



Hurricane WRF: 2018 Operational Implementation and Community Support

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2018 Joint WRF/MPAS Users' Workshop, June 11-15, 2018



HFIP



THE UNIVERSITY OF RHODE ISLAND



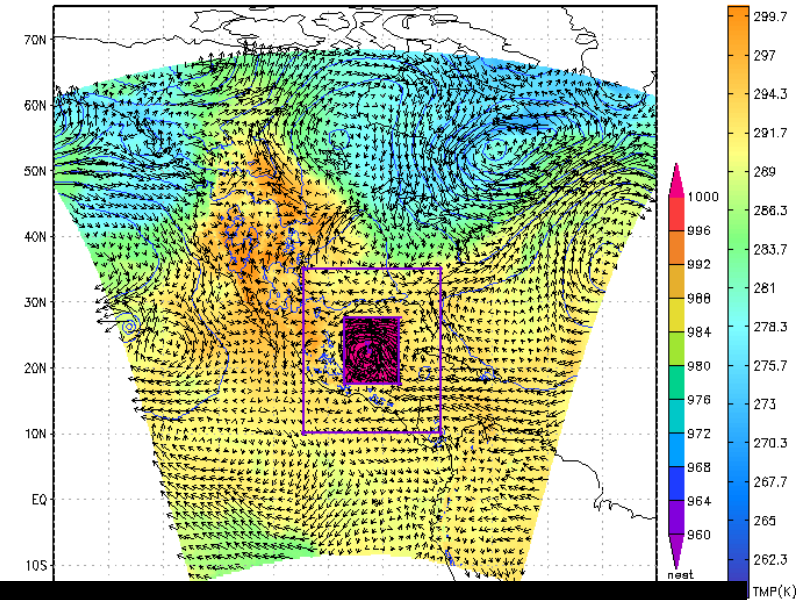
NCAR



HWRF Overview

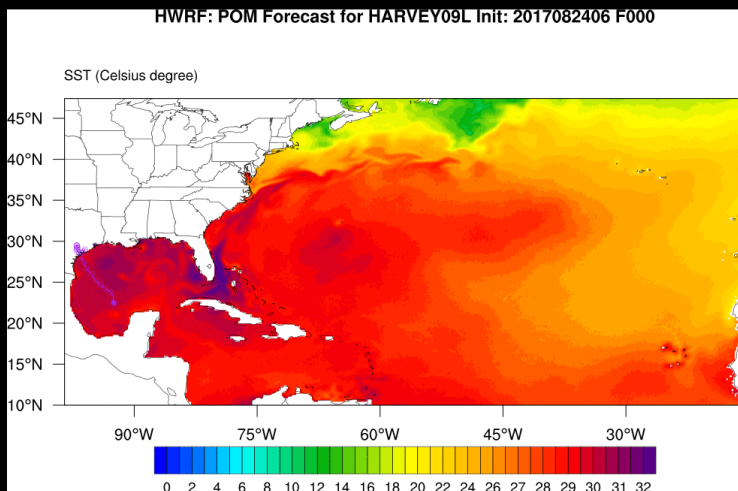
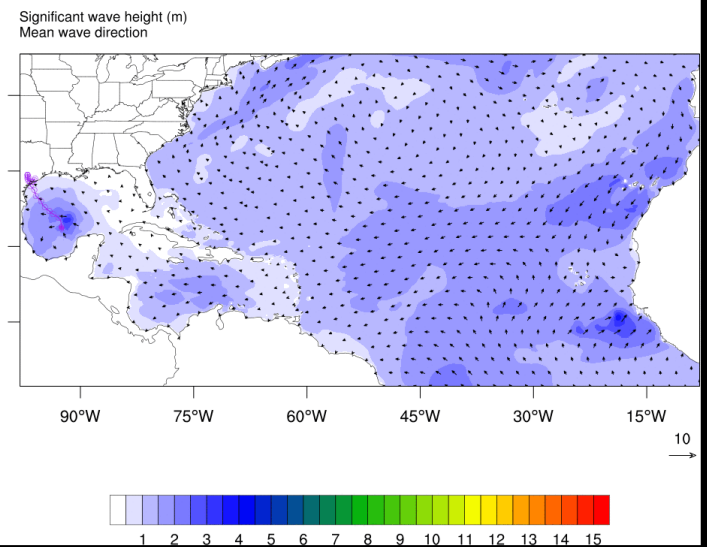
- HWRF is the NCEP operational hurricane model providing model guidance to global tropical cyclones
- Built within WRF infrastructure and based on WRF-NMM dynamic core
 - Rotated lat-lon projection
 - Arakawa E-grid
 - Hybrid sigma-pressure vertical coordinate
 - Triple nested vortex following domains
- HWRF is an air-sea coupled system

HWRF Forecast HARVEY09L INIT:2017082406 at 000 h



D

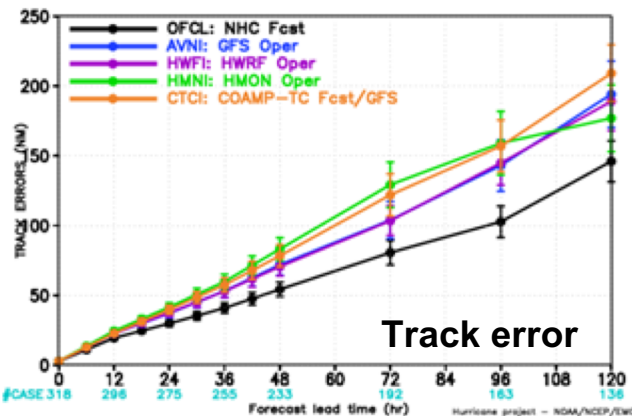
HWRF: WW3 Forecast for HARVEY09L Init: 2017082406 F000



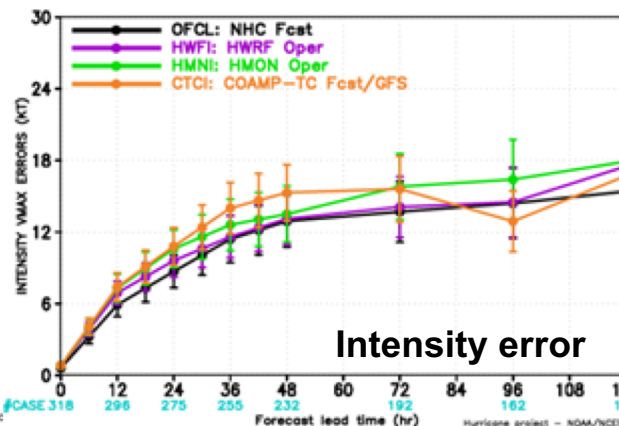
FY2017 HWRF for 2017 NATL Storms

Real-Time Performance (Early Guidance)

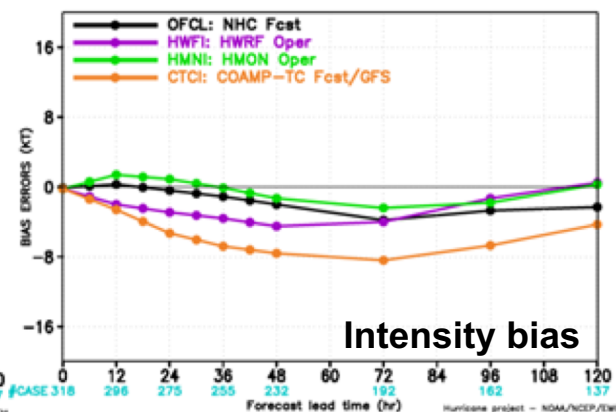
MODEL FORECAST - TRACK ERRORS (NM)
VERIFICATION FOR ATLANTIC BASIN 2017



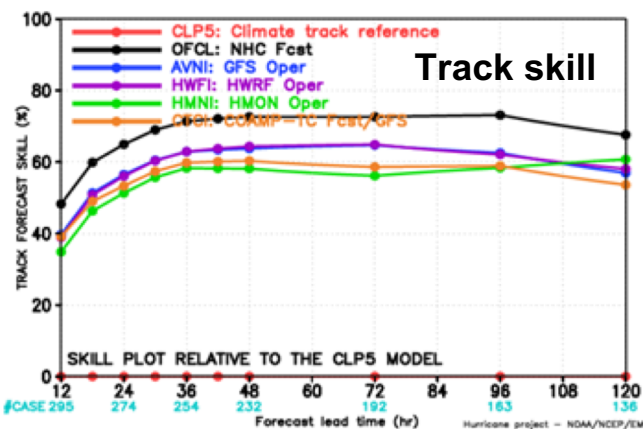
MODEL FORECAST - INTENSITY VMAX ERRORS (KT)
VERIFICATION FOR ATLANTIC BASIN 2017



