Operational Regional Hurricane Modeling at NCEP: Status and Planned Advances

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(with ongoing collaborations from AOML, DTC, NHC, GFDL, ESRL, FIU, OU, AER and others)

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NOAA / NWS / NCEP

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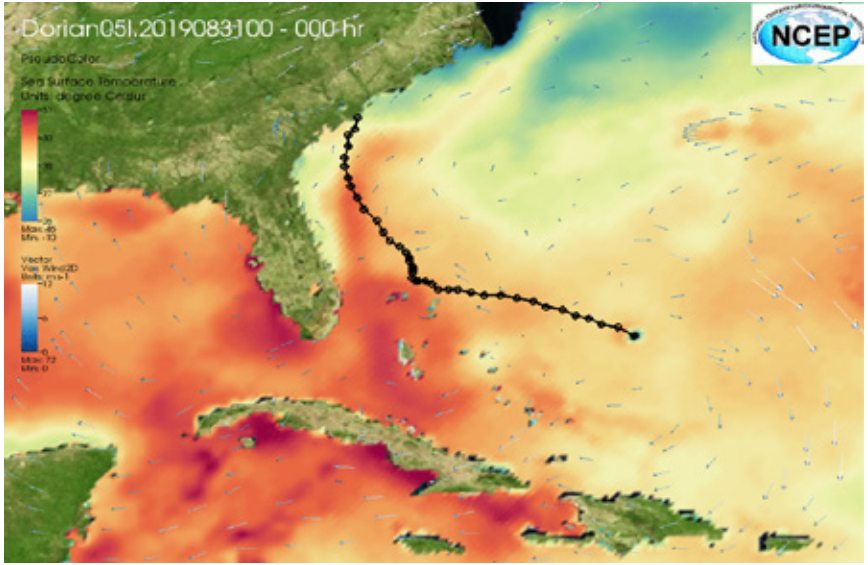
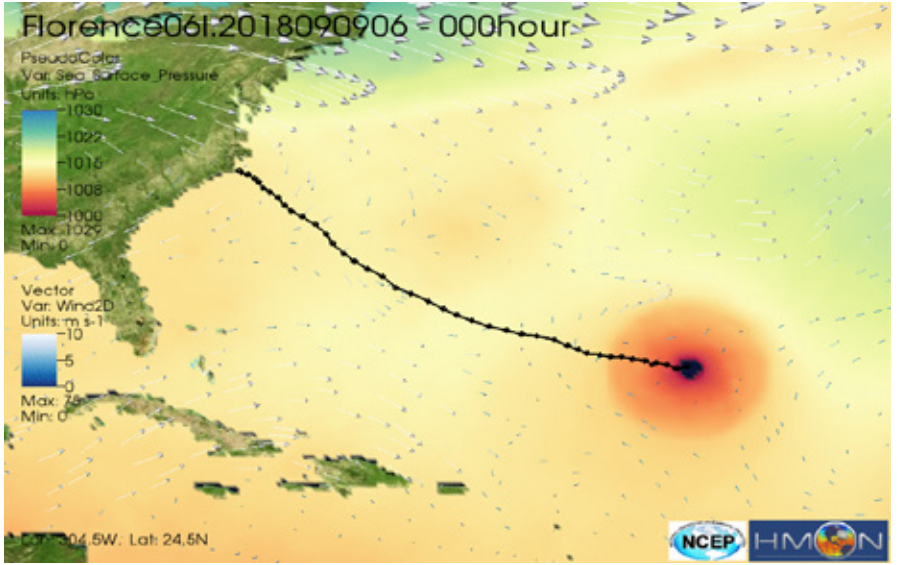
Current Operational Regional Hurricane Models at NWS/NCEP: HWRF & HMON





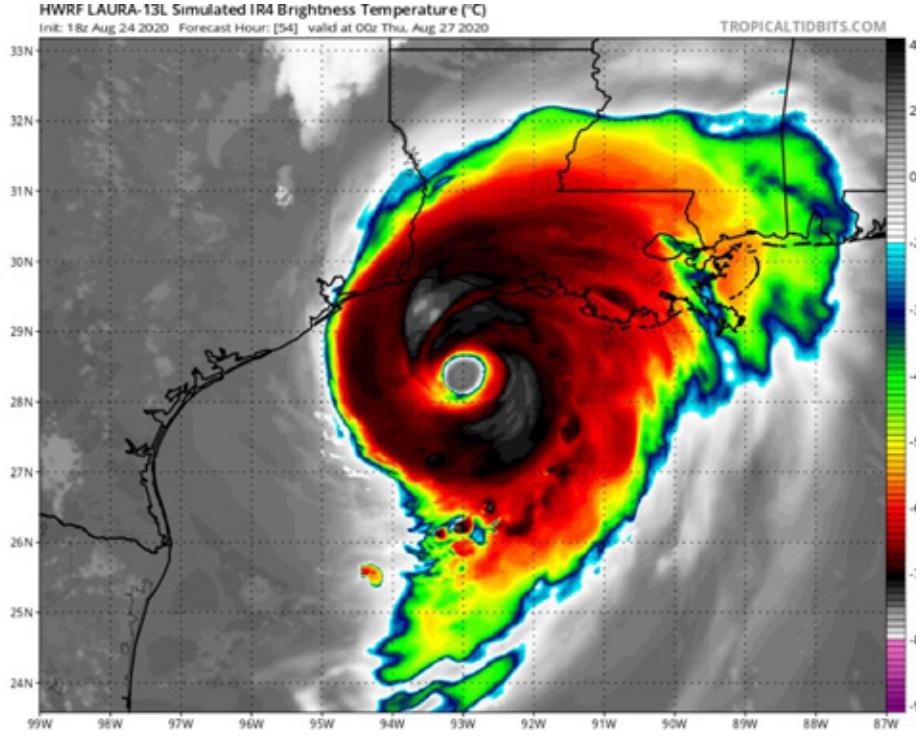
HWRF:

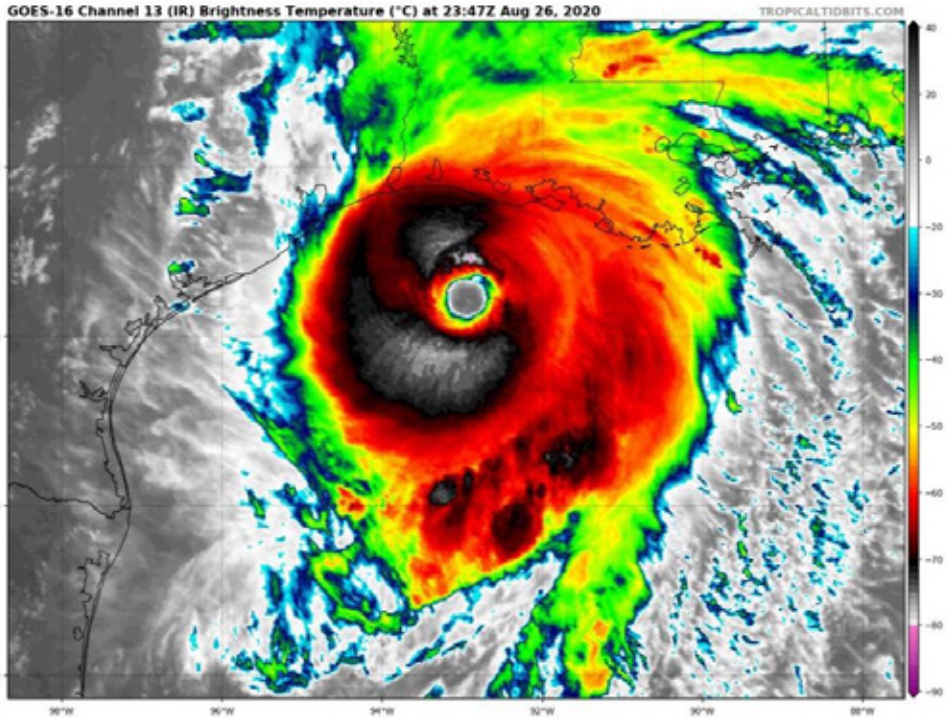
- **WRF-NMM+MPIPOM/HYCOM+WWIII Coupled System**
- **Triply nested 13.5/4.5/1.5 km resolution w/91 levels**
- **4D Hybrid EnVar DA System with Vortex Initialization, RTOFS for Ocean Initialization**
- **Advanced Physics**
- **All Global Basins (NHC and JTWC), max. 7 storms on-demand**

