2017 Hurricane Model Implementations Briefing to EMC:

Much improved operational forecast guidance for global tropical cyclones

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(on behalf of the EMC Hurricane Team)

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in collaboration with
NHC, DTC, GFDL, ESRL and HRD

EMC CCB Meeting, April 25, 2017

FY17 NCEP Operational Hurricane Models (proposed)

I. 2017 HWRF V11.0.0

II. 2017 HMON V1.0.0

EMC CCB Meeting, April 25, 2017

2017 HWRF V11.0.0

EMC CCB Meeting, April 25, 2017

Scope of FY17 HWRF Upgrades

➢ System & Resolution Enhancements

- T&E with new 2017 NEMS GFS IC/BC
- Upgrade dynamic core from WRF3.7.a to WRF3.8.1 (with bug fixes)
- Consider storm's meridional movement when determining parent domain center
- Vertical levels: L75 , model top 10hPa; (H216: L61, 2hPa model top)
- Changes nested domain size: d02 (265x532), d03 (235 x 472) (H216: 288 x 576)
- New Tracker (Tim Marchok, GFDL)

➢ Initialization/Data Assimilation Improvements

- Improve vortex initialization (new composite storm vortex)
- GSI code upgrades; new data sets for GSI (hourly shortwave, clear air water vapor and visible AMV's from GOES)
- Fully Cycled HWRF ensemble hybrid DA for TDR and priority storms
- Change in blending threshold (from 50 to 65 Kt)
- HDOBS data assimilation

-- Green: Included in Baseline
-- Orange: Tested Separately

Scope of FY17 HWRF Upgrades (cont.)

➢ Physics Advancements

- Update F-A Microphysics
- Scale-aware SAS scheme upgrades
- Update momentum and enthalpy exchange coefficients(Cd/Ch)
- Partial cloudiness modification for RRTMG (DTC)
- ~~Grell-Freitus Convection Scheme~~
- ~~Cloud cover method modification for RRTMG~~
- ~~In-cloud mixing (Ping Zhu, FIU)~~

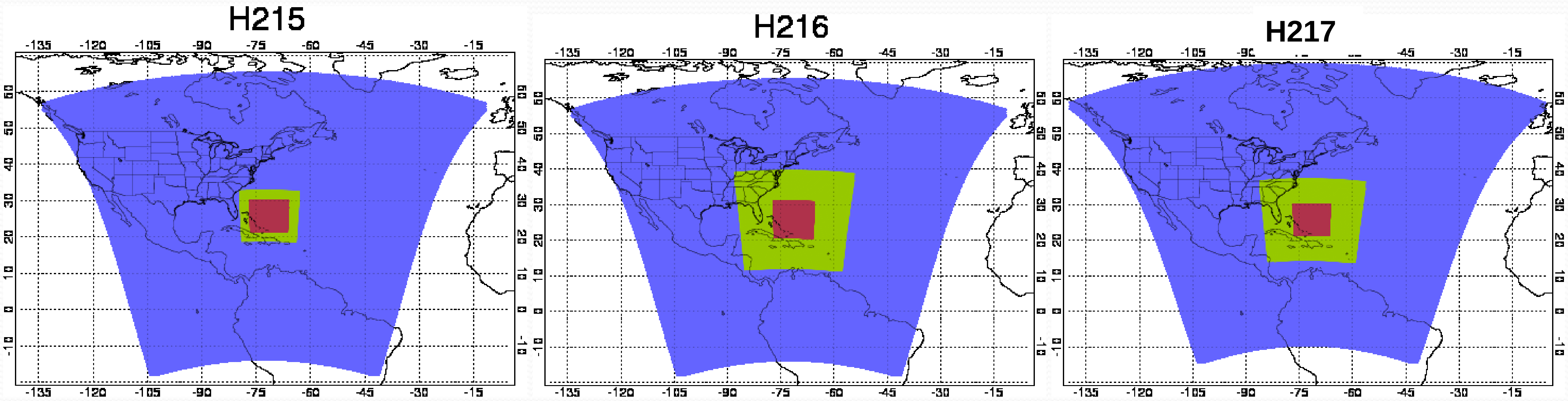
➢ Coupling Upgrades

- Reduced coupling time step from 9min to 6 min for both ocean and waves
- Increased vertical level for POM from 24 to 41 levels, reduce dt from 270s to 180s
- Waves Boundary Conditions
- RTOFS init for CPAC, HYCOM ocean coupling for WPAC, NIO

➢ First time in 2017....

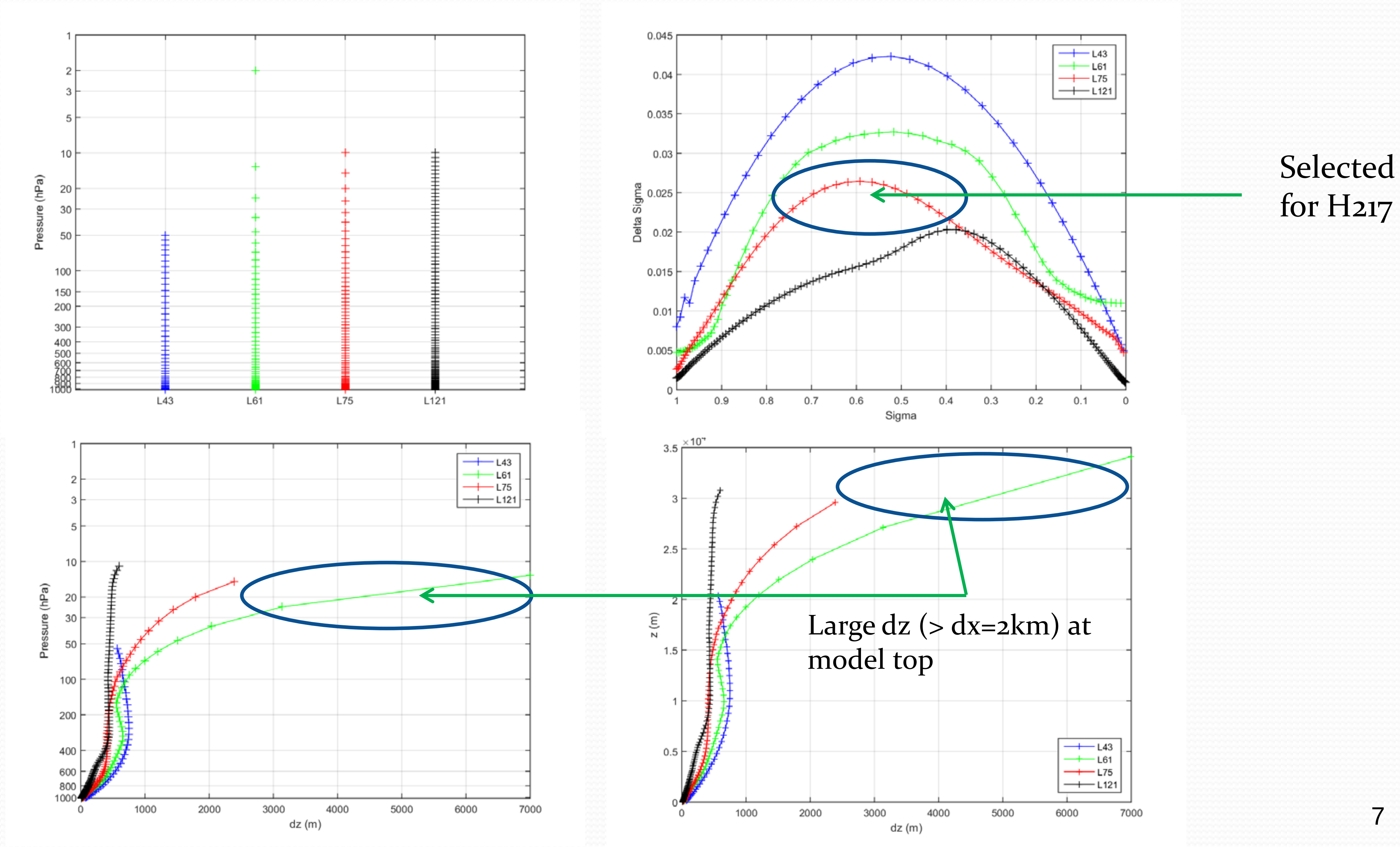
- **Fully Cycled Hybrid EnKF DA**
- **75 vertical levels, optimized nested domains (for NHC basins)**
- Use of NEMSIO (IC) and GRIB2 (LBC) files for inputs
- HDOBS data assimilation
- RTOFS init for CPAC
- Ocean coupling (replace MPIPOM with HYCOM) for WPAC, NIO

Domain Size Adjustment for H217 with higher vertical resolution: Hurricane Joaquin (2015)



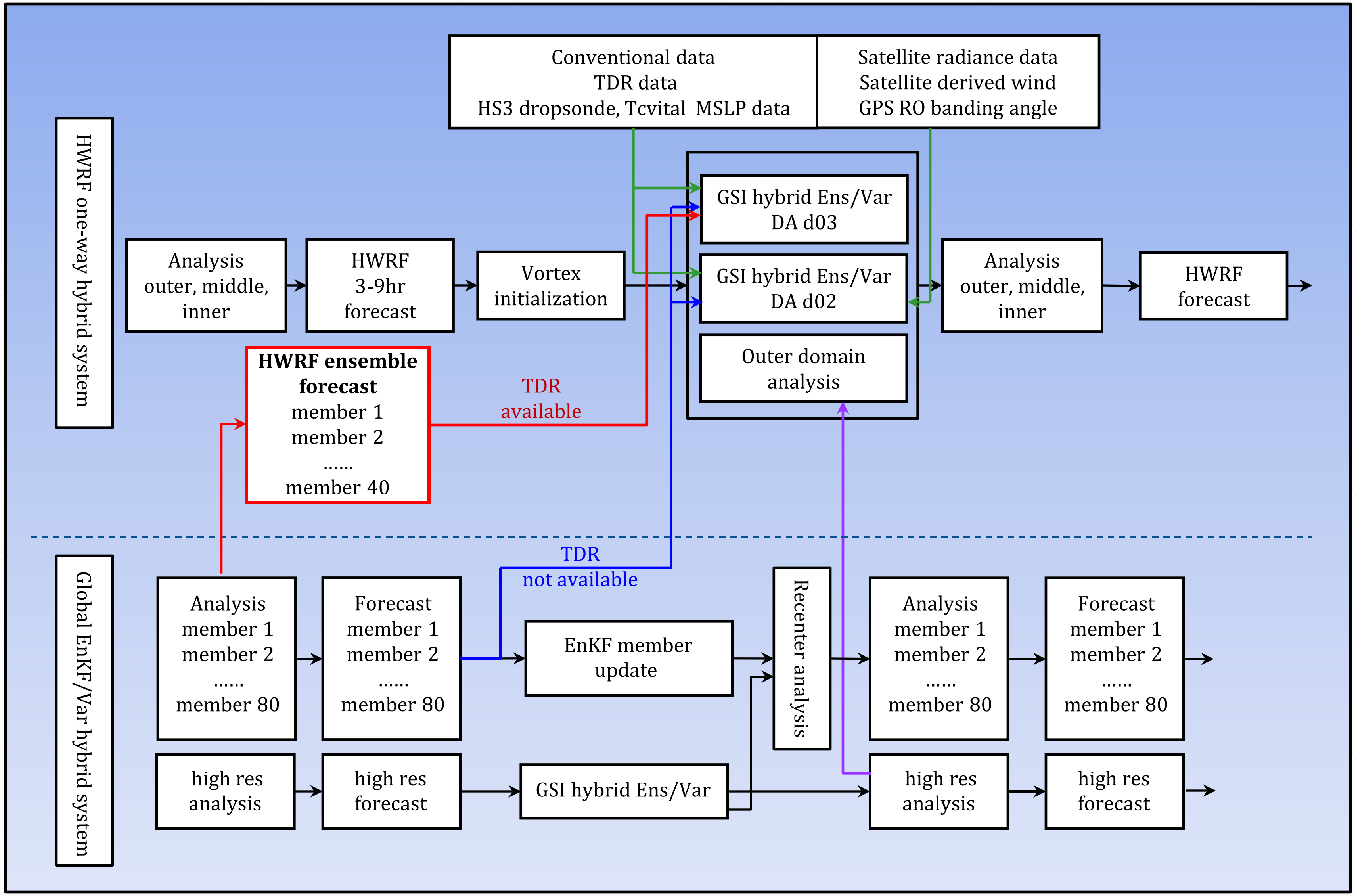
	H215	H216	H217
d01:	288 x 576	288 x 576	288 x 576
d02:	142 x 274	288 x 576	265 x 532
d03:	256 x 472	288 x 576	235 x 472
Levels:	61	61	75
Top:	2 mbar	2 mbar	10 mbar

The new 75 vertical level/distribution compared to alternatives



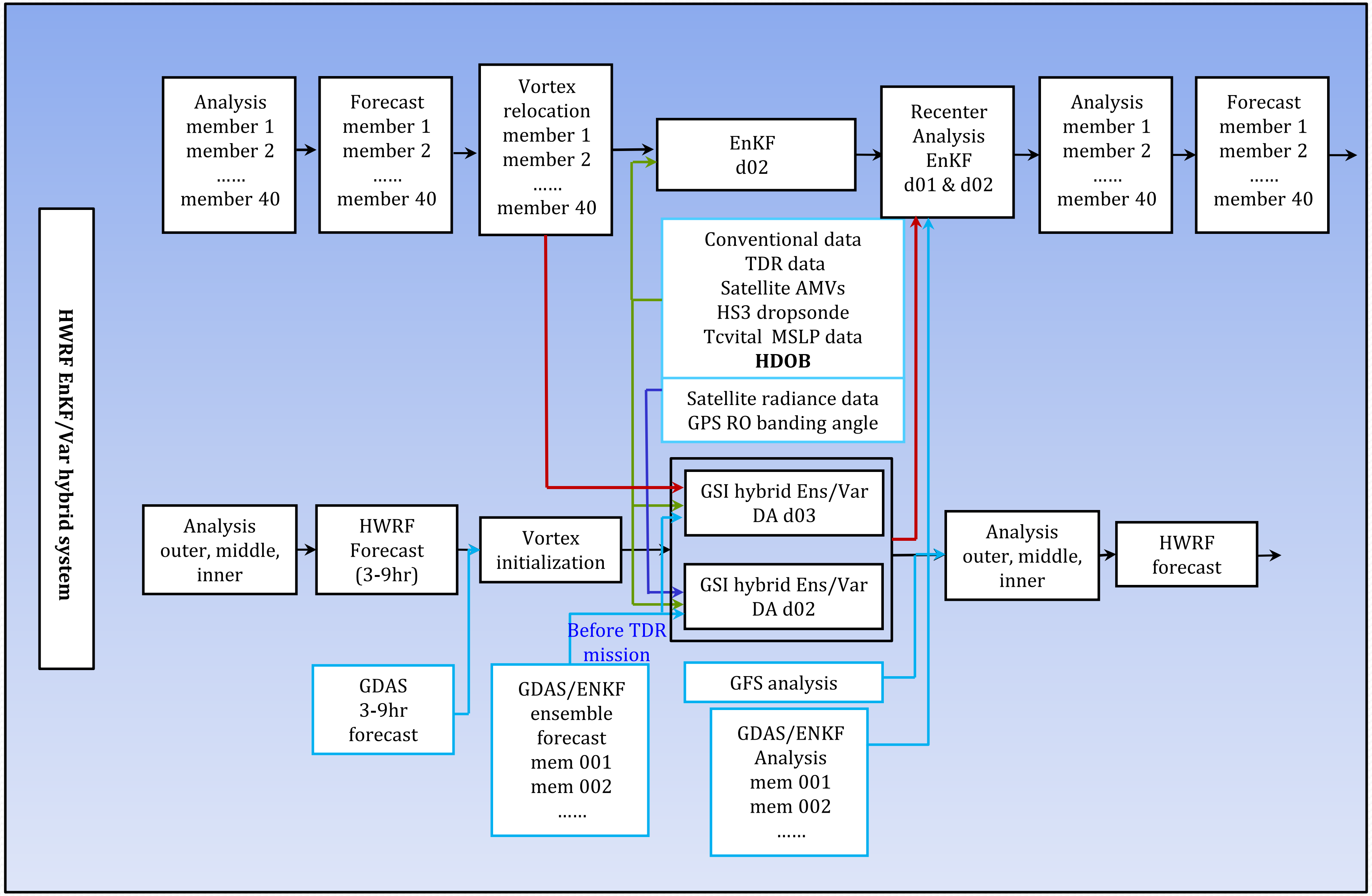
2016 HWRF Hybrid Data Assimilation System

Warm-start HWRF ensemble for TDR storms



2017 HWRF Hybrid Data Assimilation System

Cycled HWRF EnKF Ensemble Hybrid for TDR storms



2017 HWRF Physics Advancements

- **Changes in Scale Aware SAS**

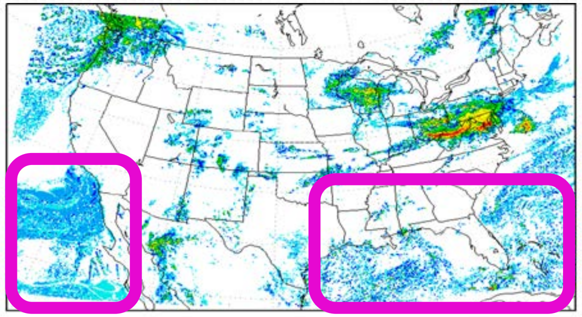
  - Updates in scale awareness:
    - Mass flux reduction by clouds is advected before they complete their turnover time
    - For dx < 8km, the cloud base mass flux is proportional to the mean updraft velocity and is not given by the Arakawa-Schubert quasi-equilibrium
    - Shallow convection cloud base mass flux is now a function of the cumulus updraft velocity averaged over the whole cloud depth
  - Reduced rain conversion rate with decreasing air temperature above the freezing level
  - Enhanced entrainment in dry environment
  - Precipitation changes in shallow convection to reduce presence of low clouds
  - Separation criteria between deep and shallow: cumulus depth is changed to 200mb (from 150mb)

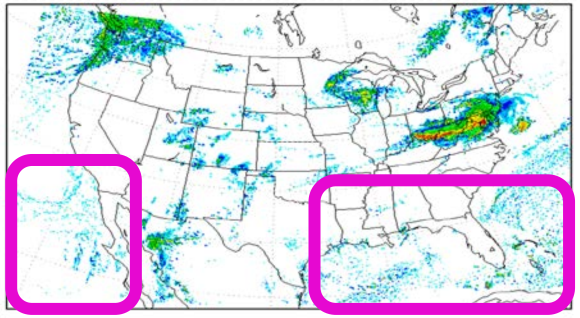
Ferrier-Aligo Microphysics Change (courtesy EMC Mesoscale Team)

Problem / Solution

Old | New

High reflectivity bias in PBL clouds / Added a drizzle parameterization (allows larger number of droplets)

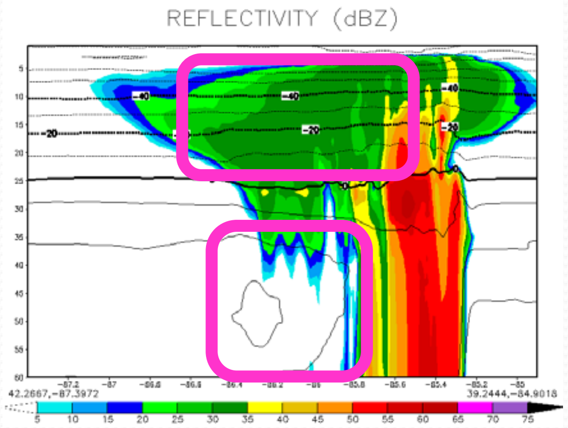


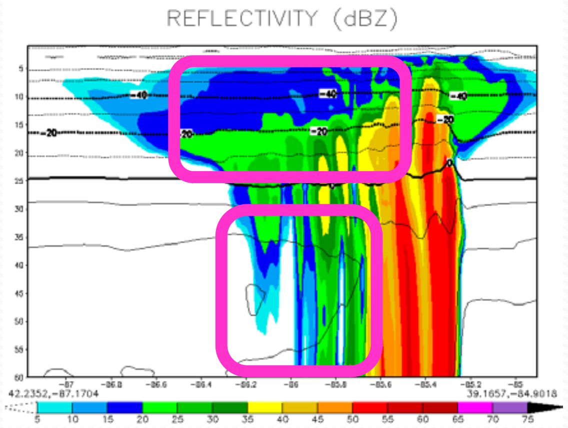


12Z 23 June 2016

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)





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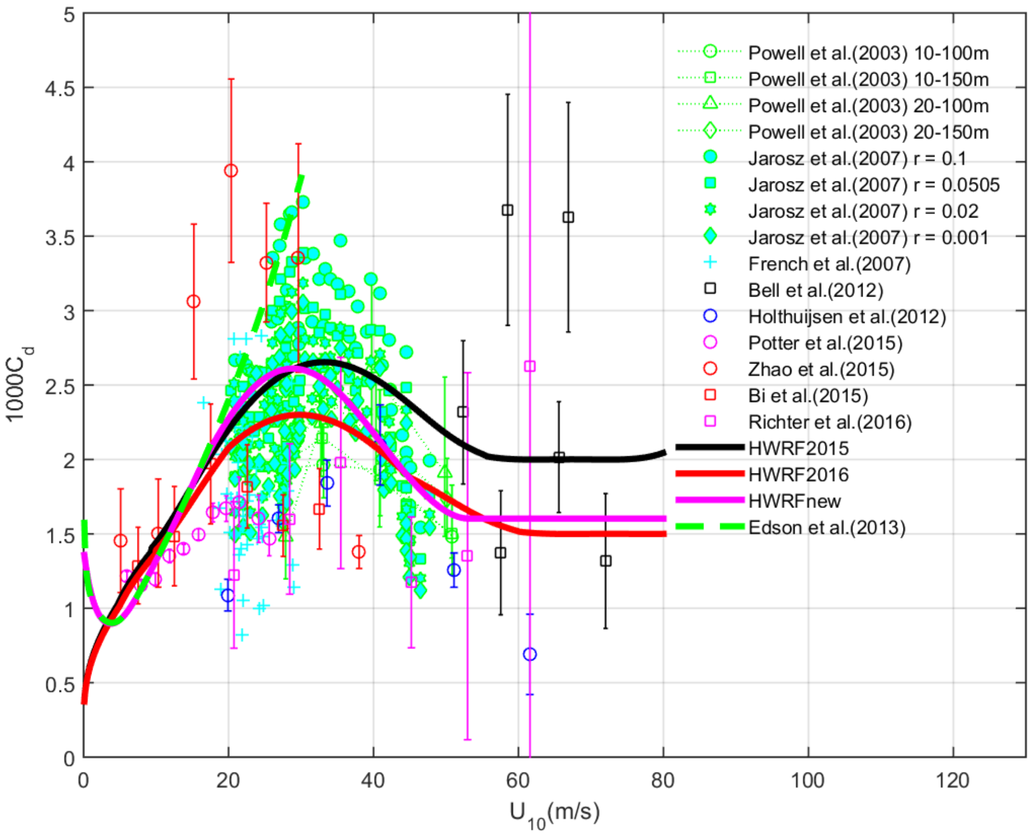
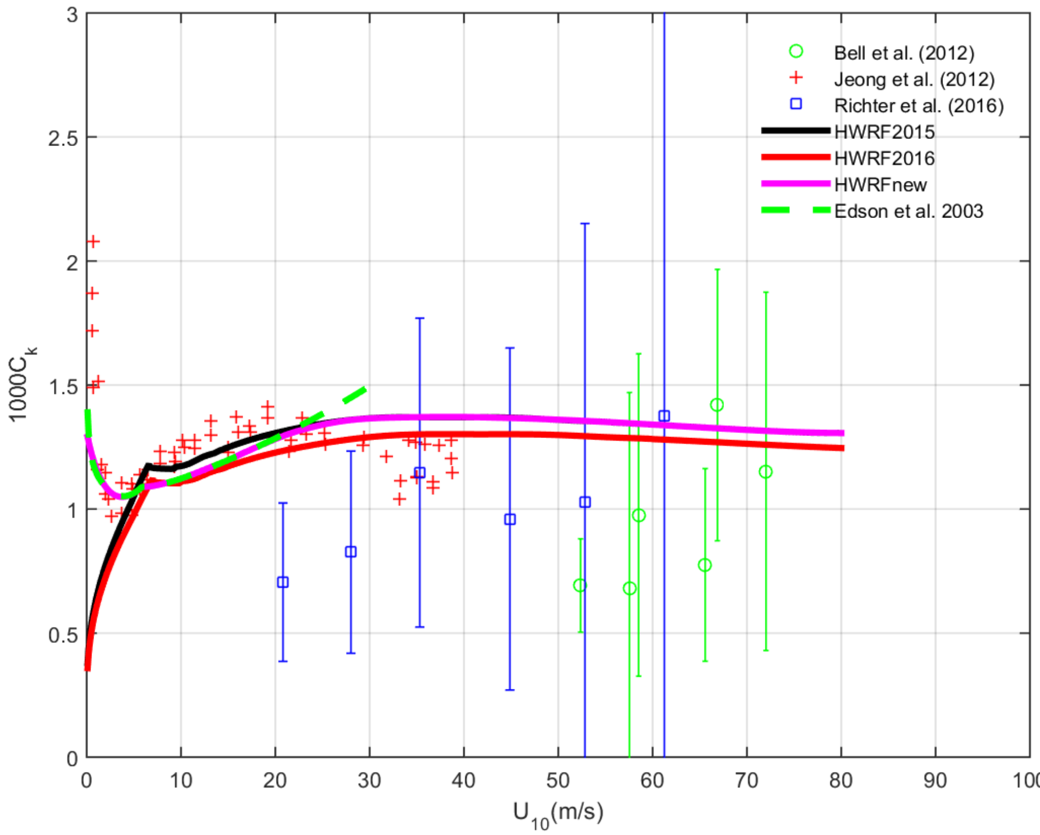
2017 HWRF Physics Advancements

C_d under high winds



C_k under high winds



2017 HWRF Configurations (for NATL & EPAC)

- H216: FY16 HWRF using 2016 GFS
- H17A: FY16 HWRF using 2017 GFS
- H17B: baseline experiment
  - Framework upgrades with 2017 GFS
- H17P: H17B + physics upgrades
  - Updated scale-aware SAS scheme
  - Updated microphysics scheme
  - Partial cloudiness modification in RRTMG
- H17F: H17P + 75 vertical level + modified d02, d03
- **H217:** H17F + new Cd/Ck + DA advancements + new tracker
  - **Proposed FY17 HWRF configuration**

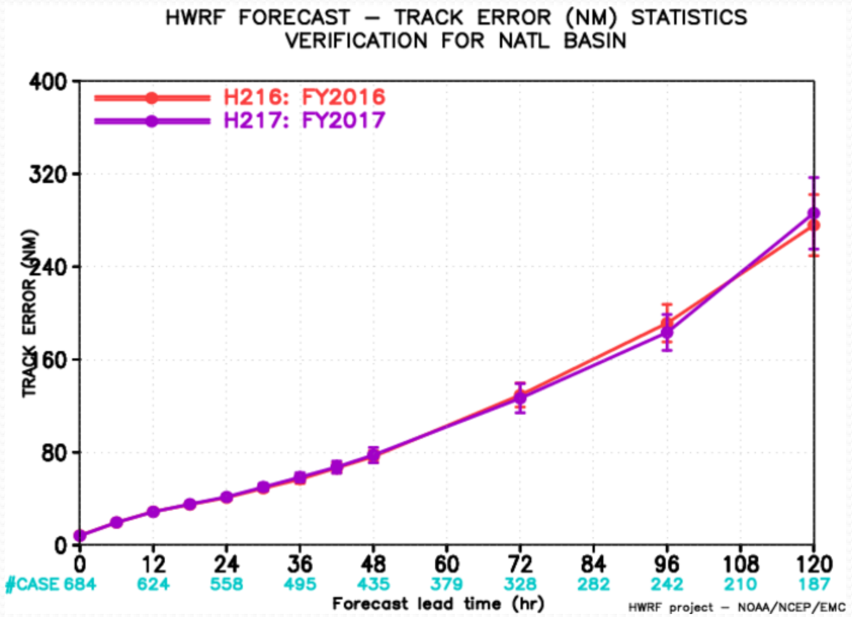
HWRF Upgrade Plan for 2017 Implementation

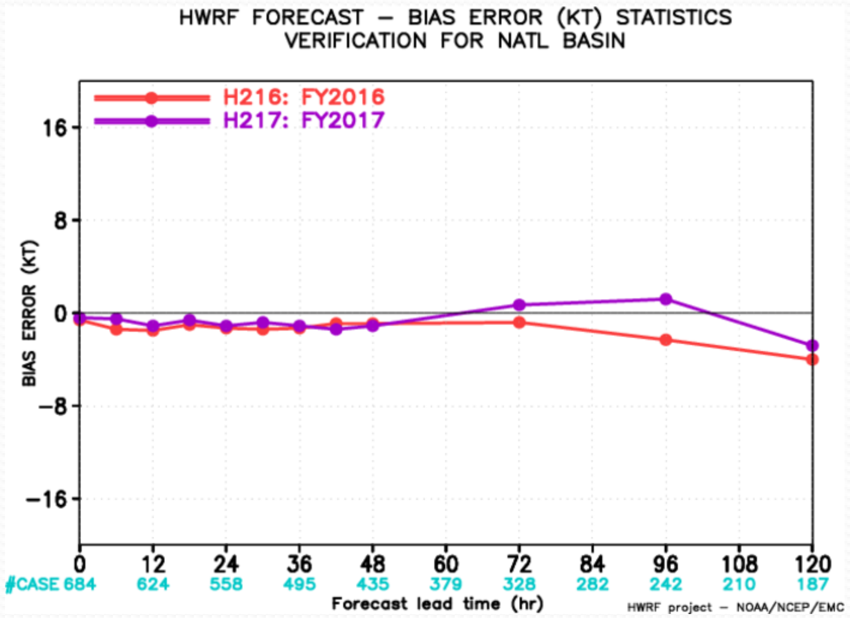
Multi-season Pre-Implementation T&E

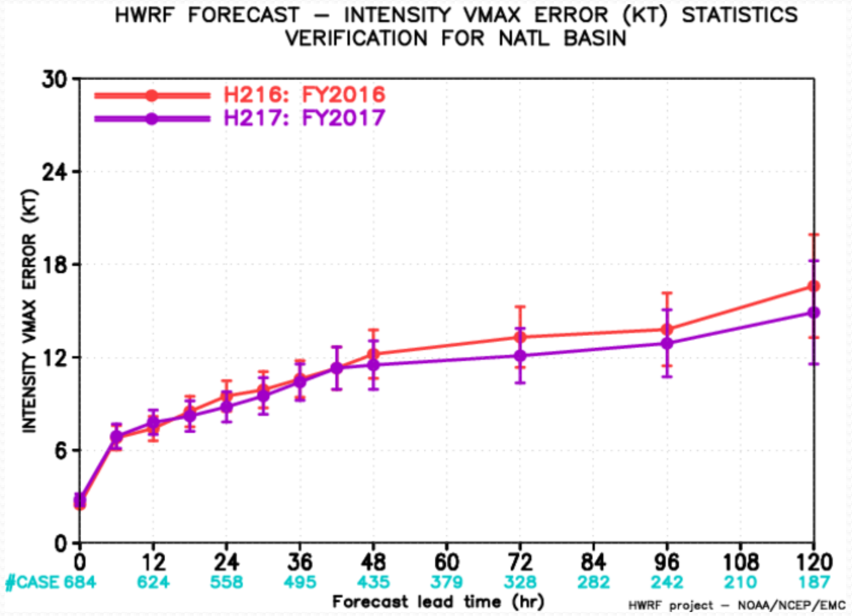
	Model upgrades	Physics and DA upgrades		75 levels	Combined
	Baseline (H17B)	**Data Assimilation changes (H17T)**	**Physics changes (H17P)**	**H17F**	**H217**
Description	1. Framework upgrade to HWRFV3.8a; domain center; 2. New 2017 GFS upgrade 3. U10 fix, smaller coupling time step. 4. GSI upgrades.	1. HDOBS 2. Blending threshold 3. Fully self-cycled EnKF	Assess impact of physics changes	Baseline + all physics changes + 75 levels + DA changes	Baseline + all physics changes + all DA upgrades + new Cd/Ck + + new tracker
Cases	Three-season 2014-2016 simulations in ATL/EPAC cases (~2000)	Only Aircraft DA cases for 2014-2016	Priority cases (~400 cases in each basin)	Priority cases for 2014-2016 retrospectives in ATL/EPAC (~2000)	**Three-season 2014-2016 retrospectives ~5000 simulations in all TC basins**
Platform	WCOSS/Jet/Theia	WCOSS/Jet/Theia	WCOSS/Jet/Theia	WCOSS Cray	**WCOSS Cray**

HWRF Verification for Atlantic Storms (2014-2016)

