2018 Operational Hurricane Model Upgrades at NCEP

Much improved operational forecast
guidance for global tropical cyclones

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in collaboration with
HRD, DTC, NHC, GFDL, ESRL, CCU, OU and others.

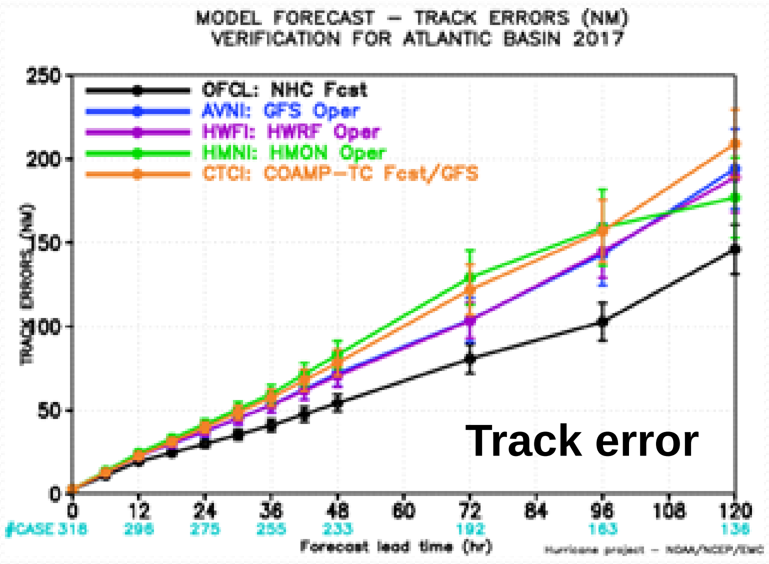
HFIP Meeting, August 22, 2018

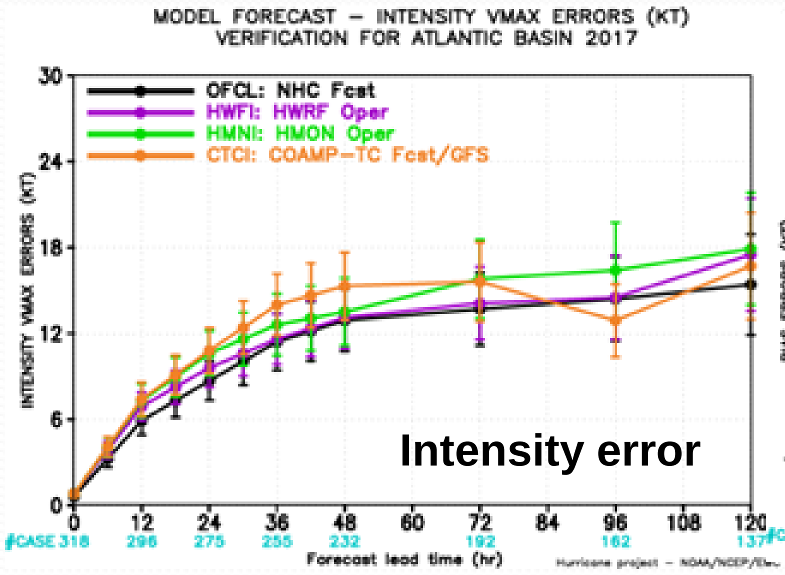
Outline

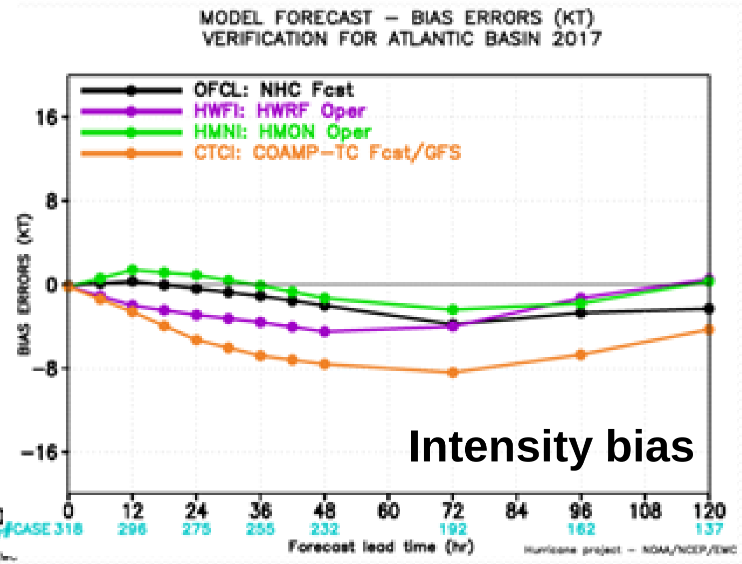
- 2017 Performance
- 2018 HWRF upgrades (H218)
- H218 performance in the NATL and EPAC Basins
- 2018 HMON upgrades (M218)
- M218 performance in the NATL and EPAC Basins
- H218, M218 maintain diversity
- A word on current/future plans

HWRF/HMON in the 2017 North Atlantic Basin

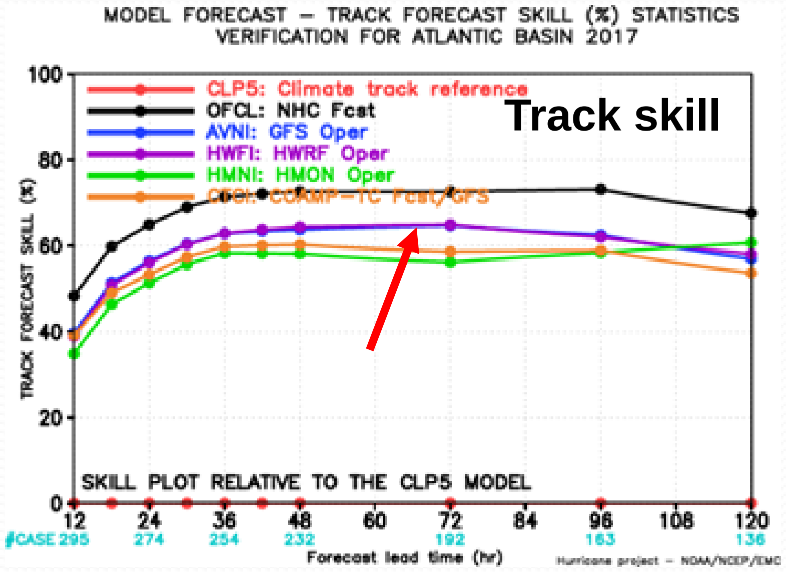
Real-Time Performance (Early Guidance)

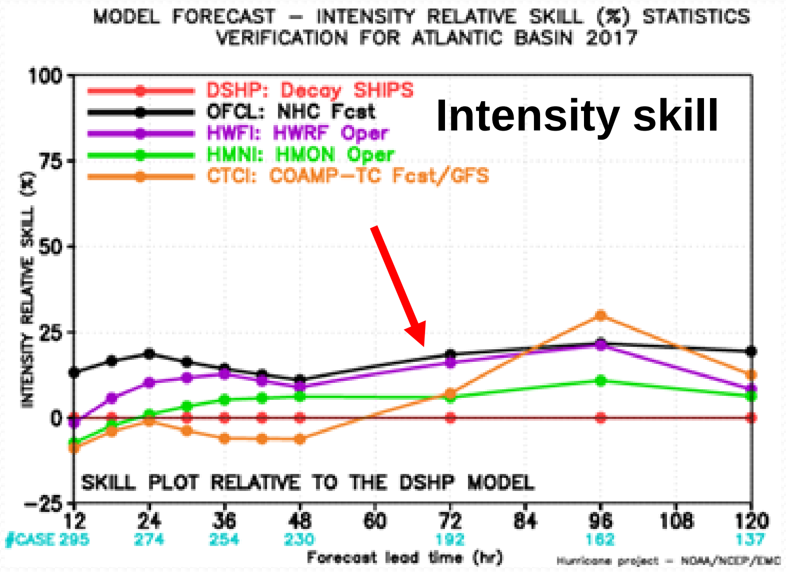






HWRF
HMON
CTCX
GFS
OFCL

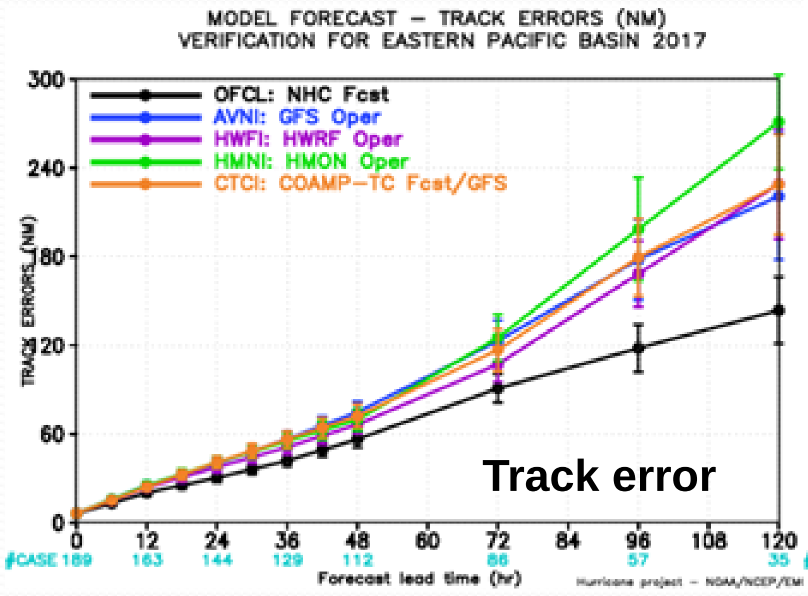


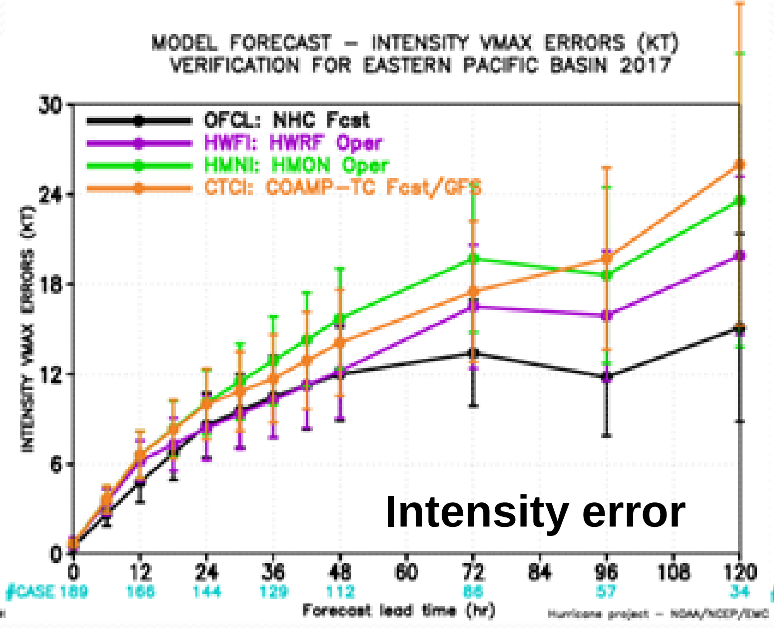


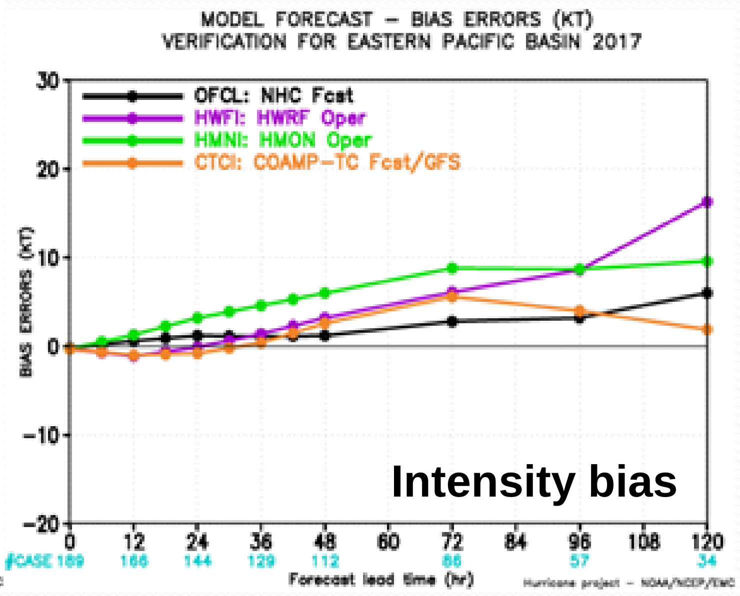
HWRF had the best skill for track and intensity of all NCEP dynamical models in the 2017 NATL basin.

HWRF/HMON in the 2017 Eastern Pacific Basin

Real-Time Performance (Early Guidance)







HWRF
HMON
CTCX
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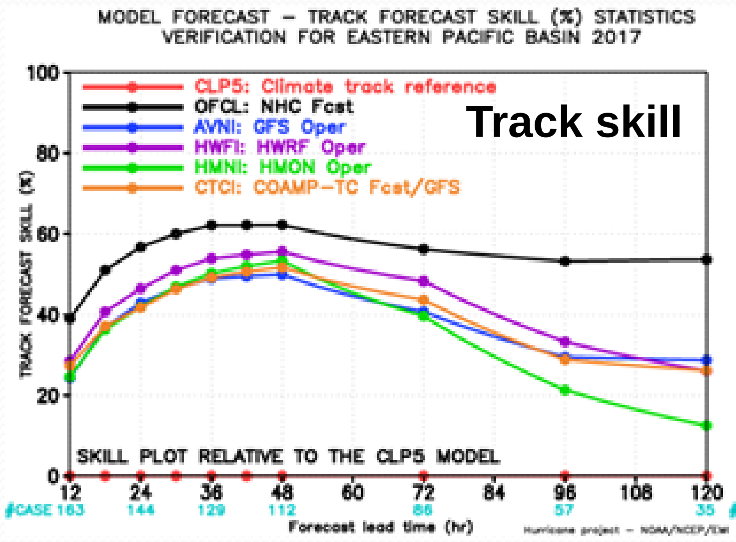
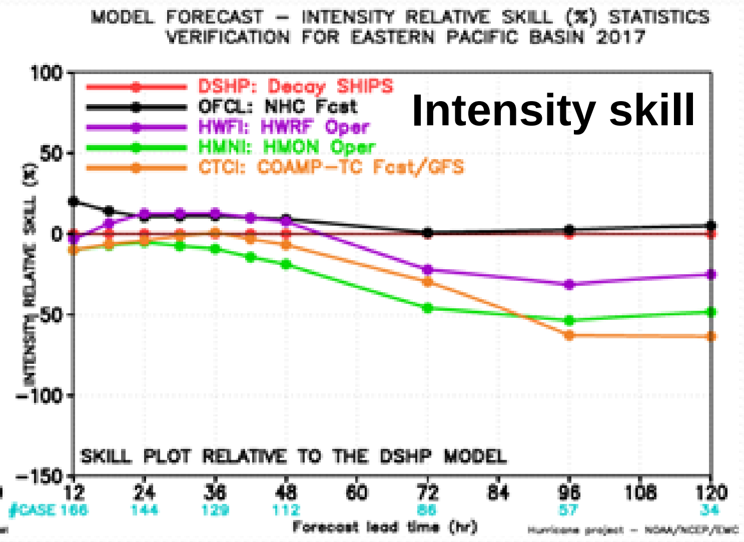




FY18 NCEP Operational Hurricane Models

I. 2018 HWRF v12.0.0

II. 2018 HMON v2.0.0

FY18 HWRF (H218) Upgrades

- **System & Resolution Enhancements**
  - Framework upgrade to HWRFV3.9.1 with bug fixes
  - T&E with 2017 GFS IC/BC
  - Increase horizontal resolution to 1.5/4.5/13.5 km, with adjusted domain sizes for d01, d02 and d03
  - Increase vertical resolution for non-NHC basins to 75 levels
  - Code optimization (IBM analyst)

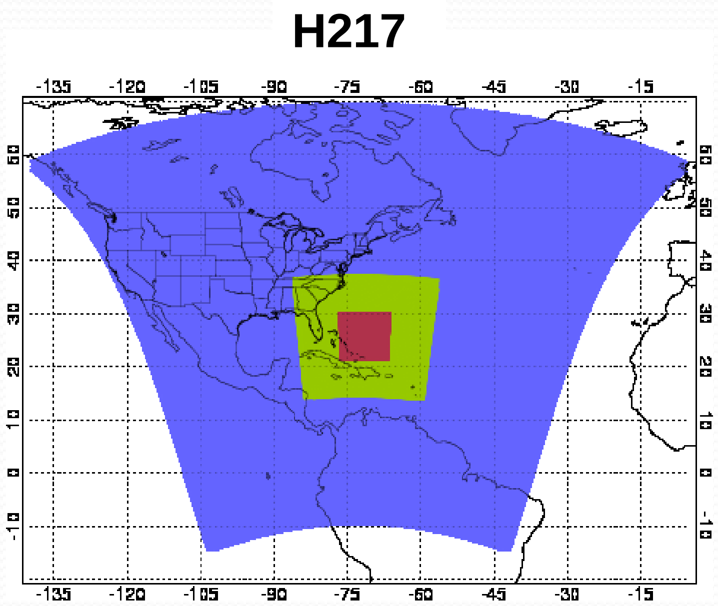
- **Initialization/Data Assimilation Improvements**
  - Stochastic physics for DA ensembles
  - GSI upgrades, changes (disable SSMI Channel 2)
  - Admit new data sets (GOES-16 AMV's, NOAA-20, SFMR, Dropsonde drifts, TDR from G-IV)
  - ~~Extend DA to Western Pacific Basin~~
  - ~~Use full ensemble co-variances~~

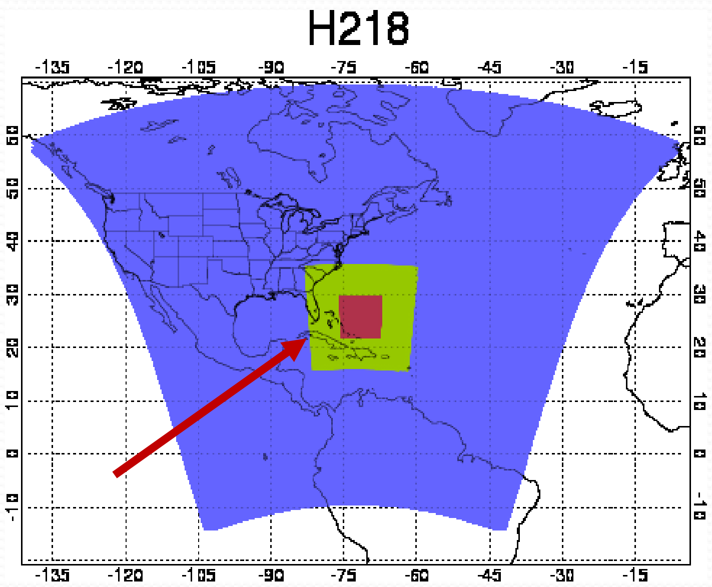
- **Physics Advancements**
  - Radiation, RRTMG- cloud overlap (DTC)
  - Adjust horizontal diffusion and damping coefficients
  - ~~Updates/options for PBL schemes (GFSEDMF changes for in-cloud mixing; YSU)~~
  - ~~Update/tune scale-aware SAS scheme or adopt G-F cumulus scheme~~

- **Coupling and other upgrades**
  - Unified HMON/HWRF coupler
  - Use of double precision coordinates in coupler for moving nests
  - Add ocean coupling (HYCOM) for Southern Hemisphere basins
  - Wave initial conditions from global wave model

Items in Red: first time in 2018

Adjusted Domain Sizes for 2018 HWRF with Higher Horizontal Resolution





Res:	2/6/18 km
d01:	288 x 576 (77.7º)
d02:	265 x 532 (23.9º)
d03:	235 x 472 (7.1º)

Res:	1.5/4.5/13.5 km
d01:	390 x 780 (77.2º)
d02:	268 x 538 (17.8º)
d03:	268 x 538 (5.9º)

Modified Cloud Overlap Method for RRTMG Radiation Scheme

“Maximum-random” (FY2017 HWRF)

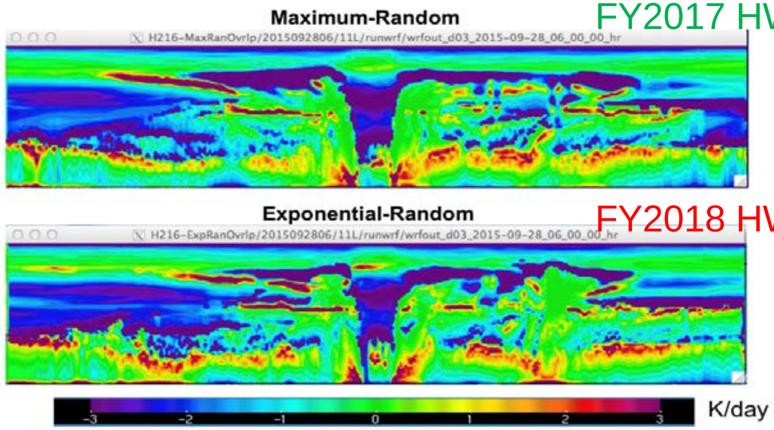
• Continuous cloud layers overlap as much as possible; blocks of cloud layers with clearance between are oriented randomly