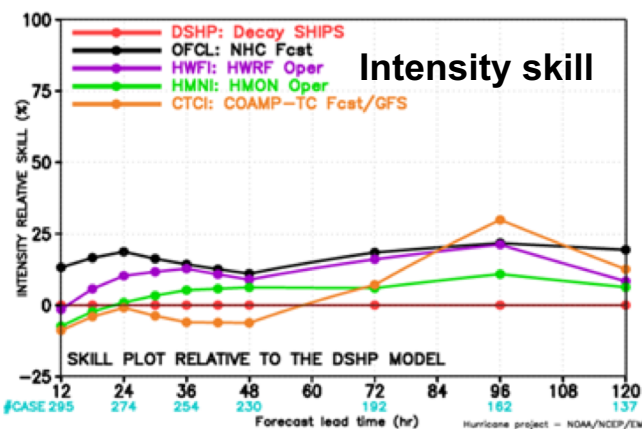
MODEL FORECAST - BIAS ERRORS (KT)
VERIFICATION FOR ATLANTIC BASIN 2017



MODEL FORECAST - TRACK FORECAST SKILL (%) STATISTICS
VERIFICATION FOR ATLANTIC BASIN 2017



MODEL FORECAST - INTENSITY RELATIVE SKILL (%) STATISTICS
VERIFICATION FOR ATLANTIC BASIN 2017



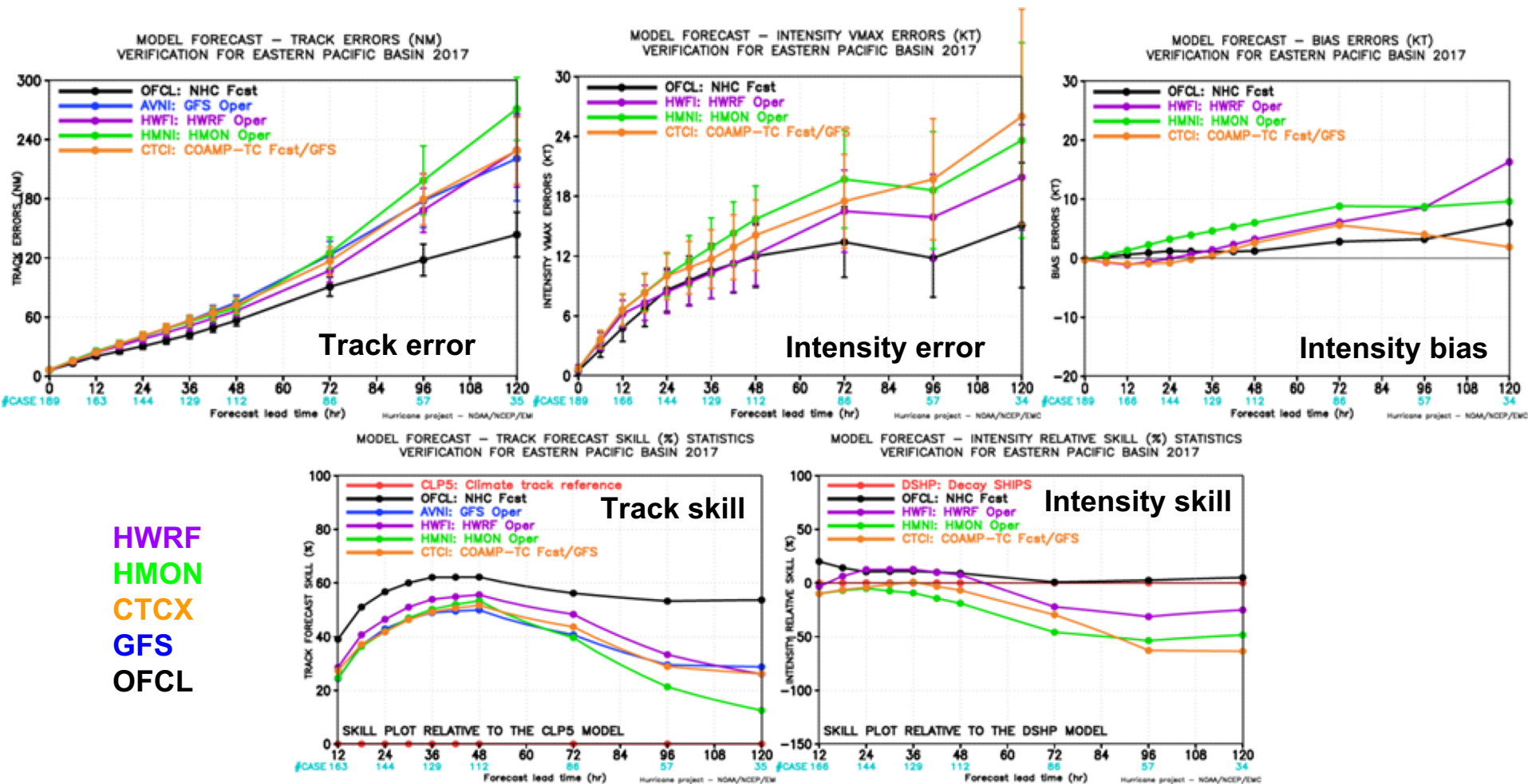
HWRF
HMON
CTCX
GFS
OFCL

Track guidance close to GFS forecast

Best intensity forecast among dynamical guidance models

FY2017 HWRF for 2017 EPAC Storms

Real-Time Performance (Early Guidance)



Better track forecast than GFS and other regional guidance models
Best intensity forecast among dynamical guidance models



Highlights of FY2018 HWRF Upgrades



- Infrastructure Enhancements

- Upgrade dynamic core from WRF3.8.1a to WRF3.9.1 (with bug fixes)
- T&E with 2017 4D-Hybrid GDAS/GFS IC/BC
- Increase horizontal resolution from (18/6/2-km) to (13.5/4.5/1.5-km)
- Slightly reduced domain sizes for the two nested domains
- Unify the vertical level configuration for all global TC basins (L75 with a model top of 10 hPa)
- ~~Increase parent domain size (collaboration with HRD)~~

- Vortex Initialization/DA Improvements (collaboration with HRD)

- GSI code upgrades and disable SSMI channel 2 data
- Stochastic physics for self-cycled DA ensemble members
- Admit new data sets (GOES-16 AMVs, NOAA-20, SFMR, TDR from G-IV)
- Considering dropsonde drifting

- Physics Advancements

- Adjust the horizontal diffusion and convergence damping coefficients
- Upgrade the RRTMG scheme with a modified cloud overlap method (DTC visitor program)
- ~~In-cloud mixing modification for GFS EDMF PBL scheme (collaboration with Zhu, FIU)~~
- ~~YSU PBL scheme (collaboration with Fovell, University at Albany - SUNY)~~

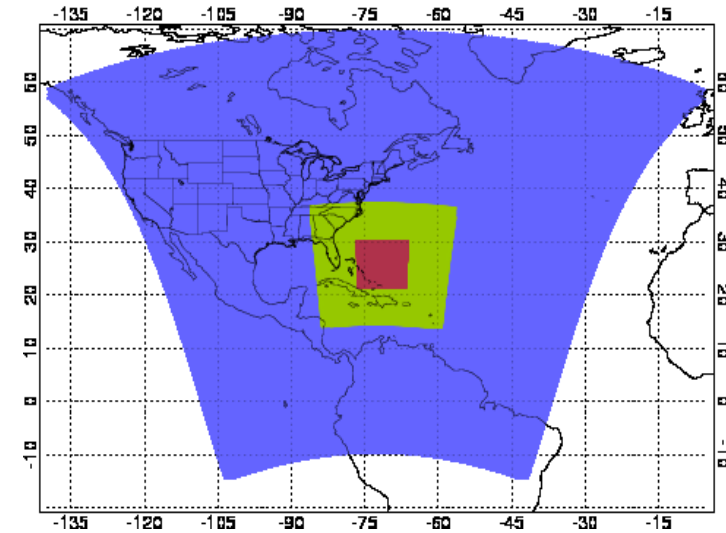
- Air-Sea Interaction and Coupling

- Unified HWRF/HMON coupler with double precision coordinates from the HWRF component
- Add a POM ocean domain for the CPAC basin
- Enable ocean coupling (with HYCOM) for Southern Hemisphere basins
- Sea surface wave initial condition from global wave model

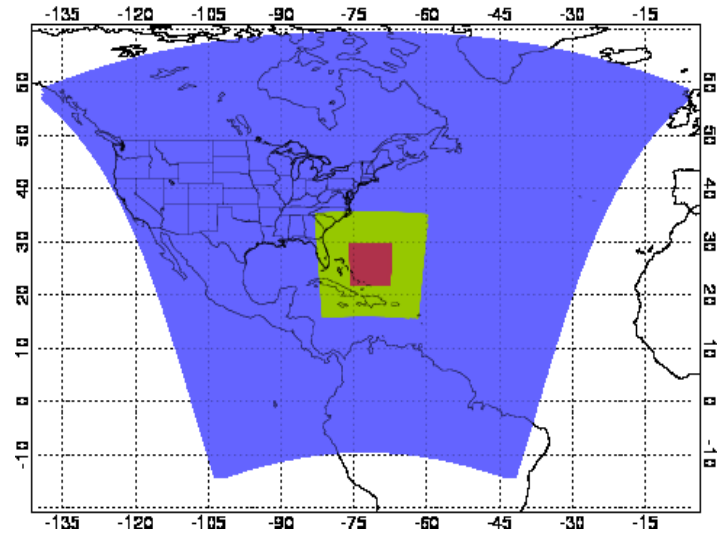
Toward High Resolution Convection Resolving Modeling in Operational HWRF

FY2017 HWRF: 18/6/2 km

FY2018 HWRF: 13.5/4.5/1.5 km

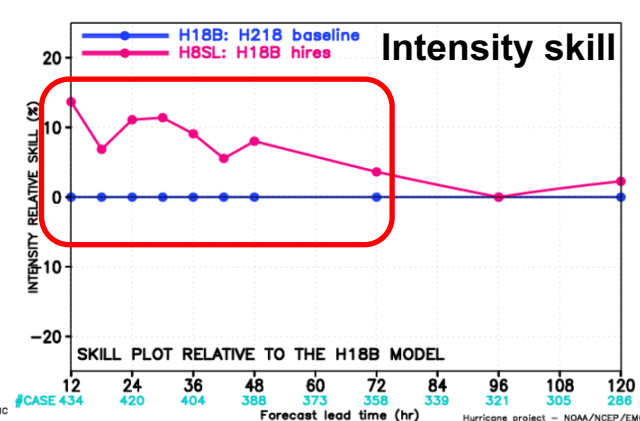
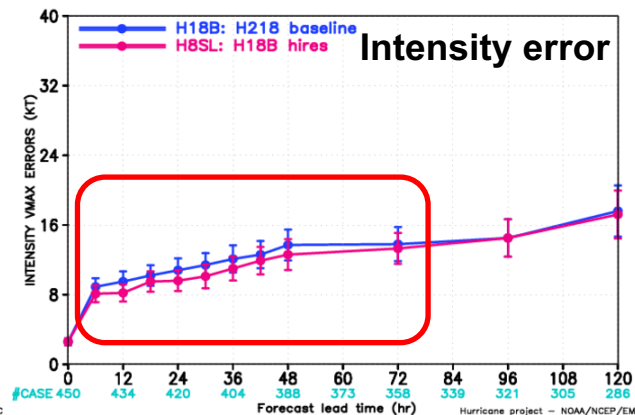
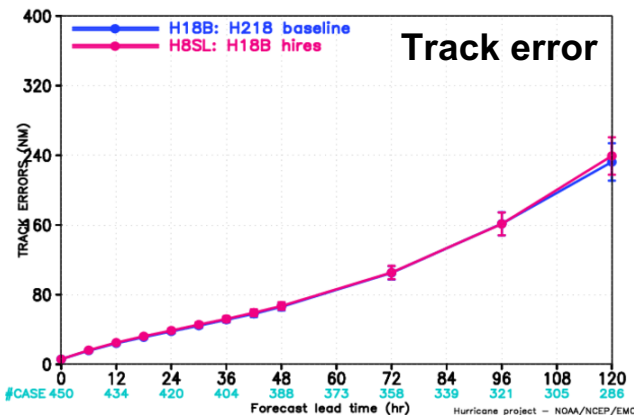


