2020 HWRF Implementation Science Briefing

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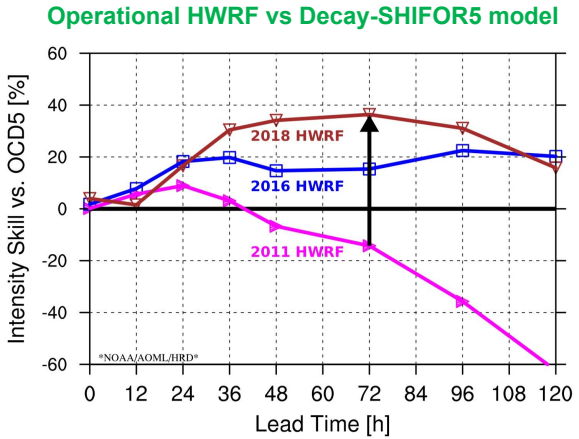
in collaboration with
HRD, DTC, NHC, GFDL, ESRL, CCU, OU, AER and others.

April 10, 2020

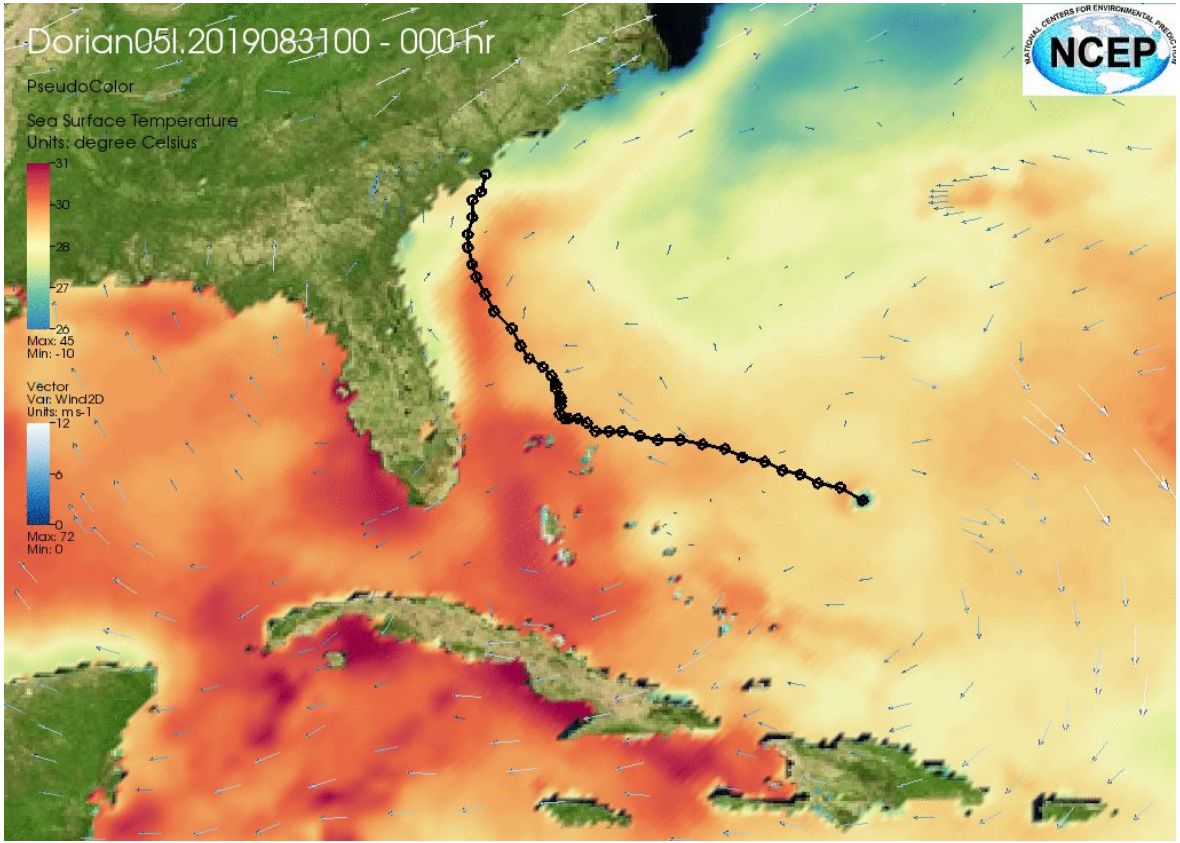
Operational HWRF v12 (Hurricane Weather Research and Forecast) System

- HWRF continuously improved in the past decade through support from HFIP
- Successful community modeling approach for accelerated transition of research to operations
  - ❖ Three nested domains at a horizontal resolution of 13.5/4.5/1.5 kms
  - ❖ Formal vortex initialization and GSI-based data assimilation
  - ❖ Actively coupled to Ocean models in all global basins
  - ❖ Actively coupled to Wave model (WW3; one-way only) in NHC basins
  - ❖ Inner-core DA including real-time data from recon missions (TDR, dropsondes, SFMR etc.)



Expanded international partnerships & collaborations

Operational HWRF v12 (Hurricane Weather Research and Forecast) System



2019083100Z cycle HWRF forecast for Hurricane Dorian slowing/stalling over Bahamas before turning North-West/North.

Scope of FY20 HWRF Upgrades

➢ System & Resolution Enhancements

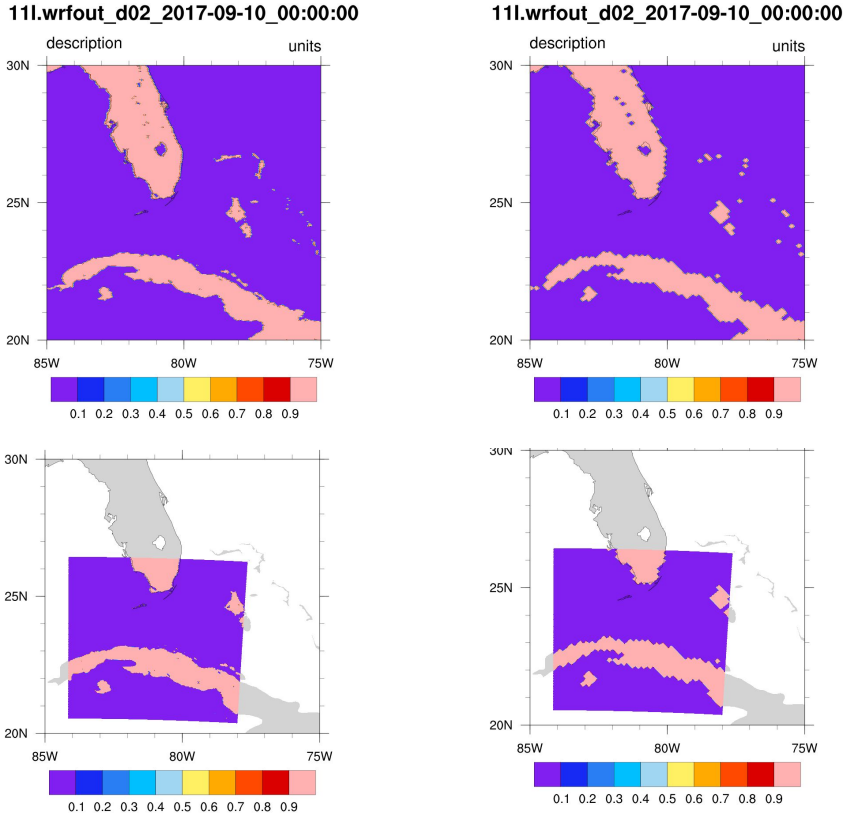
- Framework upgrade to HWRFV4.0a with bug fixes
- Optimize and unify the domain sizes of ghost domains used for initialization and DA
- Increase and optimize the sizes for all three model domains and use 91 nodes instead of 81 nodes to speed up the forecast job
- Adjust the horizontal mixing length scale parameter (coac) for D02 and D03 (nested domains)
- Use high-resolution land-sea masks for the moving nests
- Apply three-hourly (instead of six-hourly) lateral boundary conditions from GFS
- ~~Tested calling physics schemes more frequently~~
- ~~Tested using a flow-dependent horizontal mixing length scale~~
- ~~Tested the basin-scale configuration, which could not fit within the operational time window (together with HRD collaborators)~~

- Green indicates upgrades to be included in H220 configuration
- Items in Red: first time in 2020
- Orange denotes experiments made for the final decision

Hurricane Irma: Comparison of coastlines for the HWRF nested domains with and without high-resolution mask

D2@4.5 KM

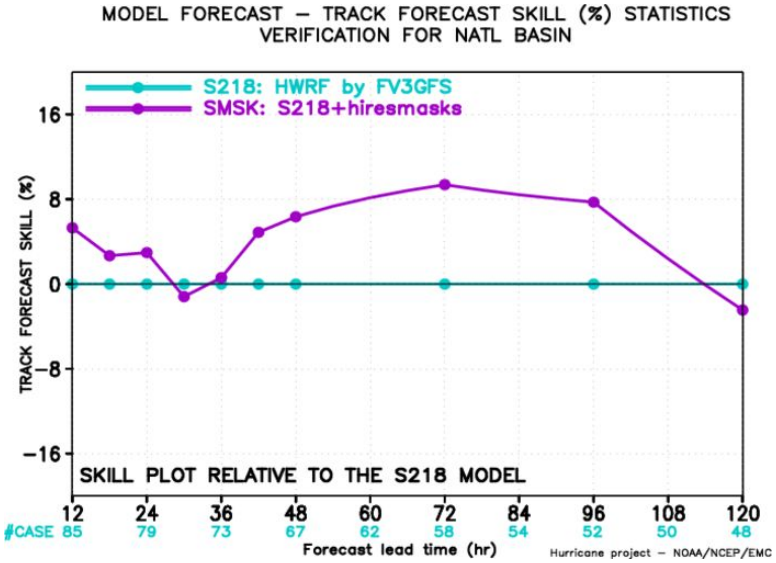
D3@1.5 KM

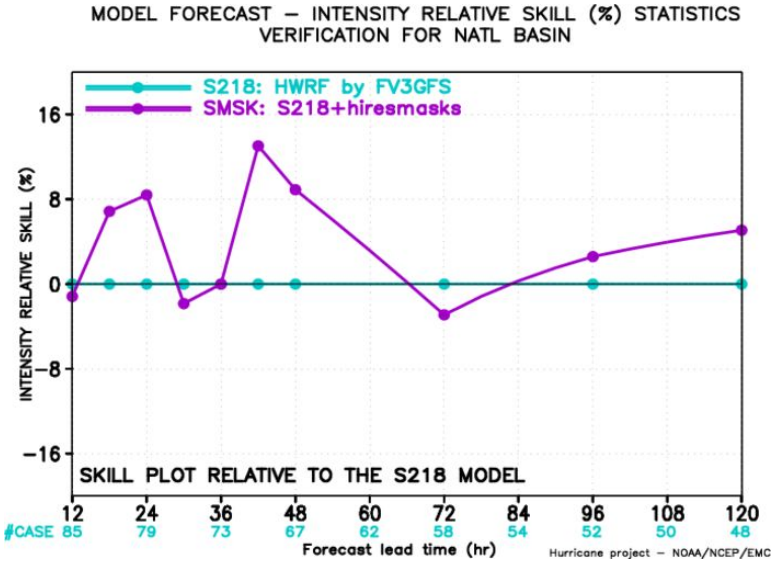


Using Hurricane Irma (2017) as an example, high-resolution land-sea masks are compared for outer nest domain (D2) (top left panel) with operational HWRF (top right panel) and for inner nest domain with high-resolution mask (bottom left) with operational HWRF (bottom right).

The high-resolution mask provides a much improved representation of coastlines (and orography) for Florida, Cuba and the Bahamas.

HWRF with High-Resolution Mask: Much Improved track and Intensity skill for Hurricanes Irma and Harvey





Based on results for Hurricanes Irma and Harvey, there is good improvement in track skill (left panel) and intensity skill (right panel) when high-resolution mask is introduced in the HWRF configuration.