“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 = ~1-2 km) controls rate of exponential transition

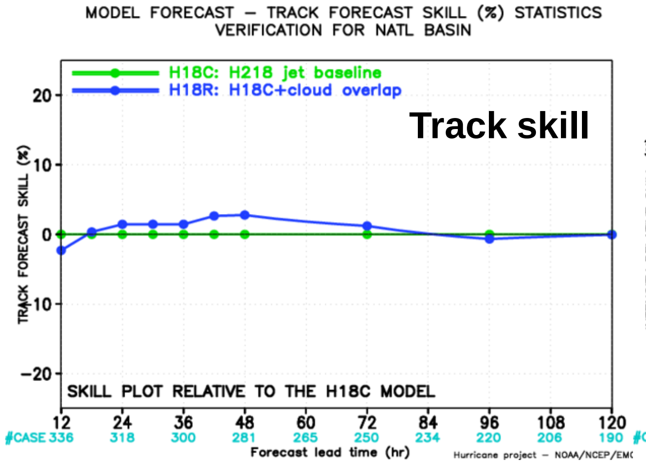
Radiative Heating Rates - LW

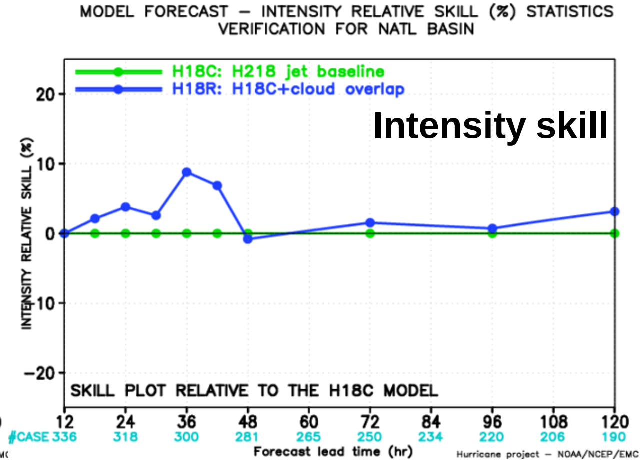


FY2017 HWRF

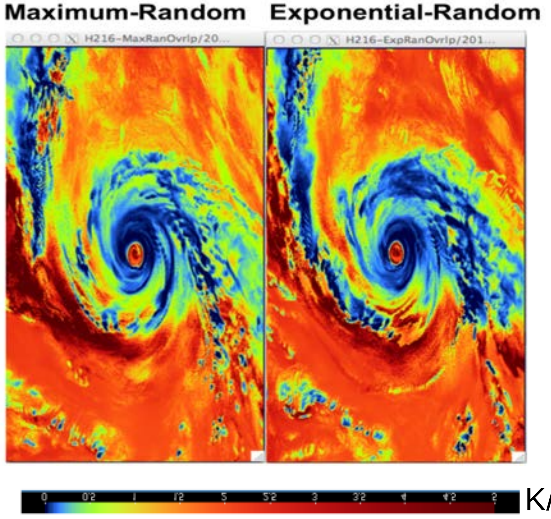
FY2018 HWRF

Vertical west-east slice: through Joaquin eye





Radiative Heating Rates - SW

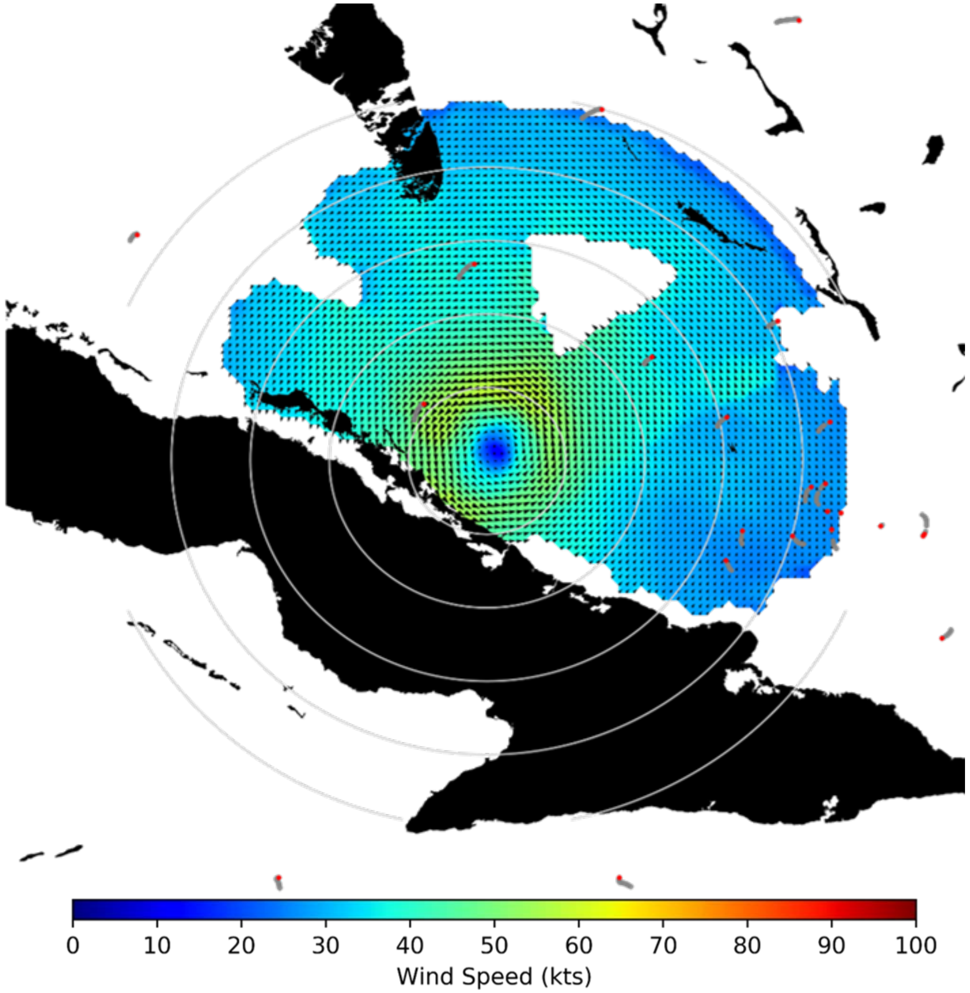


FY2017 HWRF FY2018 HWRF

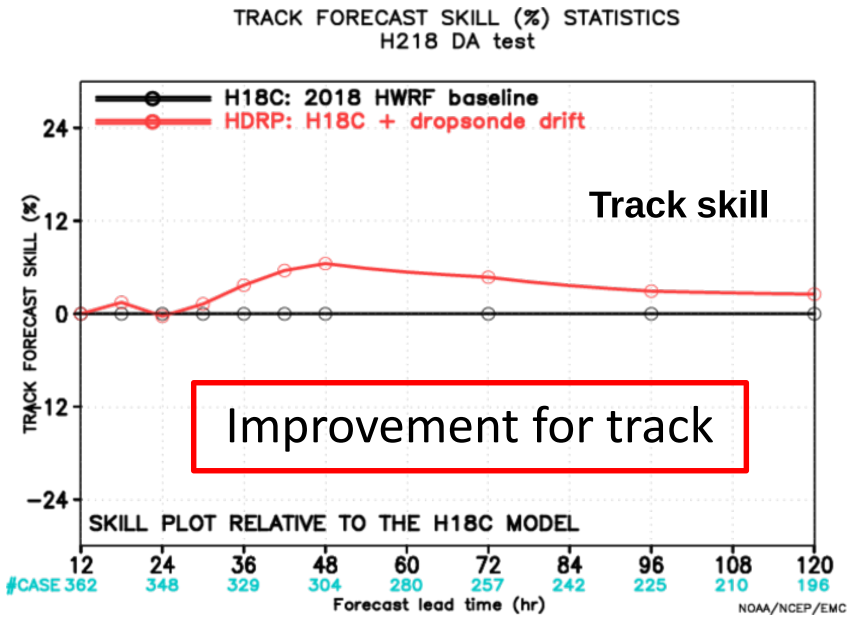
Inner nest at ~900 hPa, Joaquin

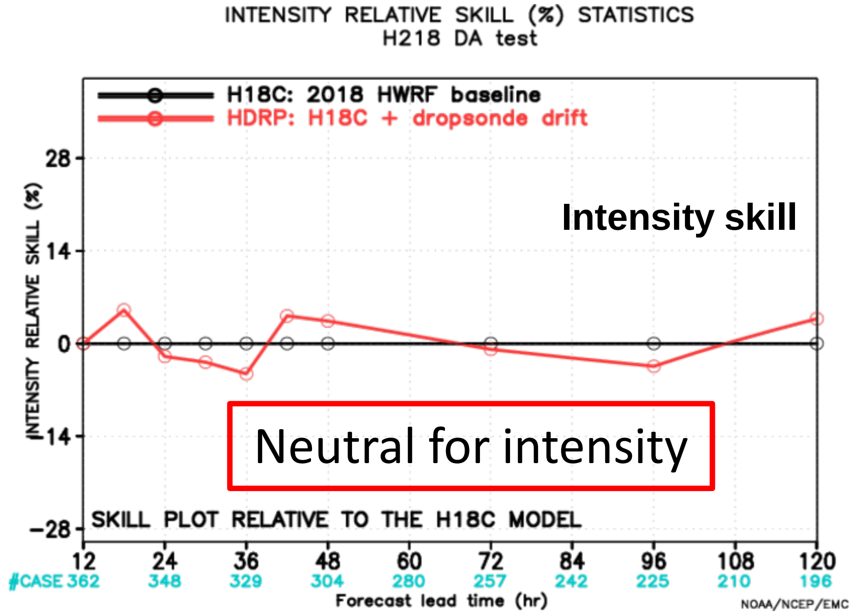
Overall positive impacts for both track and intensity

Dropsonde Drift Calculations



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.



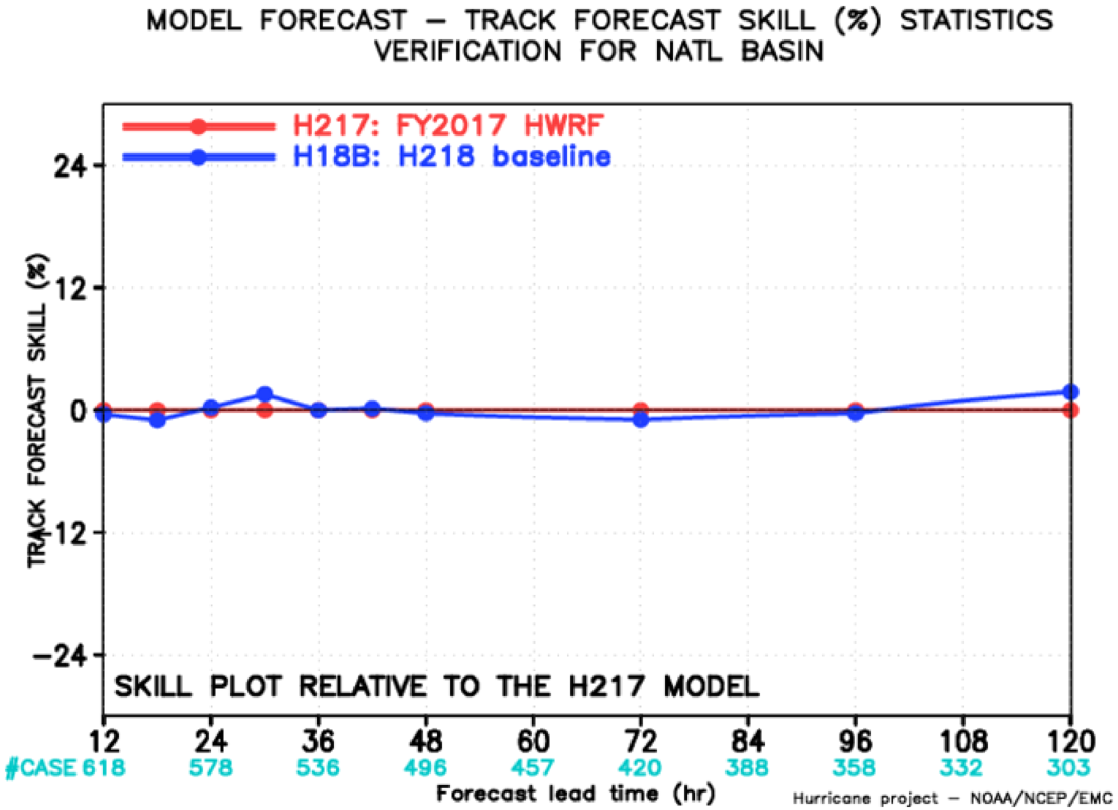


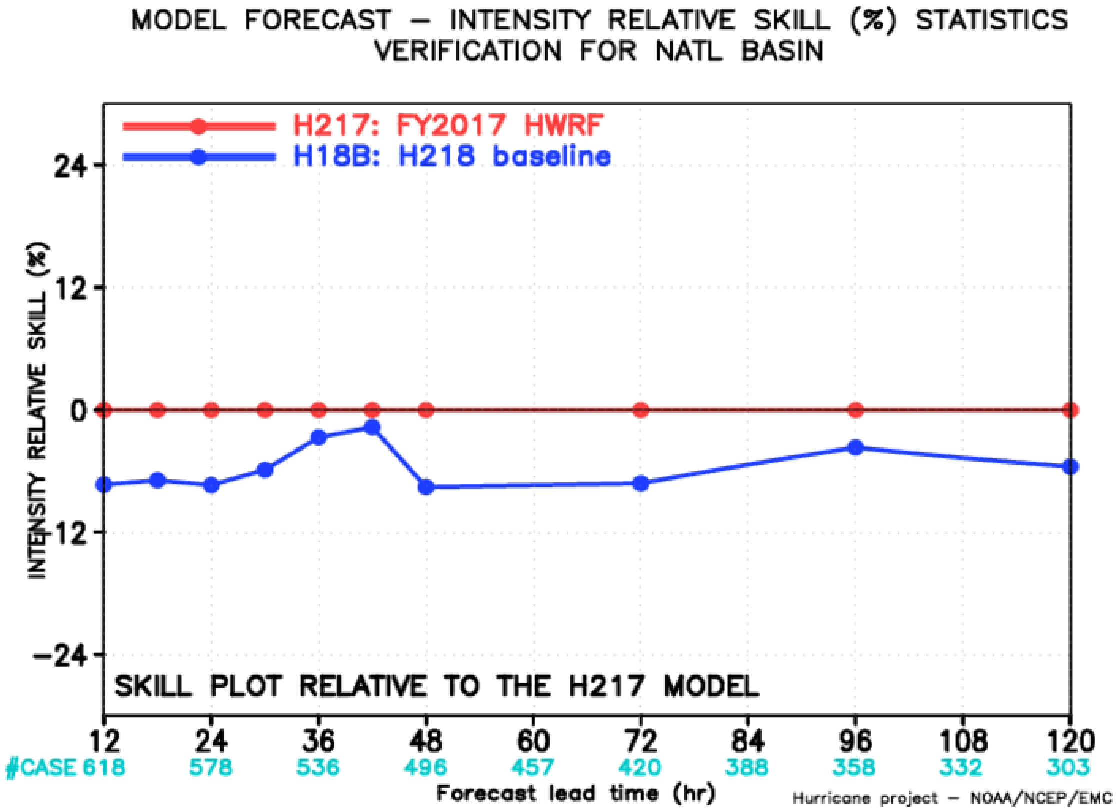
2018 HWRF Configurations (for NATL & EPAC)

- H217: FY17 HWRF using 2017 GFS
- H18B: baseline experiment
  - Framework and GSI upgrades
  - Unified HWRF/HMON coupler

H18B ≡ H217 (with no other system, physics or DA upgrades in 2018)

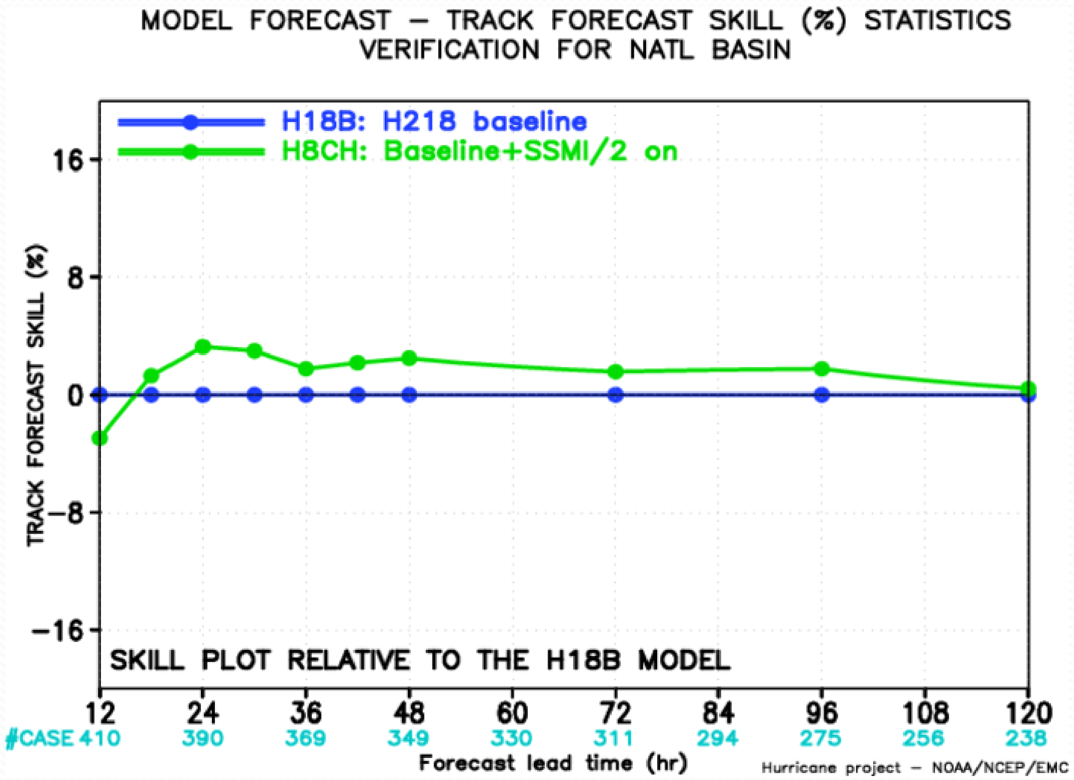
H18B Performance: Track and Intensity Skill

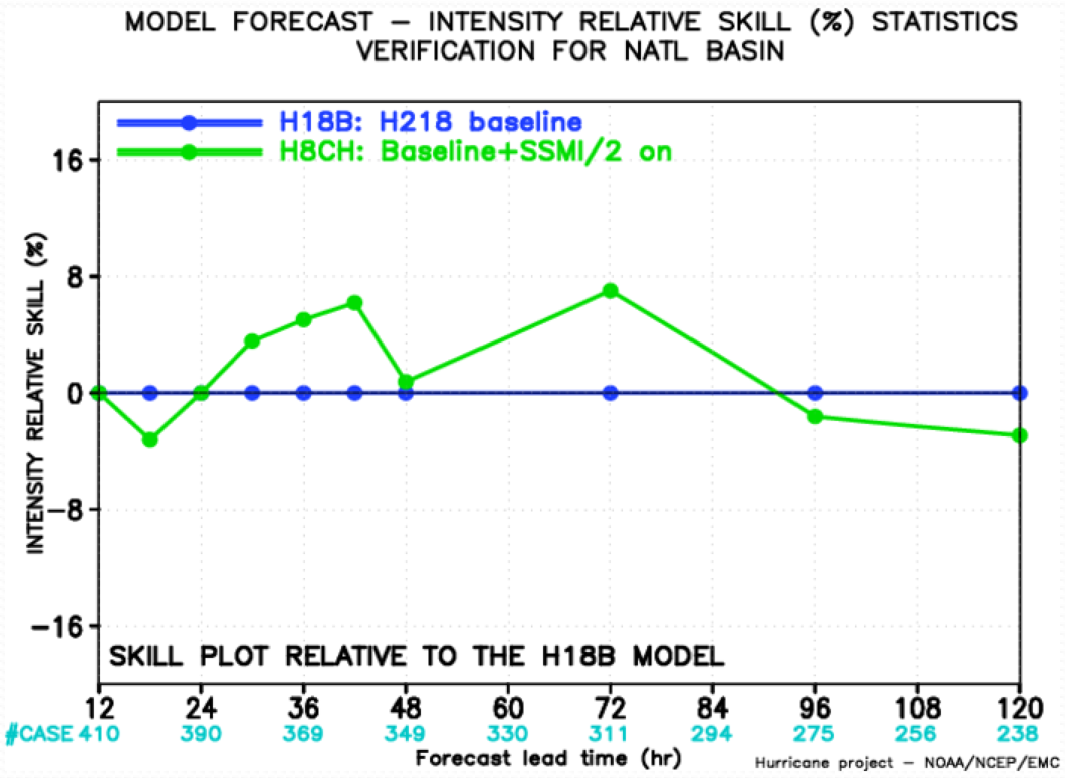




Track skill for H18B is neutral with respect to H217 but intensity is considerably behind. The intensity skill is degraded by almost 8% at Days 1 and 2. Intensity skill remain behind by more than 5% at Days 3 and 5.

