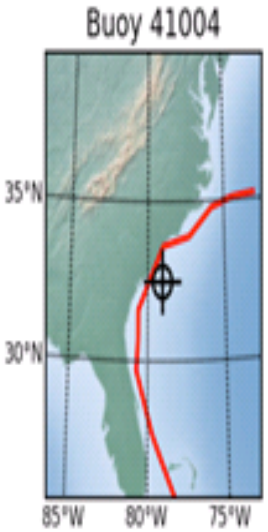






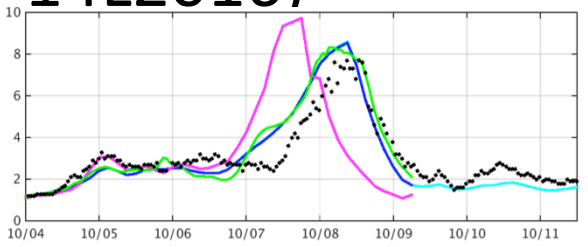
2017 HWRF WW3 Forecast

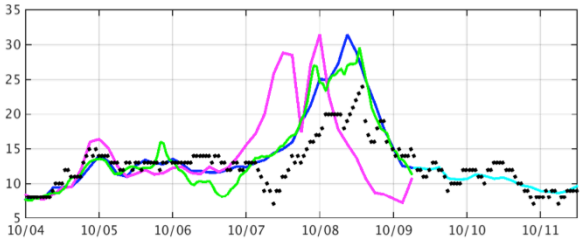
(Hurricane Matthew 14L2016)