MODEL FORECAST — TRACK ERRORS (NM)
VERIFICATION FOR NATL BASIN



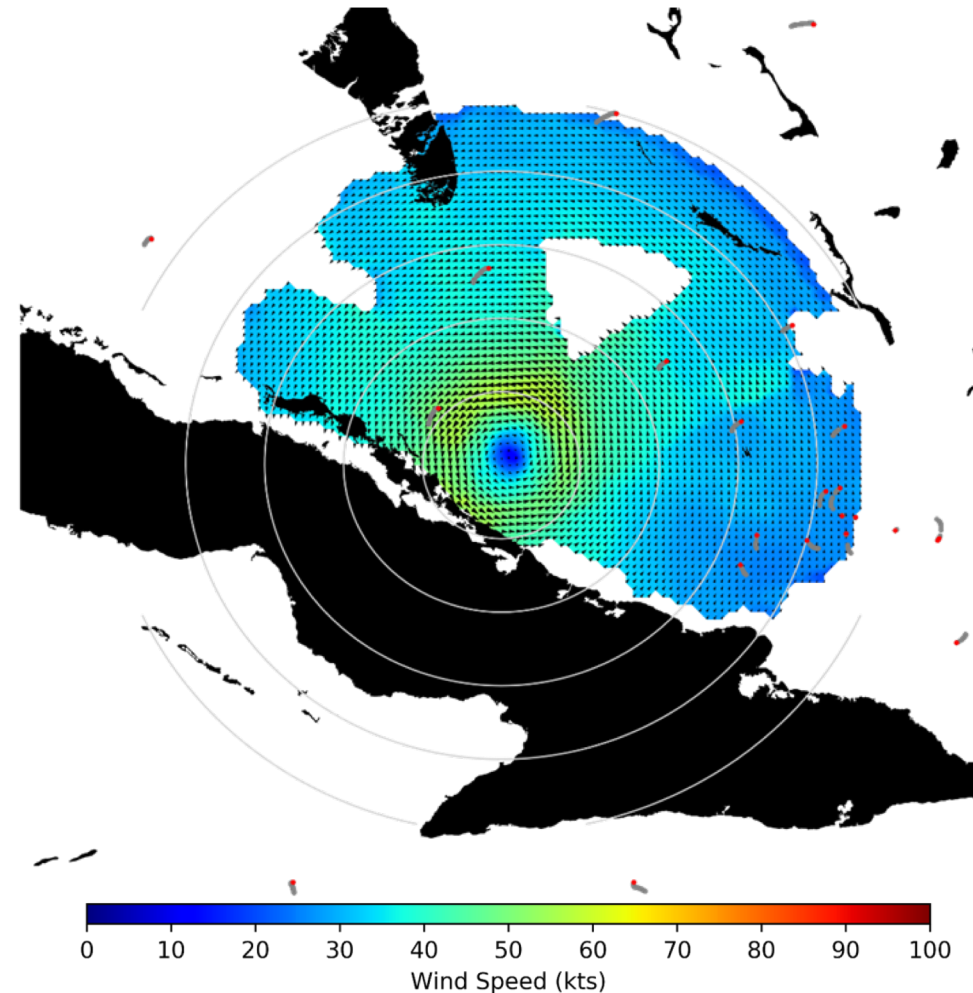
MODEL FORECAST — INTENSITY VMAX ERRORS (KT)
VERIFICATION FOR NATL BASIN

MODEL FORECAST — INTENSITY RELATIVE SKILL (%) STATISTICS
VERIFICATION FOR NATL BASIN



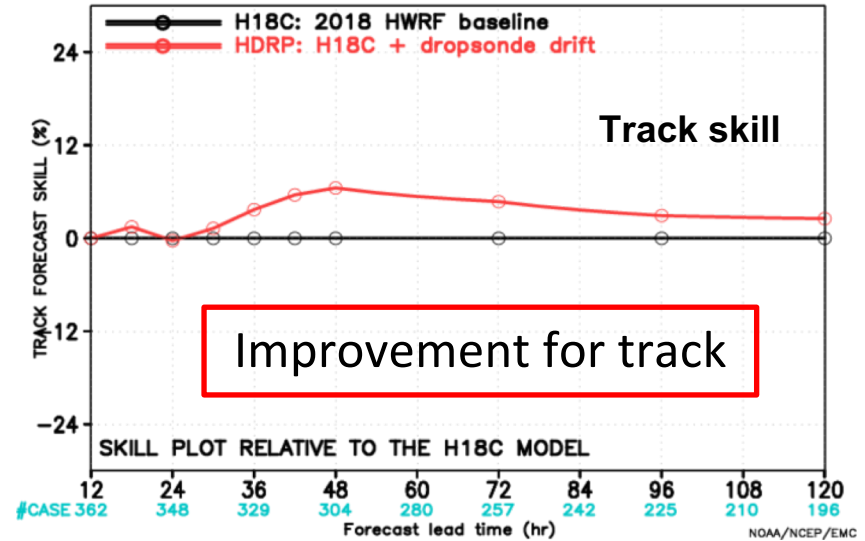
Overall neutral impact for track while substantial improvements for intensity

Considering Dropsonde Drifting

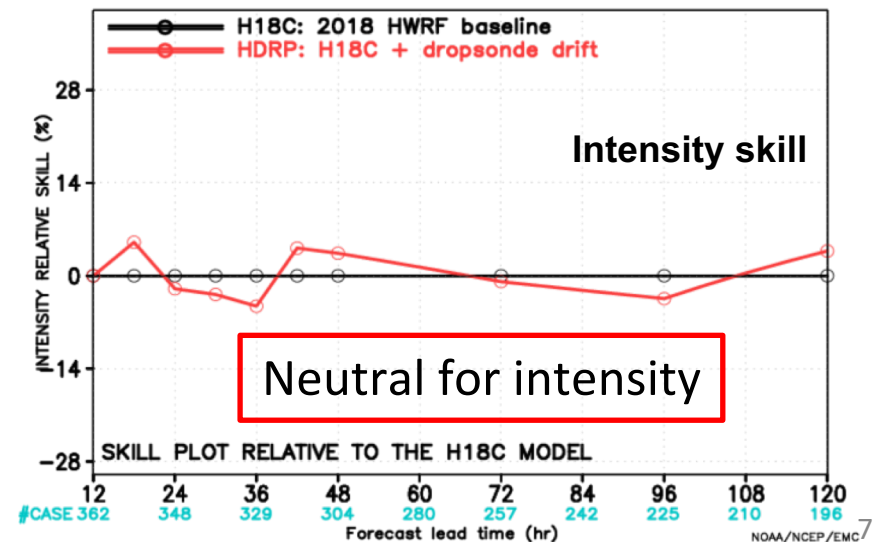


Observed radar winds (shaded) and wind vectors (arrows), and the **dropsonde release locations (red)**, and subsequent computed dropsonde advection trajectories (grey) for Hurricane Irma (11L2017) on 08 September.

TRACK FORECAST SKILL (%) STATISTICS
H218 DA test



INTENSITY RELATIVE SKILL (%) STATISTICS
H218 DA test



Modified Cloud Overlap Method for RRTMG Radiation Scheme

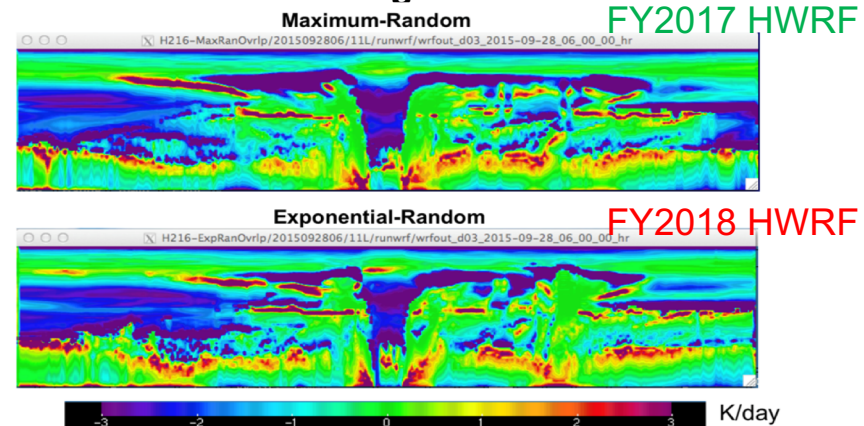
“Maximum-random” (FY2017 HWRF)

- Continuous cloud layers overlap as much as possible; blocks of cloud layers with clearance between are oriented randomly

“Exponential-random” (FY2018 HWRF)

- Continuous cloud layers use overlap that transitions exponentially from maximum to random with distance through clouds, blocks of cloud layers with clearance between are oriented randomly
- Constant decorrelation length ($Z_0 \sim 1\text{-}2\text{ km}$) controls rate of exponential transition

