Advancing the State of the Art in Tropical Cyclone Modeling At NOAA's National Weather Service National Center for Environmental Prediction (NWS/NCEP)

Keynote presentation at the 50th Typhoon Committee Technical Conference at NHMS, Ha Noi, Viet Nam on February 26, 2018

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Outline

- HWRF Upgrades for 2017 (H217)
- HWRF verification in global tropical cyclone basins
- HWRF-HYCOM coupling in 2017
- HWRF real time performance in 2017
- HMON (new model) verification
- HWRF & HMON plans for 2018
- HWRF & HMON future plans and transition to FV3

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,
- Vertical levels: L75 (H216: L61), changes to nested domain sizes (details on next slide)
- New Tracker (Tim Marchok, GFDL)

➢ Initialization/Data Assimilation Improvements

- GSI code upgrades; new data sets for GSI, improved vortex initialization
- Fully Cycled HWRF ensemble hybrid DA for TDR and priority storms
- Change in blending threshold (from 50 to 65 Kt)
- HDOBS data assimilation

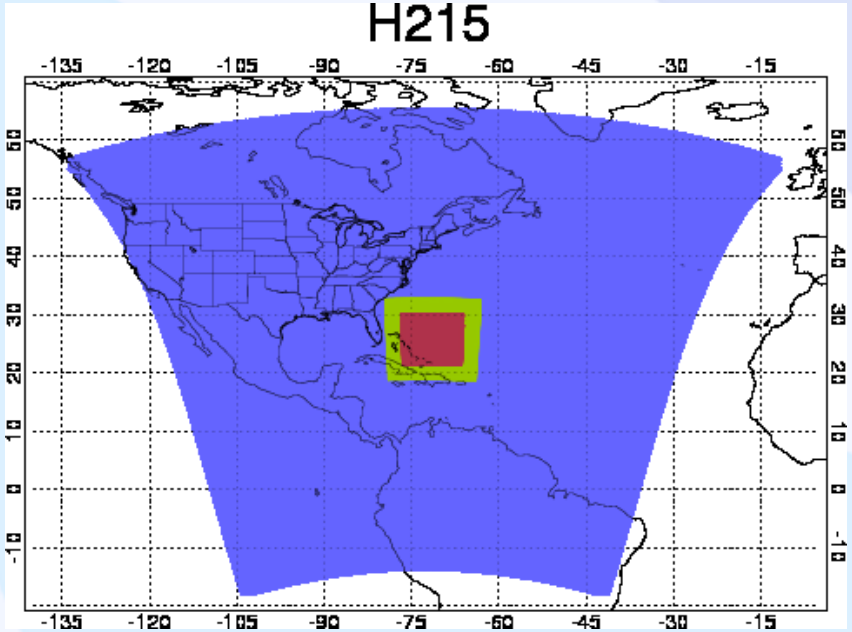
➢ Physics Advancements

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

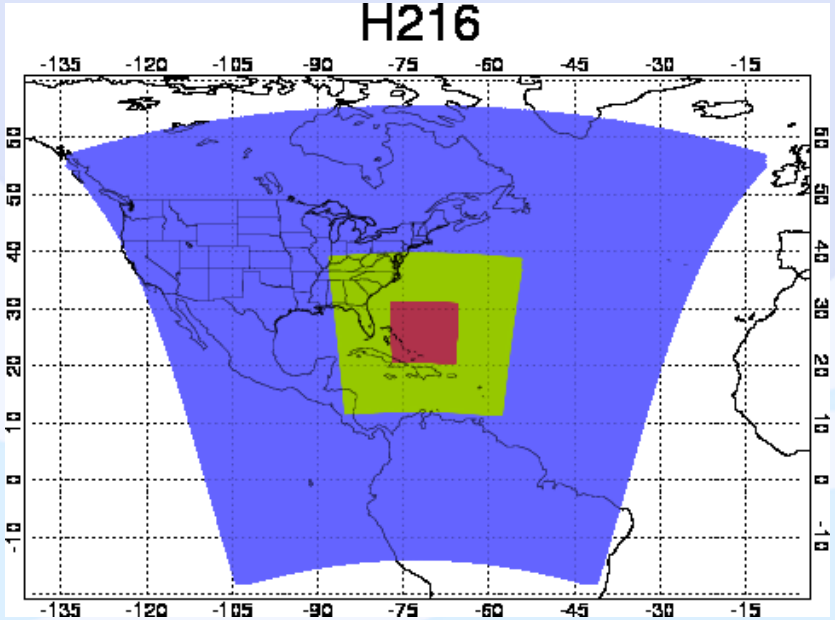
➢ Coupling Upgrades

- Reduced coupling time step for both ocean and waves
- Increased vertical levels for POM
- Waves Boundary Conditions
- RTOFS initialization for CPAC, HYCOM ocean coupling for WPAC, NIO

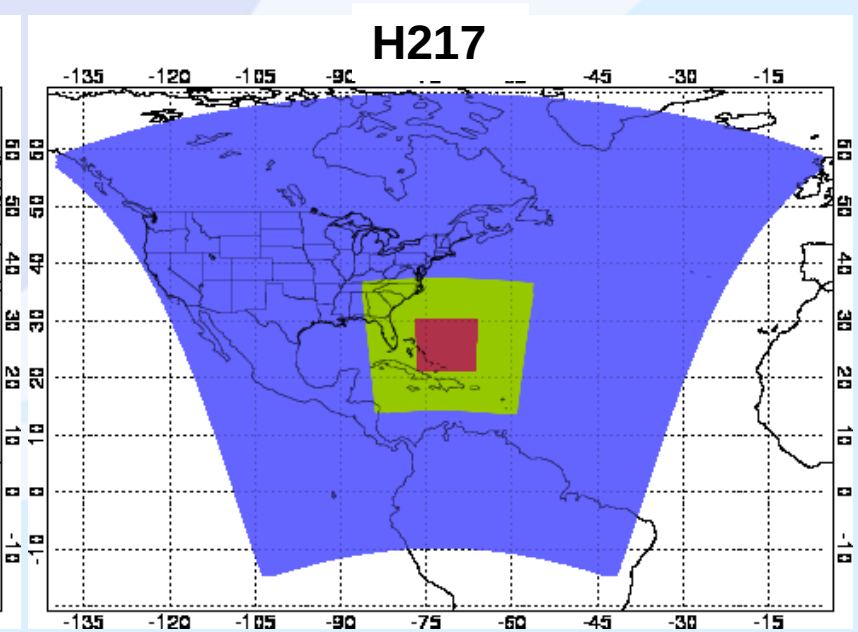
Domain Size Adjustment for H217 with higher vertical resolution



d01:288 x 576
d02:142 x 274
d03:256 x 472
Levels: 61
Top: 2 mbar



do1:288 x 576
d02:288 x 576
d03:288 x 576
Levels: 61
Top: 2 mbar

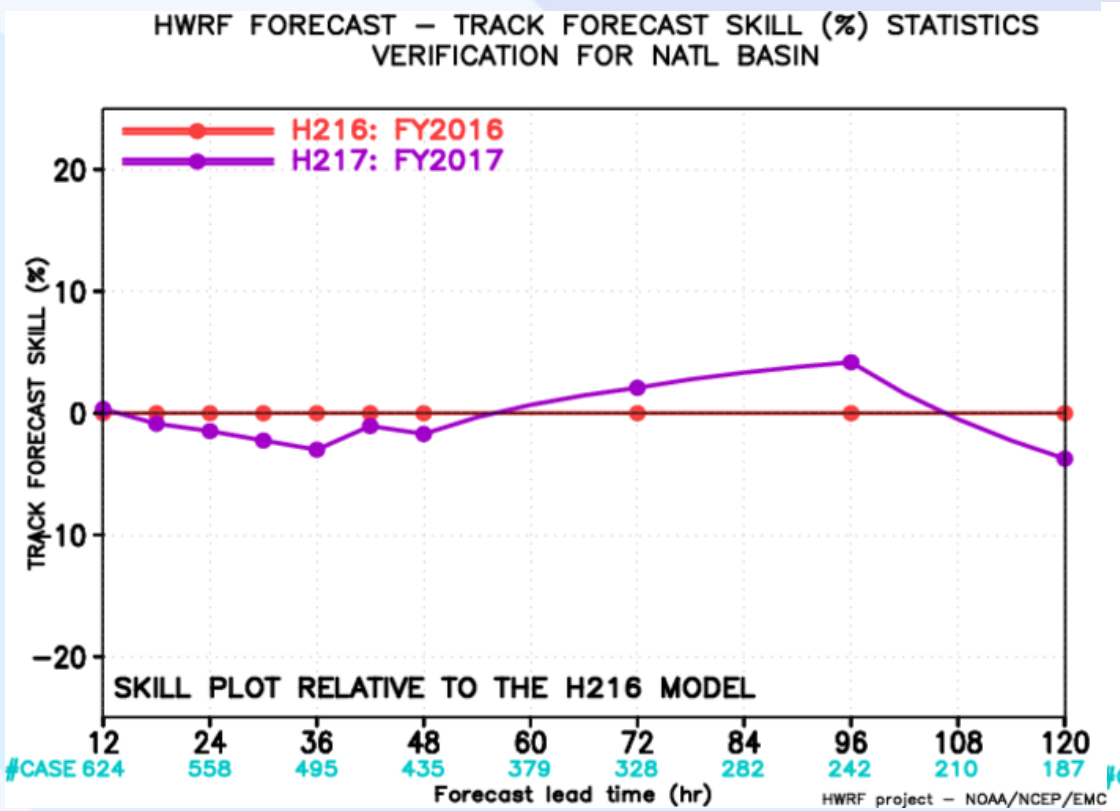


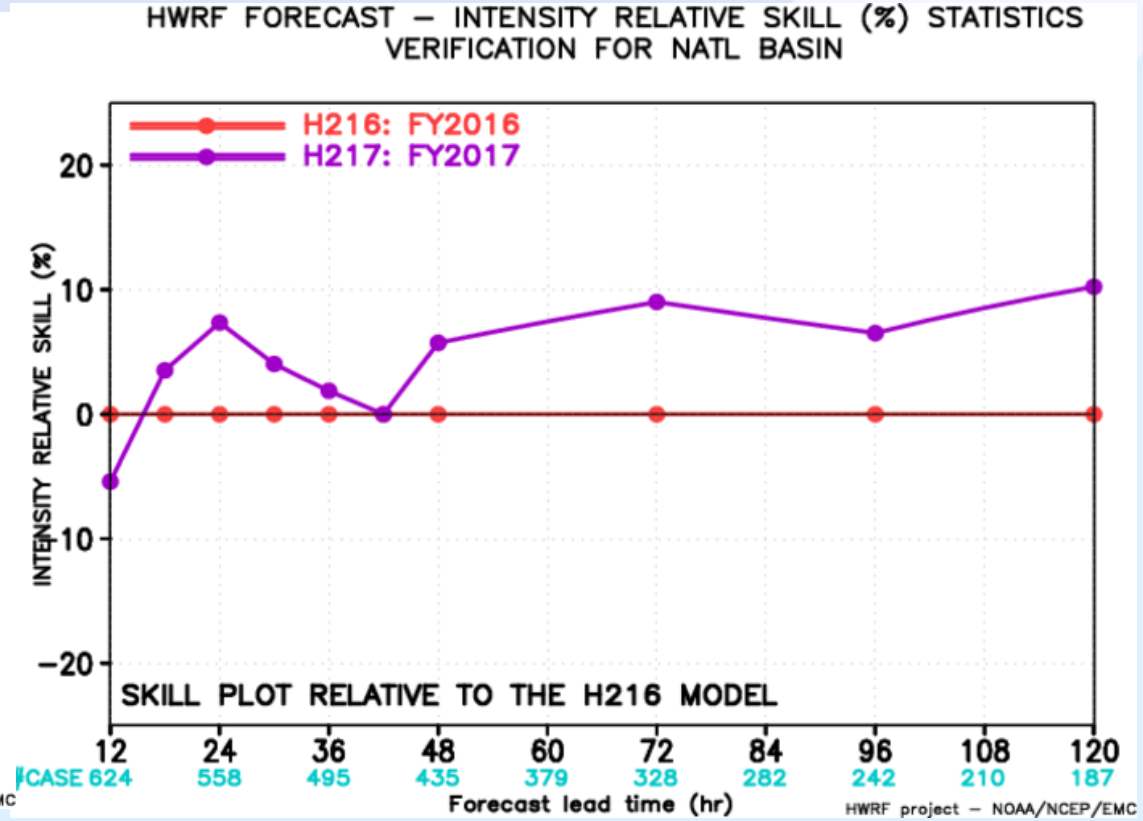
d01:288 x 576
d02:265 x 532
d03:235 x 472
Levels: 75
Top: 10 mbar

Scope of FY17 HWRF Upgrades (cont.)

- **First time in 2017….**
  - **Fully Cycled Hybrid EnKF DA**
  - **75 vertical levels, optimized nested domains**
  - Use of NEMSIO (IC) and GRIB2 (LBC) files for inputs
  - HDOBS data assimilation
  - **RTOFS initialization for CPAC**
  - **Ocean coupling (replace MPIPOM with HYCOM) for WPAC, NIO**

Track and intensity skills for NATL storms (Late Model)

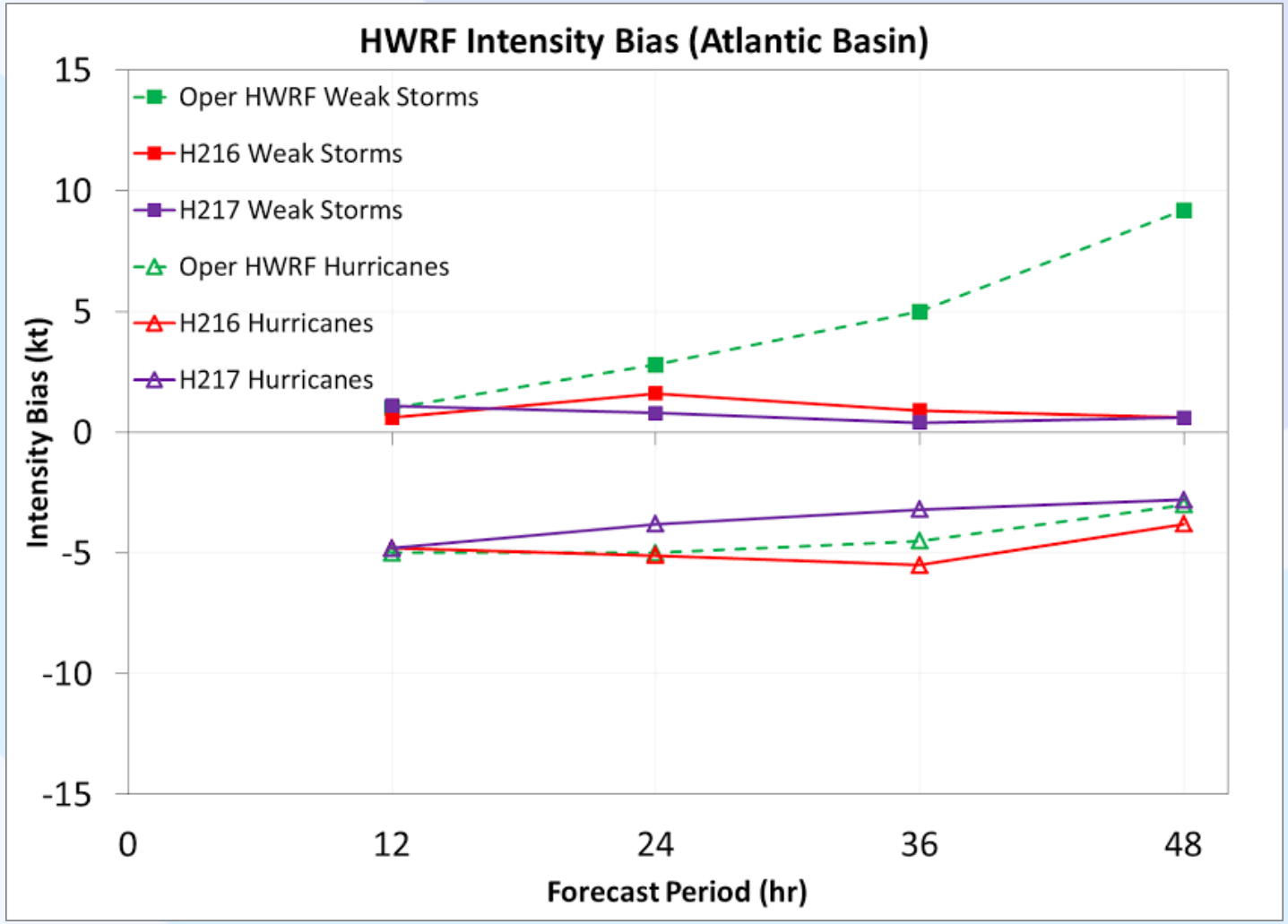




- The track skill for H217 is very close to H216 but there is improvement from hrs 60-108 hr.

- The improvement in intensity skill for H217 is evident at almost all lead times and is close to 10% at Days 3 and 5.

HWRF bias for NATL storms for 2016 season

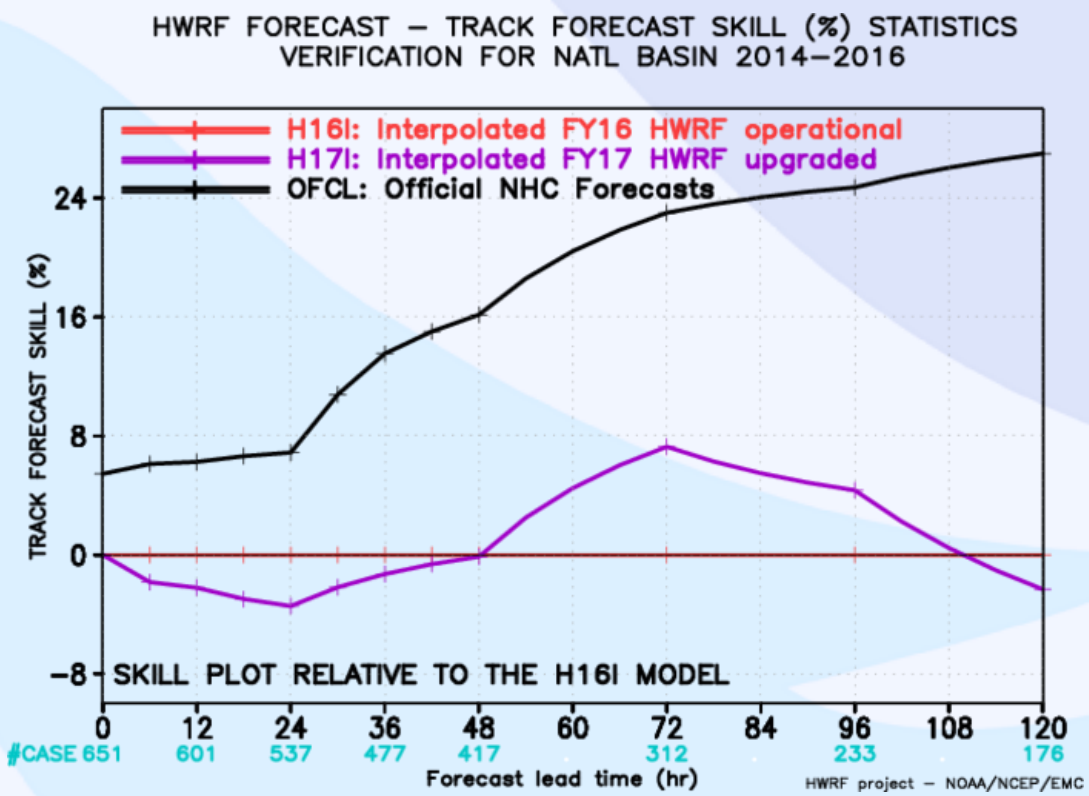


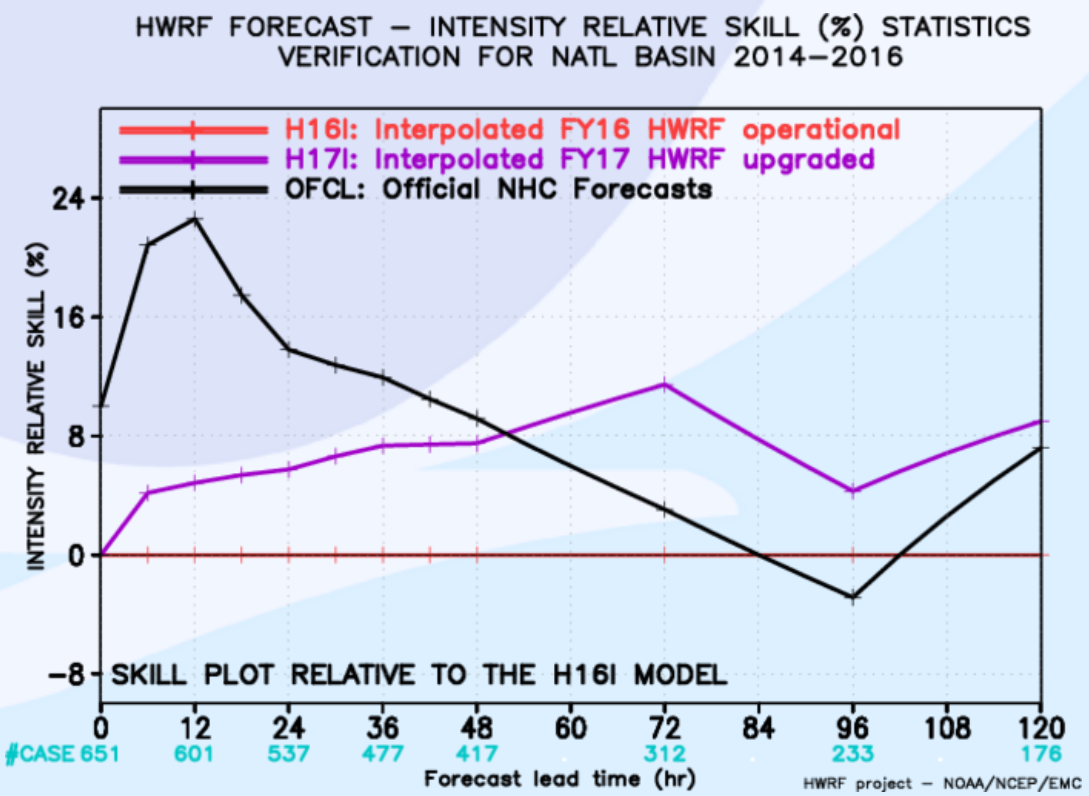
There is improvement in reducing positive bias for weaker storms (< 50 kt) for H217 as compared to H216.