Scope of FY20 HWRF Upgrades

➢ Physics Advancements

- Sync the scale-aware SAS convection scheme with a recent GFS version, but keep using HWRF's detrainment rate
- Use the unified F-A microphysics scheme (consistent with the versions used in HMON and NAM) with bug fixes
- Use the exponential random cloud overlap method (cldovrlp=5) with a constant decorrelation length (idcor=0) in the RRTMG radiation scheme
- ~~Tested turning on the separate species advection in the F-A microphysics scheme~~
- ~~Tested a new sub-grid scheme (SGS) in the convective area~~
- ~~Tested a modification to remove possible K-discontinuity near the PBL top~~
- ~~Tested the MYNN PBL scheme (together with DTC/HRD collaborators)~~
- ~~Tested turning off the convection scheme on the innermost nested domain (D03)~~
  - Green indicates upgrades to be included in H220 configuration
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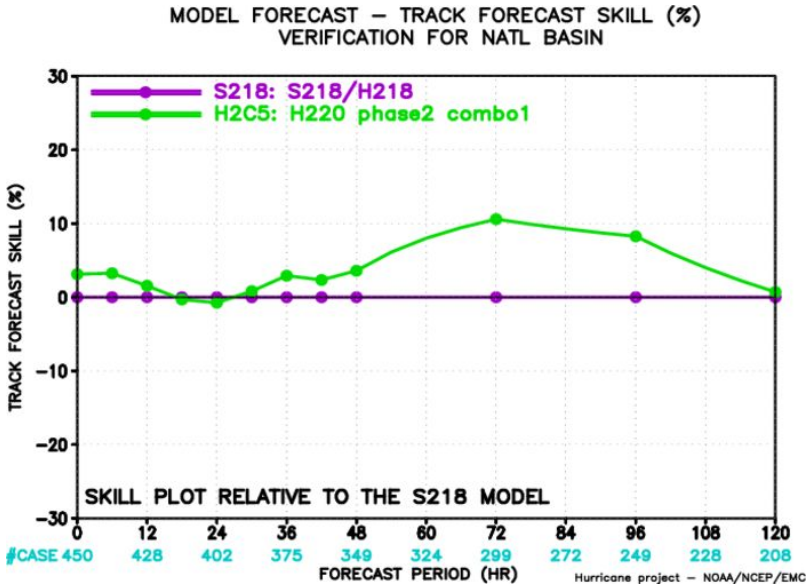
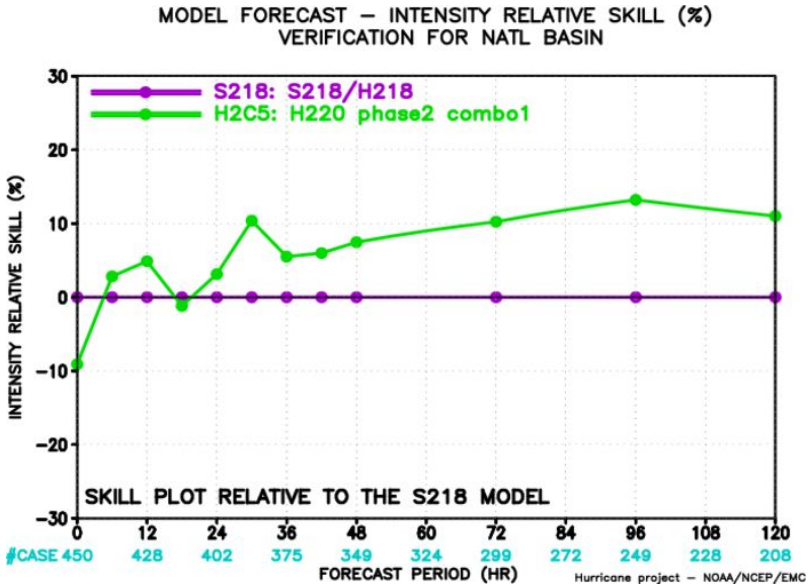
Track and Intensity skill for NATL basin (2018-2019) (Physics and System Improvements)





H2C5: with all systems and physics improvements

Improvement in track skill are > 10% for Days 3 and 4 while improvements in intensity skill are close to 10% for most lead times beyond Day 2.

Scope of FY20 HWRF Upgrades

➢ Initialization/Data Assimilation Improvements

- Turn off smoothing in VI and turn off intensity correction when Pmin is shallower than OBS and Vmax is stronger than OBS
- Adopt new settings for the DA/GSI increment blending
- Implement a new domain merging method and procedure to handle the transition from HWRF analysis to GFS analysis
- Update preprocessing of the TEMPDROP data
- Sync with a recent version of the master branch for ProdGSI
- Un-flag and turn off thinning for the ASCAT data
- Assimilate NEXRAD radial wind data from coastal radar sites
- Assimilate additional satellite observations used in GFS (GOES 16, 17; SNPP, NOAA-20)
- ~~Tested assimilation of some additional AMV data~~
- ~~Tested turning off ensemble relocation for the HWRF DA ensemble~~

  - Green indicates upgrades to be included in H220 configuration
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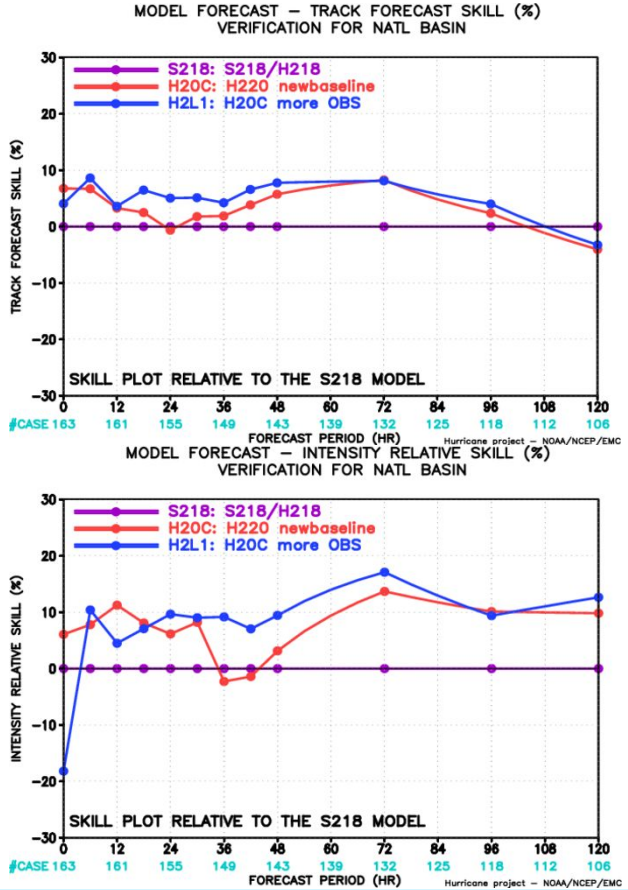
DA related Upgrades and Impacts

- Unflag and use a different thinning method for the ASCAT data
- Bug fixes for the domain merging method and the tempdrop data preprocessing
- Changes for the DA/GSI increment blending
  - Lower the GSI increment blending wind threshold from 64kt to 50kt
  - For vmax in the range of 50-64kt, using wave-number 0+1 for DA/GSI increment blending
  - For vmax stronger than 64kt, using the wave-number 0 (instead of 0+1) for DA/GSI increment blending
  - For the new merging method, increase the environment transition/relaxation radius from 250 to 300 km



Scope of FY20 HWRF Upgrades

Air-Sea Coupling upgrades

- Improve regridding of initial data from RTOFS to the POM grid
- Use a newer version HYCOM for ocean coupling for JTWC basins and update the ocean lateral boundary condition specification
- Switch to RTOFS data (instead of GDEM climatology) to initialize ocean for the NATL basin (same as EPAC)
- ~~Tested HYCOM coupling for NHC basins~~
- ~~Test and tune three-way atmosphere-wave-ocean coupling~~

Post-processing upgrades

- Sync with a newer version of UPP develop branch (DTC)
- Use the latest version of GFDL tracker (from Tim Marchok, GFDL)

- Green indicates upgrades to be included in H220 configuration
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Proposed Strategy for Testing and Evaluation of Hurricane Retrospectives for planned FY20 Upgrades of HMON & HWRF

1. Use available **consistent** GFS forcings for 2018 (starting on 25th August) and complete 2019 Hurricane season (current operational version of FV3GFS)

2. Use **all available storms** for retrospective cases in the NATL and EPAC basins from the above time period.

Total cycles in this sample size

- HWRF in NATL: 679 forecast cycles total (including 623 non-invest cycles)
- HWRF in EPAC: 620 forecast cycles total (including 542 non-invest cycles)
- HWRF in JTWC Basins (WPAC, NIO, SH): ~500 cycles

HWRF Upgrade Plan for 2020 Implementation

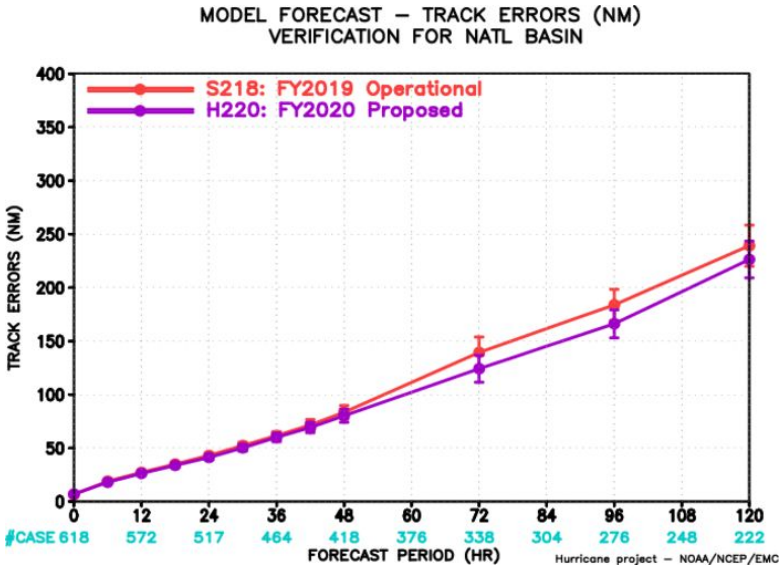
Multi-season Pre-Implementation T&E

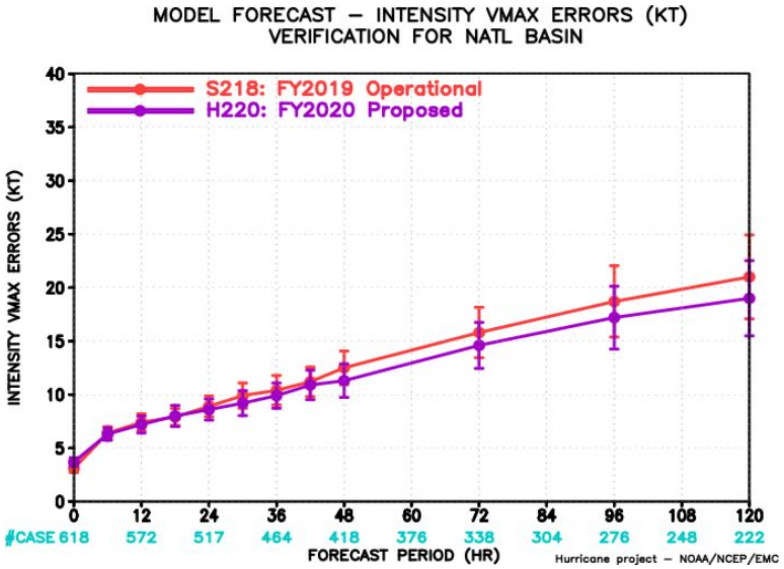
	Model upgrades	Physics and DA upgrades		Combined
	Baseline (H20C)	**VI/DA changes (H2L1/2/3, etc.)**	**Physics changes (H2P1/2/3/4, etc.)**	**H220**
Description	1. Framework upgrade to HWRFV4.0a 2. Upgrade to newer versions of GSI, UPP, and GFDL tracker 3. High res. land-sea mask for nests 4. Use 3-hourly LBC from GFS 5. VI modifications 6. Changes for the DA/GSI increment blending 7. Use a newer version merge method 8. POM-RTOFS initialization	1. Upgrade to latest GSI 2. Turn off sat. channels for cloudy area 3. Unflag and use different thinning for ASCAT 2. New threshold for IC 3. Improved merge method	Assess various impacts of physics changes	Baseline + VI/DA changes + all physics changes + others
Cases	Selected 2018-2019 NATL/EPAC priority storms (~400 cases in each basin).	Selected priority storms (~400 cases in each basin)	Selected priority storms (~400 cases in each basin)	All 2018-2019 NATL/EPAC storms with GFSV15.1 version input data (~1300 cases) and selected WPAC/SH/NIO storms (~500 cases)
Platform	WCOSS/Jet	WCOSS/Jet/Hera	WCOSS/Jet/Hera	WCOSS/Jet

HWRF Verification for North Atlantic Storms (2018-2019)

- S218/S18I: Current operational HWRF (2019) + 2018 with operFV3GFS
- **H220/H20I: Proposed FY20 HWRF configuration with operFV3GFS**