Track and Intensity skill for NATL basin (2015-2017)
(Impact of SSMI Channel 2 Data on Baseline)





With SSMI/2 data, there is improvement in track skill for all lead times of around 2-3%. Intensity skill improvements are larger (~ 6% at hr 44 and ~7% at hr 72).

2018 HWRF Configurations (for NATL & EPAC)

- H217: FY17 HWRF using 2017 GFS
- H18B: baseline experiment
  - Framework and GSI upgrades
  - Unified HWRF/HMON coupler
- H8SC: H18B + horizontal resolution changed to 13.5/4.5/1.5 km
- HP2H: H8SC + modified d02, d03 domains (H8SL)
  - Cloud overlap modifications in RRTMG
- HP3H: HP2H + data assimilation upgrades
- **H218:** HP3H + adjustment to horizontal diffusion parameters
  - **Final FY18 HWRF configuration**

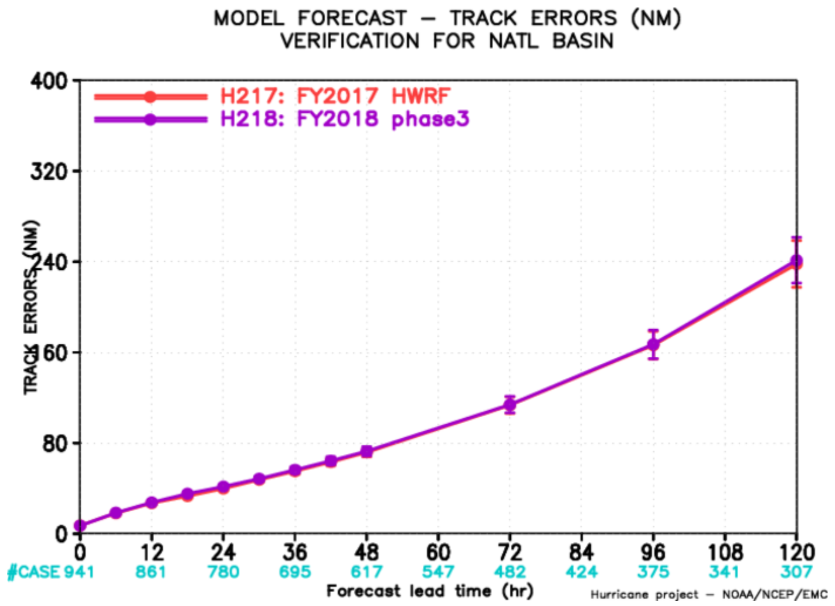
HWRF Upgrade Plan for 2018 Implementation

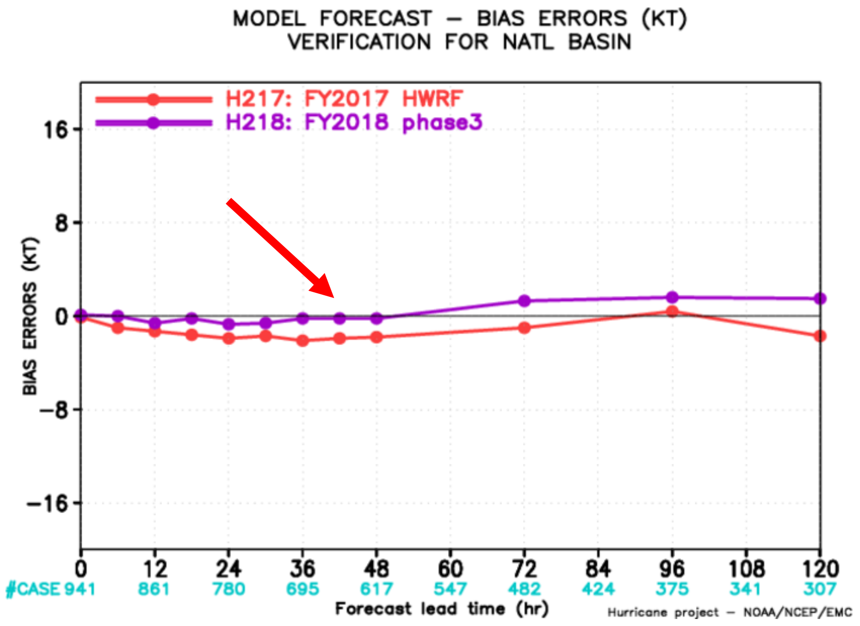
Multi-season Pre-Implementation T&E

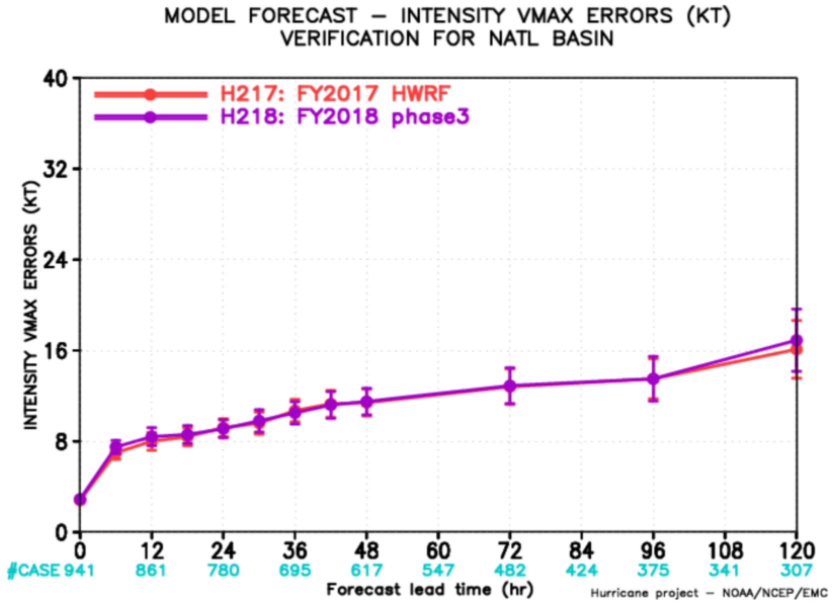
	Model upgrades	High resolution	Physics and DA upgrades		Combined
	Baseline (H18B)	**H8SC**	**Physics (HP2H)**	**Data Assimilation (HP3H)**	**H218**
Description	1. Framework upgrade to HWRFV3.9a; 2. GSI upgrades; 3. Unified Coupler.	Baseline + Higher horizontal resolution (1.5/4.5/13.5 kms)	Cloud overlap; PBL changes	Add dropsonde drifts; add SFMR, G-IV TDR; Stochastic physics DA	Baseline + all physics changes + all DA upgrades + adjusted diffusion coeffecients
Cases	Three-season 2015-2017 simulations in NATL cases (~1000)	Priority cases for 2015-2017 retrospectives in NATL (~1000)	Priority cases for 2015-2017 retrospectives in NATL (~1000)	Priority cases for 2015-2017 retrospectives in NATL/EPAC (~2000)	**Three-season 2015-2017 retrospectives ~3000 simulations in all TC basins**
Platform	WCOSS/Jet	WCOSS Cray	WCOSS/Jet	WCOSS/Jet	**WCOSS Cray/Jet**

HWRF (H218) Verification for Atlantic Storms (2015-2017)

H218 Performance (NATL Basin): Track and Intensity Errors



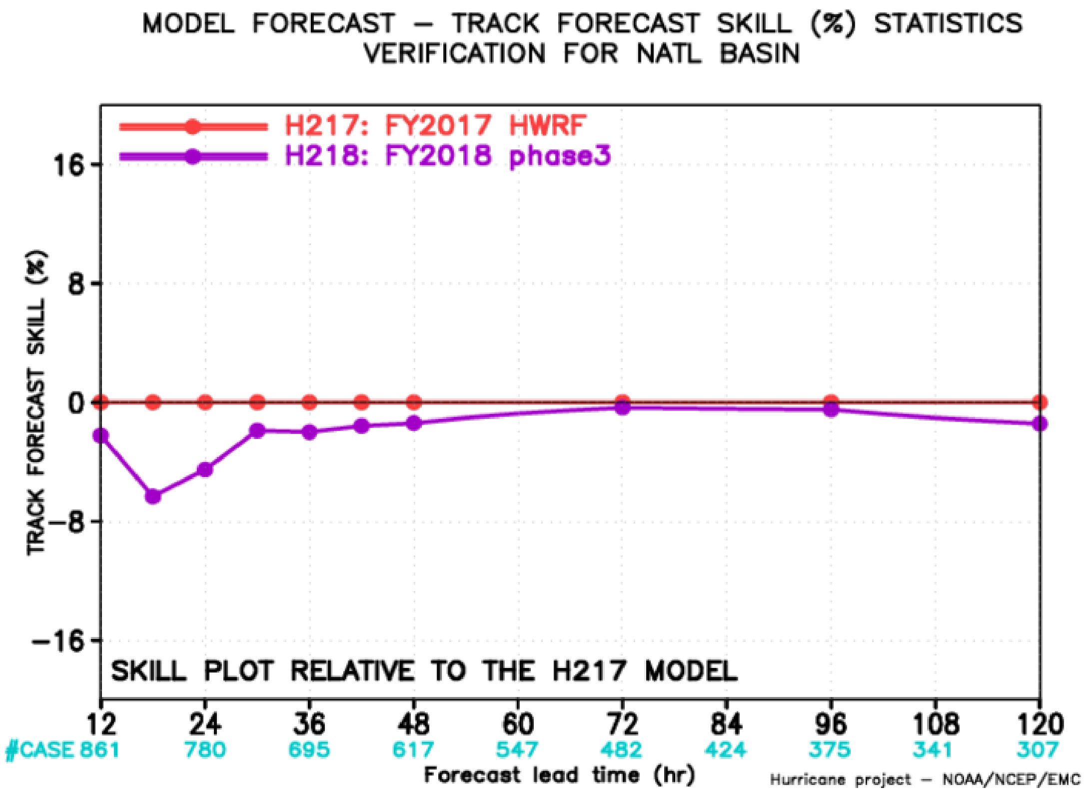


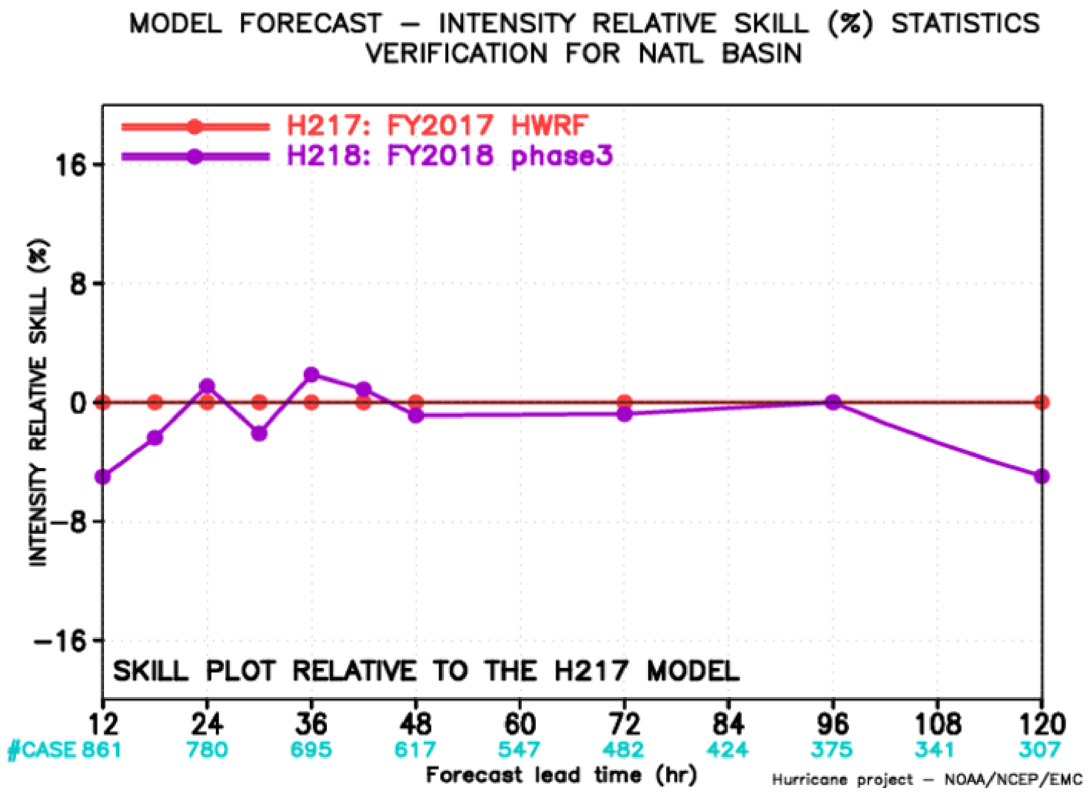


H218 has very similar track errors compared to H217. H218 has also similar intensity errors which is a substantial improvement over H18B.

H218 has much lower bias errors as compared to H217 for early lead times.

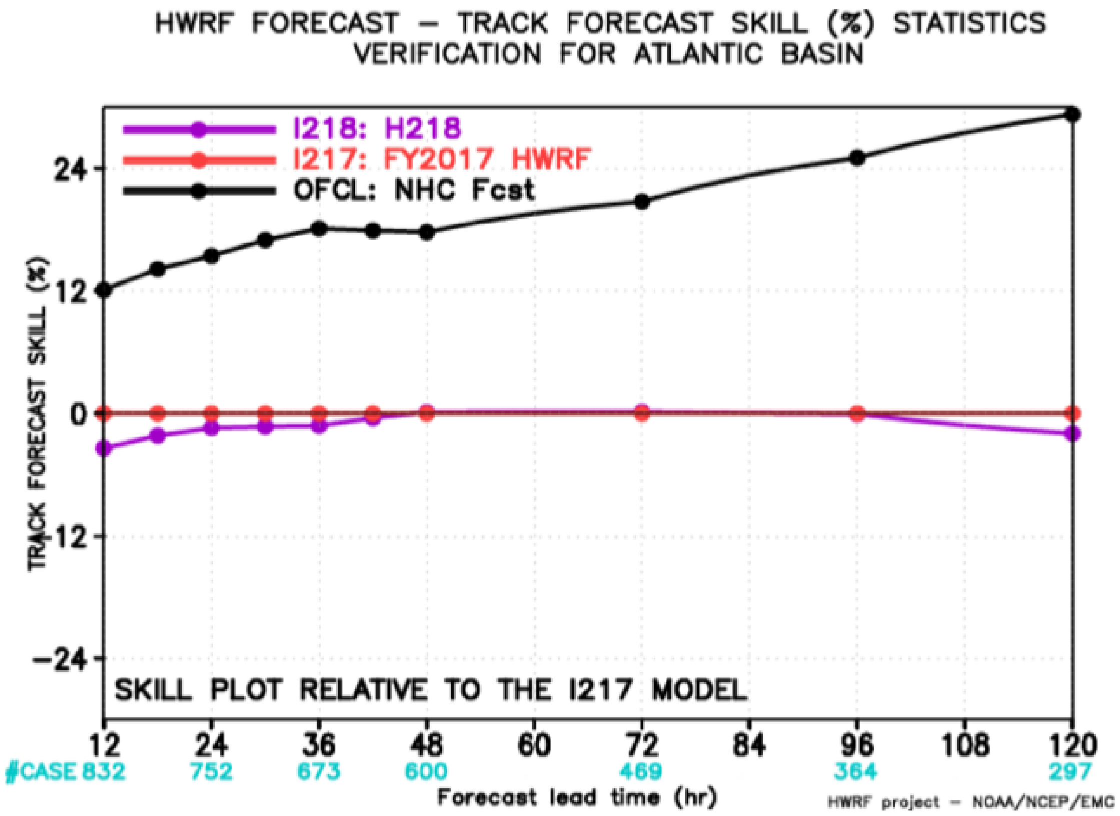
Track and Intensity Skills: NATL Basin (Late Model)

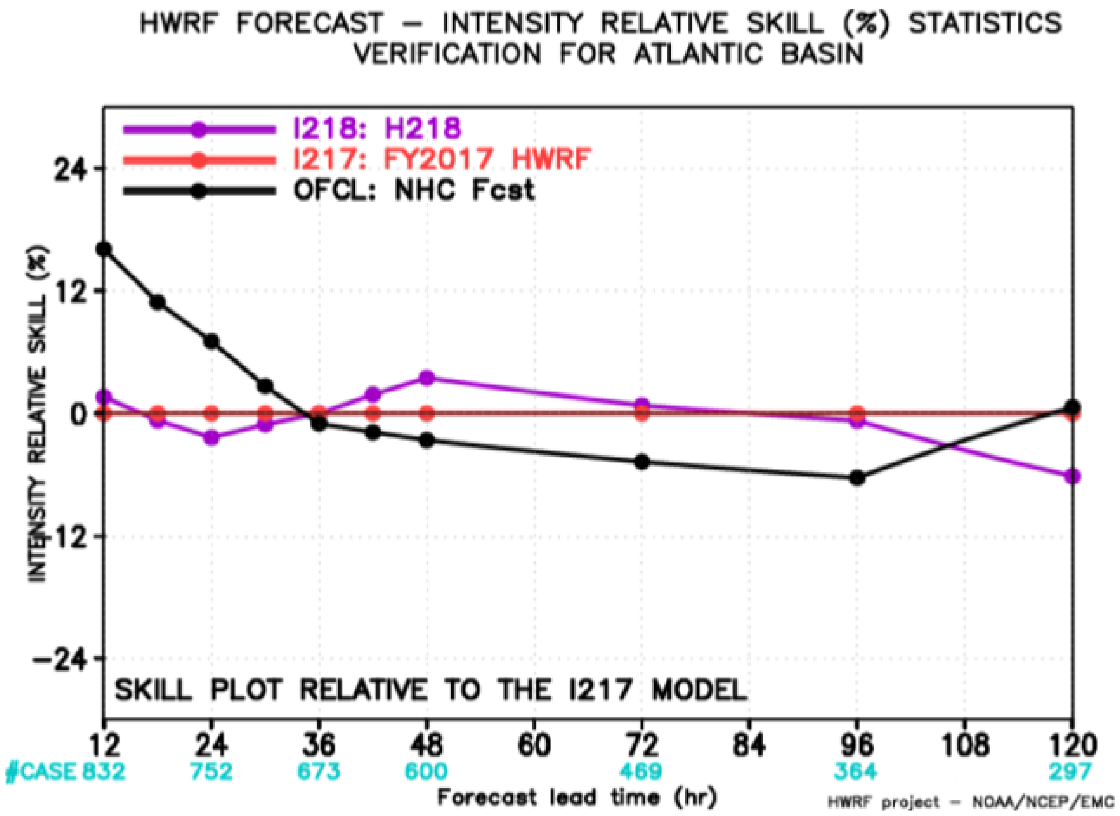




Track skill for H218 is neutral compared to H217 after 30 hrs. Intensity shows some improvements (< 2%) in the first 2 days but lower skill at Day 5. Overall both are close to neutral.