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 larger homogenous sample based on storms from the entire 2016 season (total 378 cases).

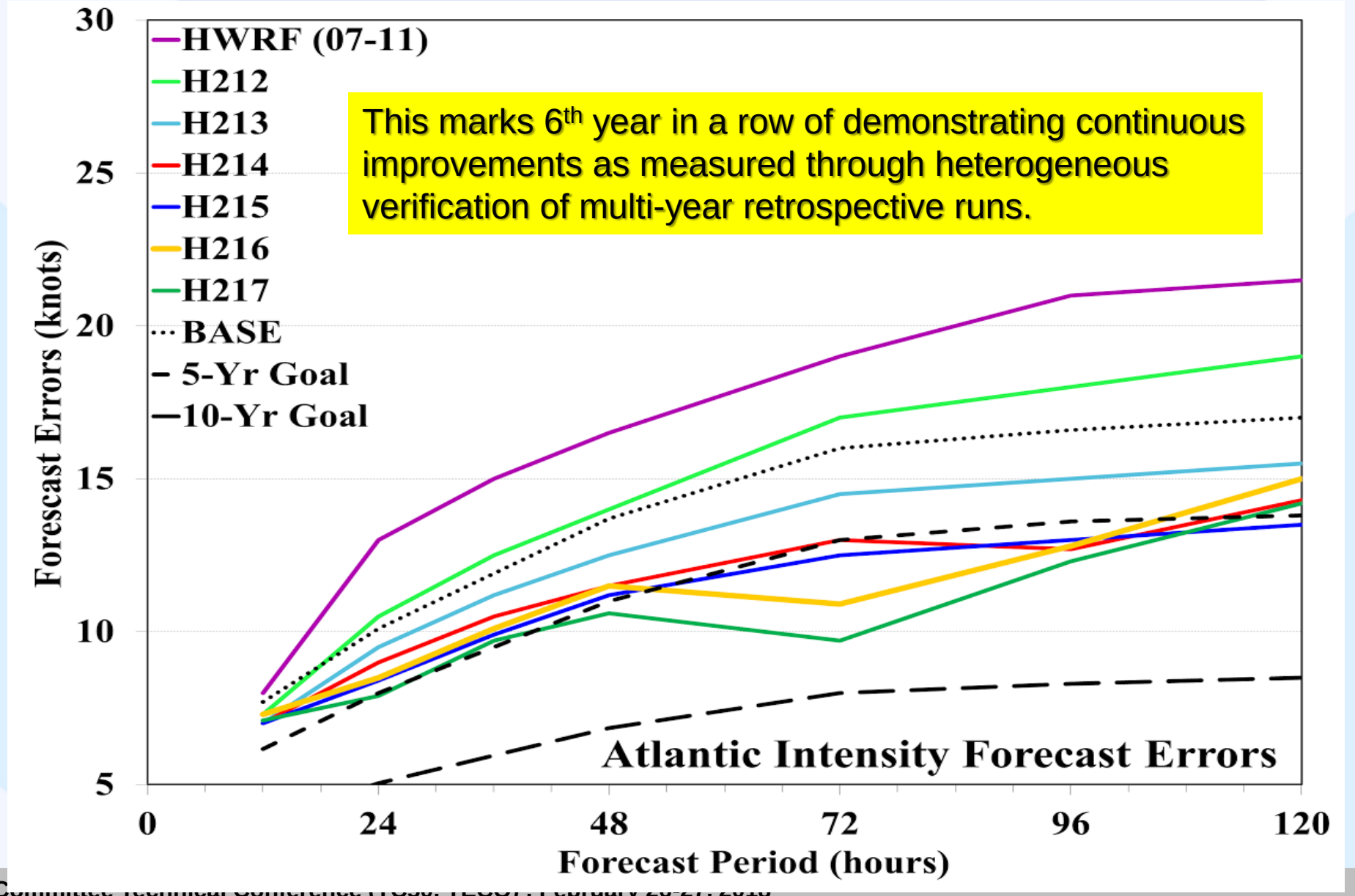
H17I performance compared to H16I in NATL (Interpolated)



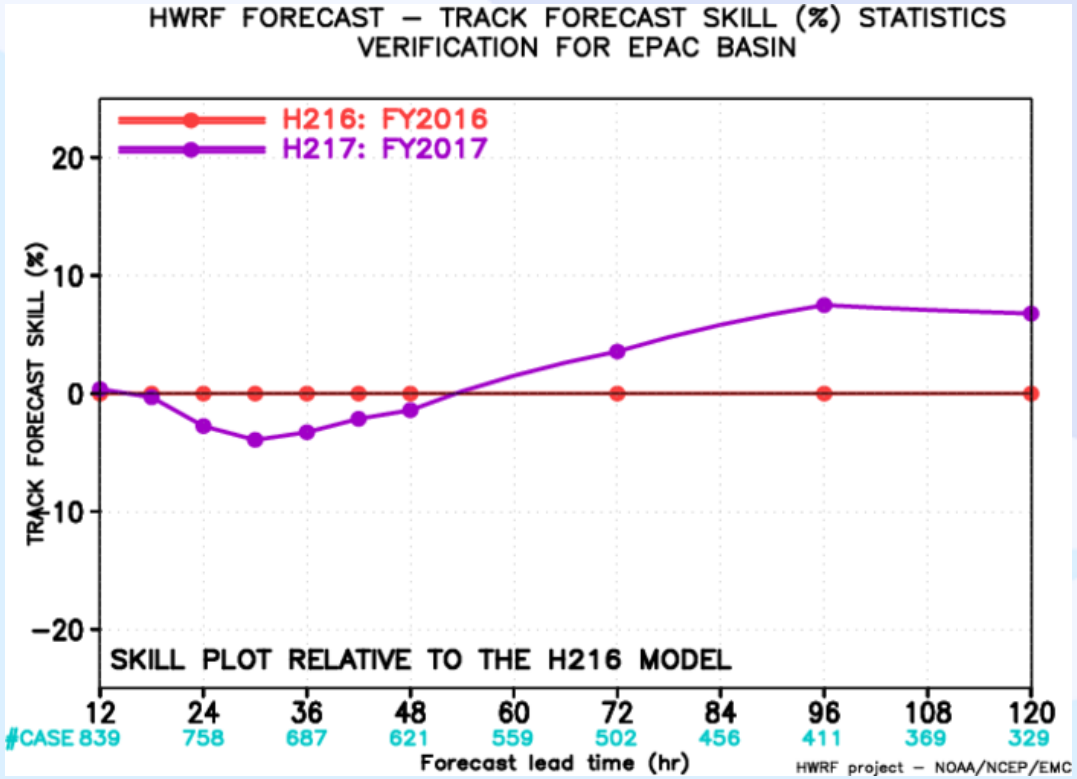


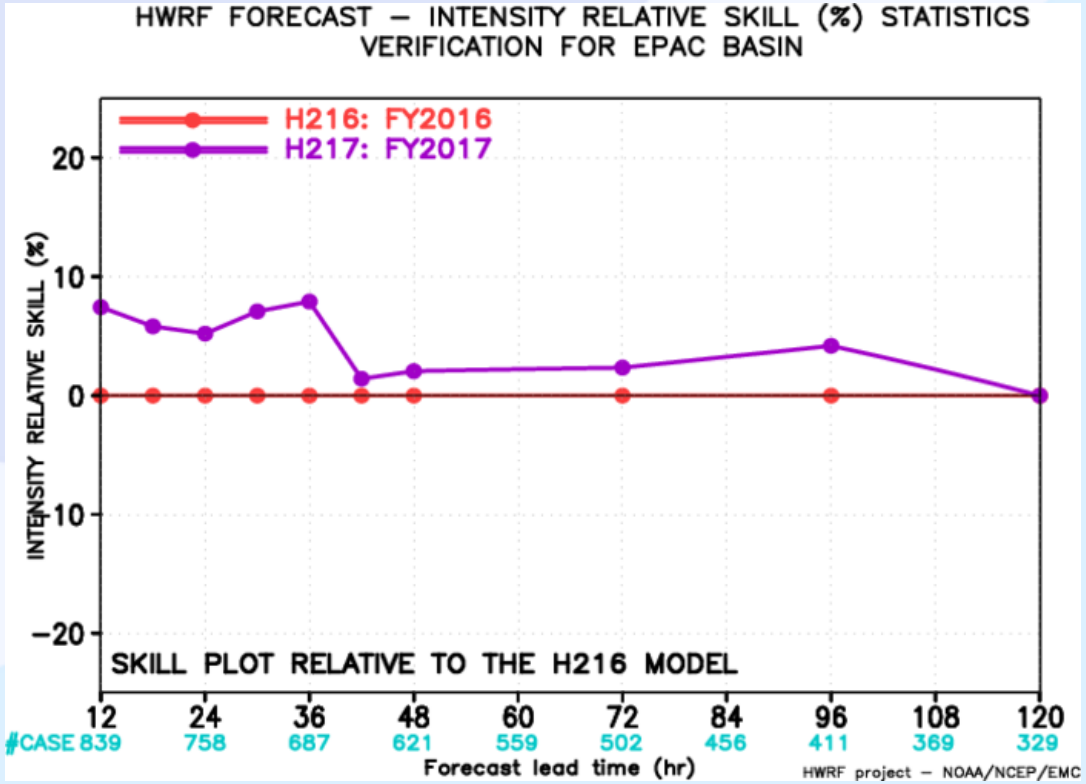
H217 tracks are overall neutral with improvements from hrs 48-108 while intensity is improved at all lead times with 10% improvement at day 3. We still need to close the gap with official tracks but are doing better for intensity as compared to official results after Day 2.

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



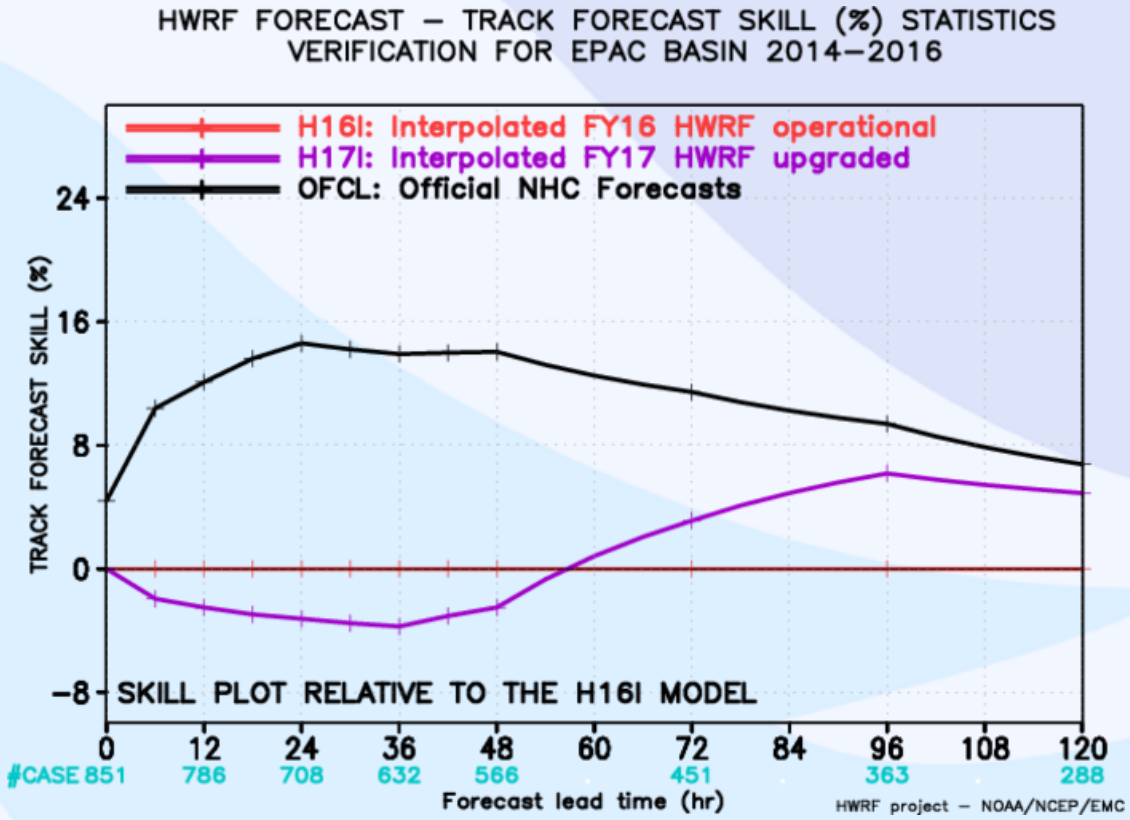
Track and intensity skills for EPAC storms (Late Model)

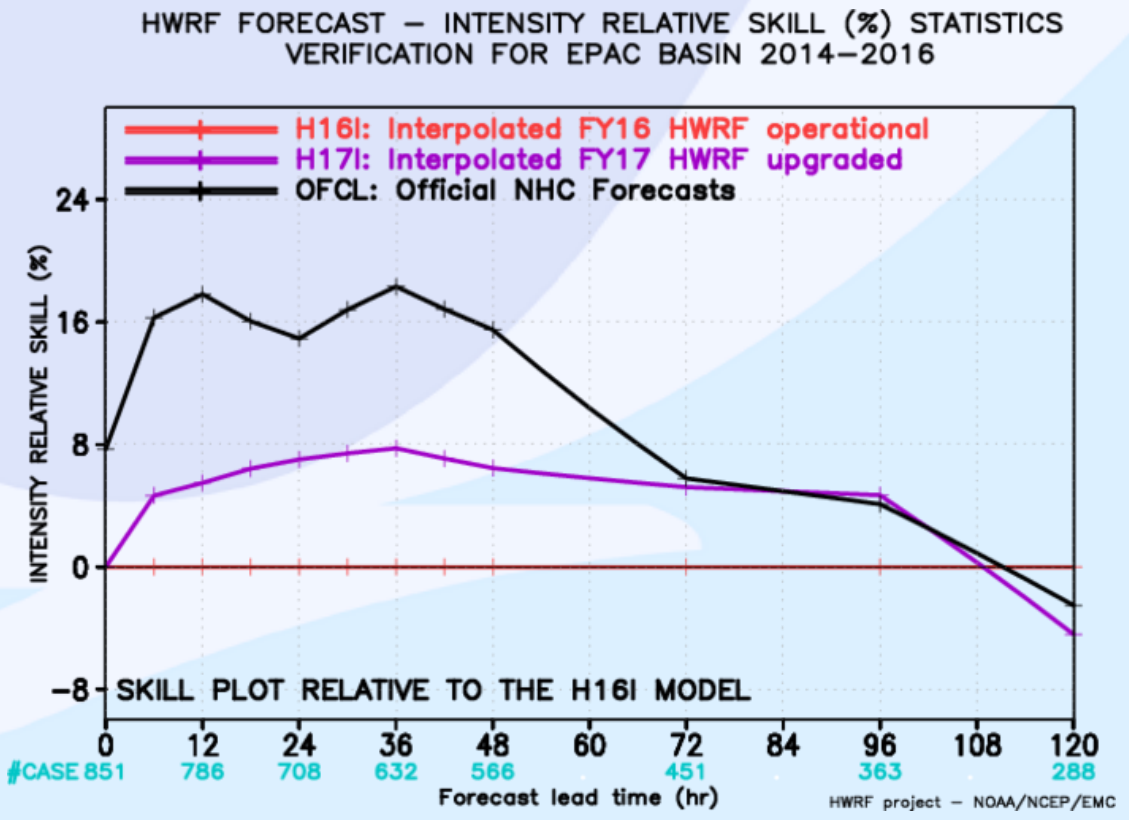




- The track skill for H217 is a little lower for hrs 18-54 but then positive for late lead times.
- Change in intensity skill for H217 is positive at all lead times and more than 5% for early forecast (hrs 12-36).