Track and intensity errors for NATL storms

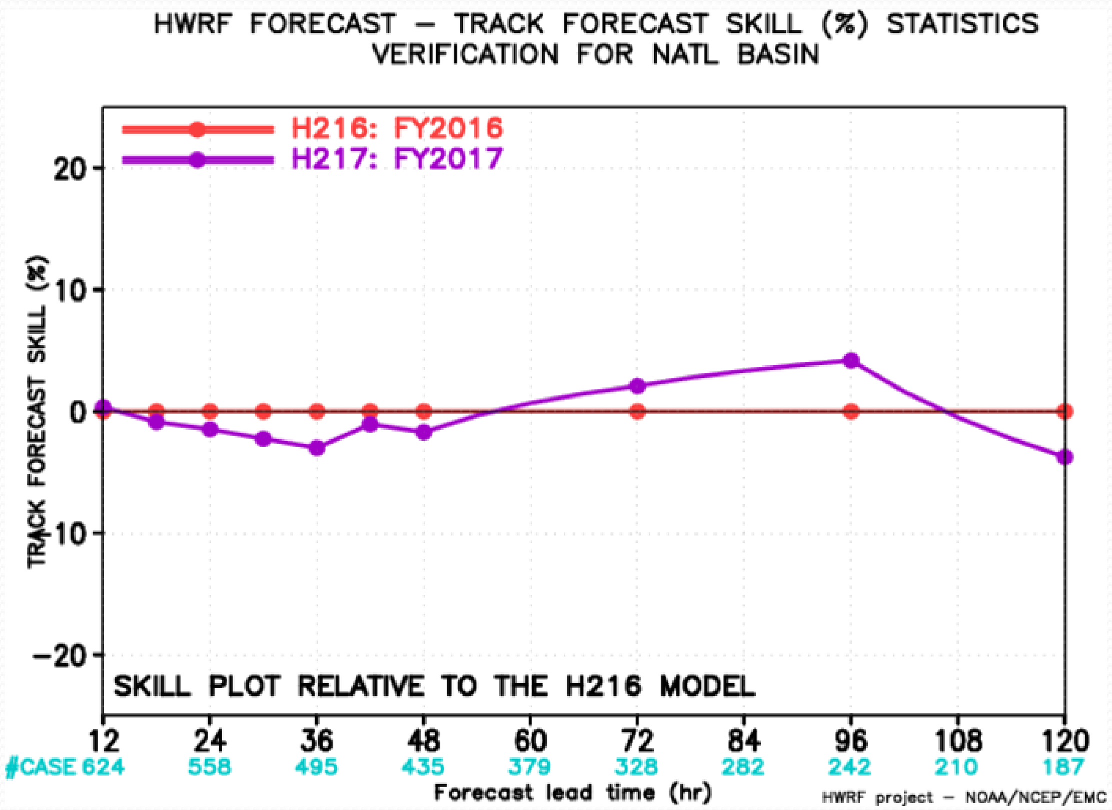


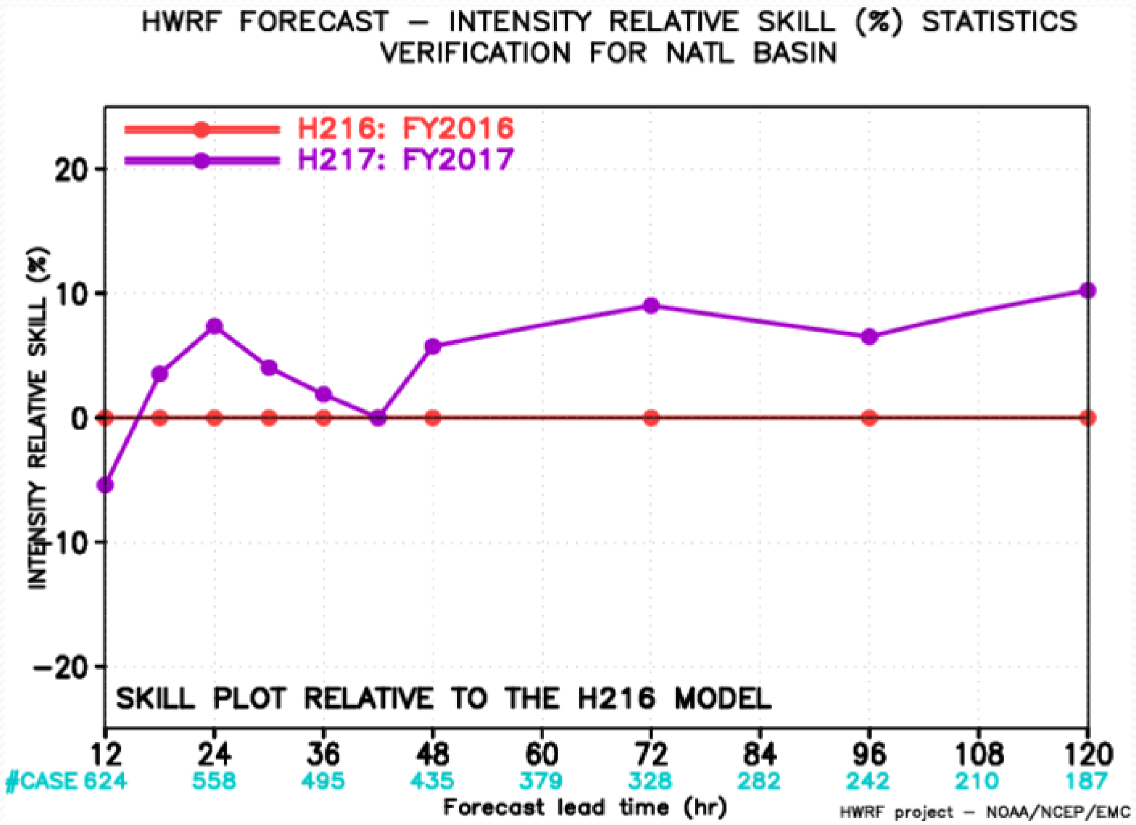




- Compared to H216, H217 track forecasts are mostly neutral.
- Compared to H216, H217 intensity forecasts indicate improvements at all lead times.
- The intensity bias errors for H217 are also lower when compared with H216.

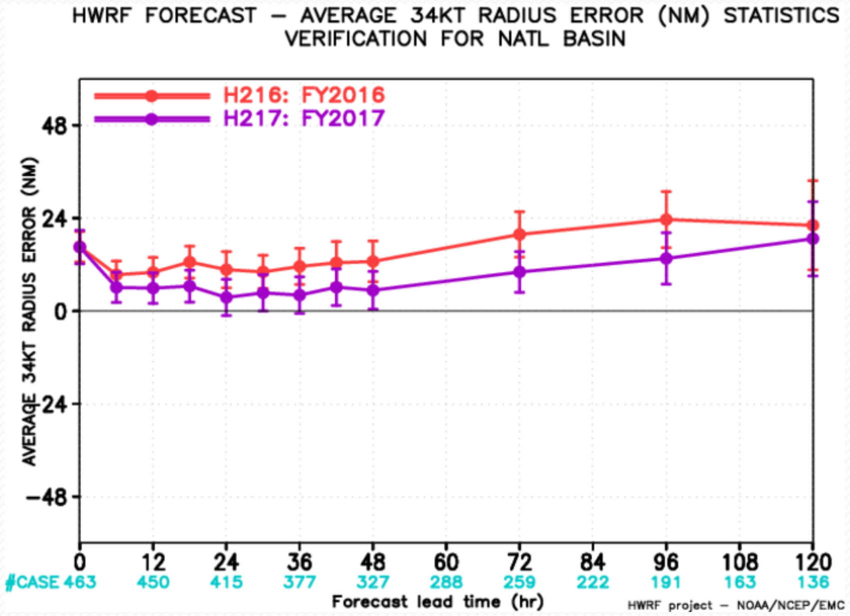
Track and intensity skills for NATL storms (late model)

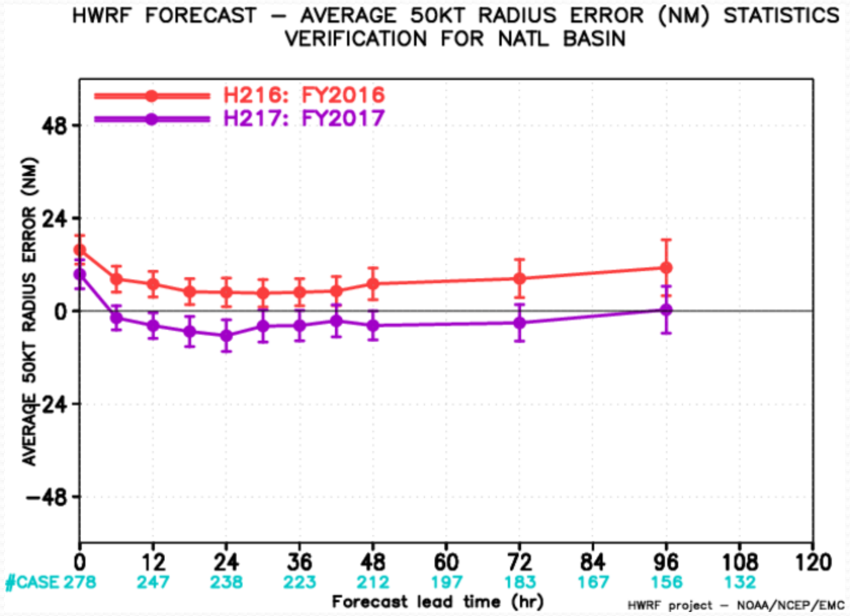


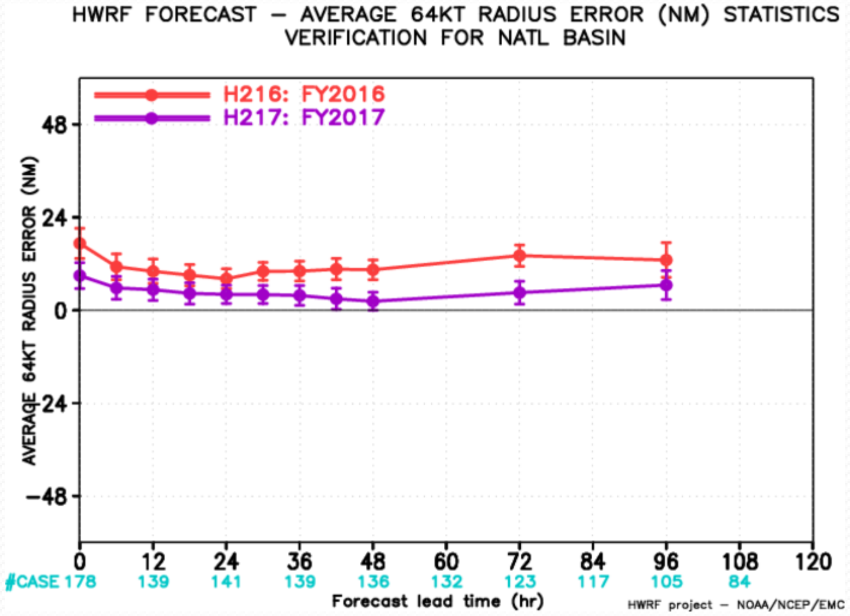


- The track skill for H217 is very close to H216 but there is improvement from hrs 60-108 hr.
- The improvement in intensity skill for H217 is evident at almost all lead times and is close to 10% at Days 3 and 5.

Size errors for NATL storms

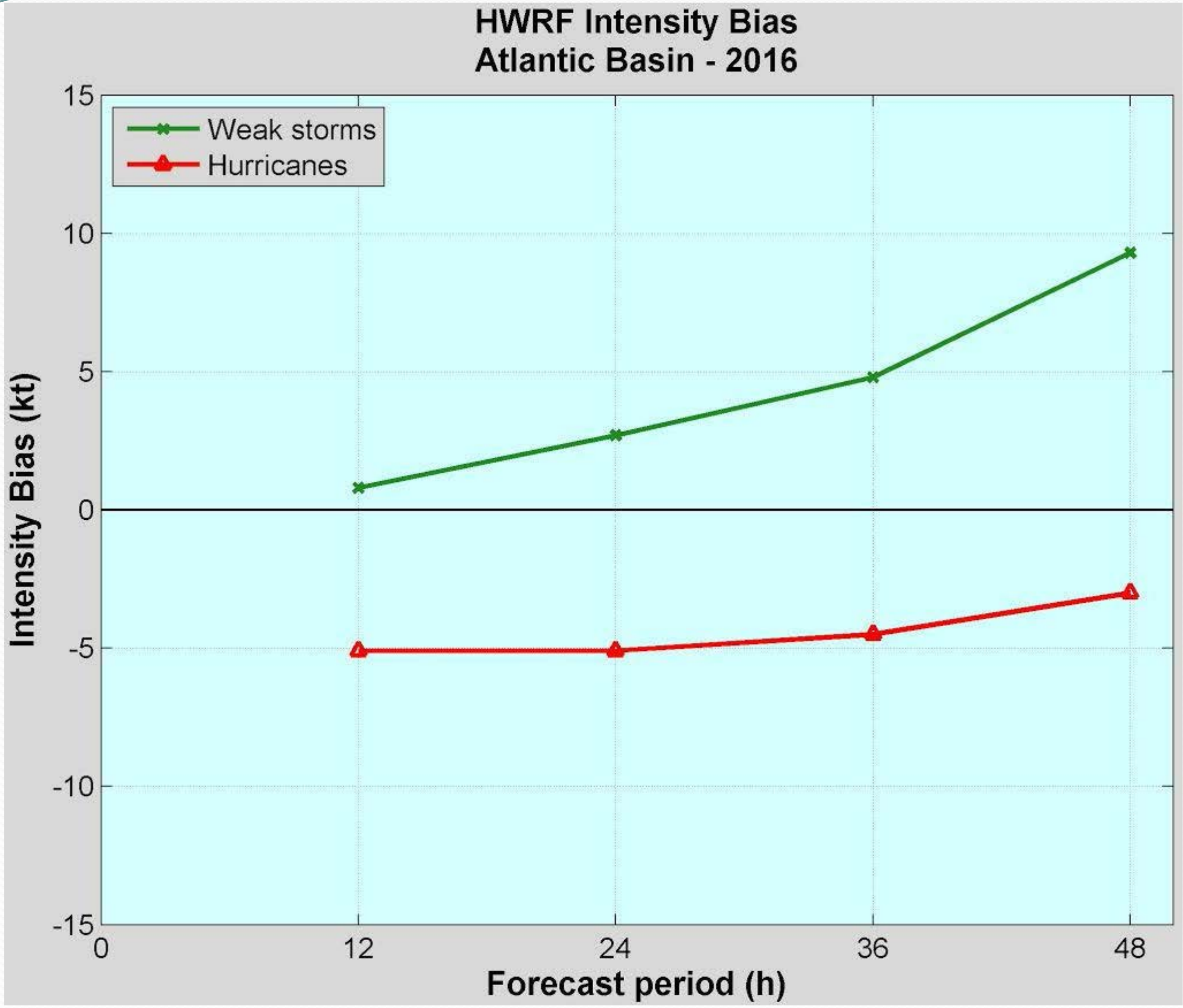






The storm size errors for H217 show improvement for all lead times and for all radii sizes (34, 50 and 64 kts).

HWRF bias for NATL storms for 2016 season

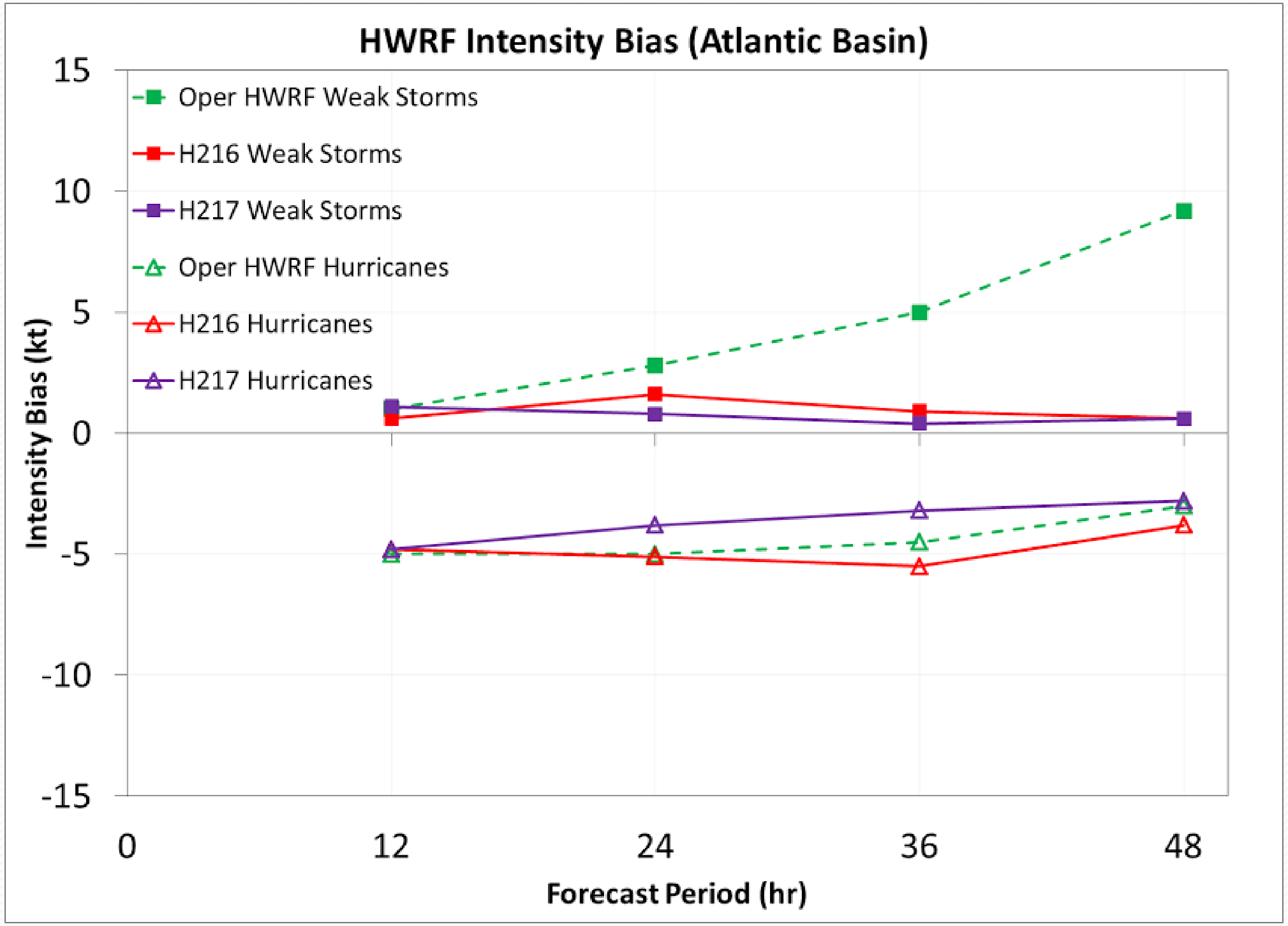


We noticed that early in a tropical cyclone (<50 kt), HWRF was too high and then as a hurricane, HWRF consistently too low

This type of changing bias is challenging for forecasters.

--- Reported by Eric Blake (NHC) at HFIP Meeting 01/2017.

HWRF bias for NATL storms for 2014-2016 season

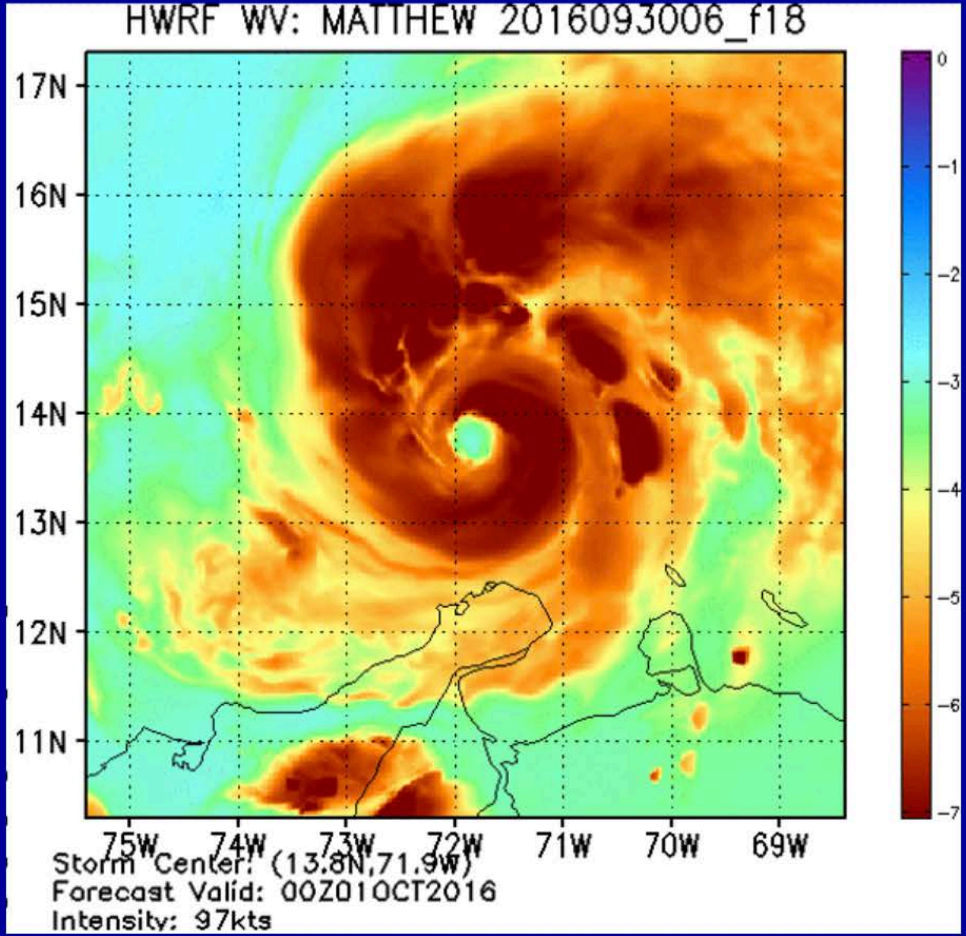


There is improvement in reducing positive bias for weaker storms (< 50 kt) for H217 as compared to H216.

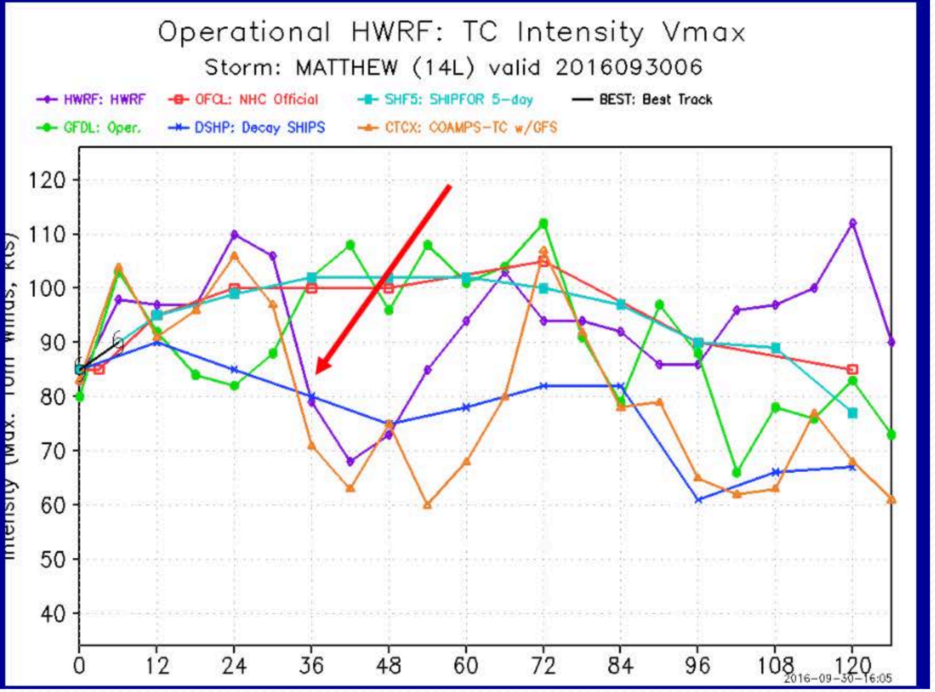
There is also improvement in reducing negative bias for Hurricanes (<50 kt) for H217 as compared to H216.

** These H216 and H217 results are from a much larger homogenous sample based on storms from 2014-2016 seasons with more than 250 total verifiable cases.

Collapse of inner core of Matthew in HWRF



For some HWRF forecasts of Matthew when it was over the Caribbean, the eyewall unrealistically collapsed. This had to have an effect on the model-predicted intensity.



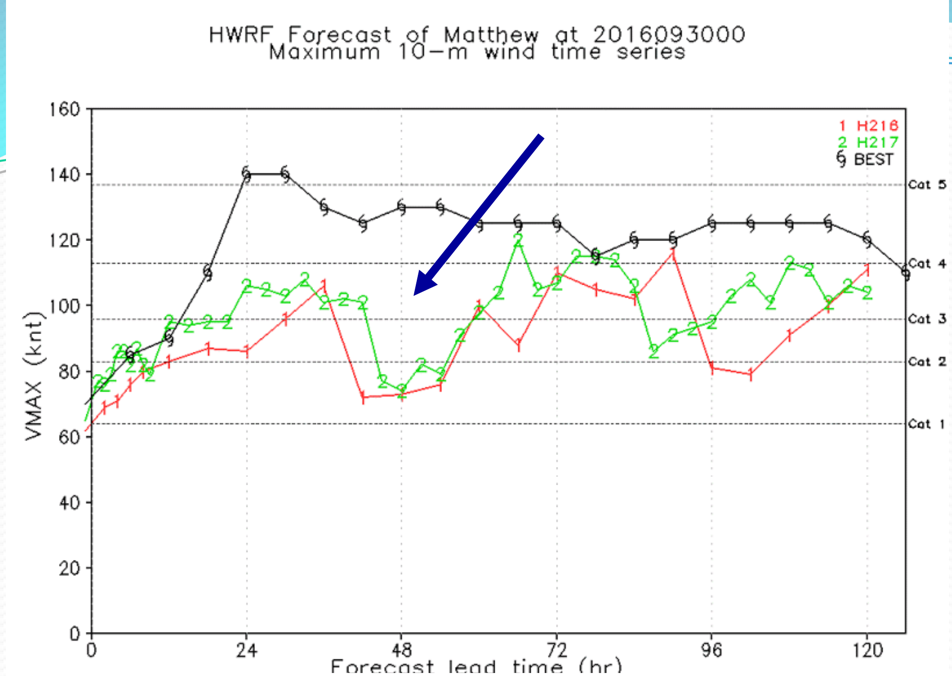
- Continue diagnostics to help identify areas for HWRF improvement

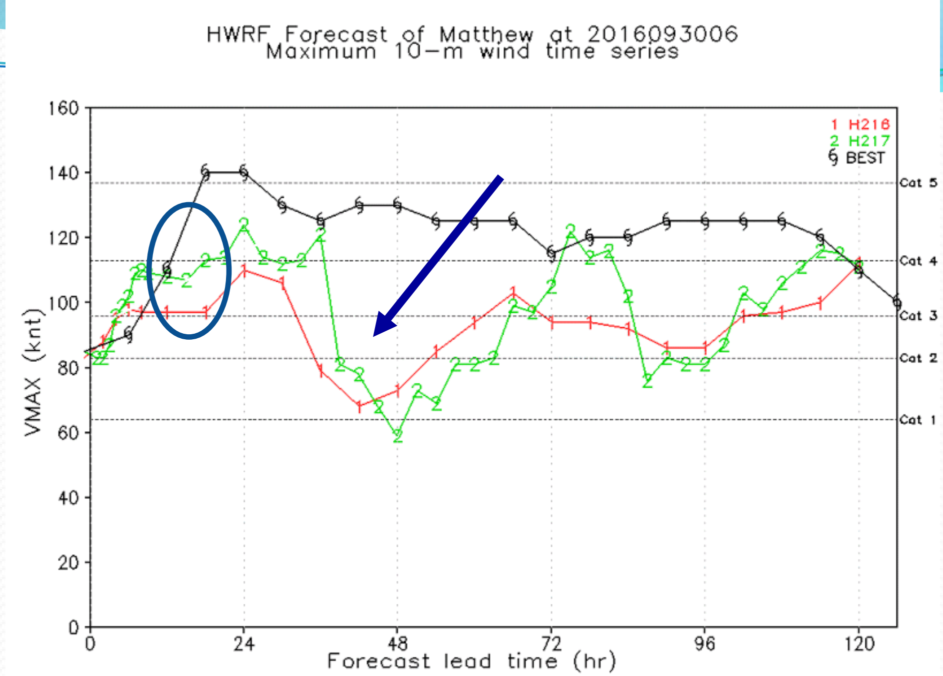
…Case studies…

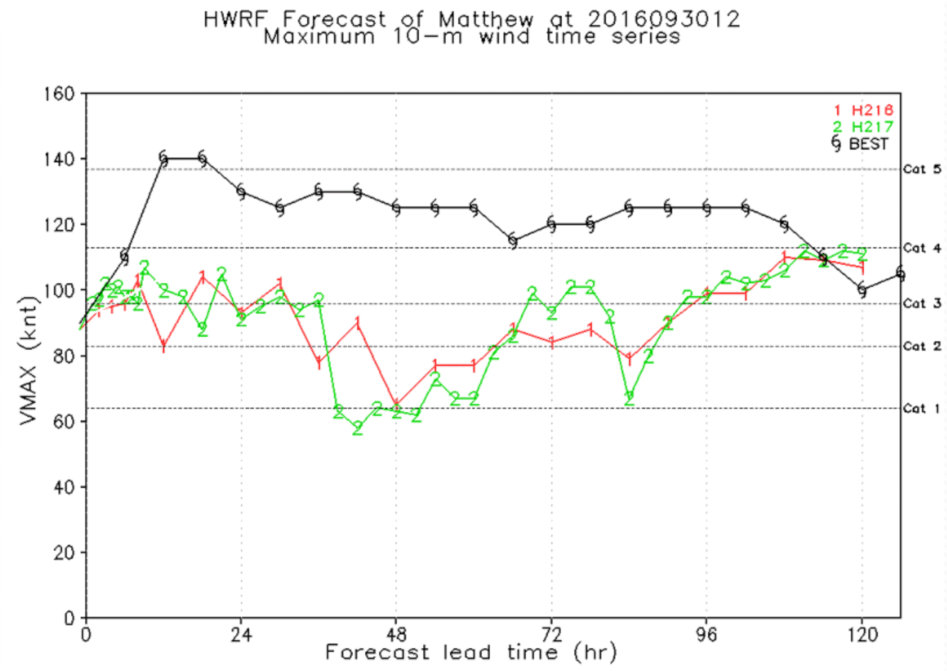
Blake et al. HFIP meeting, 01/2017

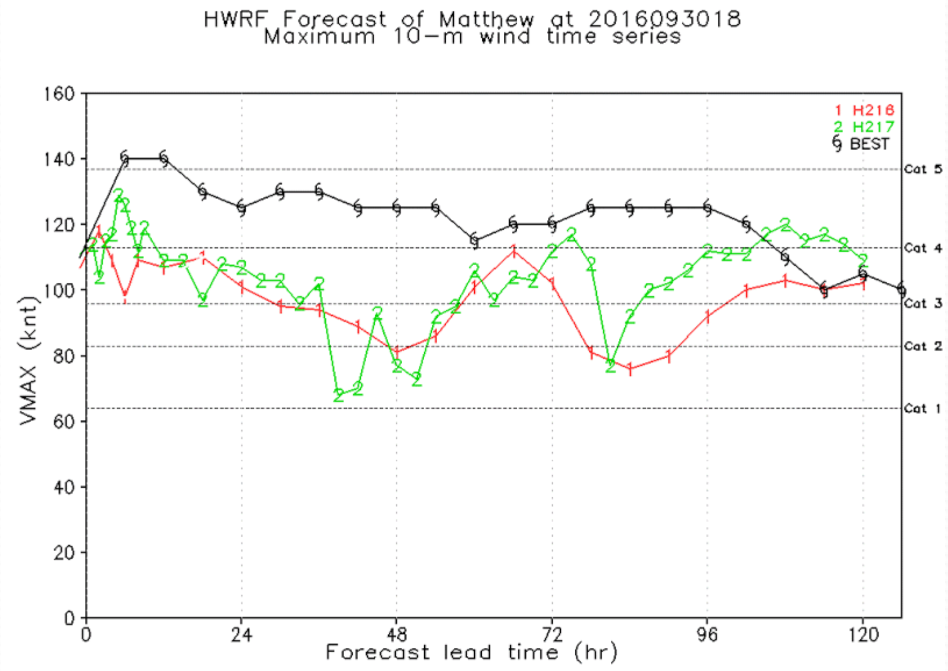
Intensity oscillations in:

2016093000
2016093006
2016093012
2016093018



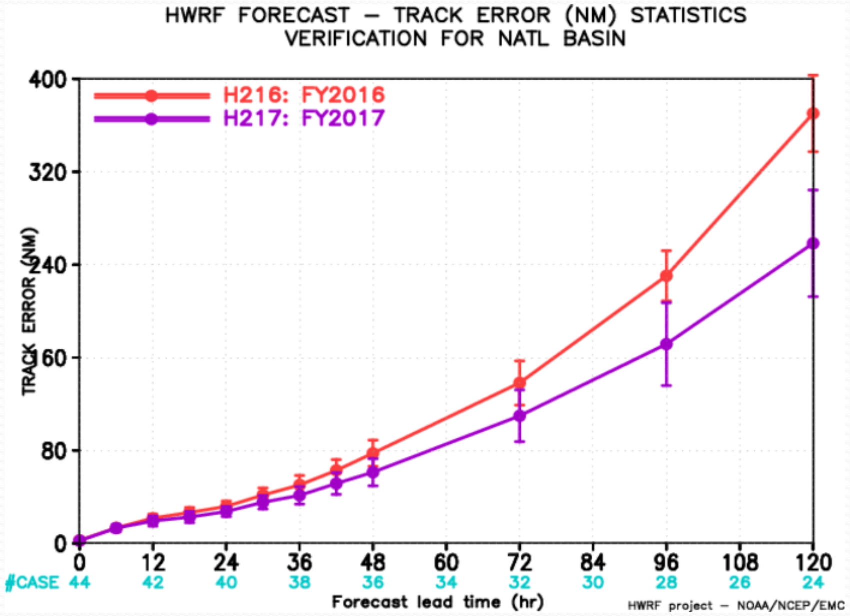


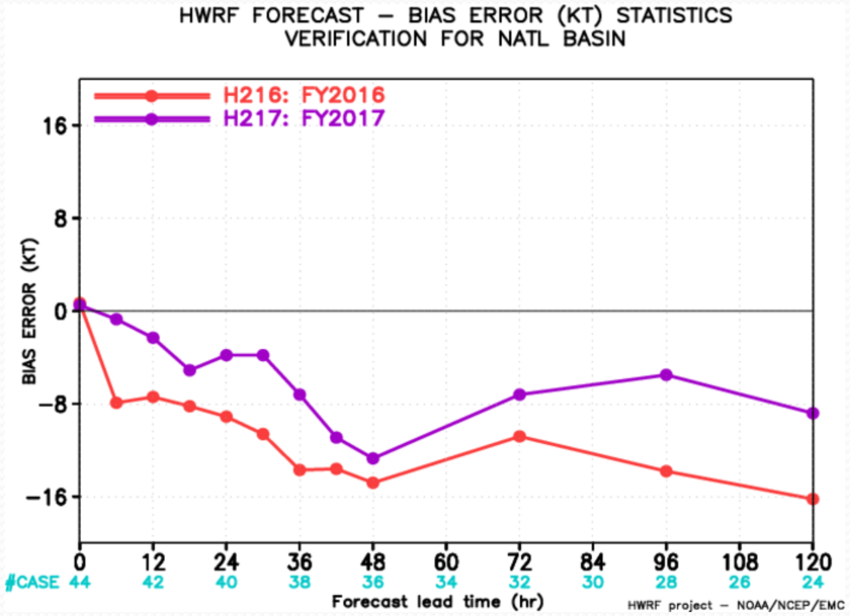


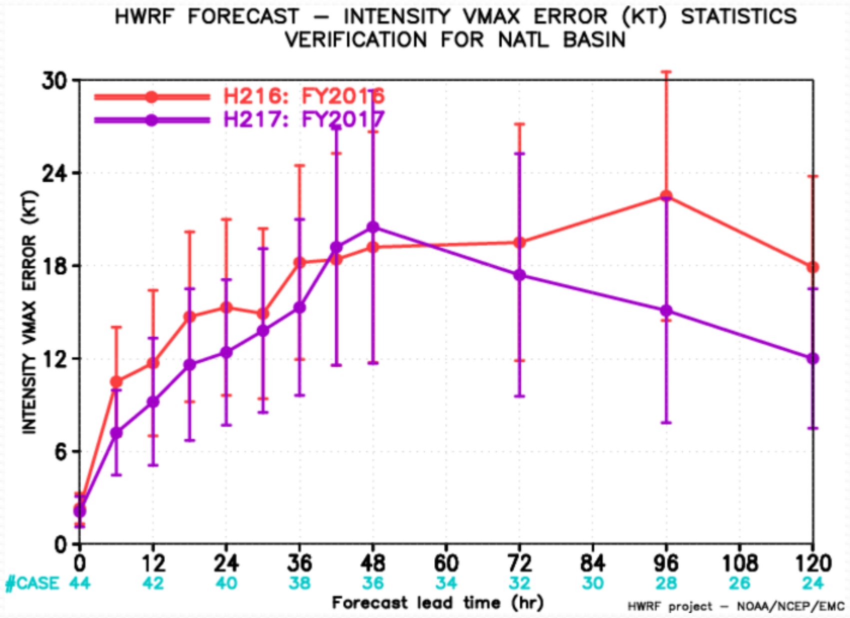


H217 exhibits similar behavior as H216 and CTCX but H217 has better RI representation.