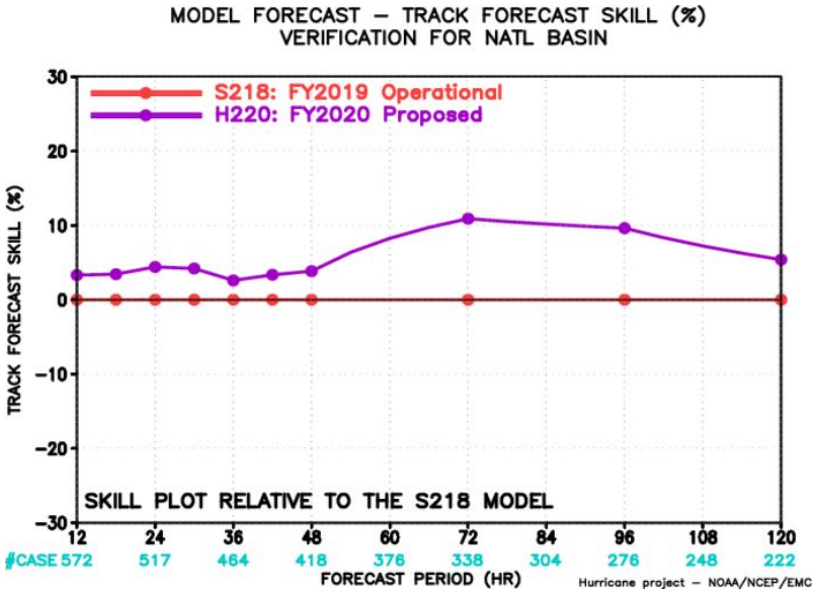
Track and Intensity errors for NATL basin (2018-2019) (Late Model)

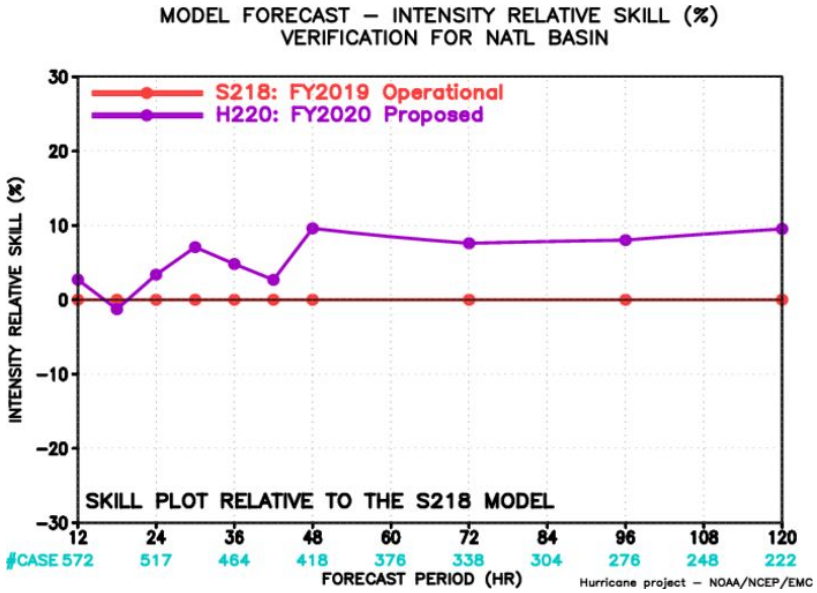




There are significant improvements in track and intensity for the NATL basin with H220. These improvements are noteworthy for the extended lead times beyond Day 2.

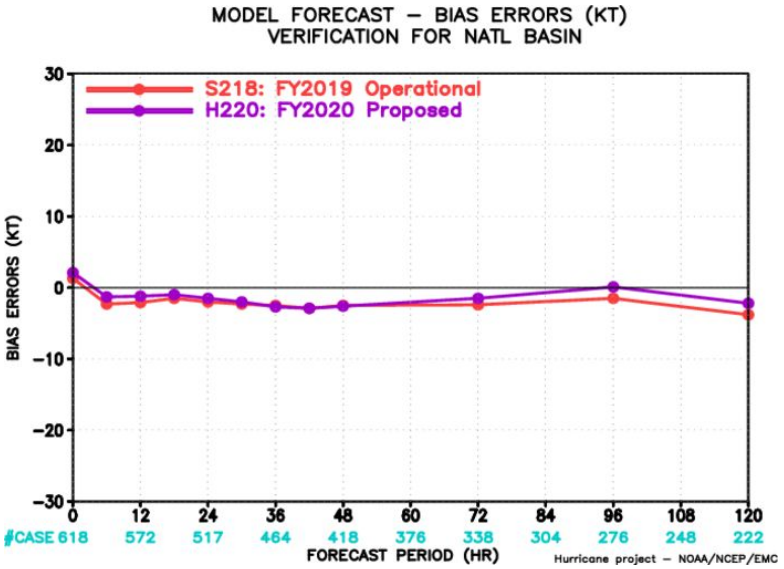
Track and Intensity skill for NATL basin (2018-2019) (Late Model)

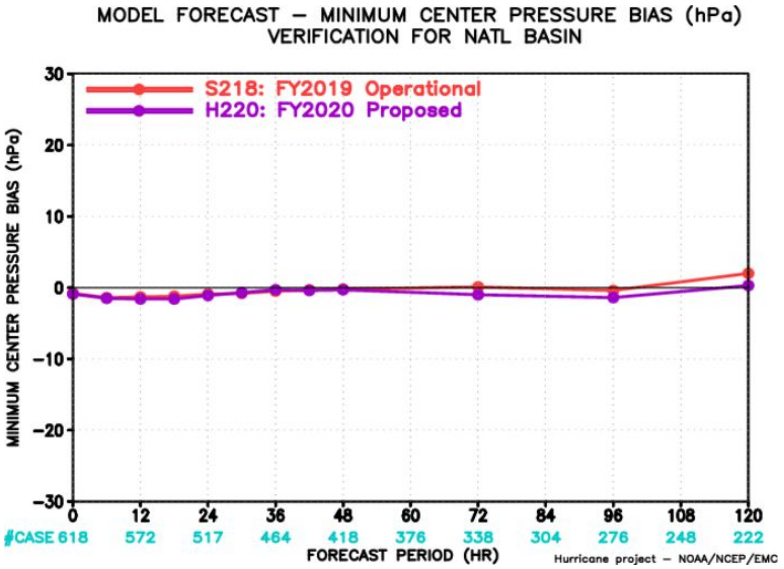




Increase in track skill at all lead times with good improvement in track skill ~ 10% for Days 3 and 4. Improvements in intensity skill are also close to 10% for most lead times beyond Day 2.

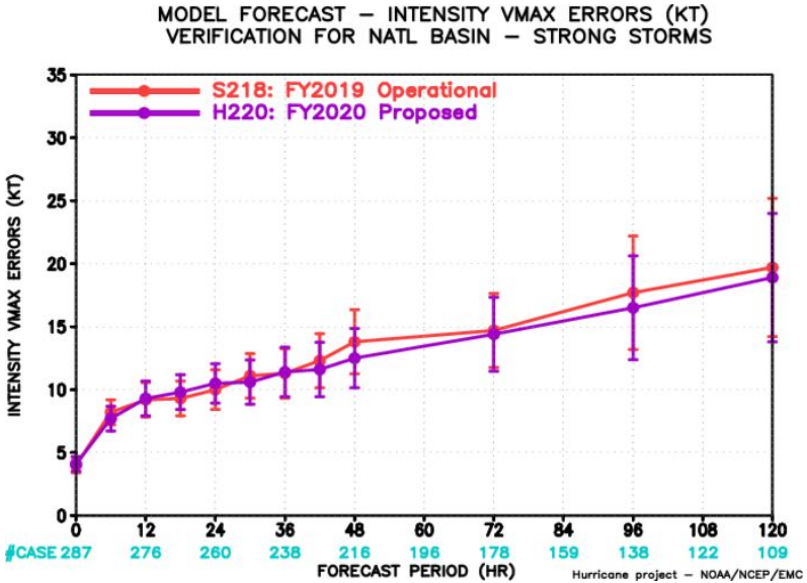
Intensity and MSLP bias for NATL basin (2018-2019) (Late Model)

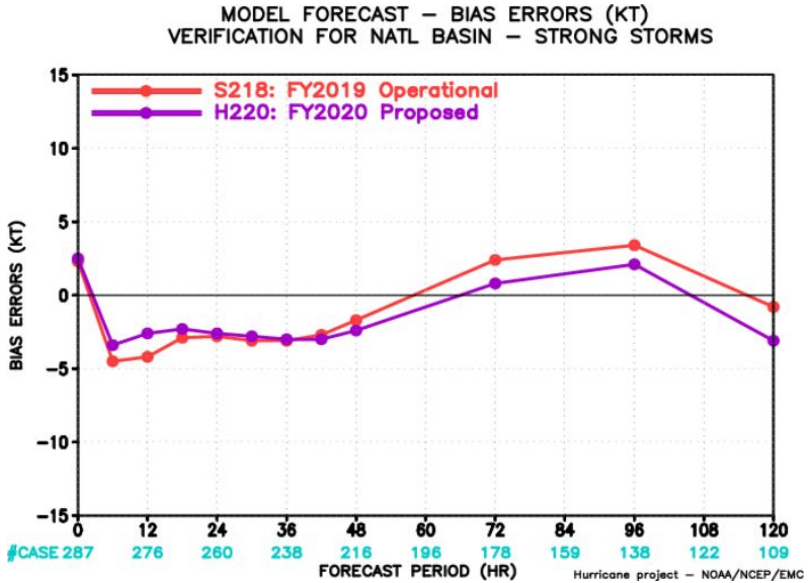




There are good reductions in intensity biases for the NATL basin with H220. Larger improvements in MSLP bias errors show up at Day 5.

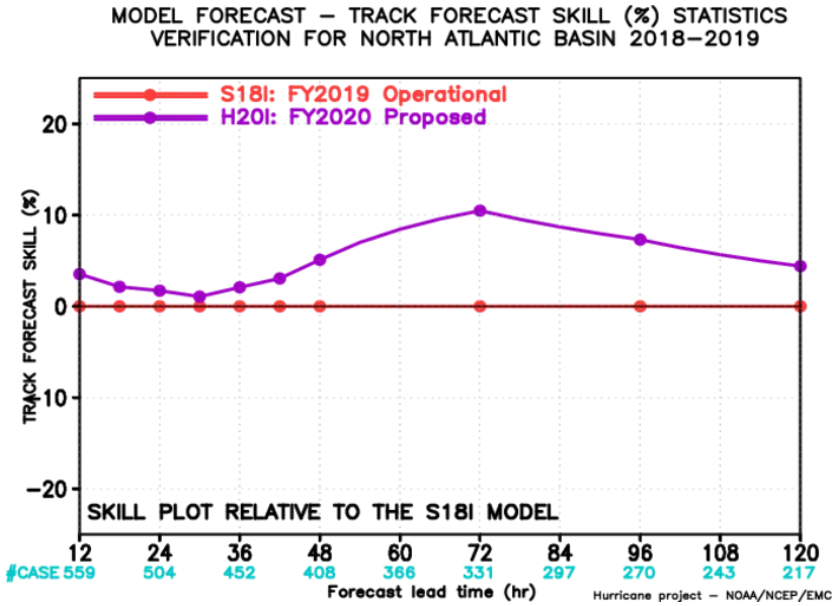
Intensity skill improvements for NATL basin (2018-2019) (Strong Storms > 50 kt)

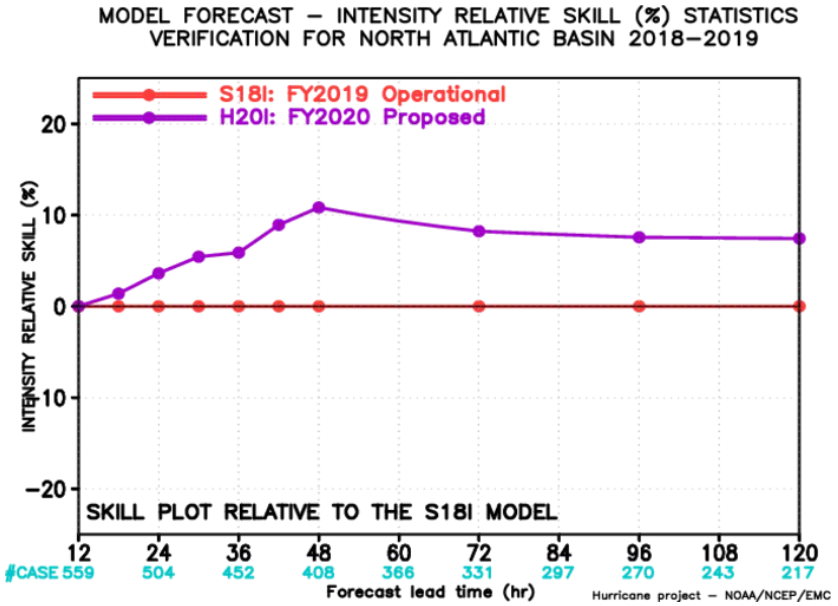




Both intensity errors and bias errors are reduced for H220 for strong storms at all lead times as compared to S218 for the NATL basin.