HMON:

- **NMMB+HYCOM Coupled System**
- **18/6/2 km resolution w/71 vertical levels**
- **Advanced Vortex Initialization, Advanced Physics**
- **RTOFS for Ocean Initialization**
- **NHC Basins, max. 5 storms on-demand**

FY20 HWRF/HMON Operational Performance



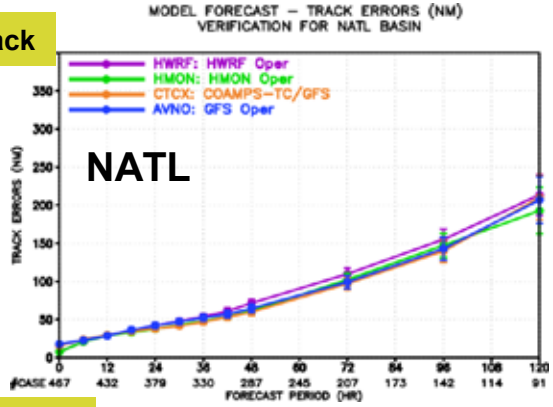


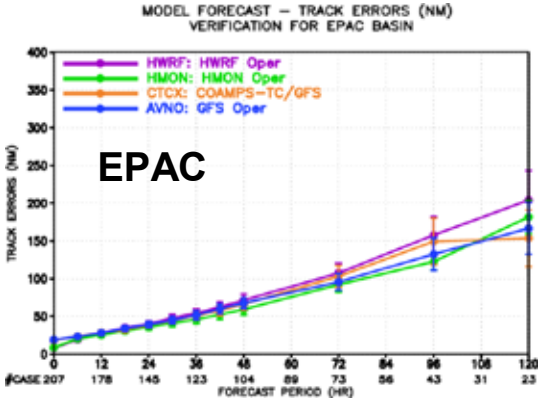
Comparison between HWRF's forecast @ 54 hrs (left panel) and the actual satellite image (right) from GOES-16 nearing Laura landfall.

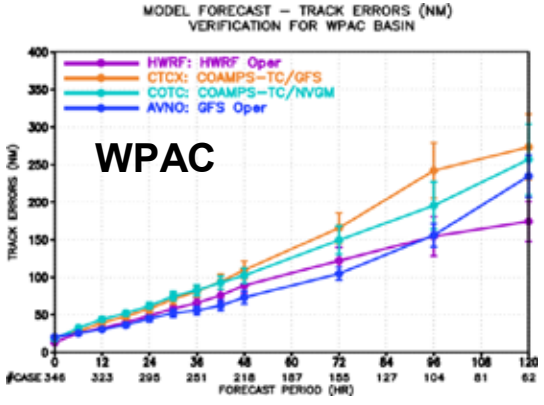
Thanks Levi Cowan!

Operational GFS/HWRF/HMON vis-à-vis Dynamic Models: Track and Intensity Errors for 2020 (Late Results)

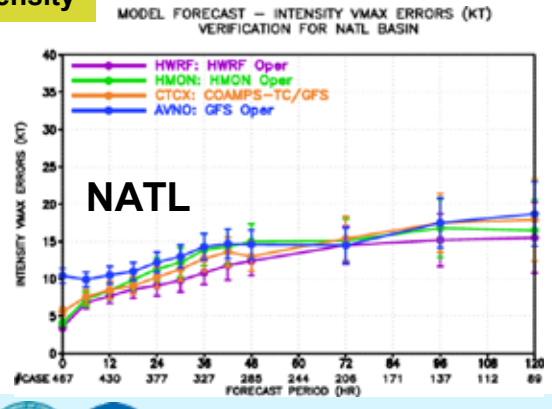
Track

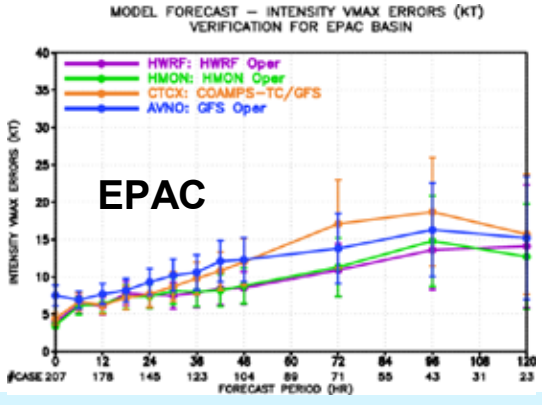


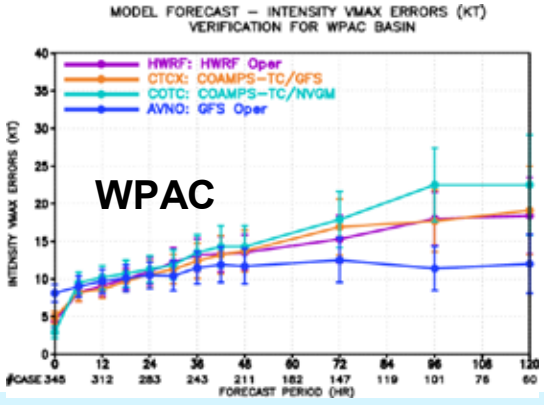




Intensity







Operational GFS, HWRF and HMON for 2020 Season: Highlights

❖ NATL Basin:

- ❖ Operational HWRF has the best intensity skill for all lead times. Average max errors are ~ 15 kts at Day 5
- ❖ Operational HMON has the best track skill for Days 4 and 5 with GFS a close second.
- ❖ Overall -- HWRF intensity performance was outstanding in the Gulf of Mexico (not shown).

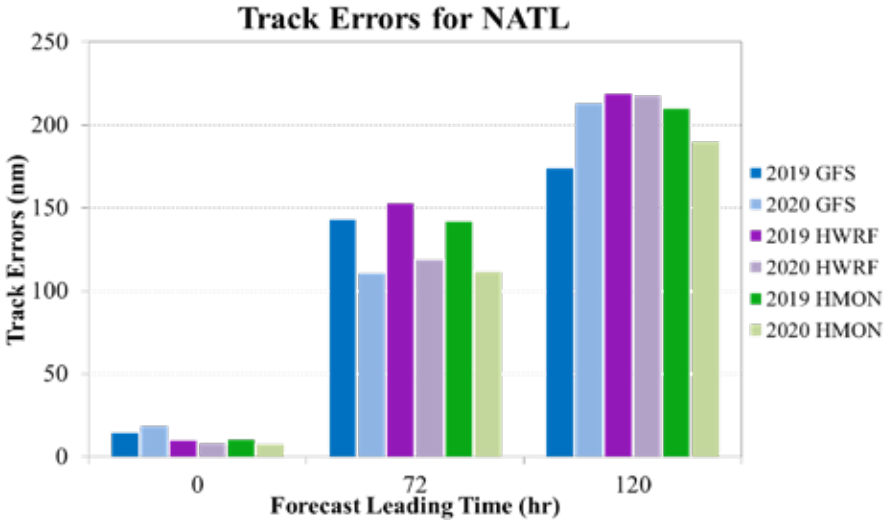
❖ EPAC Basin:

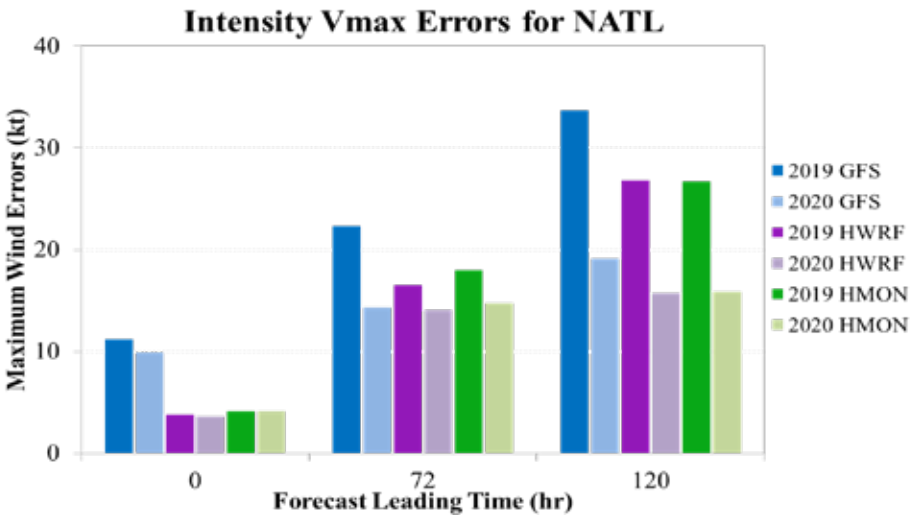
- ❖ Both Operational HWRF and HMON have the best intensity skill by far for all lead times. Again, average max errors ~ 15kts.
- ❖ Operational HMON and GFS had the lowest track errors.
- ❖ EPAC had much fewer storms this year.

❖ WPAC Basin:

- ❖ Operational GFS has the best intensity skill at all lead times.
- ❖ Operational GFS has the lowest track errors till Day 4; HWRF has the best track skill at Day 5

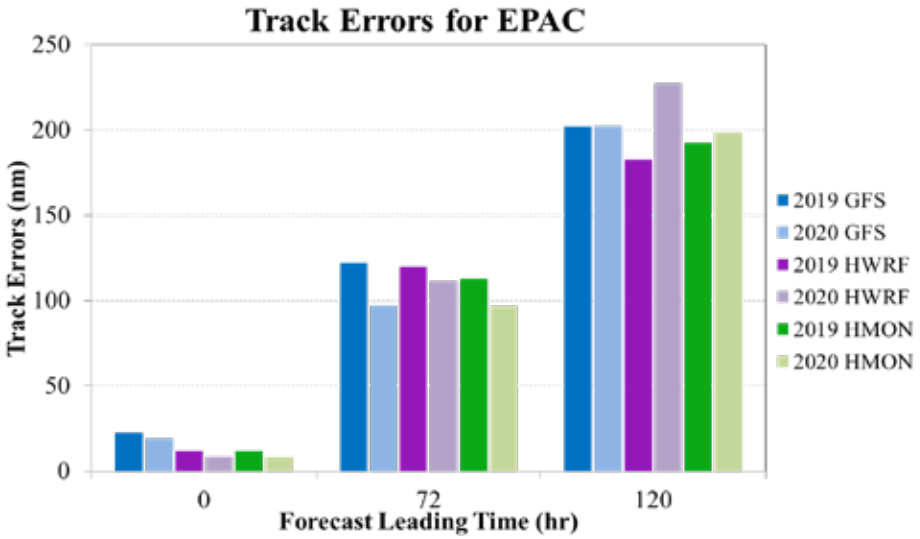
Operational GFS, HWRF and HMON for 2020 Season: NATL Basin

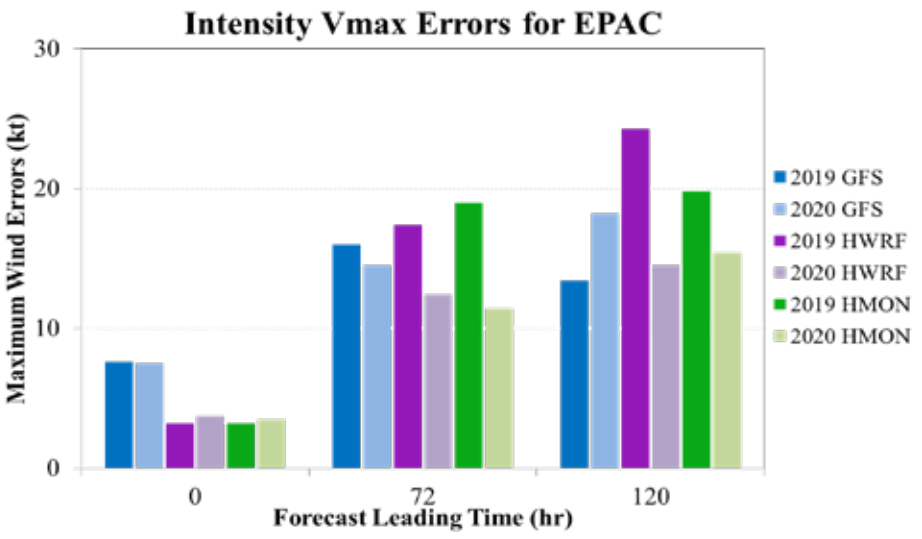




Track errors show very good improvements for 72 hr forecasts while intensity errors show excellent improvements for both 72 hr and 120 hr forecasts in the NATL basin for the 2020 season.

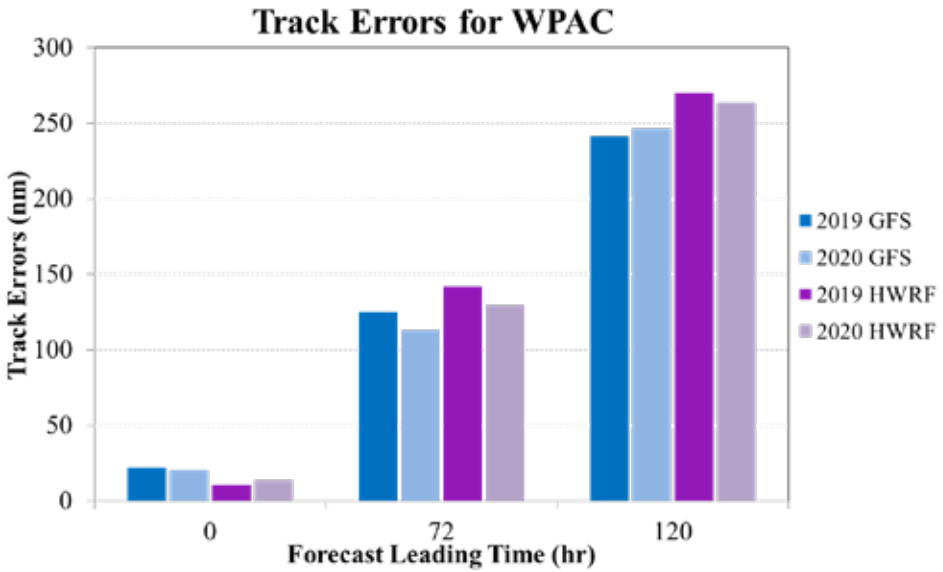
Operational GFS, HWRF and HMON for 2020 Season: EPAC Basin

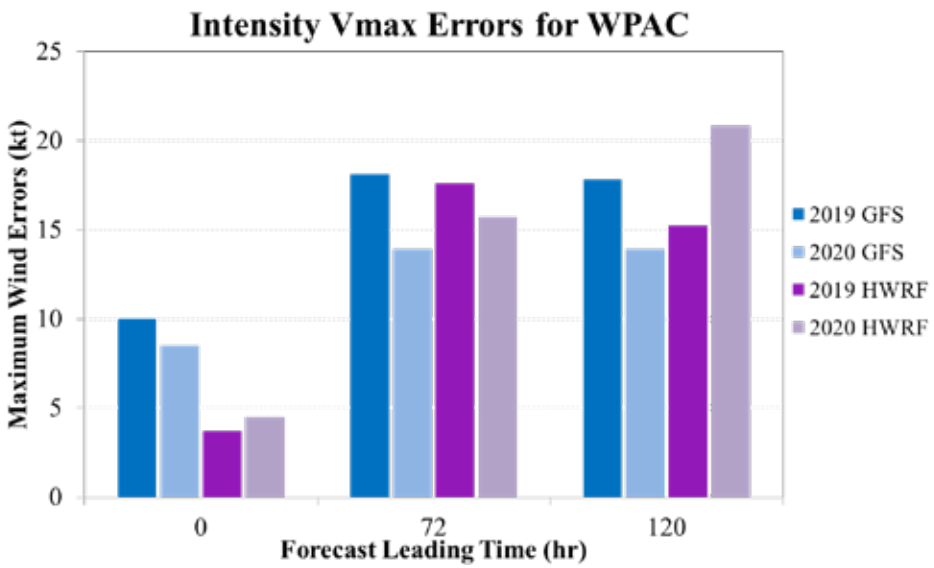




Track errors show very good improvements for 0 and 72 hr forecasts while intensity errors show excellent improvements for 72 and 120 hr forecasts (for HWRF & HMON) in the EPAC basin for the 2020 season.