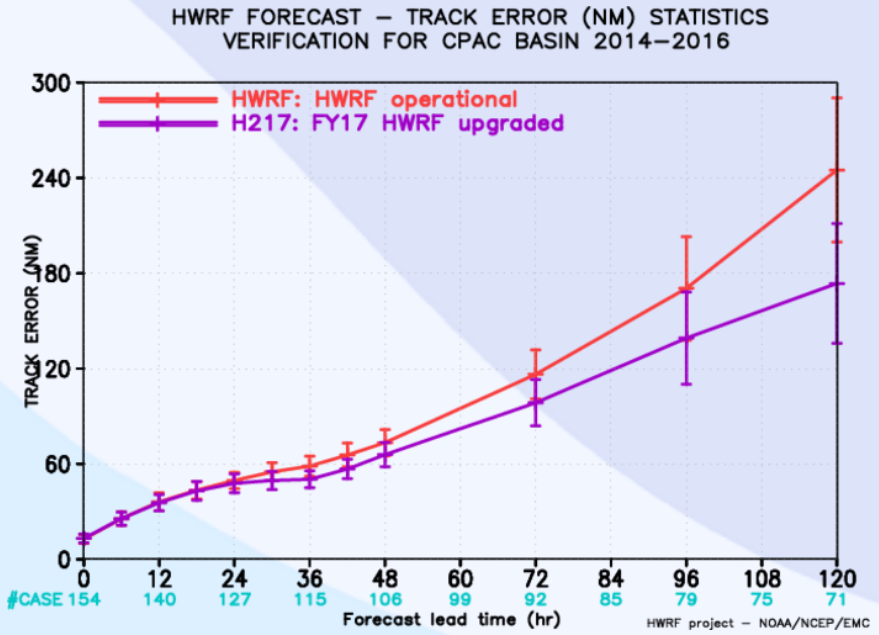
H17I performance compared to H16I in EPAC (Interpolated)

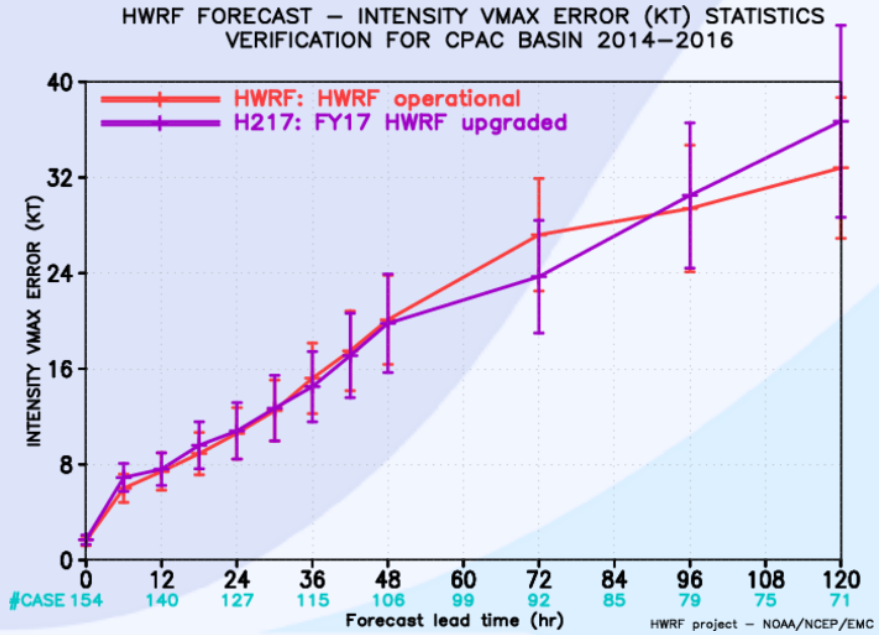


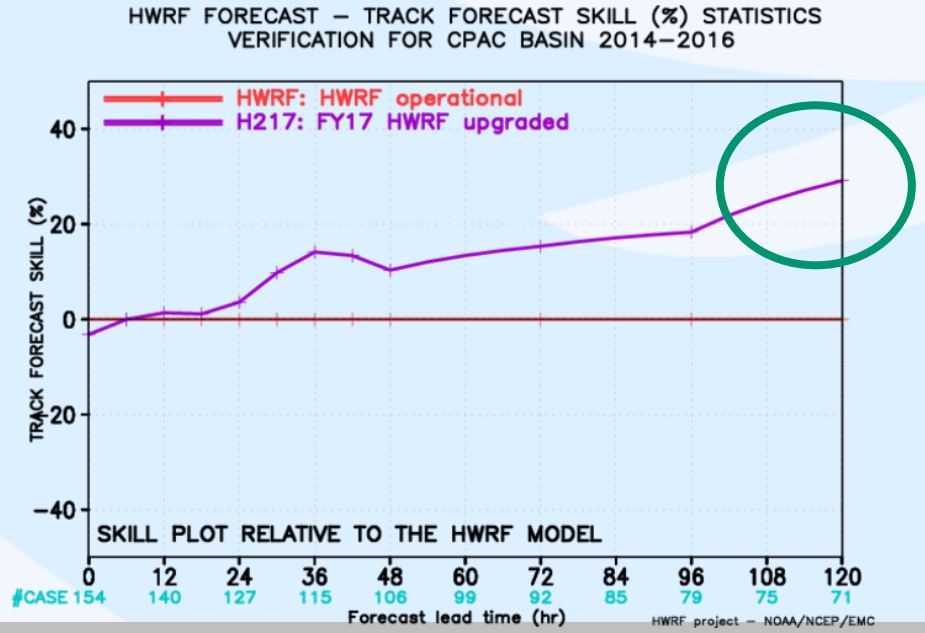


H217 tracks are initially a little degraded but then show improvements after hr 60. The intensity skill is improved at all lead times with 8% improvement at hr 36. We still need to close the gap with official tracks and intensity for the first 3 days, but are doing better for track and intensity after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

H217 performance compared to H216 in CPAC



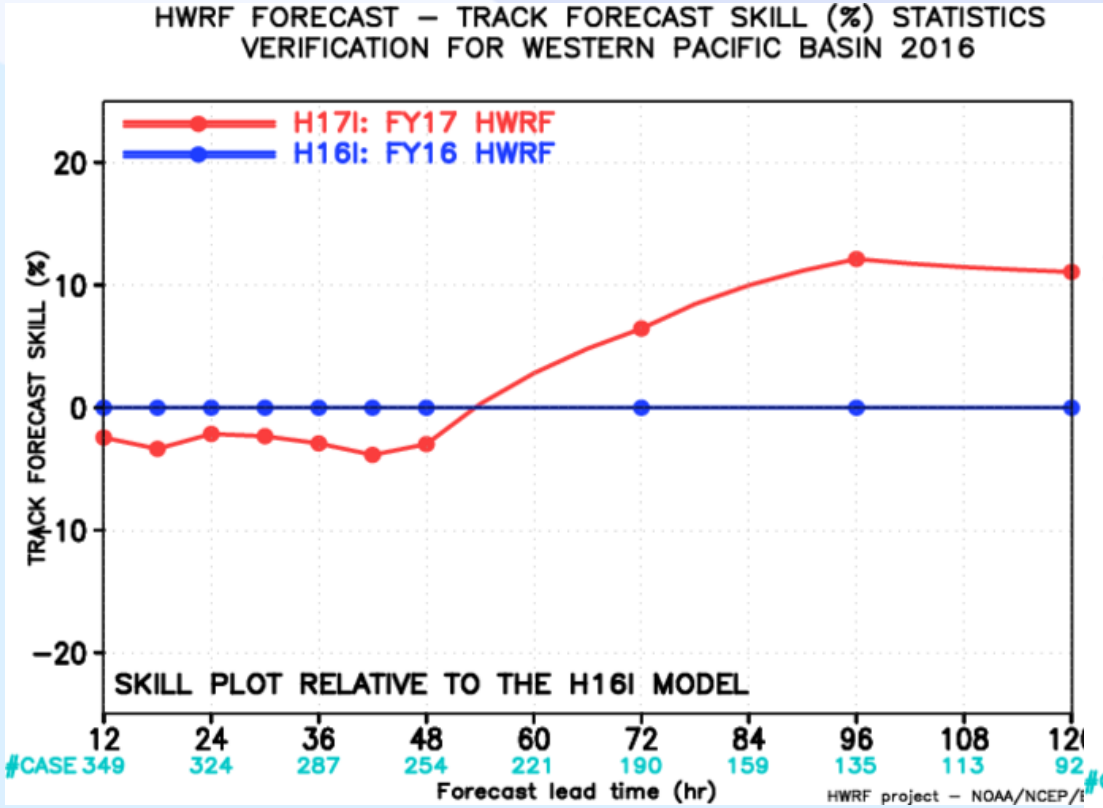


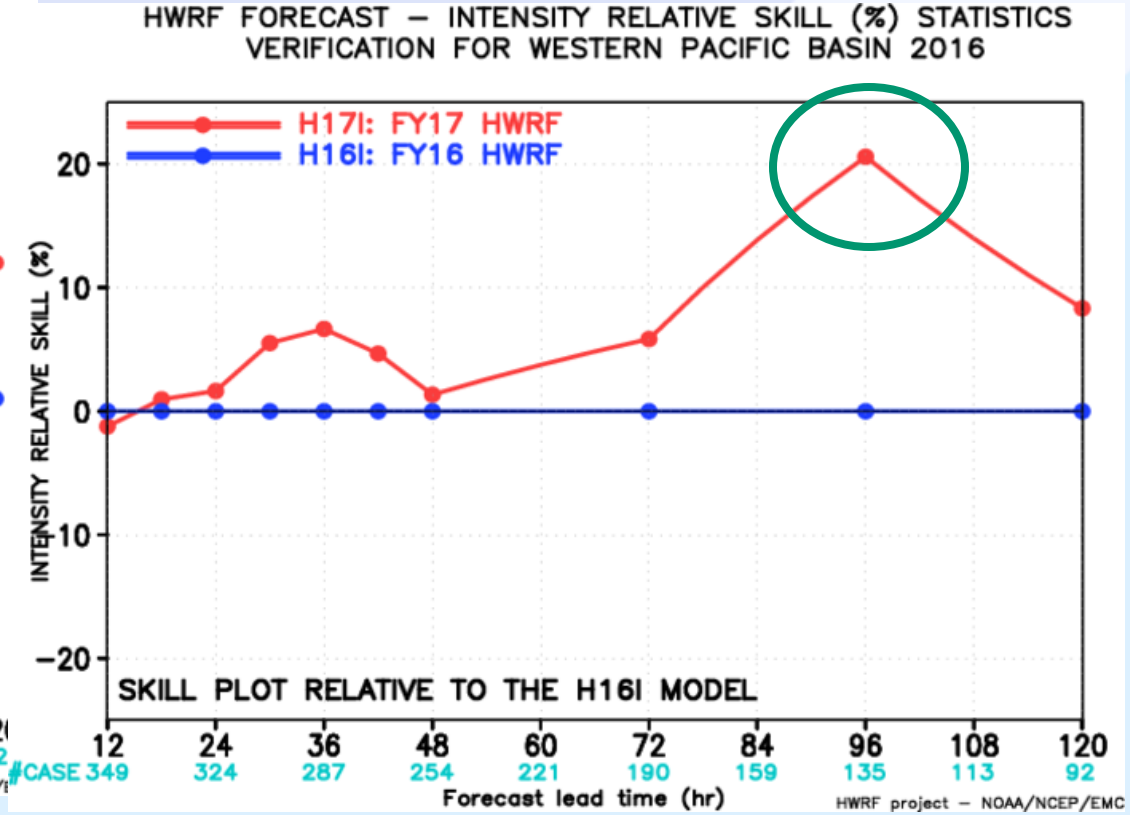


- H217 shows significant improvements in track performance especially after Day 1 with more than 25% improvement by Day 5.
- Intensity is also improved for Day 3 but neutral overall.

HWRF Verification for 2016 Western North Pacific Storms

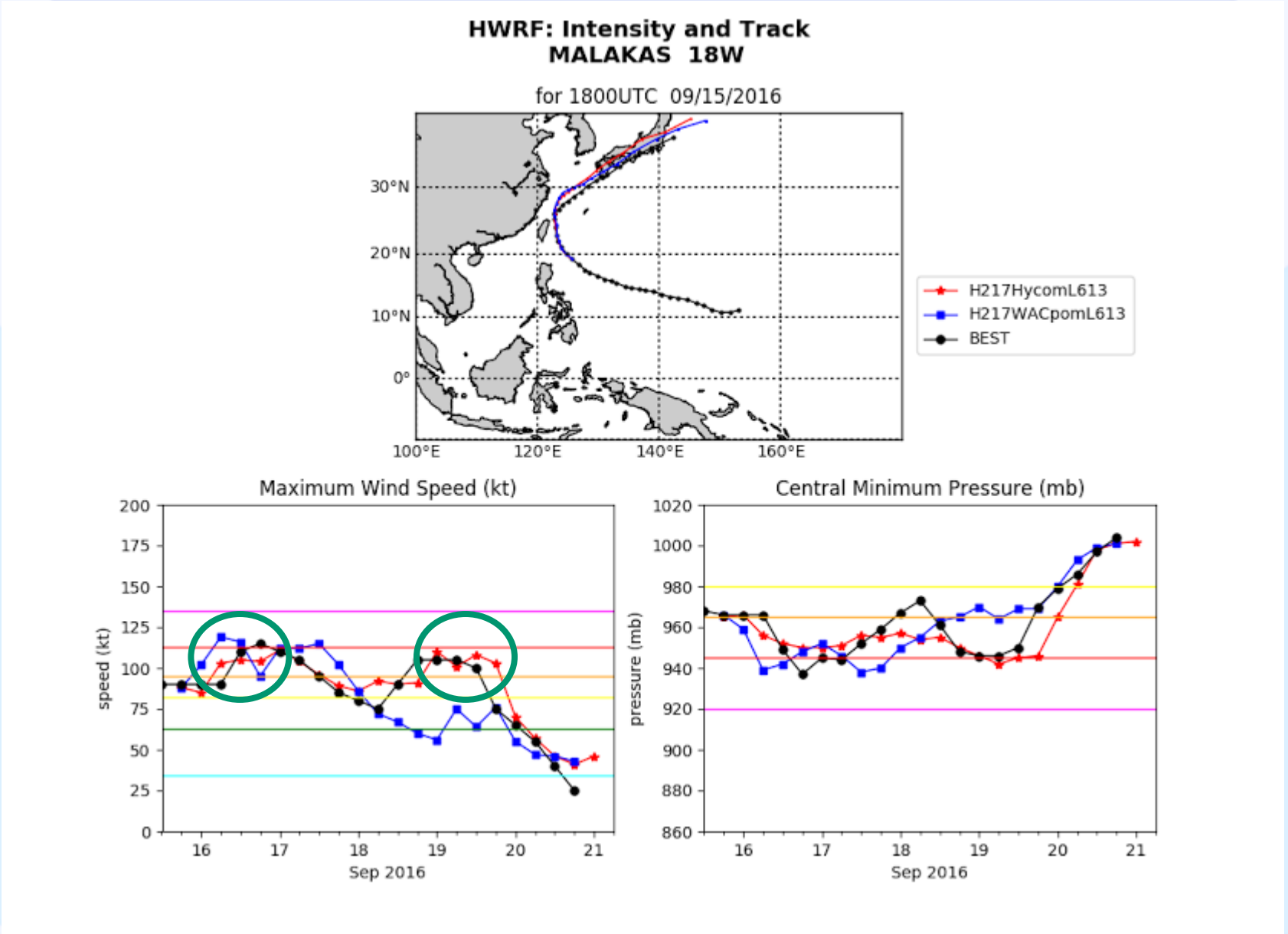
H17I performance compared to H16I in WPAC (Interpolated)



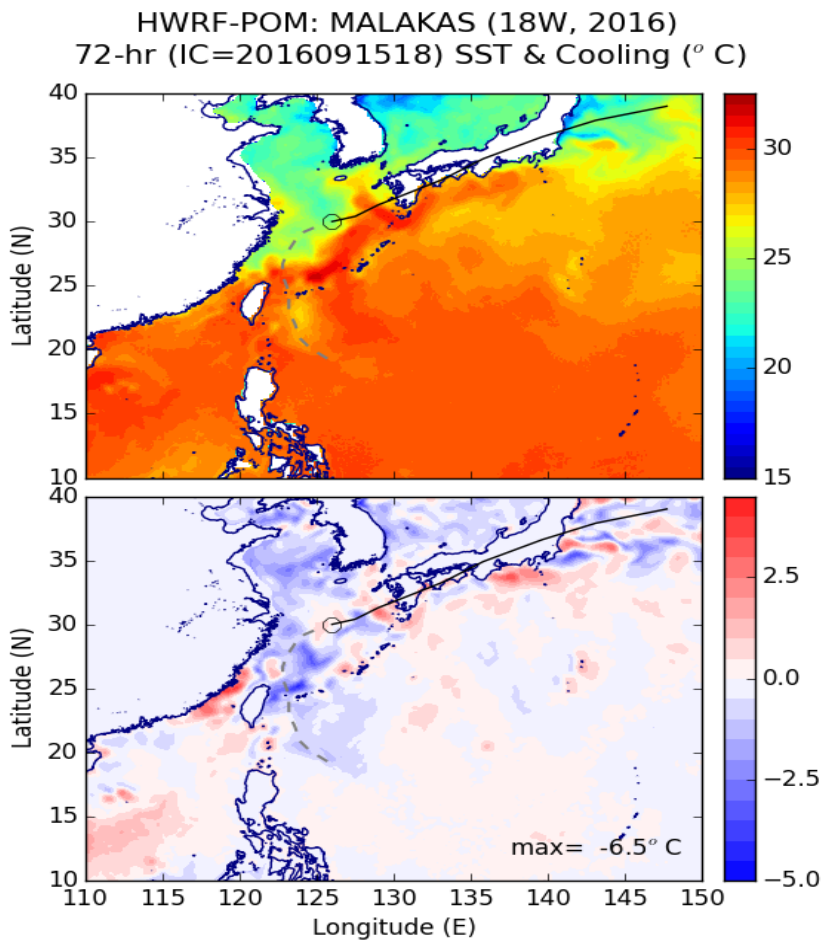


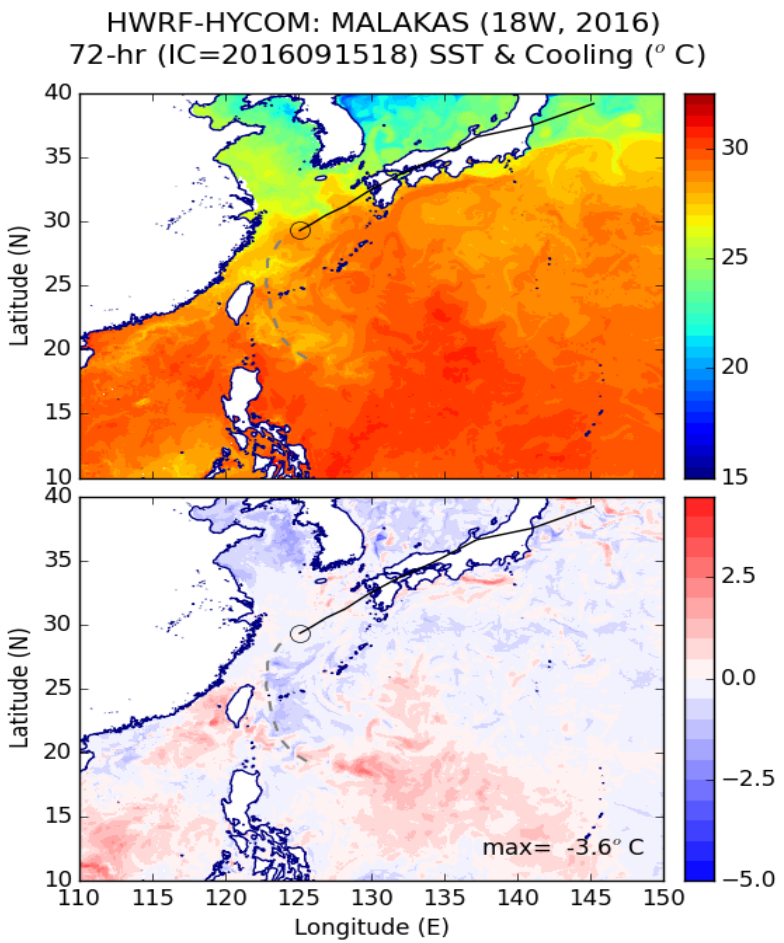
H217 tracks are initially a little degraded but then show improvements after hr 54 with an improvement of more than 10% by Day 4. The intensity skill is improved at all lead times with more than 20% improvement at Day 4.

Impact of using HYCOM in H217 for WPAC storms



Impact of using HYCOM in H217 for WPAC storms

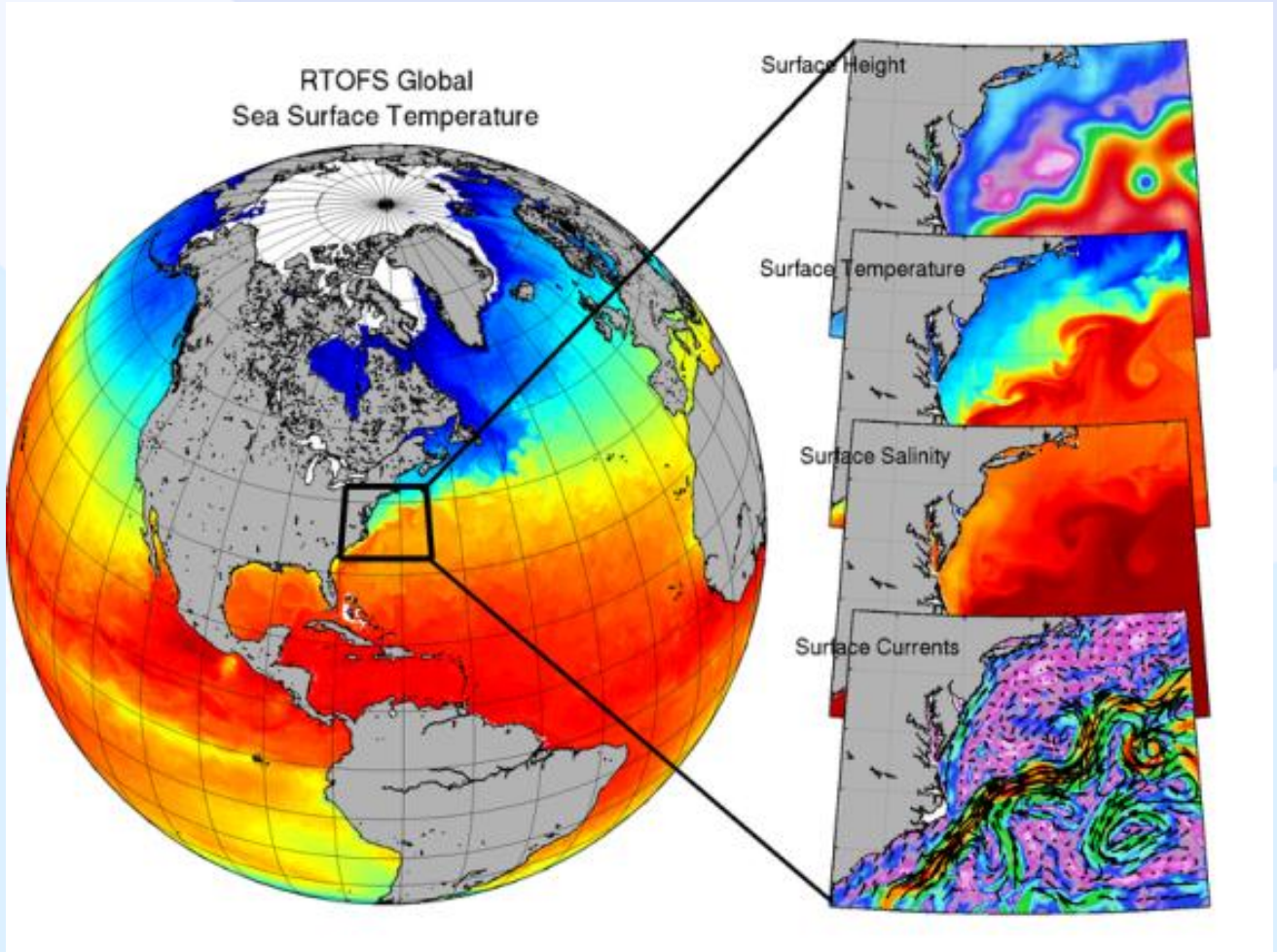




SST (top panel) and SST change (bottom panel) for Malakas, where the 2nd intensification took place before it made landfall in Japan. POM overpredicted reduction in SST's (left panel) and hence failed to intensify the storm because of relatively cold water on the shelf (< 26°C), unlike HYCOM (right panel) which has a better SST representation.