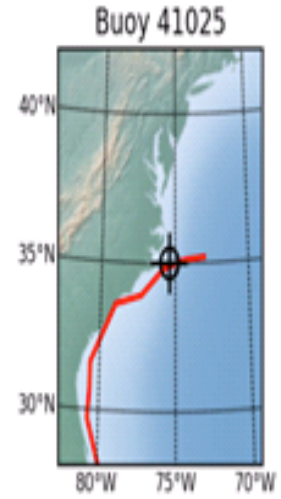


multi_1
multi_2
H216
H217
buoy

2016-10-04
00z

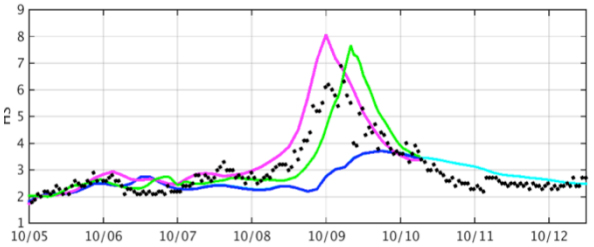


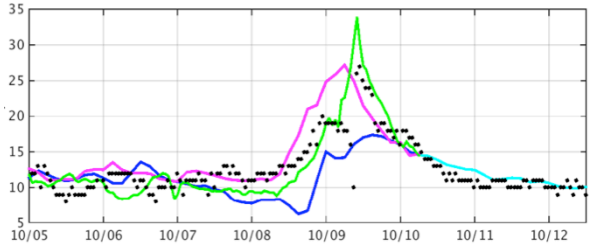




multi_1
multi_2
H216
H217
buoy

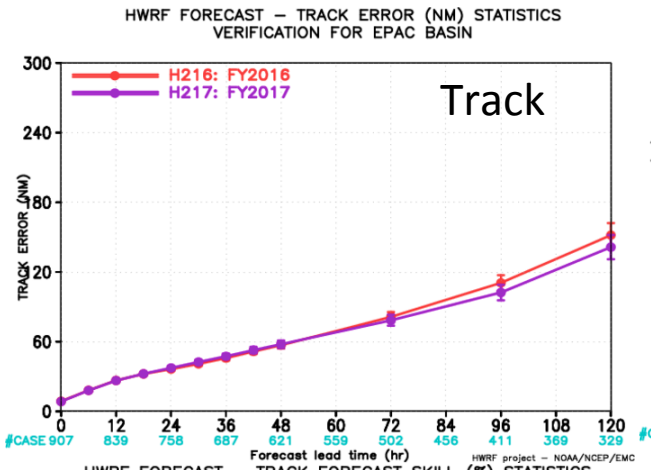
2016-10-05
00z

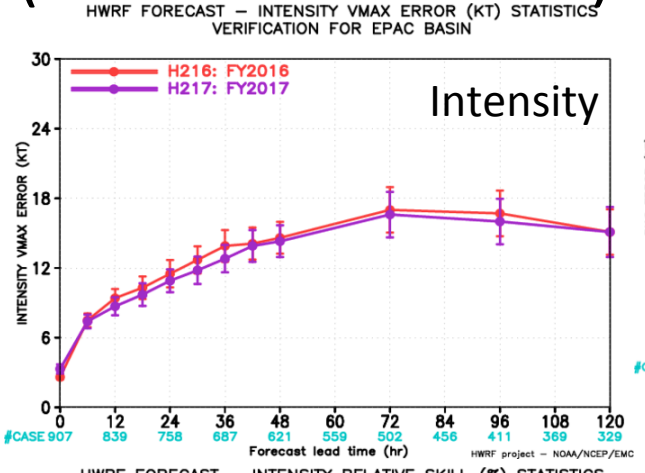


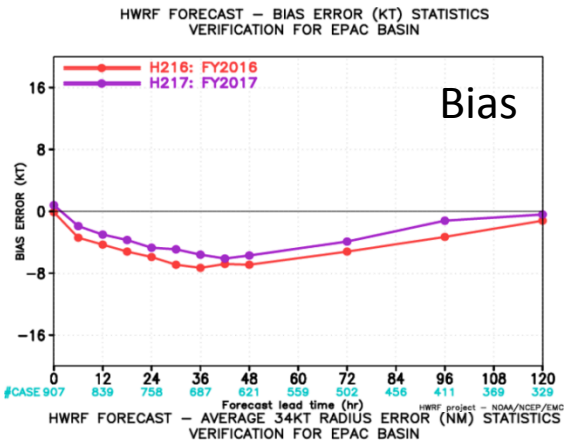


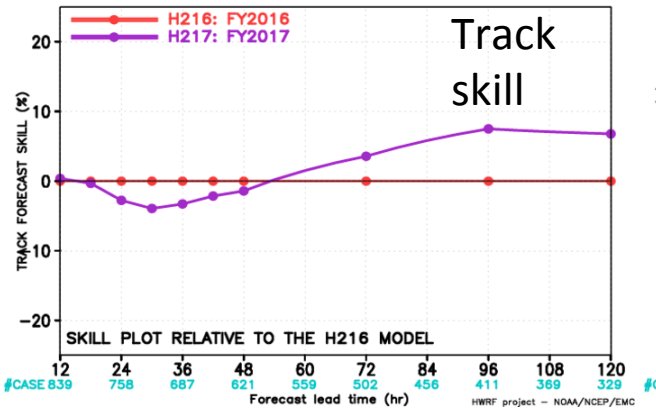
The NCEP hurricane wave model (multi_2) will be discontinued in NCEP operations with FY2017 HWRF upgrade

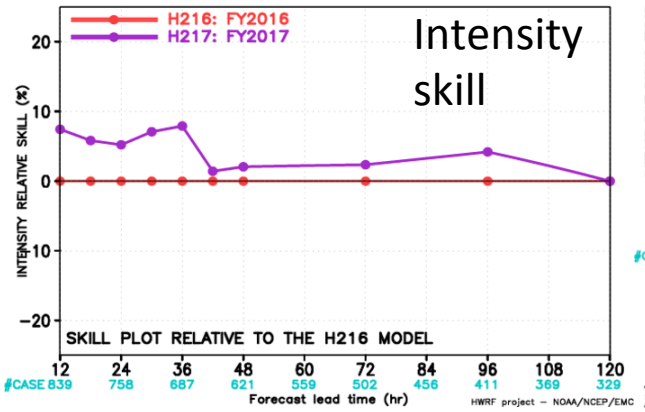
Evaluation of 2017 HWRF for EPAC (2014-2016 storms)