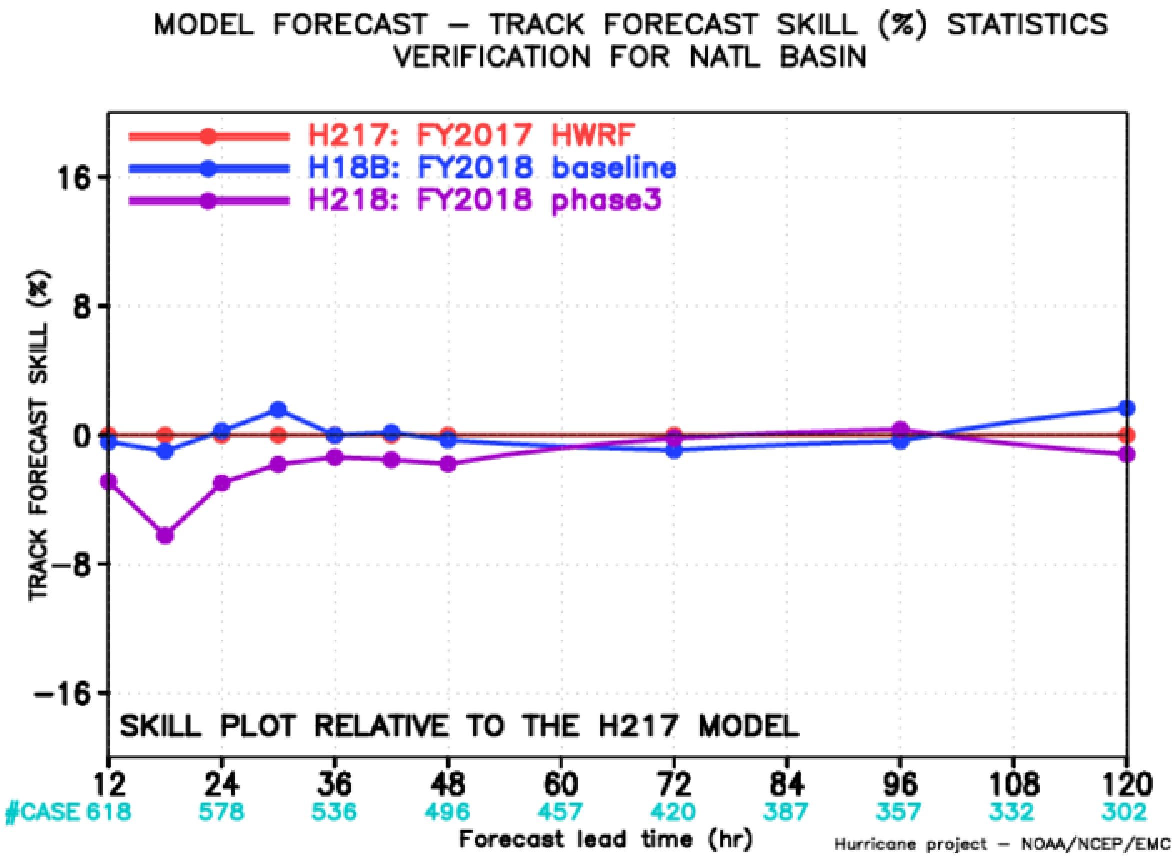
Track and Intensity Skills: NATL Basin (Early Model)

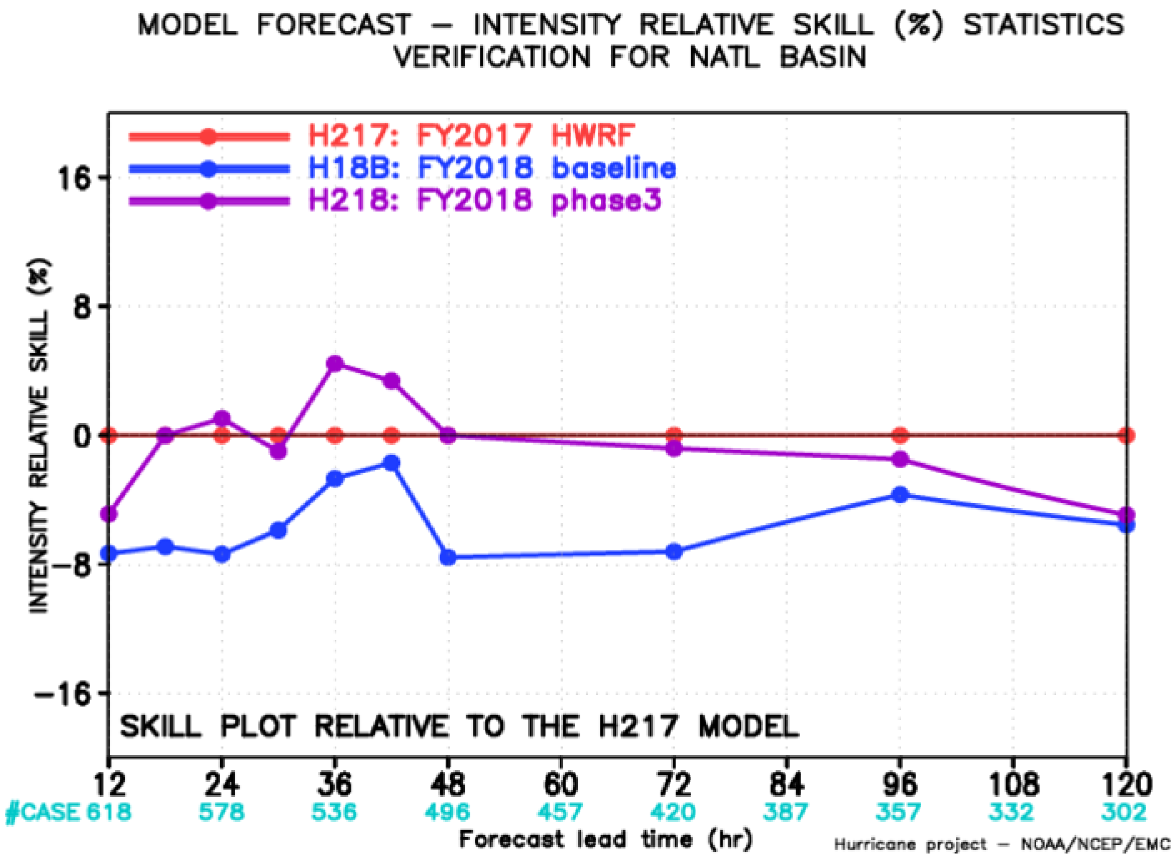




Track skill for H218 is neutral with respect to H217 results. Intensity skill is neutral to positive through Day 4 but negative at Day 5. H218 beats official intensity forecasts between hrs 36 and 108.

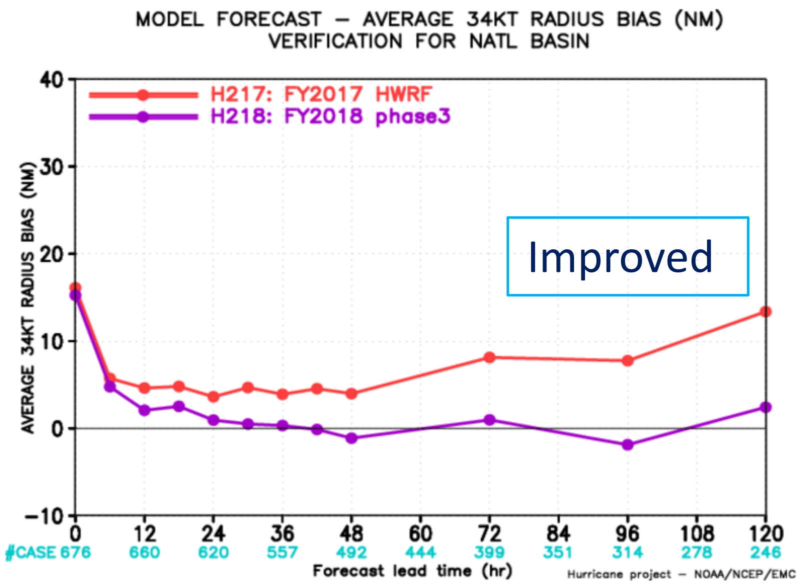
H218 and H18B vs H217 (NATL Basin): Track and Intensity Skills

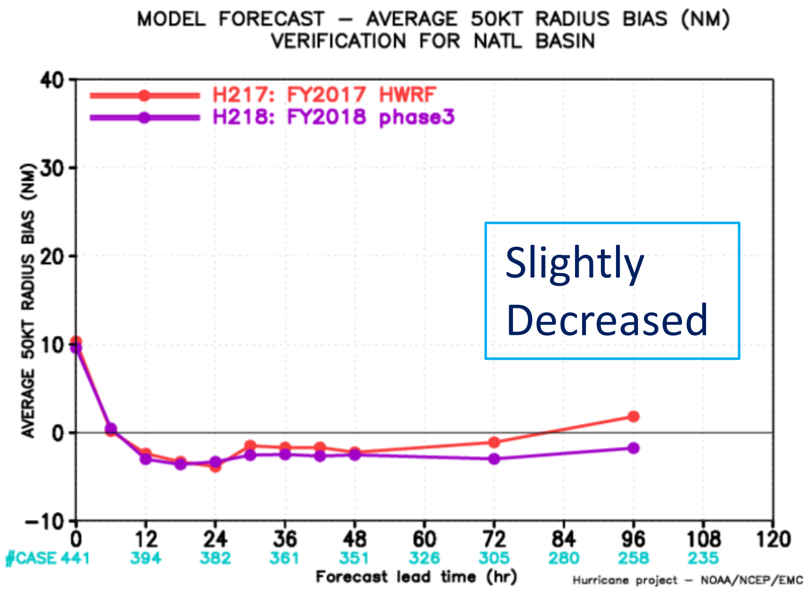


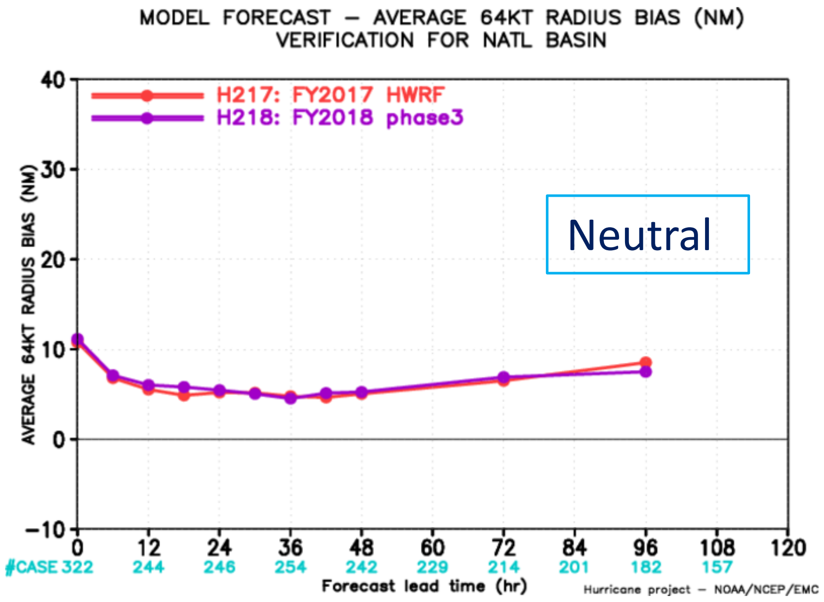


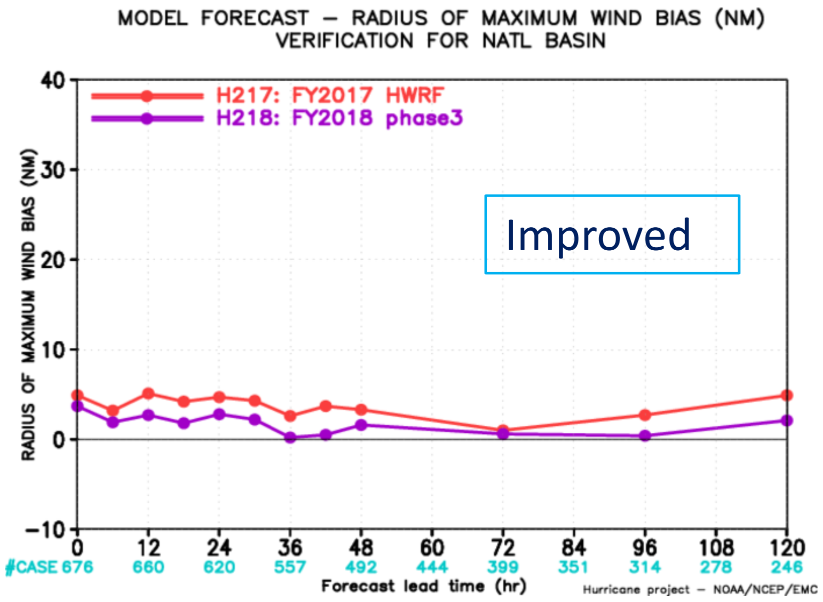
Track skill for H218 and H18B are very similar and neutral with respect to H217. For this homogenous sample, intensity skill of H218 is ahead of H18B by >5% through Day 3.

H218 Performance (NATL Basin): Storm Size Improvements*



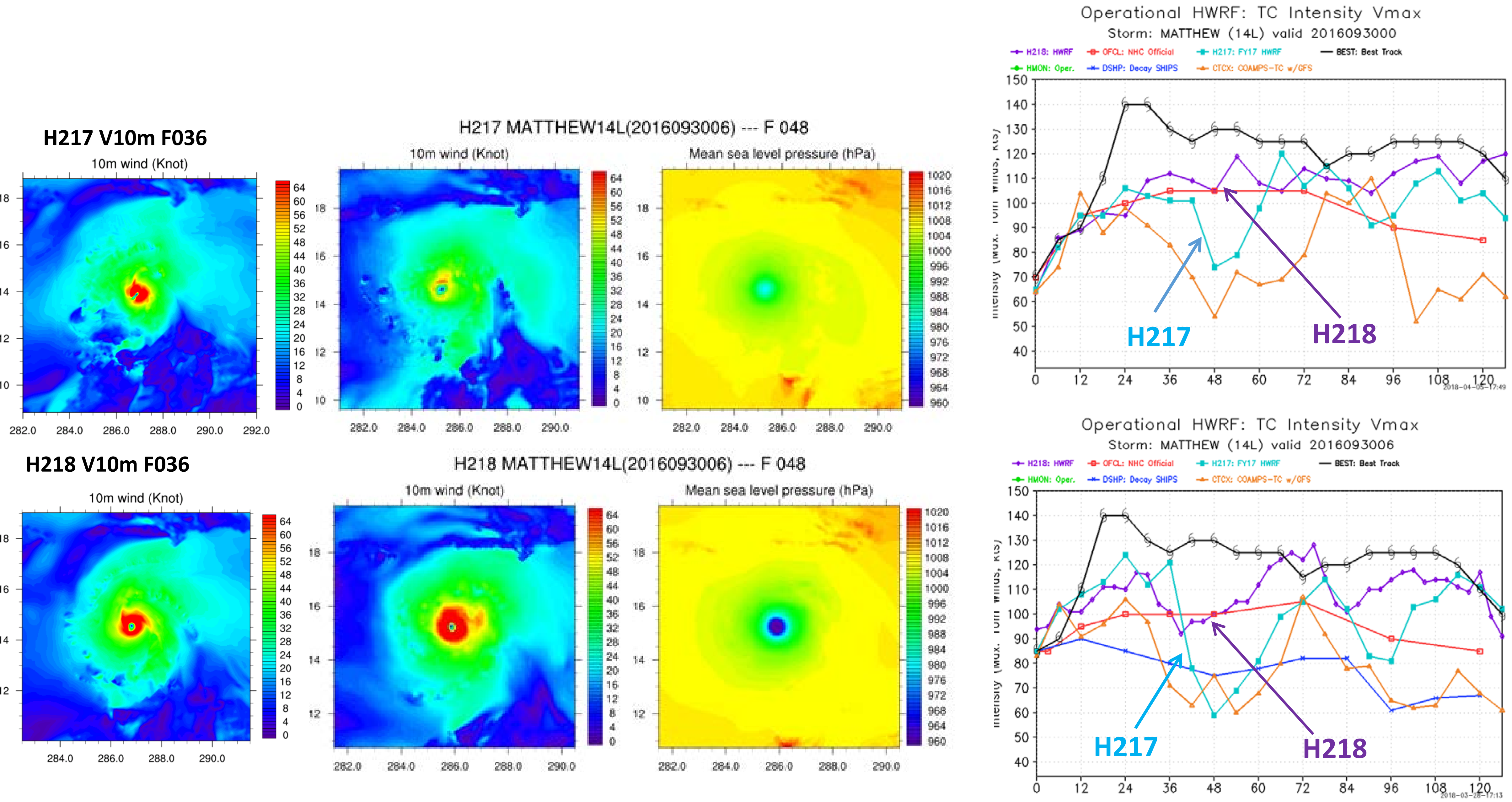




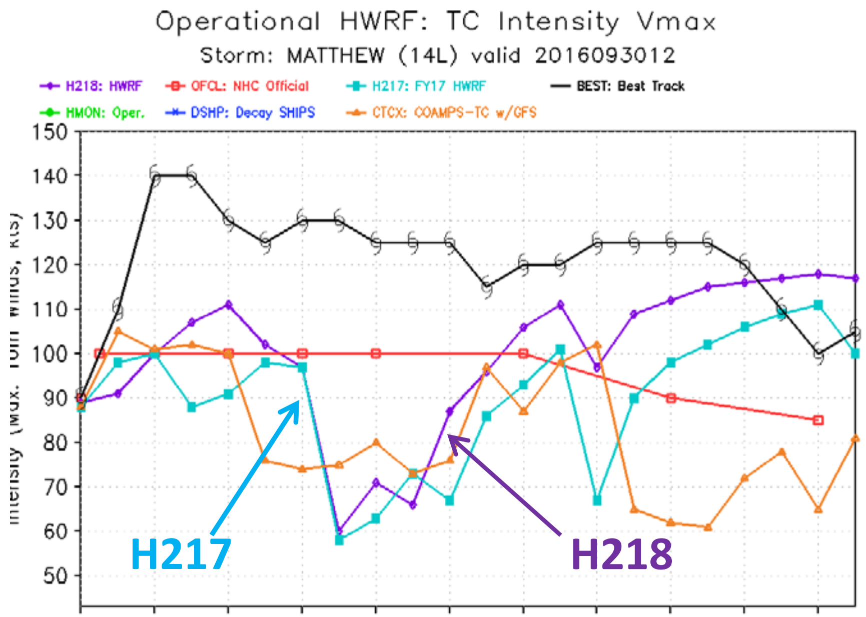


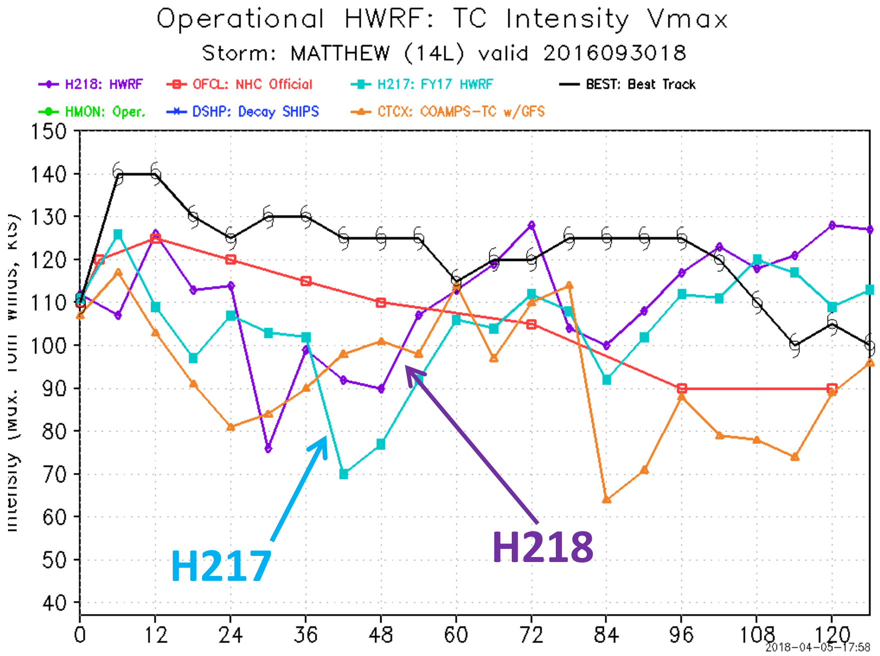
* official storm size estimates can have large errors for non-recon storms especially for RMW

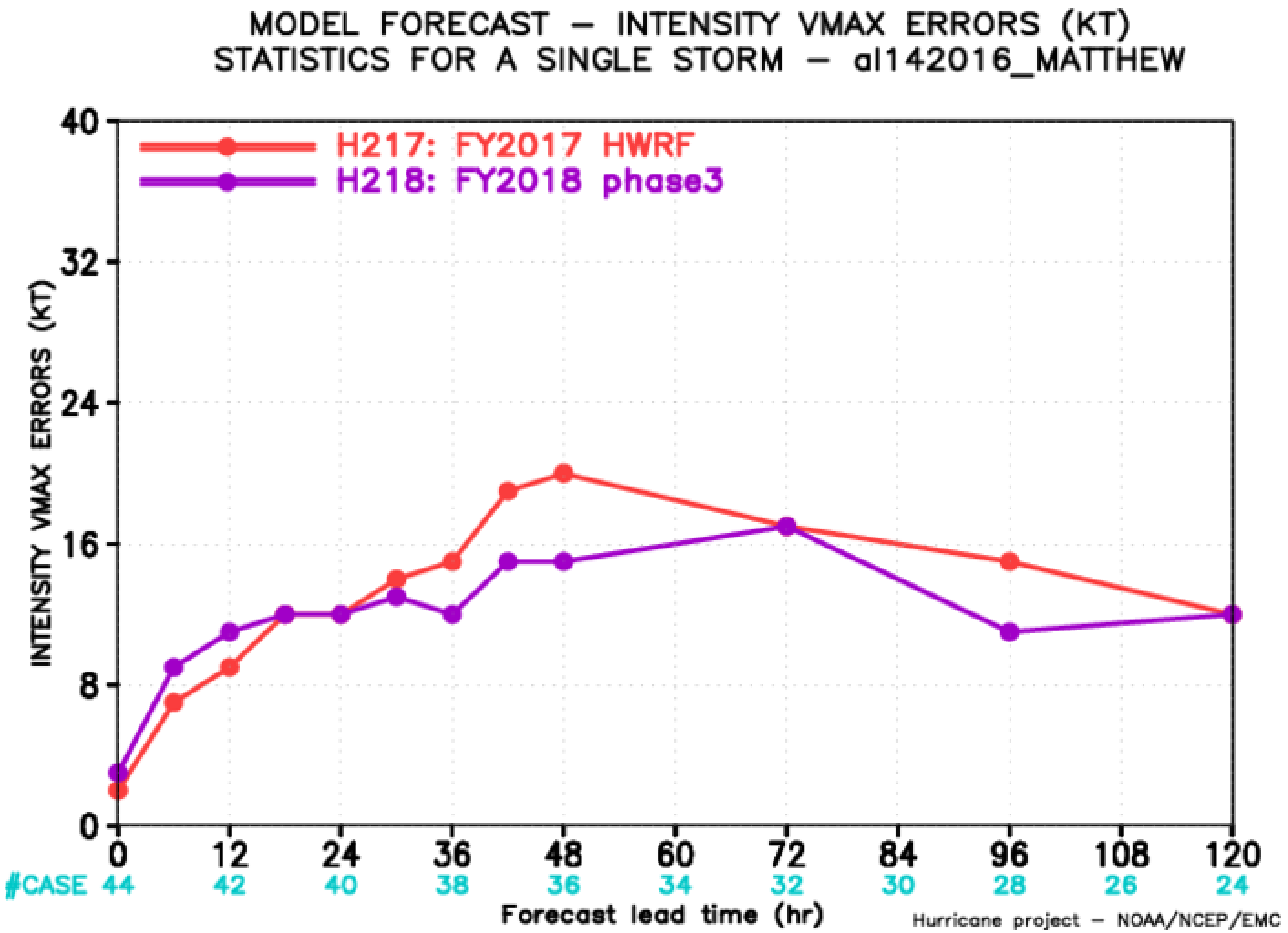
Intensity Oscillations for Matthew Improved in H218



Even though not eliminated, overall errors are reduced.