Impact of RTOFS V1.1 Upgrade on Operational HWRF

RTOFS Global: 1/12 Degree Global Domain



Primary Users:

NWS:
EMC,OPC,NHC,
WFO/NWPS

NOS:
CO-OPS, CSDL,
IOOS RA's

OAR:
AOML/HRD

US Coast Guard

Primary research partners: NRL, ESRL, AOML, NESDIS, JCSDA, JAEA (Japan), UMD, FSU, MSU

RTOFS GLOBAL Version 1.1

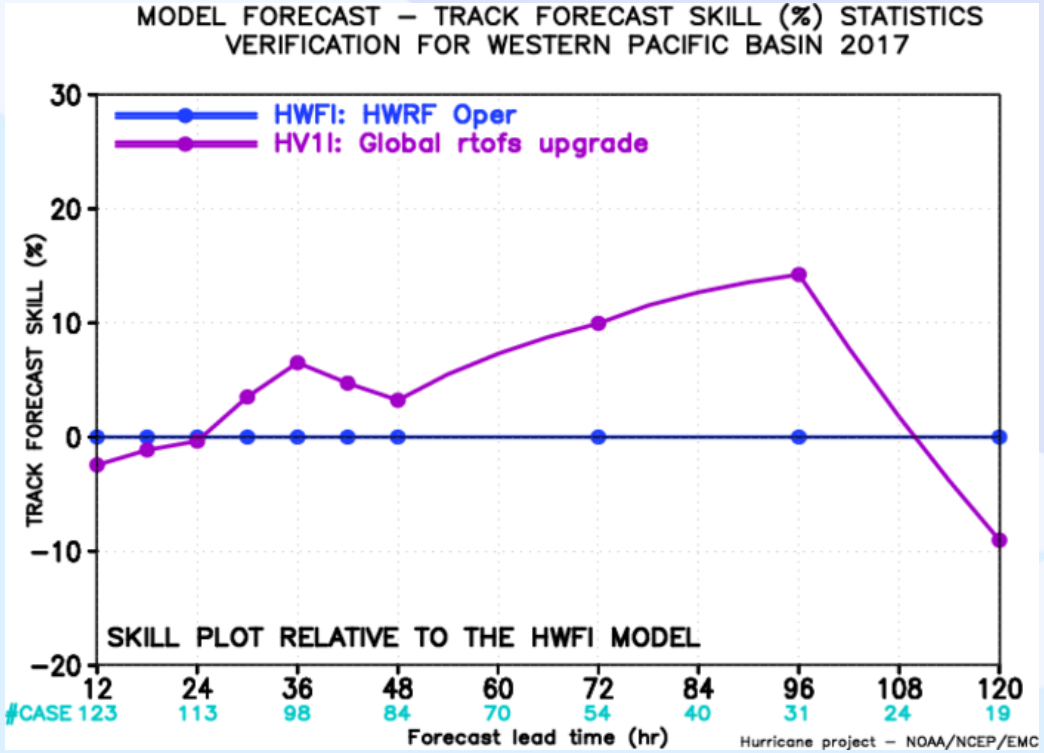
Primary upgrades:

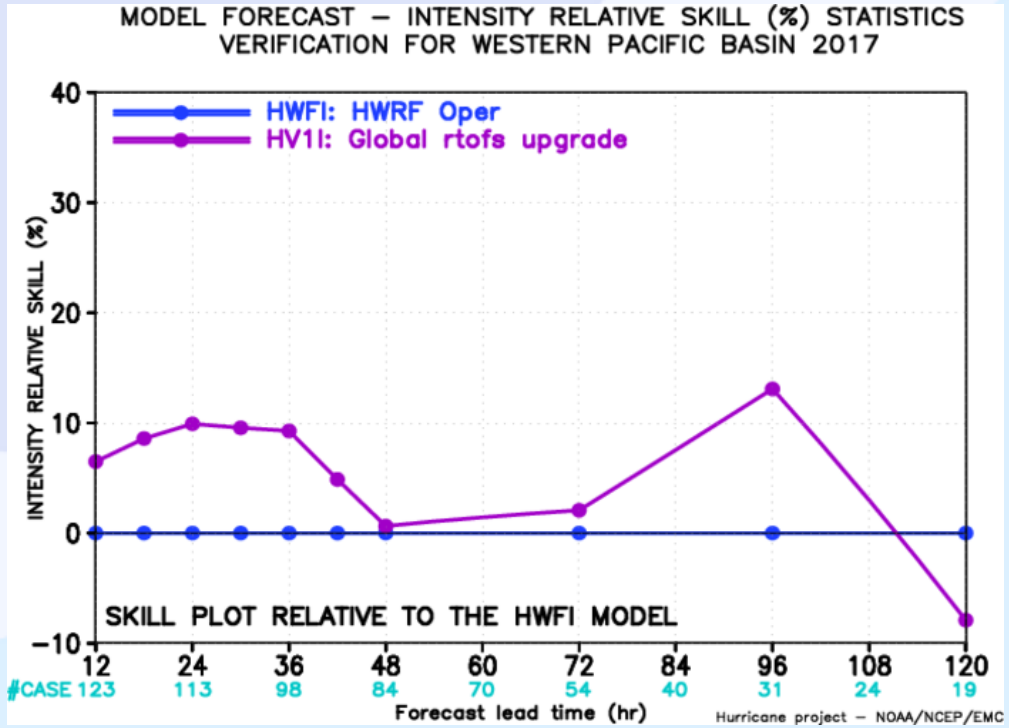
- 41 hybrid layers (increased from 32 layers), iso-levels mostly in the top 200m
- Improved bathymetry which allows better representation of shallow points (minimum depth 5m)
- Updated climatology fields from GDEM 3 to GDEM 4
- An updated equation of state (17 terms vs 9 terms)
- Source code upgrades allow for coupling of other components, ESMF, portable software
- NCODA changes: new observations, sub-surface projections of SSH

- **Two-way coupled HYCOM with Los Alamos CICE v4 (Community Ice CodE) (which replaces Energy-Loan Sea-Ice model)**
  - **1 hour coupling frequency**
  - **Using ESMF v4.0 (non-NUOPC)**

Developed fully at US Navy (GOFS 3.1) with independent validations by operational Navy.

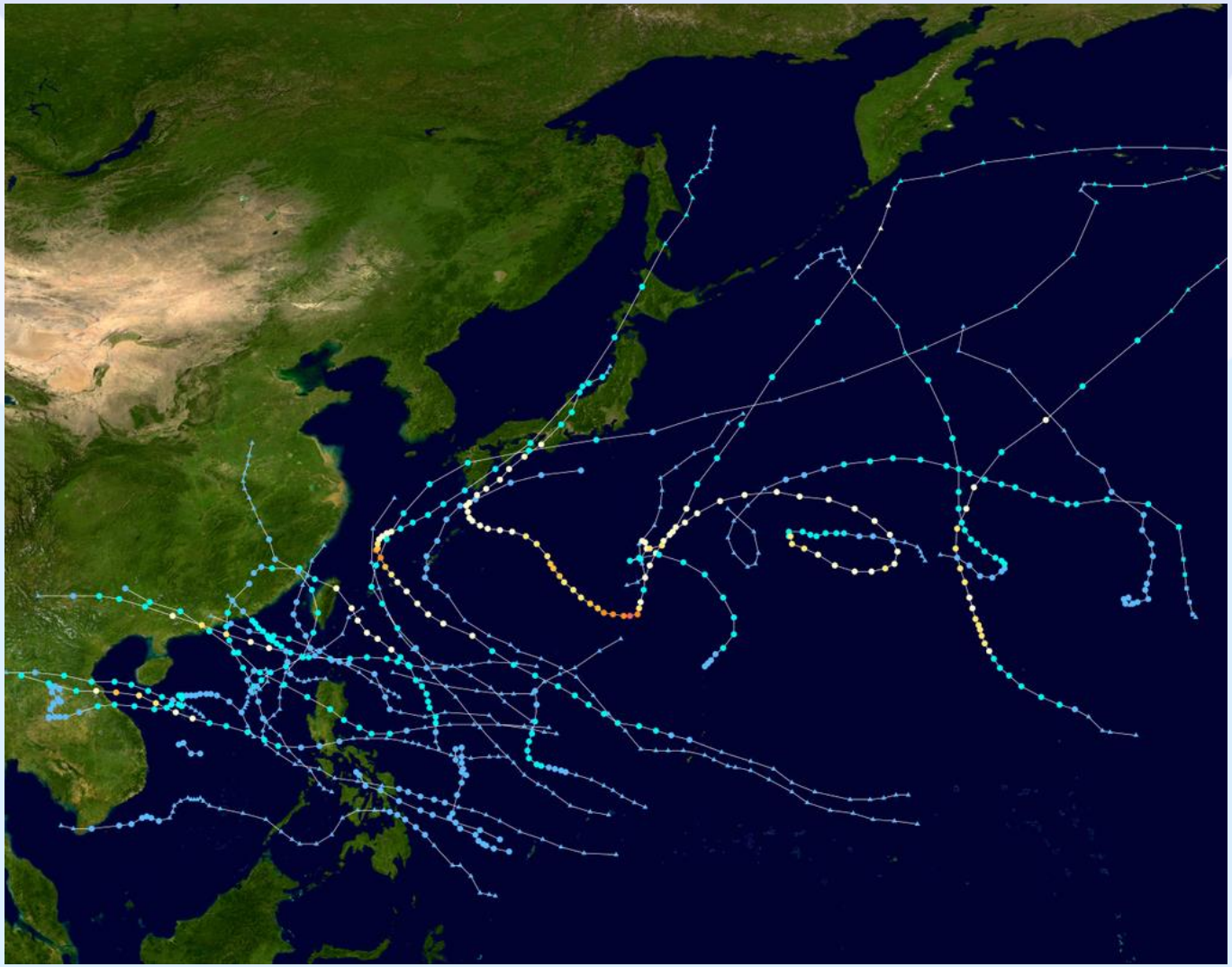
Track and intensity skills for WPAC storms (early model)



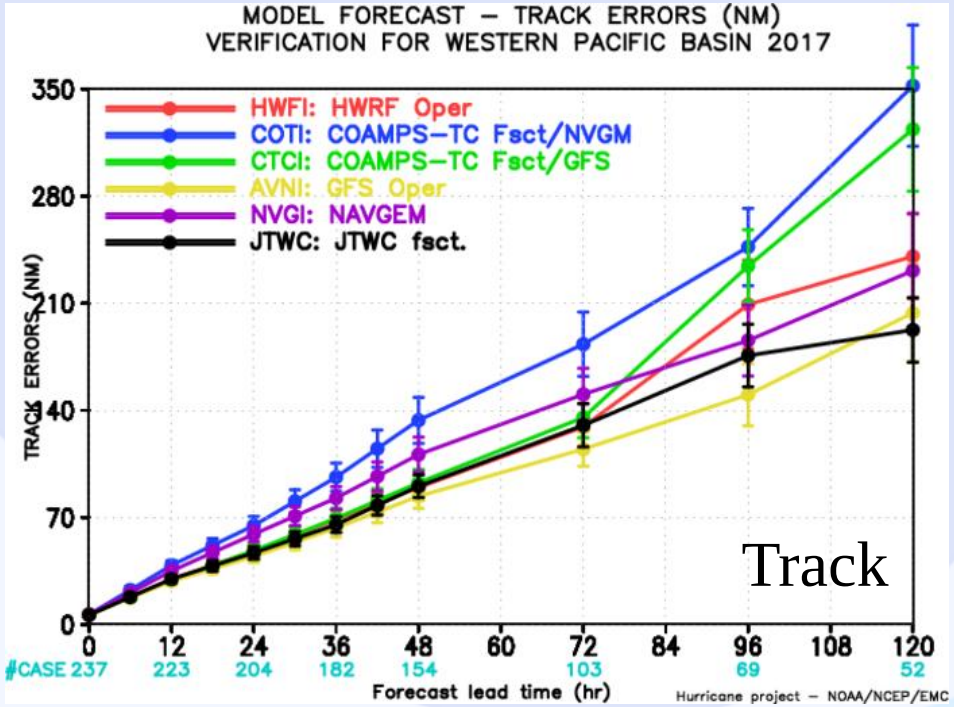


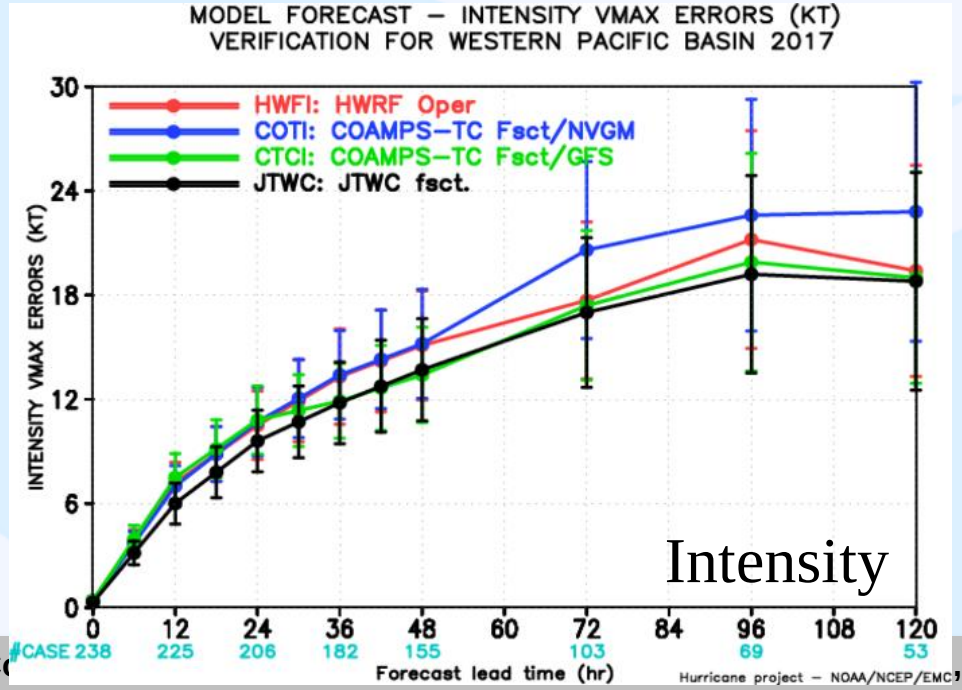
- The track skill for HV1I is significantly improved (> 10% on Day 4).
- Intensity skill is mostly positive except for Day 5, neutral overall.

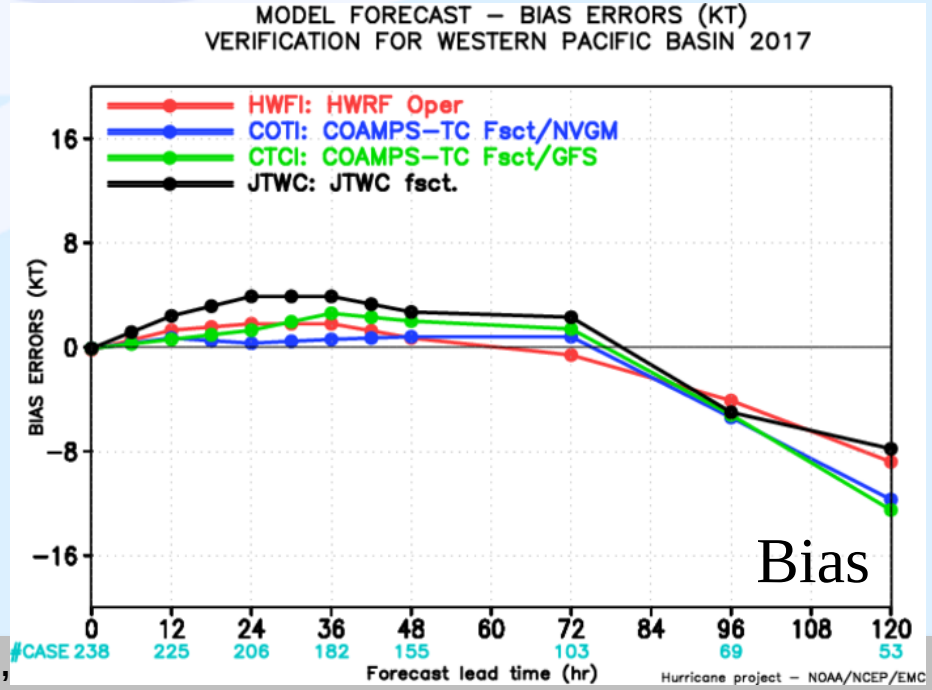
Western Pacific Basin 2017



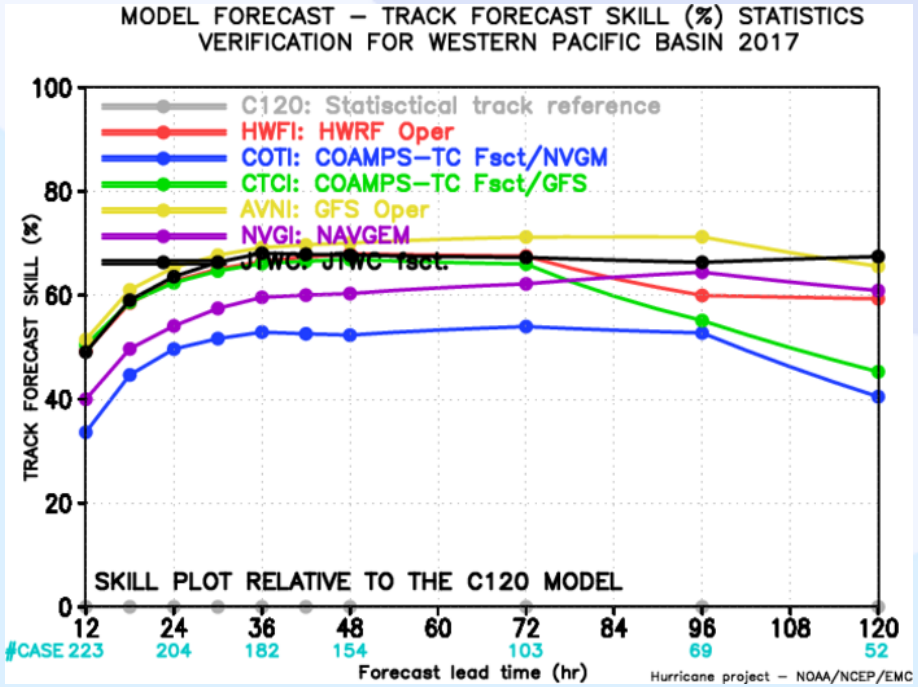
Early model

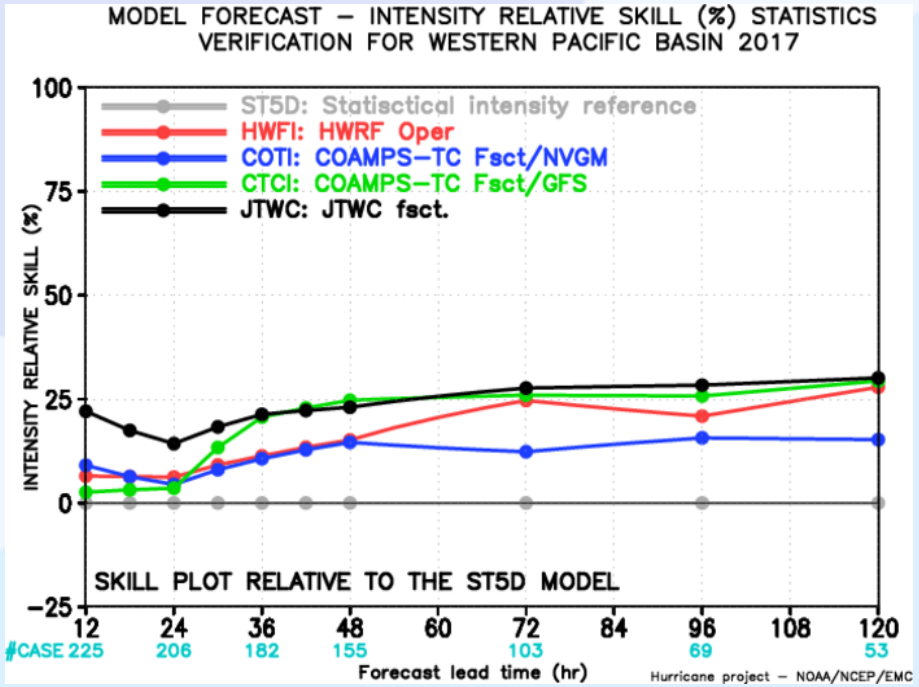

MODEL FORECAST – TRACK ERRORS (NM)
VERIFICATION FOR WESTERN PACIFIC BASIN 2017
HWFI: HWRF Oper
COTI: COAMPS–TC Fsct/NVGM
CTCI: COAMPS–TC Fsct/GFS
AVNI: GFS Oper
NVGI: NAVGEM
JTWC: JTWC fsct.
TRACK ERRORS (NM)
0
70
140
210
280
350
0 12 24 36 48 60 72 84 96 108 120
#CASE 237 223 204 182 154 103 69 52
Forecast lead time (hr)
Hurricane project – NOAA/NCEP/EMC
Track