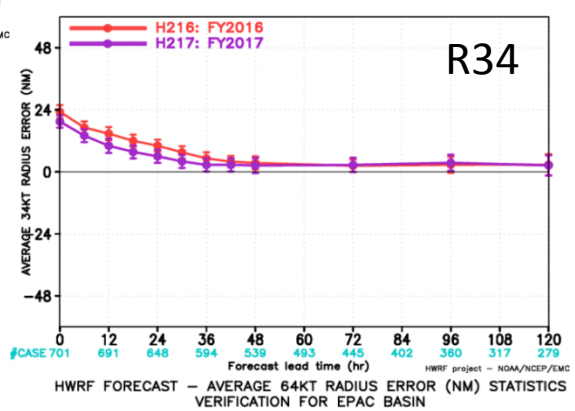


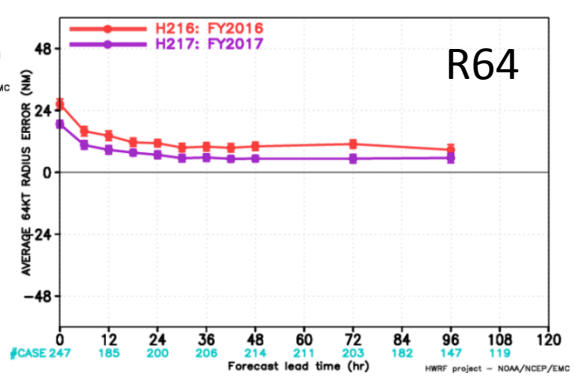






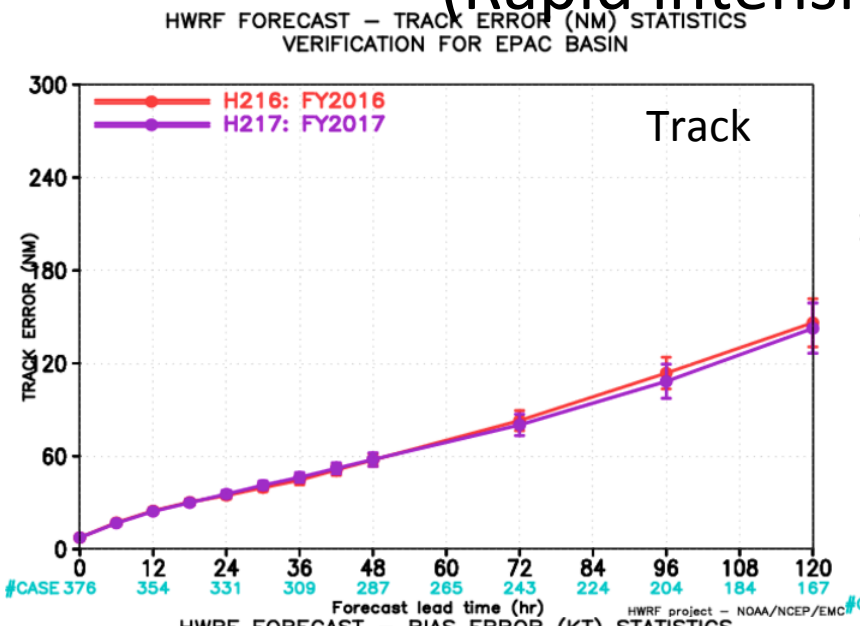


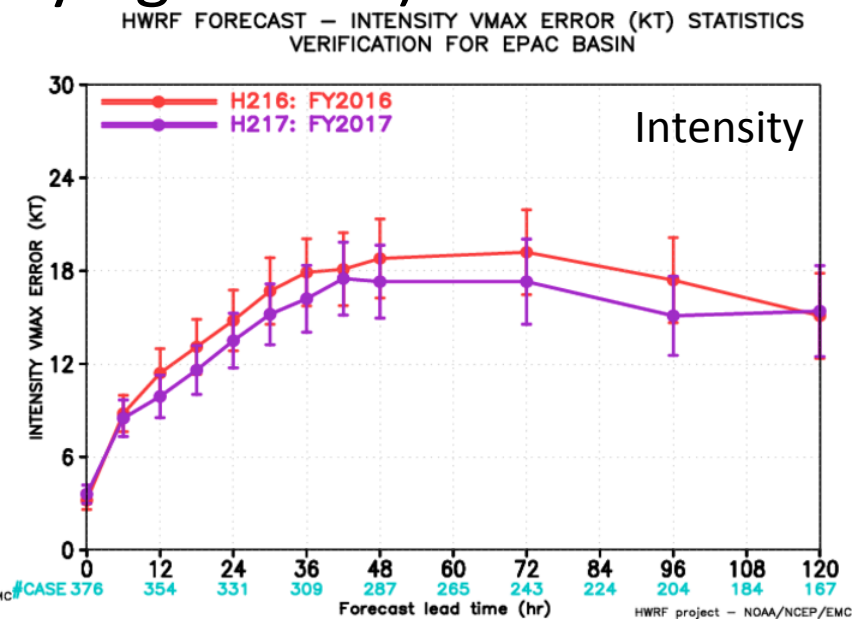


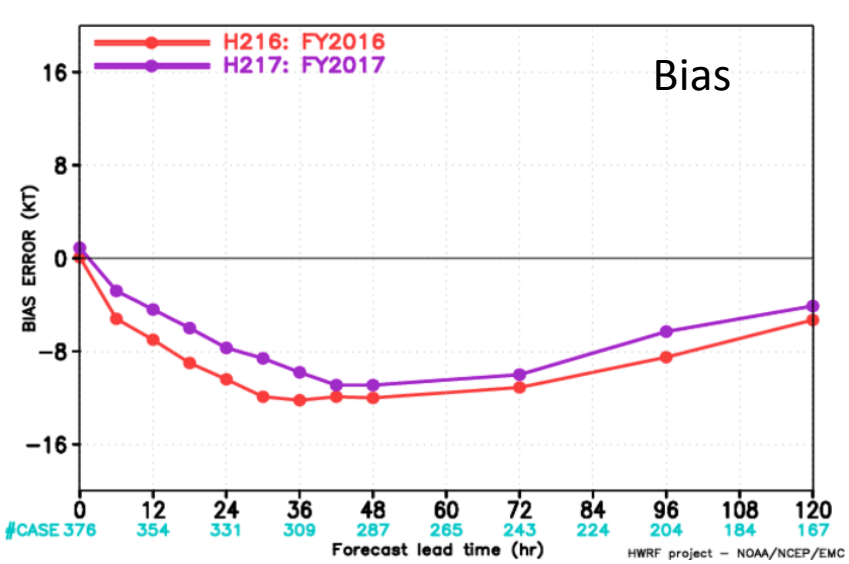


- Improved track for lead times after day 2
- Improved intensity at almost all lead times
- Smaller bias compared with H216
- Better storm size forecast

Evaluation of 2017 HWRF for EPAC (Rapid intensifying storms)