Operational GFS, HWRF and HMON for 2020 Season: WPAC Basin





Both track and intensity errors show good improvements for 72 hr forecasts in the WPAC basin for the 2020 season. For 120 hr, results are mixed -- GFS gave us reduced intensity errors for this basin but HWRF errors were higher.

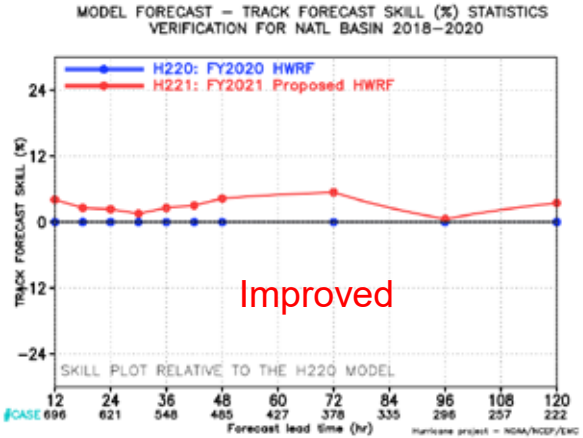
FY21 HWRF v13.1.0
and HMON v3.1 Upgrades

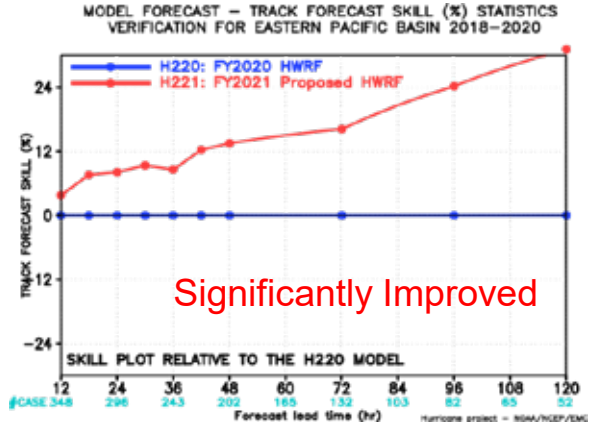
Retrospective testing with inputs from: GFS v16 and RTOFS v2

- Upstream data input: GFS v16 (Feb. 2021) and RTOFS v2 (Dec. 2020)
- T&E Period: Most of the TCs in 2018-2020 for NATL, 2019-2020 for EPAC
- H221/M221: HWRF/HMON driven by GFSV16 and RTOFS
- H220/M220: Current operational HWRF/HMON

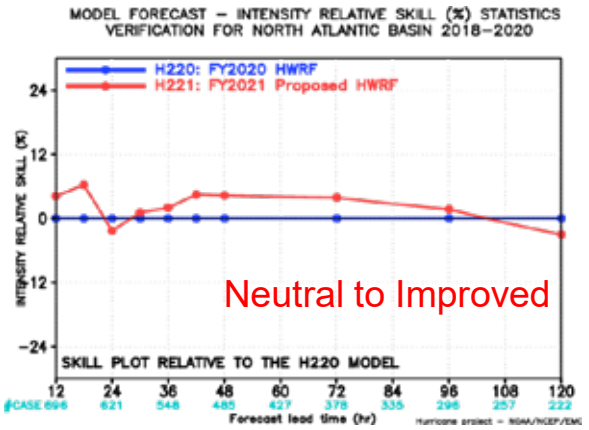
H221: HWRF (with GFS v16) vs H220: Operational HWRF

Track Forecast Skill



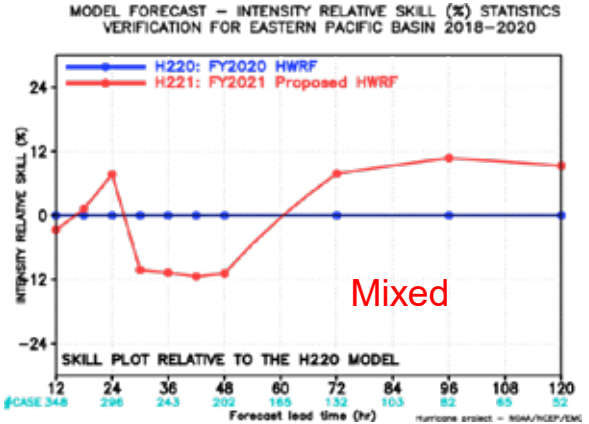


Intensity Forecast Skill



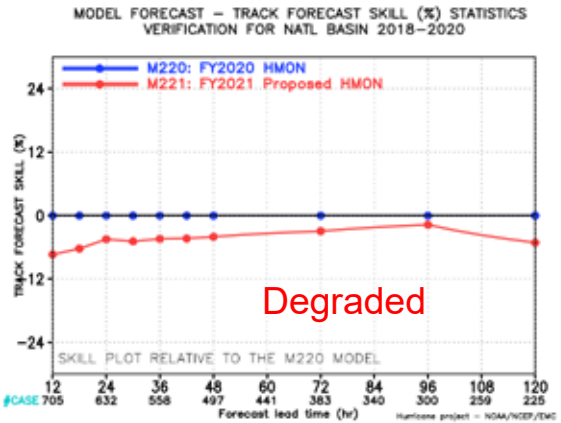
NATL

EPAC



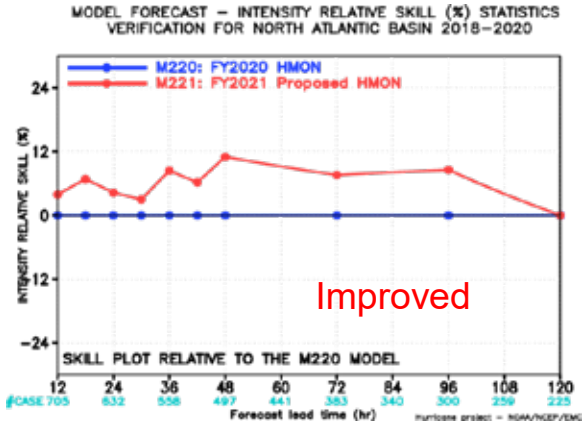
M221: HMON (with GFS v16) vs M220: Operational HMON

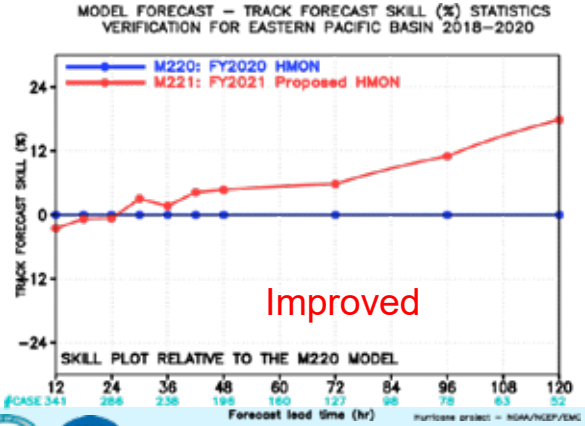
Track Forecast Skill



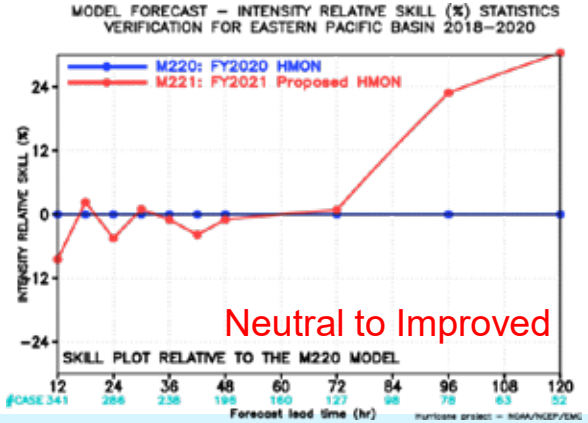
NATL

Intensity Forecast Skill





EPAC



GFS v16 Downstream Impacts on Hurricane Forecast Models

Impact on HWRF

	Track Forecast	Intensity Forecast	P-W relationship	RI POD/FAR
NATL	Positive at all lead times (~5%)	Positive at most of the lead times, except for marginally negative at day 1 and 5.	Improved	Improved POD/FAR
EPAC	Significantly positive at all lead times, >20% at day 4-5	Neutral overall. Negative between hrs 30-60 but positive for longer lead times at Days 3-5.	Neutral	Degraded POD/FAR