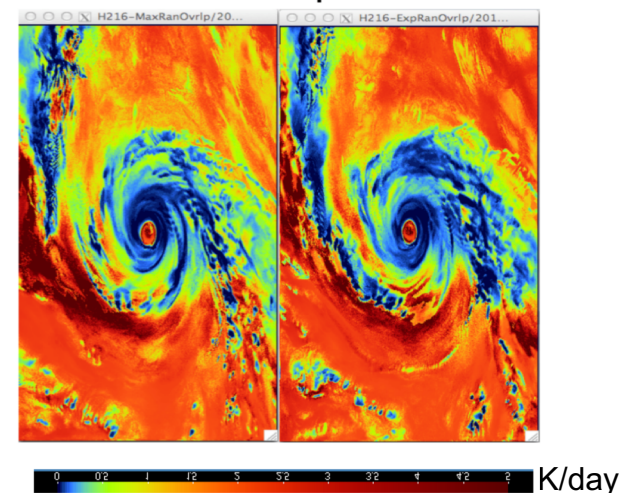
Radiative Heating Rates - LW



Vertical west-east slice: through Joaquin eye

Radiative Heating Rates - SW

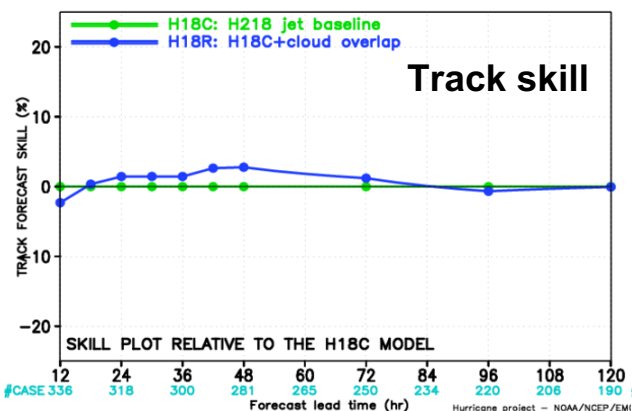
Maximum-Random Exponential-Random



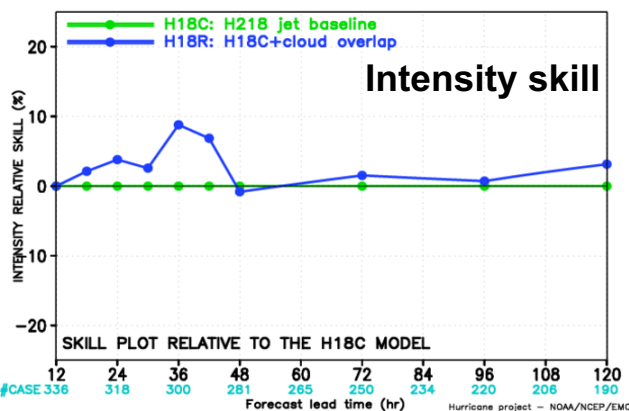
FY2017 HWRF FY2018 HWRF

Inner nest at $\sim 900\text{ hPa}$, Joaquin

MODEL FORECAST — TRACK FORECAST SKILL (%) STATISTICS
VERIFICATION FOR NATL BASIN



MODEL FORECAST — INTENSITY RELATIVE SKILL (%) STATISTICS
VERIFICATION FOR NATL BASIN



Overall positive impacts for both track and intensity



FY2018 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	75 level	10 mb
NIO	HYCOM	None	None	None	75 level	10 mb
SIO	HYCOM	None	None	None	75 level	10 mb
SPAC	HYCOM	None	None	None	75 level	10 mb

- EnKF self-cycled DA system for one TDR or priority storm
- 75 vertical levels with 10-hPa top for all global TC basins
- Ocean coupling for all global TC basins (POM for NHC basins, HYCOM for JTWC basins)
- POM RTOFS initialization for EPAC/CPAC basin
- One-way coupling to wave model for NATL, EPAC, and CPAC
- Sea surface wave IC/BC come from global wave model



H218 Performance for NATL

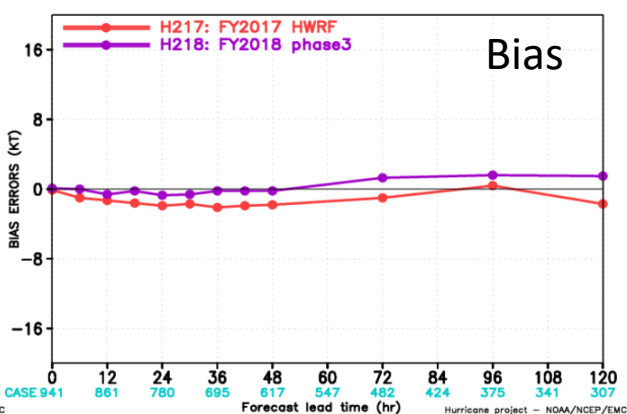
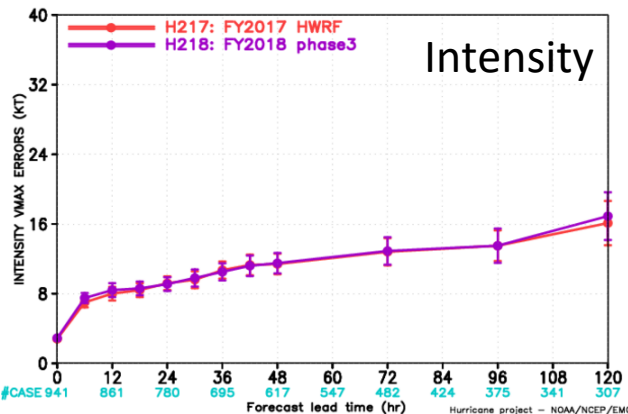
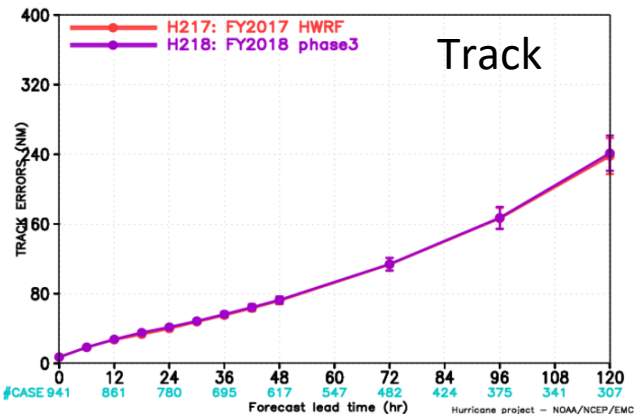
(2015-2017 storms)



MODEL FORECAST – TRACK ERRORS (NM)
VERIFICATION FOR NATL BASIN

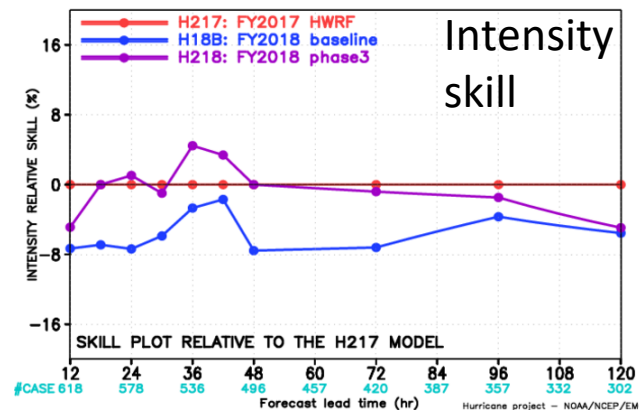
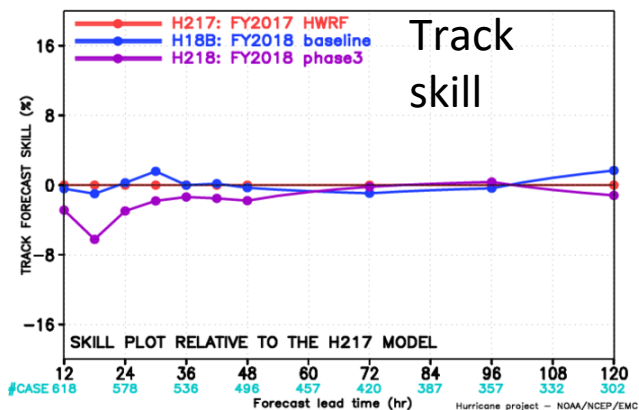
MODEL FORECAST – INTENSITY VMAX ERRORS (KT)
VERIFICATION FOR NATL BASIN