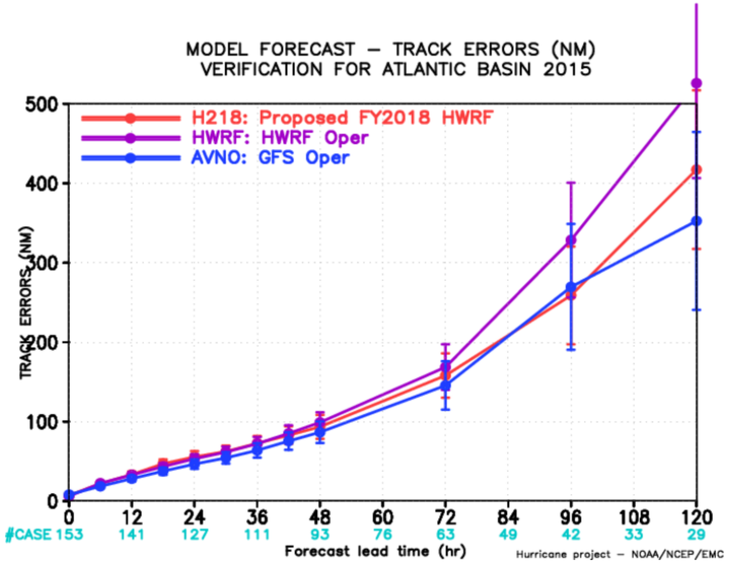


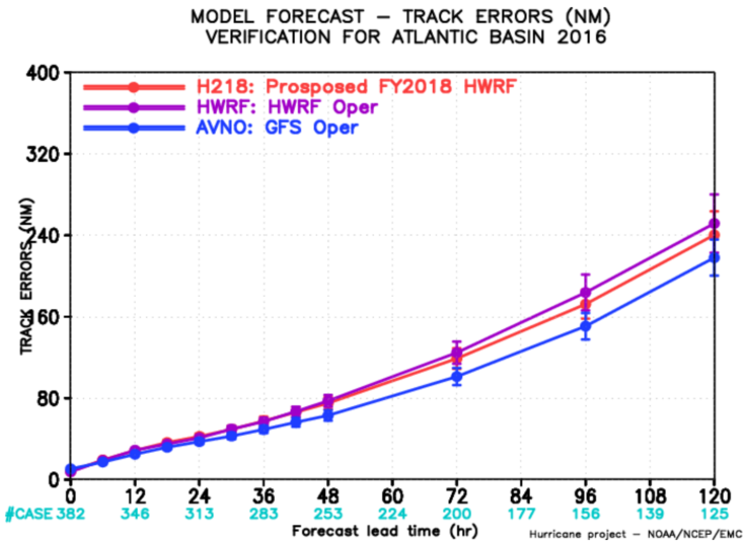


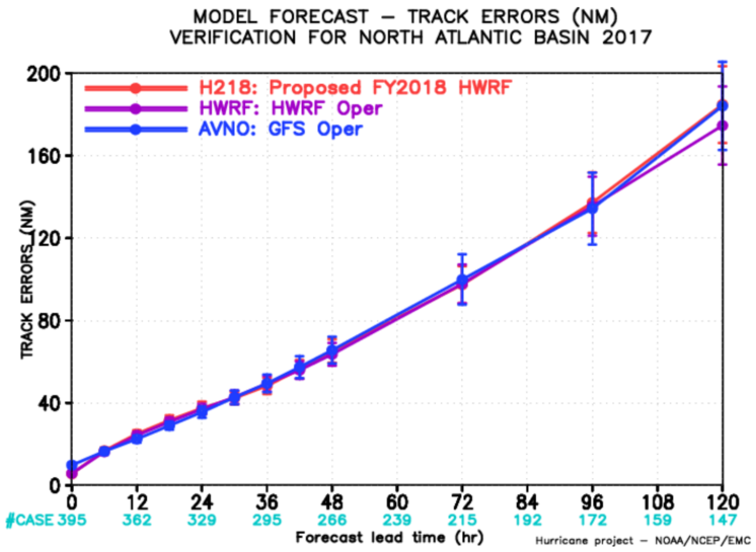


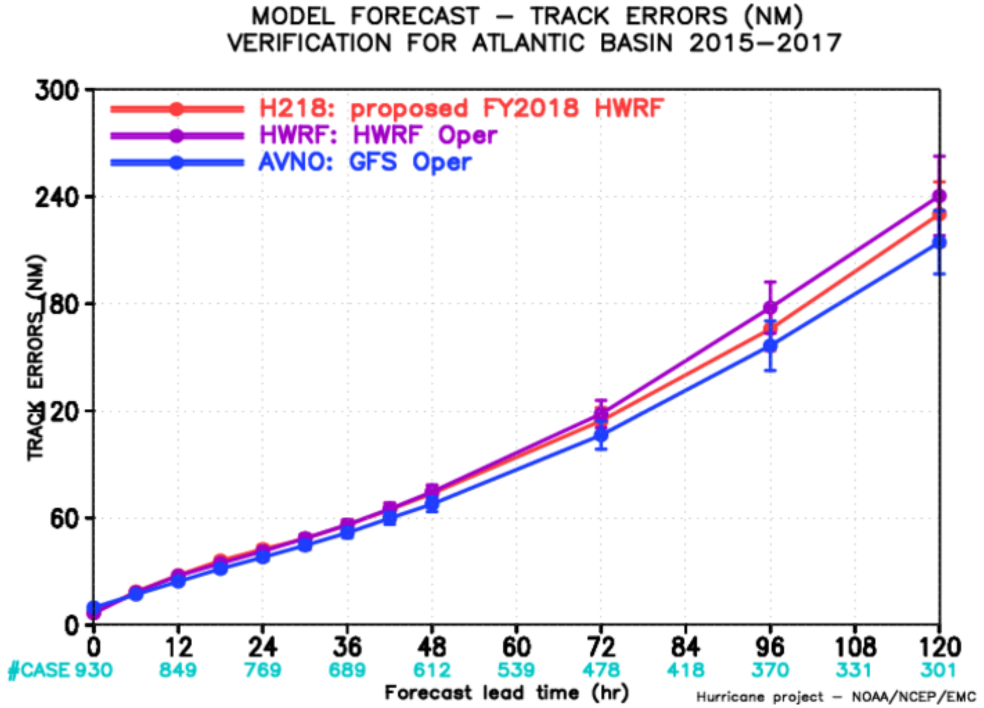
H218 intensity errors are substantially reduced for Hurricane Matthew beyond Day 1.

Historical H218 Performance (NATL Basin): Track Errors from 2015-2017



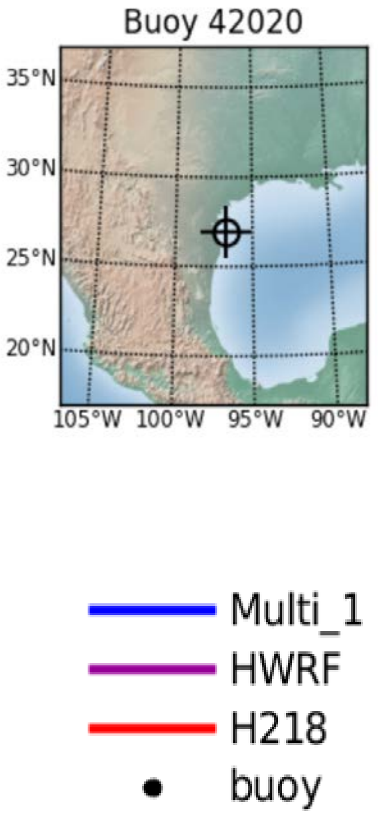


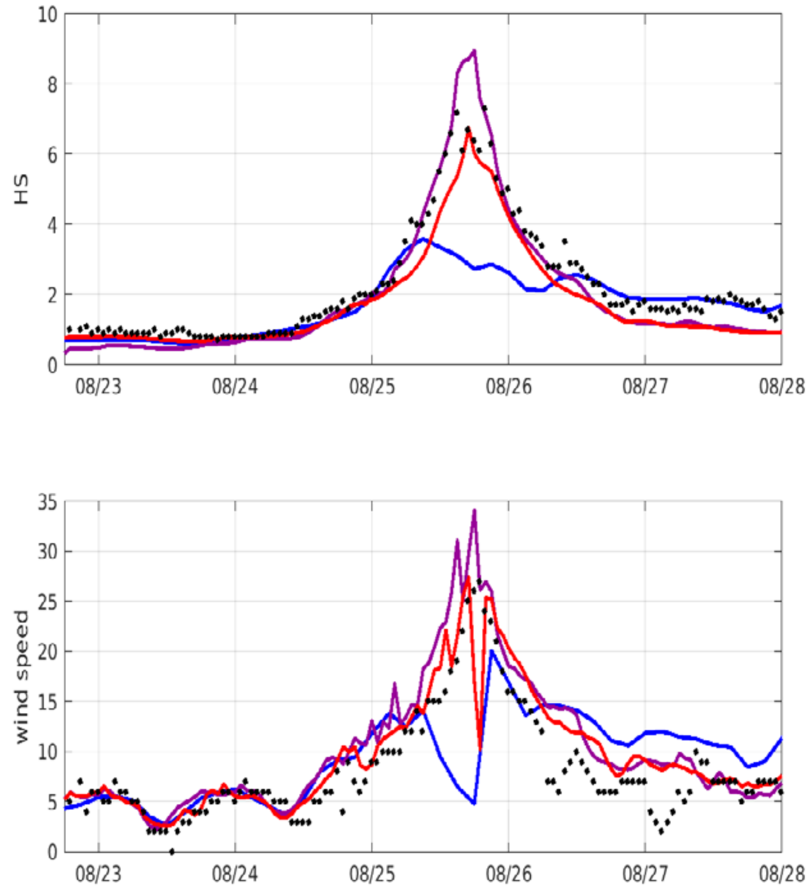




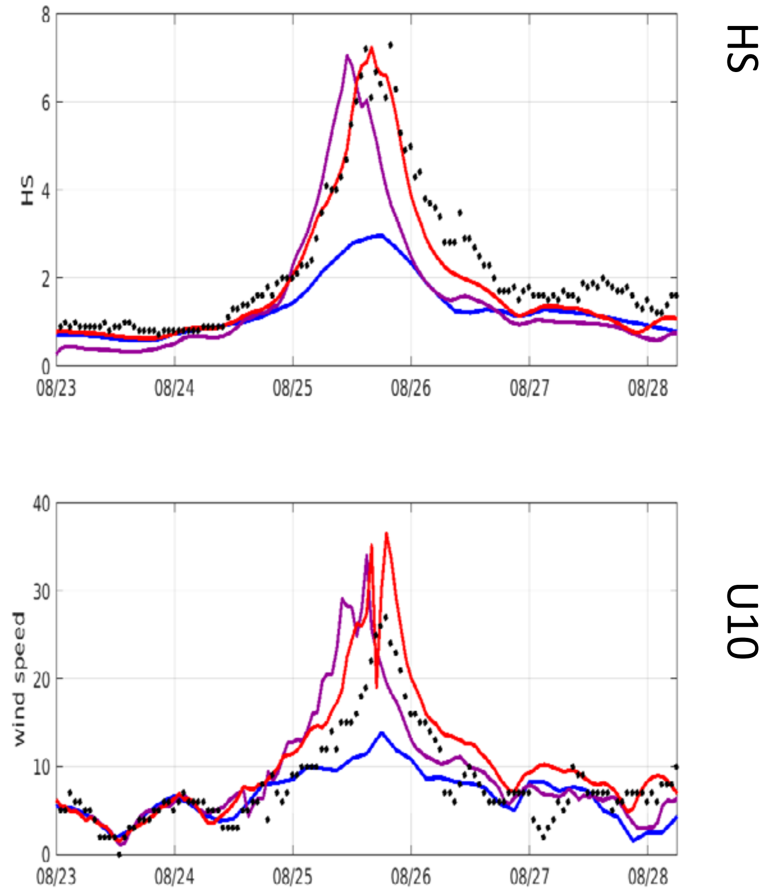
Retrospective H218 results maintain track error improvements over operational HWRF and GFS for individual years 2015-2017 (top panels) and overall (left panel) for the last 3 years.

WAVEWATCH III results for Hurricane Harvey (09L2017) with H218
(One way coupled)



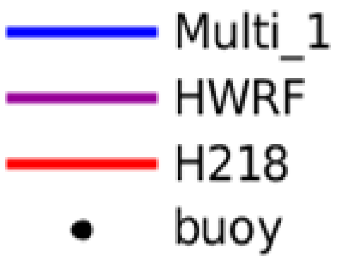


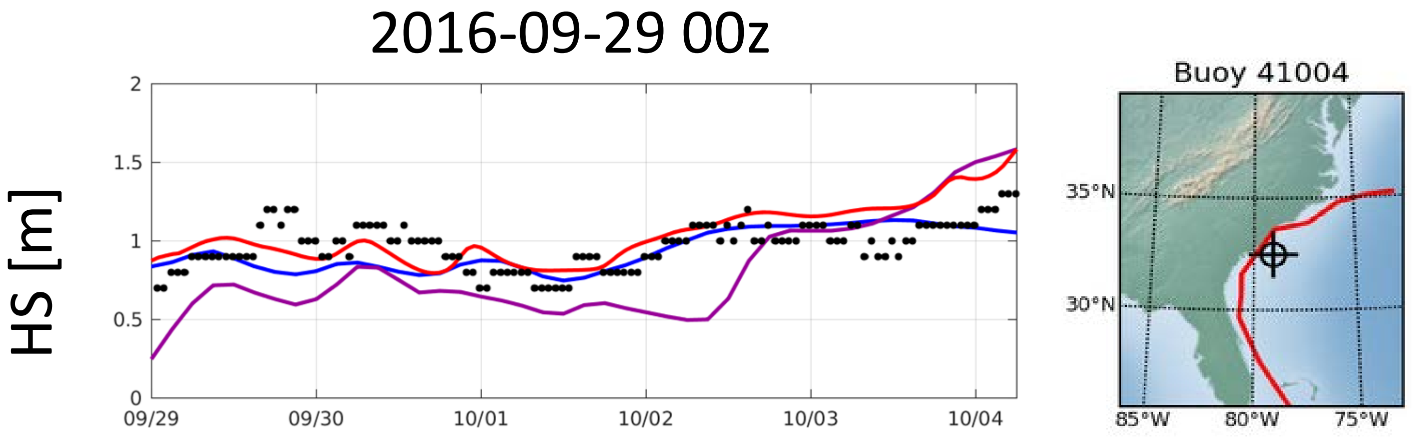
2017-08-22 18z



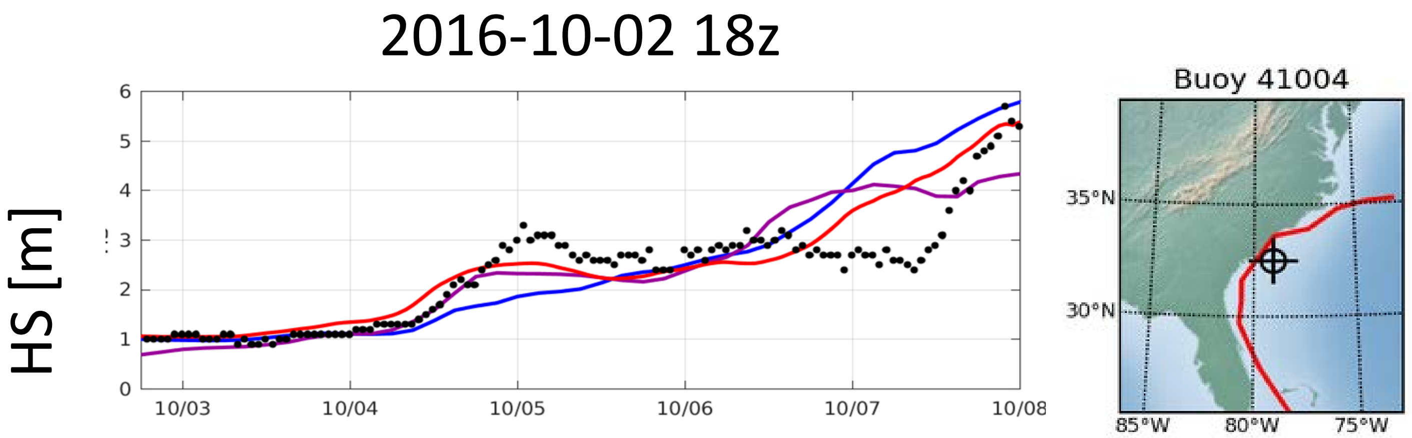
2017-08-23 00z

WAVEWATCH III results for Hurricane Matthew (14L2016) with H218 (One way coupled)



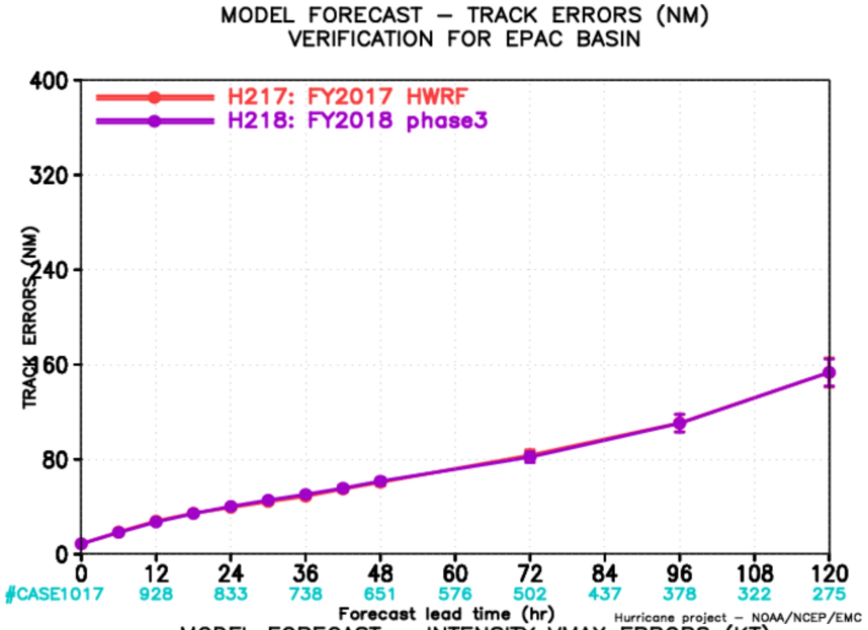


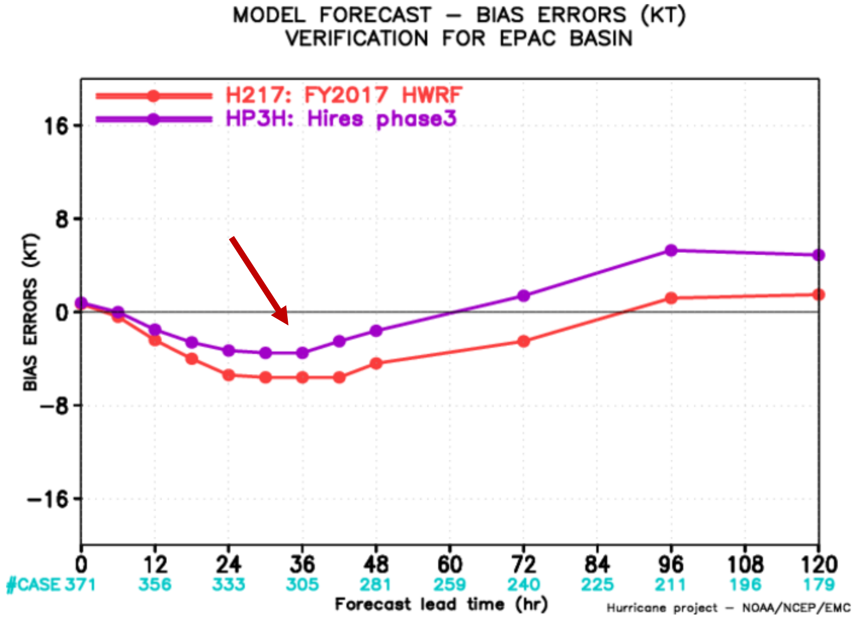
In H218 the initial condition for WW3 comes from Multi_1 (Global Wave Model). The effect of the initial condition at Buoy 41004 is evident for 12+ cycles