MODEL FORECAST – INTENSITY VMAX ERRORS (KT)
VERIFICATION FOR WESTERN PACIFIC BASIN 2017
HWFI: HWRF Oper
COTI: COAMPS–TC Fsct/NVGM
CTCI: COAMPS–TC Fsct/GFS
JTWC: JTWC fsct.
INTENSITY VMAX ERRORS (KT)
0
6
12
18
24
30
0 12 24 36 48 60 72 84 96 108 120
#CASE 238 225 206 182 155 103 69 53
Forecast lead time (hr)
Hurricane project – NOAA/NCEP/EMC
Intensity

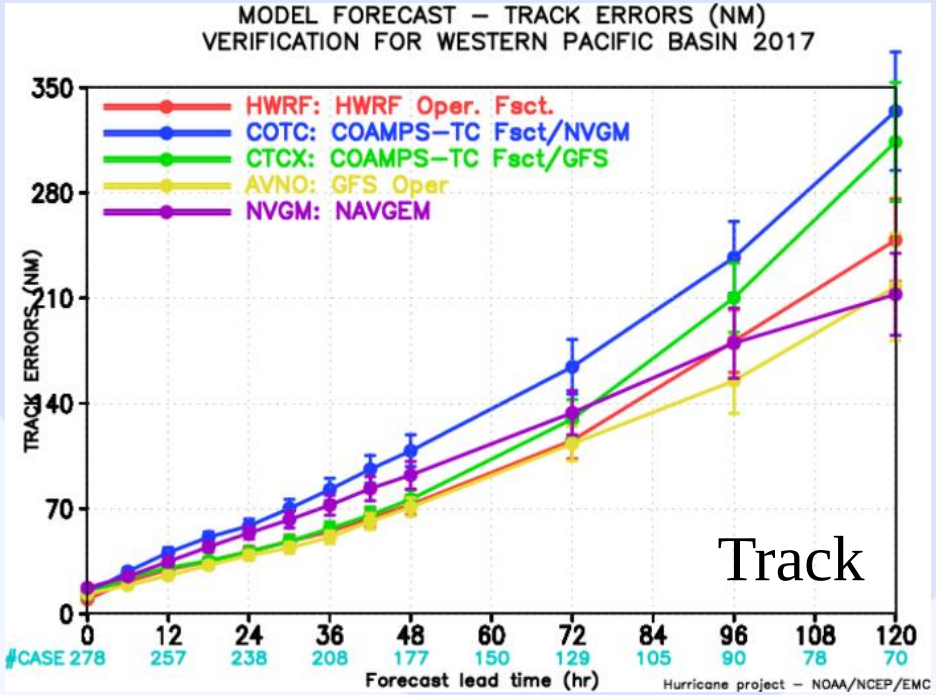

MODEL FORECAST – BIAS ERRORS (KT)
VERIFICATION FOR WESTERN PACIFIC BASIN 2017
HWFI: HWRF Oper
COTI: COAMPS–TC Fsct/NVGM
CTCI: COAMPS–TC Fsct/GFS
JTWC: JTWC fsct.
BIAS ERRORS (KT)
−16
−8
0
8
16
0 12 24 36 48 60 72 84 96 108 120
#CASE 238 225 206 182 155 103 69 53
Forecast lead time (hr)
Hurricane project – NOAA/NCEP/EMC
Bias

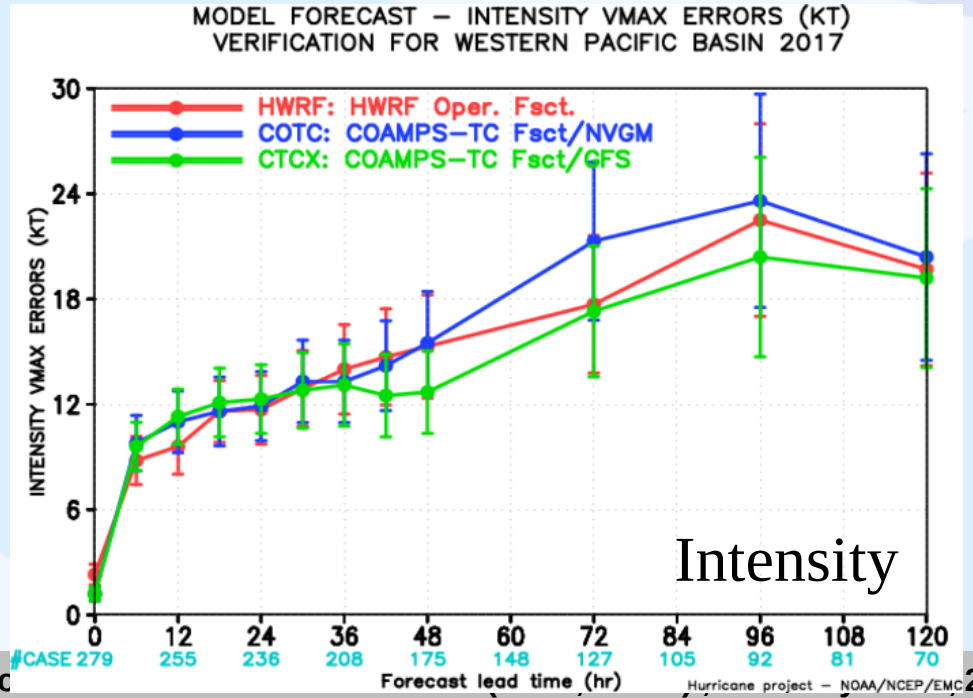
early models skill plots

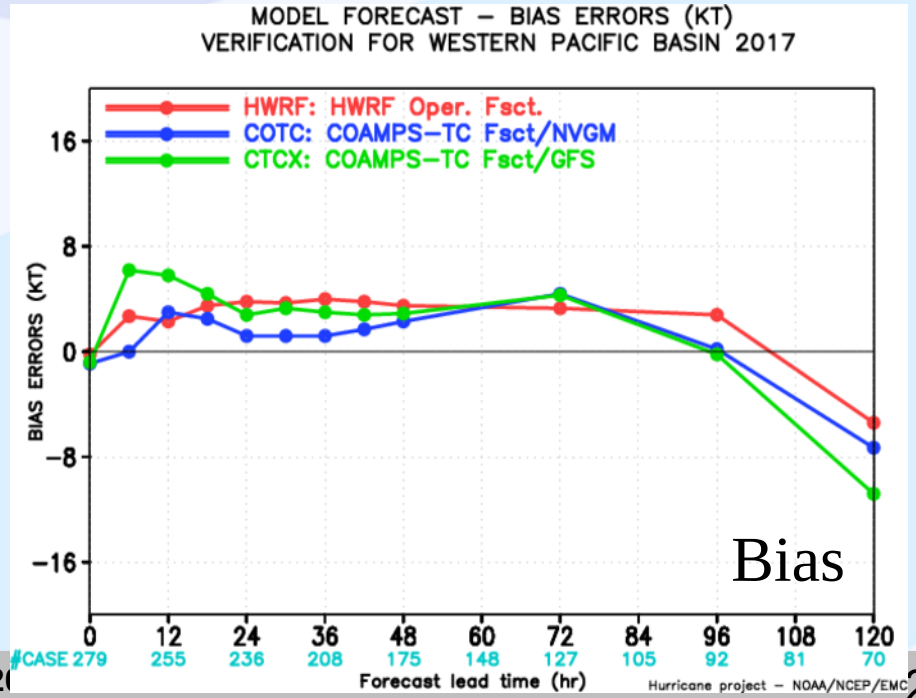




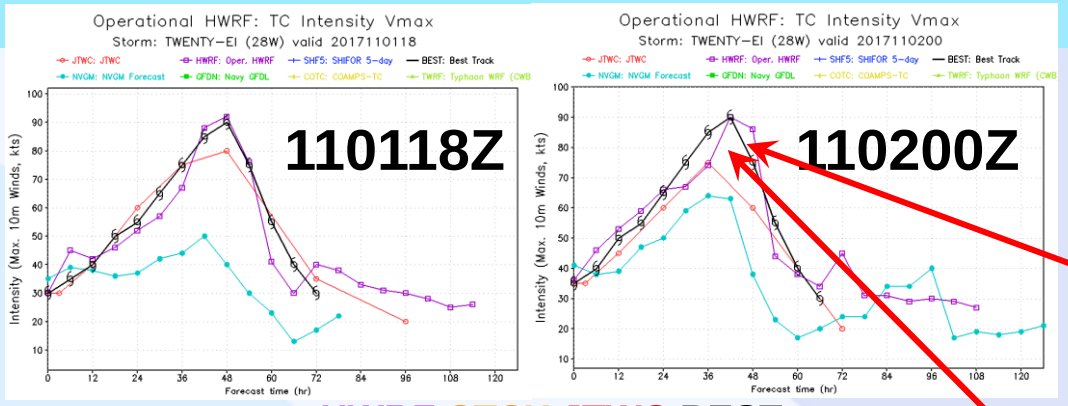
Late model


MODEL FORECAST – TRACK ERRORS (NM)
VERIFICATION FOR WESTERN PACIFIC BASIN 2017
HWRF: HWRF Oper. Fsct.
COTC: COAMPS–TC Fsct/NVGM
CTCX: COAMPS–TC Fsct/GFS
AVNO: GFS Oper
NVGM: NAVGEM
TRACK ERRORS (NM)
350
280
210
140
70
0
#CASE 278 257 238 208 177 150 129 105 90 78 70
0 12 24 36 48 60 72 84 96 108 120
Forecast lead time (hr)
Hurricane project – NOAA/NCEP/EMC
Track

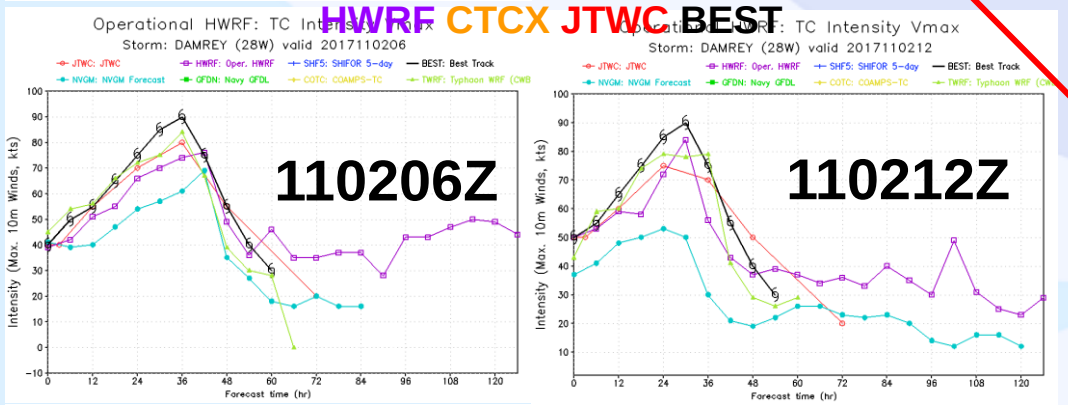

MODEL FORECAST – INTENSITY VMAX ERRORS (KT)
VERIFICATION FOR WESTERN PACIFIC BASIN 2017
HWRF: HWRF Oper. Fsct.
COTC: COAMPS–TC Fsct/NVGM
CTCX: COAMPS–TC Fsct/GFS
INTENSITY VMAX ERRORS (KT)
30
24
18
12
6
0
#CASE 279 255 236 208 175 148 127 105 92 81 70
0 12 24 36 48 60 72 84 96 108 120
Forecast lead time (hr)
Hurricane project – NOAA/NCEP/EMC
Intensity

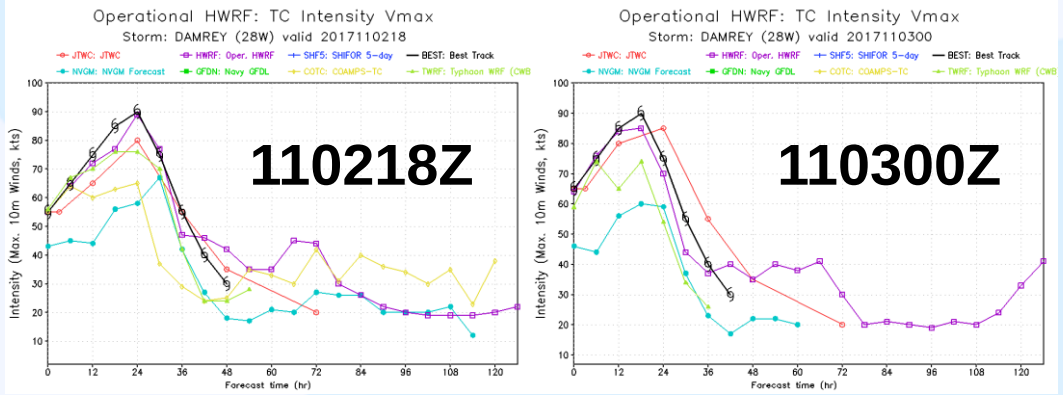

MODEL FORECAST – BIAS ERRORS (KT)
VERIFICATION FOR WESTERN PACIFIC BASIN 2017
HWRF: HWRF Oper. Fsct.
COTC: COAMPS–TC Fsct/NVGM
CTCX: COAMPS–TC Fsct/GFS
BIAS ERRORS (KT)
16
8
0
–8
–16
#CASE 279 255 236 208 175 148 127 105 92 81 70
0 12 24 36 48 60 72 84 96 108 120
Forecast lead time (hr)
Hurricane project – NOAA/NCEP/EMC
Bias

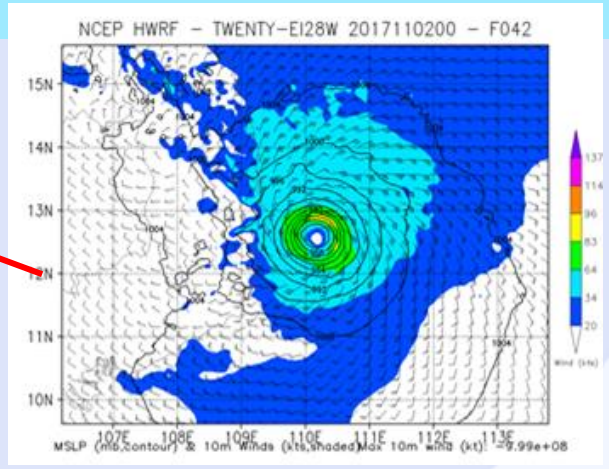
HWRF Forecast for Typhoon Damrey (28W)

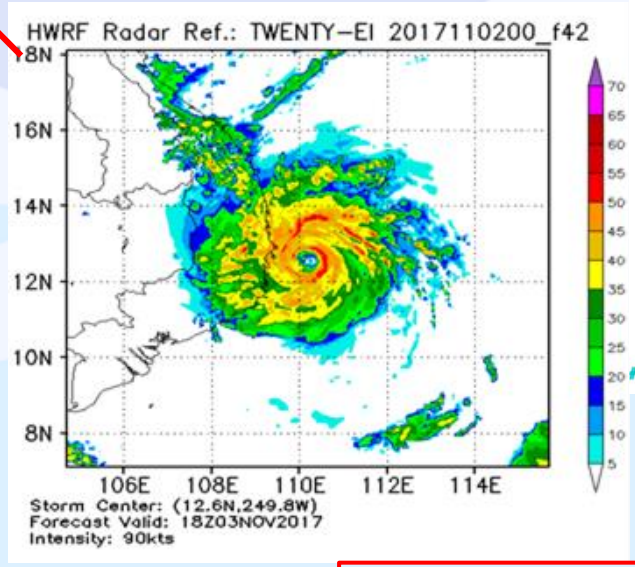


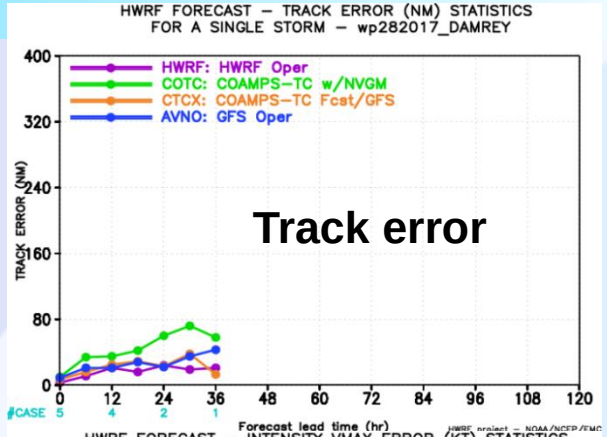
HWRF CTCX JTWC BEST

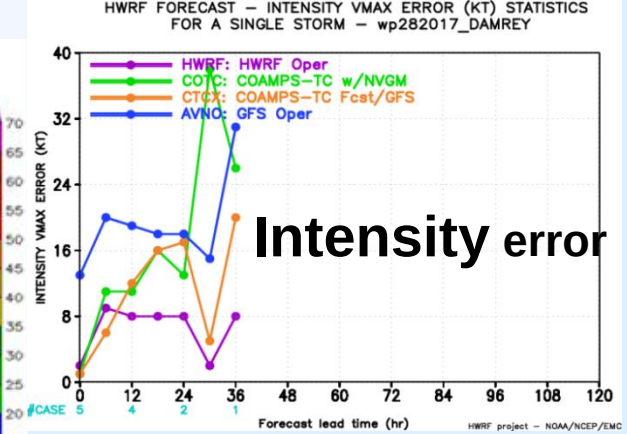












Very good track forecast
Phenomenal intensity forecast

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

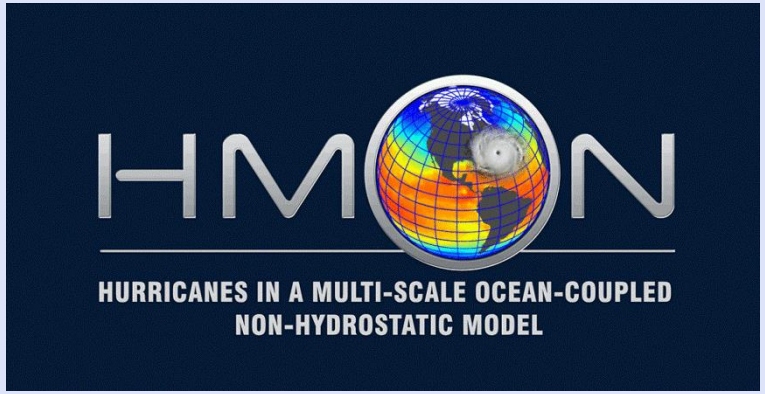
Continue the community modeling approach for accelerated transition of research to operations