MODEL FORECAST – BIAS ERRORS (KT)
VERIFICATION FOR NATL BASIN



MODEL FORECAST – TRACK FORECAST SKILL (%) STATISTICS
VERIFICATION FOR NATL BASIN

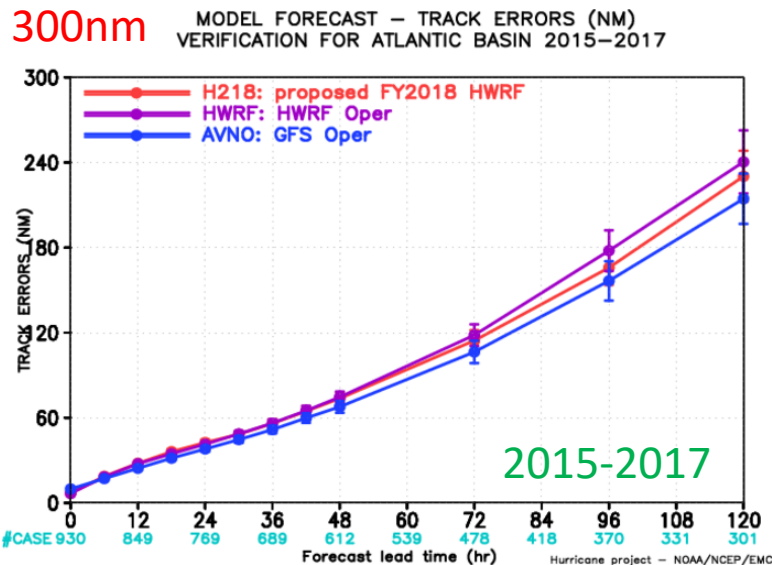
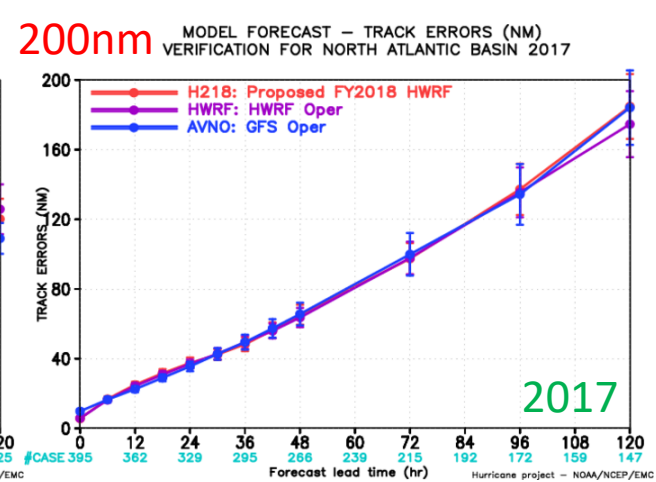
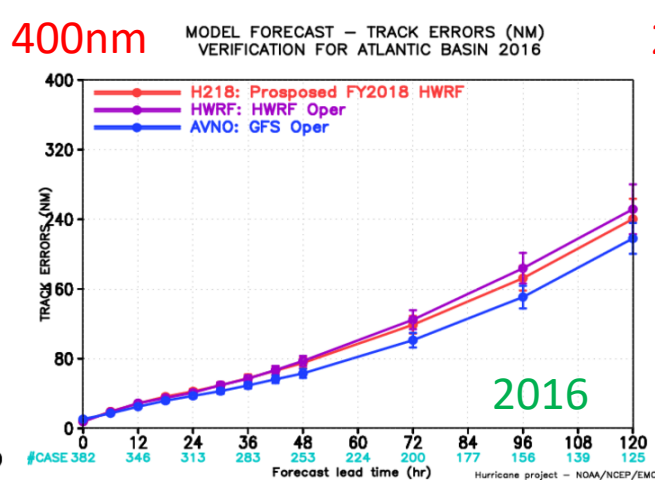
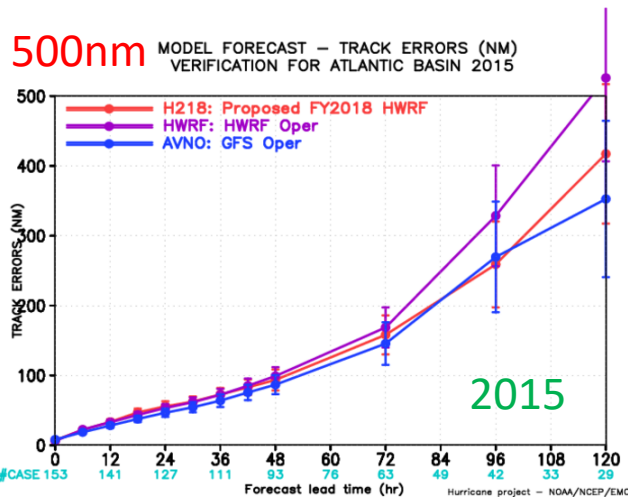
MODEL FORECAST – INTENSITY RELATIVE SKILL (%) STATISTICS
VERIFICATION FOR NATL BASIN



H217
H218
H18B

Similar track errors compared to H217 and H18B
Intensity error overall neutral to H217 except day 5,
whereas substantially better than H18B
Overall improved intensity bias compared to H217

Continuously Improved Track Forecasting H218 vs Operational HWRF for NATL



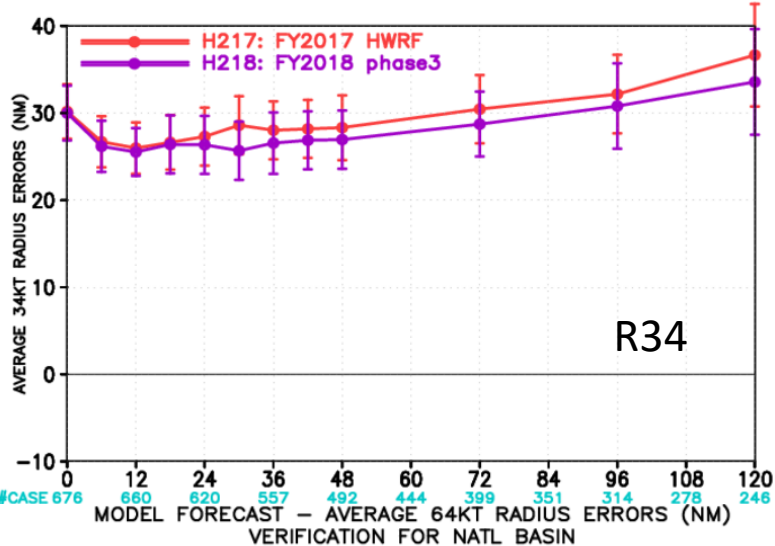
H218 HWRF
Oper HWRF
Oper GFS

Operational HWRF continuously improves track forecasts for the past three seasons, catching up GFS's track forecasts
H218 maintains track error improvements over operational HWRF

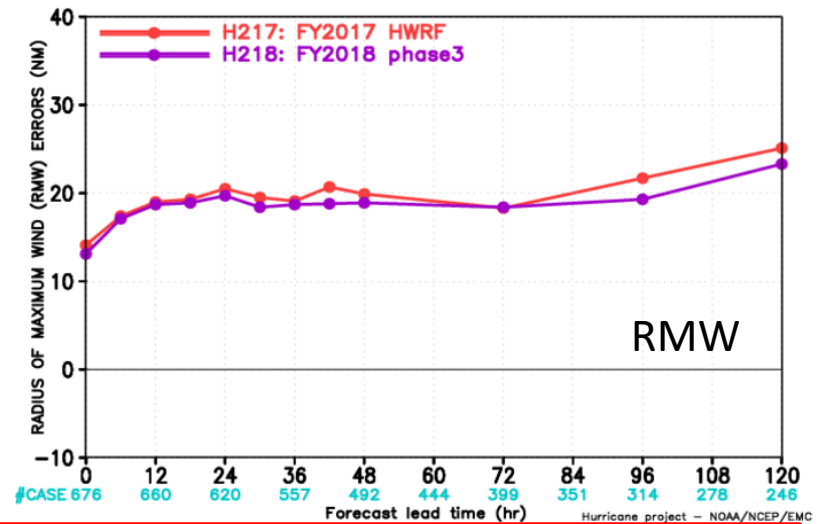
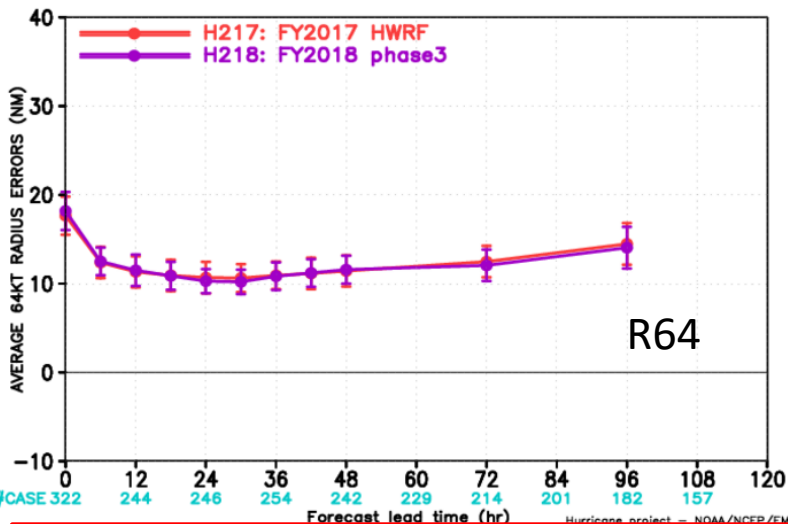
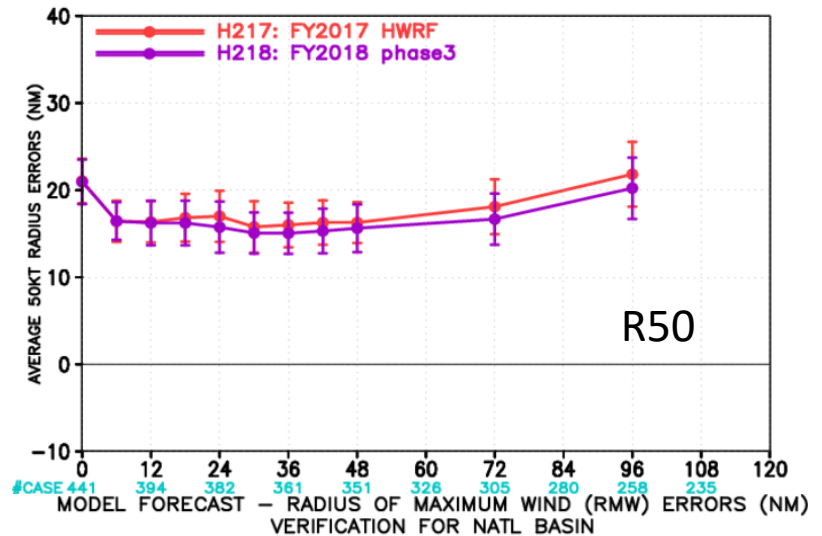
H218 Performance for NATL

(Storm size errors)

MODEL FORECAST — AVERAGE 34KT RADIUS ERRORS (NM)
VERIFICATION FOR NATL BASIN



MODEL FORECAST — AVERAGE 50KT RADIUS ERRORS (NM)
VERIFICATION FOR NATL BASIN



Storm size errors were further reduced in H218 for almost all lead times



H218 Performance for Matthew (14L2016)