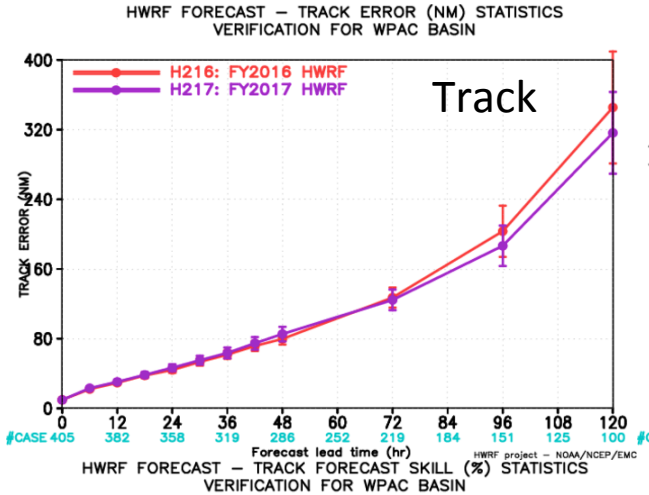


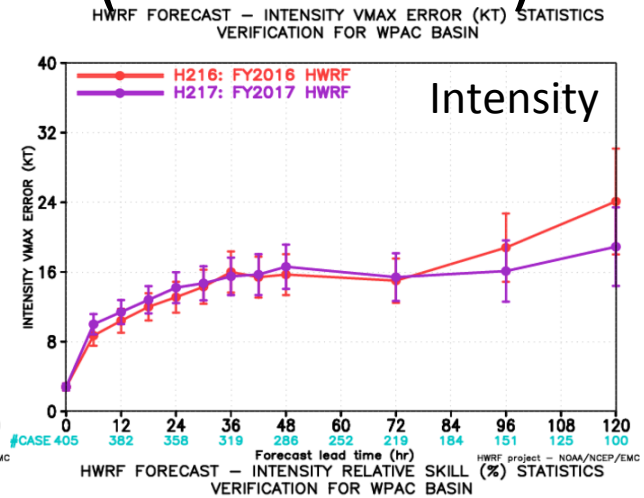


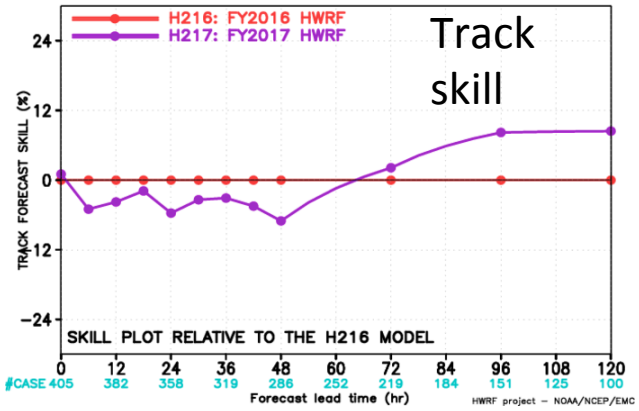


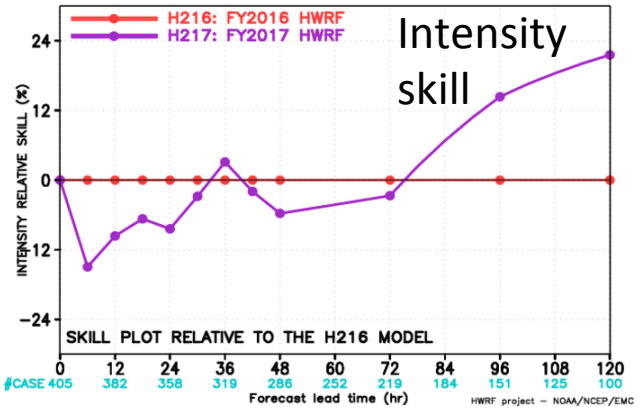
- Track errors show improvement for at lead times of days 4 and 5
- Intensity and bias errors show improvement at almost all lead times

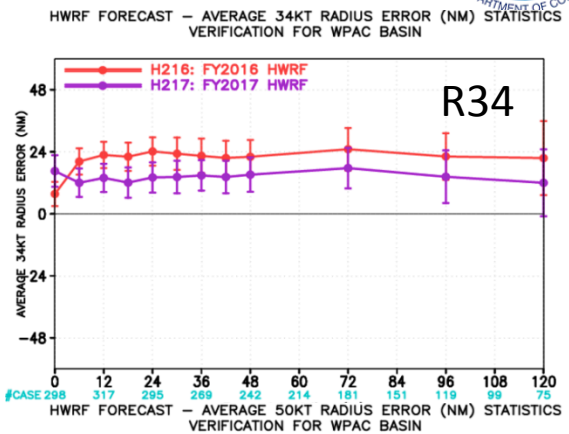
Evaluation of 2017 HWRF for WPAC (02-25W2016)

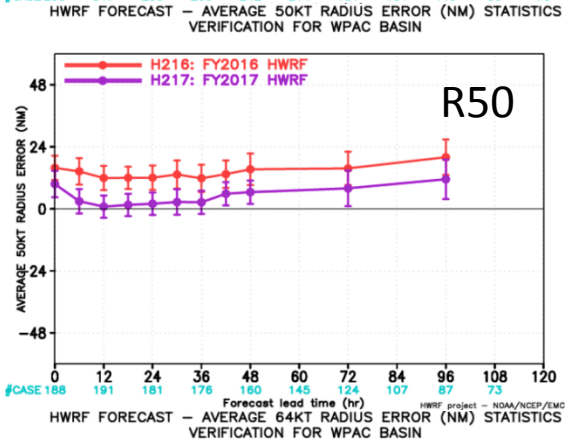


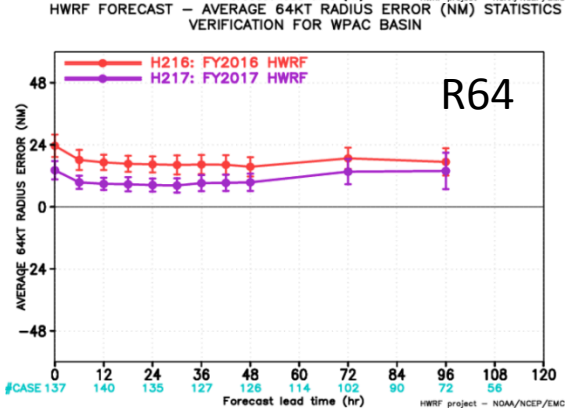












- Improved track and intensity forecasts for longer lead times after day 3
- Significantly improved storm size for all lead times