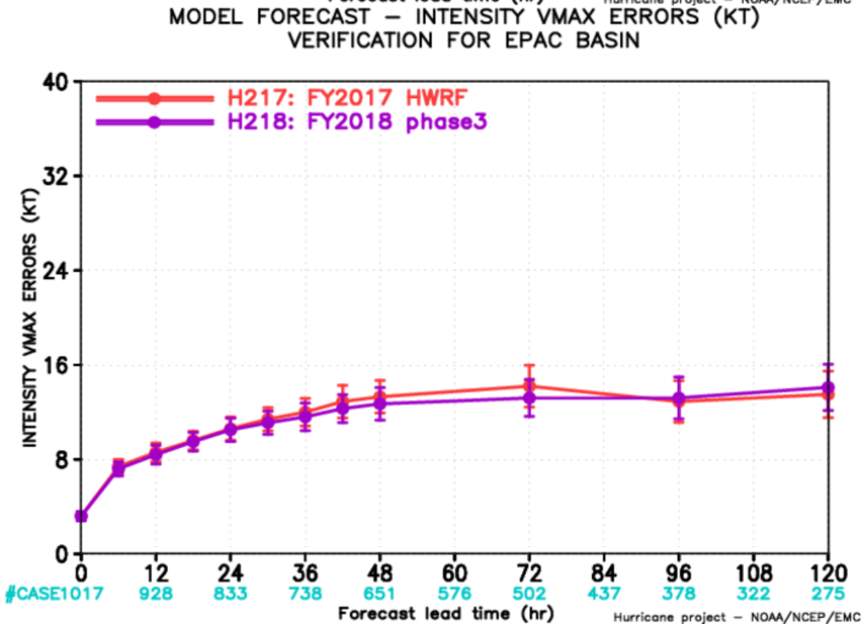


HWRF (H218) Verification for East Pacific Storms (2015-2017)

H218 Performance (EPAC Basin): Track and Intensity Errors



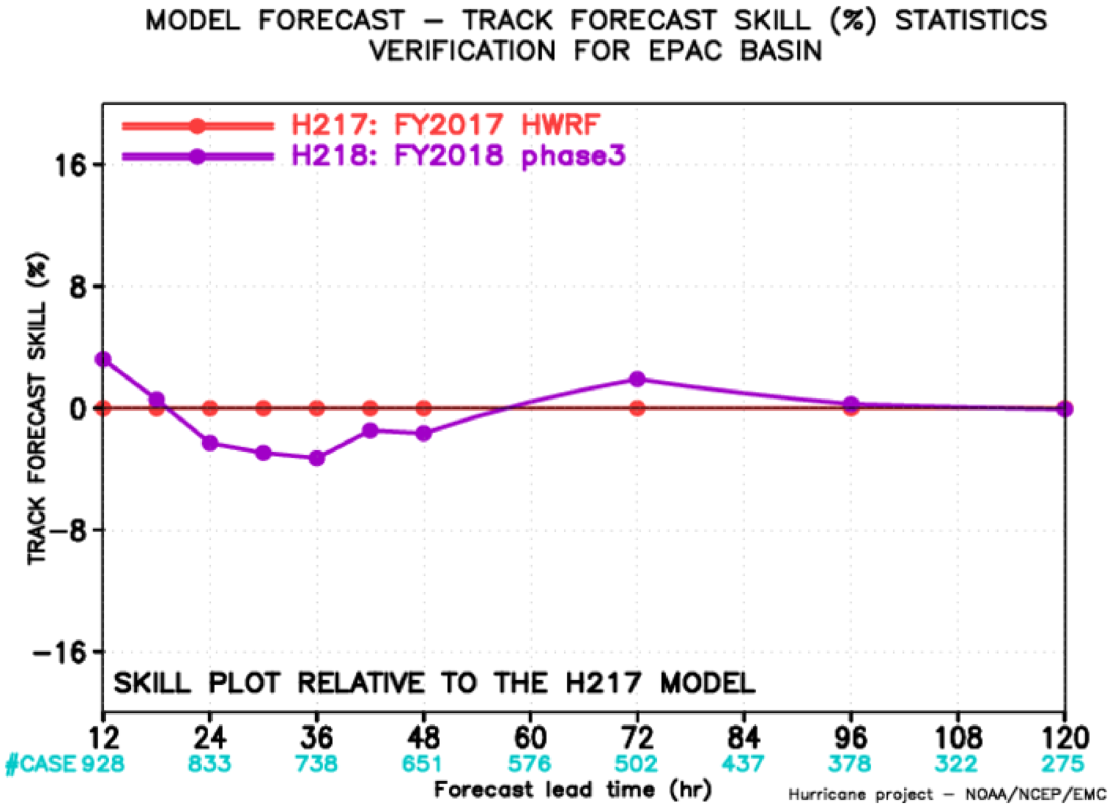


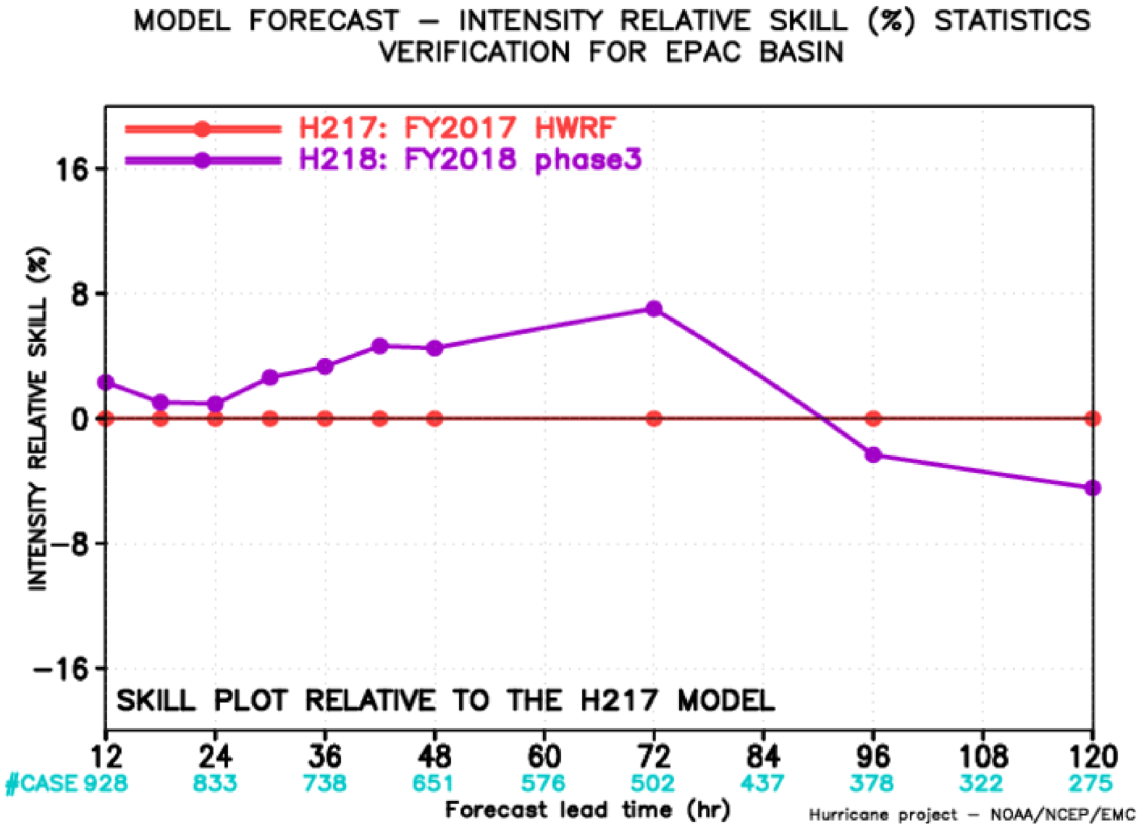


H218 has very similar track errors as compared to H217. The intensity errors are smaller up to Day 4 and then larger for Days 5.

H218 has lower bias errors for the first 3 days but larger positive bias for Days 4 and 5.

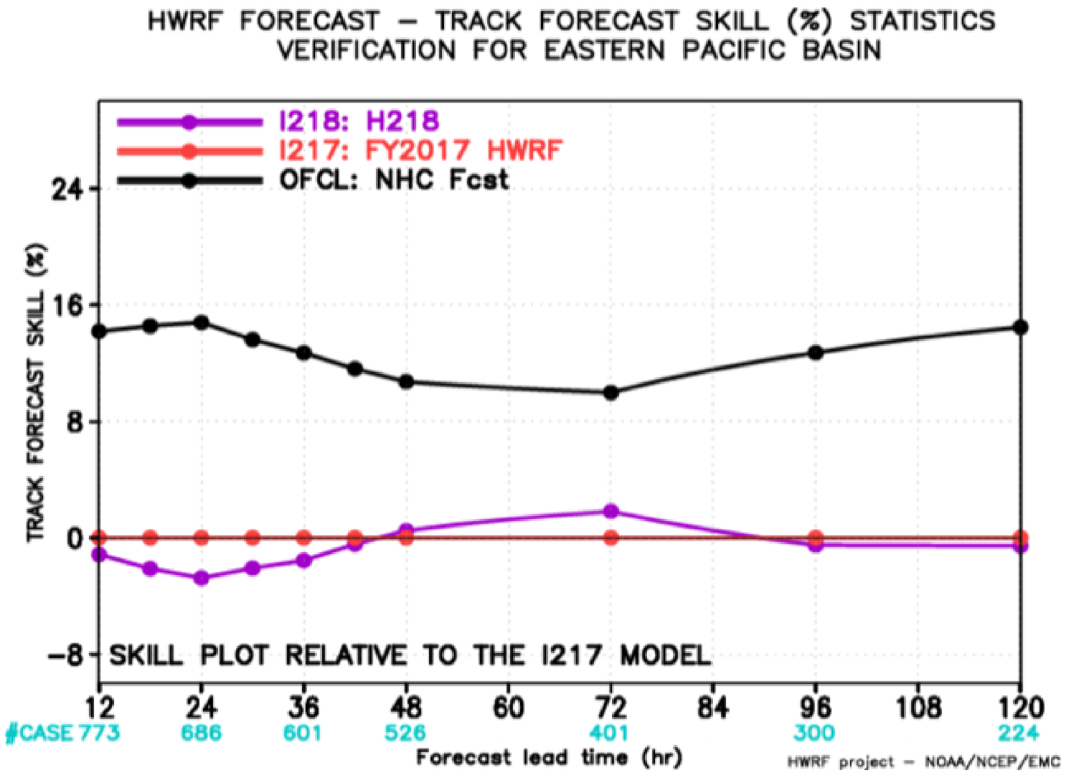
Track and Intensity Skills for EPAC Basin (Late Model)

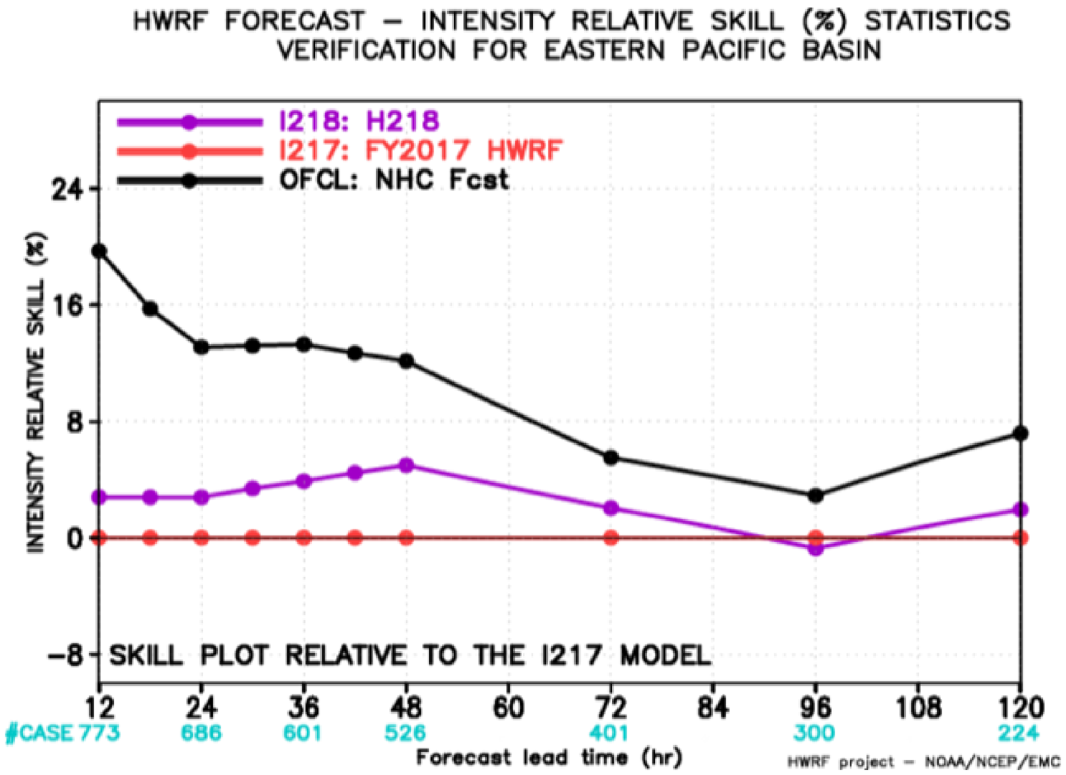




Track skill is slightly reduced for the first 2 days but is ahead for longer lead times after hr 60. Intensity skill is positive for early lead times and improved by almost 8% by Day 3. It is somewhat reduced for longer lead times.

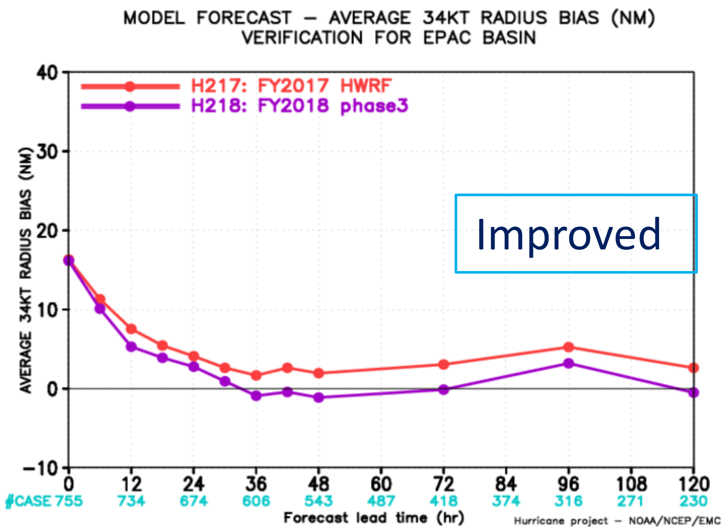
Track and Intensity Skills for EPAC Basin (Early Model)

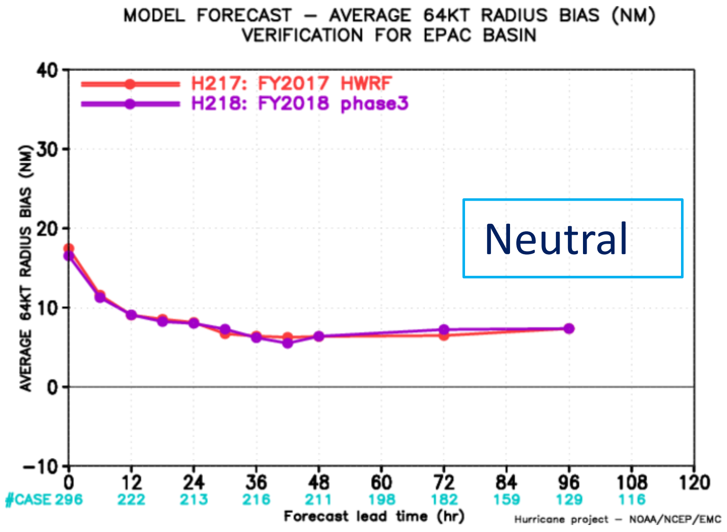


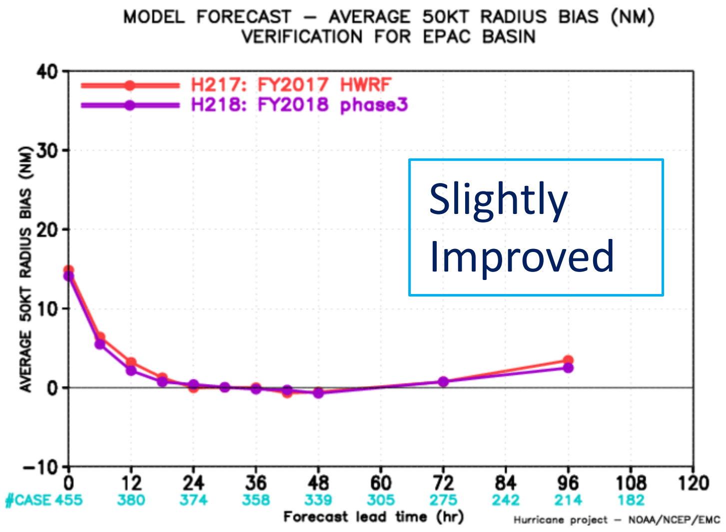


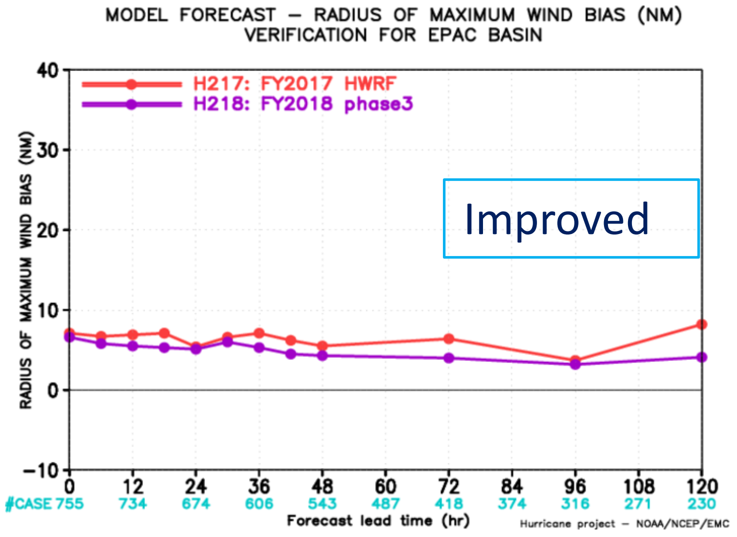
Official track and intensity skills are ahead of H218 but the gap has narrowed for intensity for longer lead times.