Intensity Oscillation

Operational HWRP: TC Intensity

609

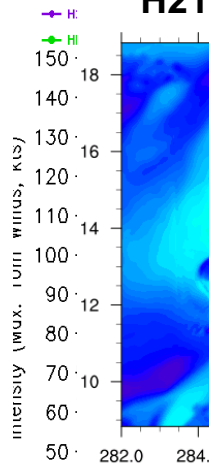
H217 MATTHEW14L(2016093006) --- F 048

H217 V10m F036

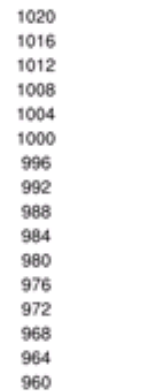
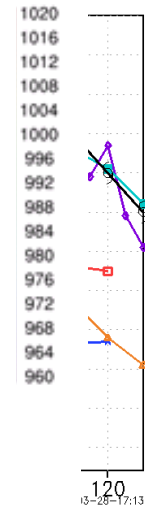
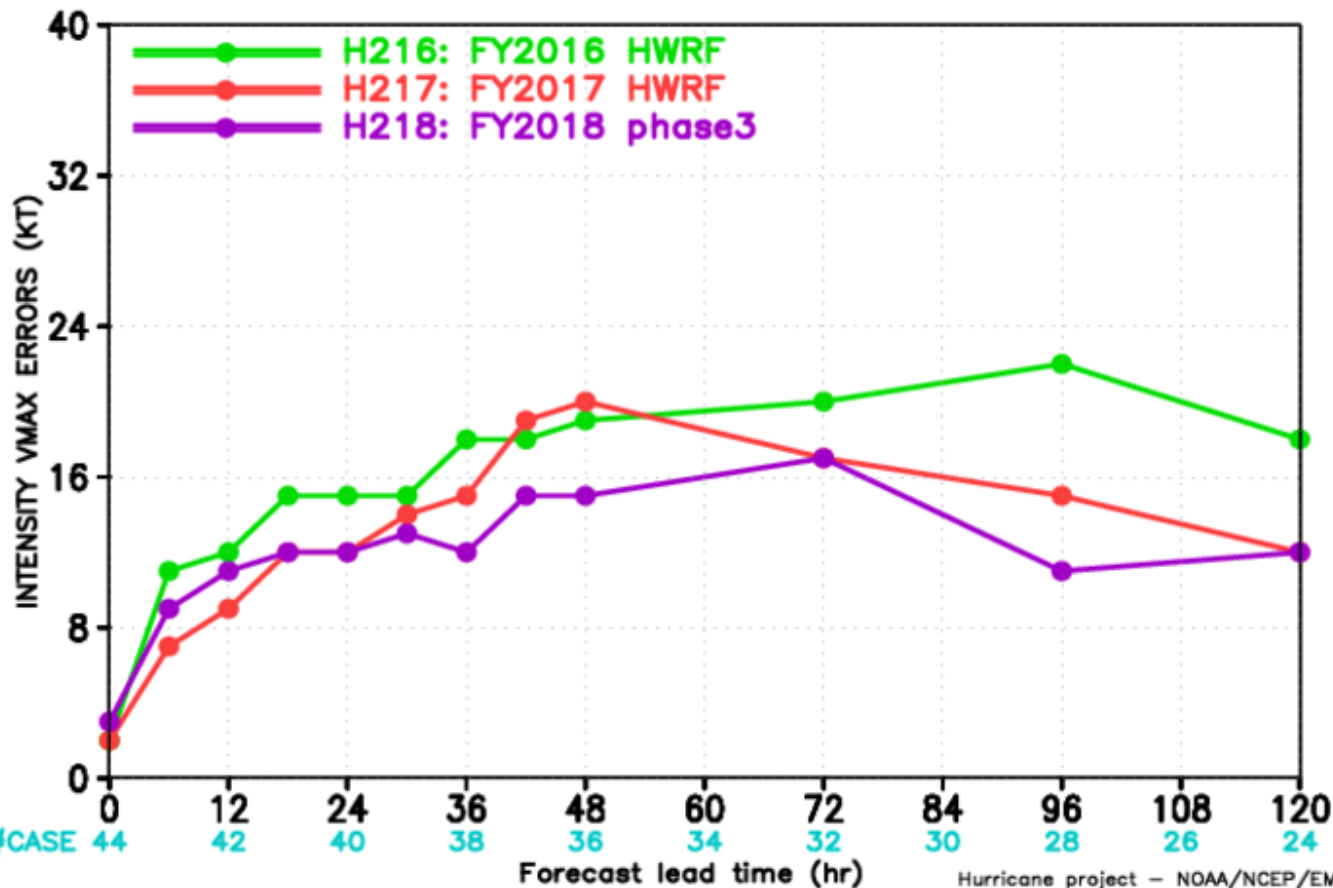
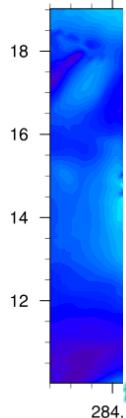
10m wind (Knot)

Mean sea level pressure (hPa)

MODEL FORECAST — INTENSITY VMAX ERRORS (KT)
STATISTICS FOR A SINGLE STORM — al142016_MATTHEW



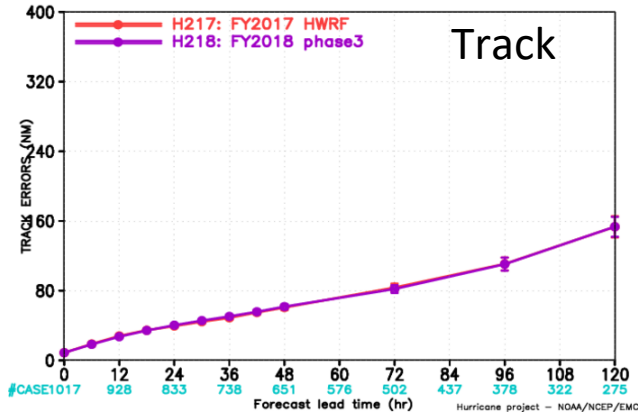
H21



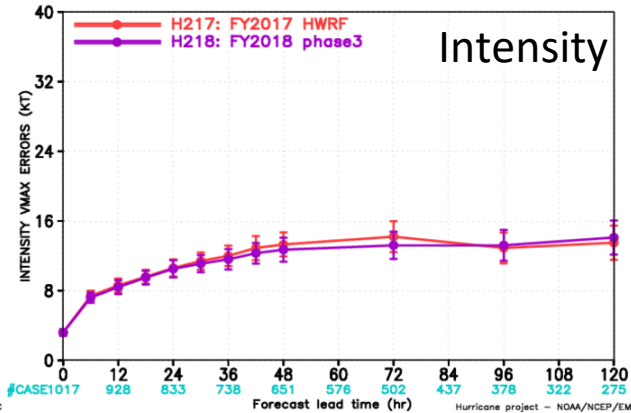
H218 Performance for EPAC

(2015-2017 storms)

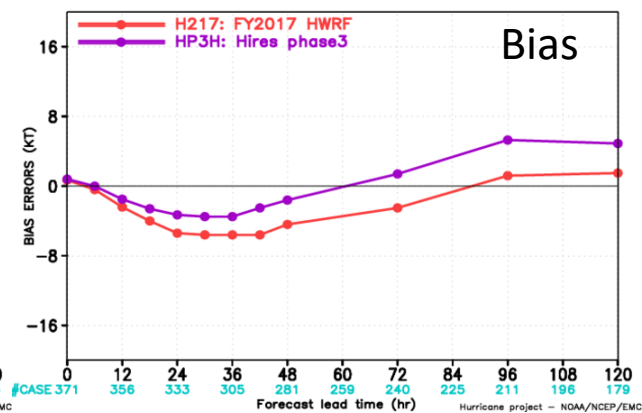
MODEL FORECAST — TRACK ERRORS (NM)
VERIFICATION FOR EPAC BASIN



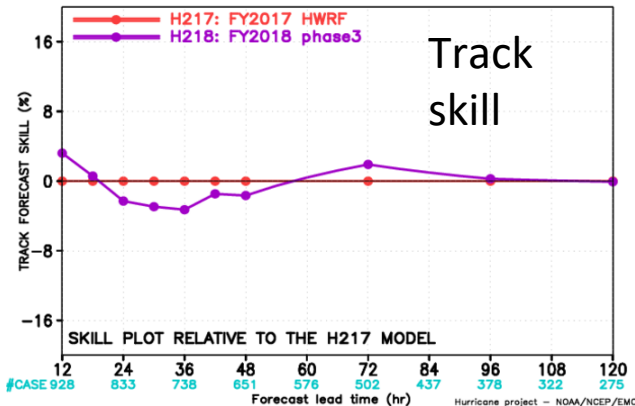
MODEL FORECAST — INTENSITY VMAX ERRORS (KT)
VERIFICATION FOR EPAC BASIN



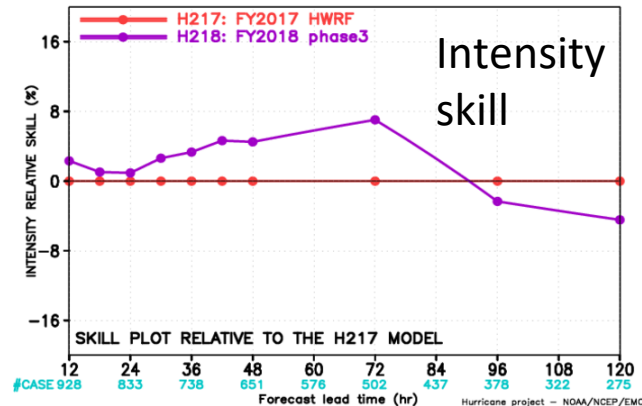
MODEL FORECAST — BIAS ERRORS (KT)
VERIFICATION FOR EPAC BASIN