Track and intensity errors for NATL storm Matthew 14L2016

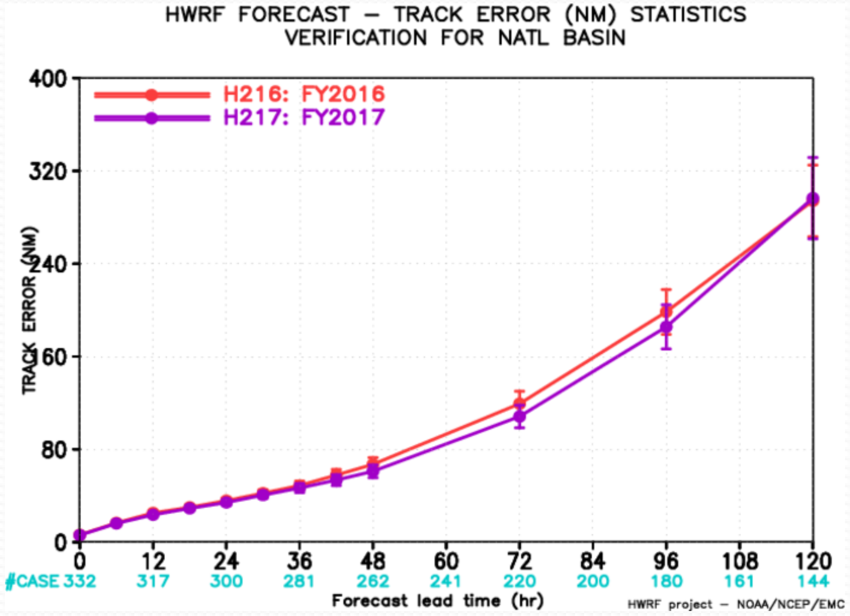


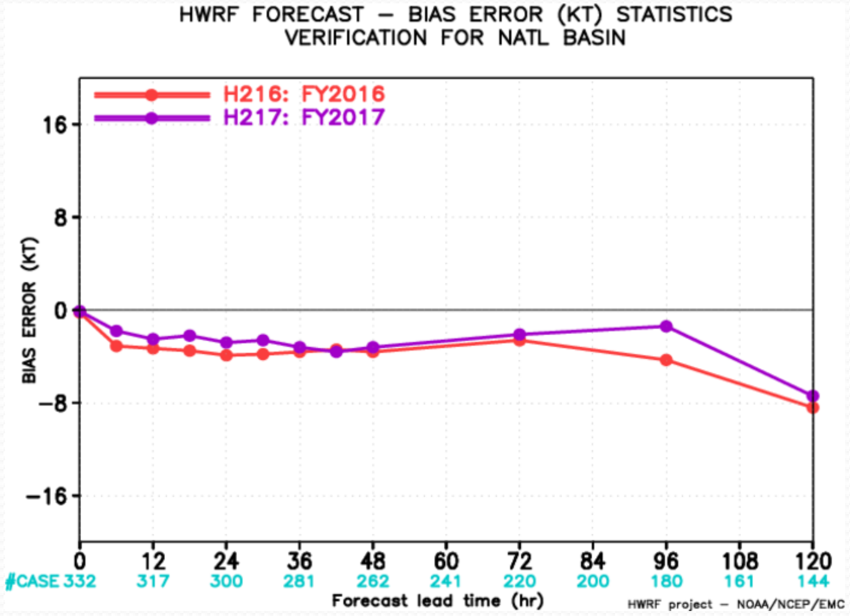


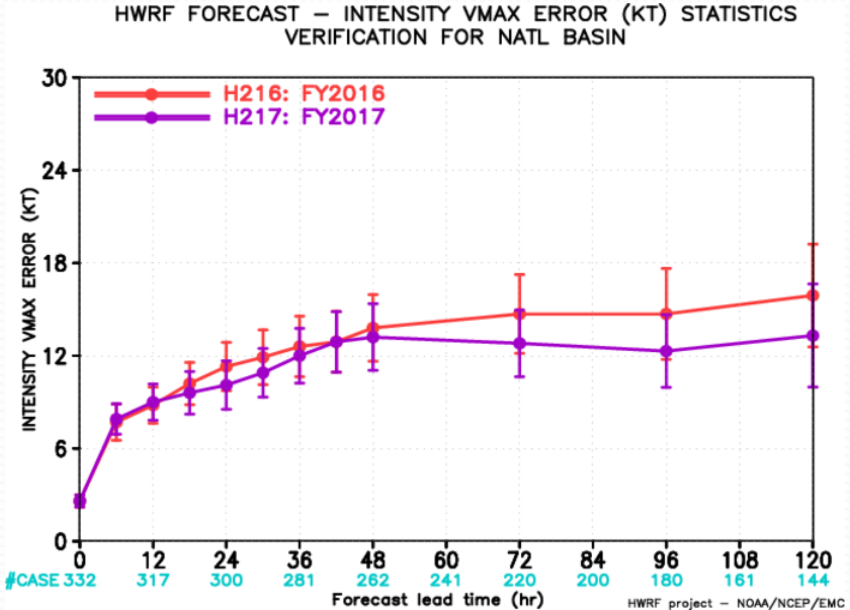


H217 shows significant improvement in track for Matthew (almost 100 NM at Day 5). Intensity errors are also lower except at Day 2. The bias errors are also lower.

Track and intensity errors for NATL basin RI storms

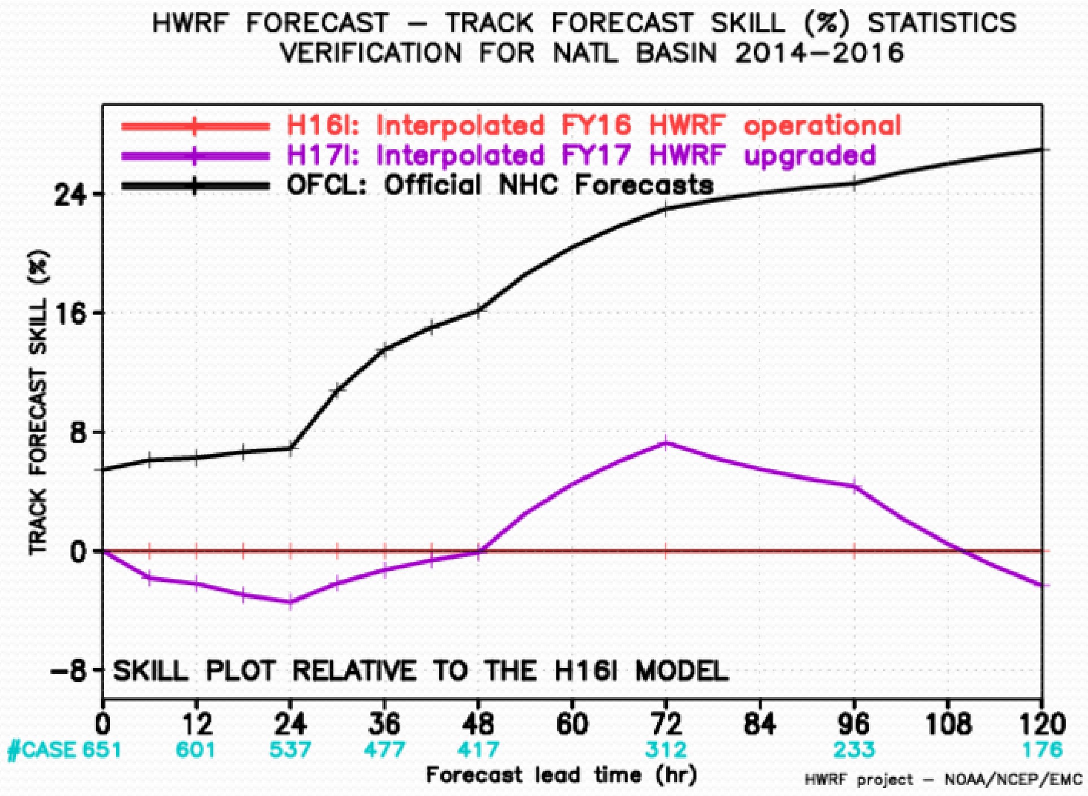


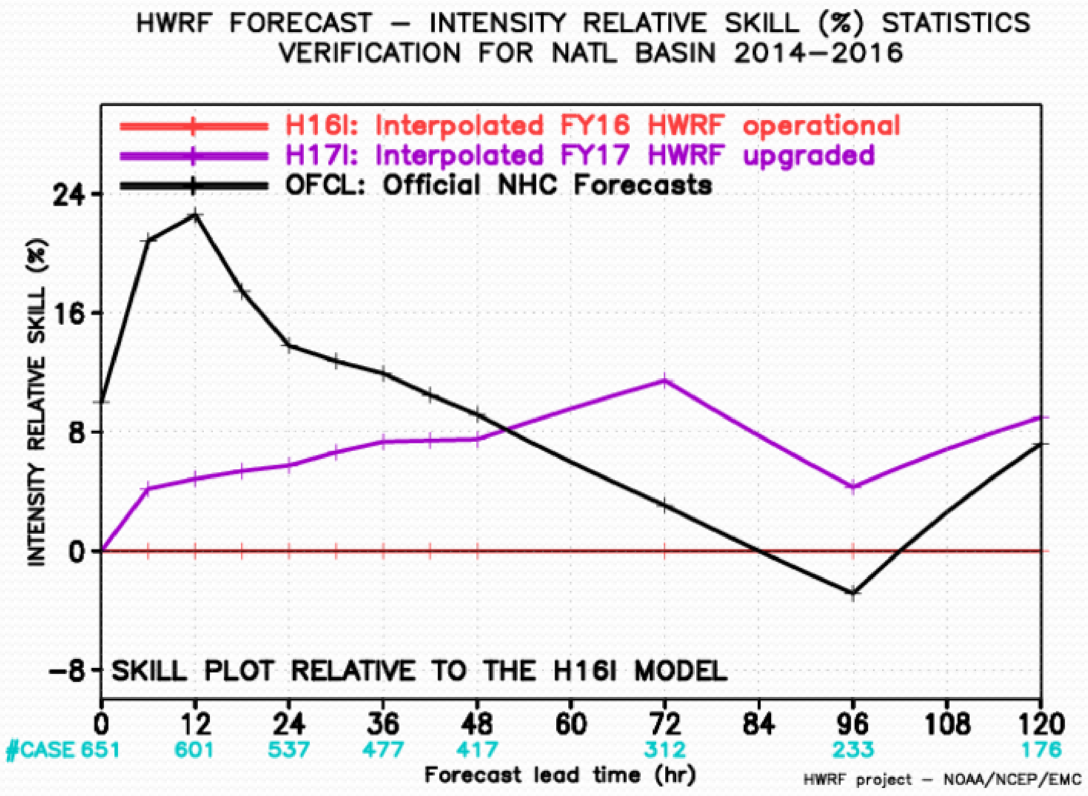




For storms exhibiting RI, the track, intensity and bias errors for H217 show improvement for all lead times when compared to H216.

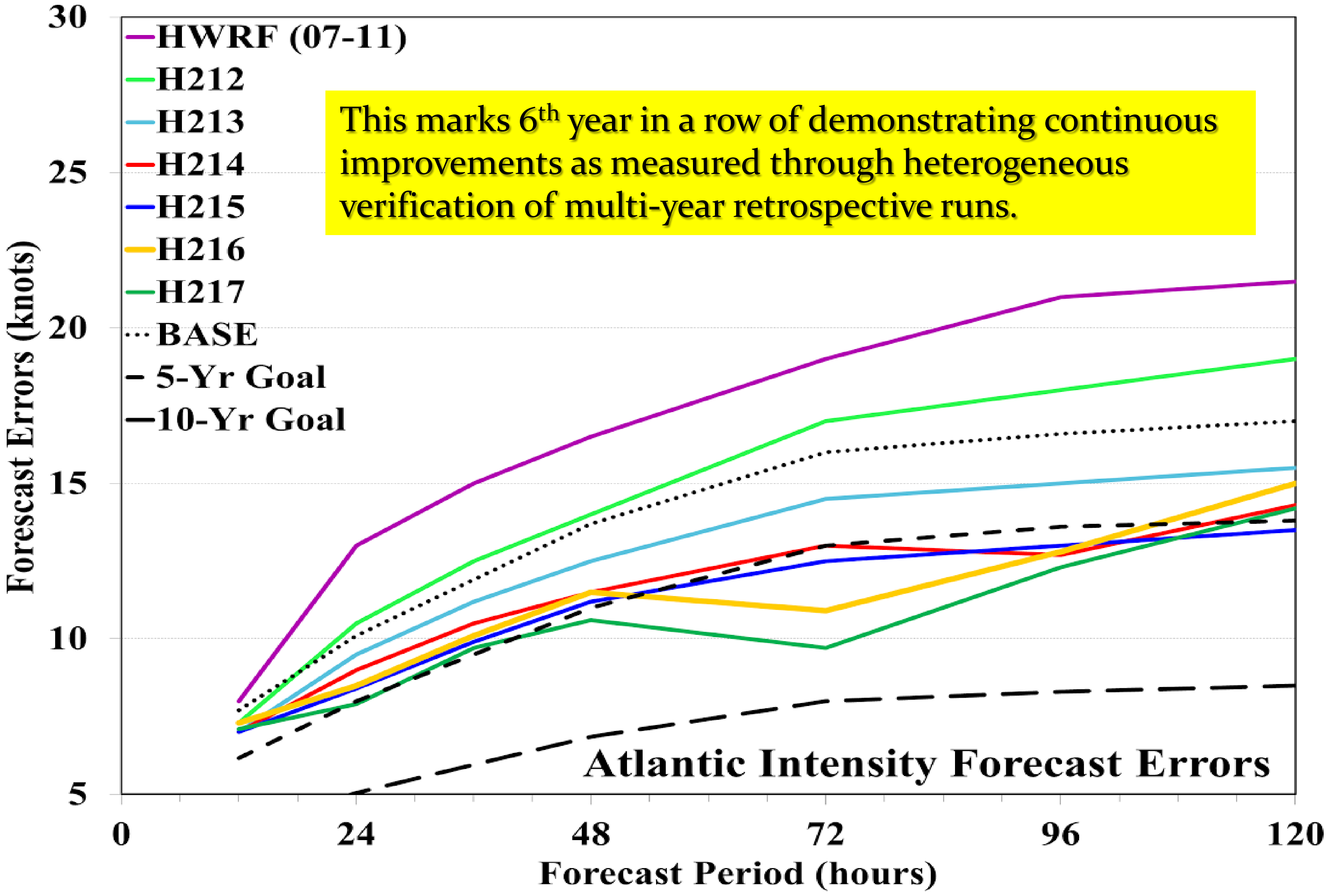
H17I performance compared to H16I in NATL (Early Models)





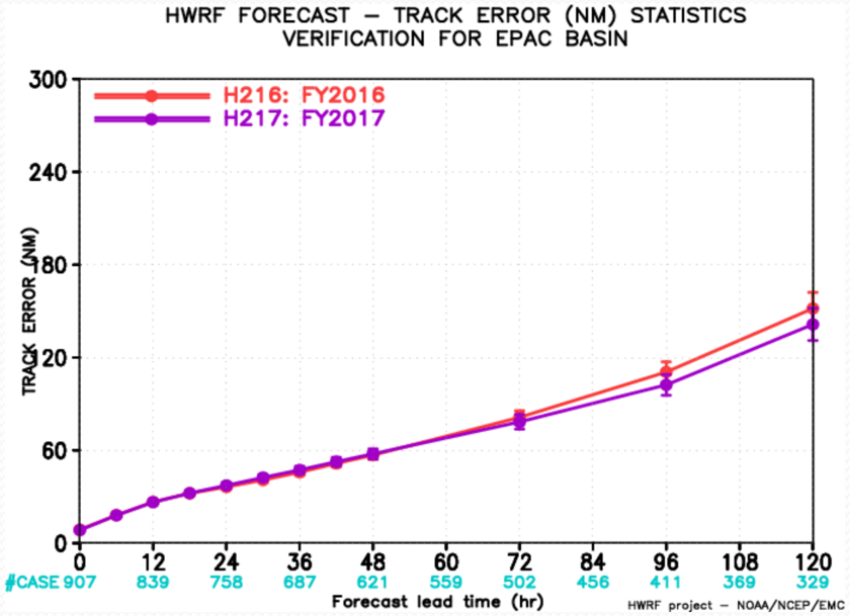
H217 tracks are overall neutral with improvements from hrs 48-108 while intensity is improved at all lead times with 10% improvement at day 3. We still needs to catch-up to official tracks but are doing better for intensity after Day 2.

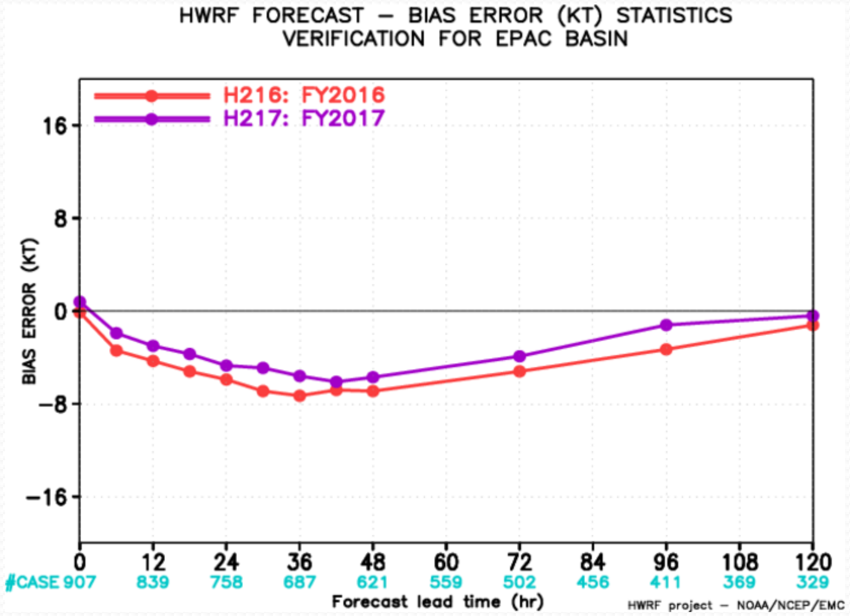
2017 HWRF: Continuing the trend of incremental but substantial improvements in NATL intensity forecasts

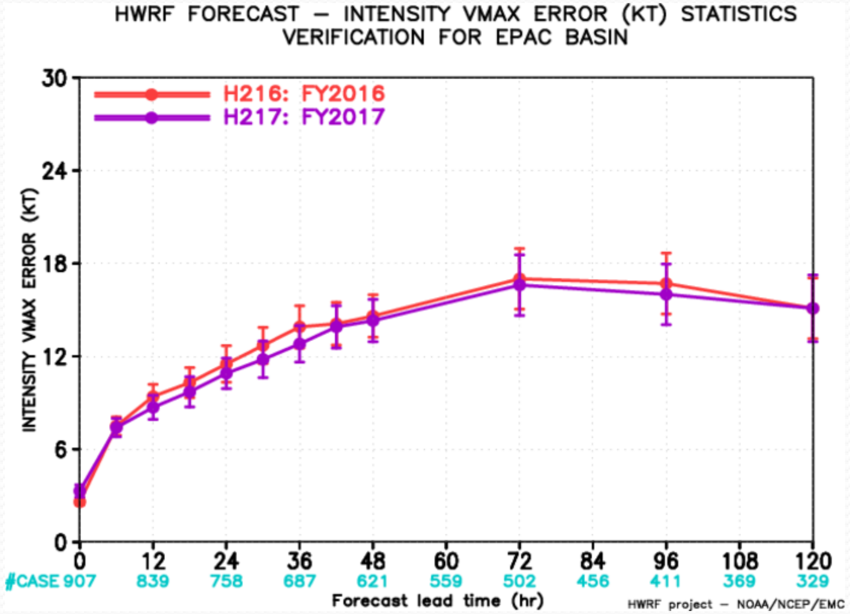


Verification for East-Pacific Storms (2014-2016)

Track and intensity errors for EPAC storms

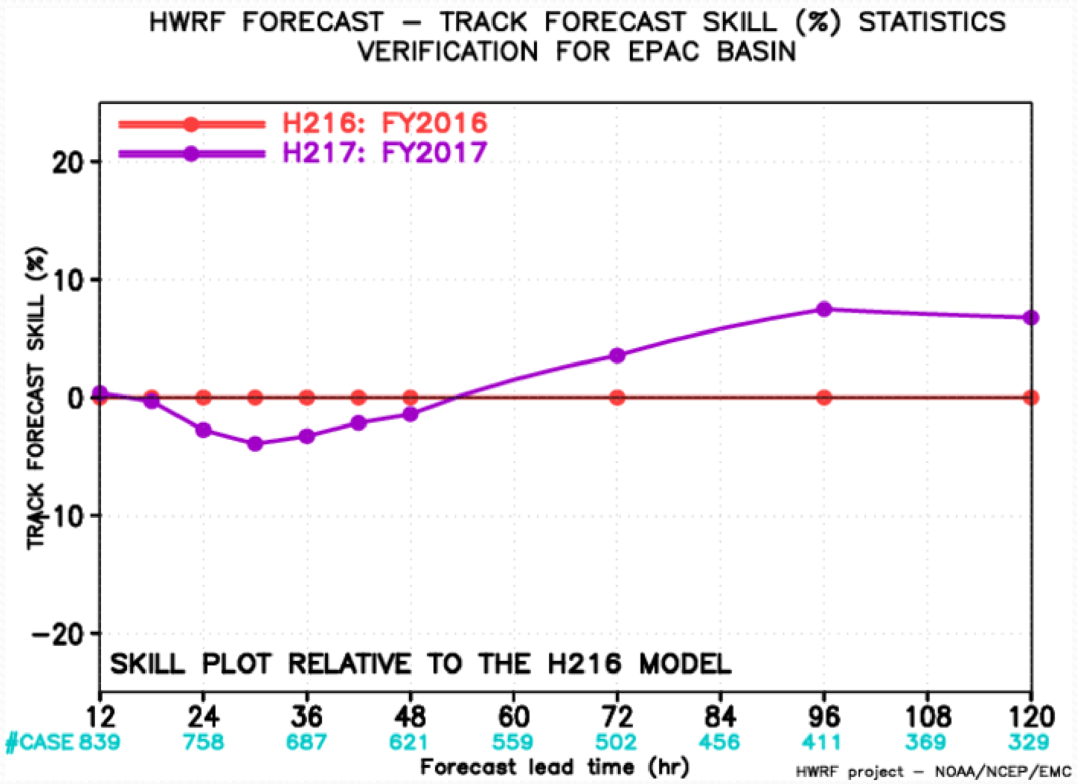


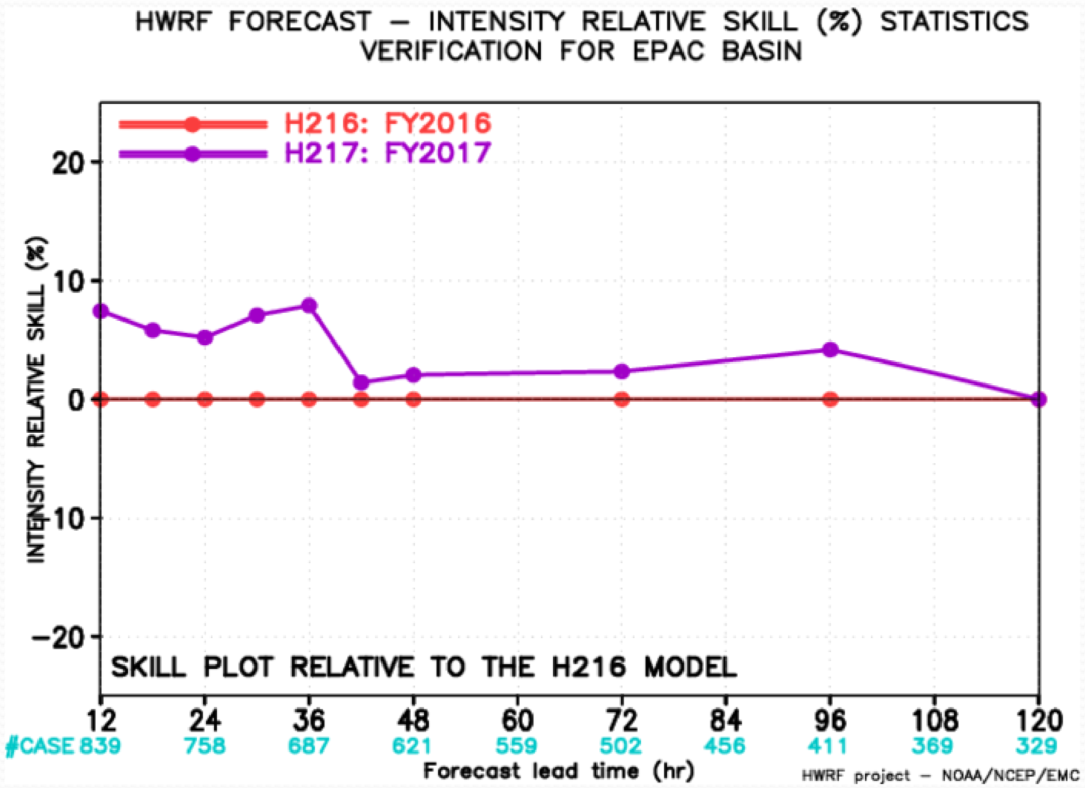




- Compared to H216, H217 track forecasts are similar till Day 3 but then show improvements after that.
- Compared to H216, H217 intensity forecast errors are mostly lower.
- The intensity bias errors for H217 are also much lower compared with H216.

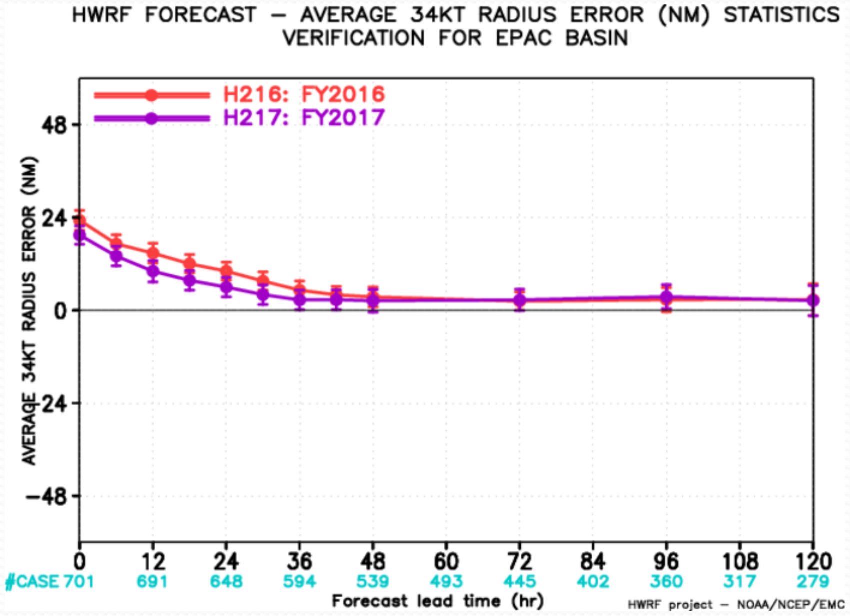
Track and intensity skills for EPAC storms (late model)

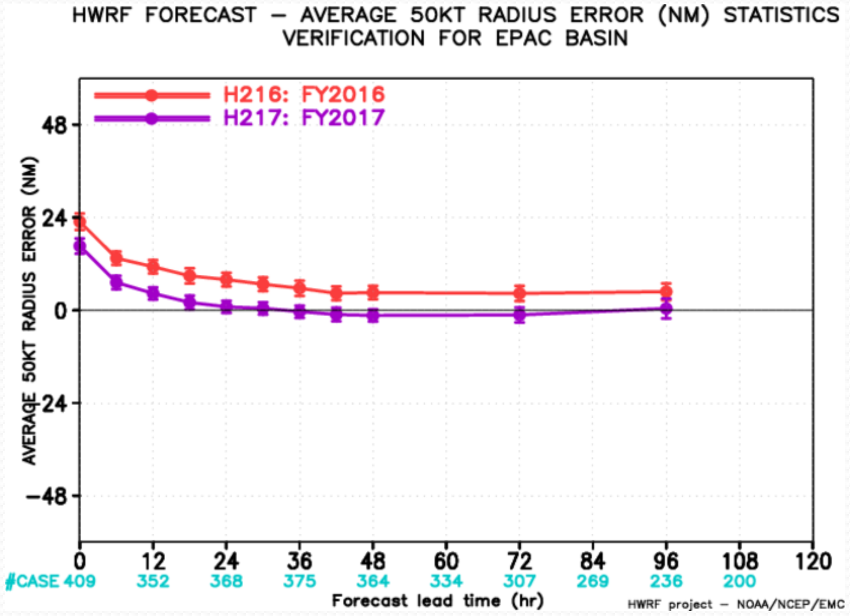


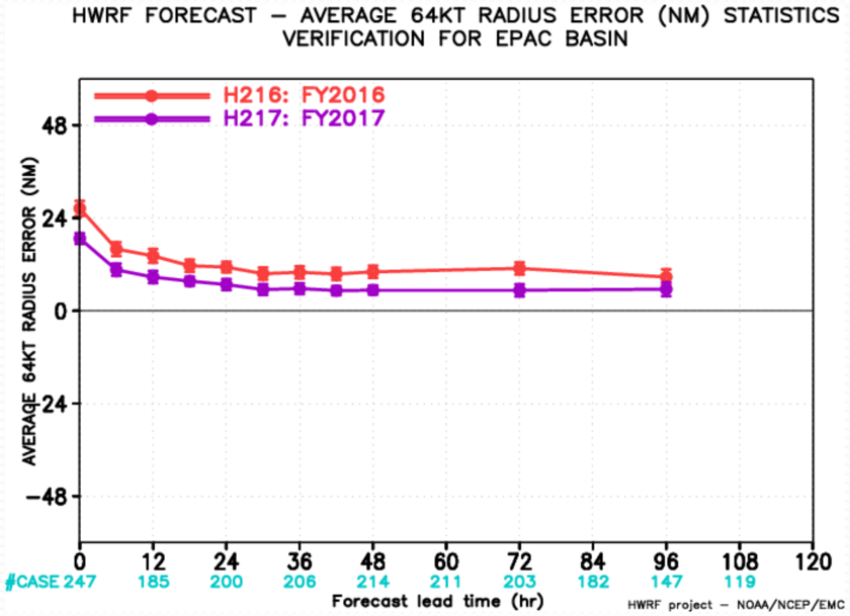


- The track skill for H217 is a little lower for hrs 18-54 but then positive for late lead times.
- Change in intensity skill for H217 is positive at all lead times and more than 5% for early forecast hours (hrs 12-36).