H218 Performance (EPAC Basin): Storm Size Improvements*









* official storm size estimates can have large errors for non-recon storms especially for RMW

Operational HWRF Configurations: 2017 (top) vs. 2018 (bottom)

Basin	Ocean	Data Assim	Ensemble	Vertical	Model Top	Horizontal Resolution
NATL	3D POM GDEM	Always	TDR self-cycled	75 level	10 mbar	18/6/2 kms
EPAC	3D POM RTOFS	Always	TDR self-cycled	75 level	10 mbar	18/6/2 kms
CPAC	3D POM RTOFS	None	None	75 level	10 mbar	18/6/2 kms
WPAC	3D HYCOM	None	None	61 level	10 mbar	18/6/2 kms
NIO	3D HYCOM	None	None	61 level	10 mbar	18/6/2 kms
SIO	None	None	None	43 level	50 mbar	18/6/2 kms
SPAC	None	None	None	43 level	50 mbar	18/6/2 kms
NATL	3D POM GDEM	Always	TDR self-cycled	75 level	10 mbar	**13.5/4.5/1.5 kms**
EPAC	3D POM RTOFS	Always	TDR self-cycled	75 level	10 mbar	**13.5/4.5/1.5 kms**
CPAC	3D POM RTOFS	None	None	75 level	10 mbar	**13.5/4.5/1.5 kms**
WPAC	3D HYCOM	None	None	**75** level	10 mbar	**13.5/4.5/1.5 kms**
NIO	3D HYCOM	None	None	**75** level	10 mbar	**13.5/4.5/1.5 kms**
SIO	**3D HYCOM**	None	None	**75** level	**10** mbar	**13.5/4.5/1.5 kms**
SPAC	**3D HYCOM**	None	None	**75** level	**10** mbar	**13.5/4.5/1.5 kms**

Summary

- Further enhancements suggested for 2018 operational HWRF include:
  - Upgrades in model components consistent with observations, data assimilation improvements including GSI and improved ocean initializations.
- H218 retrospective evaluation of 2015-2017 hurricane seasons (total 941 verifiable cycles in NATL, 1017 in EPAC) demonstrated neutral to improved forecasts compared to FY17 operational HWRF (H217) and substantially improved over the baseline H18B driven by 2017 GFS;
- Results from H218 for the Atlantic basin and the North East Pacific suggested modest improvement compared to H217 for intensity (< 5%) and neutral performance for tracks;
- Results suggest reduction in intensity errors and bias for strong storms (initial intensity > 50 kts) for both (NATl, EPAC) basins;
- Storm size errors and bias were reduced for both basins at all lead times;

Summary (cont.)

- The one –way coupled WaveWatch III in H218 gives better results for Significant Wave Heights as compared to 2017 operational HWRF;
- Evaluation metrics in the skill space confirmed some positive improvements from H217;
- Horizontal and vertical high resolution, and ensemble based inner-core DA pave way for the planned future Hurricane Analysis and Forecast System (HAFS), while also bringing immediate benefits in the operations;
- Centralized HWRF Development Process for both research and operations with community involvement is critical for making further enhancements;
- Seek more direct engagement of HFIP supported researchers for active participation in model evaluation, enhancements and future R2O;
- **Full credit to the entire EMC Hurricane team, NHC, HRD team and DTC team for another successful execution of pre-implementation T&E for implementing improved HWRF model in operations.**

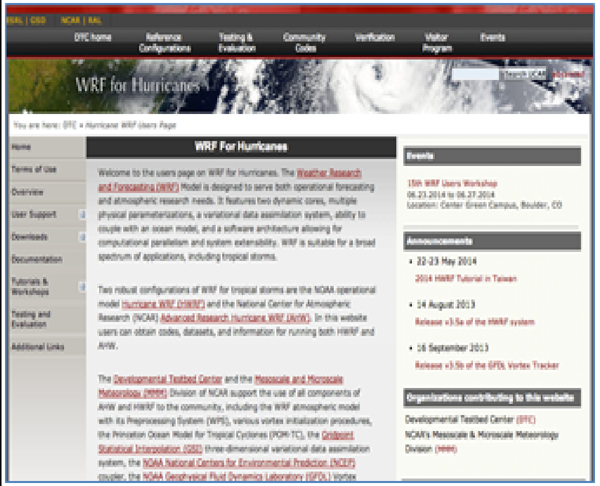
HWRF as a unique global tropical cyclone model

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

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

Developmental Testbed Center Support

www.dtcenter.org/HurrWRF/users



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

Current release: HWRF v3.5b (2013 operational with several patches)

Next: HWRF v3.6a (2014 operational) 08/2014, concurrent with operational implementation

DTC Developmental Testbed Center

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

NATIONAL HURRICANE CENTER

Japan Meteorological Agency

International partnerships for accelerated model development & research

HMON

THE HURRICANE MULTISCALE OCEAN-COUPLED NON-HYDROSTATIC MODEL

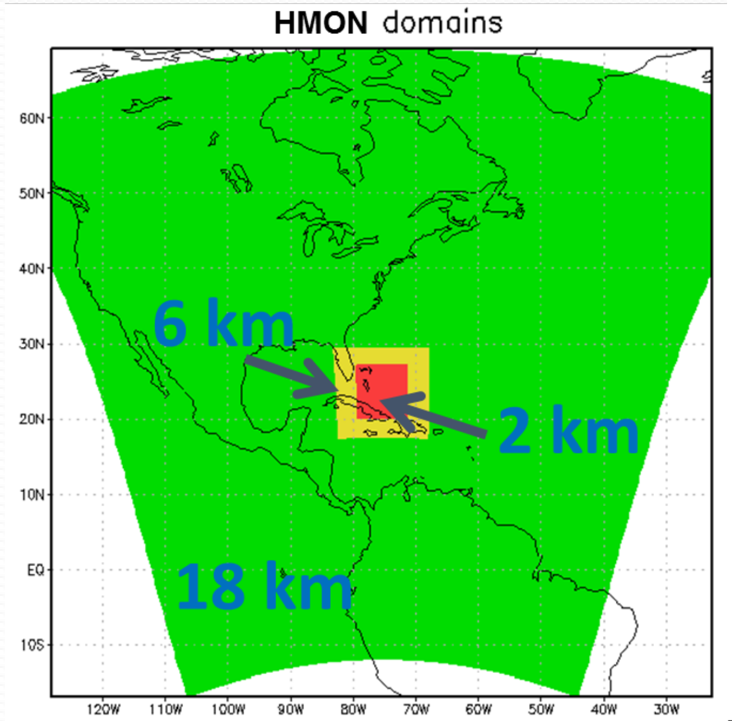
2018 HMON V2.0.0

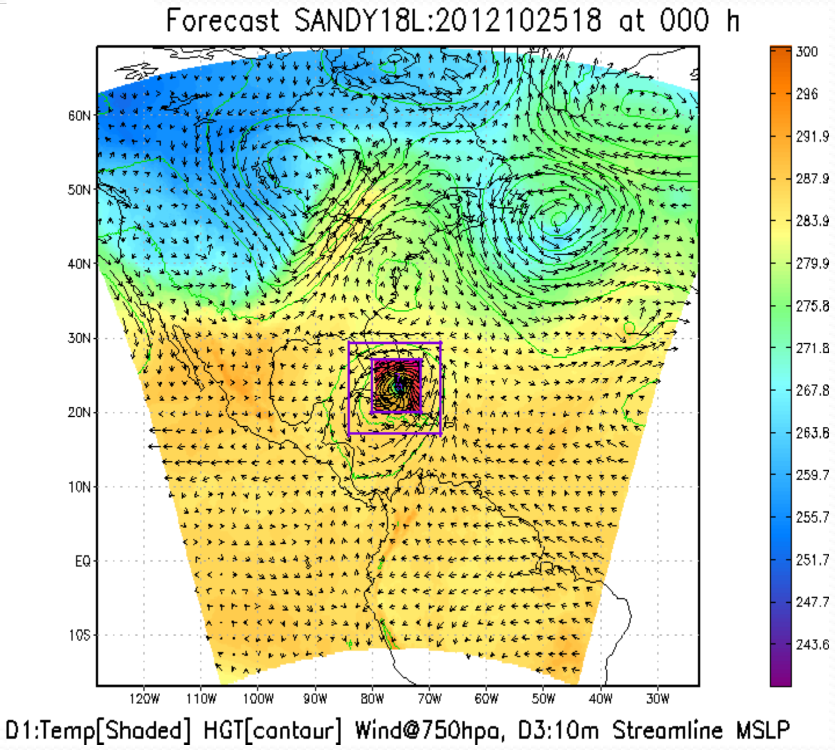
HIWPP

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

NGGPS

HMON: Hurricanes in a Multi-scale Ocean coupled Non-hydrostatic model





Operational HMON : First version implemented in 2017 (by replacing legacy GFDL Hurricane Model)

HMON: Implements a long-term strategy at NCEP/EMC for multiple static and moving nests globally, with one- and two-way interaction and coupled to other (ocean, wave, land, surge, inundation, etc.) models using NEMS-NUOPC infrastructure.

Scope of FY18 HMON Upgrades

➢ System & Resolution Enhancements

- Upgrade to the latest NMMB dynamic core with bug fixes
- Increase vertical levels from 42 to 51
- NMMB Dycore optimization (IBM analyst)
- Change diffusion parameterization

➢ Initialization/Data Assimilation Improvements

- Updated composite vortex
- Change co-ordinates for VI

➢ Physics Advancements

- Use scale-aware SAS scheme
- Update momentum and enthalpy exchange coefficients(Cd/Ch)
- Use GFS-EDMF PBL scheme
- ~~Explore use of MYJ surface layer + MYJ PBL~~

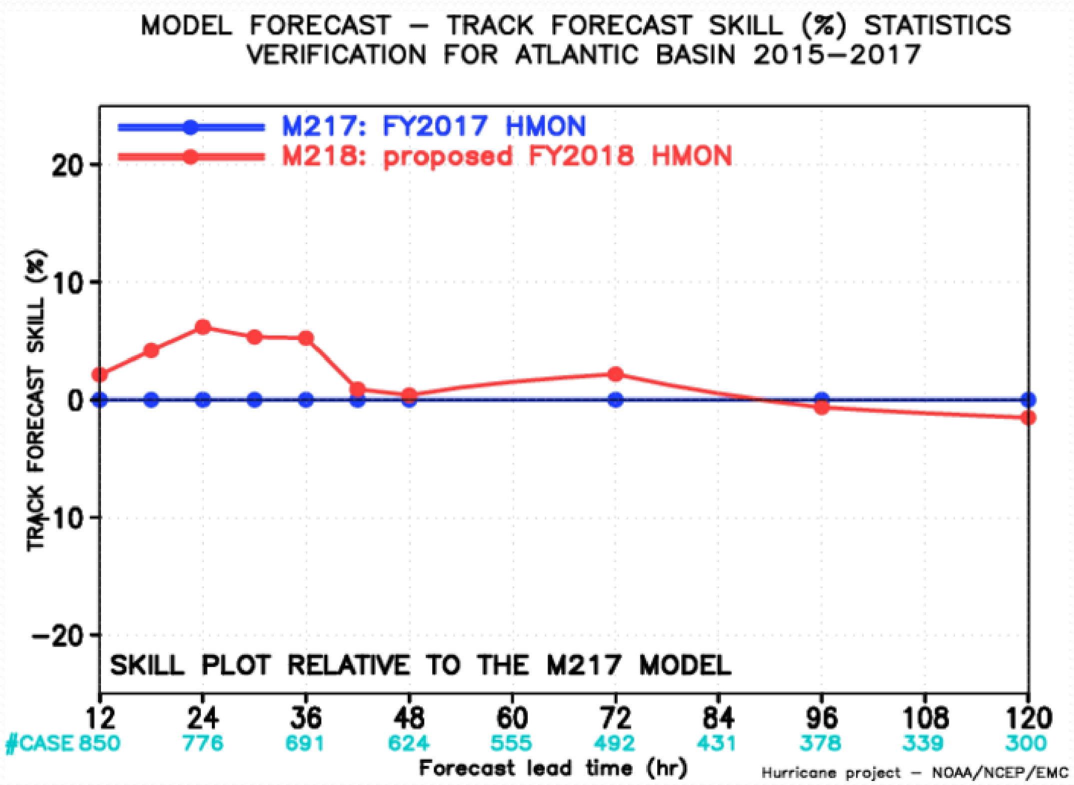
➢ Coupling Upgrades

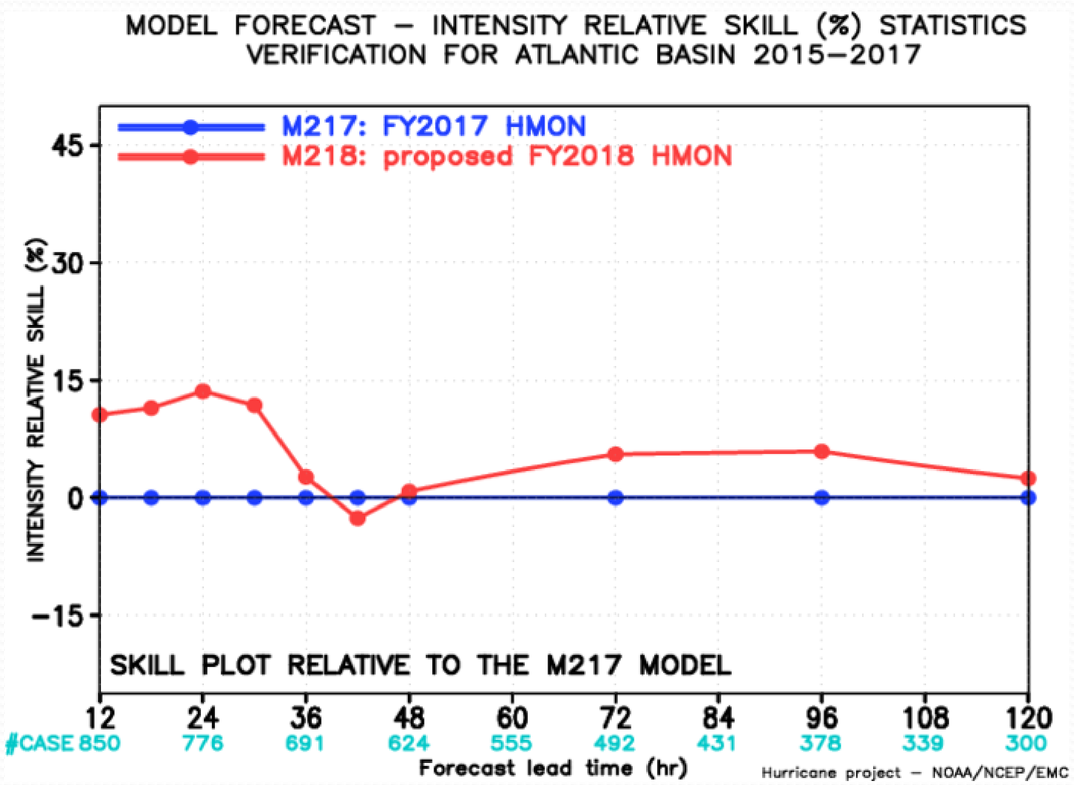
- Add HYCOM coupling in NATL basin
- Use unified HWRF/HMON coupler

Items in Red: first time in 2018

HMON (M218) Verification for North Atlantic Storms (2015-2017)

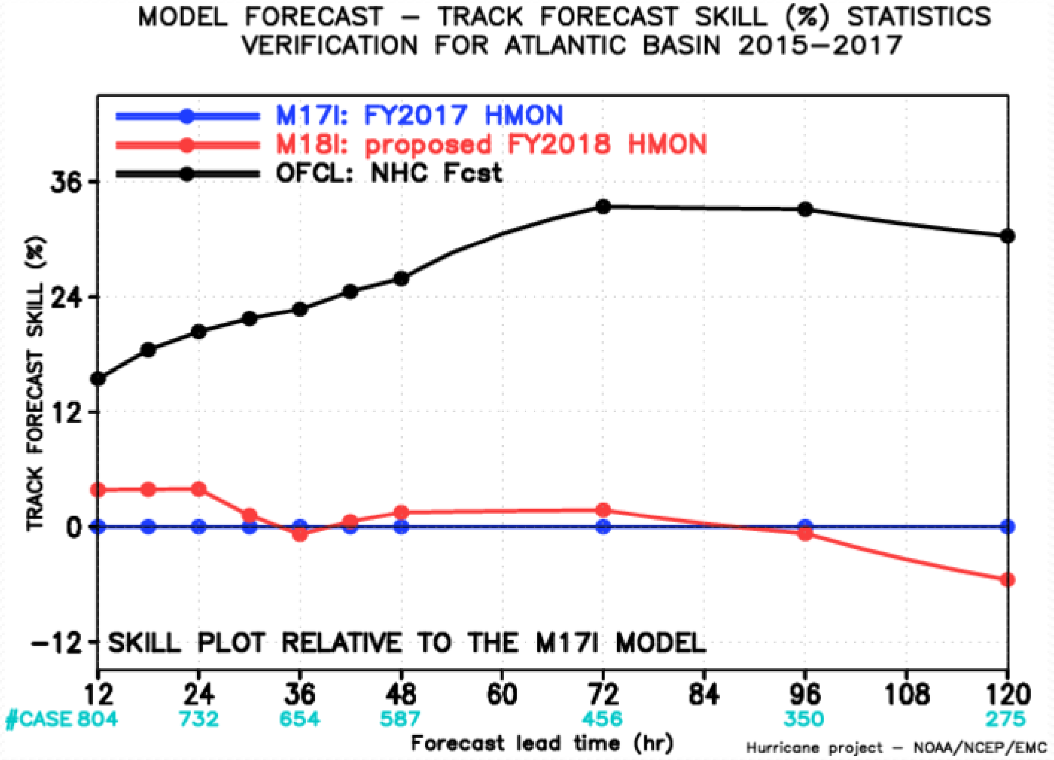
Track and Intensity skill for NATL basin (2015-2017)
(Late Model)

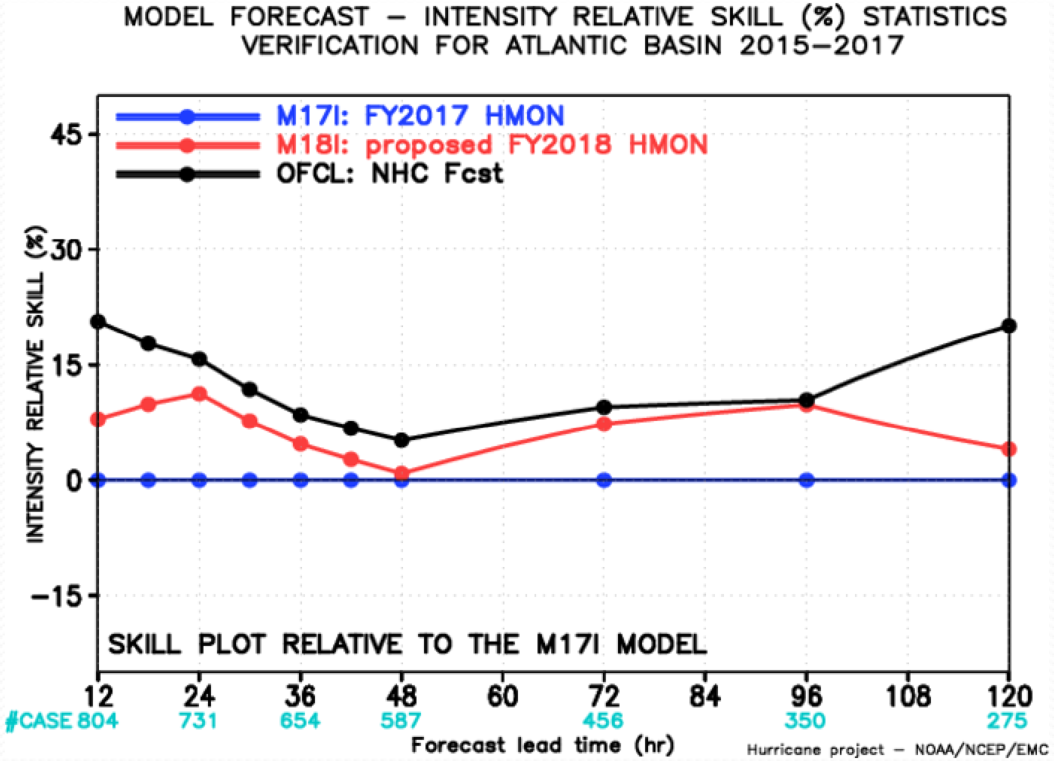




There is improvement in track skill for the early lead times of around 6% (at hr 24) while it is mostly neutral beyond day 2. Intensity skill improvements are significant at early lead times (~ 15%) and then again for late lead times at Days 3 and 4 of about 6-7%.