Impact on HMON

	Track Forecast	Intensity Forecast	P-W relationship	RI POD/FAR
NATL	Negative at all lead times after day-1 (<~5%)	Positive at all lead times, ~10% between day 2-4	Improved	Degraded POD Neutral FAR
EPAC	Significantly positive after day 1, >10% at day 4-5	Neutral before day 3, Significantly positive at day 4 and 5 (>20%)	Improved	Improved POD/FAR

Note: H221/M221 Produce stronger storms than H220/M220

HWRF/HMON Configuration (maintain diversity)

Note: Items in Red are different

	HWRF	HMON
Dynamic core	Non-hydrostatic, NMM-E	Non-hydrostatic, NMM-B
Nesting	13.5/4.5/1.5 km; 77°/18°/6°; 75 vertical levels; Full two-way moving	18/6/2 km; 75°/12°/8°; 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 98 mins	43 nodes in 100 mins*

Future Implementations/Plans

- FY21/22 – **Second Moratorium (**new WCOSS available in July 22**)**
- FY23 – HAFS Initial Operational capability

Hurricane Analysis and Forecast System (HAFS): A collaborative Project in UFS Framework

07 DTC

06 OFCM/AOC

05 ESRL/NESII

04 ESRL/GSD

01 NCEP/EMC

02 AOML/HRD

03 GFDL

Transition to UFS Applications

Planned 2020 HAFS Real-time Experiments

1. **HAFS v0.1A:** FV3-based Stand-Alone Regional HAFS in the NATL basin with ocean-coupling.

1. **HAFS v0.1B:** FV3-based Global HAFS with high resolution static nest nest in the North Atlantic Basin

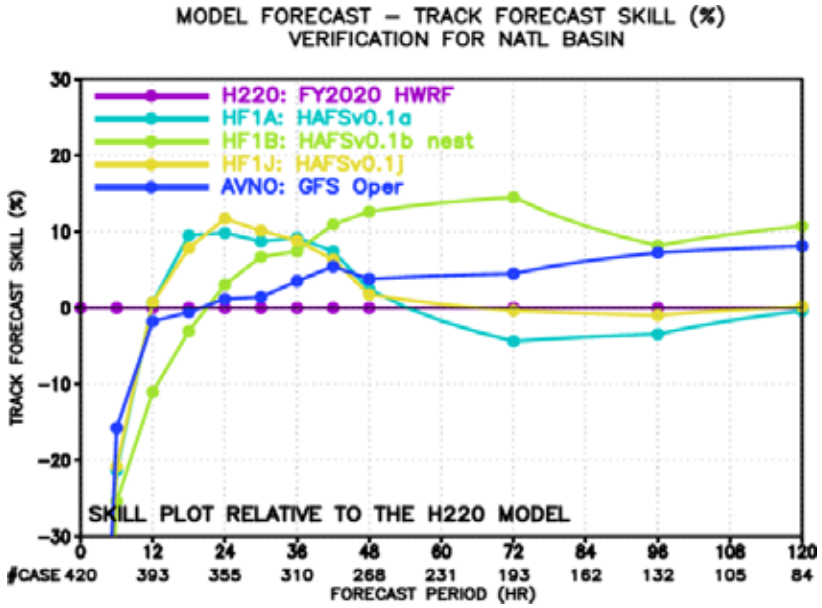
1. **HAFS v0.1E:** FV3-based Stand Alone Regional HAFS Ensemble Prediction System Experiment for the North Atlantic Basin

1. **HAFS v0.1J:** FV3-based Stand Alone Regional HAFS with the new Extended Schmidt Gnomonic (ESG) grids for forecasts in the North Atlantic and North-East Pacific Basins.

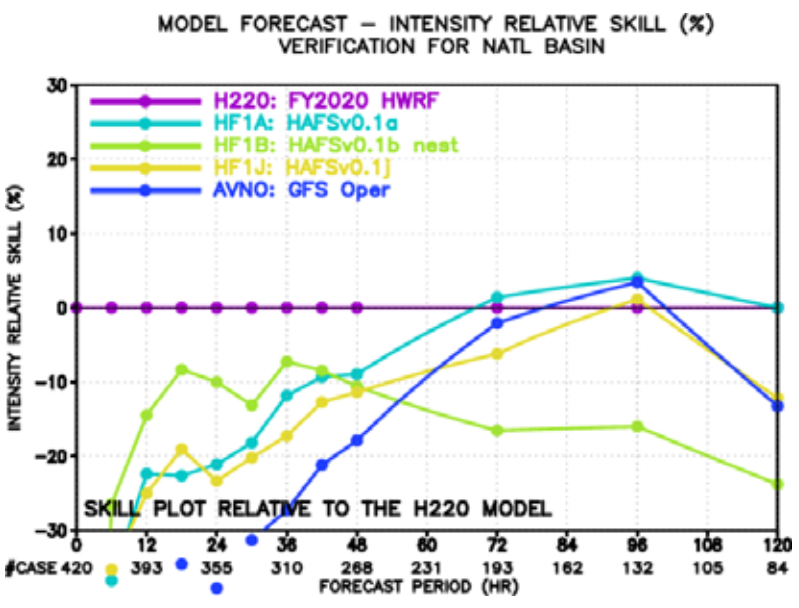
HAFS Performance for 2020 NATL Storms (03-30L)

HWRF
HF1A
HF1B
HF1J
AVNO

Track skill



Intensity skill

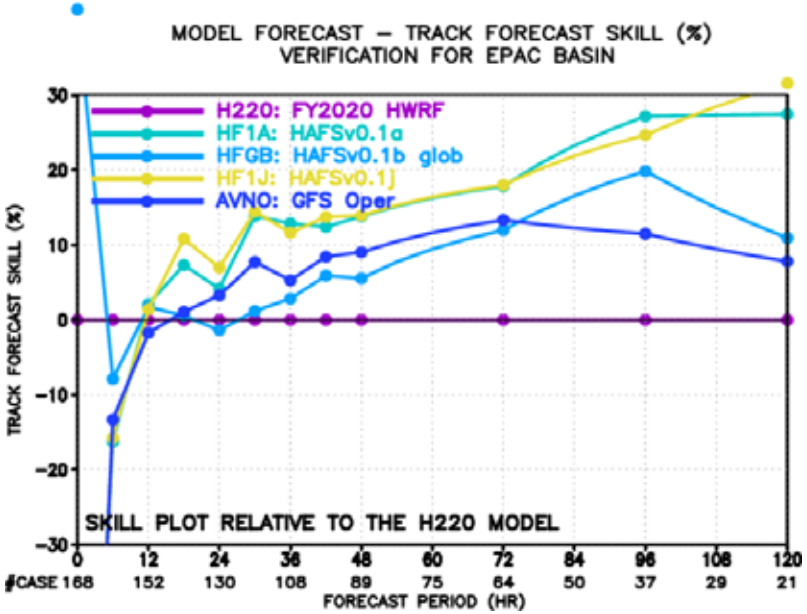


HAFS-B (nest) had the best track skill overall followed by HAFS-J and HAFS-A. All HAFS configurations lag in intensity skill behind operational HWRF for early lead times. HAFS-A catches up to HWRF by Day 3.