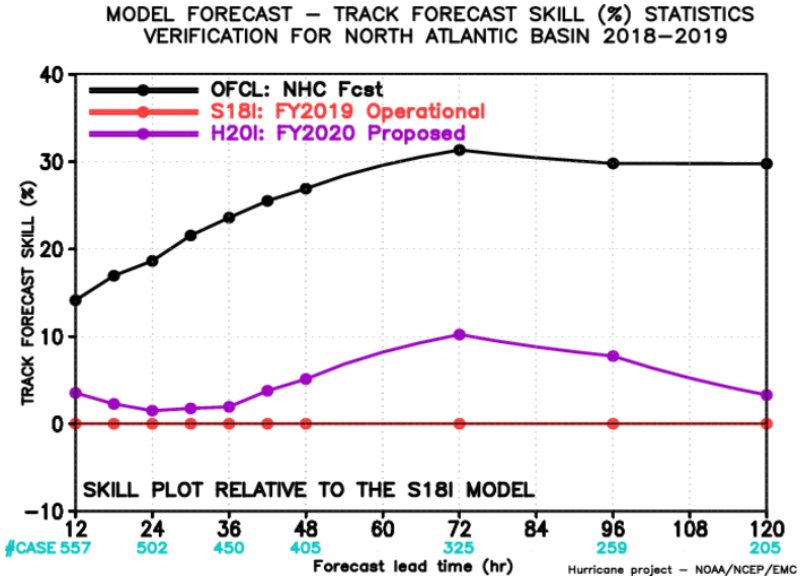
Track and Intensity skill for NATL basin (2018-2019) (Early Model)

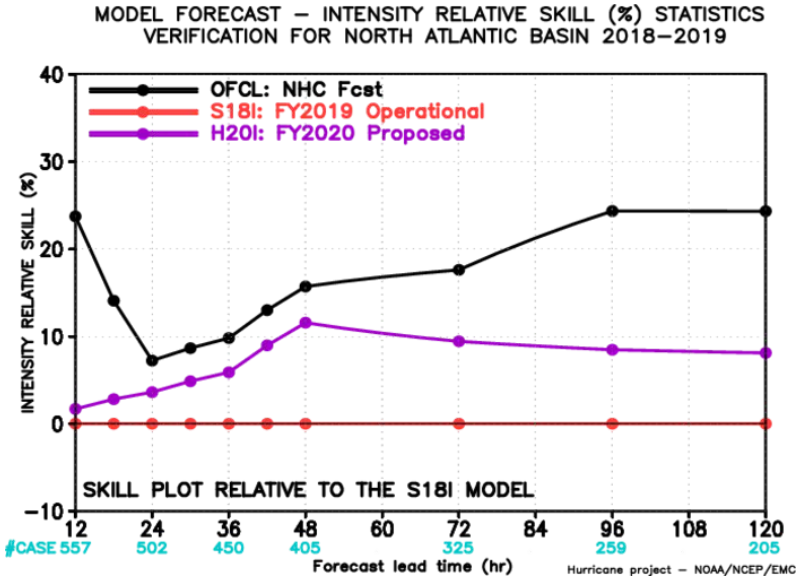




Early model results also show similar significant improvements in skill in both track and intensity as compared to S18I. While these improvements are impressive for track skill beyond Day 2, the improvements in intensity can be seen at all lead times.

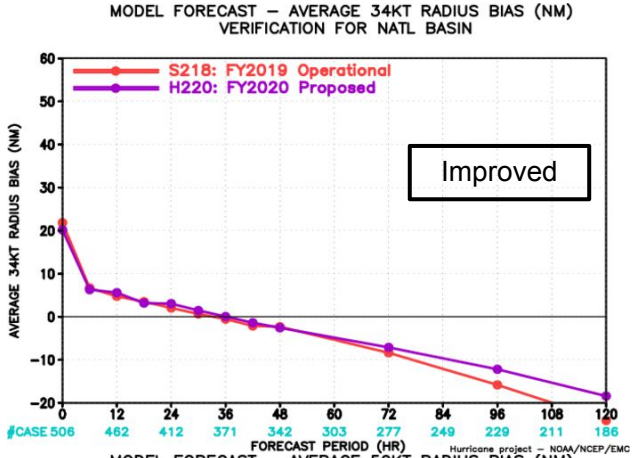
Track and Intensity skill for NATL basin (2018-2019) (Early Model)

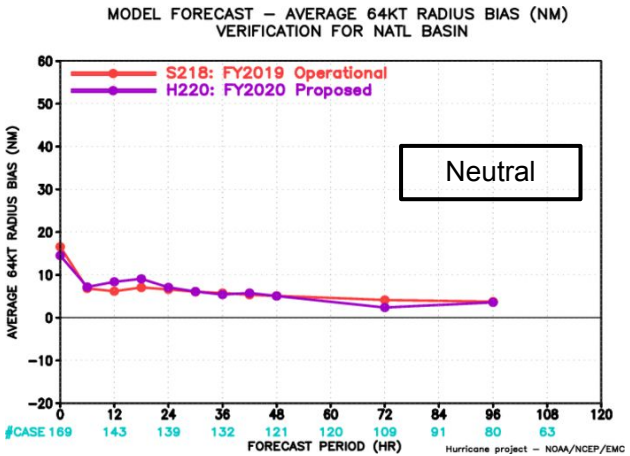


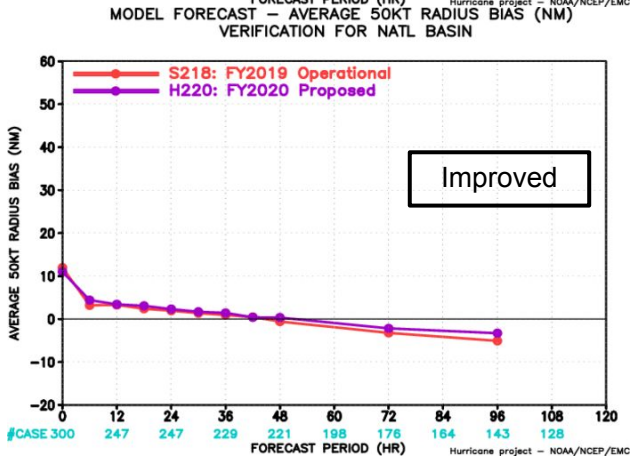


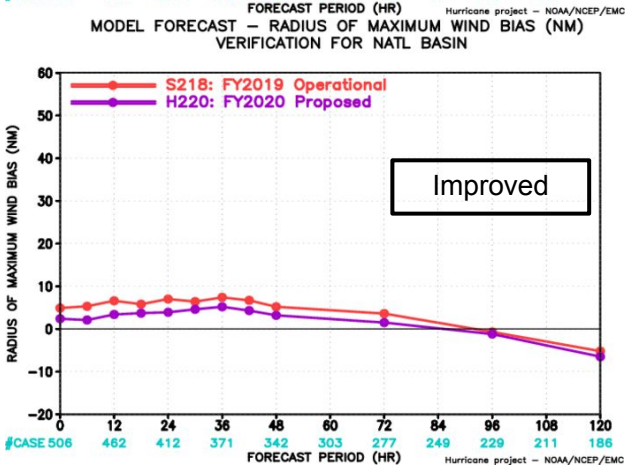
Improvements in track and intensity skill for the proposed HWRF (H20I, purple line) over operational HWRF (S18I, red line) when compared with the official skill (black line).

Storm Size Errors for NATL basin (2018-2019)

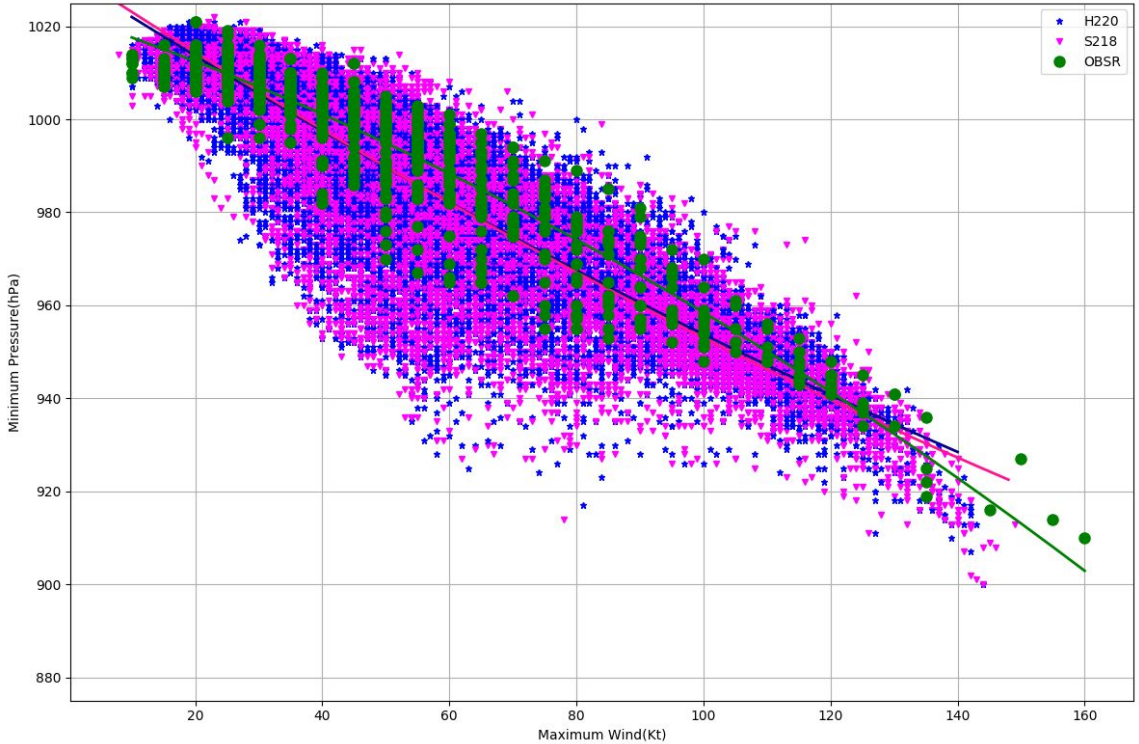








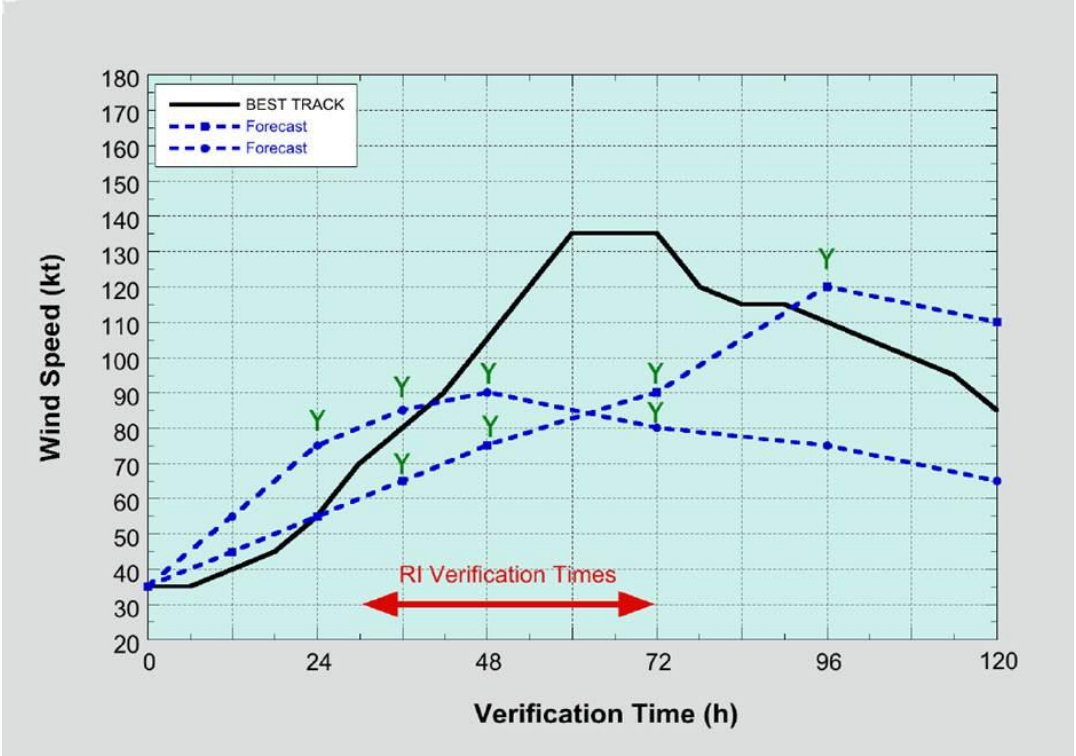
Pressure/Wind relationship for the NATL basin (2018-2019)



