NATIONAL WEATHER SERVICE

Planned FY23 Hurricane Modeling at NWS/NCEP: Operational implementation of the first version of Hurricane Analysis and Forecast System (HAFS)

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Hurricane Analysis and Forecast System (HAFS):

A collaborative Project in UFS Framework

Overview

- HAFS isa UFS-based application, focusing on transitioning tropical cyclone modeling research to operations.
- HAFS is an atmosphere-ocean-wave coupled TC forecast system, featuring convection-allowing high-resolution storm-following nests, vortex initialization, inner-core data assimilation, TC-calibrated model physics.
- HAFS has been running in real time for four years (2019-2022), an Initial Operational Capability (IOC) is planned for 2023, which requires two configurations replacing operational HWRF/HMON

Objectives (aligned with HFIP goals)

- Reduce forecast guidance errors, including during RI, by 50% from 2017 baselines;
- Produce 7-day forecast guidance as good as the 5-day forecast guidance in 2017;
- Improve guidance on pre-formation disturbances, including genesis timing, and track and intensity forecasts, by 20% from 2017;
- Improve hazard guidance and risk communication based on social and behavioral science, to modernize the TC product suite (products, information, and services) for actionable lead-times for storm surge and all other threats

Acknowledgement to HAFS model active developers

Atmospheric model dynamics/configurations/workflow **NCEP/EMC** Avichal Mehra, Bin Liu, Dusan Jovic, JungHoon Shin,Vijay Tallapragada, Biju Thomas, Jun Wang, Zhan Zhang **AOML/HRD** Ghassan Alaka, S. Gopalakrishnan, William Ramstrom, Xuejin Zhang, **DTC** Kathryn Newman, Mrinal Kanti Biswas, Linlin Pan **GFDL** Rusty Benson, Lucas Harris, Timothy Marchok, Joseph Mouallem	**Ocean/Wave coupling through CMEPS** **NCEP/EMC** Maria Aristizabal, Matthew Masarik, Jessica Meixner, John Steffen **AOML/HRD** Lew Gramer **AMOL/PhOD** Hyun-Sook Kim **NRL/ESMF** Rocky Dunlap, Dan Rosen, Gerhard Theurich, Ufuk Turuncoglu,	**Data Assimilation** **NCEP/EMC** Li Bi, Ting Lei, Xu Li, Daryl Kleist **AOML/HRD** Jason Sippel, Sarah D. Ditchek **OU** Xu Lu, Xuguang Wang **UM/CIMAS** Altug Aksoy, Dan Wu **UMD** Joseph Alan Knisely, Kenta Kurosawa, Jonathan Poterjoy **SUNY/U at Albany** Ryan Torn, Eun-Gyeong Yang
Model Pre- and Post-processes **NCEP/EMC** Hui-Ya Chuang, Bantwale Enyew, Qingfu Liu, Yonghui Weng, Chuan-Kai Wang, Wen Meng, Lin Zhu	**Atmospheric Physics** **NCEP/EMC** Jongil Han, Xu Li, Chunxi Zhang, Weiguo Wang, Fanglin Yang **AOML/HRD** Andrew Hazelton **UAH** Xiaomin Chen	**Verification/Evaluation** **NCEP/EMC** Olivia Ostwald, Jiayi Peng **NHC** Michael Brennan, Ben Trabing, David Zelinsky, Jon Martinez