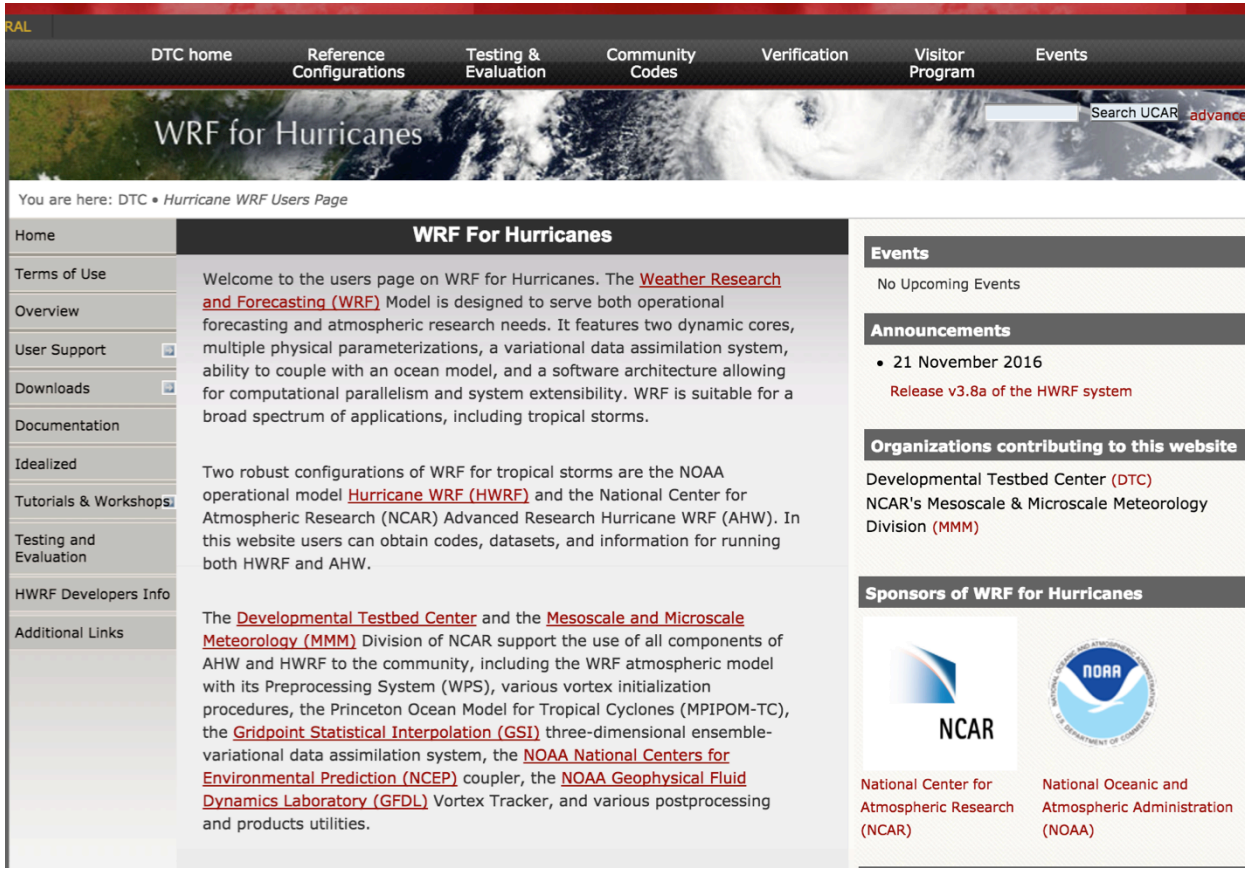
Successful R2O in 2017 HWRF Upgrades

- **EMC/NCEP**: Model physics upgrades including scale-aware SAS scheme, Ferrier-Aligo microphysics scheme, adjustment of air-sea exchange coefficients; framework upgrades including vertical resolution change, etc. ; GSI upgrades; HYCOM ocean coupling; and pre-implementation T&E
- **DTC:** Community support including code management; partial cloudiness modification of RRTMG scheme; and testing candidate physics schemes
- **HRD/AOML:** Knowledge sharing for framework and physics upgrades; triggers for self-cycled EnKF DA for TDR/priority storms
- **FIU:** Candidate PBL scheme modification
- **URI**: RTOFS initialization for CPAC basin; increasing vertical levels for POM
- **OU:** Self-cycled EnKF GSI upgrade
- **GFDL:** Vortex tracker upgrade
- **NHC/CPHC/JTWC/NWS-PR**: Diagnostics and evaluation of the HWRF pre-implementation tests and real-time guidance

This upgrade is a result of multi-agency R2O efforts

Developmental Testbed Center Support

www.dtcenter.org/HurrWRF/users



Yearly releases, code downloads, datasets, documentation, online tutorial, helpdesk

1300+ registered users

Stable, tested code

Benchmarks available

Support to HWRF developers in code management

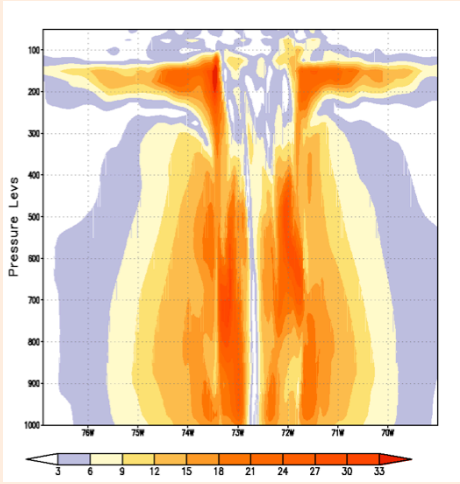
Current release: HWRF v3.8a (2016 operational) November 2016
Next release: HWRF v3.9a (2017 operational) August/September 2017

Developmental Testbed Center

HWRF community code

HWRF public release

- End-to-end atmosphere-ocean coupled HWRF system corresponding to operational model of the year
  - Freely available and fully supported
- Additional research capabilities
  - Idealized tropical cyclone
  - 27/9/3 km domain configuration
  - Reduced d02/d03 grid sizes
  - Alternate physics schemes
  - Alternate configurations (i.e.: DA, ocean, input datasets)



HWRF developer support

DTC provides specialized support for HWRF developers using repository code

Streamlines transition of new developments to the HWRF model

DTC visitor program

The DTC is interested in engaging with the community about new developments that could be evaluated for HWRF