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT

NATIONAL HURRICANE CENTER

Japan Meteorological Agency

International partnerships for accelerated model development & research



2017 HMON V1.0.0

(A new Operational Hurricane Model at NCEP)

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

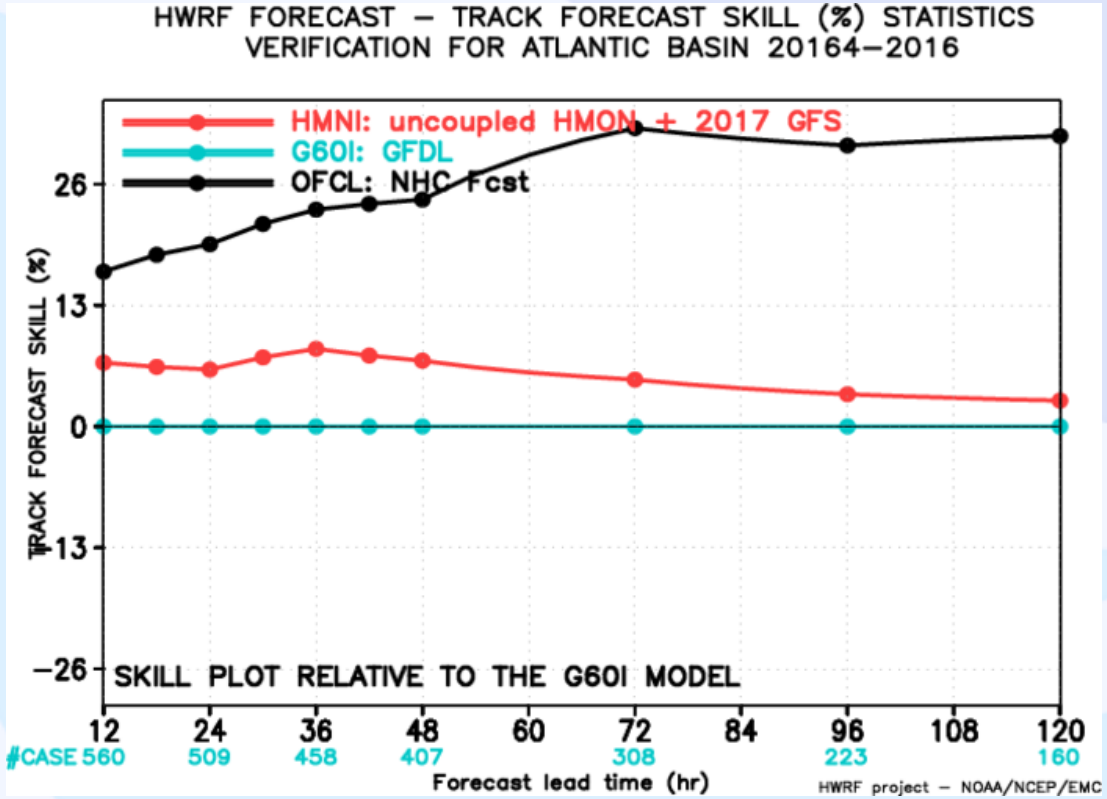
Development supported by NGGPS, HFIP and HIWPP programs

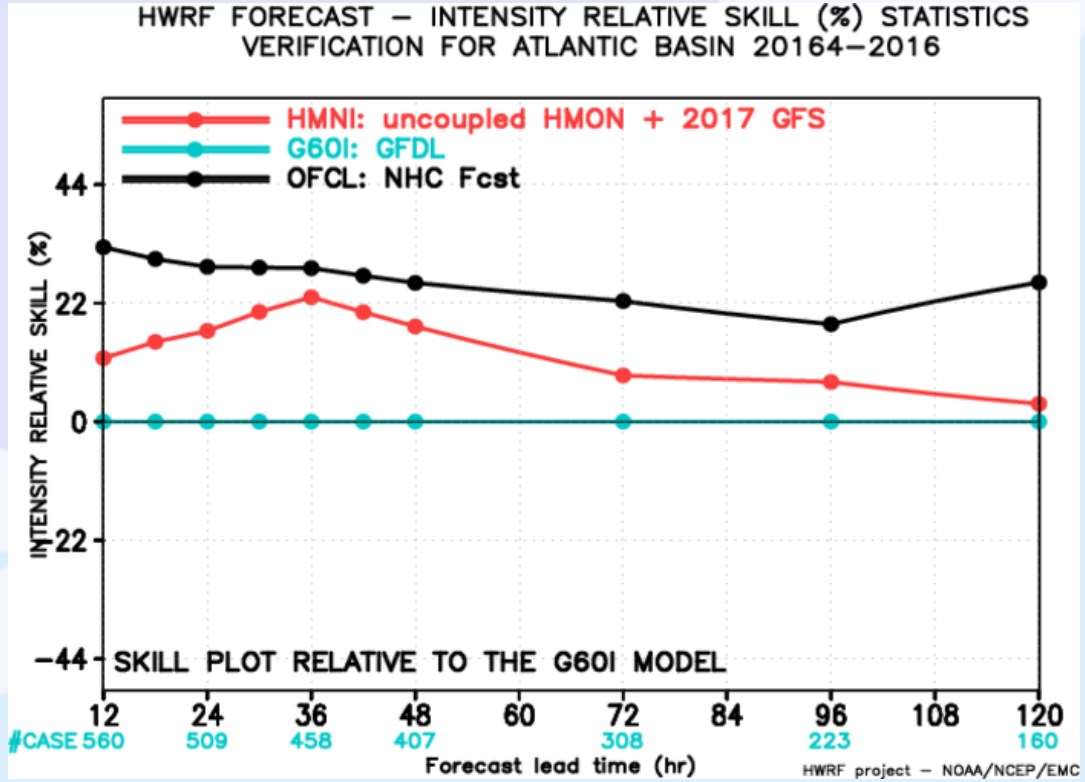
Provides high-resolution intensity forecast guidance to NHC along with HWRF (replacing the legacy GFDL hurricane model)

HWRF vs GFDL vs HMON
(Maintain Diversity of Hurricane Numerical Guidance)

	2017 HWRF	2016 GFDL	2017 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

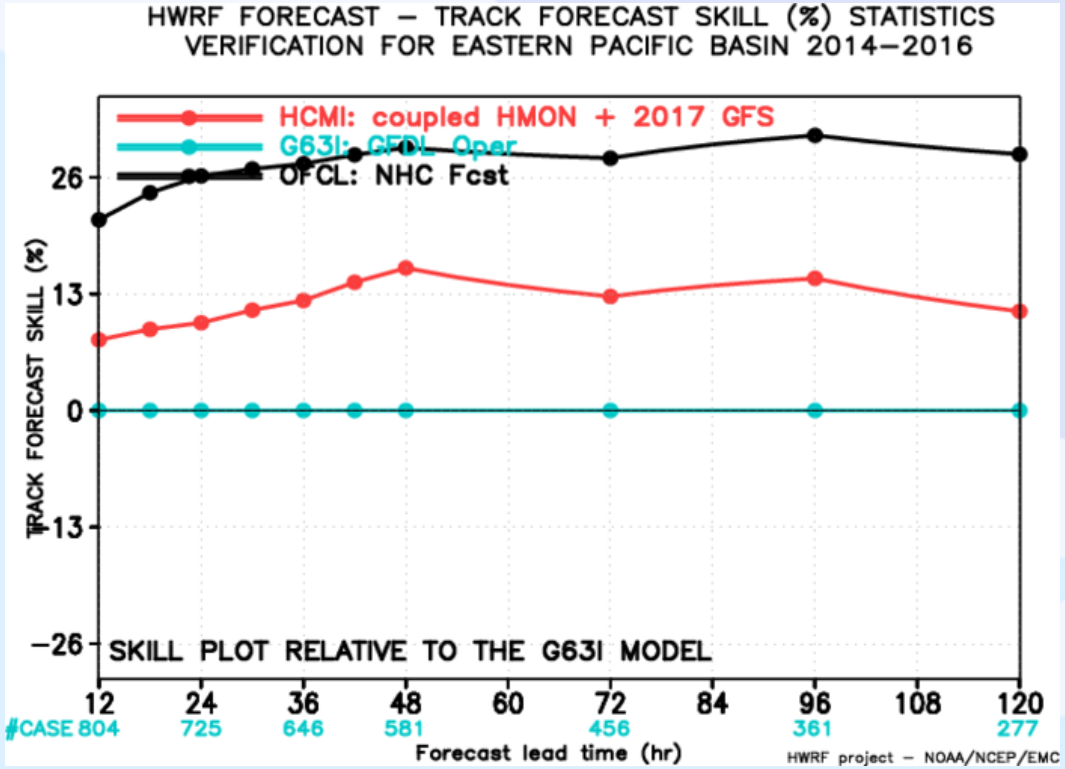
2014-16 Atlantic Basin: Relative to GFDL (Interpolated)

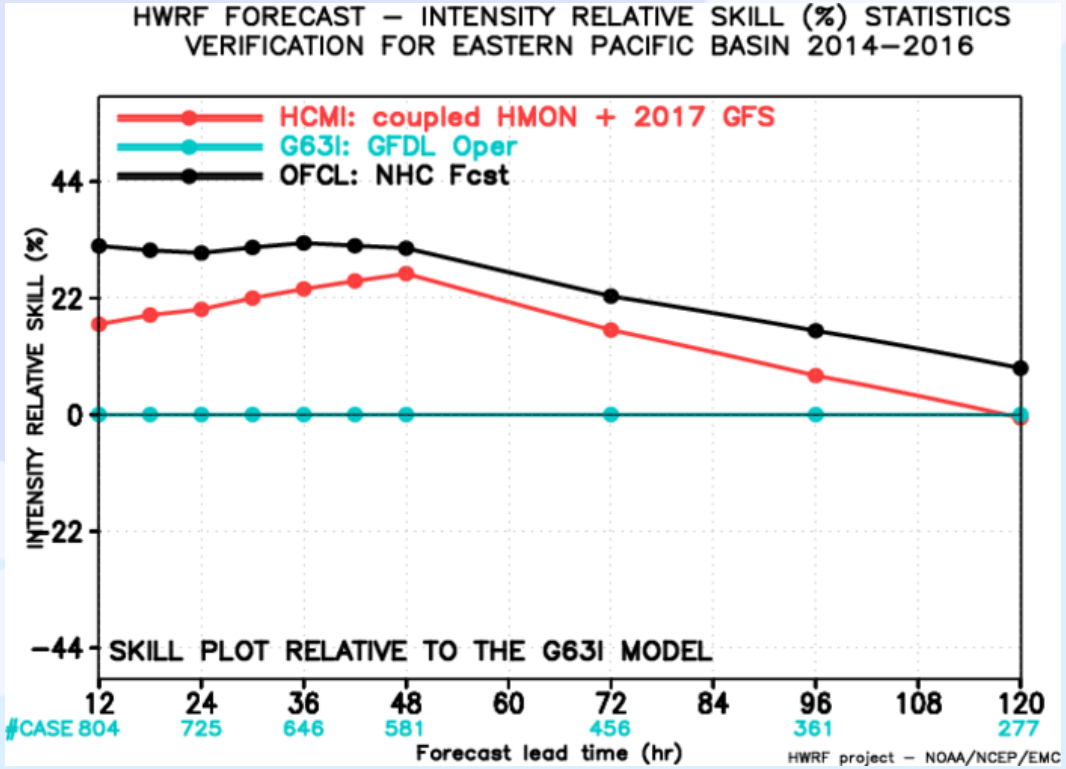




HMON has improved track skills as compared to GFDL at all lead times with an average improvement of more than 5%. It also has improved intensity skills with a mean improvement of >10%. Both tracks and intensity need to close gap with the official skill.

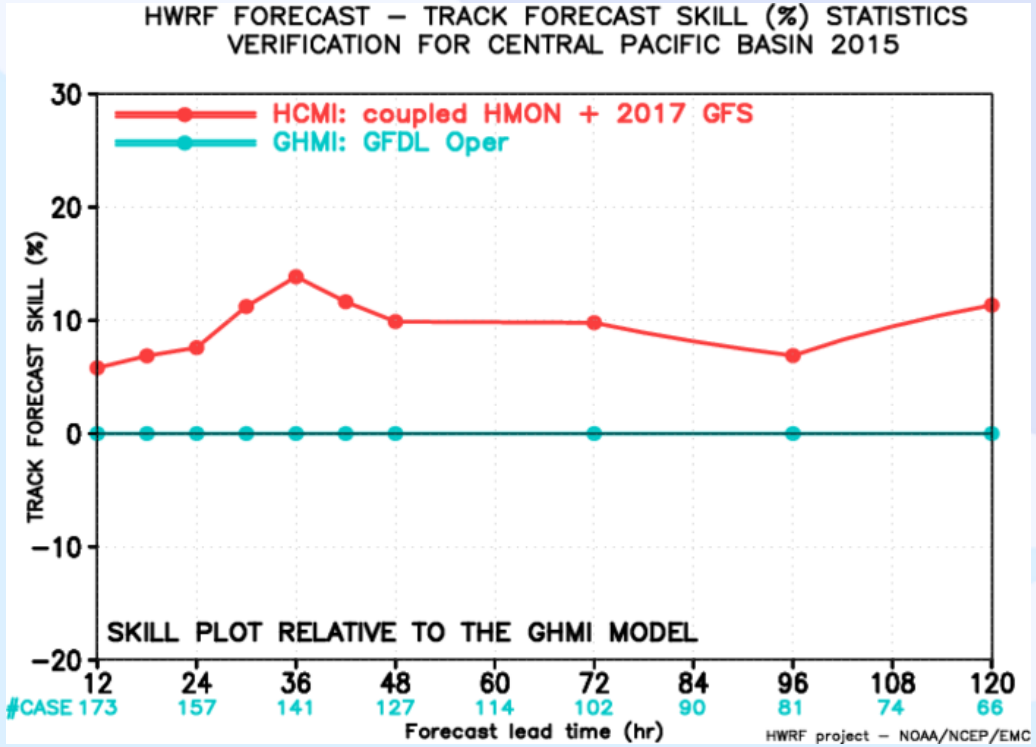
2014-16 East Pacific Basin: Relative to GFDL (Interpolated)

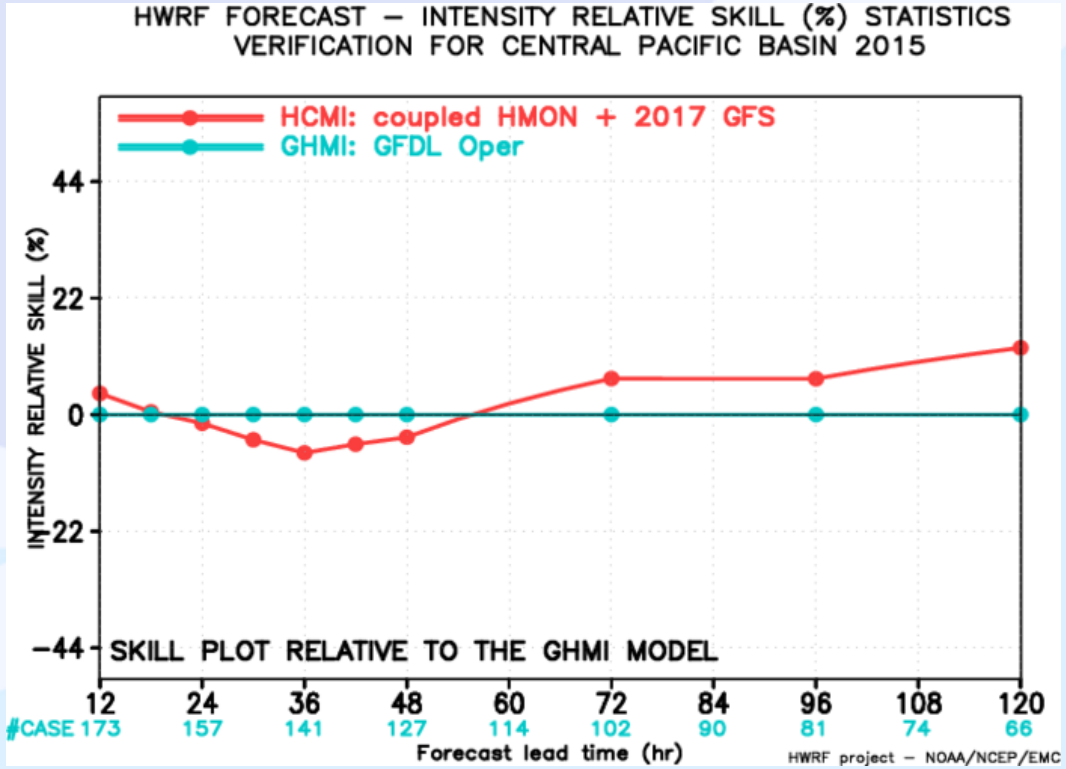




HMON has improved track and intensity skills as compared to GFDL but still needs to close gap with official skill especially for longer lead times for intensity.

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.