Size errors for EPAC storms

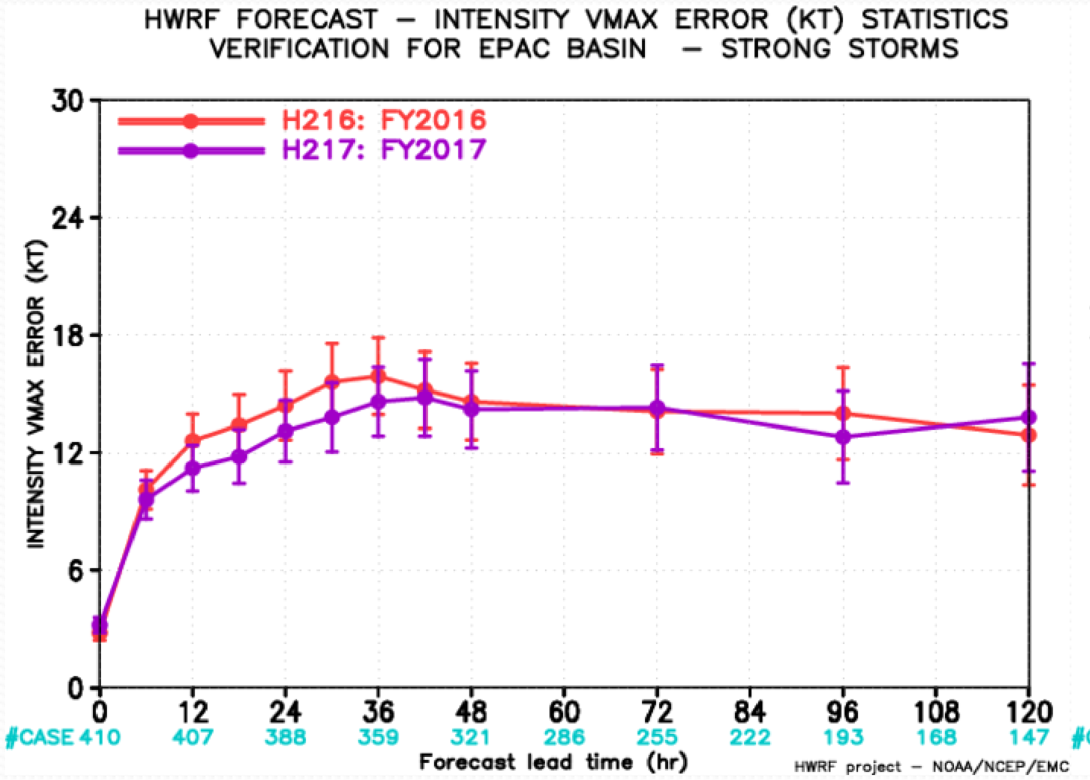


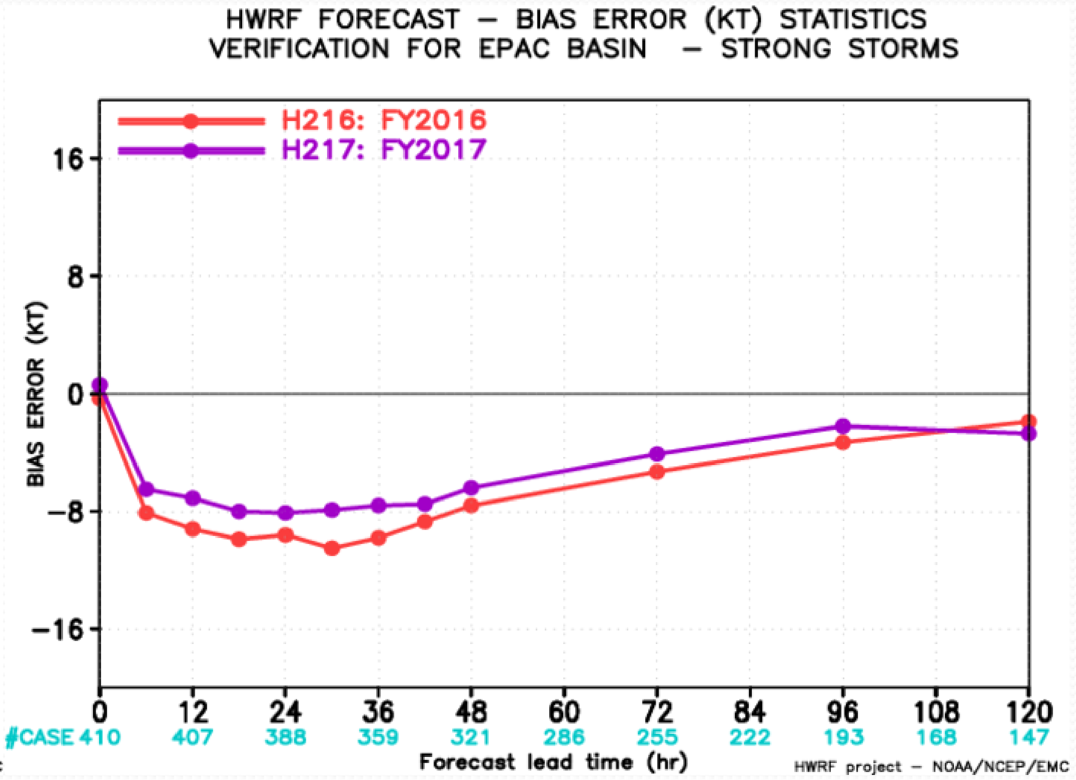




The storm size errors for H217 show improvement for all lead times and for all radii (34, 50 and 64 kts).

Maximum Intensity and bias errors for EPAC storms with strong cycles (initial intensity > 50kts)

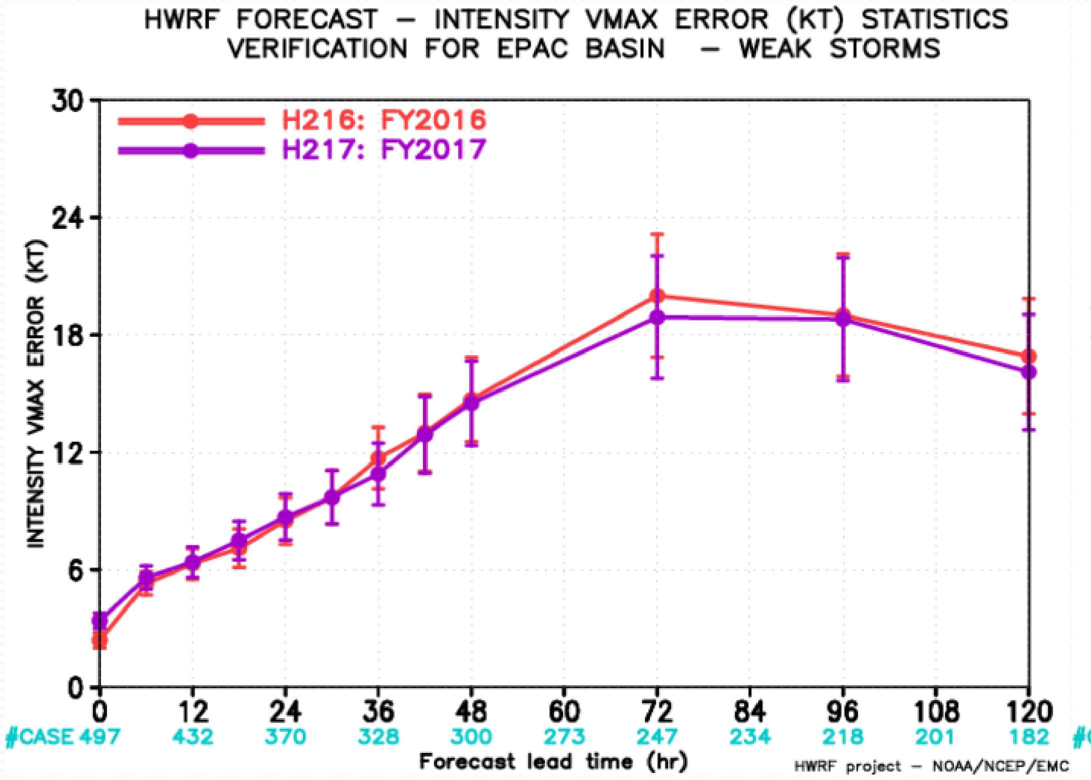


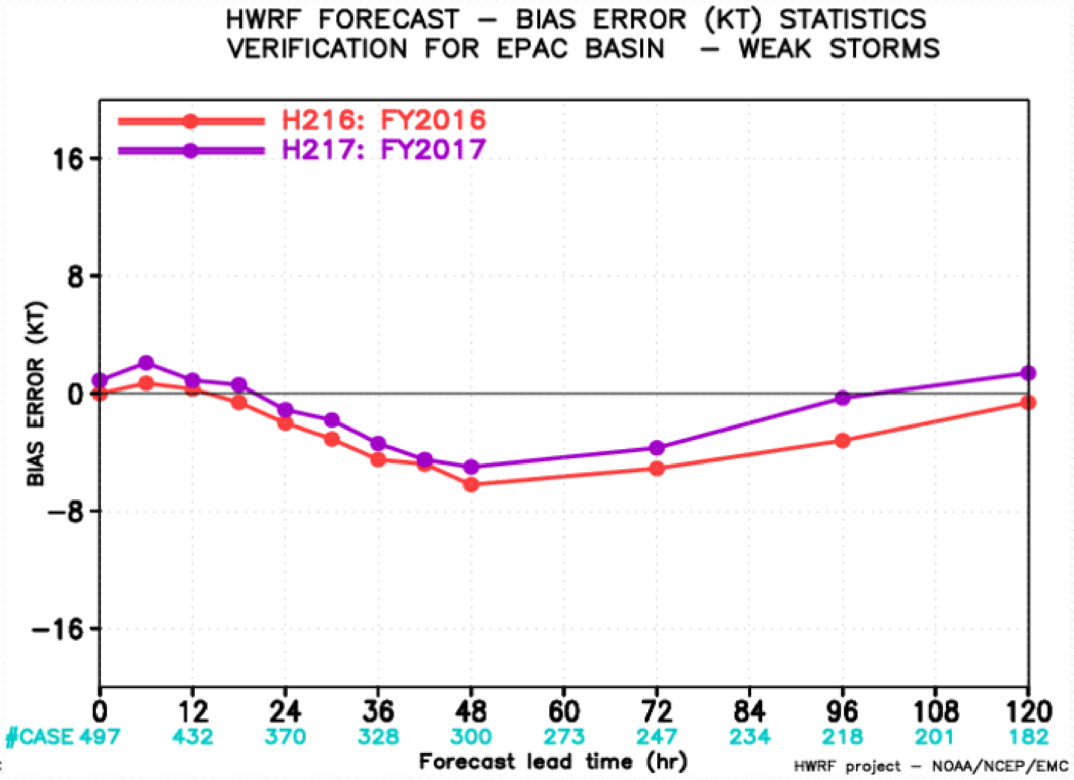


- For storms with strong cycles, the Vmax errors for H217 are significantly lower at early lead times (hrs 6-48) and again at Day 4.

- The bias errors for such storms is also less (less negative) for H217 at all lead times.

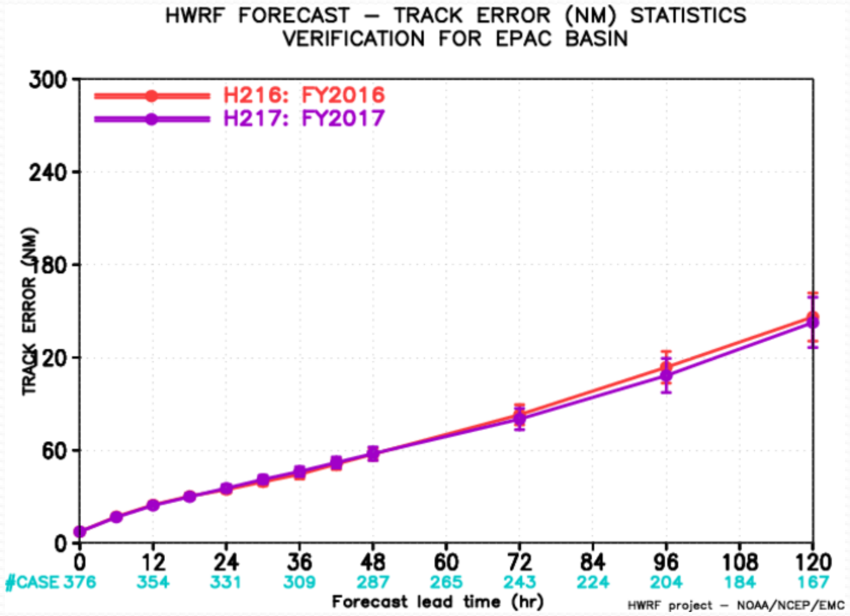
Maximum Intensity and bias errors for EPAC storms with weak cycles (initial intensity < 50kts)

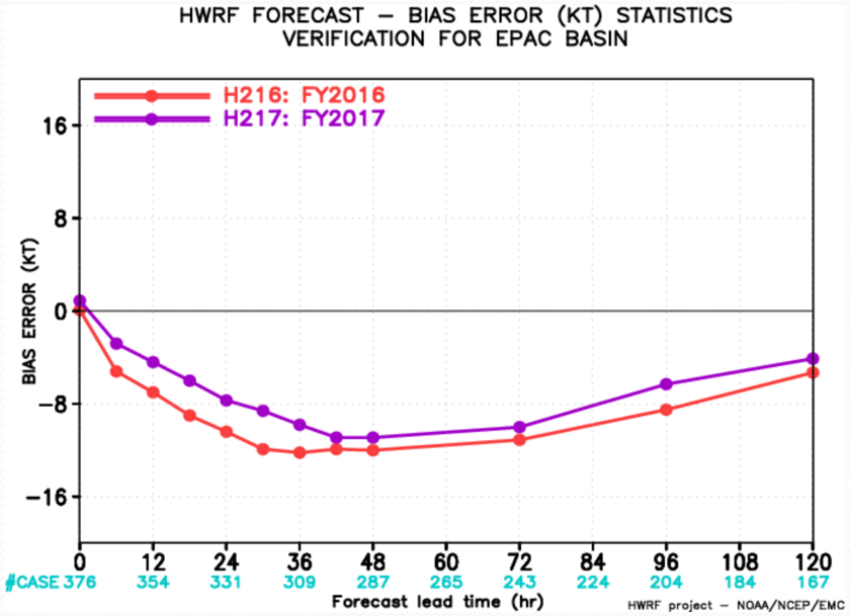


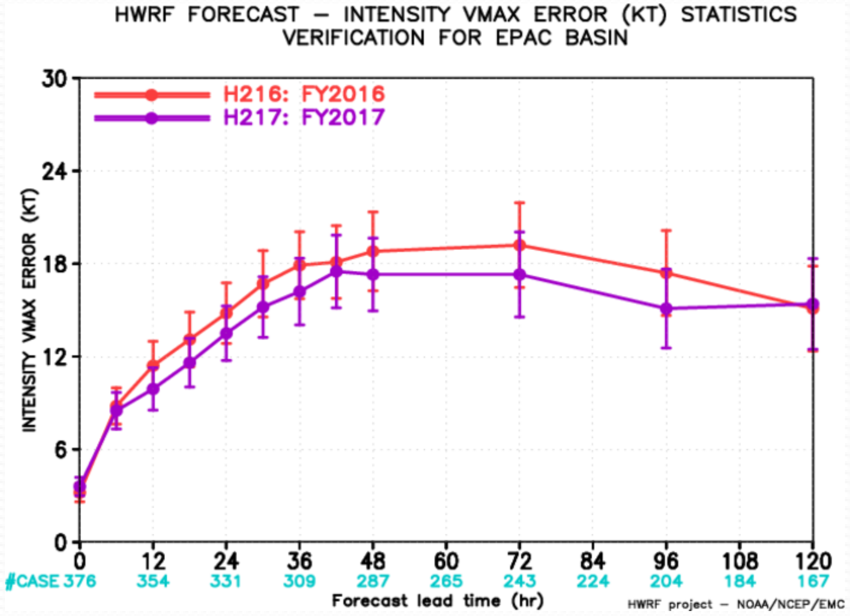


- For storms with weak cycles, the Vmax errors for H217 are neutral to slightly lower than H216.
- The bias errors for such storms for H217 are also lower than H216 for all lead times.

Track and intensity errors for EPAC basin RI storms

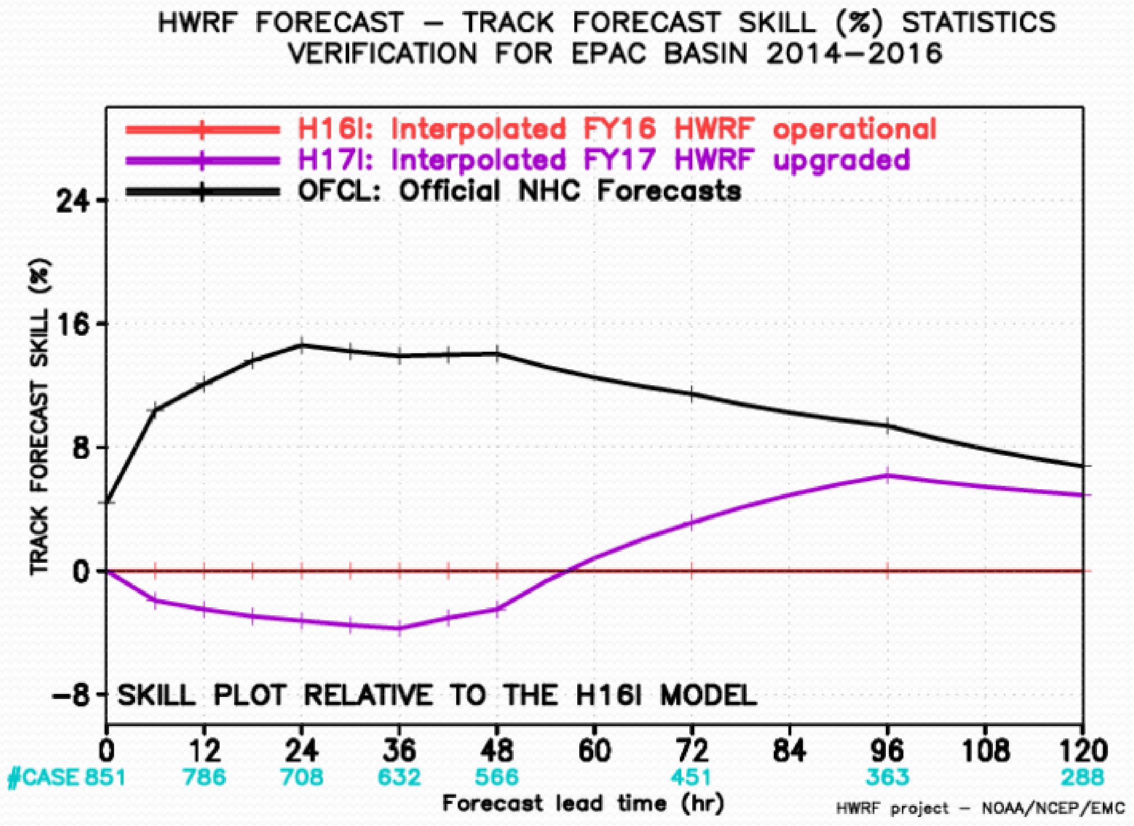


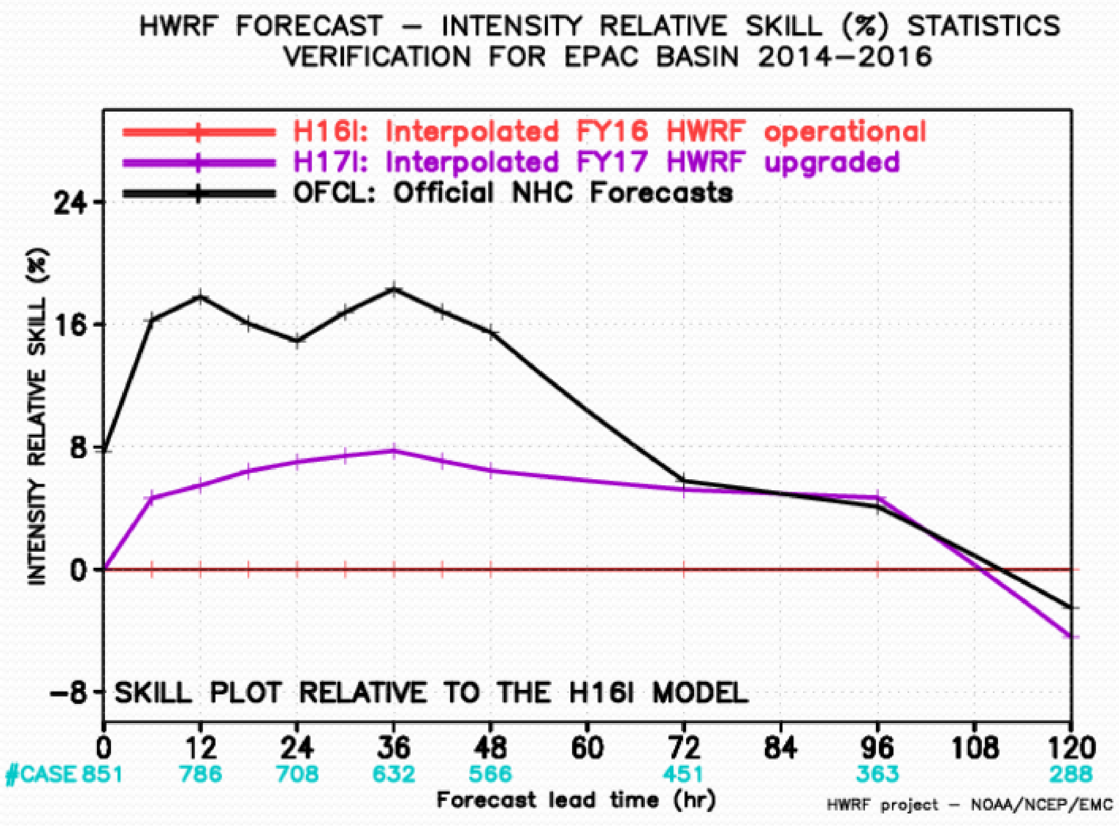




For storms exhibiting RI, track errors for H217 show improvements for Days 4 and 5 while intensity and bias errors show improvement at all lead times when compared to H216.

H17I performance compared to H16I in EPAC (Early Models)





H217 tracks are initially a little degraded but then show improvements after hr 60. The intensity skill is improved at all lead times with 8% improvement at hr 36. We still needs to catch-up to official tracks and intensity for the first 3 days, but are doing better for track and intensity after that time.

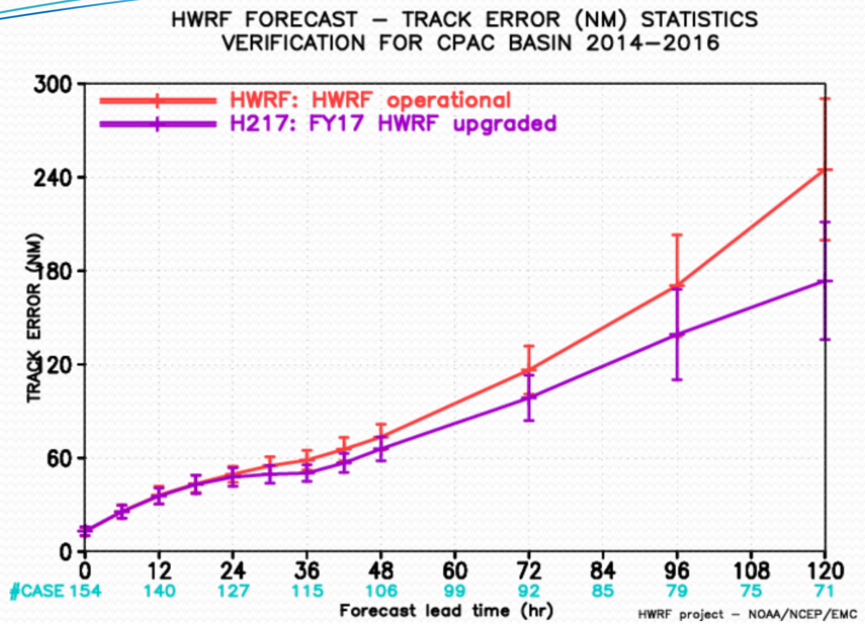
Verification for 2014-2016 Central Pacific Storms

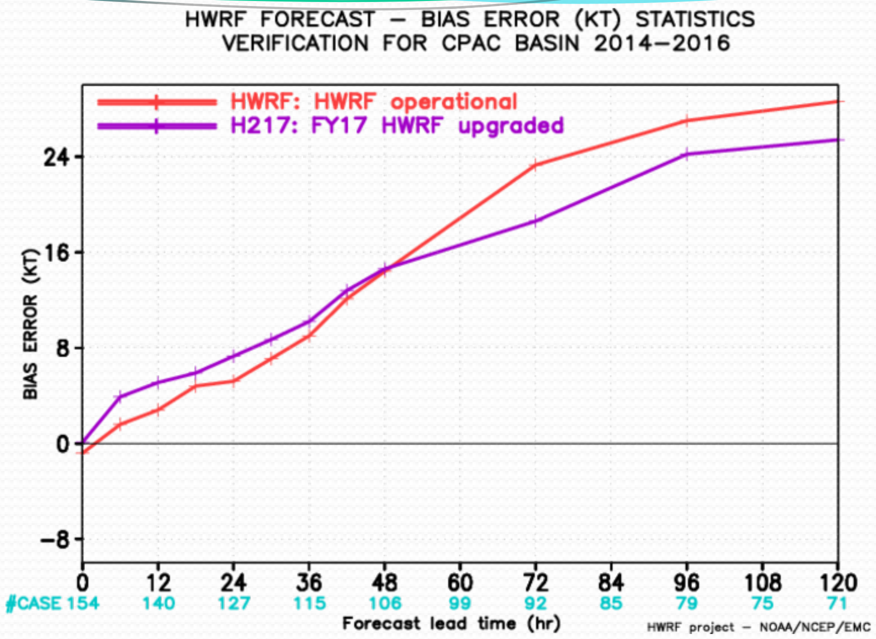
2017 CPAC Experiments

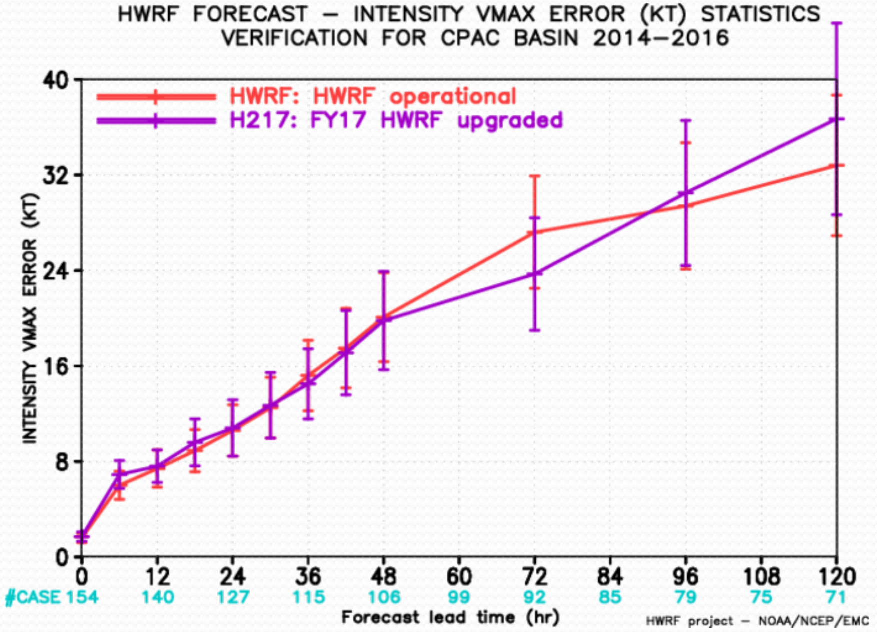
- **H216**: 2016 version of operational HWRF, 18/6/2km resolution, L61, input: T1534 L64 GFS (spectral files for both IC and BC);

- **H217**: All upgrades + coupling to MPIPOM (replacing GDEM3 with RTOFS initialization) for CPAC

H217 performance compared to H216 in CPAC







- H217 shows significant improvements in track performance especially after Day 2.
- Intensity is also improved for Day 3 but neutral overall.
- H217 also exhibits reduced positive intensity bias after 2 days.