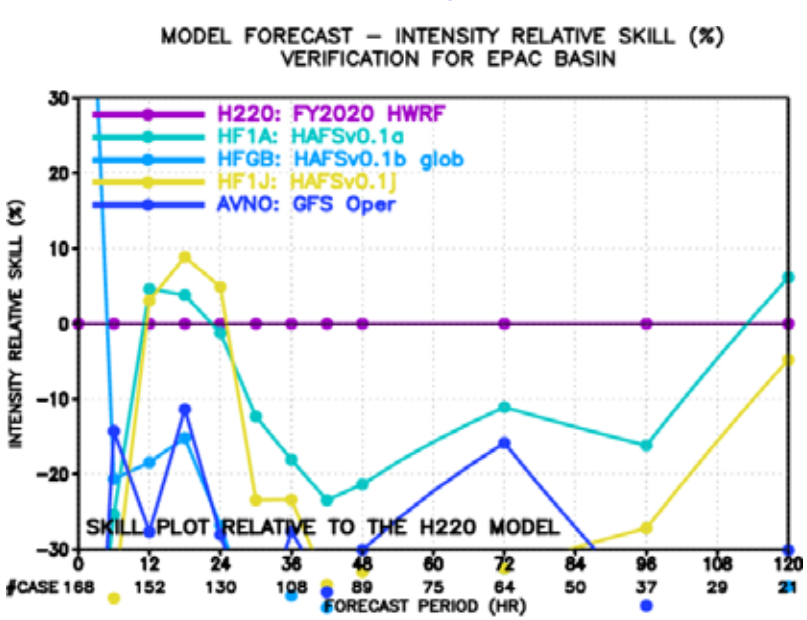
HAFS Performance for 2020 EPAC Storms (03-19E)

HWRF
HF1A
HF1B
HF1J
AVNO

Track skill



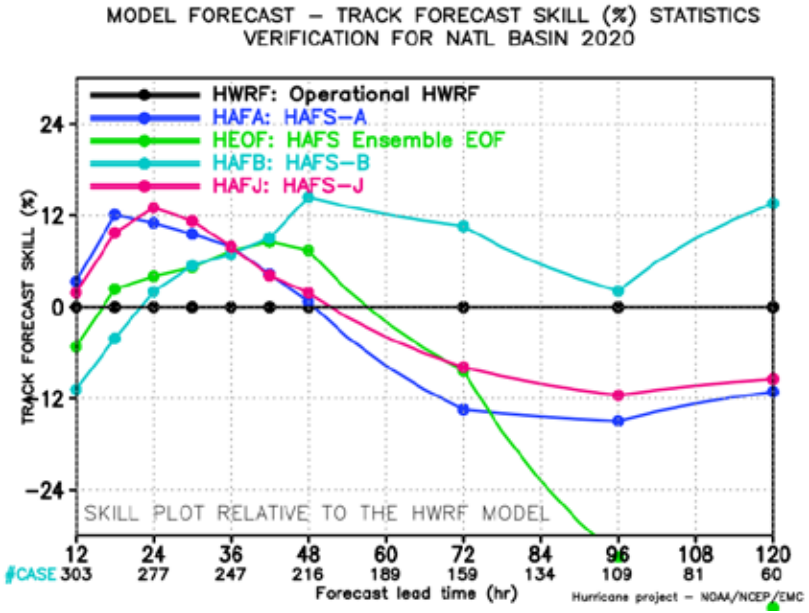
Intensity skill



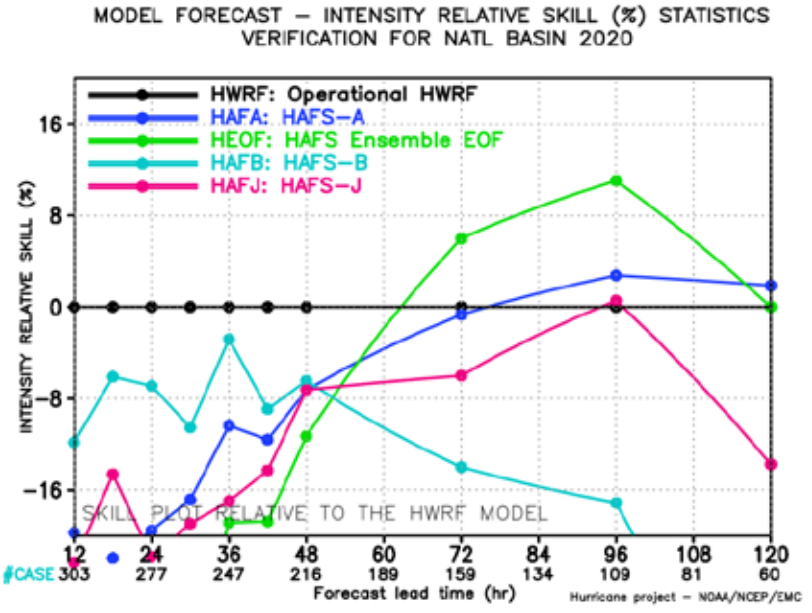
HAFS-A and HAFS-J had the best track skill followed by HAFS-B (global). All HAFS configurations lag in intensity skill behind operational HWRF.

HAFS v0.1E Performance for 2020: NATL Basin

Track skill



Intensity skill



HAFS-E has comparable track skill with HAFS-A and HAFS-J till Day-3, but lower thereafter. HAFS-E has lowest intensity errors for extended lead times for Days 3-5.

HAFS -- Ongoing Developments

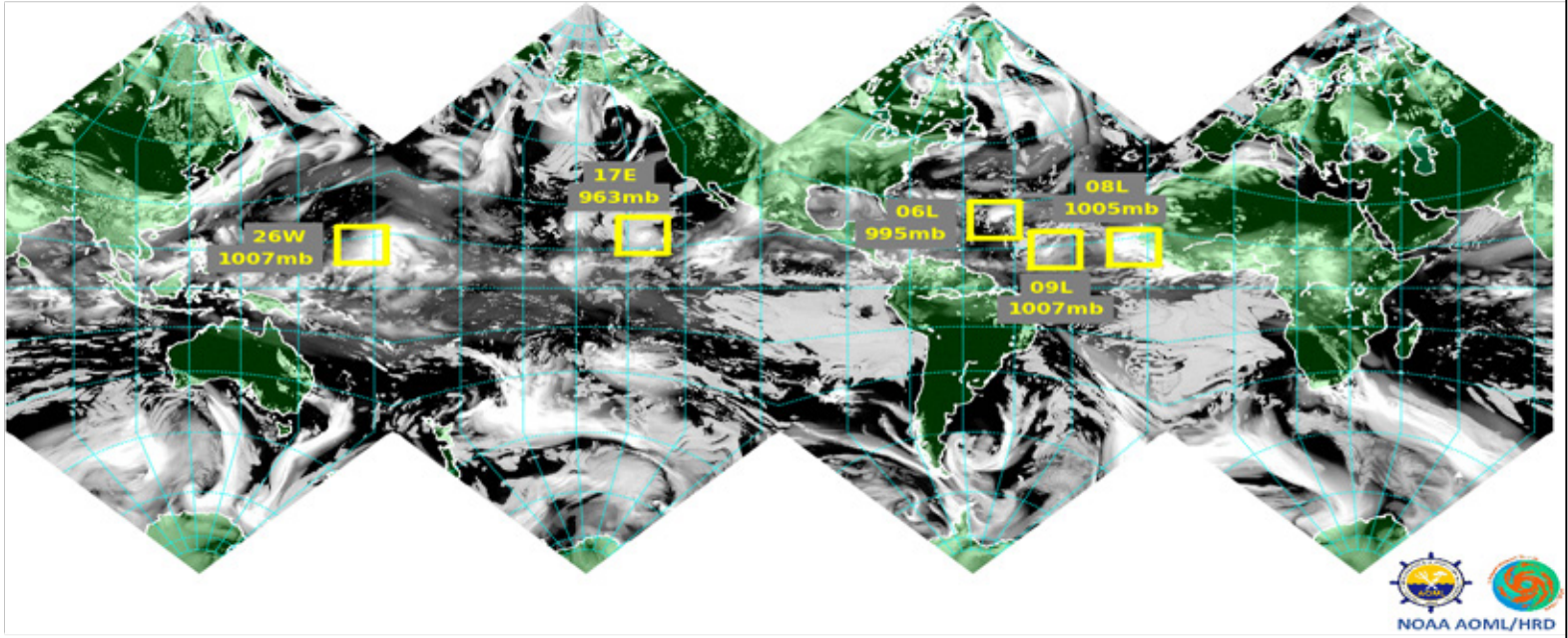
- Integrate HAFS developments for improved analysis and forecasts:
  - Leverage UFS global and UFS-CAM DA developments
  - Build a modular DA workflow for HAFS
  - Moving Nest Algorithms in FV3 -- Dynamics and Physics