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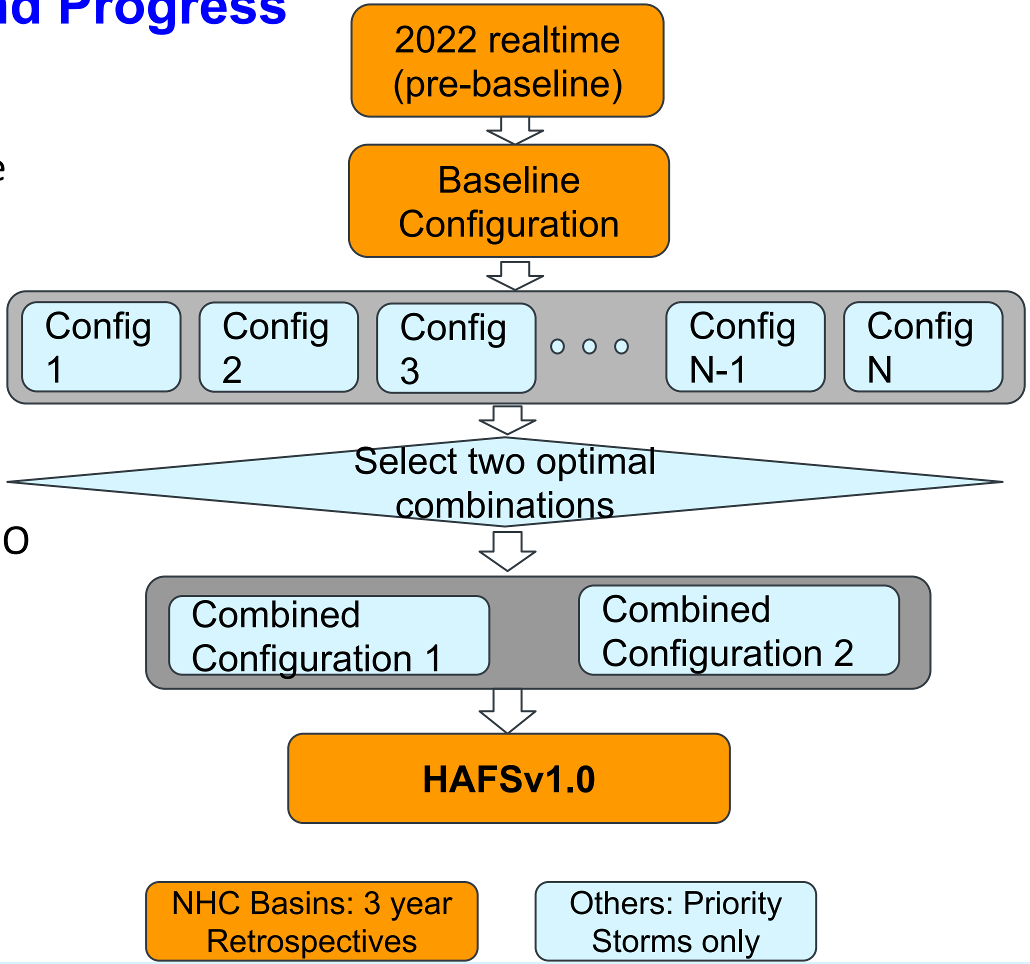
HAFSv1 Development Strategy and Progress

- Use HWRF/HMON as benchmarks.
- Phase-1: Establish baseline (from pre-baseline). Conduct 3-year retrospective runs (2020-2022) for storms in North Atlantic (NATL) and Eastern Pacific (EPAC) basins
- Phase-2: Conduct experiments with upgraded dynamics, physics, vortex initialization, data assimilation, and/or coupling separately for a set of priority storms, including TCs in CPAC*, WPAC and IO basins
- Phase-3: Combine and select promising phase-2 upgrades to finalize HAFSv1.0 configurations
- Final stage: Freeze HAFS development, and conduct 3-year retrospectives



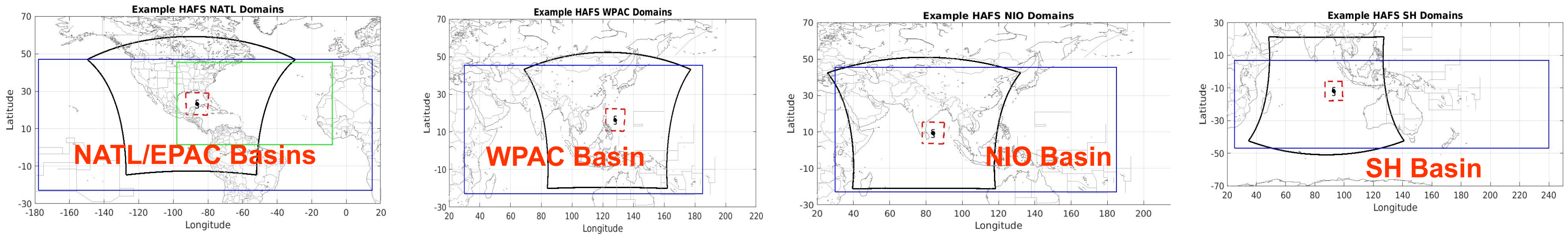
*There are no numbered/named storms in CPAC in the past 3 years, technical tests have been conducted, no T&E.