Operational HWRF Configurations: 2016 (top) vs. 2017 (bottom)

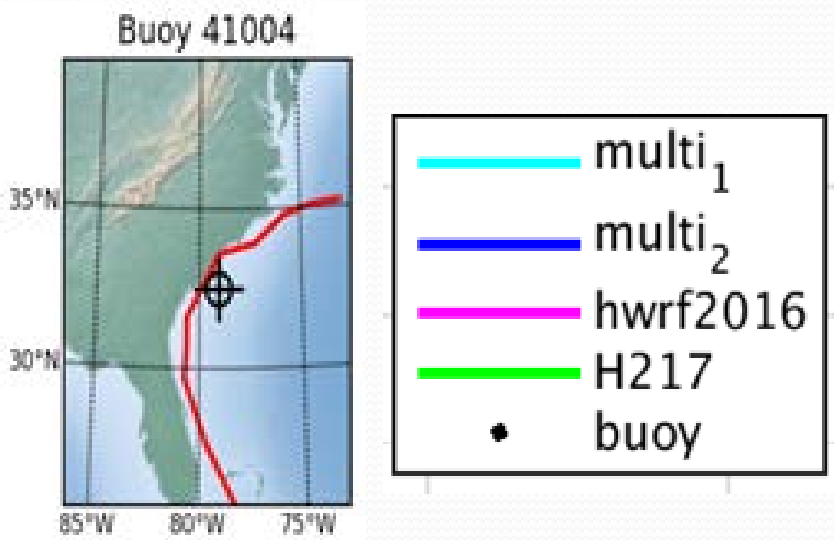
Basin	Ocean	Data Assim	Ensemble	Vertical	Model Top
NATL	3D POM GDEM	Always	TDR Only	61 level	2 mbar
EPAC	3D POM RTOFS	Always	TDR Only	61 level	2 mbar
CPAC	3D POM GDEM	None	None	61 level	2 mbar
WPAC	3D POM GDEM	None	None	43 level	50 mbar
NIO	3D POM GDEM	None	None	43 level	50 mbar
SIO	None	None	None	43 level	50 mbar
SPAC	None	None	None	43 level	50 mbar

Basin	Ocean	Data Assim	Ensemble	Vertical	Model Top
NATL	3D POM GDEM	Always	TDR self-cycled	**75** level	**10** mbar
EPAC	3D POM RTOFS	Always	TDR self-cycled	**75** level	**10** mbar
CPAC	3D POM **RTOFS**	None	None	**75** level	**10** mbar
WPAC	**3D HYCOM**	None	None	**61** level	**10** mbar
NIO	**3D HYCOM**	None	None	**61** level	**10** mbar
SIO	None	None	None	43 level	50 mbar
SPAC	None	None	None	43 level	50 mbar

Summary

- Further enhancements suggested for 2017 operational HWRF include:
  - Upgrades in model physics consistent with observations, data assimilation improvements including GSI and improved ocean initializations for CPAC.
- H217 retrospective evaluation of 2014-2016 hurricane seasons (total 684 verifiable cycles in NATL, 907 in EPAC, 154 in CPAC) demonstrated improved forecasts compared to both FY16 operational HWRF (H216) and baseline H17B driven by 2017 GFS;
- Results from H217 for the Atlantic basin and the North East Pacific suggested additional 5-10% improvement compared to H216 for intensity and modest (< 5%) improvement in track;
- Results suggest significant reduction in intensity errors and bias for storms undergoing RI for both (NATl, EPAC) basins;
- There was reduction in intensity errors and bias for strong storms (initial intensity > 50 kts) for both (NATl, EPAC) basins;
- Storm size errors were further reduced for both basins at all lead times;
- Results from H217 for the Central Pacific basin suggested a significant improvement in track (> 10%) and neutral for intensity;

WAVEWATCH III results for Hurricane Matthew (14L2016) with H217 (One way coupled)



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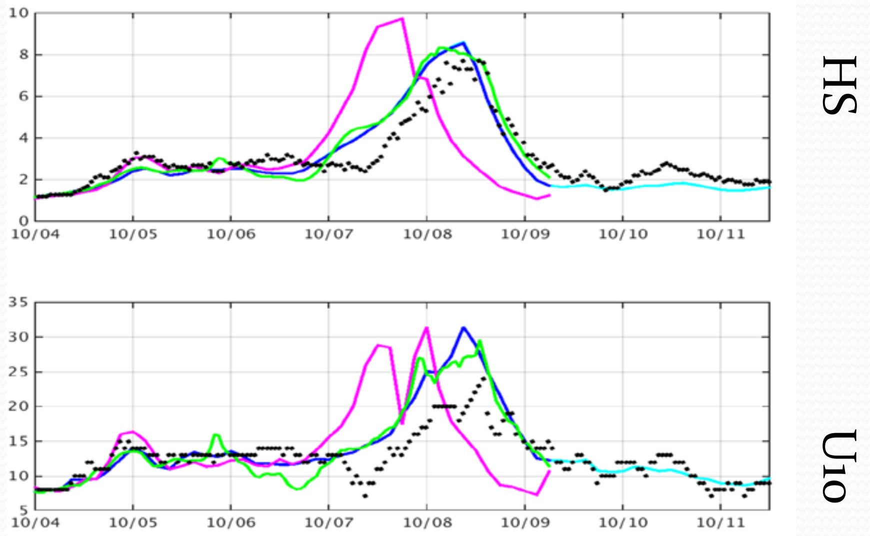

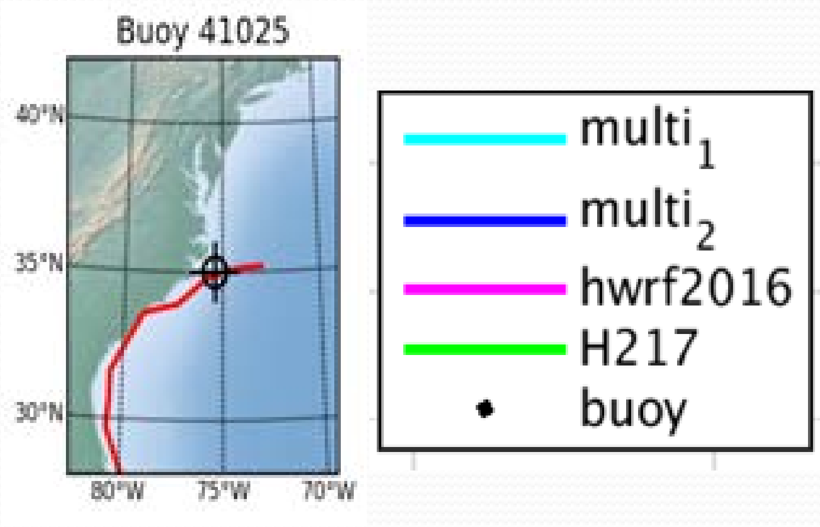

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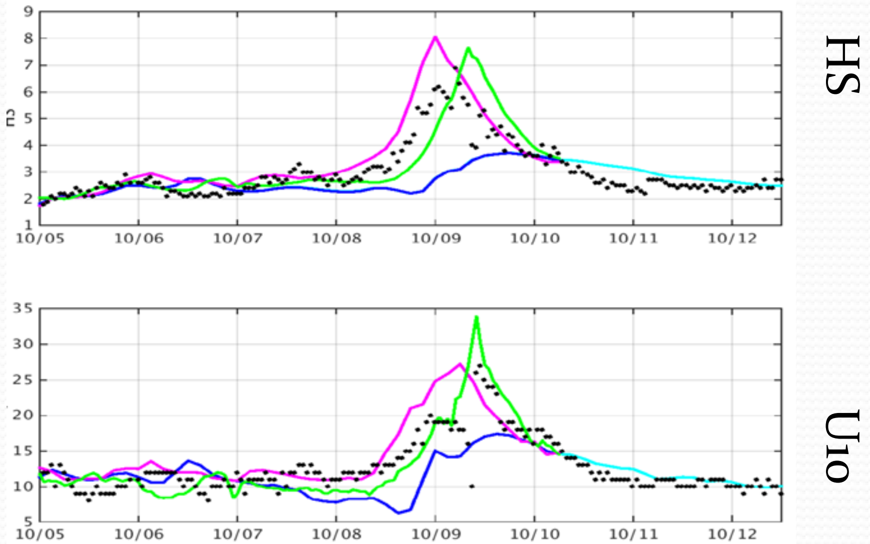
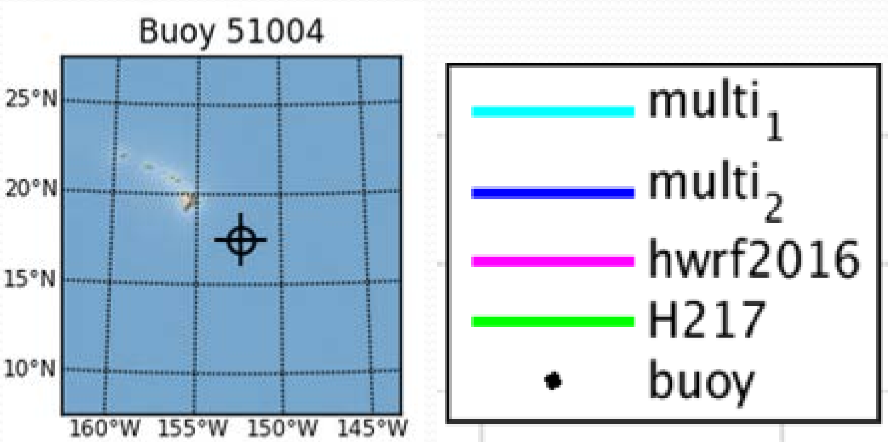
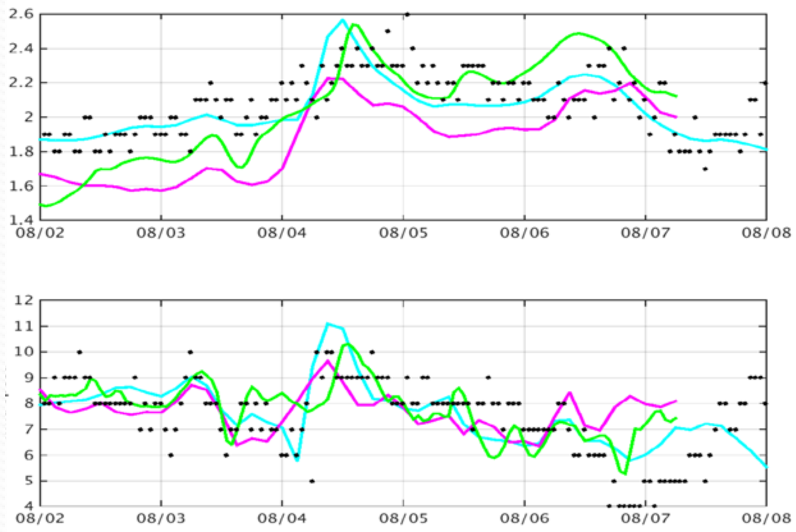


WAVEWATCH III results for Tropical Storm Howard (EP092016) with H217 (One way coupled)

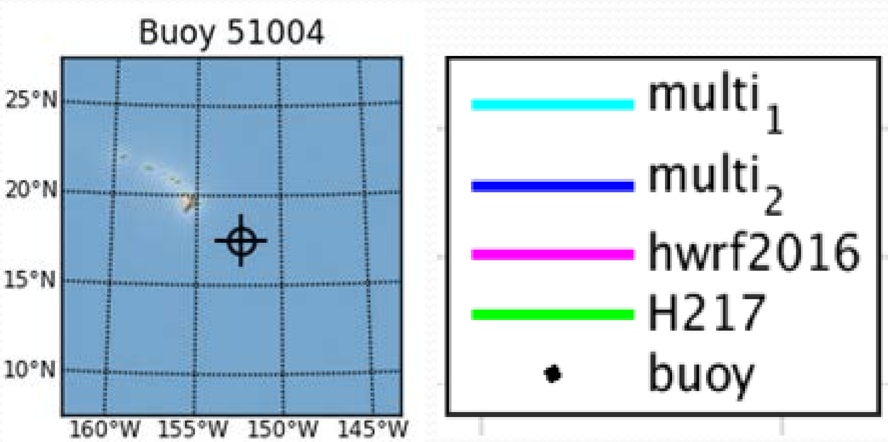


2016-08-02 00z



HS

U10



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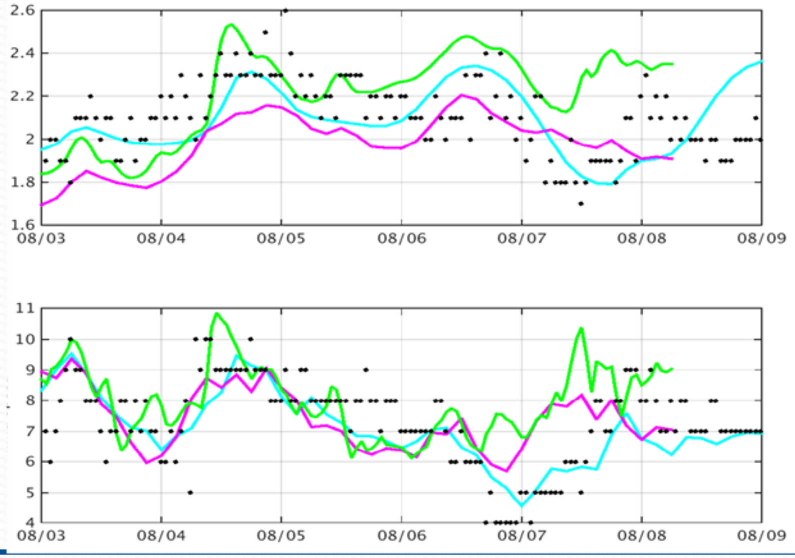


HS

U10

Summary (cont.)

- The one –way coupled WaveWatchIII in H217 gives much better results for Significant Wave Heights as compared to 2016 operational HWRF. **The Hurricane Wave Model (multi-2) will be discontinued in NCEP operations with 2017 HWRF upgrade**;
- Evaluation metrics in the skill space confirmed the positive improvements from H216;
- High-resolution ensemble based TDR DA paves way for the next generation vortex scale DA efforts supported by HFIP, while 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 for another successful execution of pre-implementation T&E for implementing improved HWRF model in operations.**

What it takes in operations to run 2017 HWRF

- Resource requirements:
  - FY17 HWRF H217: 1512 cores or 63 nodes on Cray (identical to FY16 HWRF except for maximum storms increased to 8),
  - Run maximum eight storms in all global basins simultaneously.
  - No changes in delivery time (before t+6);

IT Testing (completed)

Test Objective	Comment
Missing GDAS EnKF members (total 80 mem)	if Nmissing >= 40, hybrid EnKF/GSI else conventional GSI
TDR (Tailed Doppler Radar) test	GSI will be done w/wo TDR for D03
Missing ICs from GDAS data	HWRF fails with proper error message
Missing BCs from GFS data	HWRF fails with proper error message
Missing previous cycle’s 6-hr forecast output	HWRF runs to completion in cold start mode
Zero length data files for GSI	Initialization and analysis runs to completion
Missing input data files for GSI	Initialization and analysis runs to completion
Missing loop current for ocean initialization	POM runs to completion using climatology
Failed ocean initialization	HWRF runs in un-coupled mode
Tracker fails to identify initial storm location	Swath generator fails with proper error message
Test at least one storm in each basin	**HWRF runs to completion**
Cross dateline and Greenwich test	Make sure HWRF model and scripts properly handle the specially situations.
Bugzilla Entries	Operational failure of 20160112 12/18Z

Code Hand-Off and Release Notes

- Release Notes (includes dependencies for ocean coupling); HWRF setup; triggering for HWRF ensembles
- IT testing
- Implementation instructions
- Workflow diagram

SVN Tag for HWRFV11.0.0 (entire system):

https://svnemc.ncep.noaa.gov/projects/hwrf/branches/hwrf.v11.0.0

Next Steps

1. Retrospective T&E at EMC: **April 10, 2017 --- Completed**
2. Briefing to NHC: **April 13, 2017 ----- Completed**
3. NHC Evaluation and Recommendations: **April 24, 2017 -- Completed**
4. Briefing to EMC Director and CCB: **April 25, 2017 --- Now Completed**
5. Briefing to NCEP Director's Office: **April 28, 2017 (scheduled)**
6. Submission of Codes to NCO: ***April 28, 2017 --- Code hand-off, submission of RFC forms, release notes and flow diagram***
7. TIN for 2017 HWRF : ***May 3, 2017***
8. NCO IT Testing : ***????***
9. Briefing to NCEP Director's Office: ***????***
10. Implementation by NCO: **

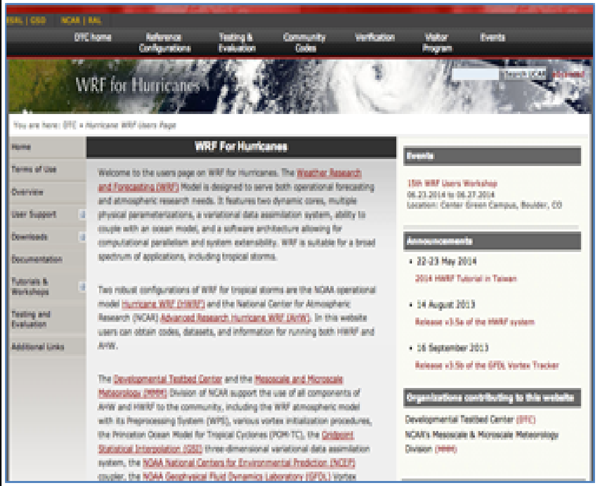
** ***Recommend H217 be implemented after 2017 GFS***

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

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

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

NATIONAL HURRICANE CENTER

International partnerships for accelerated model development & research

HMON

THE HURRICANE MULTISCALE OCEAN-COUPLED NON-HYDROSTATIC MODEL

2017 HMON V1.0.0

(A new Operational Hurricane Model at NCEP)

EMC CCB Meeting, April 25, 2017

HIWPP

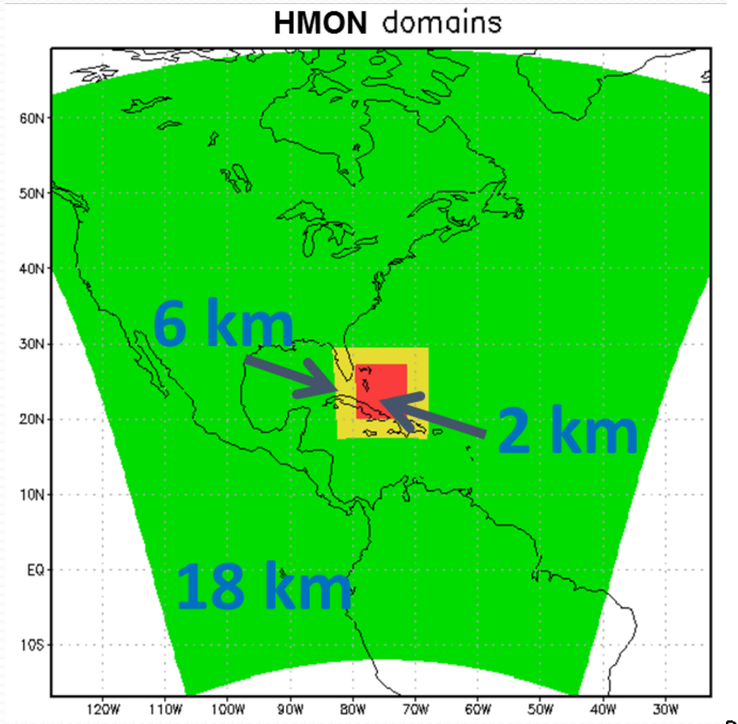
NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

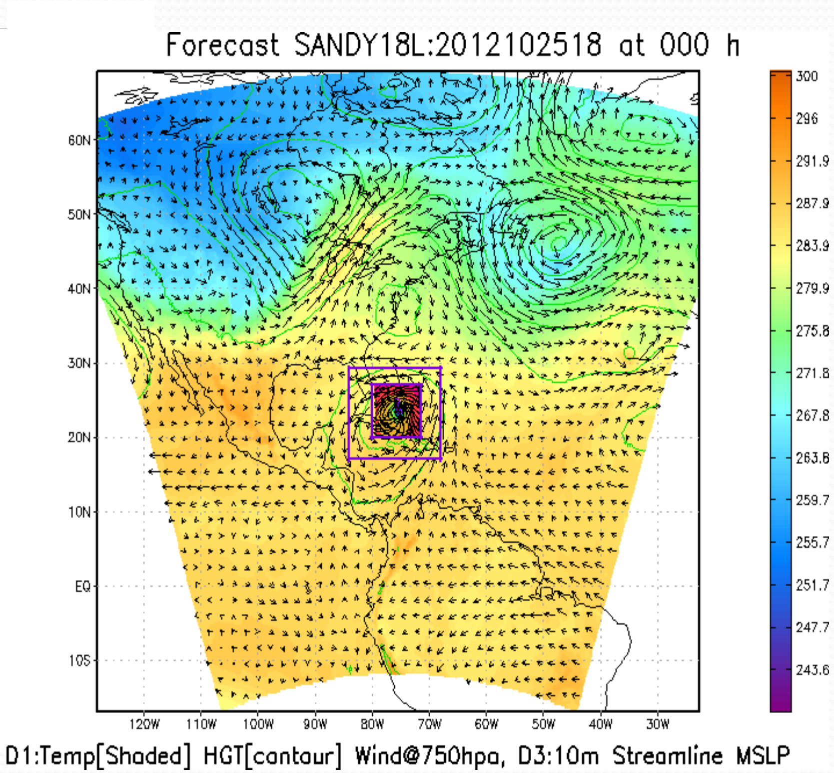
NGGPS

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

- **HMON:** Advanced Hurricane Model using NMMB (Non-hydrostatic Multi-scale Model on a B grid) 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
- Much faster, scalable and uses CCPP style physics package
- Development supported by NGGPS, HFIP and HIWPP programs
- Provides high-resolution intensity forecast guidance to NHC along with HWRF (replacing the legacy GFDL hurricane model)

HMON: A New Operational Hurricane Model at NCEP

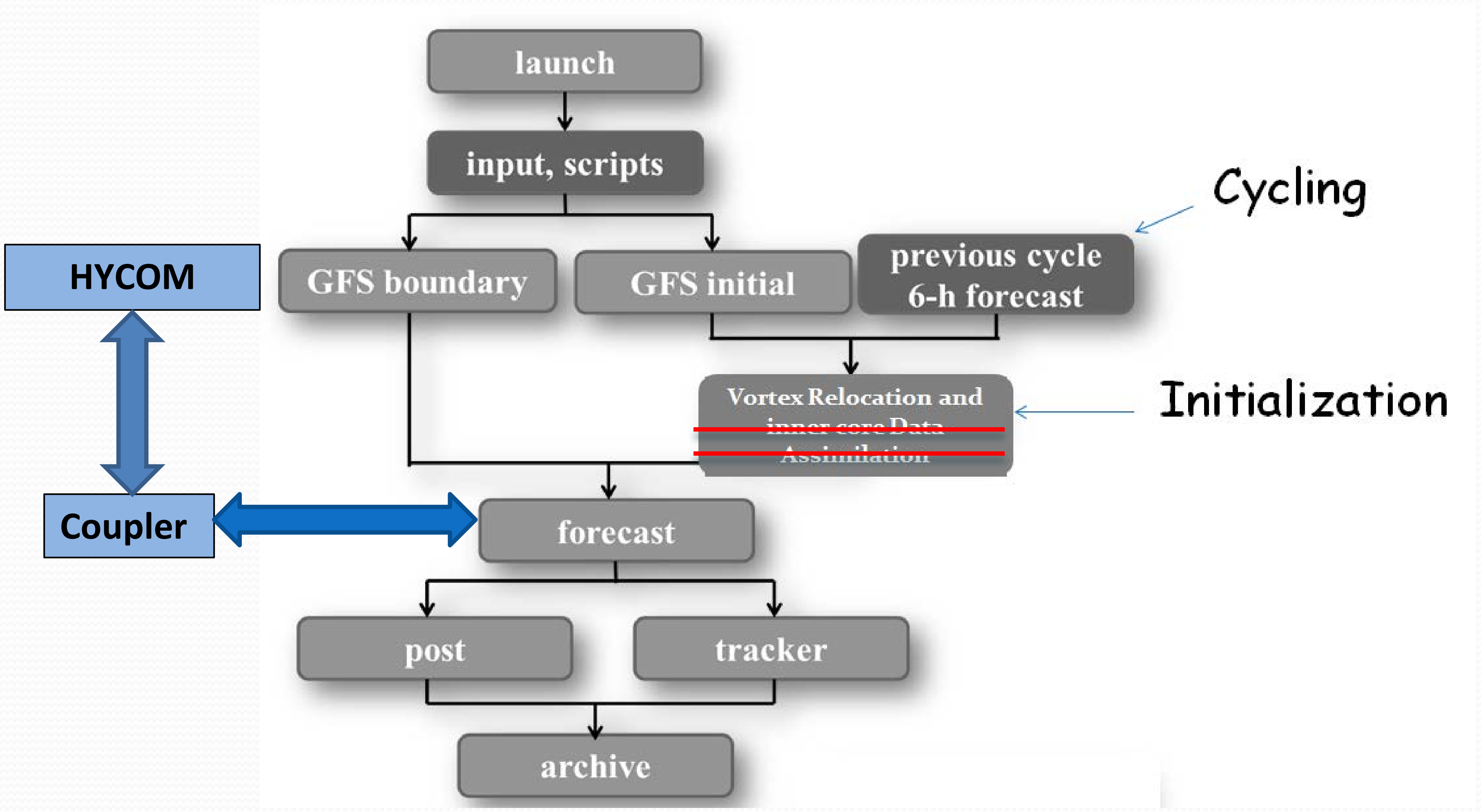




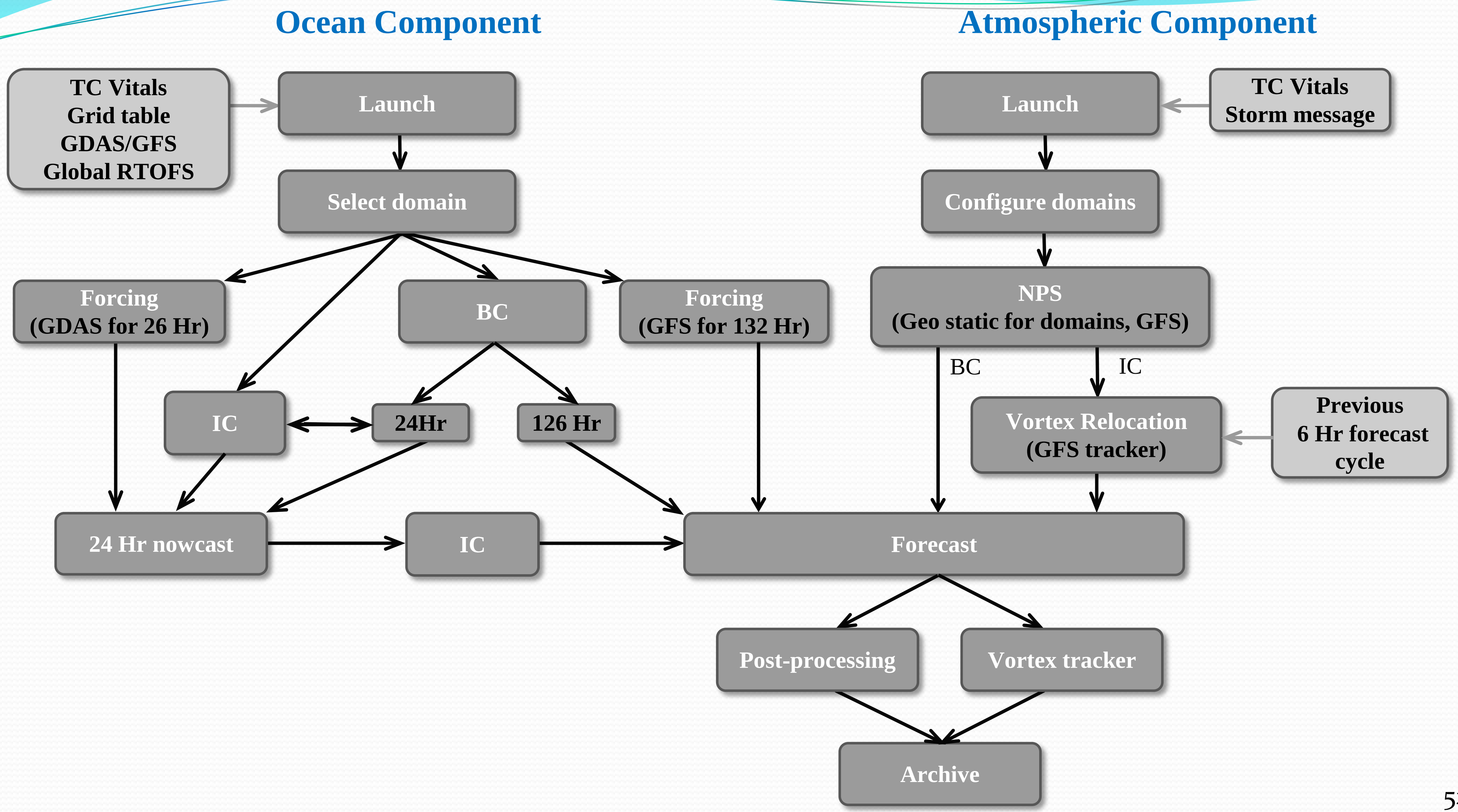
HMON: **H**urricanes in a **M**ulti-scale **O**cean coupled **N**on-hydrostatic model

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.

Design of HMON Workflow



Detailed HMON Workflow



2017 HWRF vs 2016 GFDL vs 2017 HMON

	HWRF	GFDL	HMON
Dycore	Non-hydrostatic, NMM-E	Hydrostatic	Non-hydrostatic, NMM-B
Nesting	18/6/2 kms; 75°/25°/8.3°, Full two-way moving	½.°,1/6°,1/18°; 75°/11°/5°, Two-way moving with bc	18/6/2 kms; 75°/12°/8°, Full two-way moving
Data Assimilation and Initialization	Self-cycled two-way HWRF EnKF-GSI with inner core DA (TDR); Vortex relocation & adjustment	Spin-up using idealized axisymmetric vortex	Vortex relocation & adjustment
Physics	Updated surface (GFDL),GFS-EDMF PBL, Scale-aware SAS, NOAH LSM, RRTM, Ferrier	Surface (GFDL), GFS PBL(2014), SAS, GFDL LSM, RRTM, Ferrier	Surface (GFDL), GFS PBL (2015), SAS, NOAH LSM, RRTM, Ferrier
Coupling	MPIPOM/HYCOM, RTOFS/GDEM, Wavewatch-III	MPIPOM, RTOFS/GDEM, No waves	HYCOM, RTOFS/NCODA, No waves
Post-processing	NHC interpolation method, Updated GFDL tracker	NHC interpolation Method, In-line tracker	NHC interpolation method, GFDL tracker
NEMS/NUOPC	No	No	Yes with moving nests

HMON Upgrade Plan for 2017 Implementation

Multi-season Pre-Implementation T&E

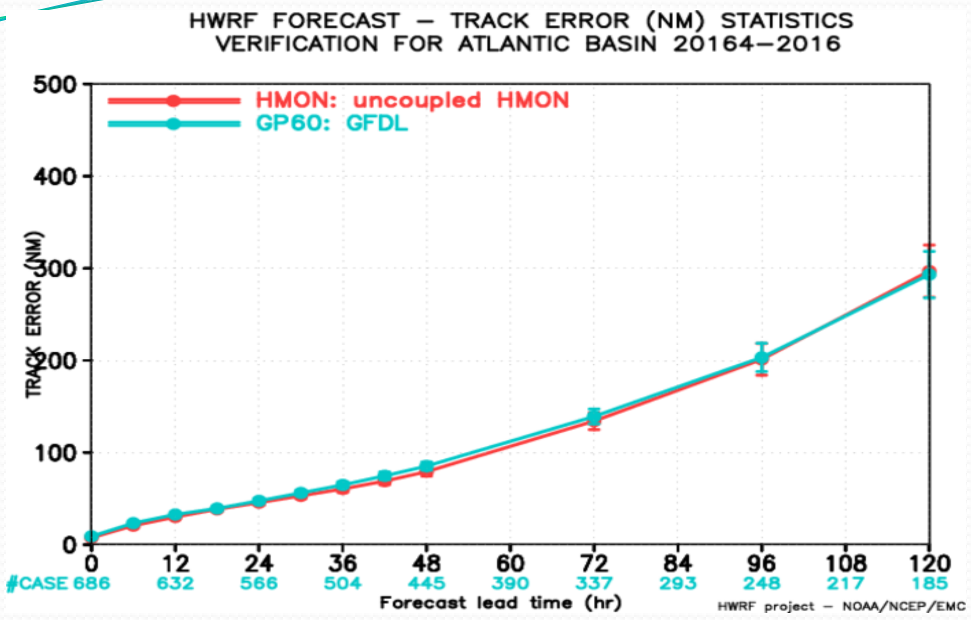
	Real-time Demonstration	2014-16 3-season retrospectives	2014-16 3-season retrospectives
	HNMMB	**HNMMB**	**HMON v1.0.0**
Description	HWRF physics package and storm motion algorithm were added to NMMB dy-core. Vortex initialization was developed. Restart capability was implemented. Post and tracker scripts were built and Python workflow was built.	(identical to real-time demo) Use 2016 GFS data	Operational framework. Ocean coupler was built and tested. Bug fixes for LSM and Microphysics. Use 2017 GFS data.
Cases	Real-time demonstration for FY16 Hurricane Season in ATL/EPAC basins	Priority cases (~500 cases in ATL/EPAC basin)	**Three-season 2014-2016 retrospectives ~3000 simulations in NATL, EPAC, CPAC basins**
Platform	Theia	WCOSS Cray/Theia	**WCOSS Cray**

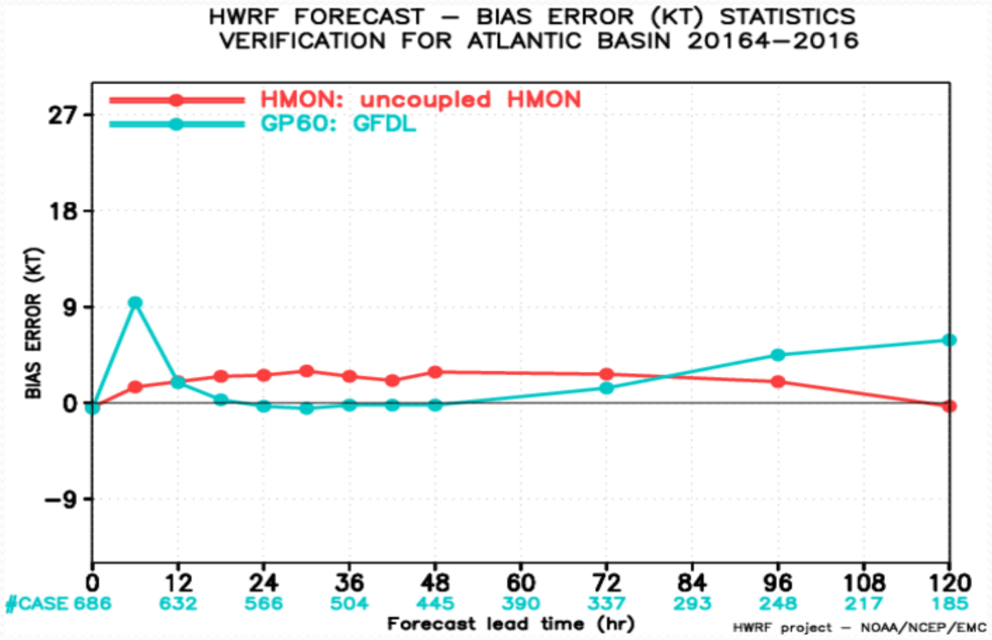
2014-2016 Retrospective Statistics for HMON

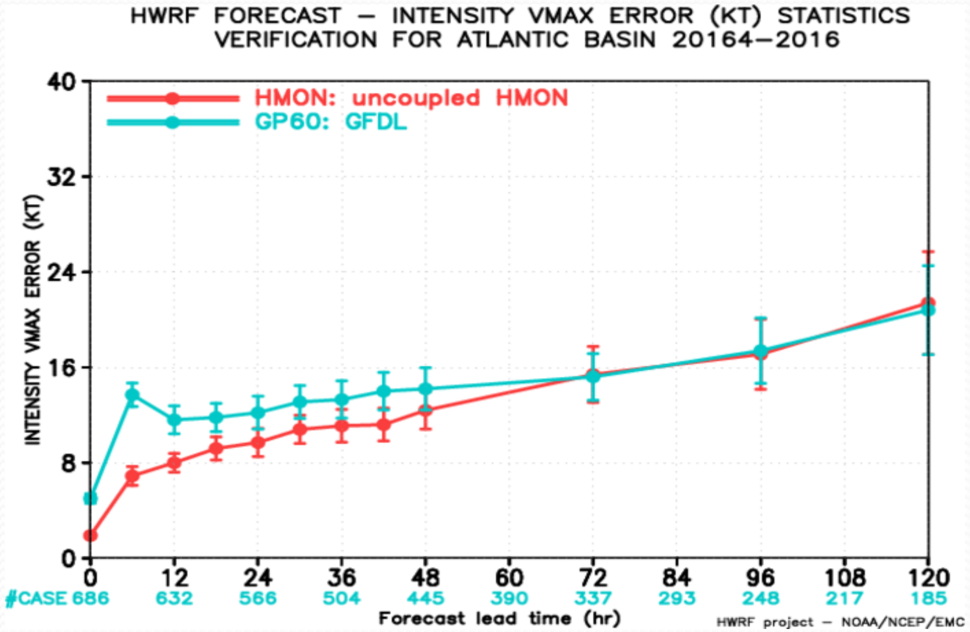
HMON Verification for Atlantic Storms (2014-2016)