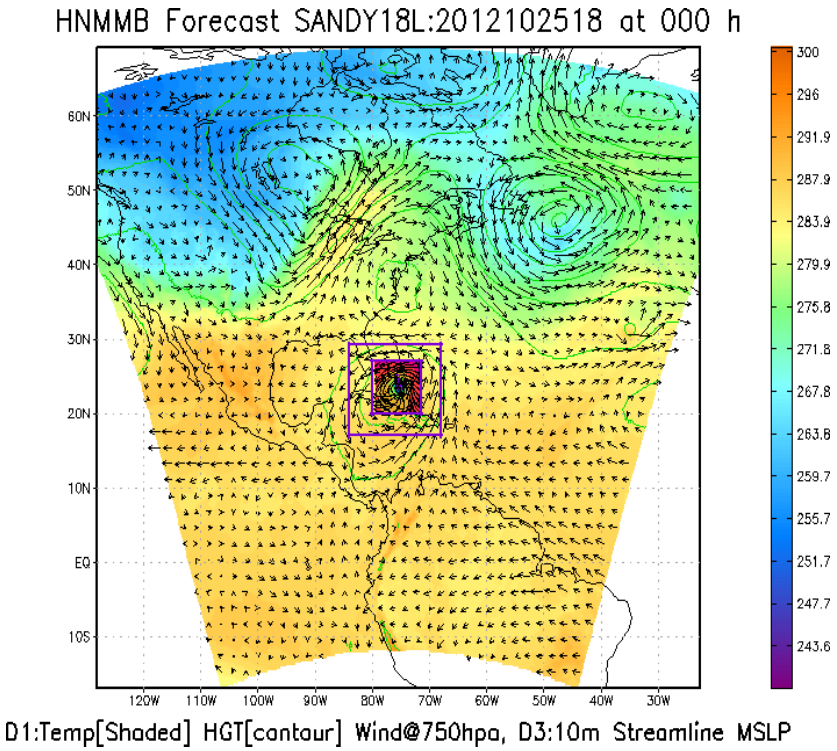
http://www.dtcenter.org/visitors/

Summary of FY2017 HWRF Upgrades

- Highlights of FY2017 HWRF upgrades include:
  - Increased vertical levels to L75 with model top of 10hPa
  - Improved vortex initialization with new composite storm vortex
  - DA upgrades and fully self-cycled EnKF hybrid DA for TDR and priority storms
  - Physics advancements including updated Ferrier-Aligo microphysics and scale-aware SAS schemes, partial cloudiness modification for RRTMG, and updated air-sea momentum and enthalpy exchange coefficients
- FY2017 HWRF retrospective implementation tests (total 684 verifiable cycles in NATL, 907 in EPAC, 405 in WPAC) demonstrated that (comparing to FY2016 HWRF):
  - Neutral to modest (< 5%) improvement for track forecast for NATL and EPAC
  - 5-10% improvement for intensity forecast for NATL and EPAC
  - Substantial reduction in intensity errors and biases for storms undergoing RI
  - Significant improvements for storm size errors for both basins at all lead times
- POM RTOFS initialization for CPAC and HYCOM ocean coupling for WPAC and NIO
- One-way coupling to WW3 for NATL, EPAC and CPAC basins with wave BC from global wave model, to replace the phase-out NCEP multi_2 hurricane wave model

HMON: **H**urricanes in a **M**ulti-scale **O**cean coupled **N**on-hydrostatic model

- HMON is **a new operational hurricane model at NCEP**. It implements a long-term strategy at NCEP/EMC for multiple static and moving nests globally, and coupled to other (ocean, wave, sea ice, surge, inundation, etc.) models using NEMS infrastructure.
  - Advanced Hurricane Model using NMMB dynamic core which is currently being used in NCEP's operational NAM and SREF systems
  - Shared infrastructure with unified model development in NEMS. A step closer towards NEMS/FV3 Unified Modeling System for hurricanes
  - Provides high-resolution intensity forecast guidance to NHC along with HWRF (replacing the legacy GFDL hurricane model)



Triple nested (18-6-2km) vortex following domains

Development supported by NGGPS, HFIP and HIWPP programs

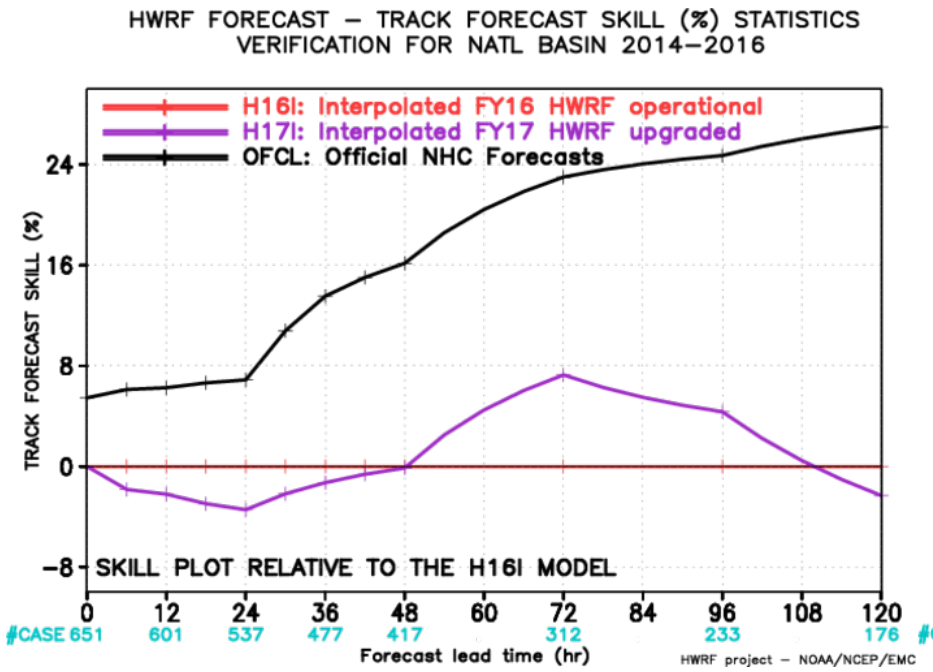
Thank you!