New Rapid Intensification Metric

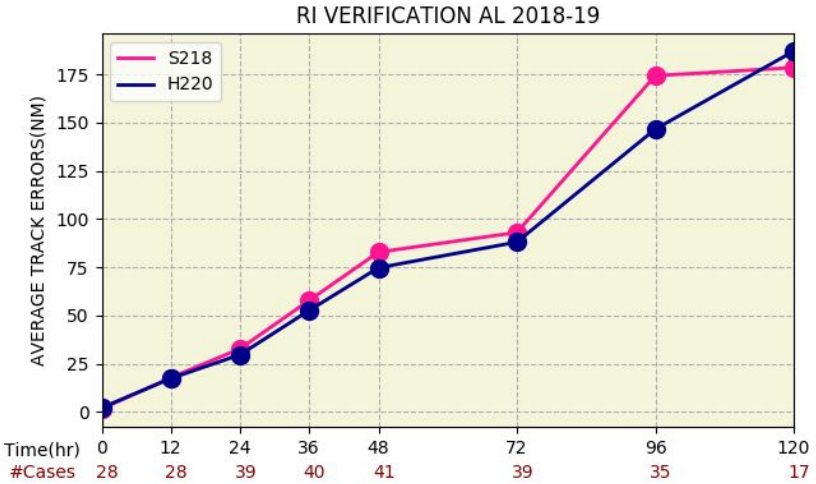
Definition* :

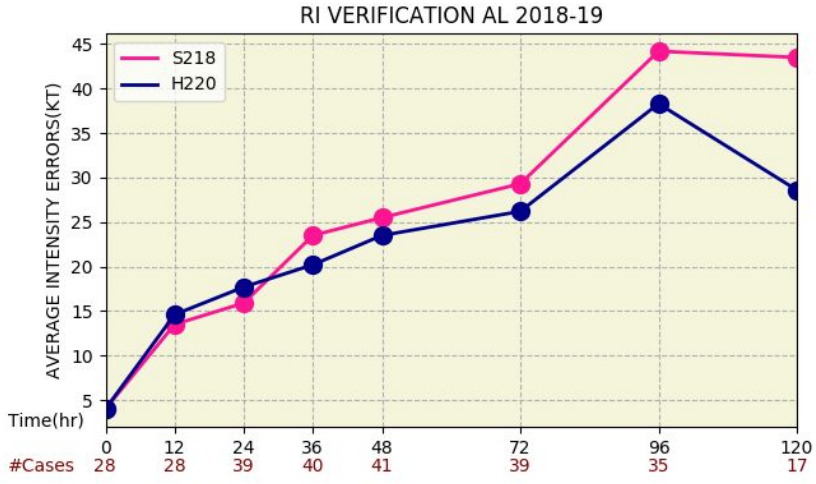
Mean errors evaluated for those subset of cycles when at verification times, RI is either ongoing or was forecasted to occur.



* From Mark DeMaria and James Franklin

New Rapid Intensification Metric



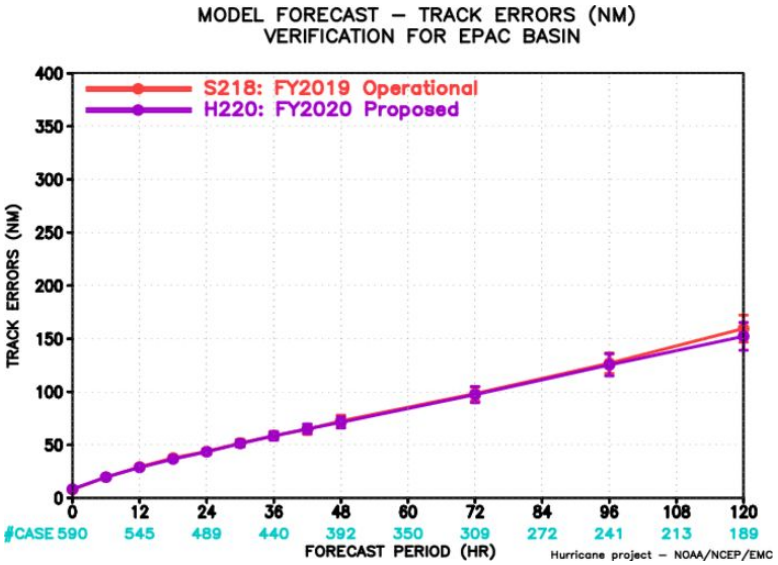


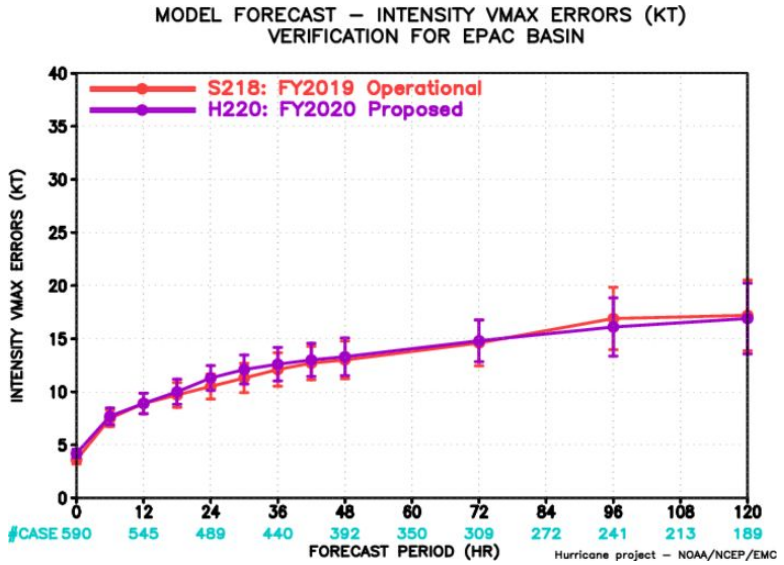
Both track and intensity errors for these selected cycles from H220 show good improvements after Day 1 when compared with results from S218.

HWRF Verification for East Pacific Storms (2018-2019)

- S218/S18I: Current operational HWRF (2019) + 2018 with operFV3GFS
- **H220/H20I: Proposed FY20 HWRF configuration with operFV3GFS**

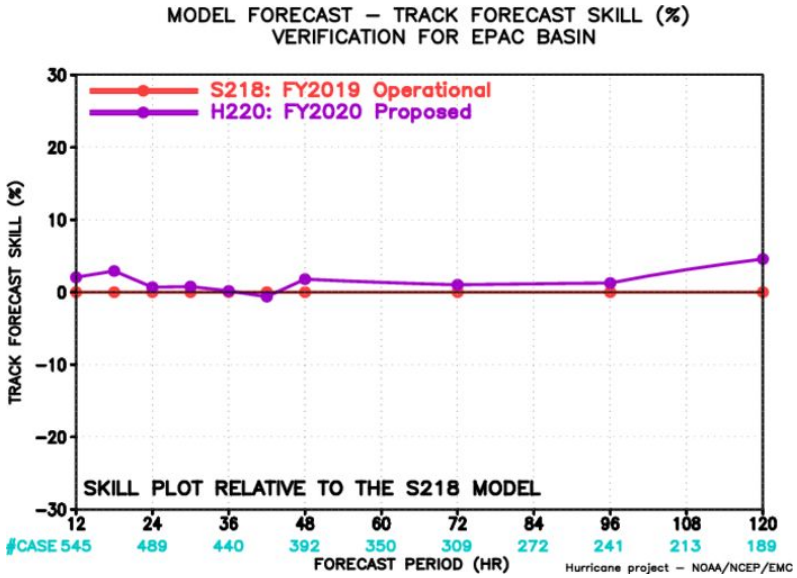
Track and Intensity errors for EPAC basin (2018-2019) (Late Model)

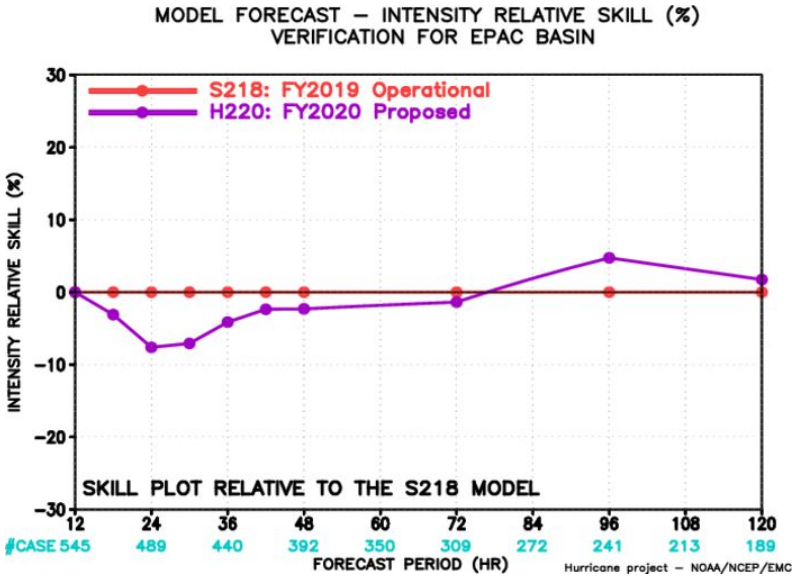




Track errors (left panel) are very similar but some reductions can be seen for day 5. Intensity errors (right panel) are also very similar with increase in errors on Day 1 but reductions for Day 4.

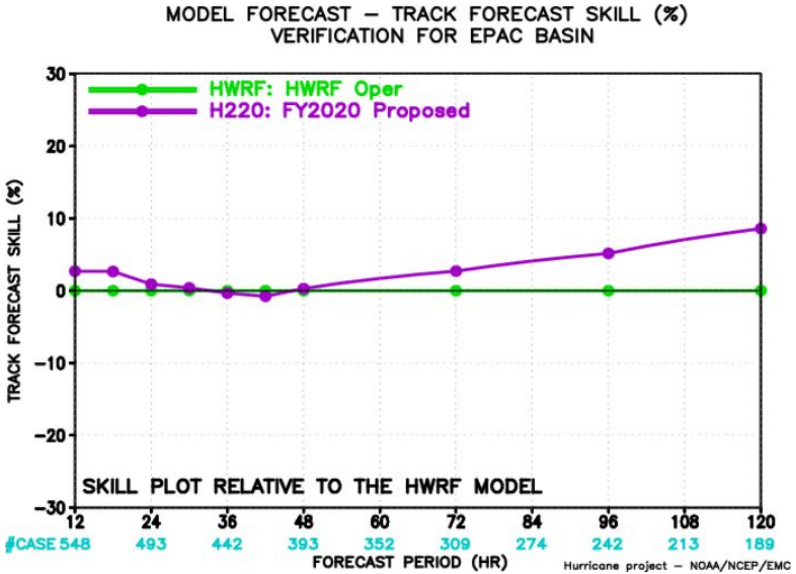
Track and Intensity skill for EPAC basin (2018-2019) (Late Model)

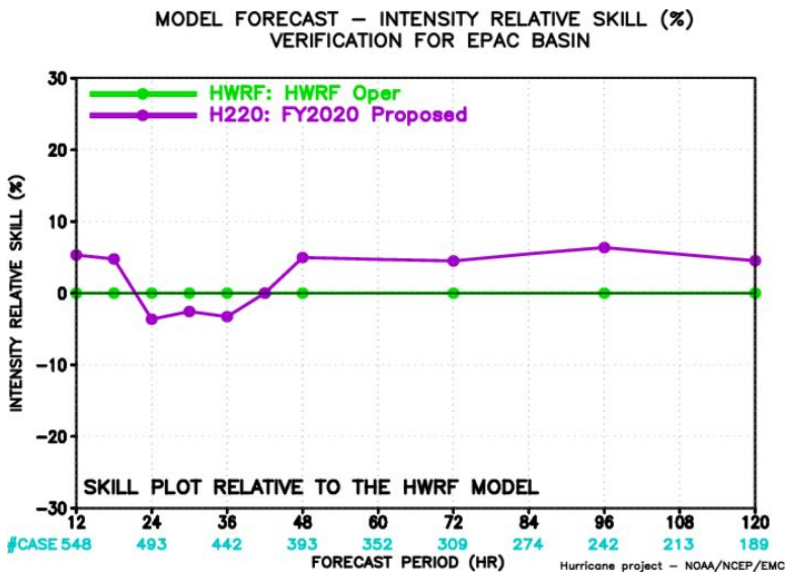




Track skill is positive for all lead times. Intensity is behind for the first 2 days, it becomes neutral and then turns positive for Days 4 and 5. Overall intensity skill is neutral.