Configuration: HWRF physics + vortex initialization + no data assimilation + no ocean coupling

2017 HMON Performance: **North Atlantic Basin**

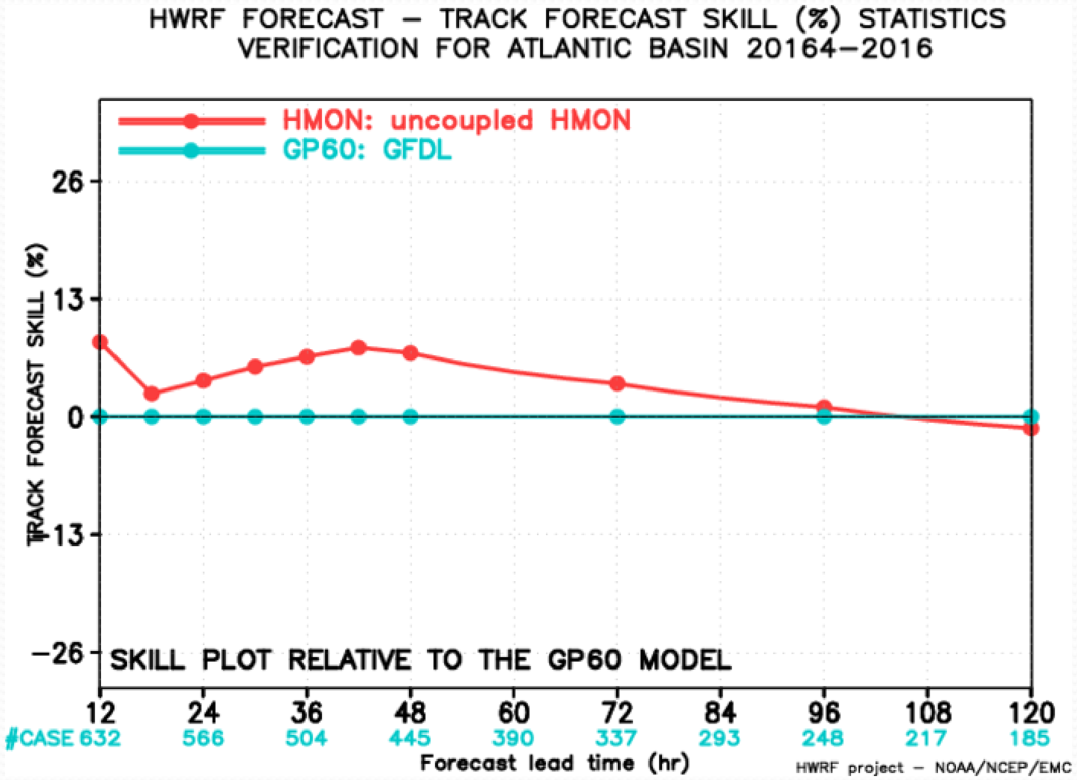


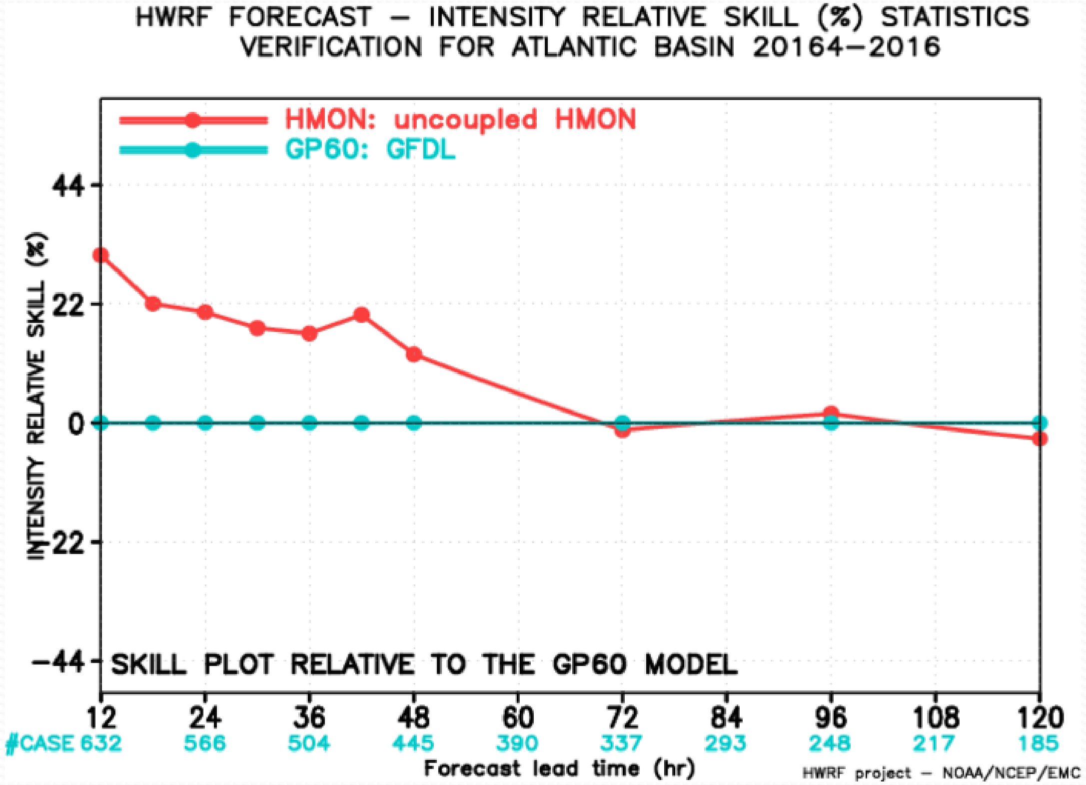




- 2017 HMON track errors show small improvements as compared to 2016 GFDL .
- Intensity errors are significantly less than GFDL for early lead-times (up to 60 hrs) and very similar beyond that.
- Intensity bias errors are less for the first 12 hrs and then again after 84 hrs.

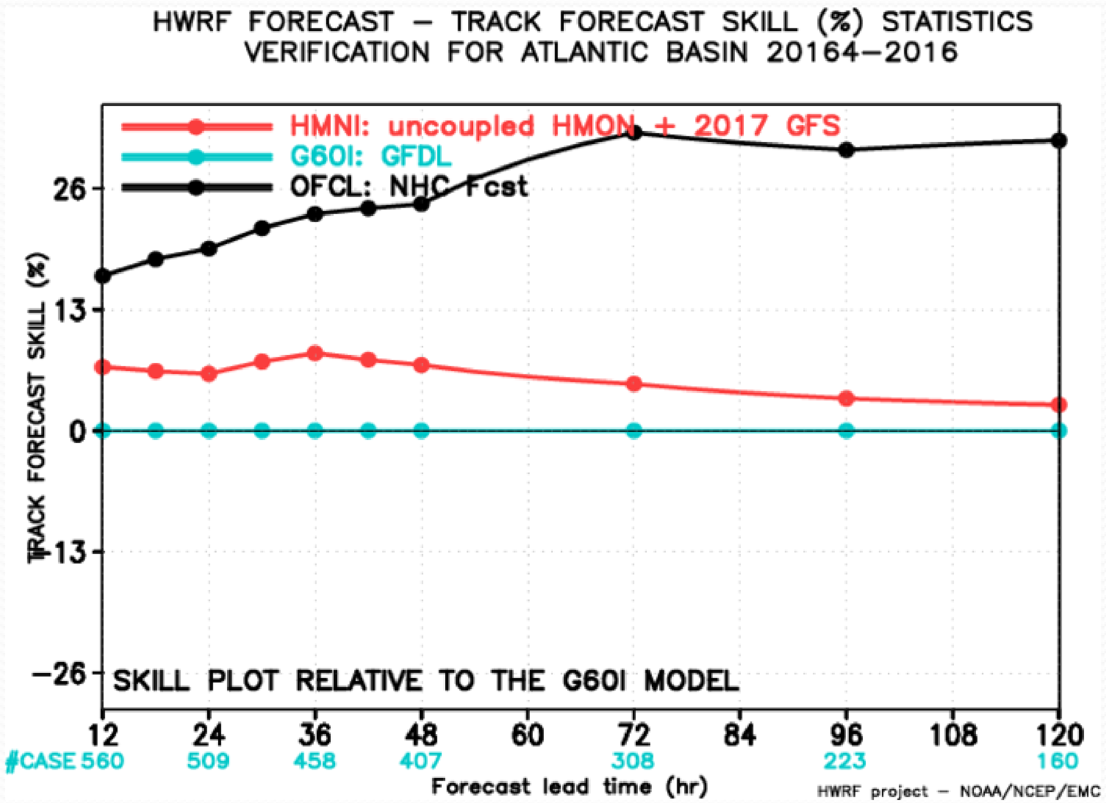
2014-16 Atlantic Basin: Relative to GFDL (Late model)

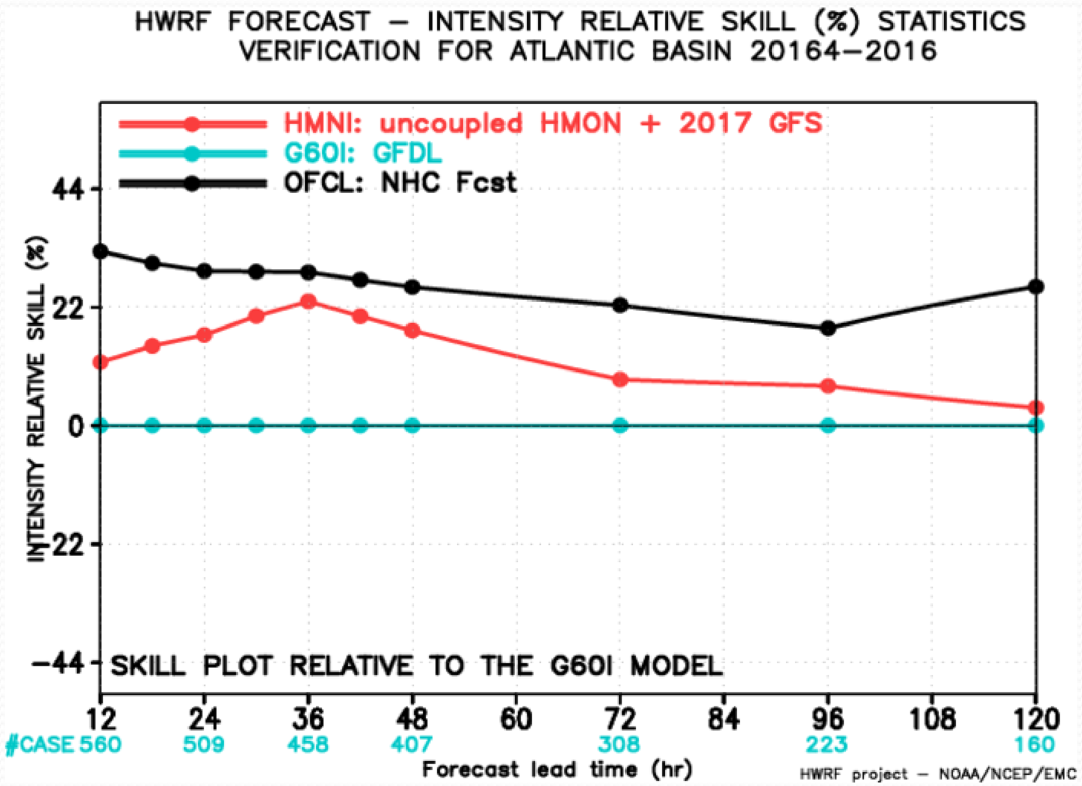




HMON has improved track skills as compared to GFDL at all lead times except for Day 5. The positive skill goes down by Day 4 for tracks and Day 3 for Intensity.

2014-16 Atlantic Basin: Relative to GFDL (interpolated)



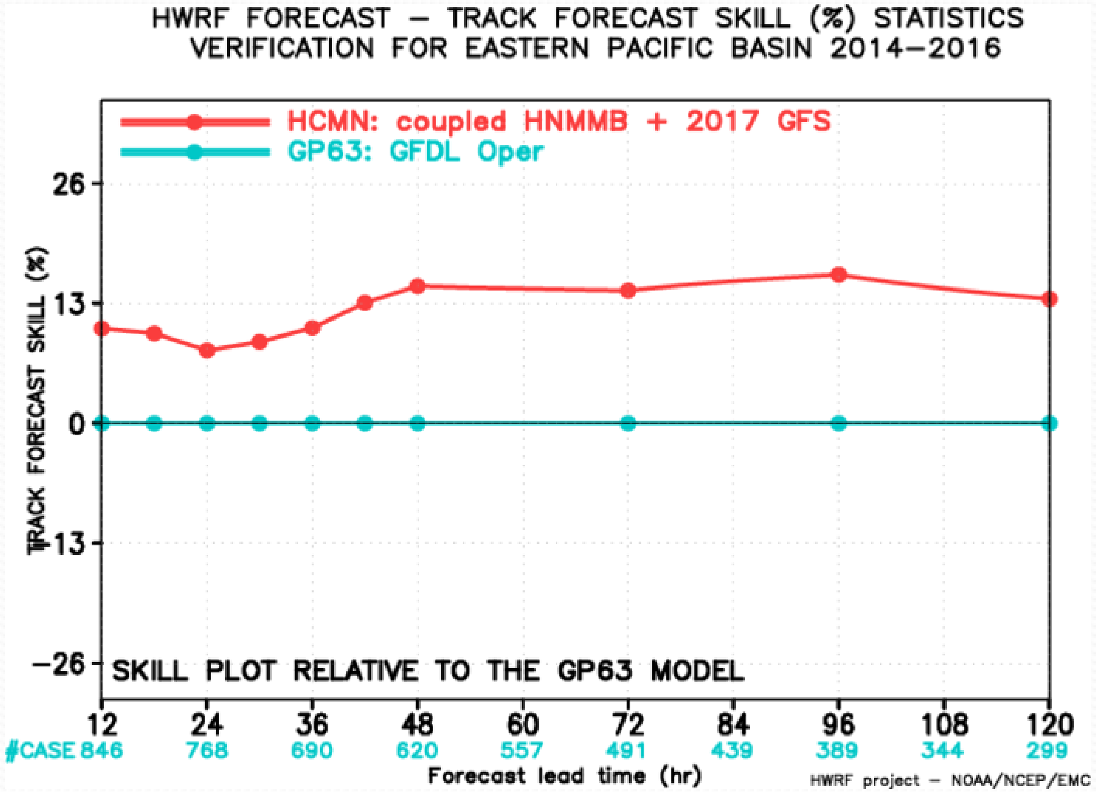


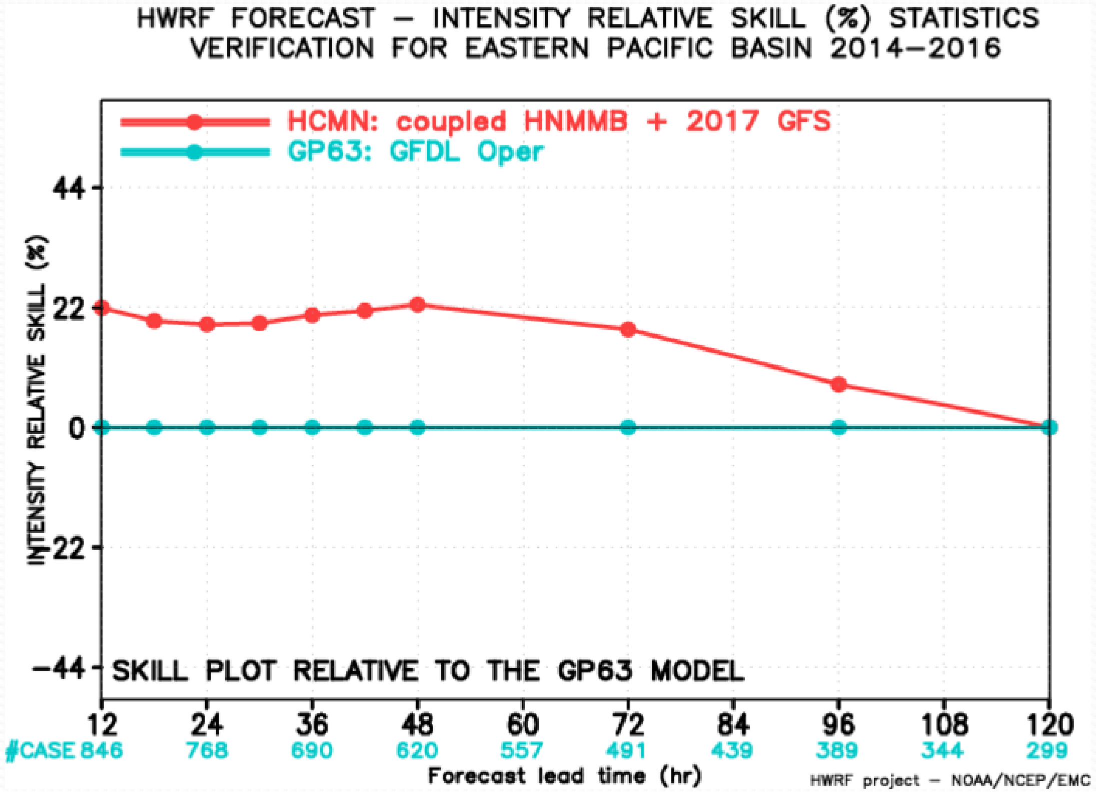
HMON has improved track skills as compared to GFDL at all lead times with an average improvement of more than 5%. It also has improved intensity skills with a mean improvement of ~10%. Both tracks and intensity need to catch up with the official skill.

HMON Verification for East Pacific Storms (2014-2016)

Configuration: HWRF physics + vortex initialization + no data assimilation + ocean coupling

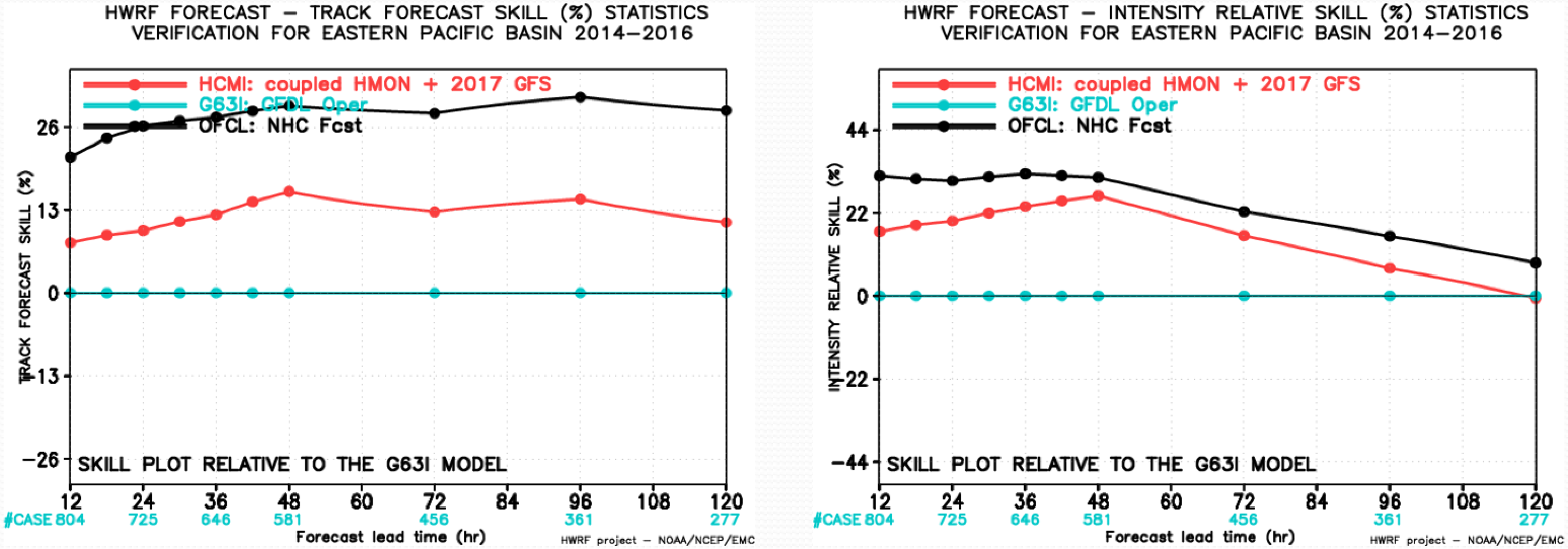
2014-16 East Pacific Basin: Relative to GFDL (Late model)





HMON has improved track skills as compared to GFDL with an average improvement of more than 12%. It also has significantly improved intensity skills with a mean improvement of ~10%.

2014-16 East Pacific Basin: Relative to GFDL (interpolated)

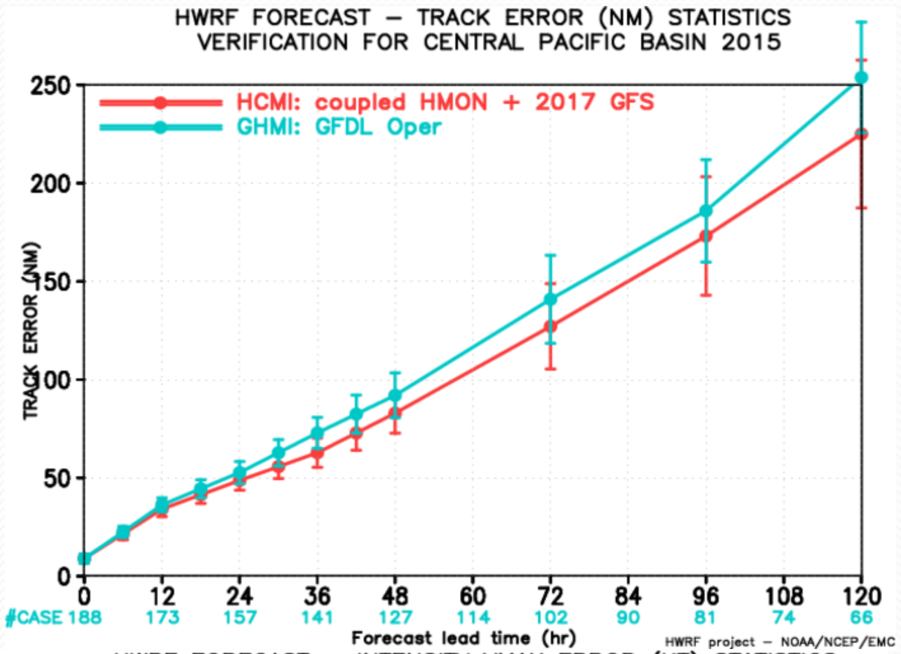


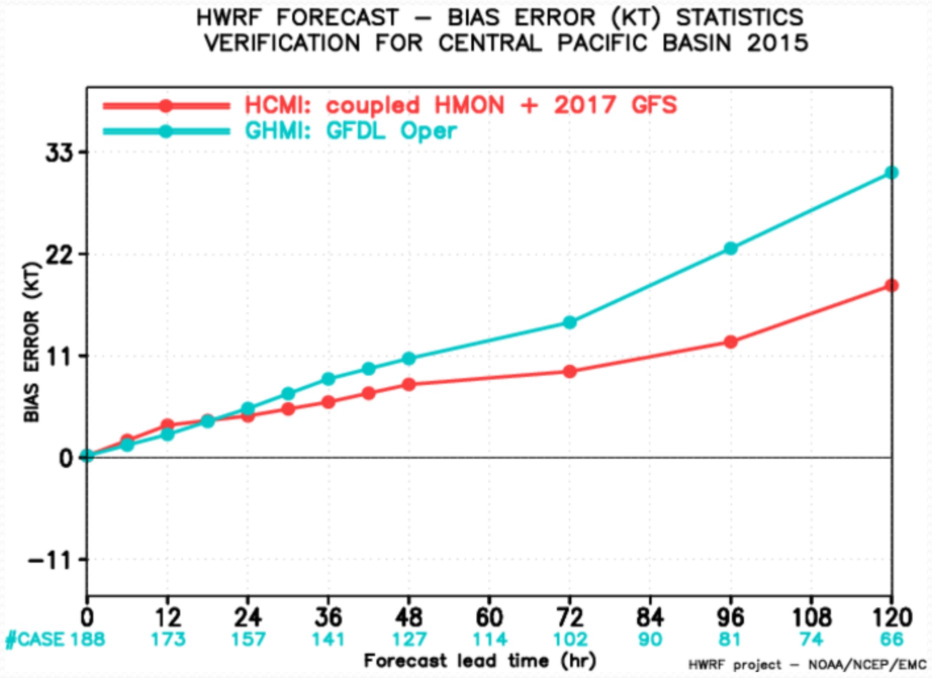
HMON has improved track and intensity skills as compared to GFDL but still needs to play catch up with official skill especially for longer lead times for intensity.

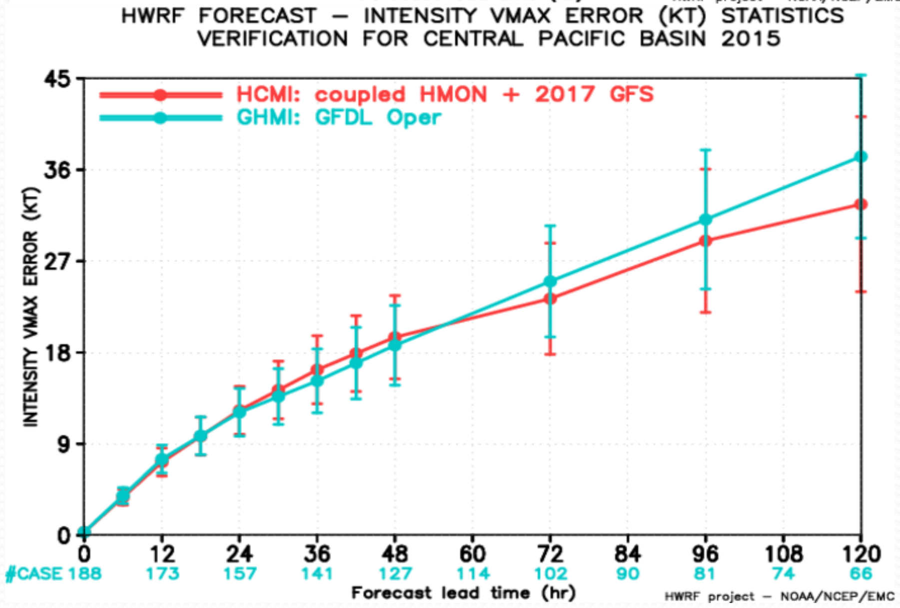
HMON Verification for Central Pacific Storms (2014-2016)

Configuration: HWRF physics + vortex initialization + no data assimilation + ocean coupling

2017 HMON Performance: **Central Pacific Basin (Late model)**

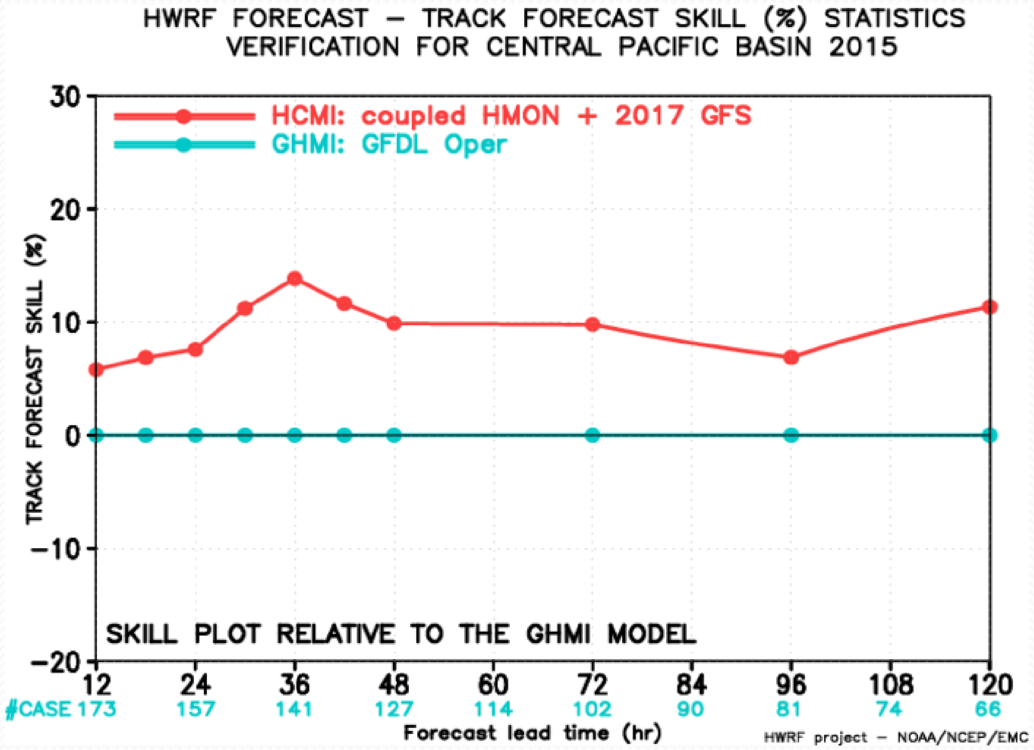


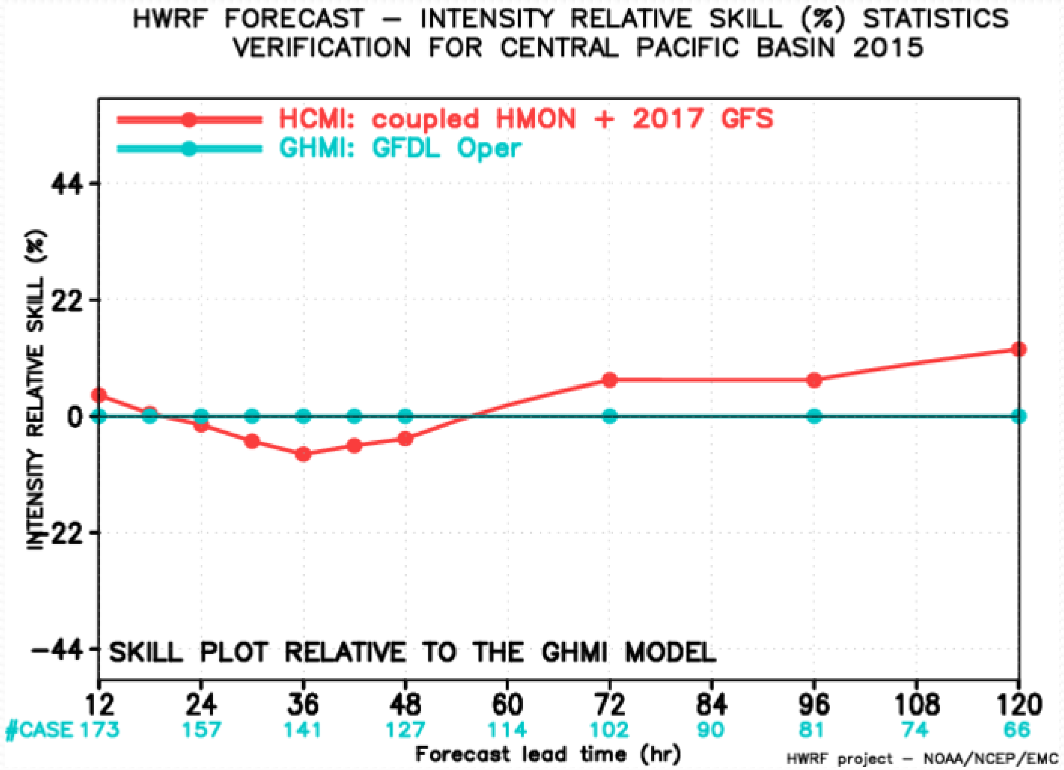




- For CPAC, HMON has much lower track errors than 2016 GFDL for tracks and intensity especially at long lead times.
- Intensity bias is also much improved for HMON at all lead times.

2014-16 Central Pacific Basin: Relative to GFDL (interpolated)





HMON has improved track skills as compared to GFDL of more than 10% while intensity skills are neutral to positive for longer lead times.

HMON verification Statistics: Summary

- Compared with GFDL, HMON consistently shows **improved performance** for track and intensity skill for the North Atlantic basin (based on 2014-16 seasons)

- Compared with GFDL, it also consistently shows **improved performance** for track and intensity skill for the North East Pacific basin (based on 2014-16 seasons)

- Compared with GFDL, track skills are much **improved** while intensity skill are **neutral** for the Central Pacific basin (based on 2014-16 seasons)

- Results are different from HWRF and usually exhibit large errors in comparison especially at longer lead-times where improvement is needed.