Potential FY18 HWRF Upgrades

System & Resolution Enhancements

- Increase domain size (d01, d02, d03) with 18/6/2 km configuration

or

- 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**

Physics Advancements

- Improve radiation, scale aware convection, surface exchange coefficients
- Improve EDMF PBL, test YSU PBL

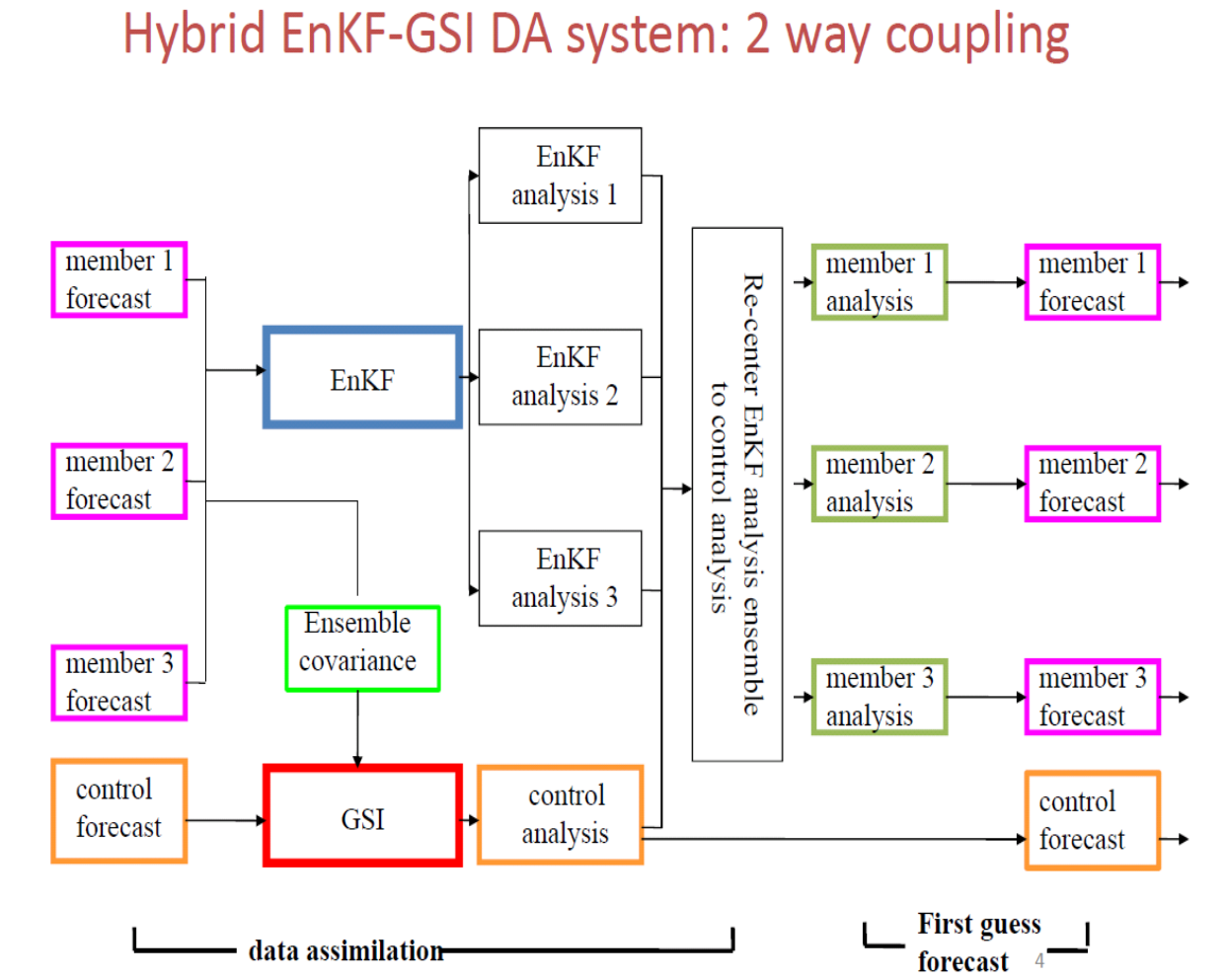
Data Assimilation & Initialization Improvements

- Stochastic physics for DA ensembles
- GSI code upgrades; add new data sets (GOES-16 AMV's, SFMR, TDR from G-IV)
- Use full ensemble covariances
- **Extend DA to Western Pacific Basin**

Coupling and other upgrades

- Unified HMON/HWRF coupler
- Extend fully Cycled EnKF two-way hybrid DA to 2 storms
- Add ocean coupling (HYCOM) for Southern Hemisphere basins

2018 Data Assimilation Upgrades (NATL and EPAC)



Advanced self-cycled HWRF EnKF-GSI Hybrid Data Assimilation System (HDAS)
Extend it to two priority storms for 2018

Scope of FY18 HMON Upgrades

➢System & Resolution Enhancements

- Upgrade to the latest NMMB dynamic core
- Add Vertical levels, revise nest domain sizes
- NMMB dycore optimization (IBM analyst)

➢Initialization/Data Assimilation Improvements

- Updated composite vortex
- Change co-ordinates for VI
- Use HWRF initialization

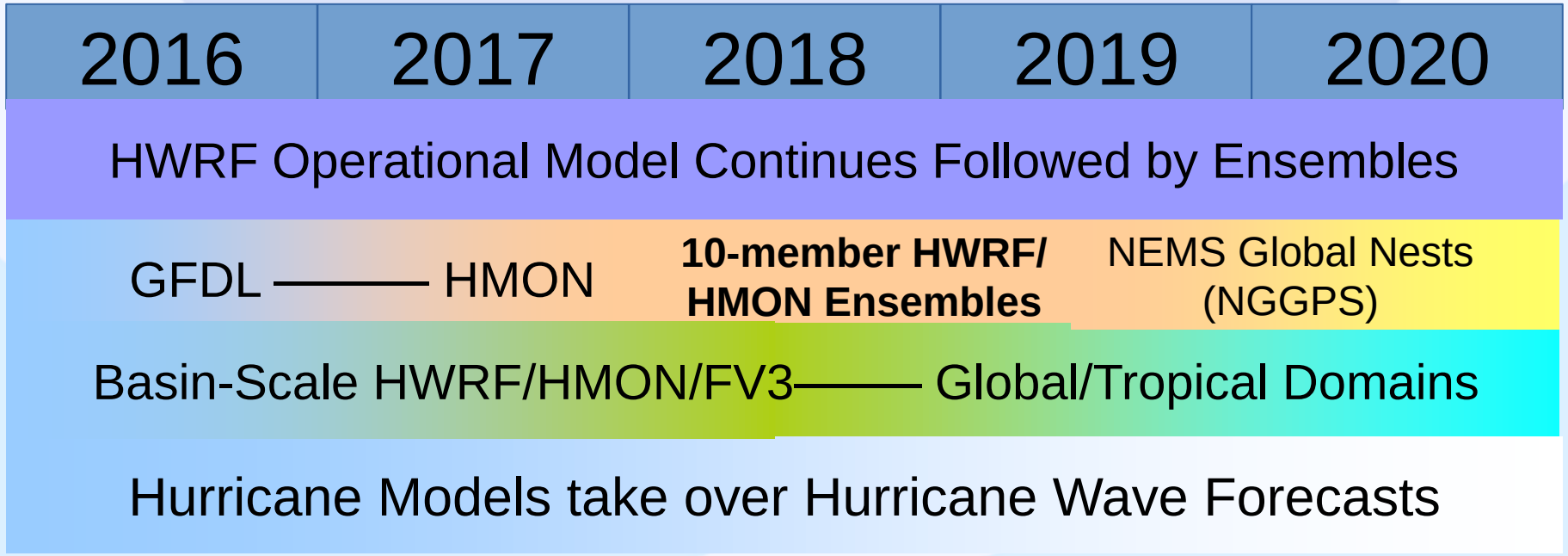
➢Physics Advancements

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

➢ Coupling Upgrades

- Add HYCOM coupling in NATL basin

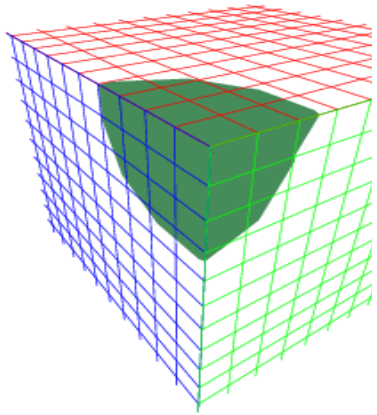
HWRF/HMON Long-Term Plans

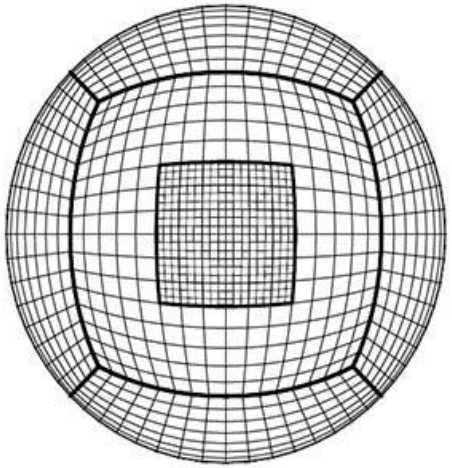


Development, T&E and Implementation Plans for HWRF & HMON

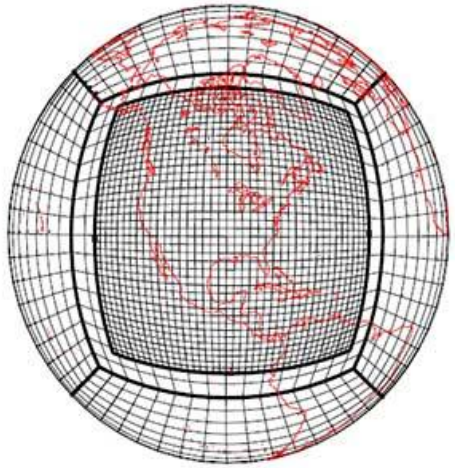
- 2017 Nov: Configuration ready
- 2017 Dec- 2018 March: Pre-implementation retrospective testing
- 2018 April: EMC CCB and code hand-off
- 2018 June: Operational Implementation

Tropical Cyclone Forecasts in FV3

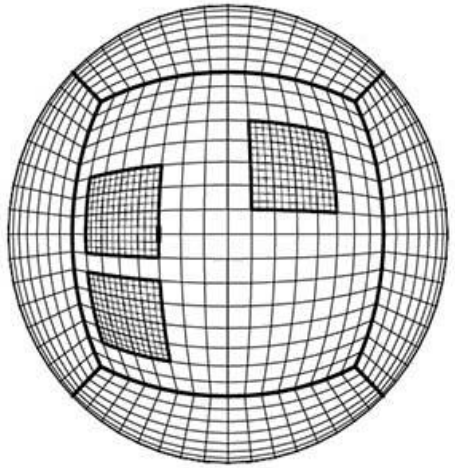




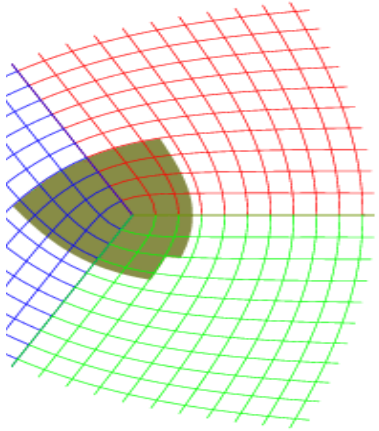
3:1 nested grid

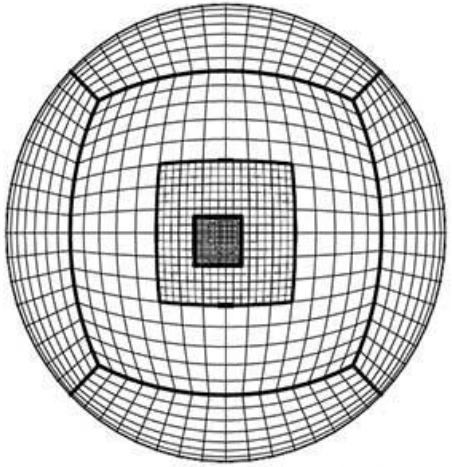


Large nest for RCMs

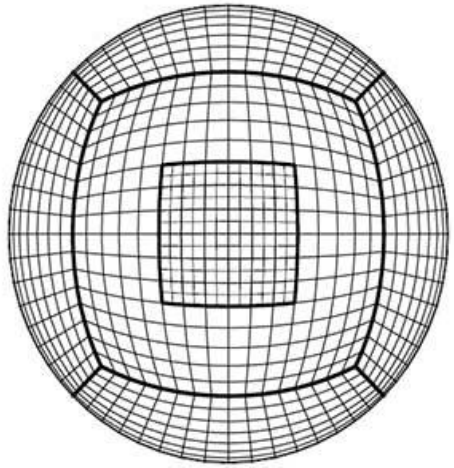


Multiple nests

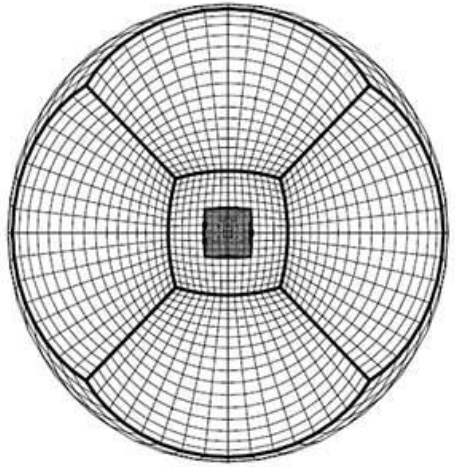




Telescoping nests

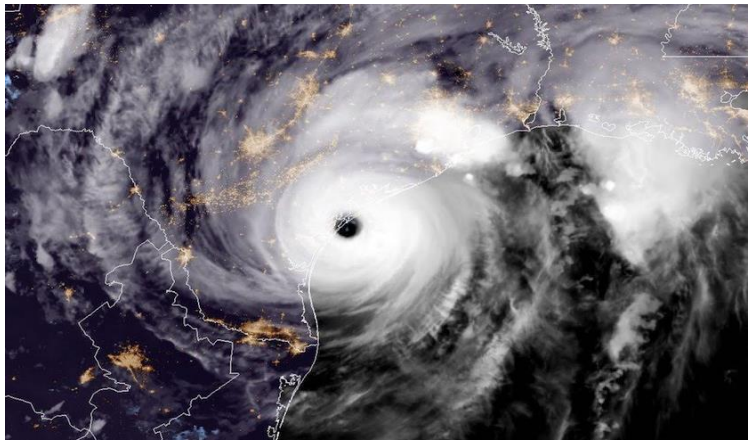


2:1 nested grid



Nest in stretched grid

Hurricanes:



Two FV3 configurations:

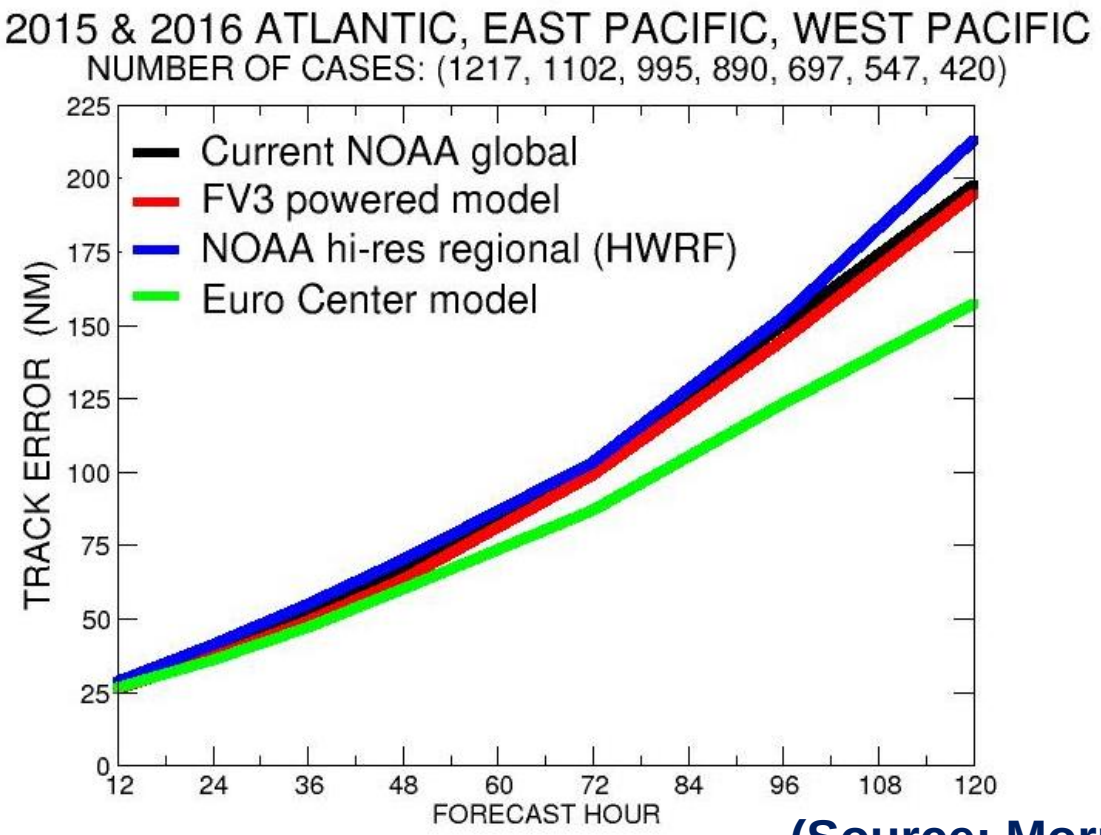
1. **The standard (uniform resolution) C768L63**
2. **Stretched C768L63 with a 3-km Atlantic Basin nest**

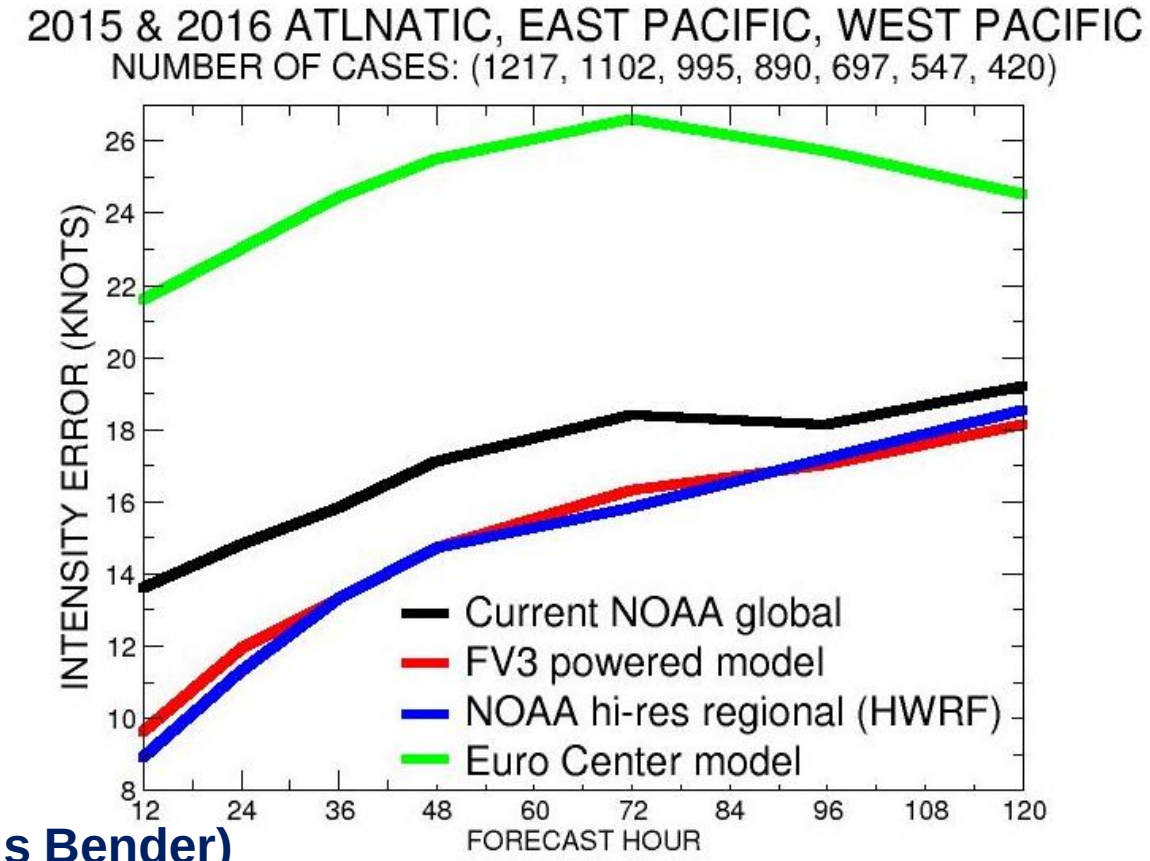
Both configurations running quasi-real-time on Jet (Gaea as the backup)

Courtesy: Morris Bender, Andrew Hazelton, Lucas Harris and SJ Lin

Statistics for 2-year period: 2015 & 2016

C768L63 (13-km) for all basins



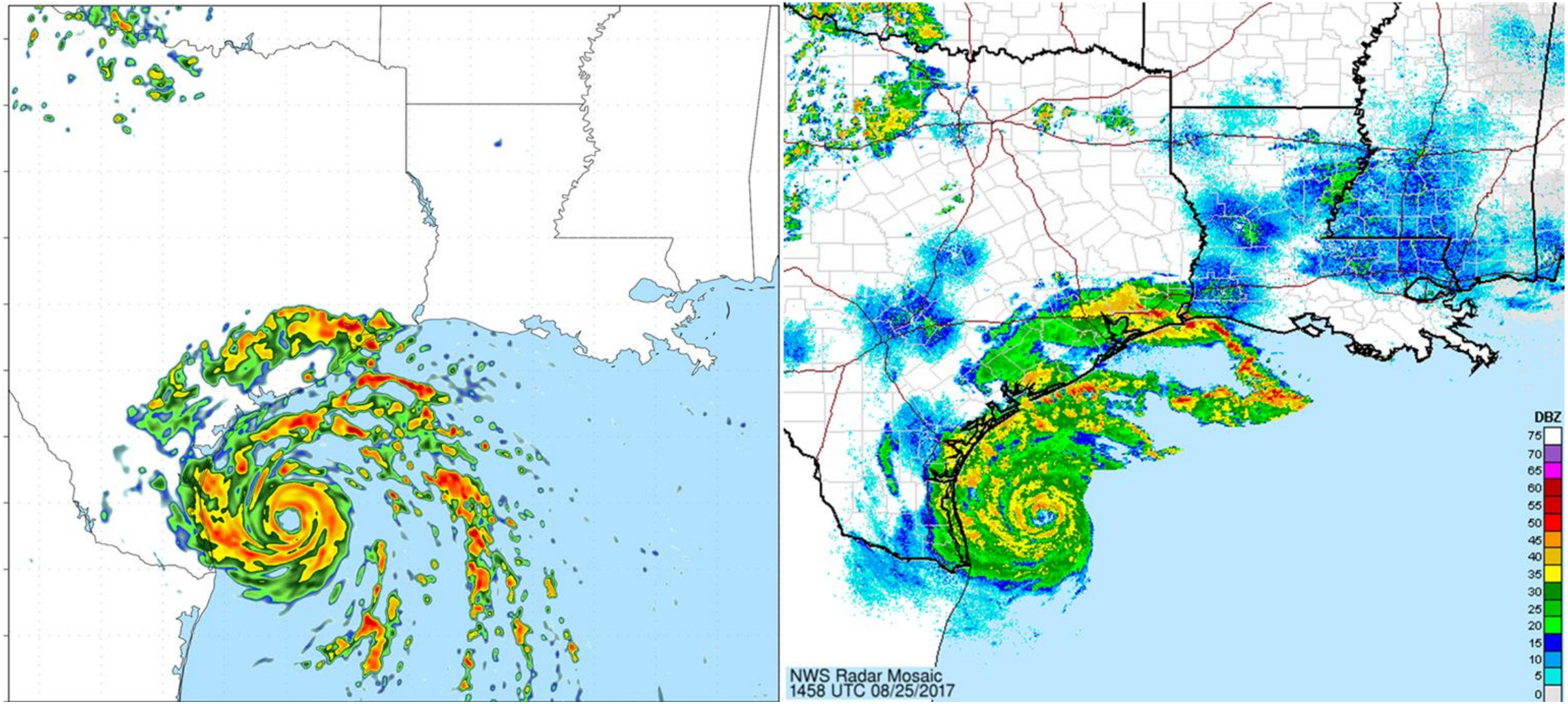


(Source: Morris Bender)