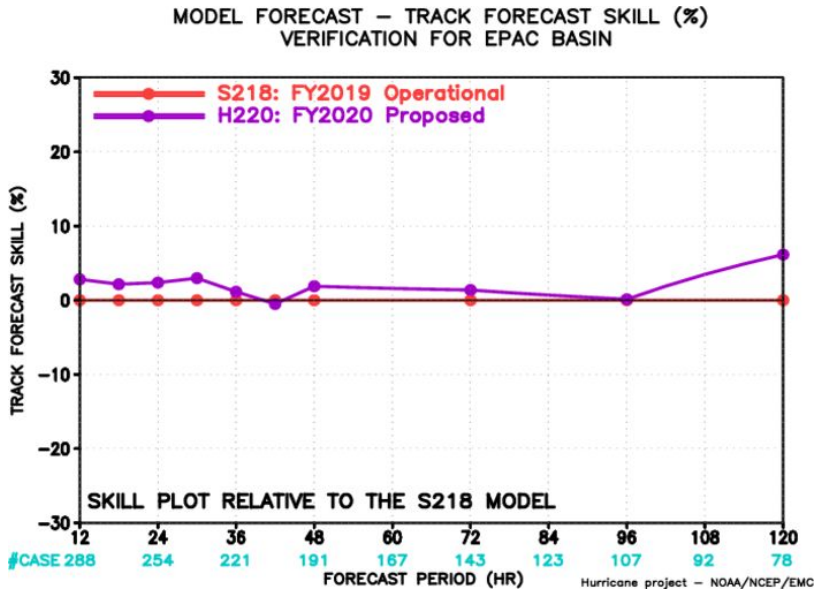
Track and Intensity skill for EPAC basin (2018-2019) (Late Model)

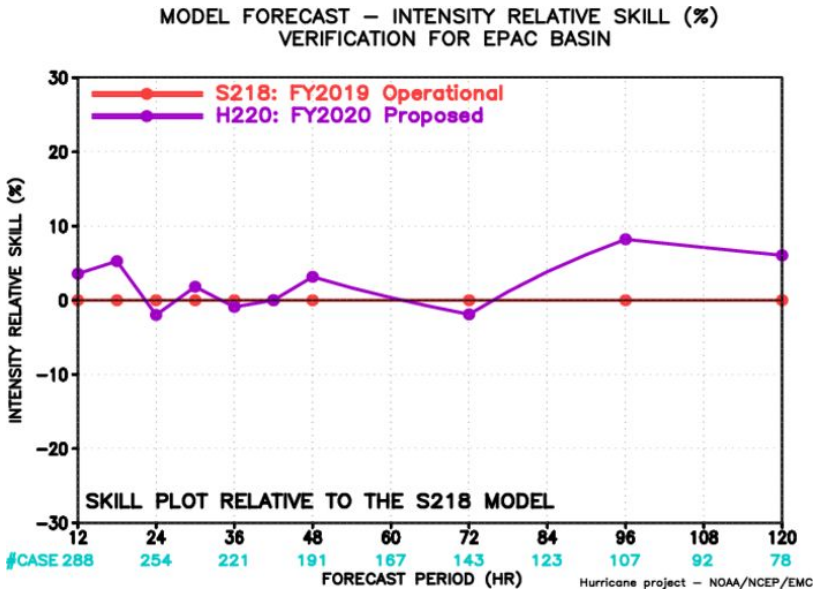




This comparison is against operational HWRF results (operHWRF) which were forced with GFS v14 conditions in 2018. Track skill is positive for all lead times other than being neutral at forecast hr 36. Intensity is also improved initially at hr 12 and then by ~ 5% beyond Day 2.

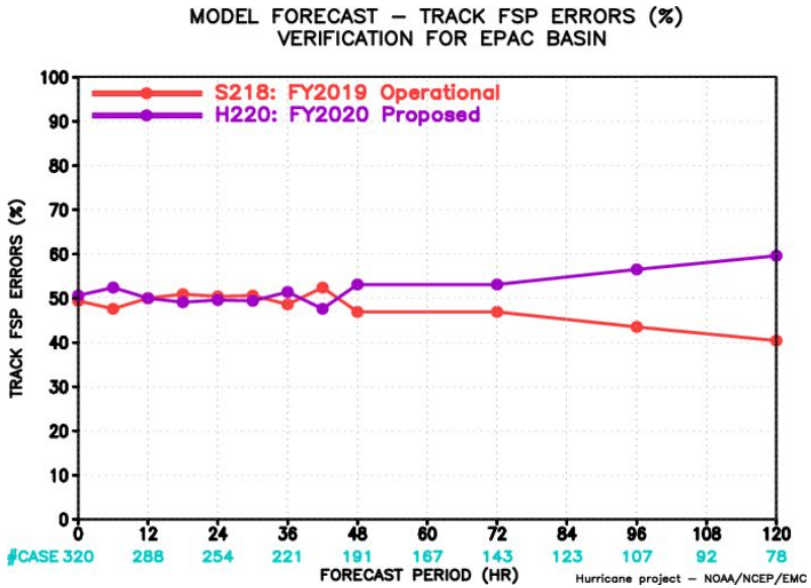
Track and Intensity skill improvements for EPAC basin (2019 Storms; Late Model)

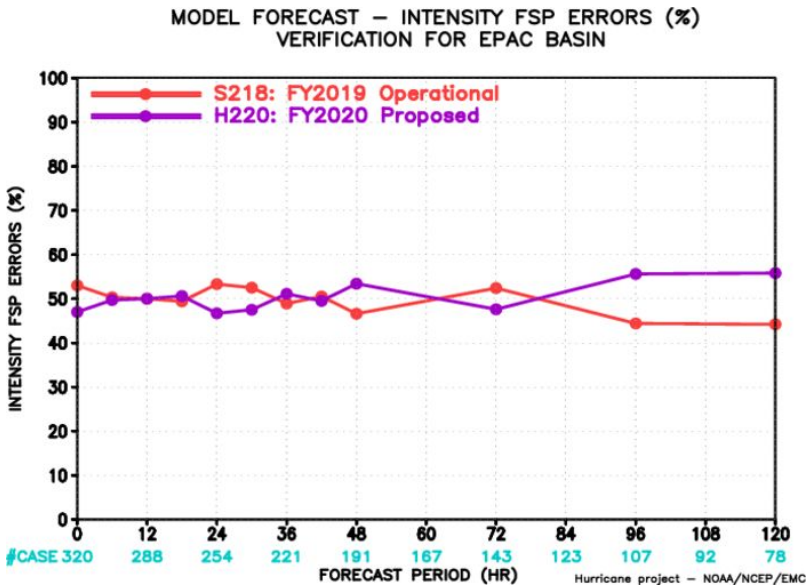




Both track and intensity skill is neutral to positive for the 2019 storms errors which indicates that most of the degradation in skill is coming from the 2018 storms. For 2018, storms during September – November timeframe do not represent a typical annual EPAC season.

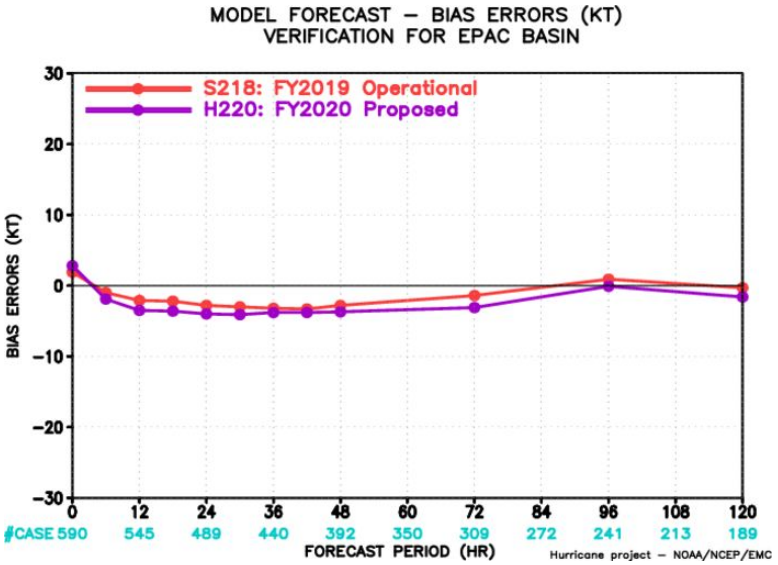
Track and Intensity FSP for EPAC basin (2019 Storms)

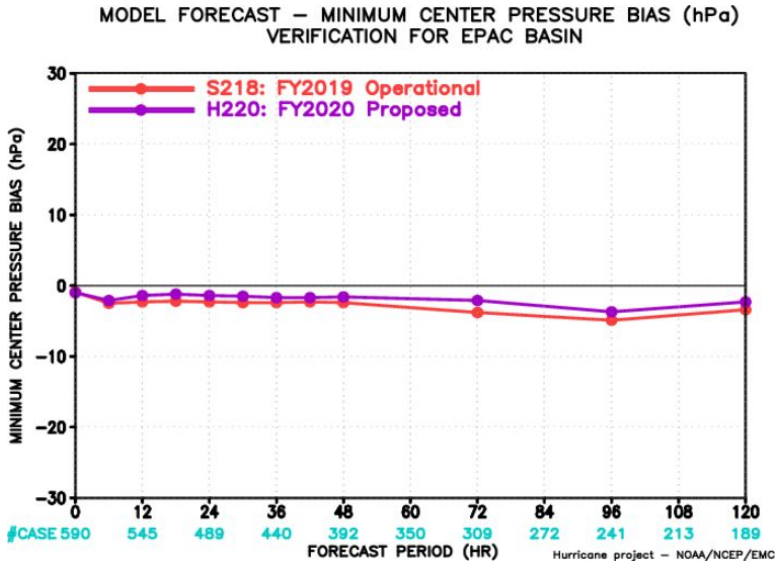




For 2019 storms, Frequency of Superior Performance (FSP) stats confirm improvements in H220 over S218 for track but intensity remains neutral for the EPAC basin.

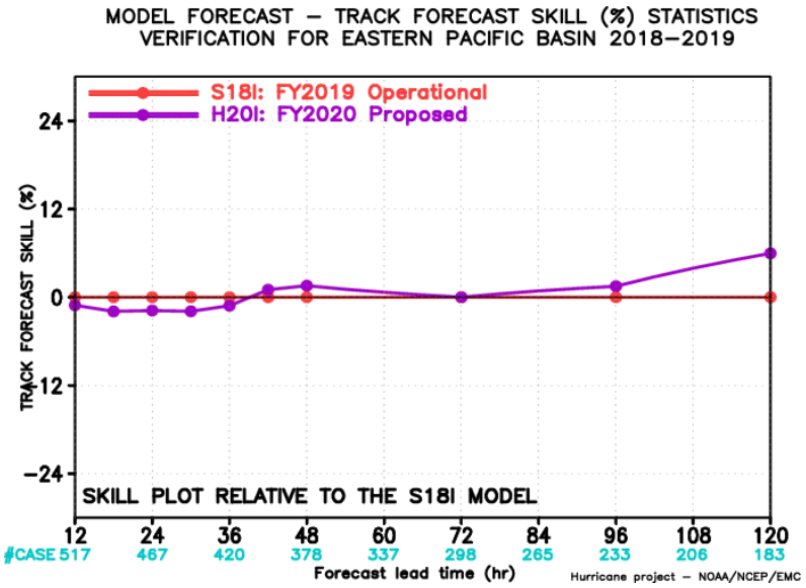
Bias errors for EPAC basin (2018-2019)
(Late Model)

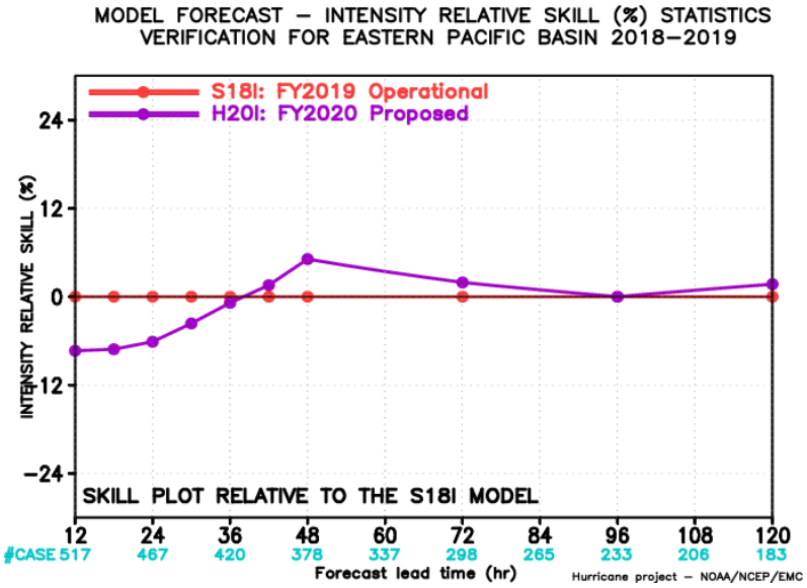




While H220 gives us a larger negative bias as compared to S218 for all lead times, bias errors in MSLP are reduced (less negative) for all lead times.