Targeted Resources for Hurricane Modeling (maximum per storm)

Operational System	2016 (nodes)	2017 (nodes)	Max Storms	Comments
HWRF (plus WW3)	63	63	8	Max storm increased by 1
WW3-multi2	7	0	0	WW3 subsumed in HWRF
GFDL	5	0	0	Discontinued
HMON	0	26*	5	Uses much less resources than HWRF
TOTAL	**75**	**89**	--	18.7% resource increase*

* Initial implementation is targeted for only 5 storms serving NHC areas of responsibility (NATL, EPAC & CPAC)

FY17 HMON Computer Resource Requirement

JOBS	Computer Resources	Run Time	Starting Time
JHMON_LAUNCH	1 core	<1min	T+3:25
JHMON_HYCOM_INIT	96 cores	~20min (several jobs)	T+3:25
JHMON_HYCOM_FORCING	24 cores, 1 node	~50min (several jobs)	T+3:25(one by one continuously until GFS GRIB 129h available)
JHMON_INIT	96 cores	~10min (several jobs)	T+3:25 (GFS GRIB available)
JHMON_BDY	96 cores	~20 min (several jobs)	T+4:00 (GFS GRIB 126h available)
JHMON_RELOCATE Run after HMON_INIT	1 core	~10min	T+3:35
JHMON_FORECAST (Coupled or Un-coupled)	620 cores, 26 nodes	~95min	T+4:20 Forecast to finish by T+5:55
JHMON_POST Run parallel with forecast job	24 cores, 1 node	~100min	
JHMON_TRACKER Run parallel with forecast job	1 node	~101min	ATCF Forecast delivered by T+6:00
JHMON_ARCHIVE	1 node	~ 10 min	
JHMON_GEMPAK	1 cores	~2min	

IT Testing

Test Objective	Comment
Missing ICs from GFS data	HMON fails with proper error message
Missing BCs from GFS data	HMON fails with proper error message
Missing previous cycle's 6-hr forecast output	HMON runs to completion in cold start mode
Failed HYCOM initialization	HMON runs in un-coupled mode
Tracker fails to identify initial storm location	HMON fails with proper error message
Test at least one storm in AL and EP basins	HMON runs to completion
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8. NCO IT Testing : ***????***
9. Briefing to NCEP Director's Office: ***????***
10. Implementation by NCO: **

** ***Recommend HMON be implemented with 2017 GFS***

NHC Evaluation and Recommendations

Dr. Richard J. Pasch
Senior Hurricane Specialist
National Hurricane Center

NHC Evaluation

H217 vs. H216:

- **AL Track:** except for a minor degradation in skill at 12 h and 120 h, H217 is more skillful than H216, especially for medium range track forecasts
- **EP Track:** H217 is slightly less skillful than H216 from 12 h - 48 h, but is about 10% more skillful from 84 h - 120 h. H217 outperforms the GFS at longer lead times
- **AL Intensity:** except between 12 h - 36 h, H217 is more skillful than H216
- **EP Intensity:** H217 is more skillful than H216 at all forecast lead times

Additional comments:

- H217 forecasts for Hurricane Matthew (e.g., 2016093006) exhibit a rapid and unrealistic breakdown of the storm's inner core, similar to what was observed operationally for H216. This remains a concern. Interestingly, HMON does not seem to exhibit the same behavior.

NHC Evaluation (Cont.)

HMON vs. GFDL:

- **AL Track:** HMON is slightly more skillful than GFDL through 96 h; the skill of HMON and GFDL is very similar at 120 h
- **EP Track:** HMON performs much better than GFDL at all lead times
- **AL Intensity:** HMON is more skillful than GFDL through 60 h, but then its skill trails off and it ends up being less skillful than GFDL from 72 h to 120 h
- **EP Intensity:** HMON is about 25% more skillful than GFDL through 60 h, but then it's skill trails off and it ends up being about the same as GFDL at 120 h

Additional comments:

- HMON is more skillful than GFDL for short- to medium-range intensity forecasts, and is even more skillful than HWRF from 36 h – 60 h for EP intensity forecasts. However, the decline in intensity skill at longer lead times is noteworthy, especially for AL track forecasts.

NHC Recommendation

Based on the mostly improved TC track and intensity predictions for a large 3-year sample of cases for the Atlantic and eastern North Pacific basins, the National Hurricane Center endorses the operational implementation of the 2017 HWRF, and accepts the introduction of HMON into operations.

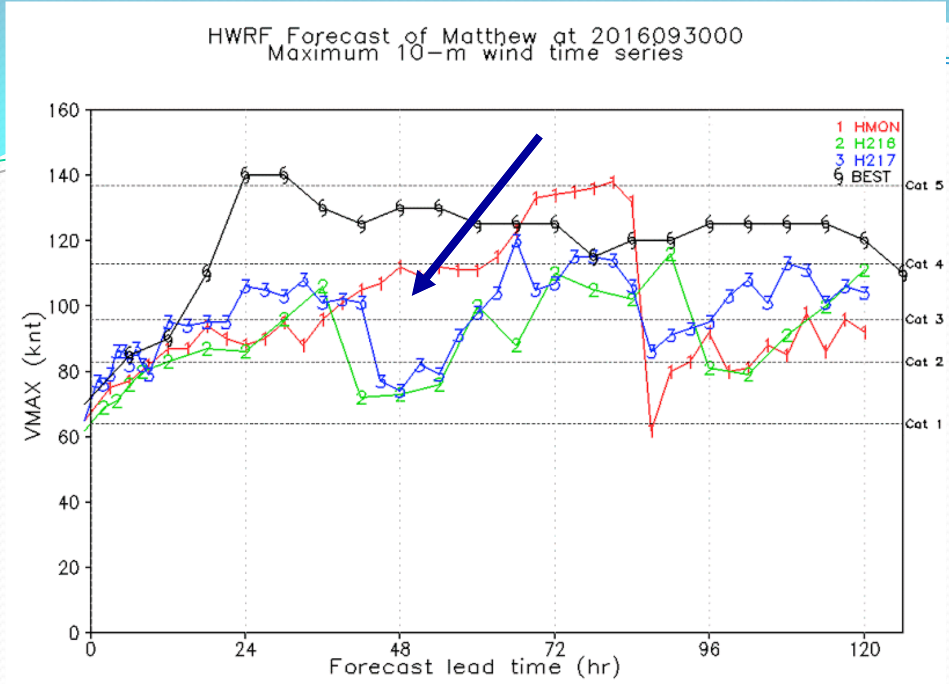
Request approval from EMC for operational implementation of the following Hurricane model configurations:

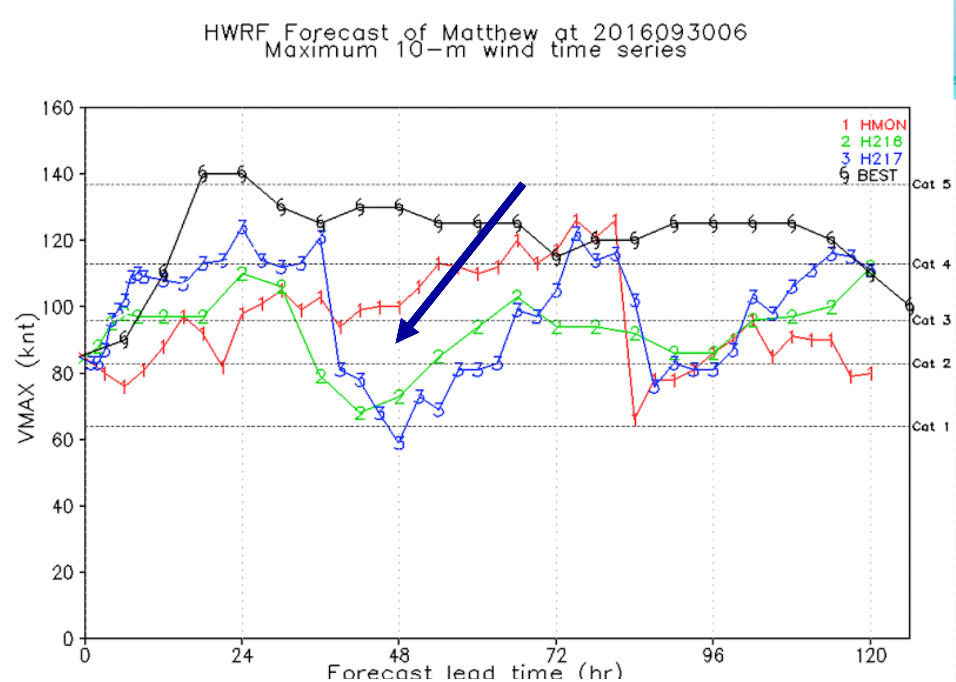
I. 2017 HWRF V11.0.0

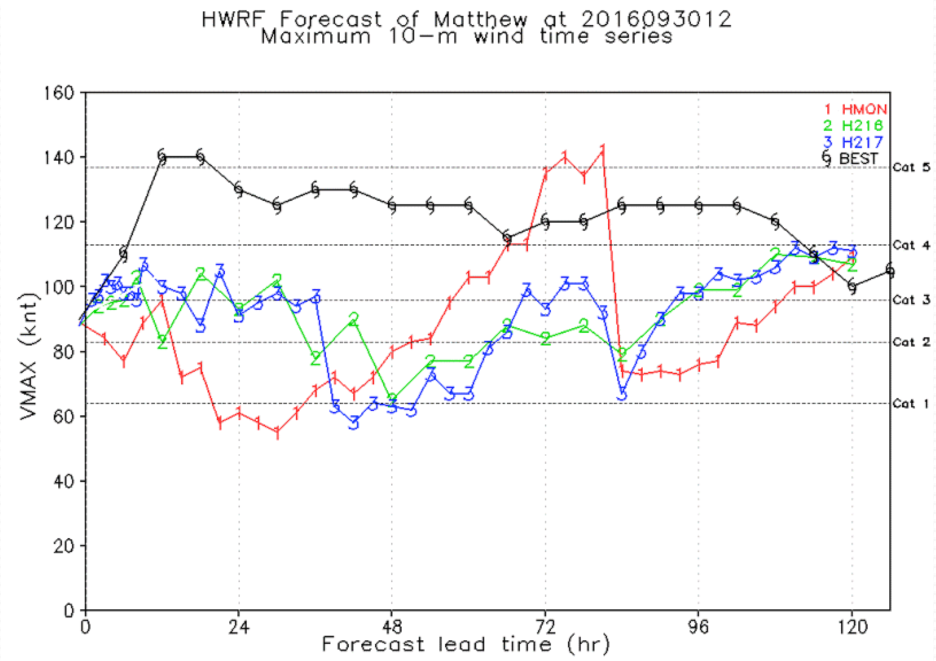
II. 2017 HMON V1.0.0

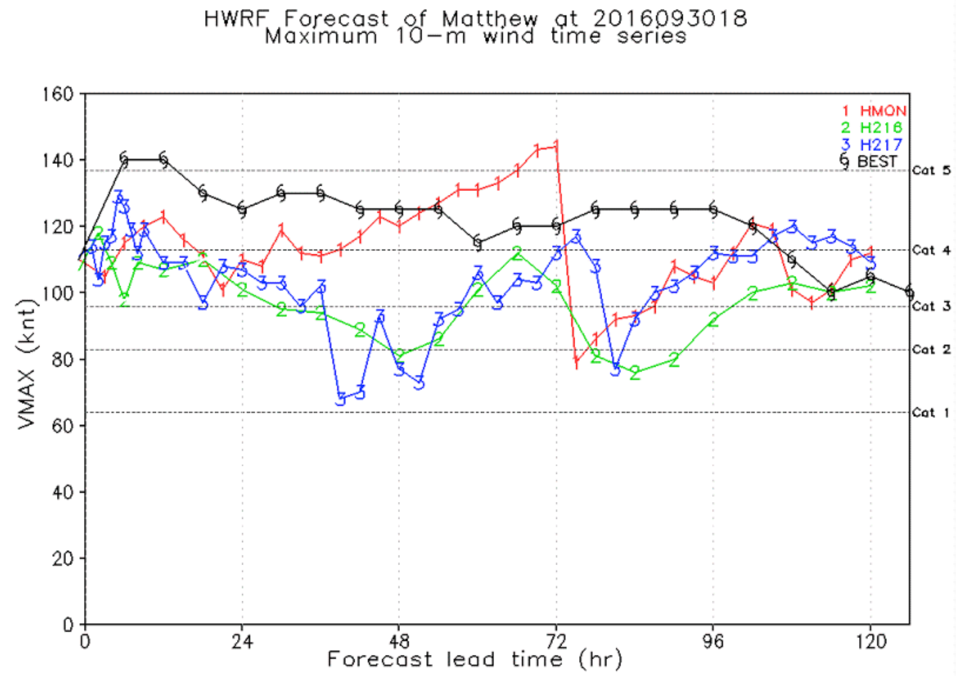
Thank You!

Supplementary Slides









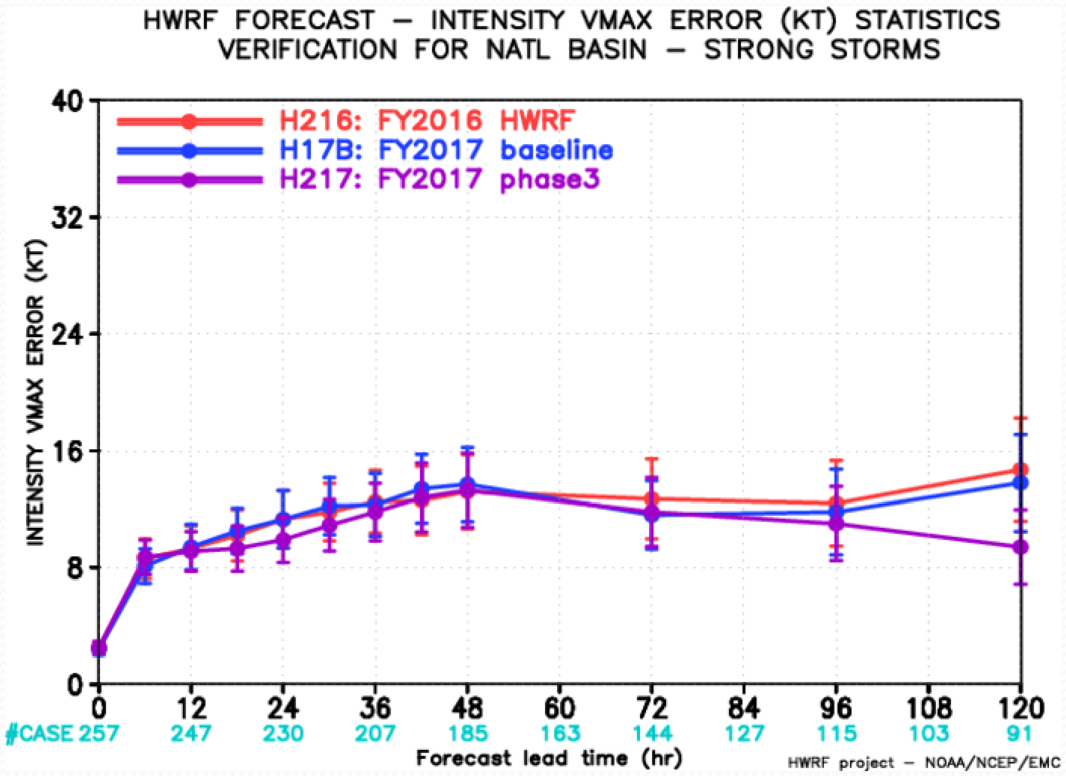
Intensity oscillations in:

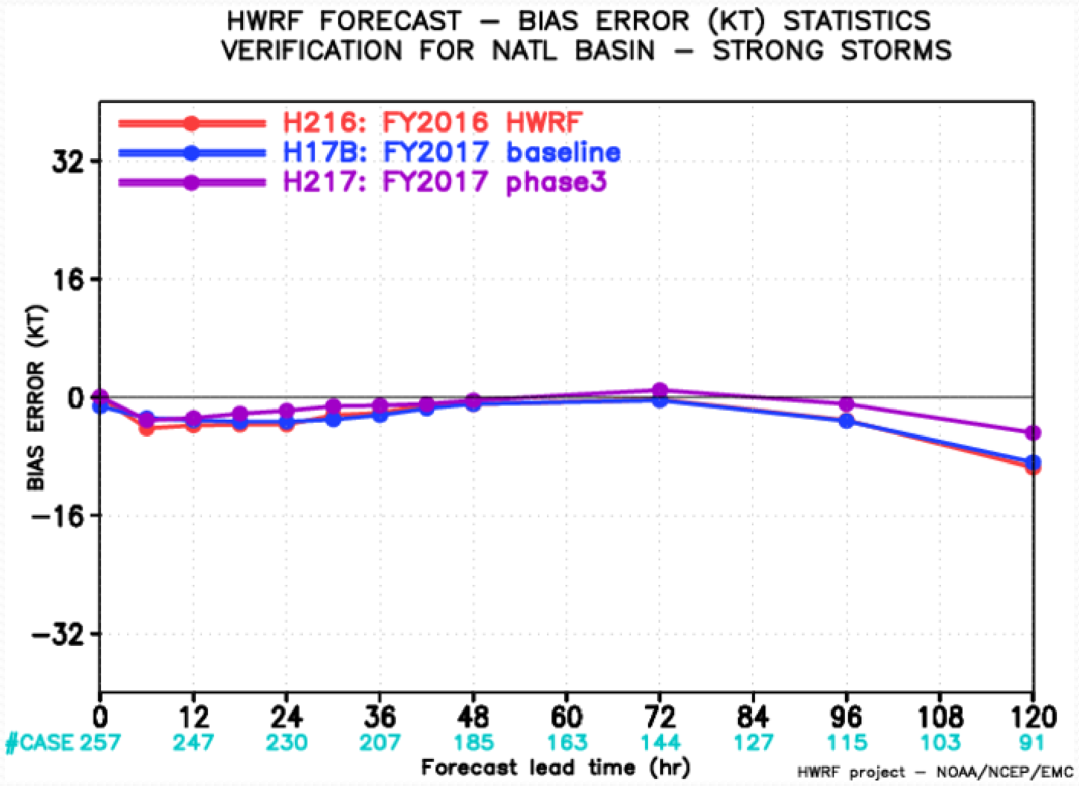
2016093000
2016093006
2016093012
2016093018

H217 exhibits similar behavior as H216 and CTCX but H217 has better RI representation.

HMON shows no oscillations but has a delayed RI phase.

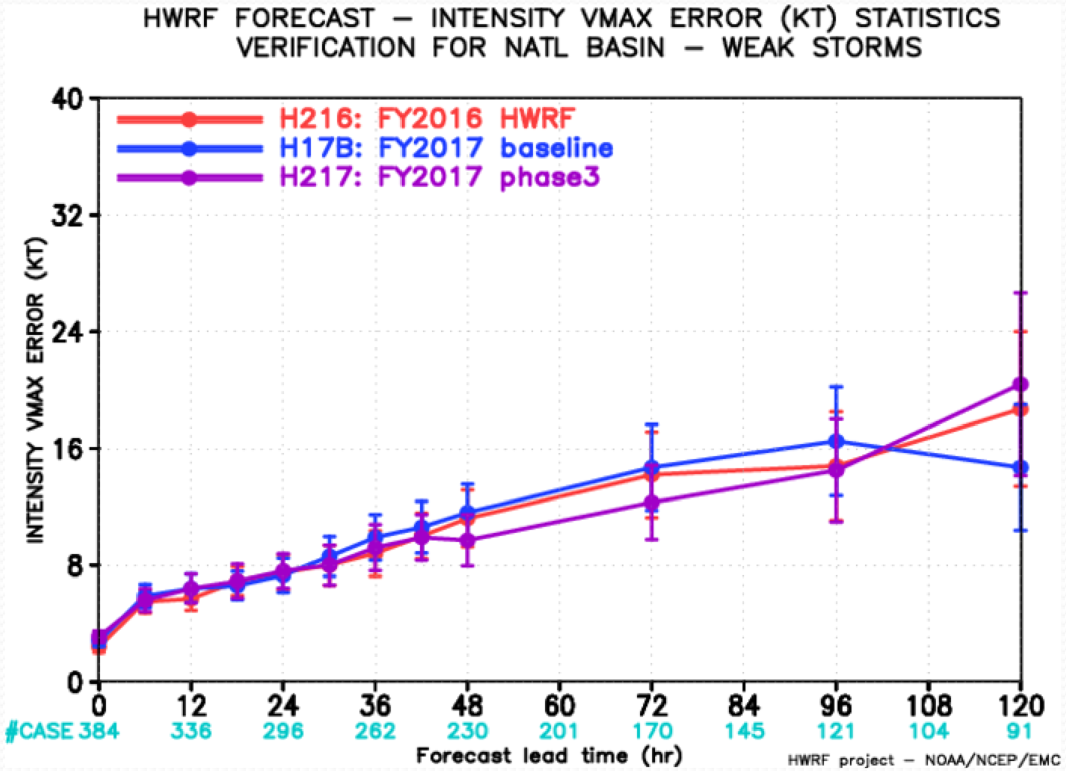
Maximum Intensity and bias errors for NATL storms with strong cycles (initial intensity > 50kts)

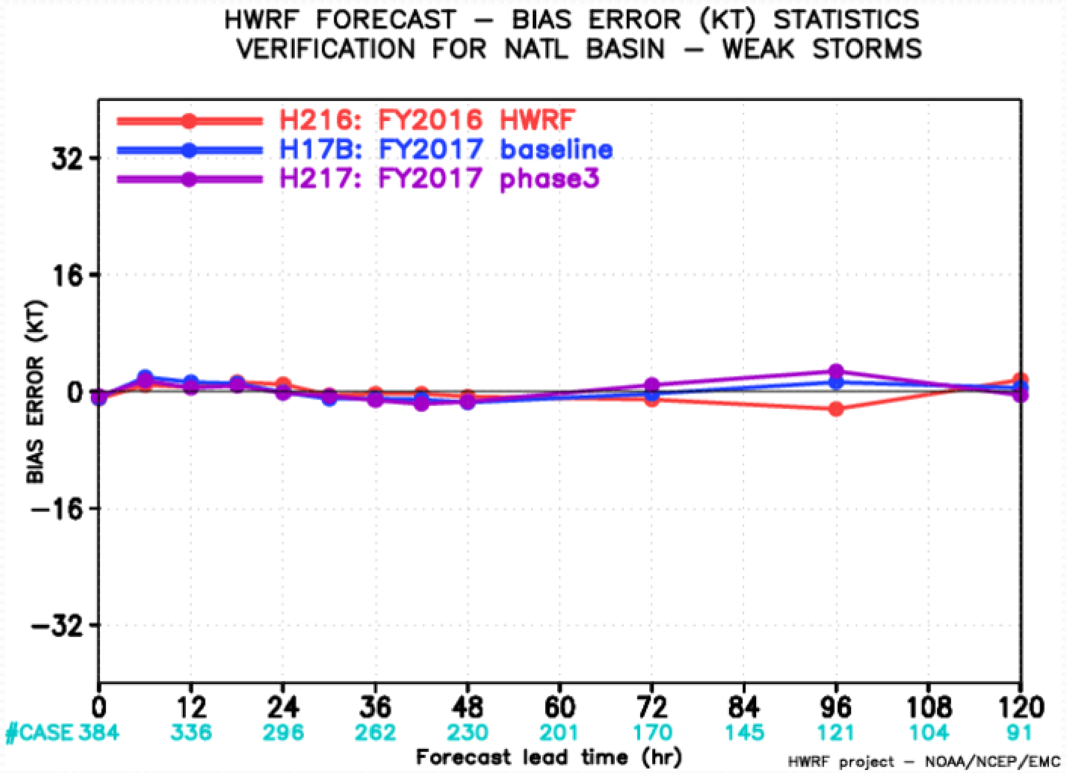




- For storms with strong cycles, the Vmax errors for H217 are significantly lower at all lead times.
- The bias errors for such storms is also less (less negative) for H217 at all lead times.

Maximum Intensity and bias errors for NATL storms with weak cycles (initial intensity < 50kts)





- For storms with weak cycles, the Vmax errors for H217 are lower at all lead times except for Day 5.

- The bias errors for such storms is very similar till hr 60. For H217 bias turns positive at hr 60 and remains positive as compared to H216 till hr 108.

FY17 HWRF Computer Resource Requirement (neutral other than increase to max 8 storms)

JOBS	Computer Resources	Run Time	Starting Time
JHWRF_PRE_MASTER	1 core/2GB	<1min	T+3:24 (first GFS grib2 analysis available)
JHWRF_WAVE_INIT	1 node		
JHWRF_OCEAN_INIT	90 core HYCOM RTOFS init	~22min	
JHWRF_INIT (Step 1) (WPS+PREP+REAL+ 3DVAR_ANALYSIS)	48 cores	~10min (several jobs combined)	T+3:24 (GFS GRIB2 available) Run times might reduce further
JHWRF_INIT (Step 2) (PREP+REAL+ 3DVAR_ANALYSIS)	48 cores	~45min (several jobs combined)	T+4:04 (one by one continuously until gfs 126h available)
JHWRF_INIT (GDAS) 3 GDAS jobs run simultaneously	3 copies of 48 cores	~25min	T+3:24 (gdas 3,6,9h fcst available) Run times might reduce further
JHWRF_ENSDA_RELOCATE (new)	40 copies of 2 nodes (16 cores), total 640 cores	~10min	Run parallel with other *INIT jobs

Green: Jobs submitted simultaneously.

FY17 HWRF Computer Resource Requirement

JOBS	Computer Resources	Run Time	Starting Time
JHWRF_RELOCATE **3 relocate run simultaneously**	**3 copies of 2 nodes**	**~25min**	**Run time might reduce further**
JHWRF_NMM_GSI_D2	**4 nodes**	**~18min**	Run parallel with GSI_D03
JHWRF_NMM_GSI_D3	**8 nodes**	**~18min**	Run parallel with GSI_D02
JHWRF_meanhx (new)	**2 nodes (42 cores)**	**~ 2 min**	Run parallel with other jobs
JHWRF_enshx (new)	**40 copies of 2 nodes (42 cores)**	**~ 2 min**	Run parallel with other jobs
JHWRF_MERGE	**1 node**	**~3min**	
JHWRF_ENKF (new)	**10 nodes (60 cores)**	**~6min**	Run after MERGE
JHWRF_FORECAST **(Coupled or Un-coupled)**	**1512 cores** **63 nodes**	**~95min**	T+4:19min Forecast to finish by T+5:54
JHWRF_POST **Run parallel with forecast job**	**2 copies of 24 cores**	**~100min**	We need to run 2 copies due to I/O speed variation

FY17 HWRF Computer Resource Requirement

JOBS	Computer Resources	Run Time	Starting Time
JHWRF_PRODUCTS **tracker, swath and others**	**1 node**	**~101min**	Run in parallel with forecast job ATCF Forecast delivered by T+6:00
JHWRF_OUTPUT **Archiving hwrf output**	**1 node due wave coupling**	**~9min**	
JHWRF_GEMPAK	**1 cores**	**~2min**	T+6.09

Hybrid-ensemble Based Data Assimilation HWRF V11.0.0, Q3FY17

J-job name	Job Description	Current Resource requirement (w/ T1534 GFS)	New Resource requirement (estimate)
JHWRF_ENSEMBLE	HWRF Ensemble 6h forecast from Global EnKF analysis. 40-member 2-nest domain(18/6)	Possible 8 storms (for AL/EP storms), each requires: 2 nodes each for 40 independent jobs for 50 min. 10 simultaneous ensemble runs will take 2 hrs to complete all 40 members	Can start at T+7:02 to be completed by T+9:30

HWRF Version 11.0
Status as of 4/25/17

G

G Project Information & Highlights

Leads: Avichal Mehra & Zhan Zhang, EMC and Steven Earle, NCO

Scope: Improved air-sea-wave coupling for HWRF; replace operational Hurricane Wave model. Further improvements to physics, vortex initialization, DA; assimilate additional aircraft and satellite data. Increase vertical resolution in some basins and use GFS NEMSIO.

Expected benefits: improved track & intensity forecast skill in all basins. Improved products including AWIPS.

Dependencies: N/A

G Schedule

Milestones & Deliverables	Date	Status
Freeze system code; deliver to NCO if applicable	1/15/17	N/A
Complete full retrospective/real time runs and evaluation	4/10/17	In progress
Deliver final system code to NCO and conduct CCB	4/25/17	In progress
Issue Technical Information Notice	5/03/17	On track
Complete 30-day evaluation and IT testing	6/12/17	On track
Operational Implementation	6/27/17	On track

EMC	NCO	Red text indicates change from previous quarter

G Issues/Risks

Issue: Complex T&E due to dependency on NEMS/GSM and RTOFS upstream requirements**; Resolution:** Use 2016 versions.

Risks: Implementation dates are dependent on completion of T&E; Ongoing disruptive Cray upgrades and maintenance

Mitigation: Conduct T&E as soon as retrospective data are available. Use white space on production machine.

G Resources

Staff: 0.75 Fed FTEs + 6 contractor FTEs; including Dev (Vortex Initialization, Physics, Coupling and DA)

Funding Source: STI

Compute: parallels: 600 nodes for 3 months (devmax/devonprod); **EMC Dev**: 400 nodes for 3 months (devhigh); **Ops**: 63 nodes per storm (Delta = 0)

Archive: 1.2 PB (Delta = 0)

R Management Attention Required	Y Potential Management Attention Needed	G On Target

FY17 HMON V1.0.0 Configuration

- Features
- Development steps
- Flowchart
- Physics options

Development Steps for HMON

1. HWRF physics package and storm motion algorithm were added to NMMB dy-core.
2. Vortex initialization was developed.
3. Restart capability was implemented.