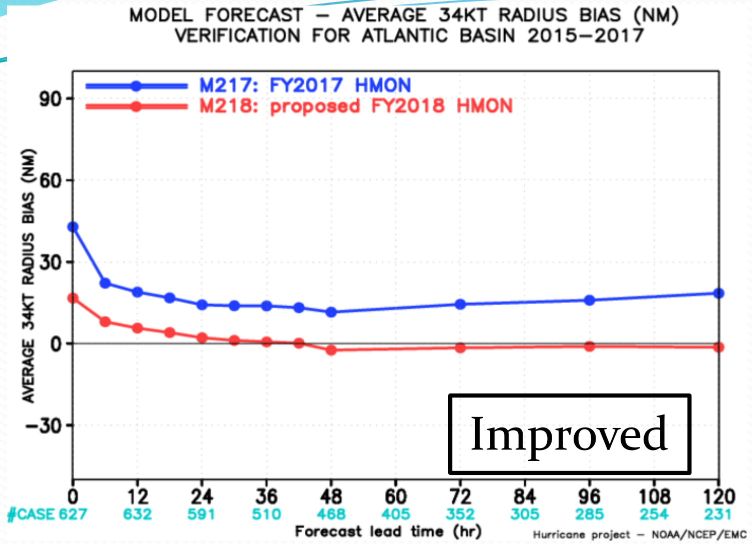
Track and Intensity skill for NATL basin (2015-2017)
(Early Model)

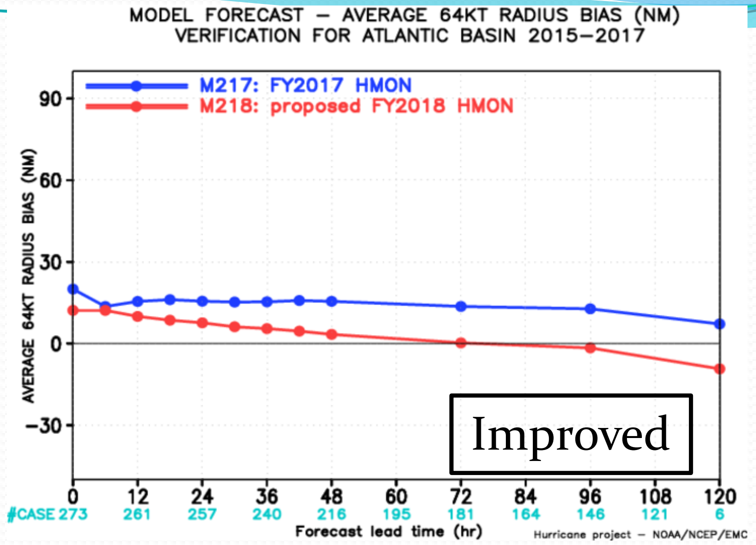


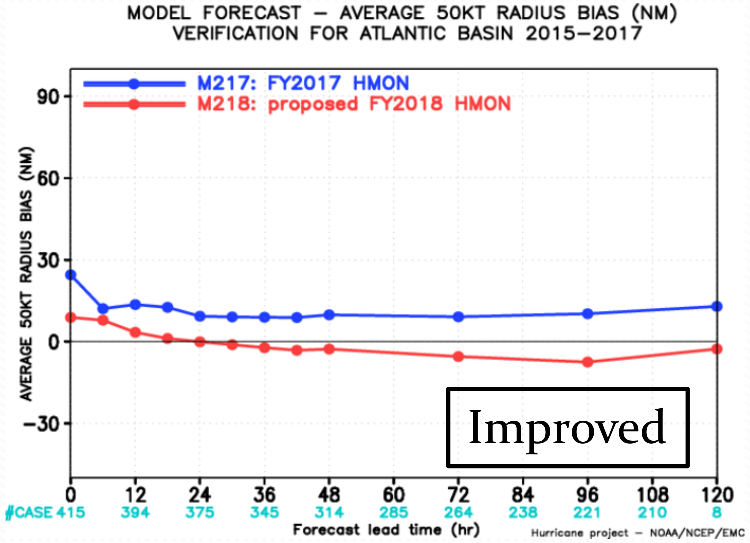


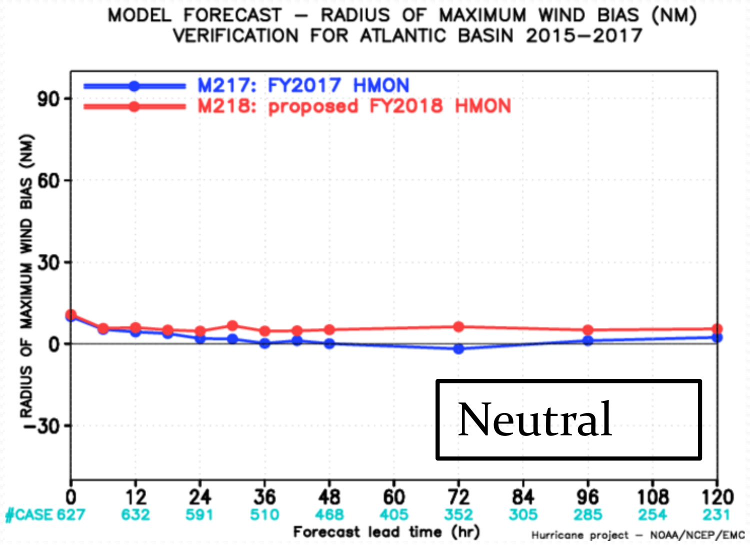
Improvements in track and intensity skill as compared to the official skill over the FY2017 HMON.

Storm Size Errors for NATL basin (2015-2017)*





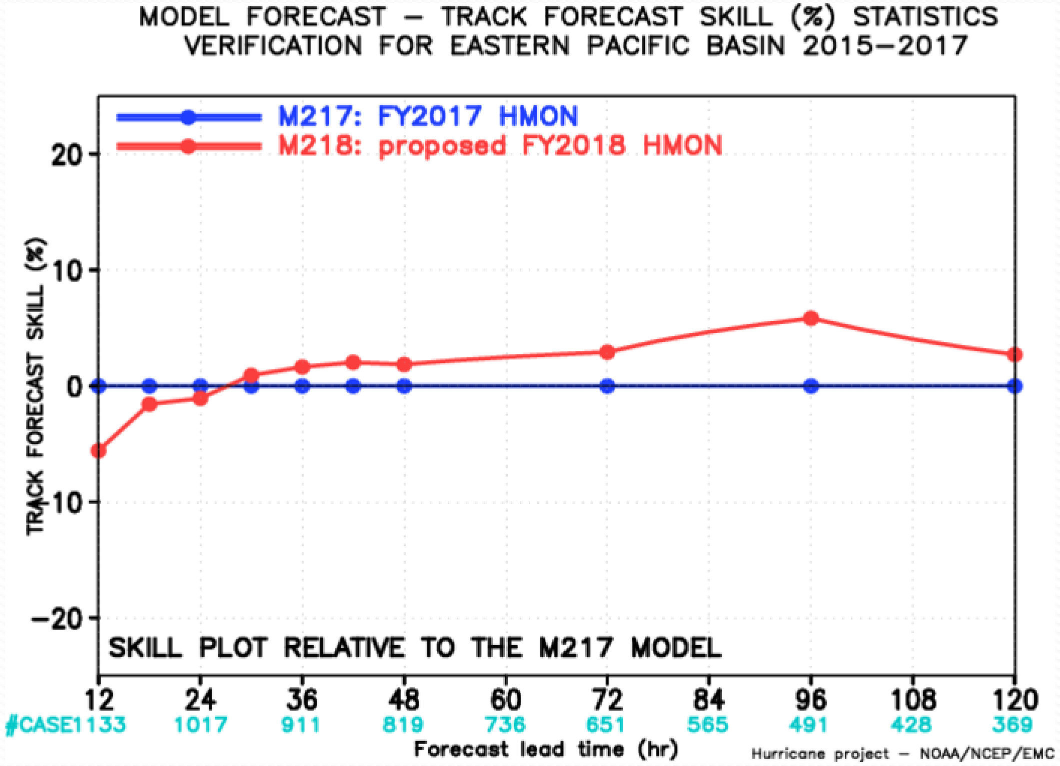


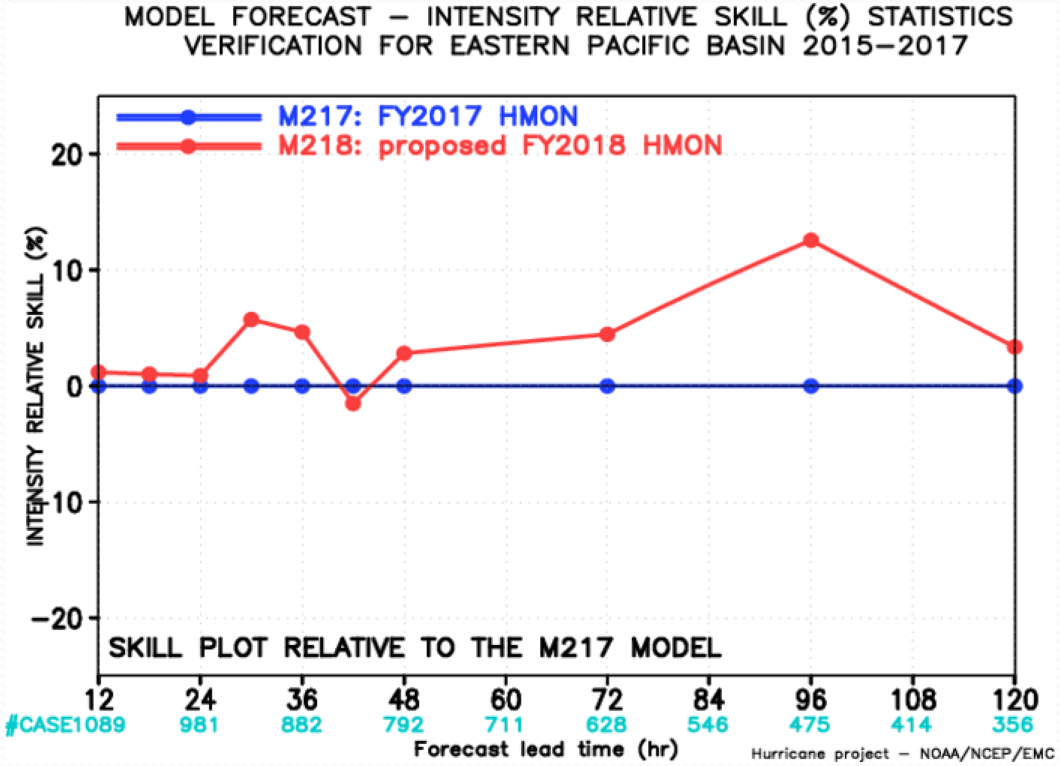


* official storm size estimates can have large errors for non-recon storms especially for RMW

HMON (M218) Verification for East Pacific Storms (2015-2017)

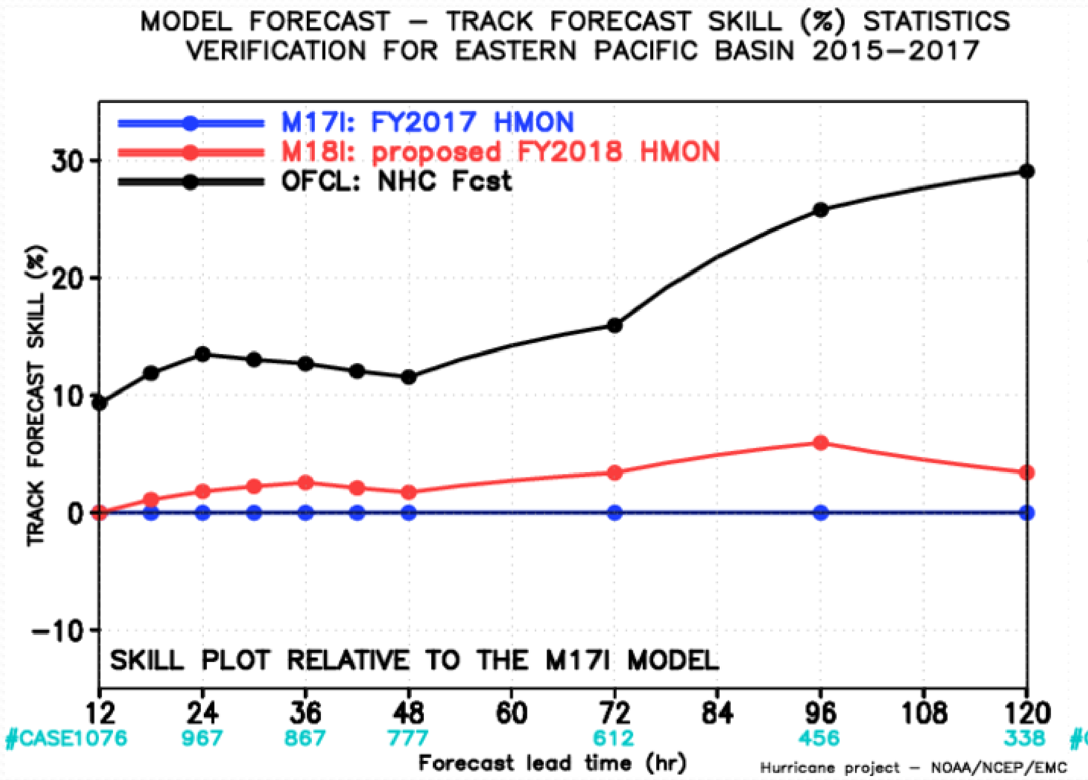
Track and Intensity skill for EPAC basin (2015-2017) (Late Model)

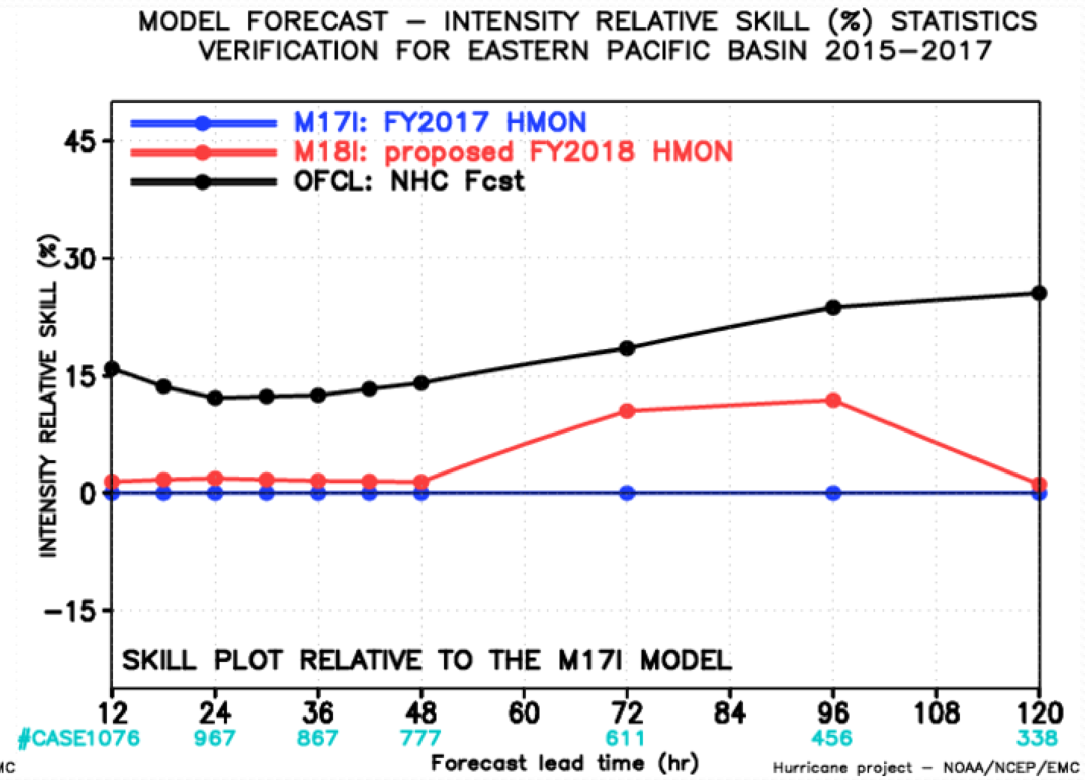




Other than for the first 24 hrs, there is improvement in track skill for all lead times which reaches around 7% at Day 4. We also find intensity skill improvements at all lead times after Day 1 with improvements peaking at day 4 (> 10%).

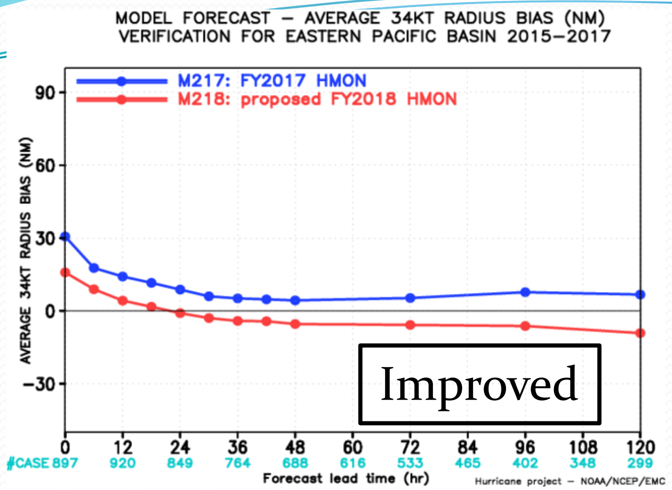
Track and Intensity skill for EPAC basin (2015-2017) (Early Model)

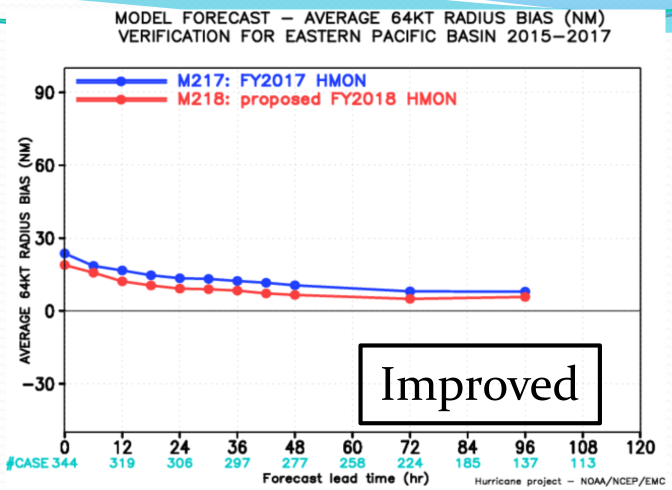


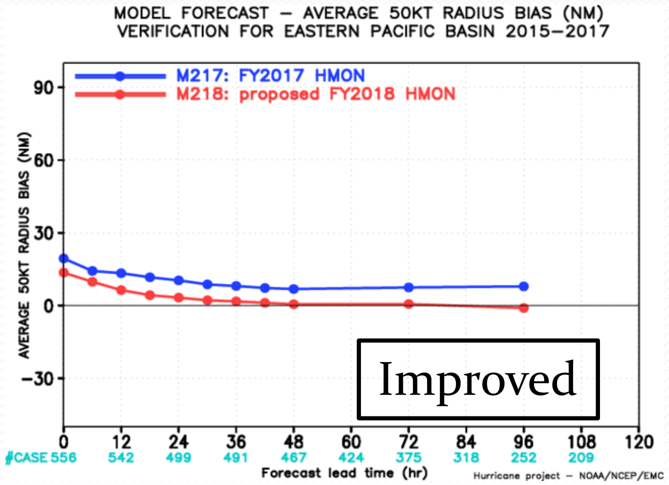


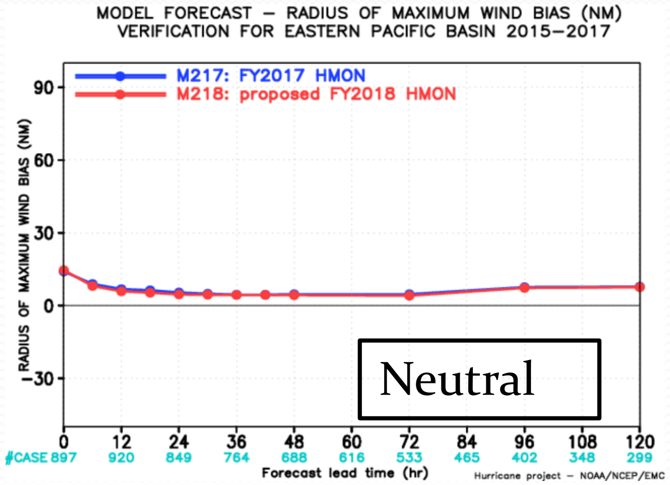
Improvements in track and intensity skill as compared to the official forecasts over the operational FY17 HMON.

Storm Size Errors for EPAC basin (2015-2017)*









* official storm size estimates can have large errors for non-recon storms especially for RMW

FY2018 HWRF/HMON configurations maintain diversity

Note: Items in Red are different

	HWRF	HMON
Dynamic core	Non-hydrostatic, NMM-E	Non-hydrostatic, NMM-B
Nesting	13.5/4.5/1.5 km; 77°/18°/6°; 75 vertical levels; Full two-way moving	18/6/2 km; 75°/12°/8°; 51 vertical levels; Full two-way moving
Data Assimilation and Initialization	Vortex relocation & adjustment, Self-cycled hybrid EnKF-GSI with inner core DA (TDR)	Modified vortex relocation & adjustment, no DA
Physics	Updated surface (GFDL), GFS-EDMF PBL, Updated Scale-aware SAS, NOAH LSM, Modified RRTM, Ferrier	Surface (GFDL), GFS-EDMF PBL, Scale-aware 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	81 nodes in 98 mins	26 nodes in 95 mins

Ongoing and Near-Term Future Plans

- Continue HWRF/HMON Development Process for both research and operations with community involvement for making further enhancements;
- Seek more direct engagement of HFIP/NGGPS supported researchers for active participation in model evaluation, enhancements and future R2O;
- Higher horizontal and vertical resolution, and ensemble based inner-core Data Assimilation pave way for the planned future Hurricane Analysis and Forecast System (HAFS), while also bringing immediate benefits to operations;
- Migrate HAFS to FV3/NGGPS based systems through accelerated support from Hurricane Supplemental funding

Thank You !