- Accelerate our ability to initialize Hurricane vortex and its environment with advanced DA methods (FY21 and FY22, development and evaluation)
  - New data ingestion and quality control methods
  - New DA algorithms and technologies for inner-core (vortex-scale) DA

- Enhance physics for Hurricane Application
  - PBL, Microphysics, Radiation, Surface physics, and the interactions among schemes

- Conduct experiments with the above advancements for improved analysis and forecast skill

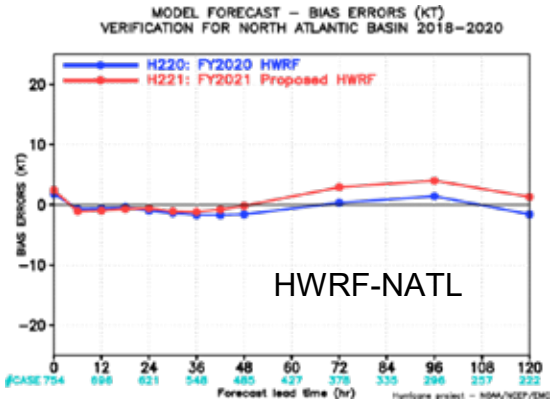
Long-term Target for HAFS/GFS

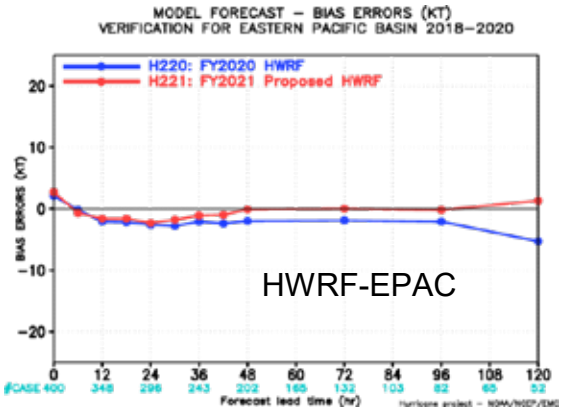


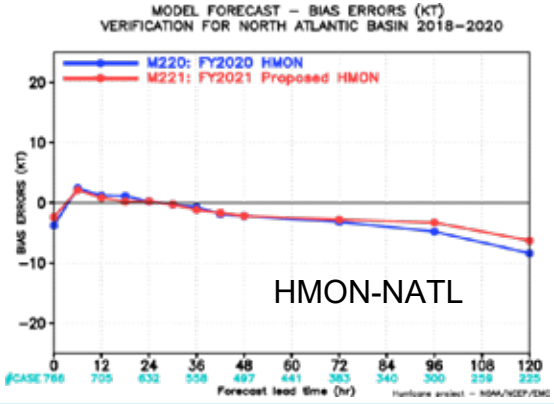
06L: Florence; 08L: Helene; 09L: Isaac; 17E: Olivia; 26W: Mangkhut

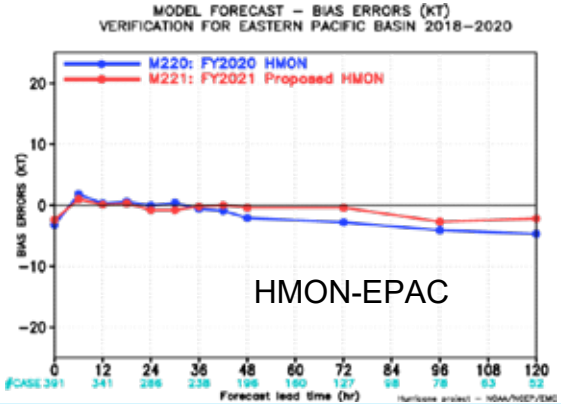
Thank You !