MODEL FORECAST — TRACK FORECAST SKILL (%) STATISTICS
VERIFICATION FOR EPAC BASIN



MODEL FORECAST — INTENSITY RELATIVE SKILL (%) STATISTICS
VERIFICATION FOR EPAC BASIN



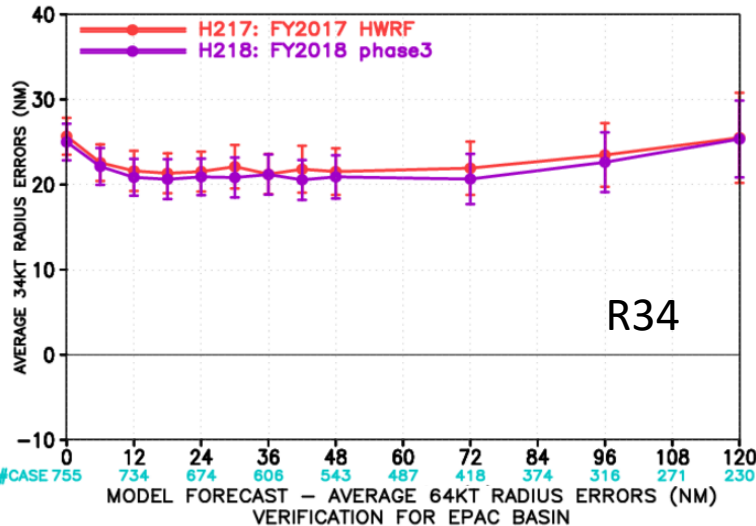
Overall neutral impact for track forecast
Improved intensity error and bias up to day 3, with
some degradation for days 4-5

H217
H218

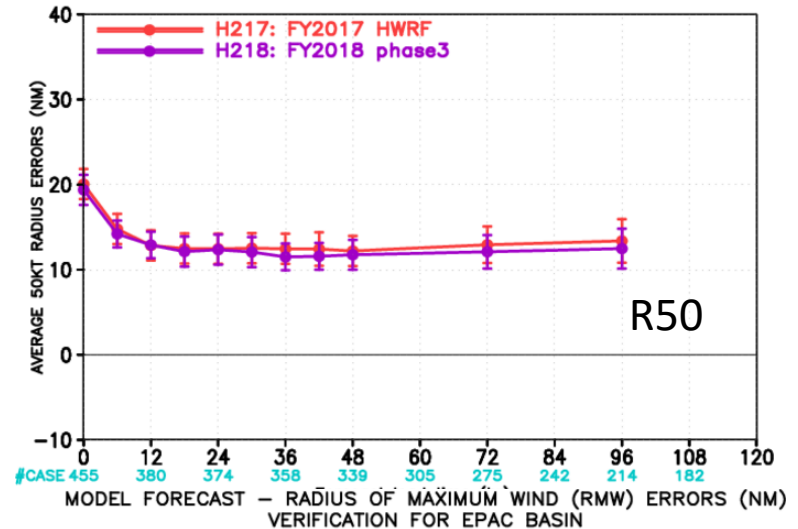
H218 Performance for EPAC

(Storm size errors)

MODEL FORECAST — AVERAGE 34KT RADIUS ERRORS (NM)
VERIFICATION FOR EPAC BASIN

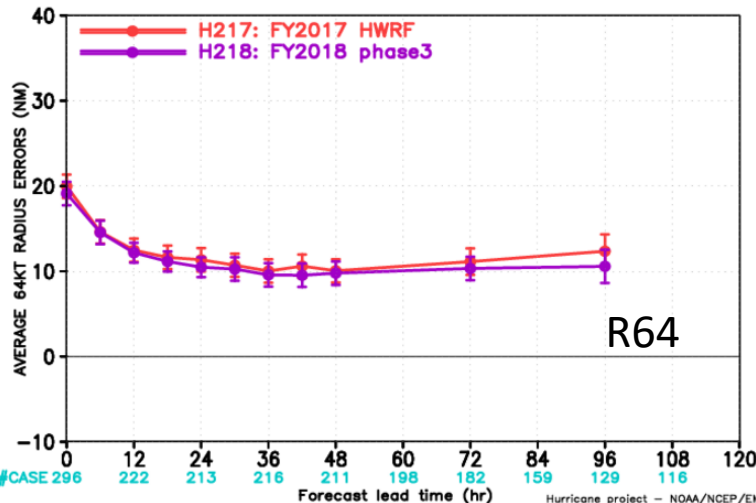


MODEL FORECAST — AVERAGE 50KT RADIUS ERRORS (NM)
VERIFICATION FOR EPAC BASIN

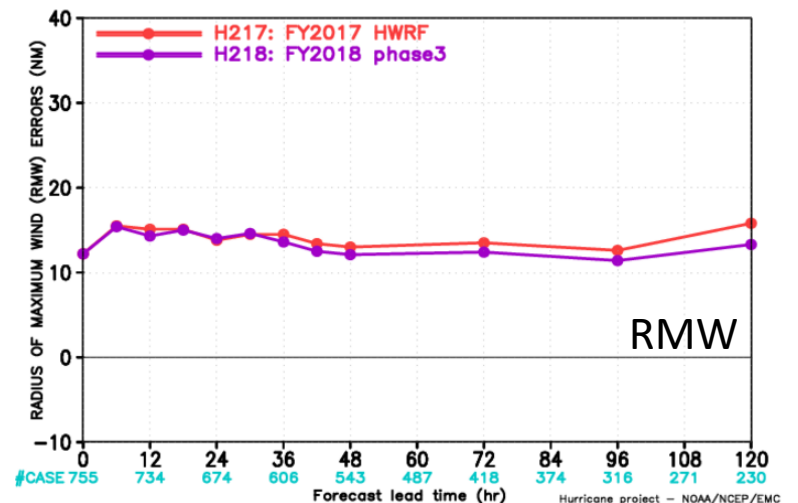


H217
H218

MODEL FORECAST — AVERAGE 64KT RADIUS ERRORS (NM)
VERIFICATION FOR EPAC BASIN



MODEL FORECAST — RADIUS OF MAXIMUM WIND (RMW) ERRORS (NM)
VERIFICATION FOR EPAC BASIN



Storm size errors were further reduced in H218 for almost all lead times

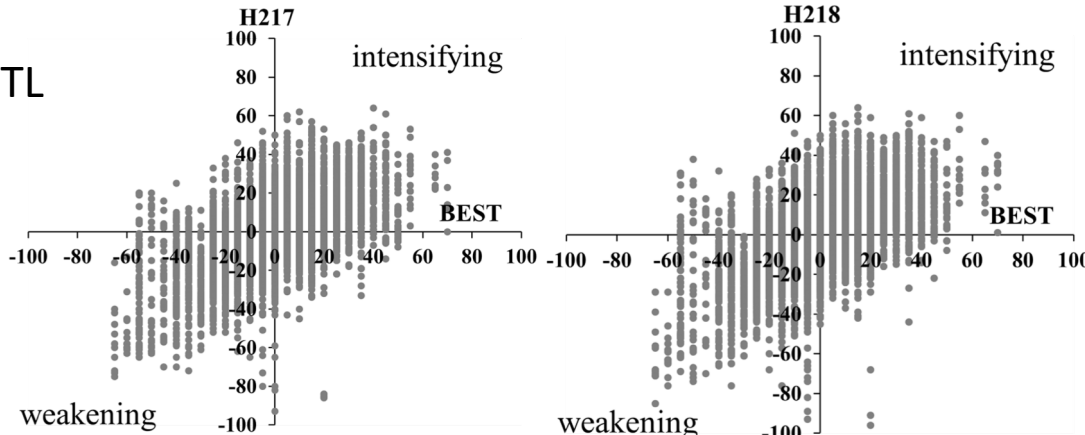
H218 Performance for NATL/EPAC

(Rapid intensification forecast)

POD: Probability Of Detection
FAR: False Alarm Rate

H218's PODs for the both basins (NATL: 20.0%; EPAC: 14.5%) are improved from H217(NATL: 16.6%; EPAC: 12.6%)
Meanwhile H218's FARs are also higher than H217

NATL



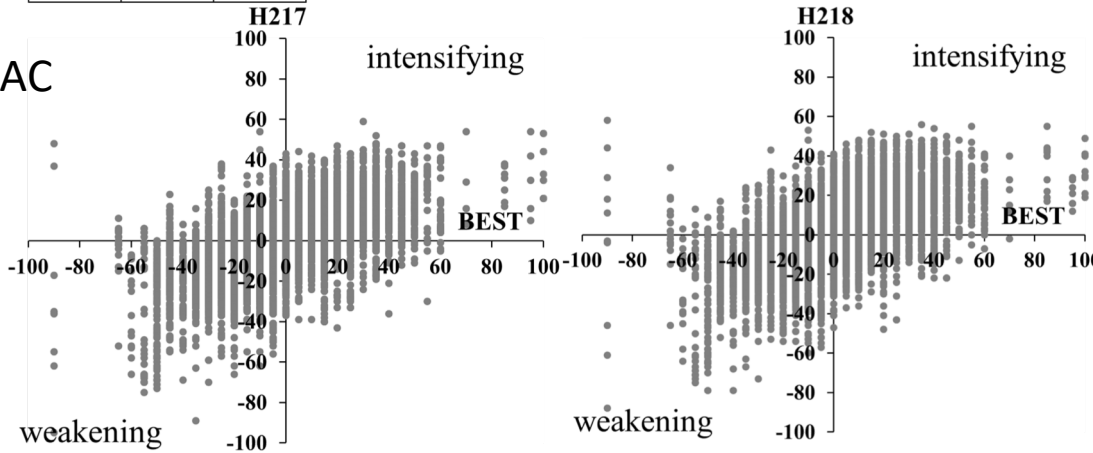
OBS \ H217	Yes	No
Yes	79	261
No	396	7894