Intensity skill is as good as HWRF

Forecast Reflectivity Structure vs. NEXRAD Observations

fvGFS Initialized 18 UTC August 24, 2017
21-hour Forecast Radar Reflectivity (Left)
and Observed Ground-Based NEXRAD Radar (Right) at 15 UTC (10 AM CDT) August 25, 2017

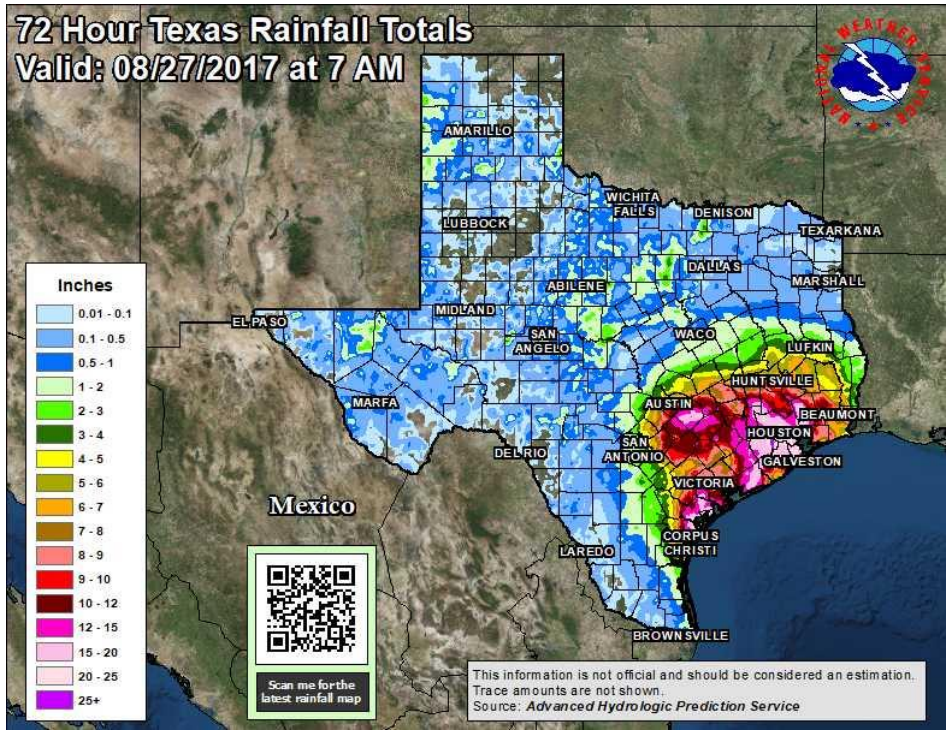


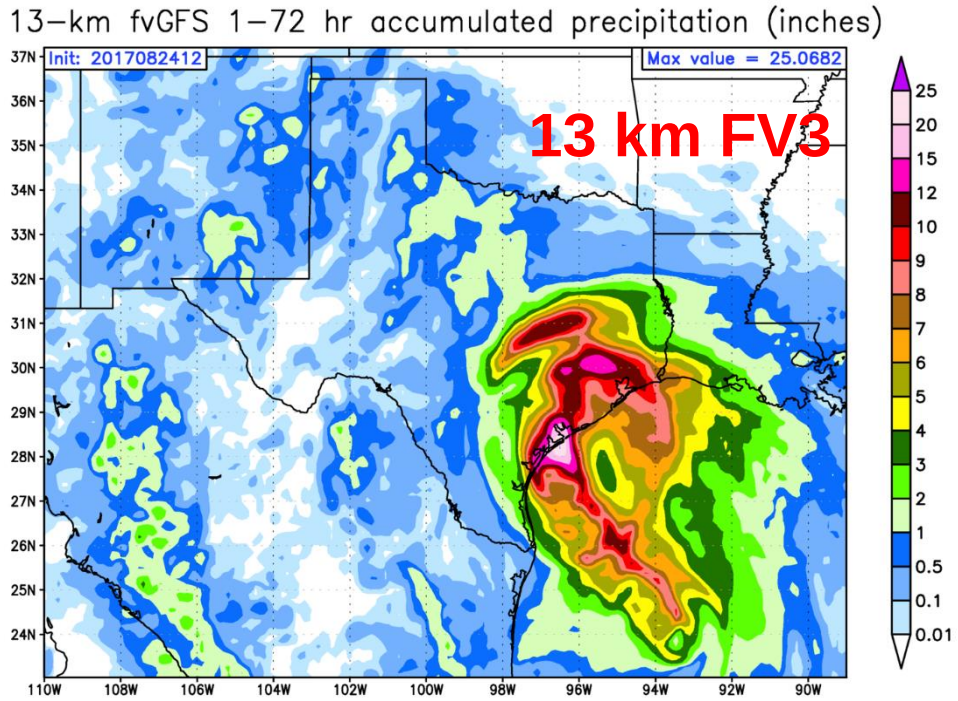
(Source: Andrew Hazelton)

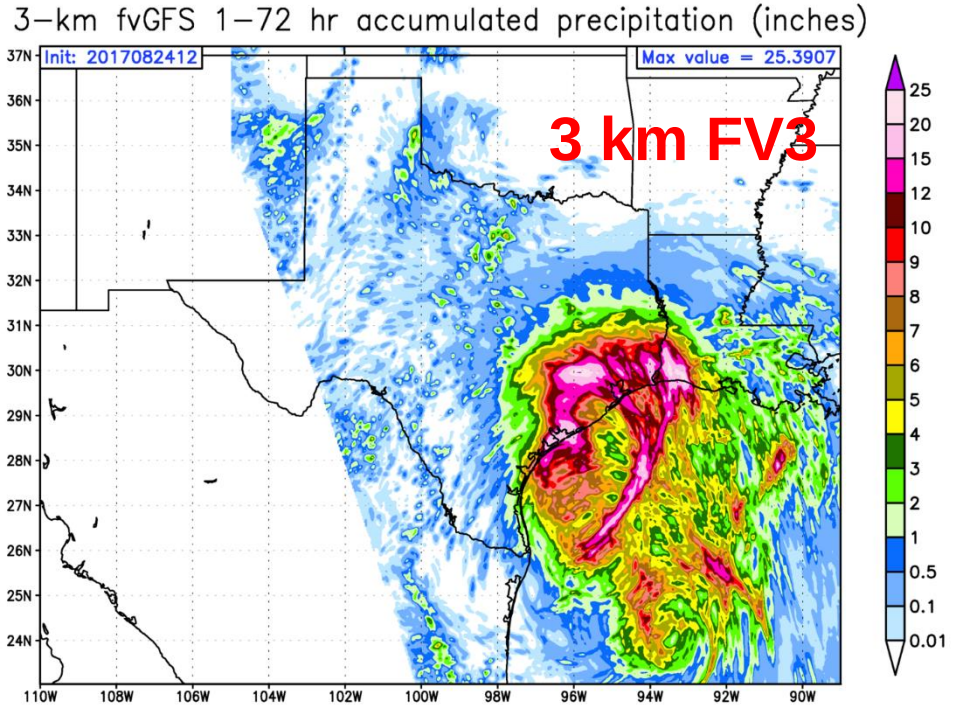
Precipitation Verifications in Inches

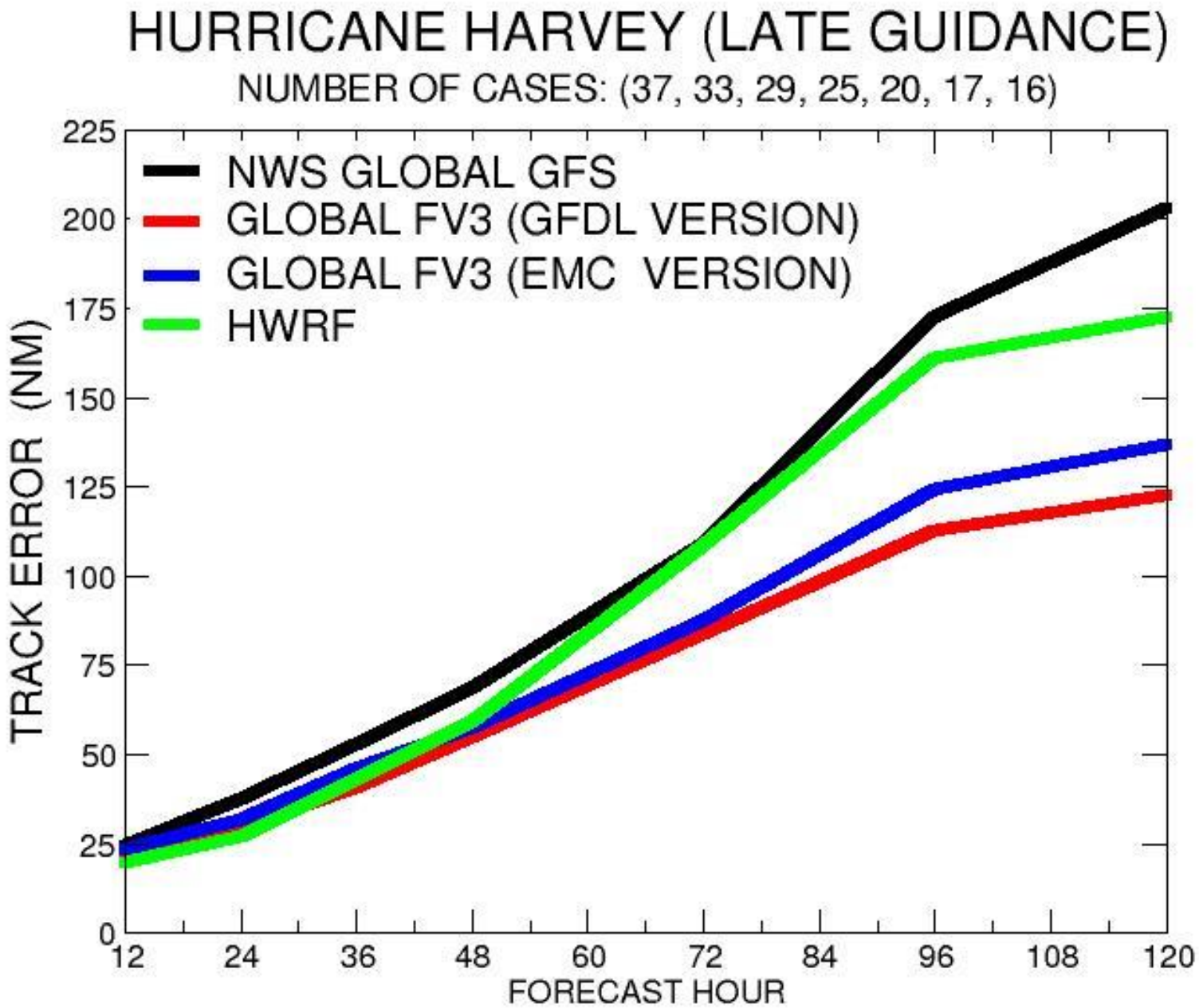
(from Thursday 8am through Sunday 8am)
INIT: 2017082412

OBSERVED 72h PRECIPITATION TOTALS

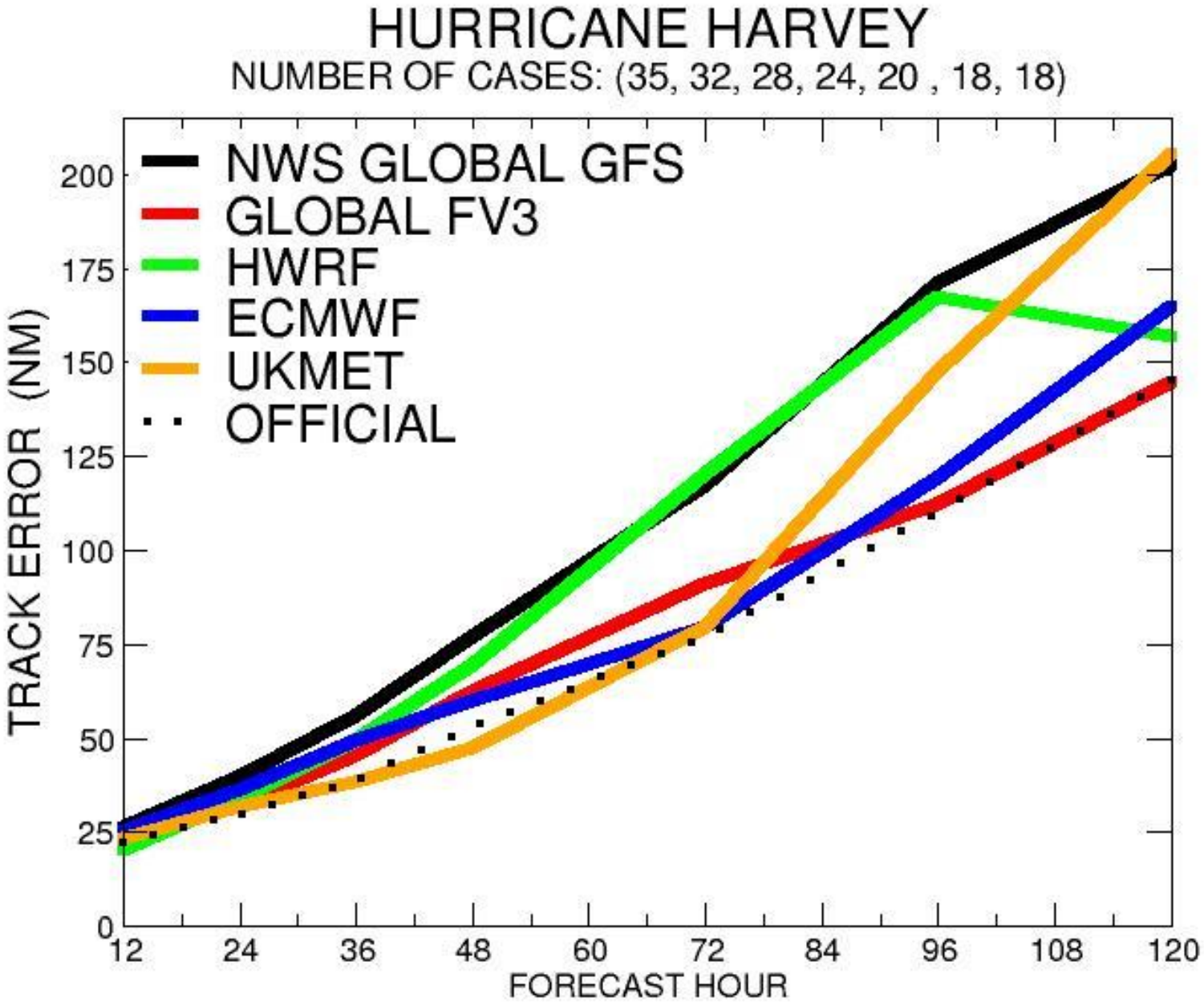








(Source: Morris Bender)

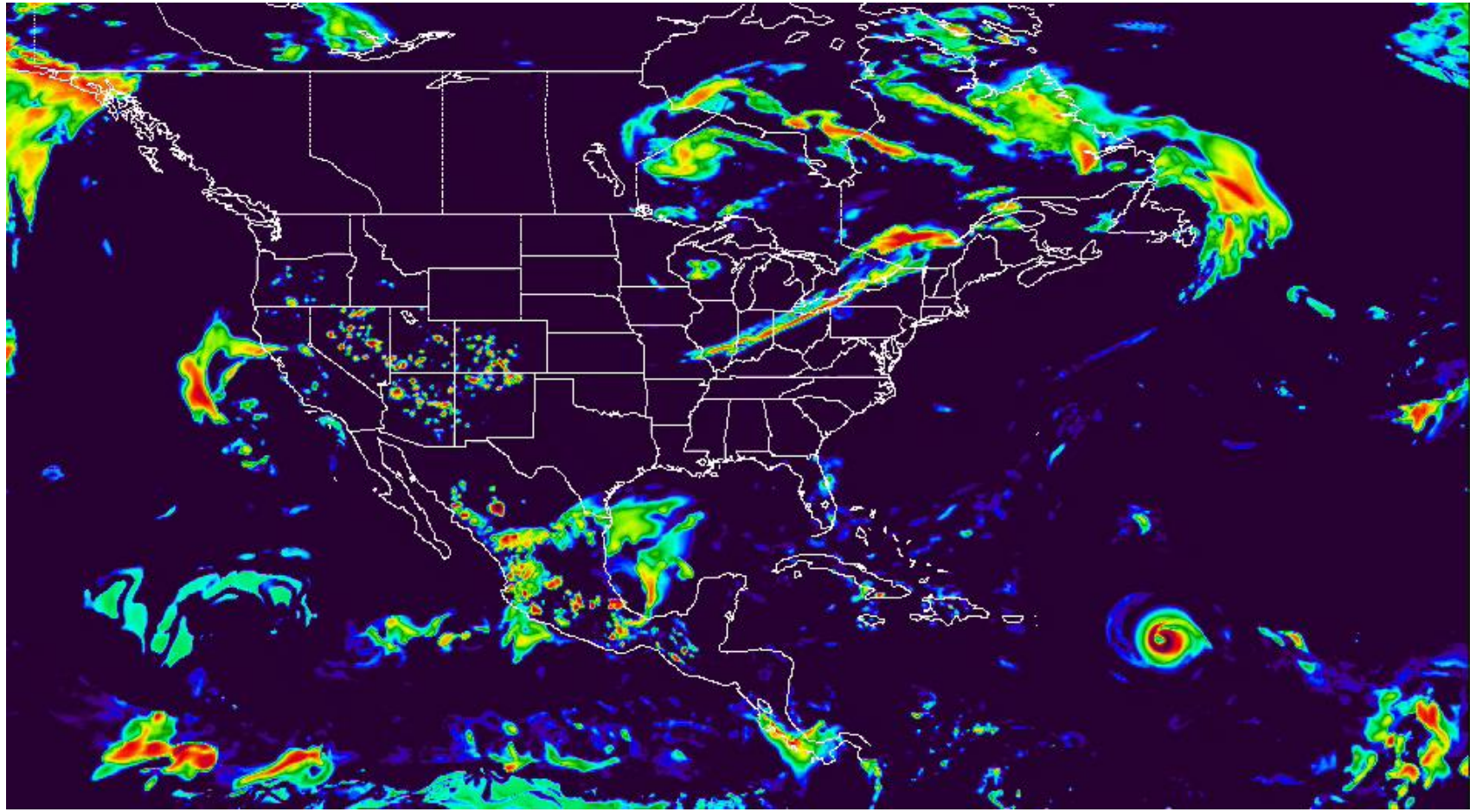


(Source: Morris Bender)

Hurricane Irma

Simulated Composite Radar Reflectivity

INIT: 00Z_20170905 fvGFS C768L63



- ncview “rainbow” color with min=-20, max=54 (dBz)
- fvGFS at C768L63 with GFDL MP

Thank You!