Model Intensity Bias Comparisons



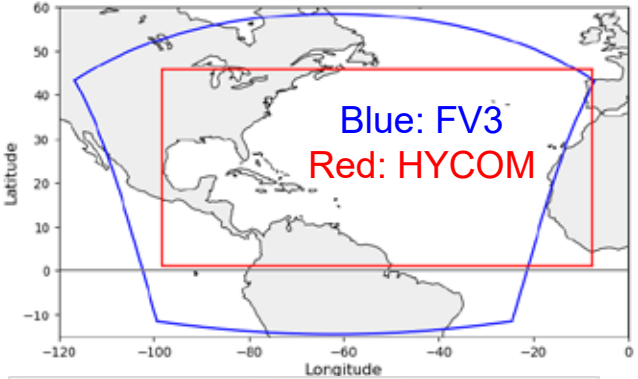


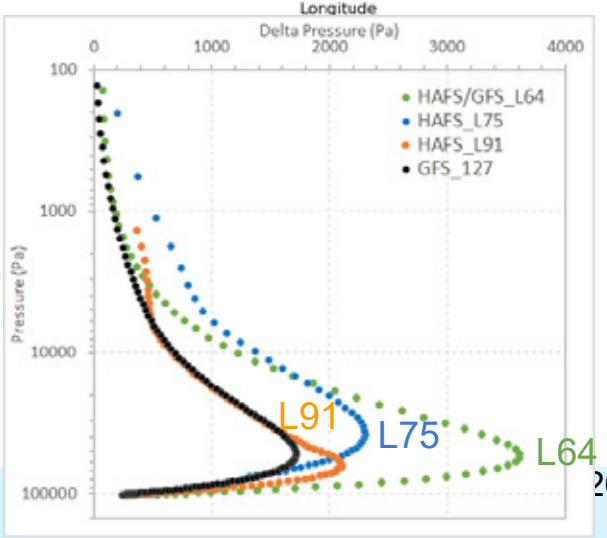




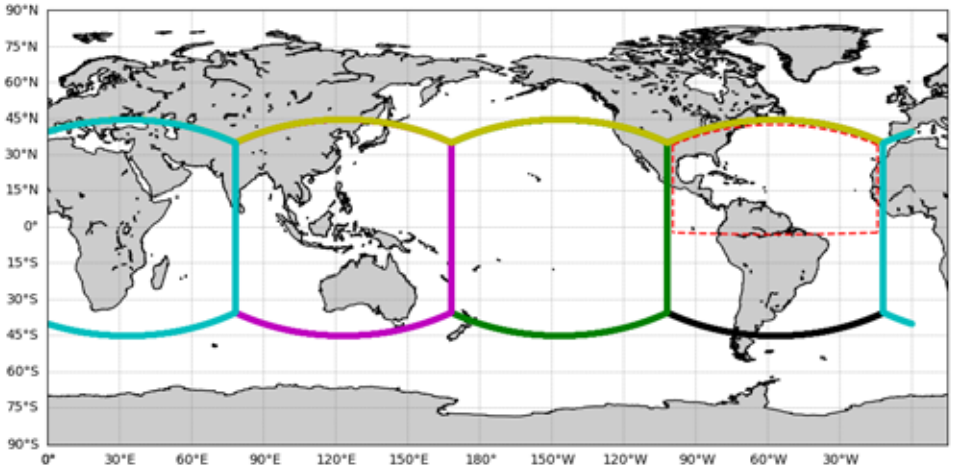
The HAFSv0.1A Configuration

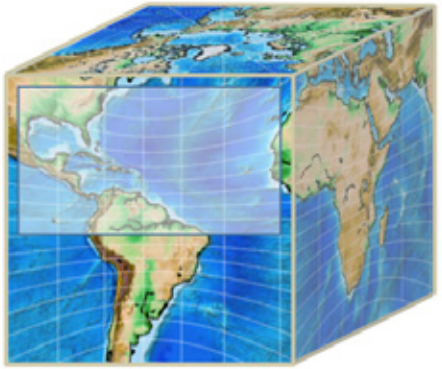
- The FV3 component (based on 2019 HAFS.v0.0A)
  - FV3 model domain (~85x72 deg)
  - 91 vertical leves from
  - Use the HAFS_V0_gfdlmp_nocpnsstugwd physics suite
    - GFDL microphysic; RRTMG radiation; No CP; Noah LSM; GFS surface layer with HWRF exchange coefficients; GFS EDMF PBL with HWRF modification; Both convective and orographic GWD are turned off; Turning off the NSST component
  - GFS NEMSIO file for IC; 3-hrly GFS grib2 files for LBC
- The HYCOM ocean model component
  - Cover NATL basin (1-45.78N, 261.8-352.5E) at a 1/12-degree resolution with 41 vertical layers
  - Ocean IC from RTOFS nowcast and/or forecasts
  - Use persistent oceanic LBC
  - Atmospheric forcing from 0.25-degree GFS grib2 files to cover non-overlapped area





The HAFSv0.1B Configuration



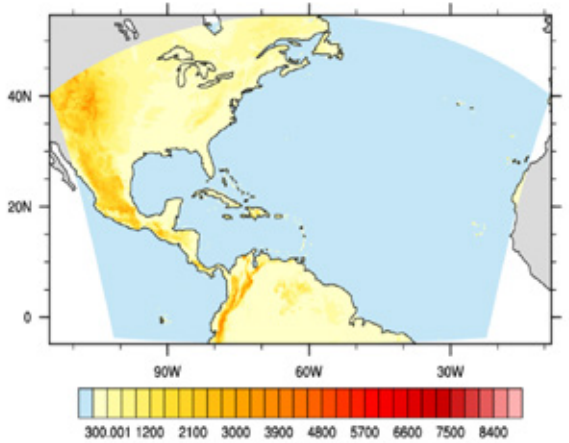


- One static nest over the Atlantic.
- Use “tropical channel” global layout of FV3.
- Forecasts length of 174 hours (7.25 days) in order to provide 7-day interpolated forecast .
- Include results for the global domain, to allow for direct comparison with operational GFS; assess impact of the nest on the global domain through 2-way feedback.
- Physics and dynamics options similar to HAFS v0.B in 2019, upgrades to PBL physics.

Goal: In addition to facilitating comparisons with operational and experimental model guidance, assess impact of high-resolution nests in HAFS on the global circulation, as well as feedback of the nests on each other.

The HAFSv0.1E Configuration

- Basic configuration, based on HAFSv0.1A
  - One control member plus 17 perturbed ensemble members
  - Coarser resolutions: ~6km vs. 3km; L64 vs. L91
  - Cumulus parameterization on
  - Twice a day (00Z and 12Z), Atlantic basin only
- IC/BC Perturbation:
  - IC/BC: GEFS grib2 (0.5x0.5)
- Model Physics:
  - Stochastic kinetic energy backscatter (SKEB)
    - Counteract excessive energy dissipation from numerical diffusion and in wave drag, and deep convection
    - Stream function is randomly perturbed to represent upscale kinetic energy transfer
  - Stochastically perturbed physics tendencies (SPPT)
    - Represents uncertainties in physical parameterizations
    - Multiplicative noise modifies total parameterized tendency
  - Stochastically perturbed PBL humidity (SHUM)
    - Represents variability in the sub-grid humidity field
    - Similar to SPPT, but directly modifies low-level humidity field instead of tendency

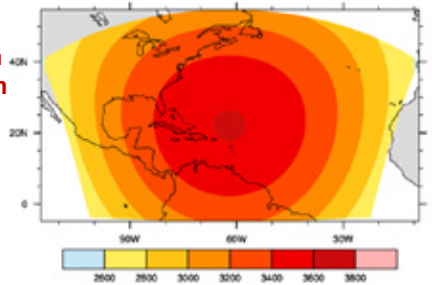


HAFS v0.1J with ESG (Extended Schmidt Gnomonic) grid - a more uniform grid for HAFS

- The default GFDL grid has non-uniform resolution over a large Atlantic domain: coarser resolution in the center; higher resolution over edges
- A more homogenous grid allows larger timestep; not necessarily limited by the minimum resolution in GFDL grid
- Easy design for large domains (e.g. basin-scale HAFS)

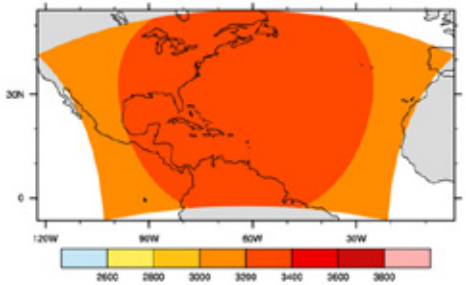
GFDL grid (default)

Min: 2.56 km
Max: 3.61 km



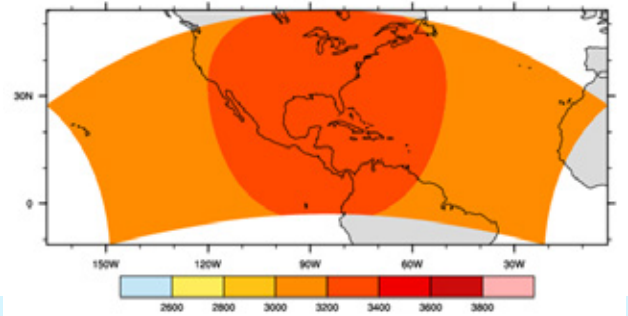
A more homogenous grid

ESG grid



Min: 3.18 km
Max: 3.22 km

A basin-scale HAFS ESG domain (North Atlantic + East Pacific)



HFIP Real-time Model Configurations

	HWRF	HWRF-B	HMON	HAFS-A	HAFS-J	HAFS-E	HAFS-B
Resolution Model top	13.5/4.5/1.5km L75 10hPa		18/6/2km L71 50hPa	~3km L91 10hPa	~3km (ESG) L64 0.64hPa	~6km L64 0.64hPa	~13-3km glb-nest L75 2hPa
Domain	D1: ~82º×78º D2:~18º×18º D3: ~6º×6º	D1: ~194º×84º D2: ~16º×16º D3: ~6º×6º	D1: ~75º×75º D2: ~12º×12º D3: ~8º×8º	~85º×72º 2881×2401	~85º×56º 3240×1920	~85º×56º 1441×961	Global (C768) ~70º×42º 2376×1428
IC/BC	GFSv15	GFSv15	GFSv15	GFSv15	GFSv15	GEFS	GFSv15
Coupling Ocean IC	POM RTOFS	POM RTOFS	HYCOM RTOFS	HYCOM RTOFS	No ocean model NSST	No ocean model NSST	No ocean model NSST
DA/VI	Yes/TDR	Yes/No TDR	No/VI	No	No	No	No
Physics Differences				**Physics Differences**			
Radiation	Modified RRTMG		RRTMG	RRTMG (30mi)	RRTMG(60mi)	RRTMG(60mi)	RRTMG(60mi)
PBL/Surf	EDMF/Updated GFDL		EDMF/GFDL	EDMF/M-GFS	EDMF/M-GFS	SHUM/M-GFS	M-EDMF/M-GFS
CP/MP	Updated SWSAS		SWSAS	No/GFDL	No/GFDL	SWSAS/GFDL	No/GFDL
LSM	Updated NOAH		NOAH	NOAH	NOAH	NOAH	NOAH