POD = 16.6%
FAR = 76.8%

OBS \ H218	Yes	No
Yes	92	356
No	368	7959

POD = 20.0%
FAR = 79.5%

EPAC



OBS \ H217	Yes	No
Yes	93	166
No	647	7114

POD = 12.6%
FAR = 65.6%

OBS \ H218	Yes	No
Yes	113	293
No	668	7699

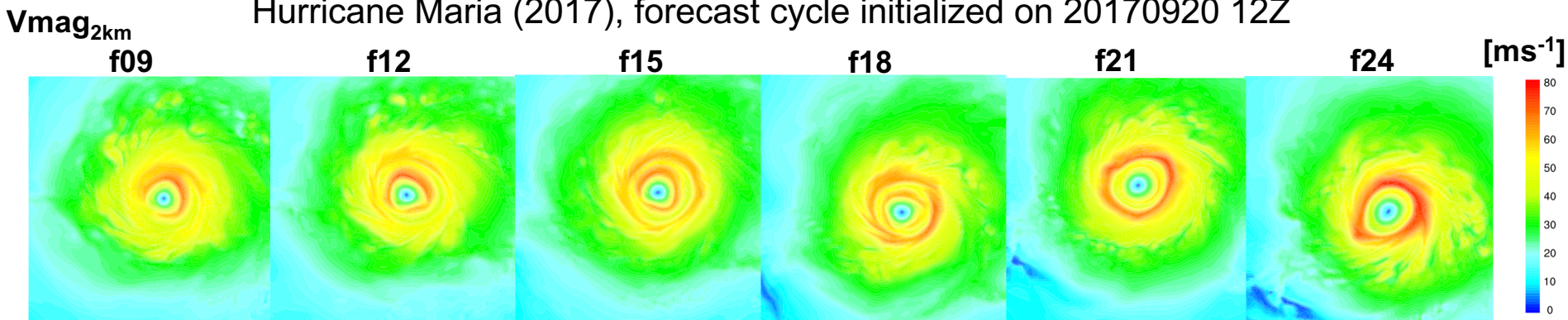
POD = 14.5%
FAR = 72.2%

H217

H218

Secondary Eyewall Formation in H218

Hurricane Maria (2017), forecast cycle initialized on 20170920 12Z

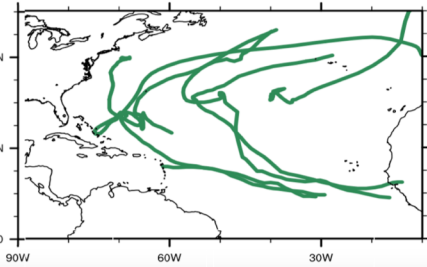
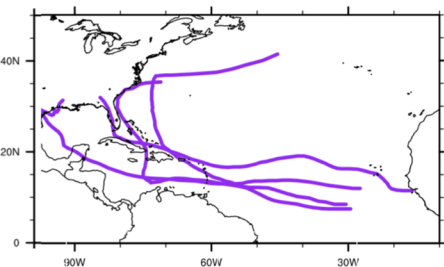


H218 shows SEs in 82% of the Maria cycles, and multiple SEs in 6% of those cycles

Major Hurricanes (2015-2017)

With SEs

Without SEs



201614L Matthew
201709L Harvey
201711L Irma
201715L Maria

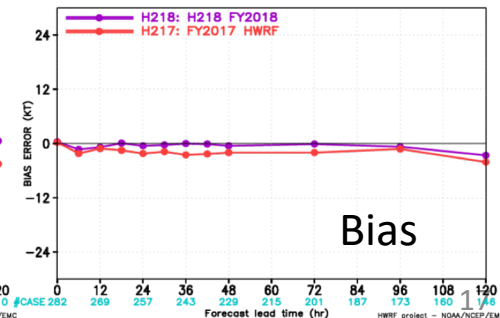
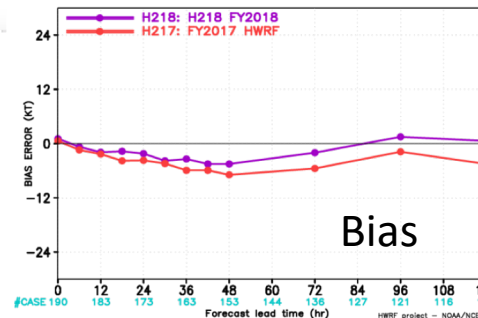
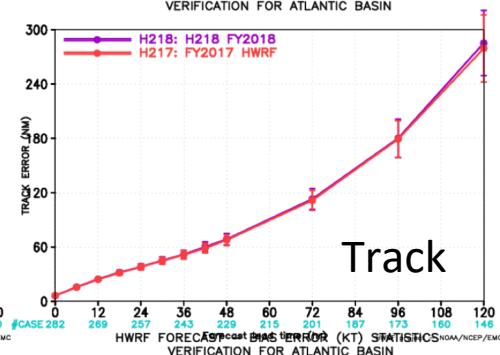
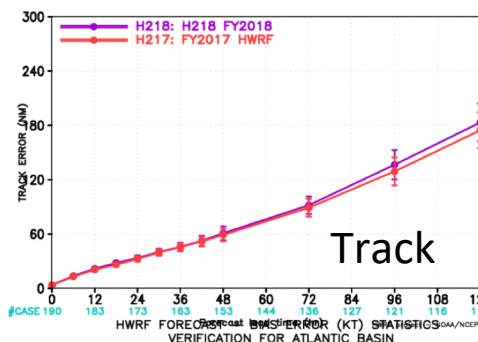
201504L Danny
201511L Joaquin
201615L Nicole
201607L Gaston

With SEs

Without SEs

HWRP FORECAST - TRACK ERROR (NM) STATISTICS
VERIFICATION FOR ATLANTIC BASIN

HWRP FORECAST - TRACK ERROR (NM) STATISTICS
VERIFICATION FOR ATLANTIC BASIN





Developmental Testbed Center Support

www.dtcenter.org/HurrWRF/users

The screenshot shows the 'HURRICANE WRF USERS PAGE' of the Developmental Testbed Center. The page has a navigation bar with links: ABOUT, TESTING & EVALUATION, COMMUNITY CODES, VISITOR PROGRAM, NEWS, and EVENTS. A sidebar on the left contains links: Home, Terms of Use, Overview, User Support, Downloads, Documentation, Idealized, Tutorials & Workshops, Testing and Evaluation, HWRF Developers Info, and Additional Links. The main content area is titled 'HURRICANE WRF' and includes a welcome message, a description of the model, two robust configurations for tropical storms, and information about the support provided by the Developmental Testbed Center. It also lists sponsors of WRF for hurricanes: NCAR and NOAA.

HURRICANE WRF

Welcome to the users page on Hurricane WRF (HWRF). The [Weather Research and Forecasting \(WRF\)](#) Model is designed to serve both operational forecasting and atmospheric research needs. It features two dynamic cores, multiple physical parameterizations, a variational data assimilation system, ability to couple with an ocean model, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications, including tropical storms.

Two robust configurations of WRF for tropical storms are the NOAA operational model [HWRF](#) and the National Center for Atmospheric Research (NCAR) Advanced Research Hurricane WRF (AHW). In this website users can obtain codes, datasets, and information for running HWRF.

The [Developmental Testbed Center](#) support the use of all components of HWRF to the community, including the WRF atmospheric model with its Preprocessing System (WPS), various vortex initialization procedures, the Princeton Ocean Model for Tropical Cyclones (MPIOM-TC), the [Gridpoint Statistical Interpolation \(GSI\)](#) three-dimensional ensemble-variational data assimilation system, the [NOAA National Centers for Environmental Prediction \(NCEP\)](#) coupler, the [NOAA Geophysical Fluid Dynamics Laboratory \(GFDL\)](#) Vortex Tracker, and various postprocessing and products utilities.

The effort to develop HWRF has been a collaborative partnership, principally between NOAA (NCEP, AOML, and GFDL) and the [University of Rhode Island](#).

EVENTS

No Upcoming Events

ANNOUNCEMENTS

- 23-25 January 2018
[Hurricane WRF Tutorial](#)
- 16 October 2017
[Release v3.9a of the HWRF system](#)

ORGANIZATIONS CONTRIBUTING TO THIS WEBSITE

Developmental Testbed Center (DTC)
NCAR's Mesoscale & Microscale Meteorology Division (MMM)

SPONSORS OF WRF FOR HURRICANES

NCAR
National Center for Atmospheric Research (NCAR)

NOAA
National Oceanic and Atmospheric Administration (NOAA)

- Yearly releases, code downloads, datasets, documentation, online tutorial, helpdesk
- 1600+ registered users
- Stable, tested code
- Benchmarks available

Support to HWRF developers in code management



Developmental Testbed Center

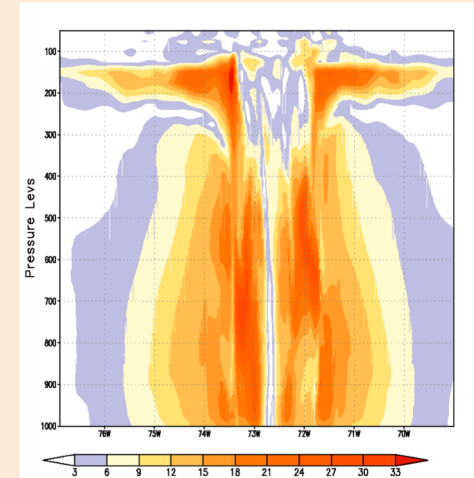
Current release: HWRF v3.9a (2017 operational) - October 2017

Next release: HWRF v4.0a (2018 operational) - planned September 2018

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 w/ landfall
 - Compatible with previous operational configurations
 - 27/9/3 km domain
 - d02/d03 grid sizes
 - vertical levels
 - model top
 - Alternate physics schemes
 - Alternate configurations (i.e.: DA, ocean, input datasets)
- Supported for all oceanic basins



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 FY2018 HWRF Upgrades

- FY2017 HWRF real-time performance
 - **Track forecast skill is substantially improved** comparing to FY2015-2016 HWRF performance for NATL (similar to GFS track forecast skill)
 - Continues providing very good intensity model guidance (**close to official intensity forecast guidance** for NATL storms)
- Highlights of FY2018 HWRF upgrades include:
 - Increased horizontal resolution from (18/6/2-km) to (13.5/4.5/1.5-km)
 - Unified vertical level configuration for all basins (L75)
 - Updated RRTMG scheme with a modified cloud overlap method
 - Stochastic physics for self-cycled DA ensemble members
 - Admitting new data sets and considering dropsonde drifting in DA
- FY2018 HWRF retrospective tests demonstrated that:
 - Track forecasts of H218 and H18B are very similar and neutral to H217
 - **Intensity forecast of H218 is substantially better than the baseline experiment for NATL storms and better than H217 for EPAC storms**
 - **Storm size errors are further reduced** at all lead times
- Ocean coupling with HYCOM for Southern Hemisphere storms
- One-way coupling to WW3 with surface wave IC/BC from global wave model



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