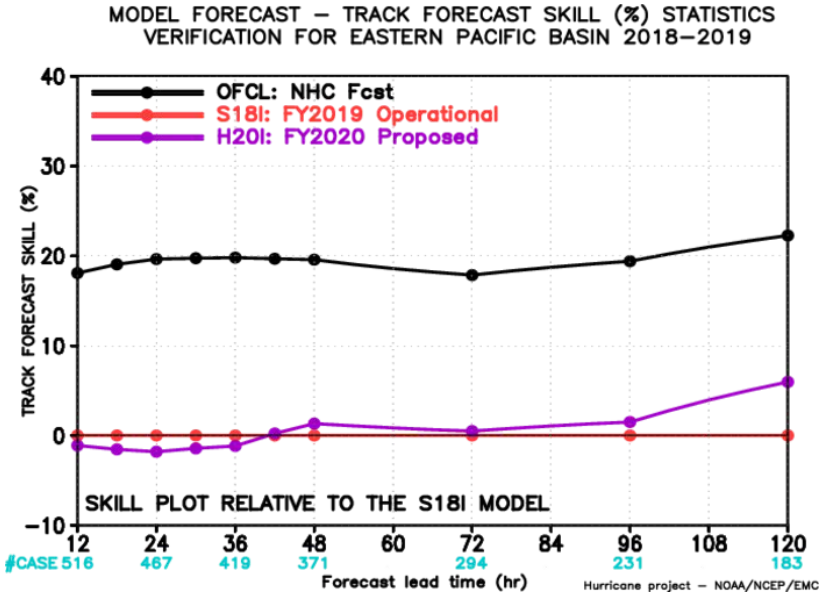
Track and Intensity skill for EPAC basin (2018-2019) (Early Model)

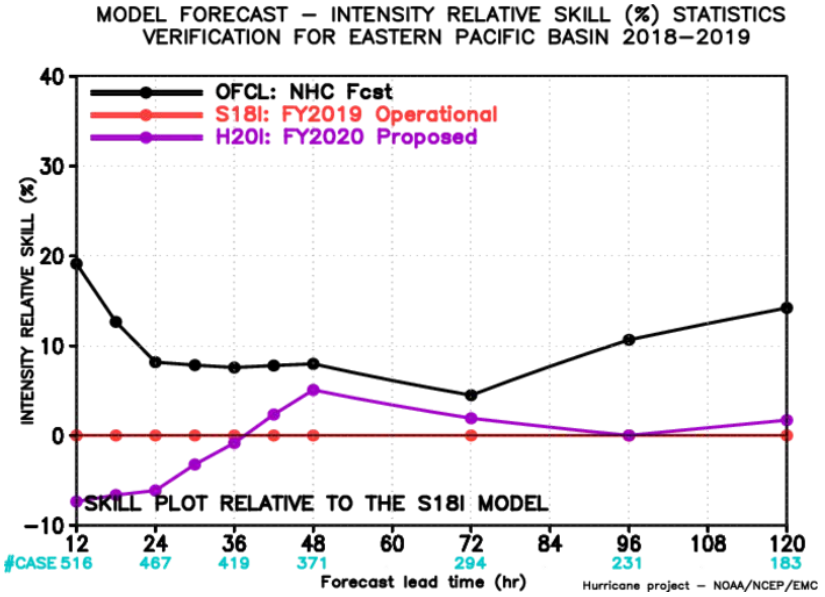




Both track and intensity skill is behind for the first 36 hrs. After that they become positive with nice improvements of around 5% for intensity on Day 2 and around 5% for track on Day 5. Overall, results as compared to S18I are neutral.

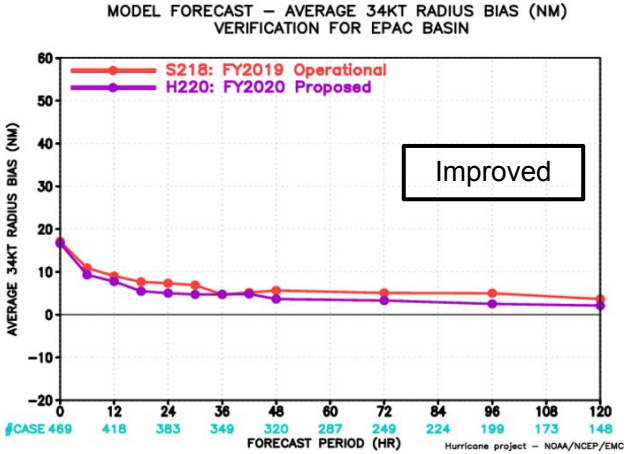
Track and Intensity skill for EPAC basin (2018-2019) (Early Model)

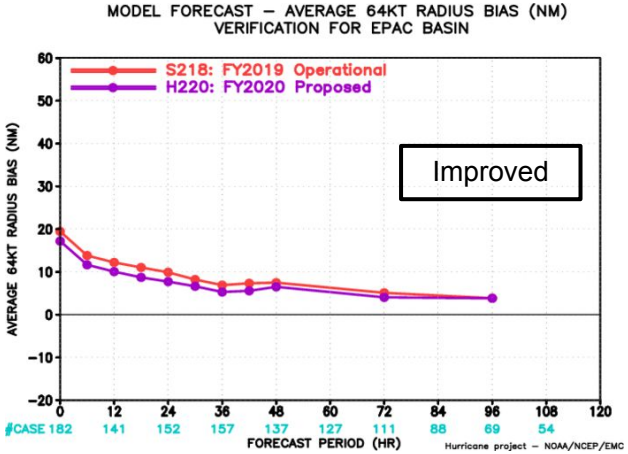


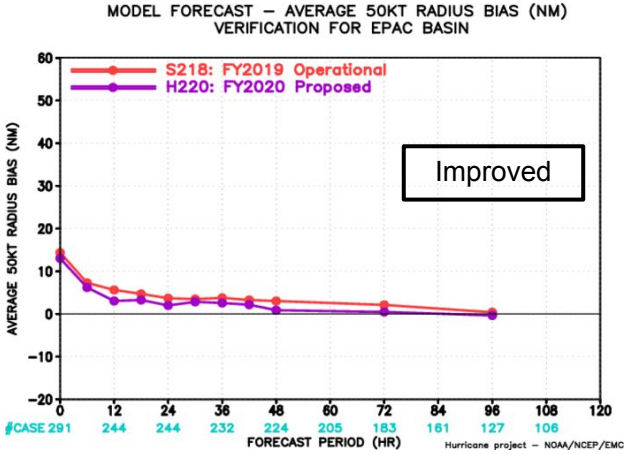


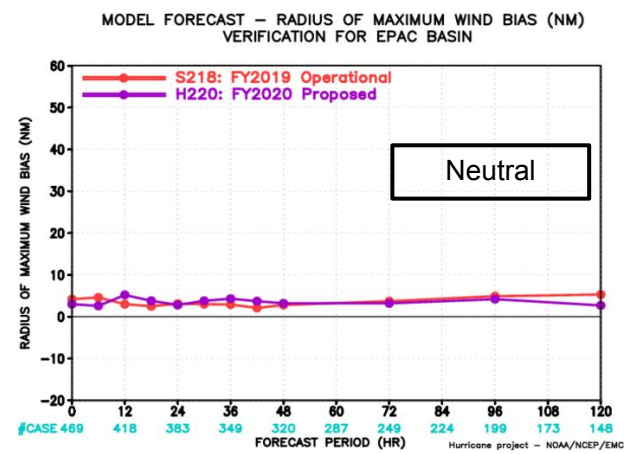
Improvements in track and intensity skill for the proposed HWRF S18I, purple line) over current HWRF (S18I, red line) when compared with the official skill.

Storm Size Errors for EPAC basin (2018-2019)

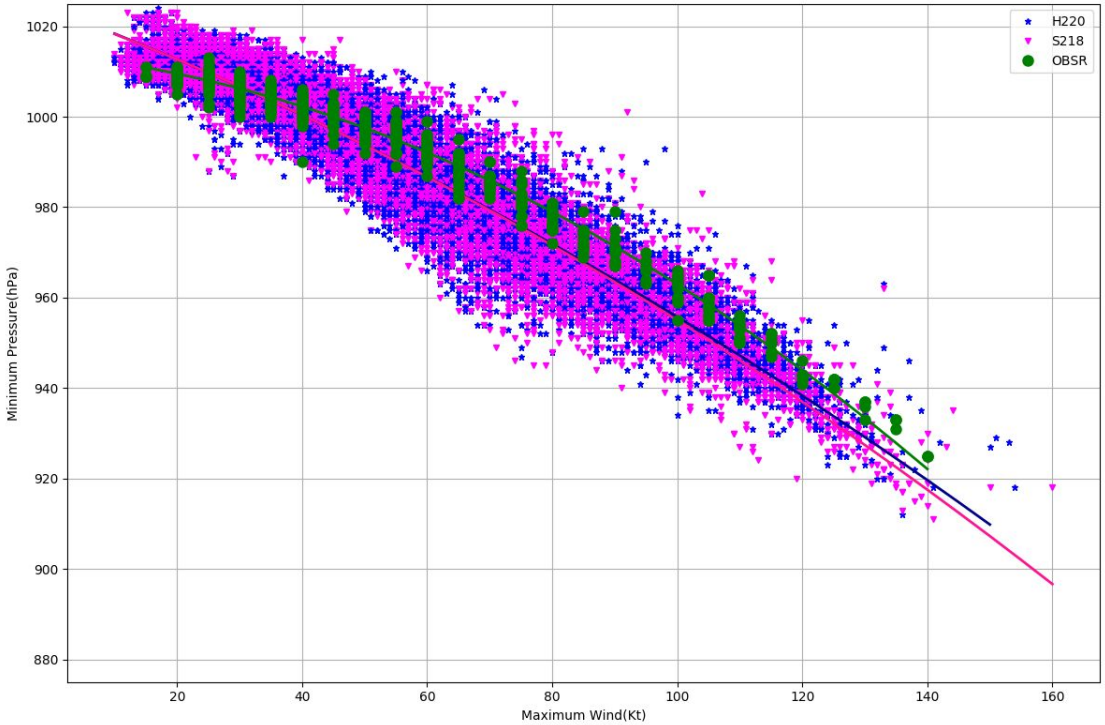






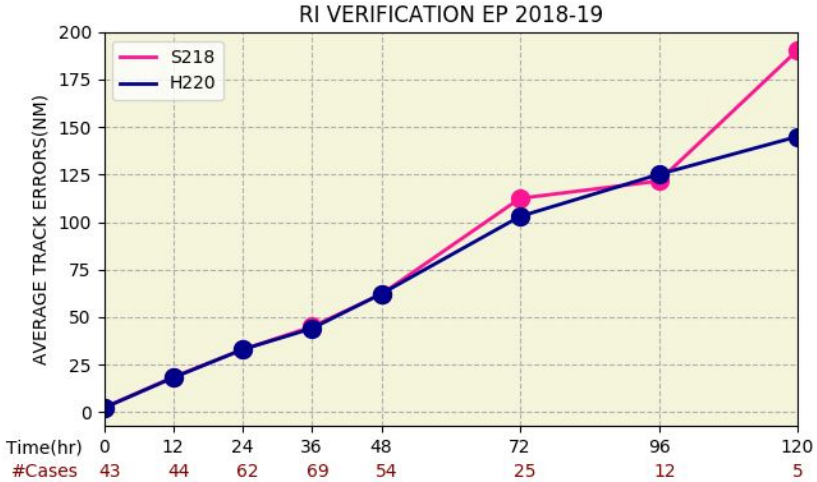


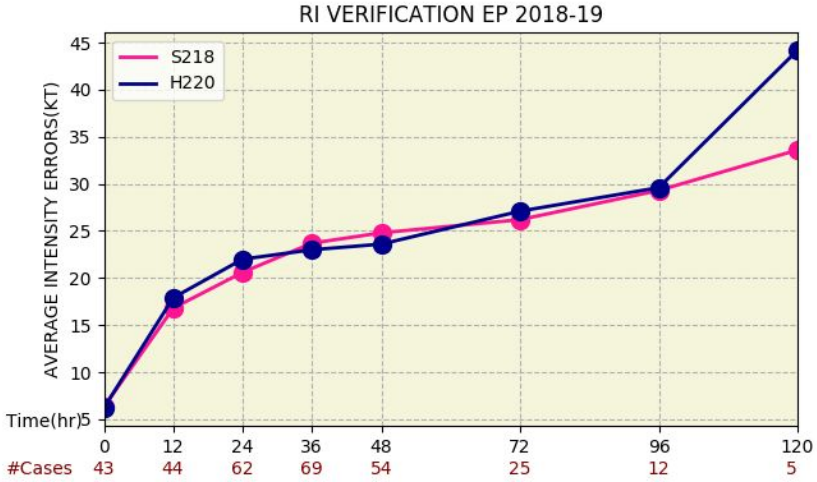
Pressure/Wind relationship for the EPAC basin (2018-2019)



Pressure-Wind relationships for H220 compare better with Observations at higher wind speeds (> 80 kts)

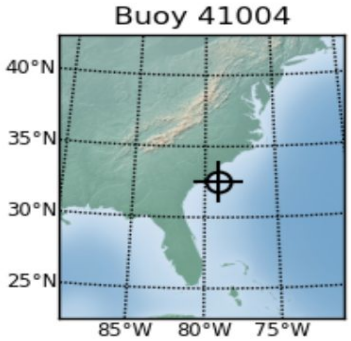
New Rapid Intensification Metric





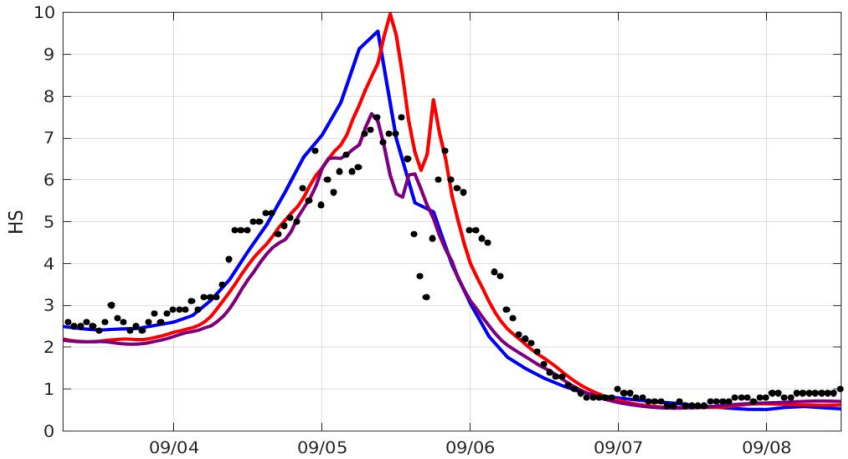
Track errors for these selected cycles are neutral or show improvements, while the intensity errors for H220 are overall neutral other than that on Day 5. But the sample size is too small for Day 5 for any firm conclusions.