   (1) , (2), and (3) via active collaboration between EMC-HRD funded by HIWPP

4. Post and tracker scripts were built.
5. Python workflow was built.
6. **Run in real-time in experiment mode for 2016 Hurricane season (using 1-5)**
7. Retrospectives (2014-2016) completed using 2016 GFS (November 2016)
8. Ocean coupler was built and tested.
9. **Retrospectives (2014-2016) completed using 2017 GFS (March 2017)**

Development Steps for HMON

Two options for earth-system component coupling:

1. EMC legacy coupler (leverage HWRF developments)
   - -- operationally ready
   - -- extensively tested, robust
   - -- configured for 3-way interactions (air-ocean-wave)

2. NEMS-NUOPC coupler
   - -- unified modeling (Future)
   - -- based on ESMF regridding/functionality/portability
   - -- extensible to multiple-storm/component configurations
   - -- extensible to FV3/NEMS based configurations
   - -- leverage other coupled systems (NWS, NRL, NASA)

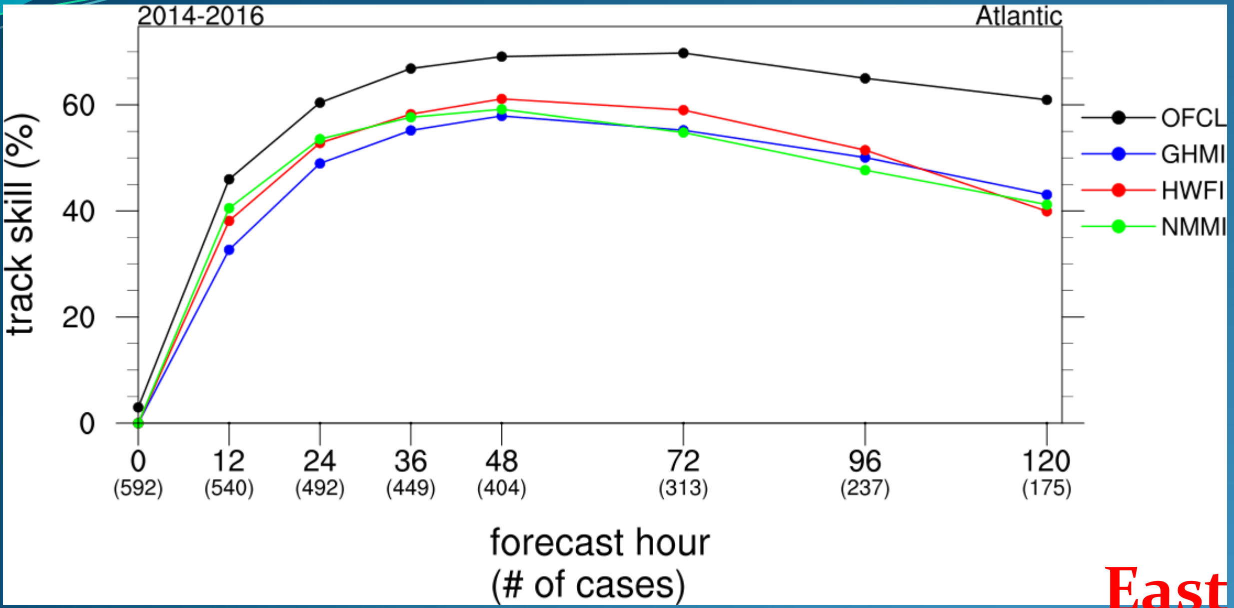
Physics options in HMON

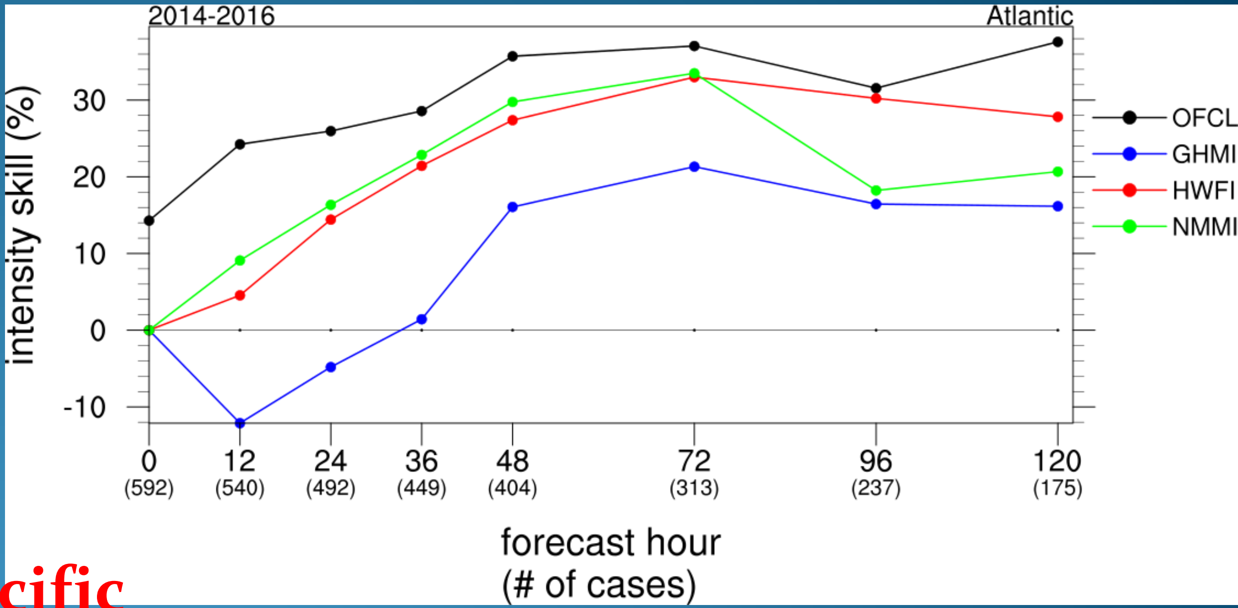
Physics Package	Option
microphysics	Fer_hires
shortwave	RRTM
longwave	RRTM
turbulence	GFSHUR
convection	SASHUR
sfc_layer	GFDL
land_surface	noah

2014-2016

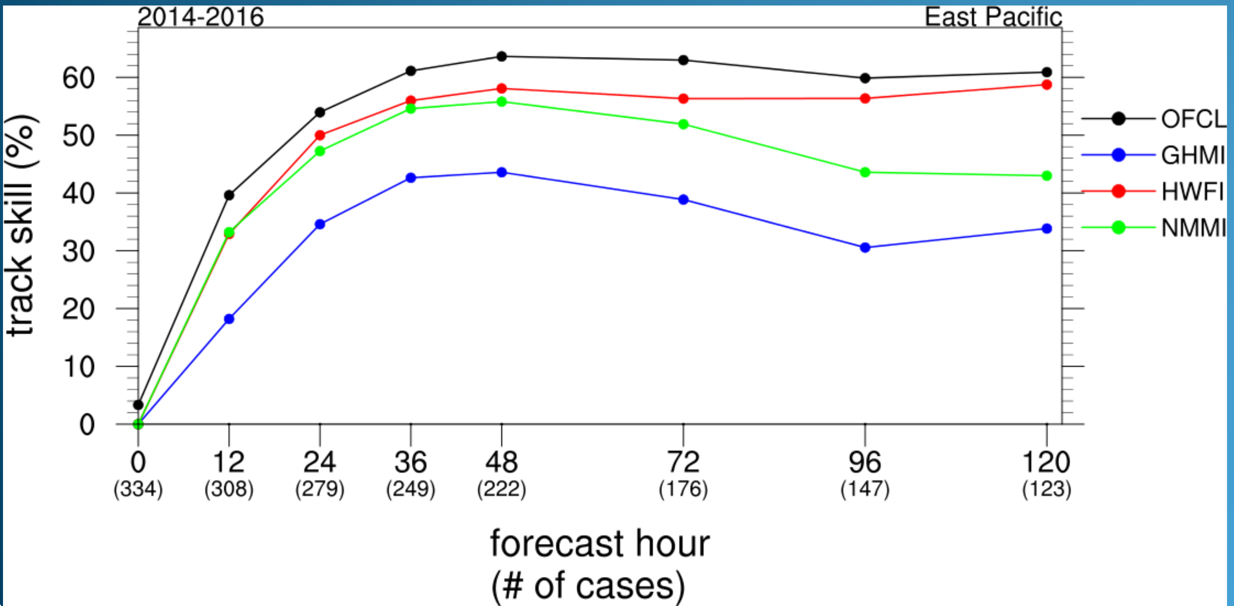
From Andrew Penny, November 2016 (NHC)

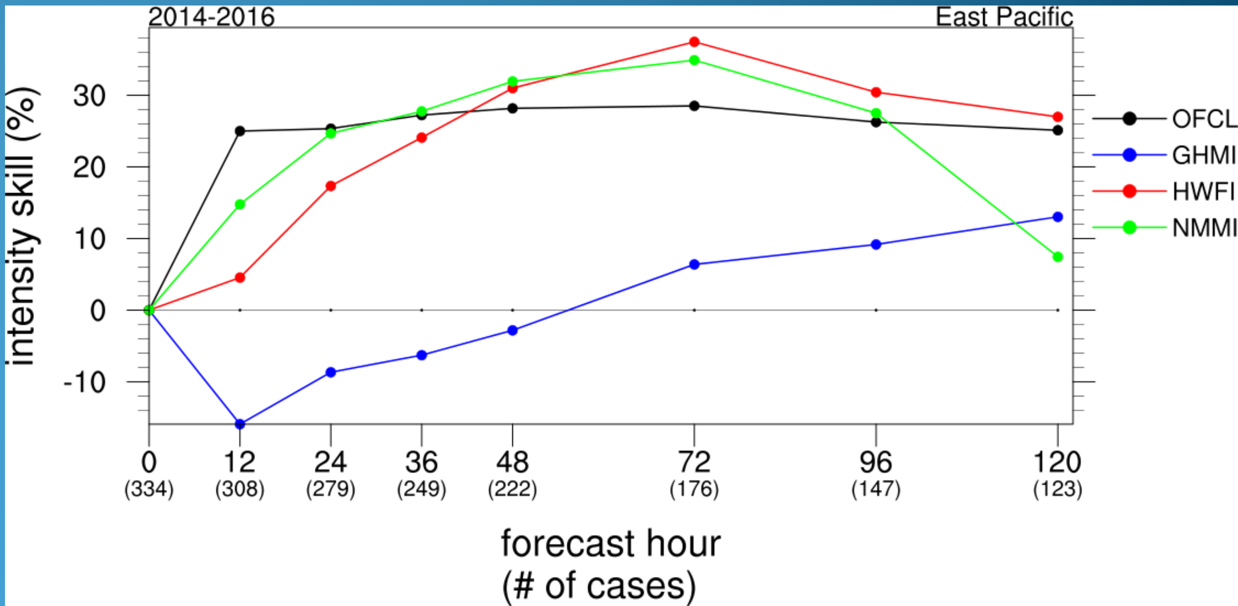
Track Skill Relative to OCD5 **Atlantic** Intensity Skill Relative to OCD5



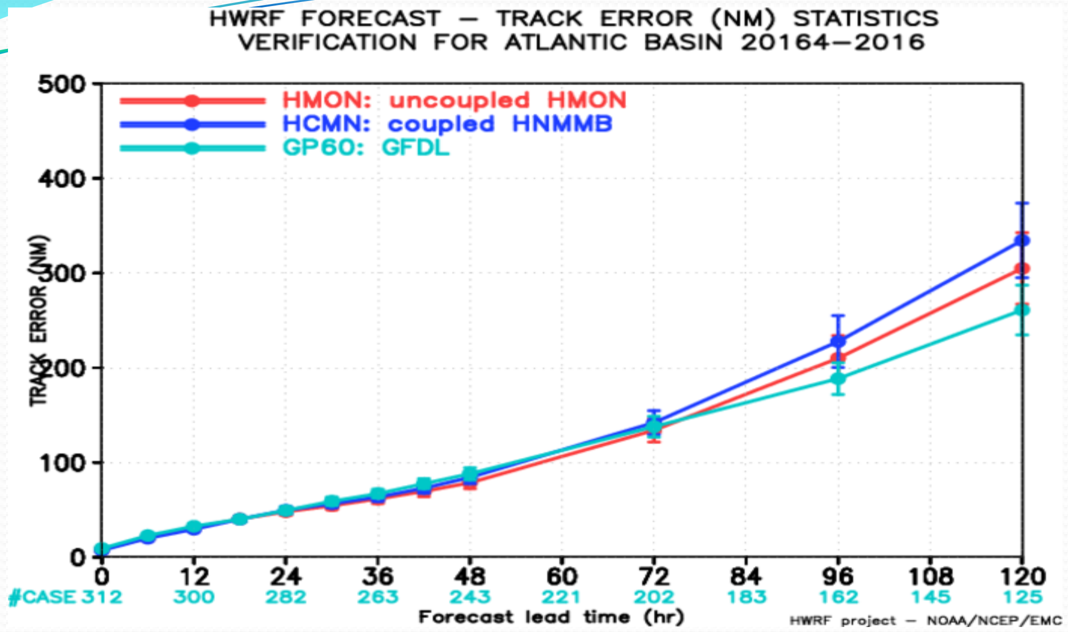


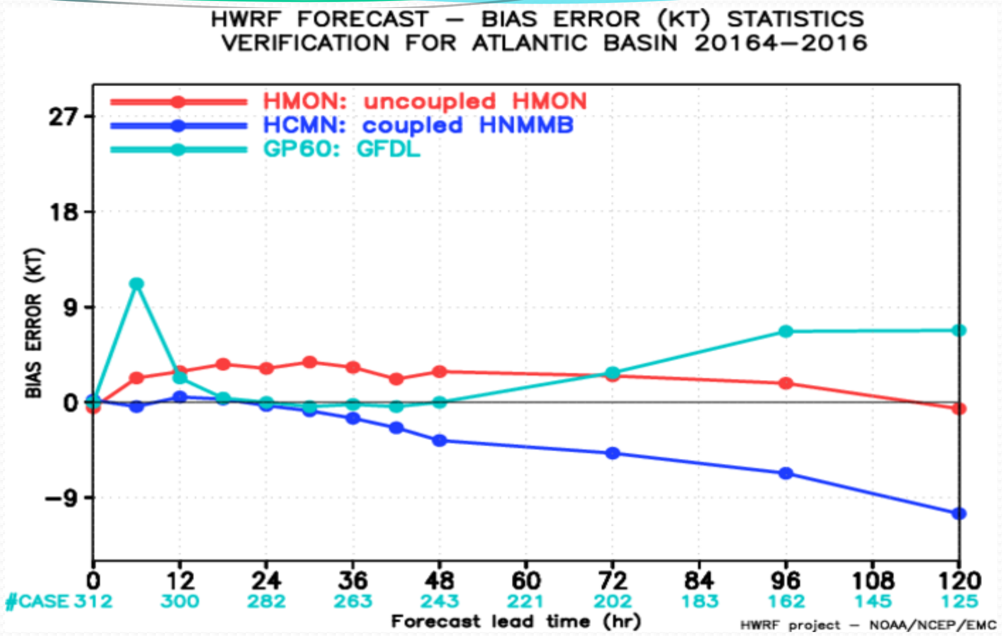
East Pacific

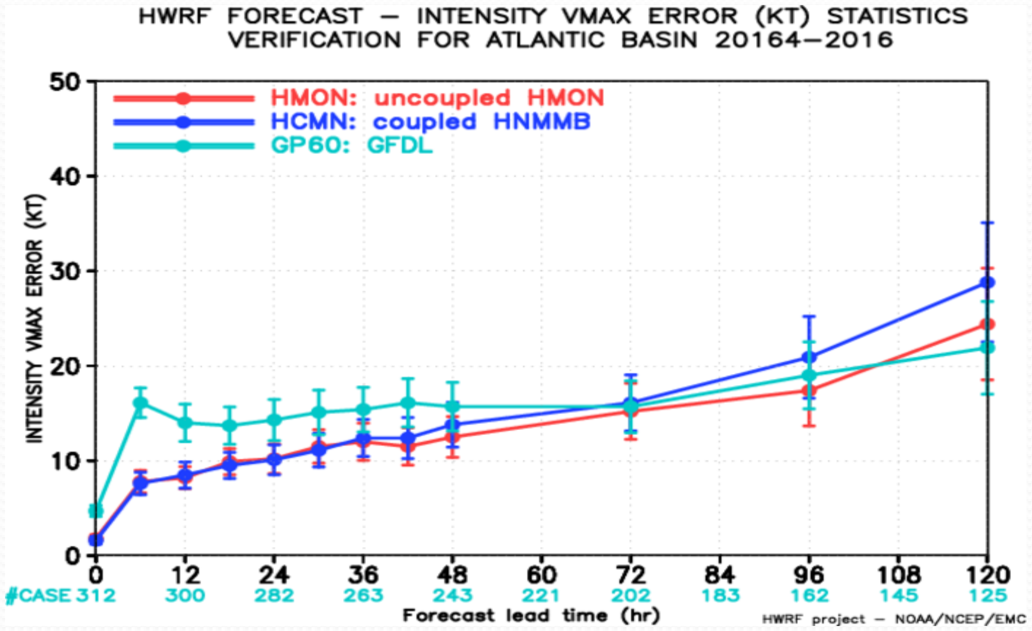




2017 HMON Performance: **North Atlantic Basin (Late Model)**



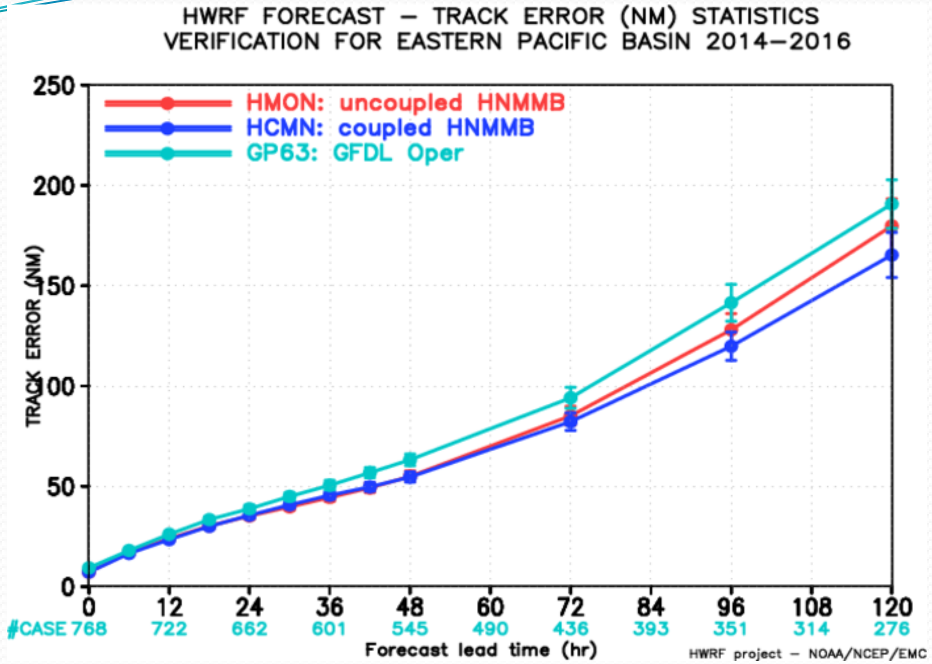


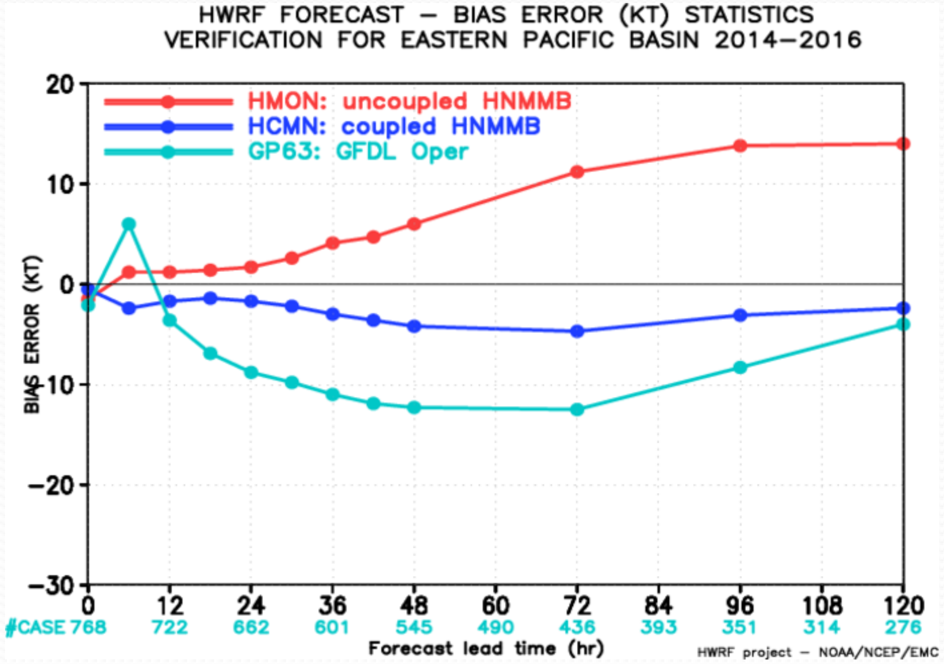


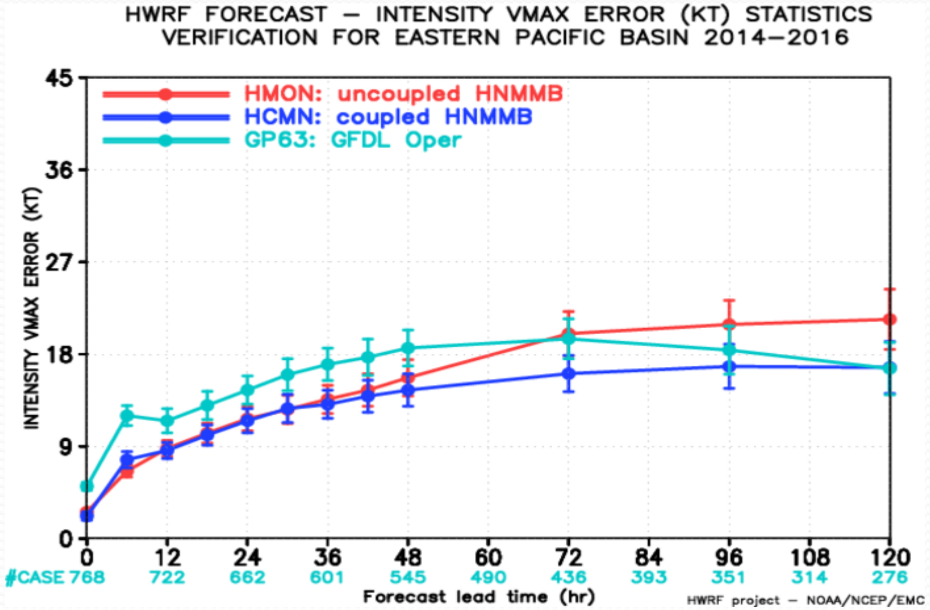
- For NATL basin, the coupled HMON runs showed much larger track and intensity errors at longer lead times.
- Intensity bias errors were lower for coupled runs for the first 36 hrs but became large negative by Days 4 and 5.

- **For NATL: uncoupled HMON configuration (propose)**

2017 HMON Performance: **East Pacific Basin**







- For EPAC, coupled HMON has much better results than uncoupled HMON and GFDL for both tracks and intensity especially at long lead times.
- Intensity bias is also much improved for coupled runs.

- **For EPAC: Coupled HMON configuration (propose)**

What it takes in operations to run 2017 MON

- Resource requirements:
  - FY17 HWRF H217: 624 cores or 26 nodes on Cray
  - Run maximum five storms for 3 basins (NATL, EPAC and CPAC) simultaneously.
  - Delivery times same as HWRF (before t+6);

HMON Version 1.0
Status as of 04/25/17

G

G Project Information & Highlights

Leads: Avichal Mehra & Tom Black, EMC and Steven Earle, NCO

Scope: Replace GFDL hurricane model with Hurricane NMMB (H-NMMB). Initial operating capability for NHC basins (ATL, EPAC and CPAC) with maximum 5 storms per cycle.Transition and tune HWRF physics, initialization, and ocean coupling for H-NMMB

Expected benefits: Improved track & intensity forecast skill compared to GFDL. Improved forecast guidance to NHC to fulfill their mission. Explore high-resolution hurricane ensemble products

Dependencies: N/A.

G Schedule

Milestones & Deliverables	Date	Status
Freeze system code; deliver to NCO if applicable	1/10/17	N/A
Complete full retrospective/real time runs and evaluation	4/07/17	In progress
Deliver final system code to NCO and conduct CCB	4/2517	On track
Issue Technical Information Notice	5/03/17	On track
Complete 30-day evaluation and IT testing	6/12/17	On track
Operational Implementation	6/27/17	On track

EMC	NCO	Red text indicates change from previous quarter

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Issue: Complex T&E due to dependency on NEMS/GSM and RTOFS upstream requirements**; Resolution:** Use 2016 versions.

Risk: Implementation dates are dependent on completion of T&E; Ongoing disruptive Cray upgrades and maintenance

Mitigation: Conduct T&E as soon as retrospective data are available. Use white space on production machine.

G Resources

Staff: 0.75 Fed FTEs + 4 contractor FTEs; including Dev (Vortex Initialization, Coupler and Physics)

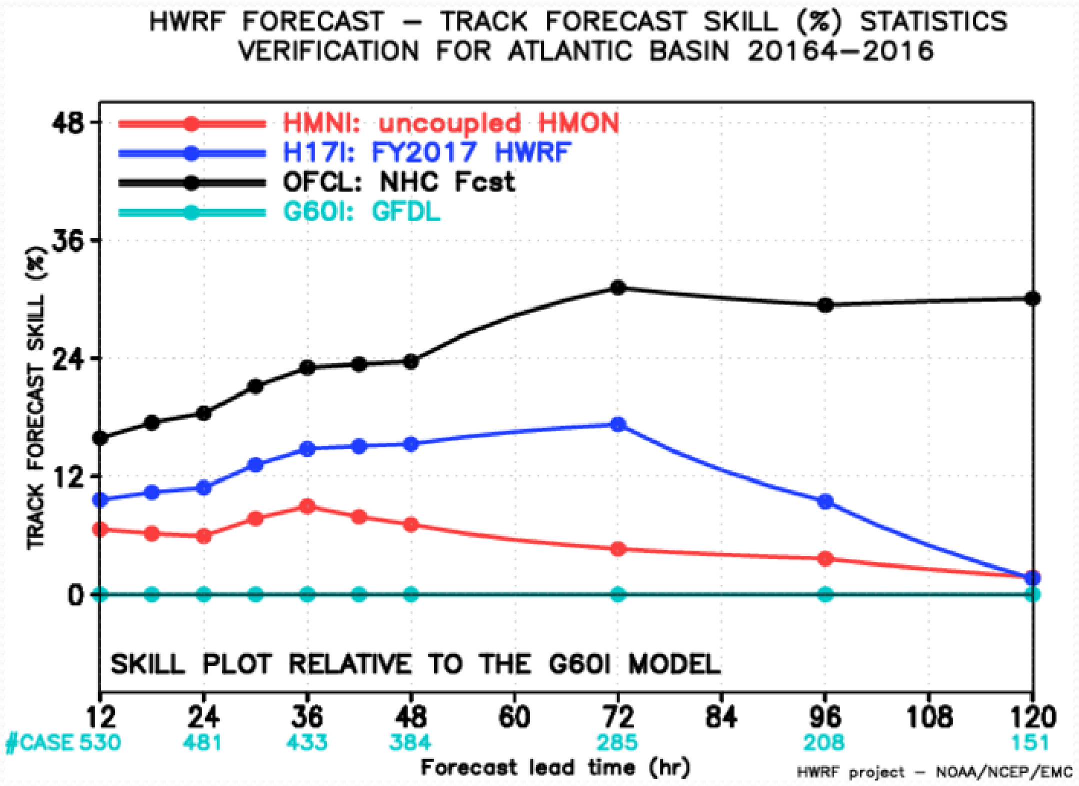
Funding Source: STI

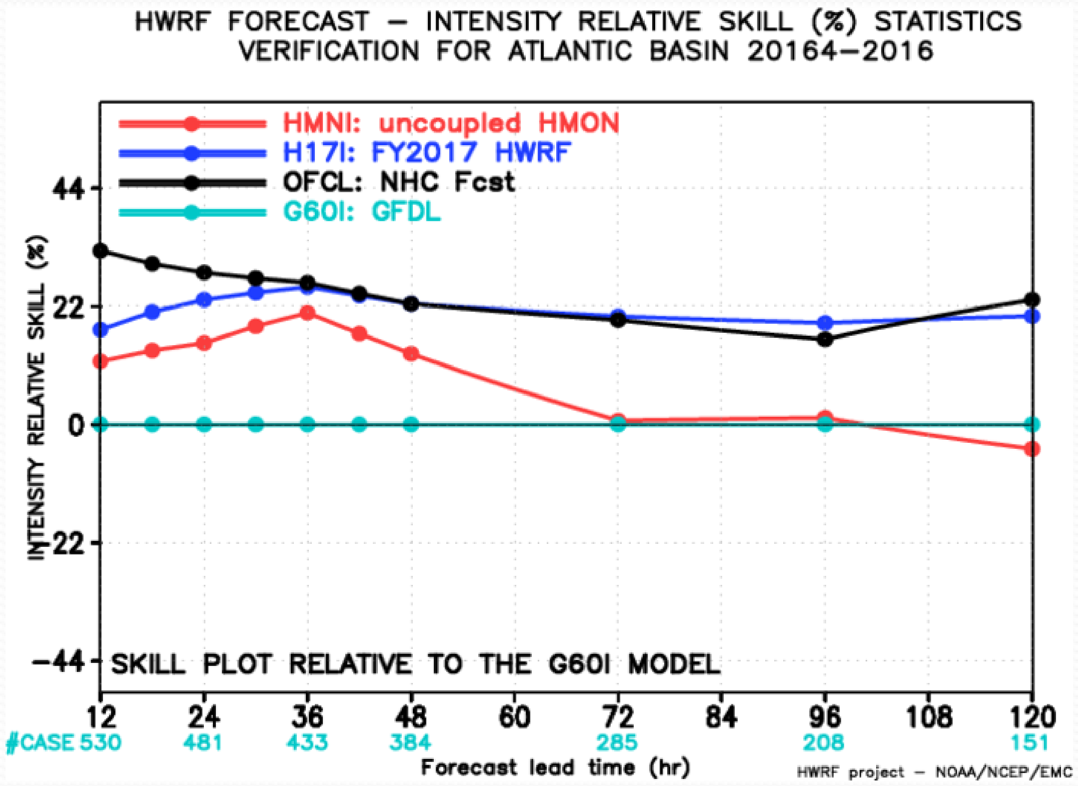
Compute: parallels: 150 nodes for 3 months (devmax/devonprod);; **EMC Dev**: 100 nodes for 3 months (devhigh); **Ops**: Delta = 26 nodes per storm

Archive: 0.3 PB (Delta = 0.3 PB)

R Management Attention Required	Y Potential Management Attention Needed	G On Target

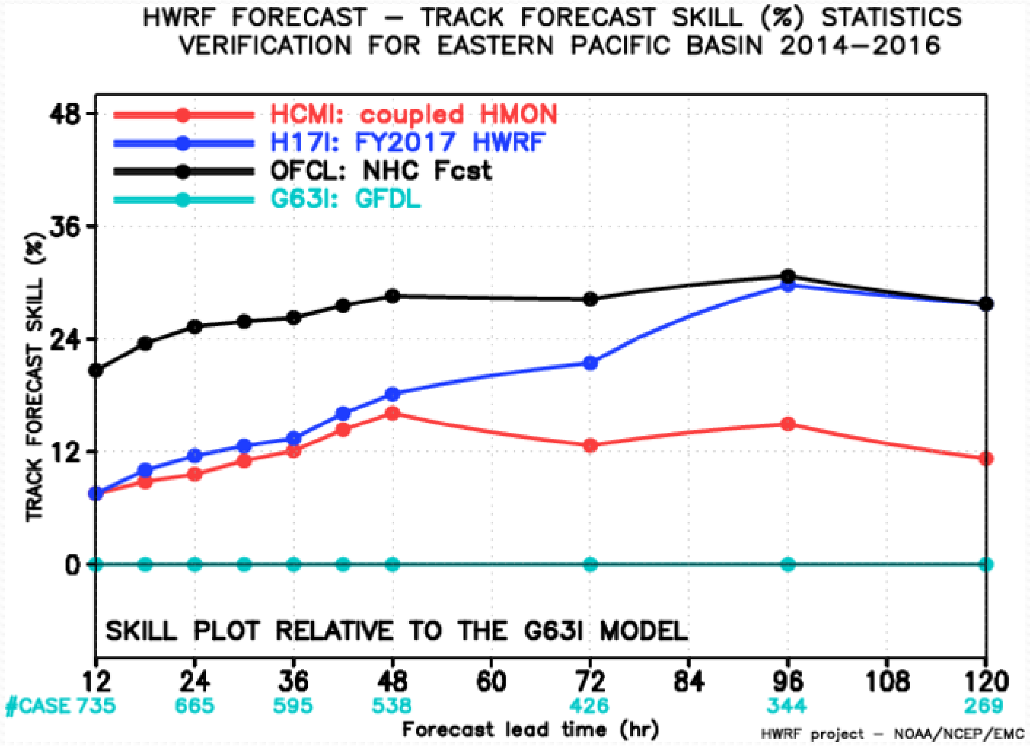
2014-16 Atlantic Basin: Relative to GFDL (interpolated)

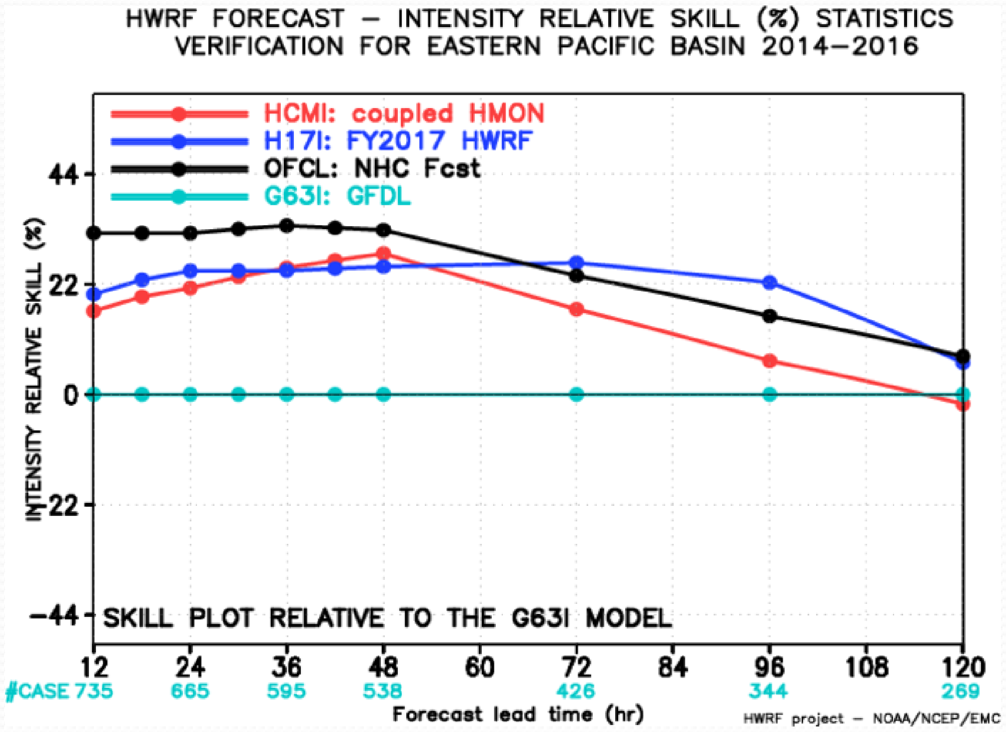




H217 catches up with official skill for intensity by hr 36 and beats it at Day 4. HMON has improved track skills as compared to GFDL at all lead times with an average improvement of more than 5%. It also has improved intensity skills with a mean improvement of >10%. Both tracks and intensity need to catch up with the official skill.

2014-16 East Pacific Basin: Relative to GFDL (interpolated)





H217 catches up with Official results by Day 4 for tracks and Day 3 for intensity in EPAC. HMON has improved track and intensity skills as compared to GFDL but still needs to play catch up with official skill especially for longer lead times.

HWRF/HMON Long-Term Plans

2016	2017	2018	2019	2020
HWRF Operational Model Continues Followed by Ensembles				
GFDL ——— HMON		**10-member HWRF/ HMON Ensembles**	NEMS Global Nests (NGGPS)	
Basin-Scale HWRF/NMMB/FV3——— Global/Tropical Domains				
Hurricane Models take over Hurricane Wave Forecasts				

Development, T&E and Implementation Plans for HWRF & HMON

- 2016 Nov: Configuration ready
- 2016 Dec- 2017 March: Pre-implementation retrospective testing
- 2017 April: EMC CCB and code hand-off
- 2017 June: Operational Implementation