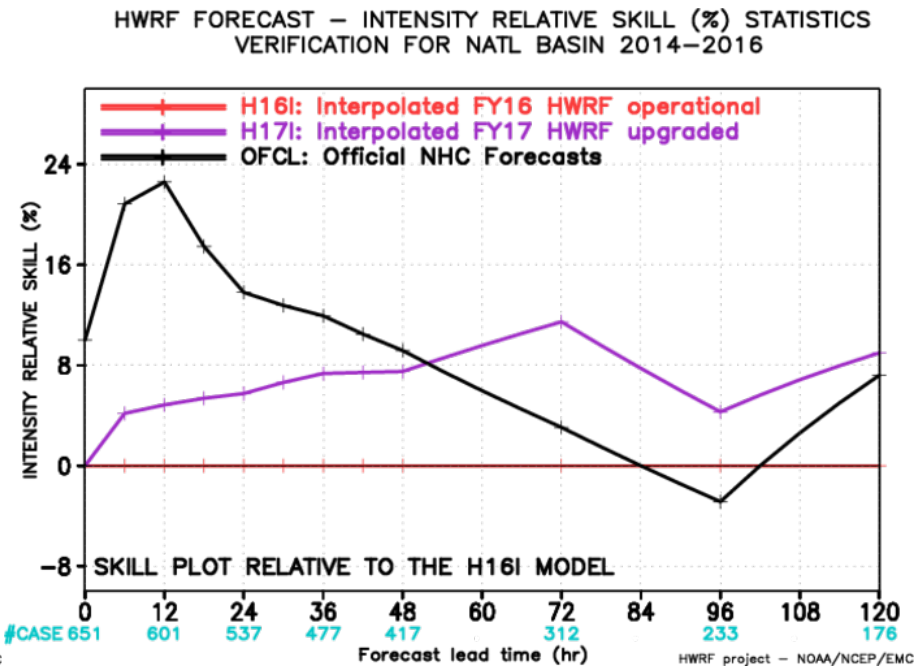
Real-time NCEP operational model guidance for all global TCs

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

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

FY2017 HWRF Performance for NATL (Early model guidance)