WAVEWATCH III results for Hurricane Dorian (05L2019) with H220 (One way coupled)



Multi_1
HWRF
H220
buoy

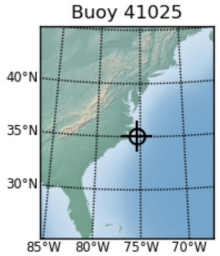
Significant Wave Height [m]

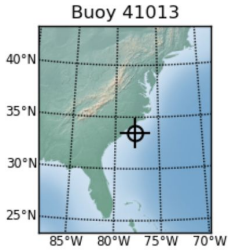


2019-09-03 06z

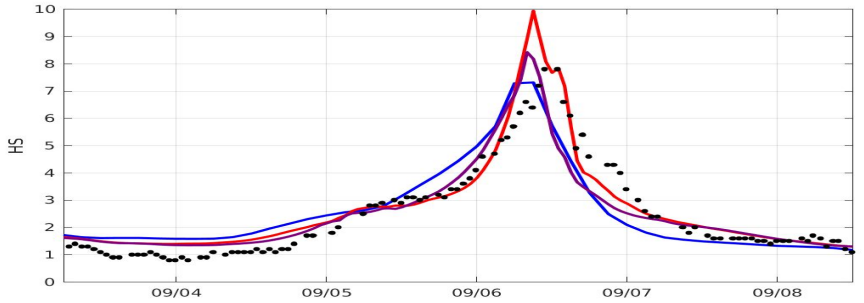
WAVEWATCH III results for Hurricane Dorian (05L2019) with H220 (One way coupled)

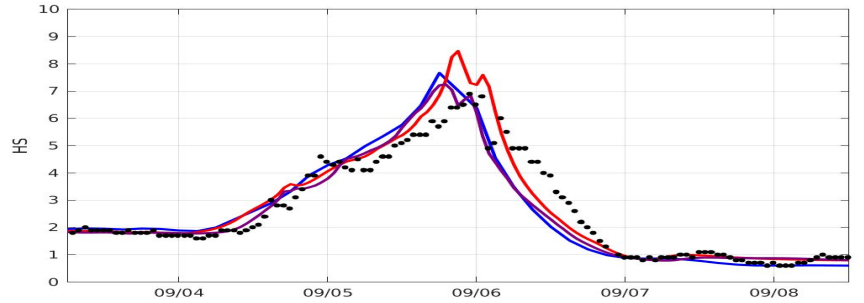
Multi_1
HWRF
H220
buoy



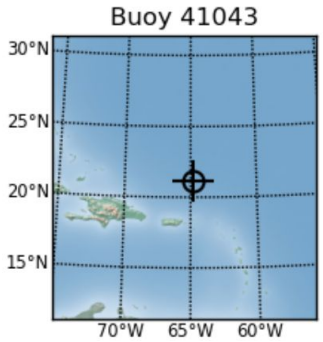


Significant Wave Height [m]
2019-09-03 06z



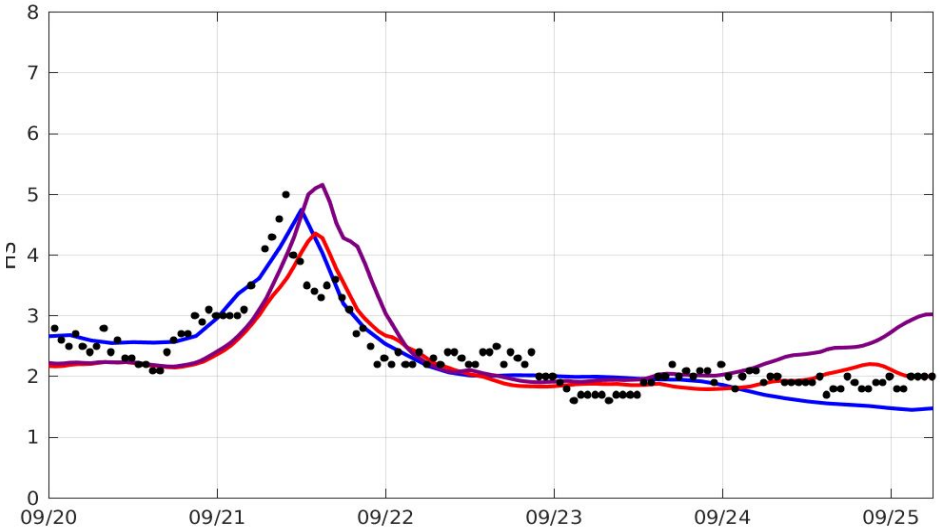


WAVEWATCH III results for Hurricane Jerry (10L2019) with H220 (One way coupled)



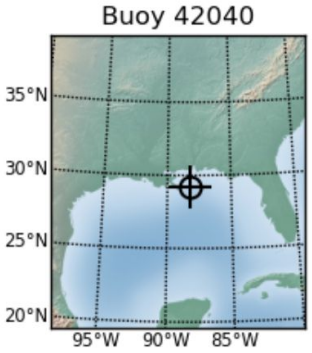
Multi_1
HWRF
H220
buoy

Significant Wave Height [m]



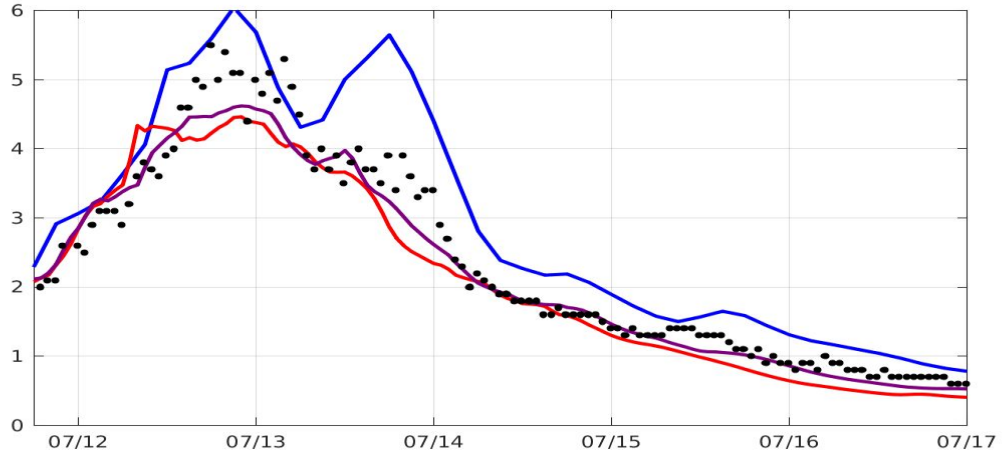
2019-09-20 00z

WAVEWATCH III results for Hurricane Barry with H220 (One way coupled)



Multi_1
HWRF
H220
buoy

Significant Wave Height [m]



2019-07-11 18z

Summary

- Further enhancements suggested for 2020 operational HWRF include:
  - Upgrades in model components consistent with observations, physics, data assimilation improvements including GSI and improved ocean initializations.
- H220 retrospective evaluation of 2018-2019 hurricane seasons (total 679 verifiable cycles in NATL, 620 in EPAC) demonstrated improved forecasts compared to current operational HWRF (S218) driven by operational FV3GFS (v15);
- Results from H220 for the North Atlantic basin suggested good improvements compared to S218 for both track and intensity (> 10%);
- Results from H220 for the North East Pacific suggested modest improvement compared to S218 for both track and intensity (max 5%);
- 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 are reduced for both basins at all lead times;
- Rapid Intensification Metrics are neutral to improved for both basins;

Summary (cont.)

- The one –way coupled WaveWatch III in H220 gives marginally better results for Significant Wave Heights as compared to operational HWRF;
- Overall, evaluation metrics in skill space confirmed positive improvements over operational HWRF;
- High horizontal and vertical resolutions, and ensemble based inner-core DA pave way for the planned future Hurricane Analysis and Forecast System (HAFS), while also bringing immediate benefits to operations;
- HWRF Development Process for both research and operations with community involvement is critical for making further enhancements and serves as a model for the broader UFS project;
- Seek more direct engagement of HFIP/NGGPS supported researchers for active participation in model evaluation, enhancements and future R2O;
- **Full credit to the entire EMC Hurricane team, NHC team, HRD team, DTC team and all our research and operational collaborators for another successful execution of pre-implementation T&E for implementing an improved HWRF model in operations.**

NHC's Verification for 2020 HWRF

Link

FY2020 HWRF/HMON Configuration (maintain diversity)

Note: Items in Red are different

	HWRF	HMON (approved)
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°; 71 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, WaveWatch-III	HYCOM, RTOFS, 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	91 nodes in 95-100 mins	43 nodes in 95-100 mins

What it takes in operations to run 2020 HWRF

- Resource requirements:

✔ Atmosphere/Ocean/Wave coupling: ~2184 cores or 91 nodes on Cray (increase from 1944 cores or 81 nodes);

✔ Run maximum 7 storms simultaneously for all global basins (5 maximum NHC storms, rest for JTWC storms);

✔ No change in delivery time (t+6)

IT Testing (Ongoing)

Test Objective	Comment
Missing GDAS EnKF members (total 80 mem)	if N missing >= 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
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	Coupler failure; TDR trigger issue, operational failure in IO basin

HWRF Version 13.0
Status as of 04/10/20

Project Information & Highlights

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

Scope: Improvements to system configuration, physics, data assimilation, vortex initialization and coupling for enhanced track and intensity skill

Implement with: HMON

Expected benefits: improved track & intensity forecast skill in all basins.

Dependencies: N/A

Schedule

Milestones & Deliverables	Date	Status
Freeze system code;	03/16/20	Completed
Complete full retrospective/real time runs and evaluation	04/03/20	Completed
Comments sought from PNS	04/14/20	On Track
OD Brief	04/15/20	Planned
Deliver final system code to NCO	04/17/20	Planned
Operational Implementation	7/20/20	Planned

EMC NCO Blue text indicates changes from previous quarter

Issues/Risks

Risks: Upgrades degrade forecast skill; **Mitigation**: Revert back to baseline stable configuration.

Resources

Staff: 1 Fed FTEs + 7 contractor FTEs; including Dev (Vortex Initialization, Physics, Coupling and DA)

Funding Source: STI & HSUP

Compute: EMC devonprod: 250 nodes for 4 months (devonprod); **EMC Dev**: 600 nodes for 5 months (devmax/devhigh); **Ops**: (Delta = 20%)

Archive: (Delta = TBD)

Next Steps

1. Retrospective T&E at EMC: **April 3, 2020 --- Completed**
2. Results shared with NHC: **April 3, 2020 ----- Completed**
3. NHC Evaluation: **April 9, 2020 -- Completed**
4. Briefing to EMC Director: **April 10, 2020 --- Now Completed**
5. Briefing to NCEP Director's Office: **April 15, 2020 (scheduled)**
6. Submission of Codes to NCO: ***April 17, 2020--- Code hand-off, submission of RFC forms, release notes and flow diagram***
7. SCN for 2020 HWRF : ***June 1, 2020***
8. NCO IT Testing completed: ***June-July, 2020***
9. IT briefing to NCEP Director's Office: ***July 15, 2020 (tentative)***
10. Implementation by NCO: ***July 20, 2020 (tentative)***