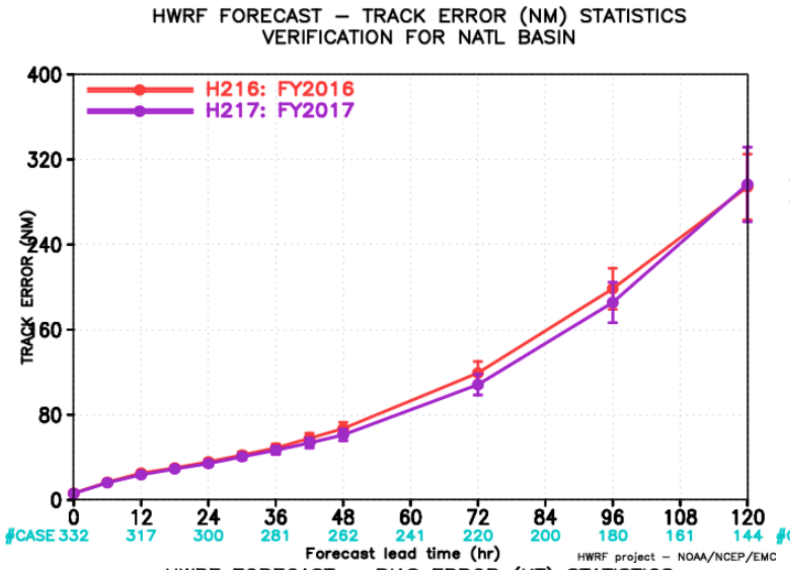


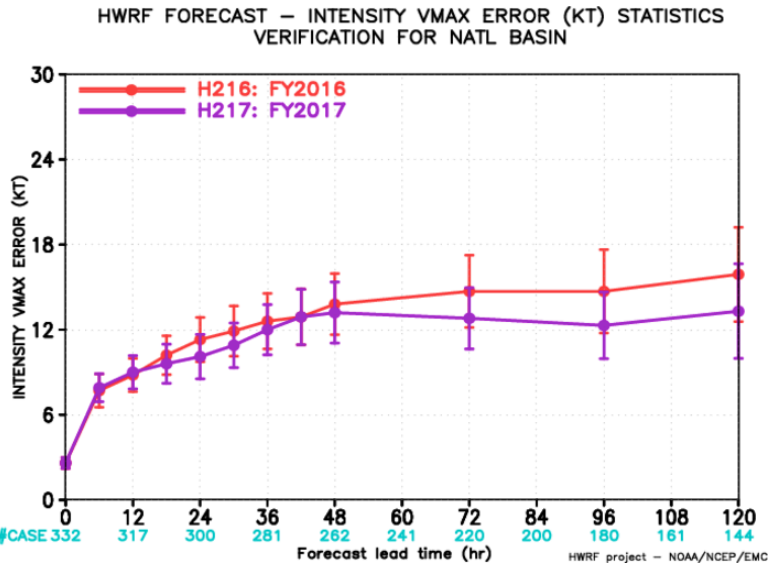


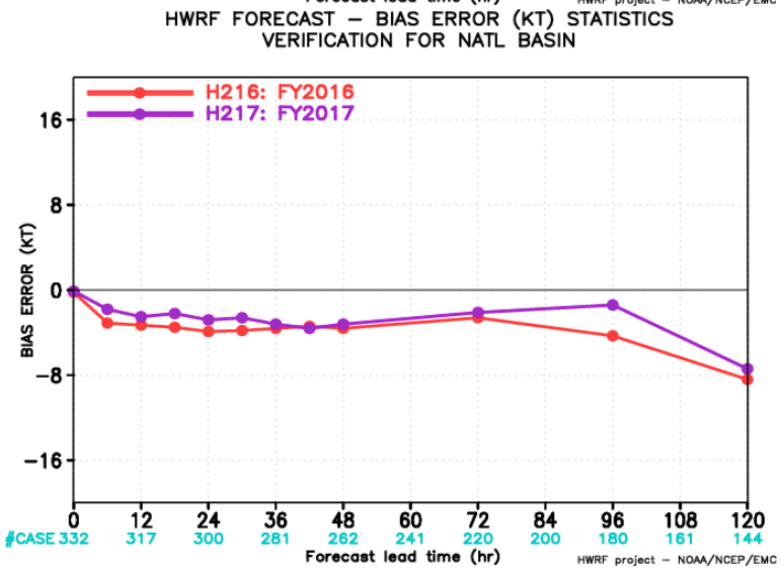
- Comparing to FY2016 HWRF, tracks are overall neutral with improvements for lead times of 48-108 hrs, while intensity is improved at all lead times with 10% improvement at day 3
- Meanwhile, still need to catch-up to official tracks, but are doing better for intensity after day 2

Evaluation of 2017 HWRF for NATL

(Rapid intensifying storms)

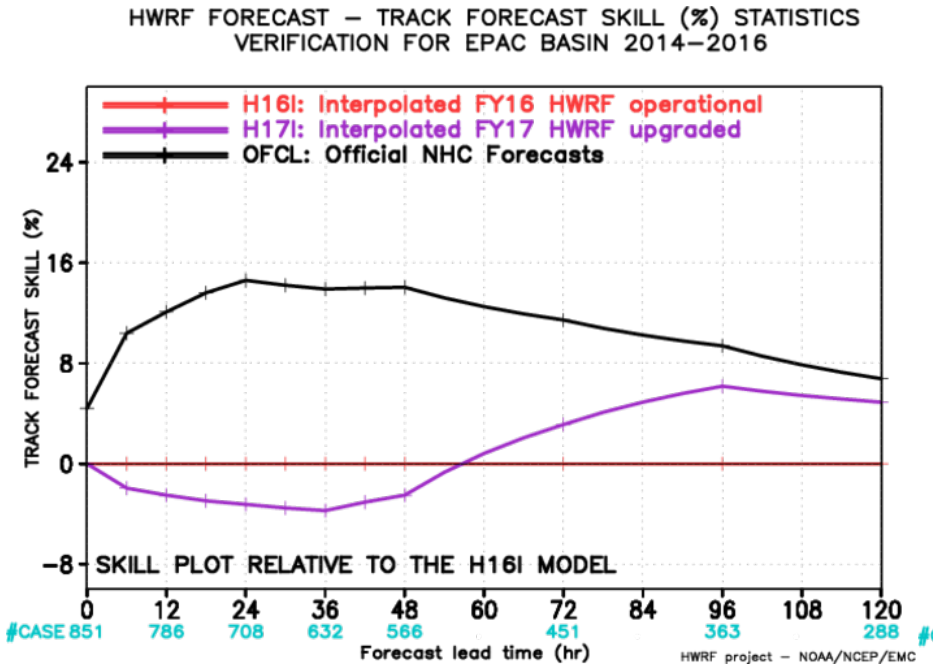


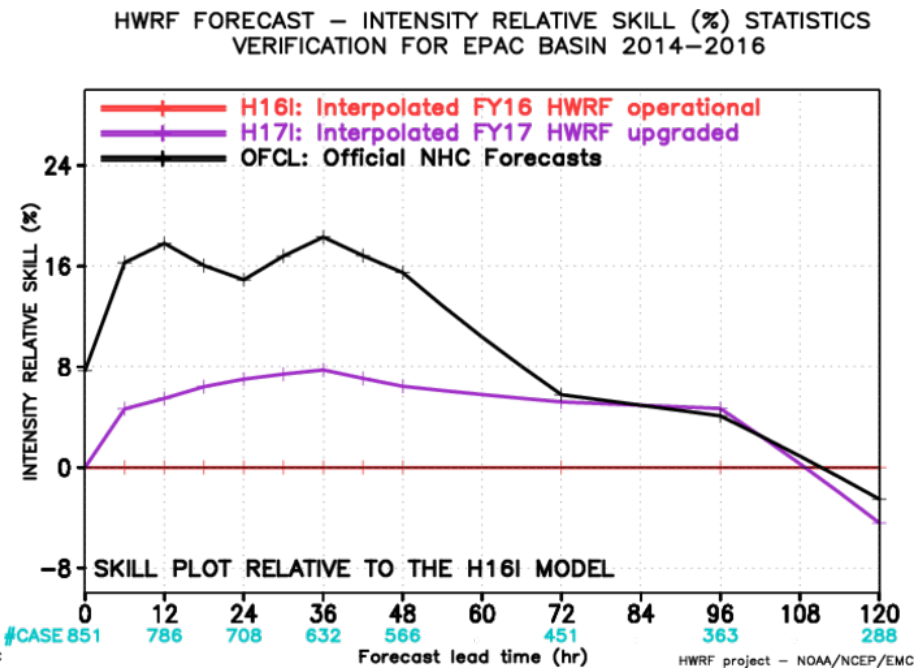




For RI storms, the track, intensity and bias errors for H217 show improvement for all lead times

FY2017 HWRF Performance for EPAC (Early model guidance)





- Comparing to FY2016 HWRF, track forecast is initially a little degraded but then show improvements after hr 60, and intensity skill is improved at all lead times with 8% improvement at hr 36
- Still need to catch-up to official tracks and intensity for the first 3 days, but intensity is very close after day 3