Scope of HAFS v1.0 Upgrades (from HAFS v0.3, 2022 real time)

- **System Framework**
  - ESG grids with moving nest
  - Improve Model Efficiency
  - Improve Workflow
- **Moving nest improvement**
  - Balance moving nest boundary mass for terrain consistency
- **CMEPS based Coupling Upgrades**
  - HYCOM coupling flux bugfix
  - Extended HYCOM domain
  - VIIRS veg type
  - One-way wave coupling
- **Model Physics calibration for TC**
  - Adjust mixing length scales
  - Adjust entrainment parameter in convection
- **Initialization/Data Assimilation Improvements**
  - Adjust vortex initialization threshold
  - Upgrade 3DEnVar to 4DEnVar using GDAS ensemble
  - NEXRAD related GSI parm name list option changes
  - Use enhanced GOES-16 AMVs and GOES-18 AMVs
- Data Assimilation will be active only for NHC/CPHC basins

Two Configurations for HAFS IOC

HAFSv1.0	Domain*	Resolution*	DA/VI	Ocean/Wave Coupling	Physics	Basins
HFSA	Storm-centric with one moving nest, parent: ~78x75 deg, nest: ~12x12 deg	Regional (ESG), ~6/2 km, ~L81, ~2 hPa model top	Vmax > 50 kt warm-cycling VI and 4DEnVar DA	Two-way HYCOM, one-way WW3 coupling for NHC AOR	Physics suite-1	All global Basins NHC/CPHC/JTWC Max 7 Storms Replace HWRF
HFSB	Storm-centric with one moving nest, parent: ~75x75 deg, nest: ~12x12 deg	Regional (ESG), ~6/2 km, ~L81, ~2 hPa model top	Vmax > 40 kt warm-cycling VI and 4DEnVar DA	Two-way HYCOM No Waves	Physics suite-2	NHC/CPHC Max 5 Storms Replace HMON



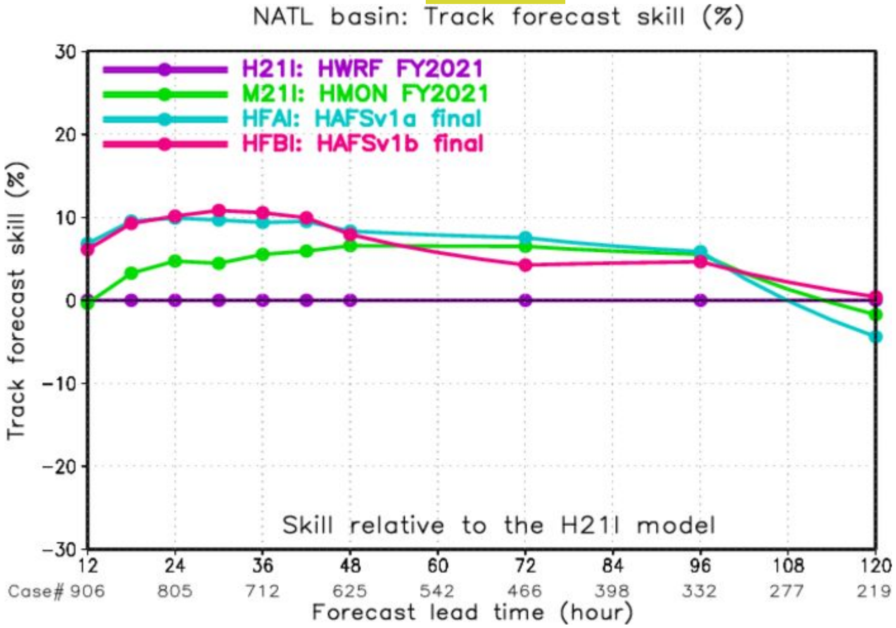
atmospheric domain, ocean domain, wave domain

HAFS Physics Schemes

	Suite 1	Suite 2	Reference
Land/ocean Surface	NOAH LSM VIIRS veg type, HYCOM	NOAH LSM VIIRS veg type HYCOM	Ek et al. (2003) …
Surface Layer	GFS, HWRF TC-specific sea surface roughnesses	GFS, HWRF TC-specific sea surface roughnesses	Miyakoda and Sirutis (1986); Long (1984, 1986)
Boundary Layer	Sa-TKE-EDMF, TC-related calibration, **mixing length tuning**	Sa-TKE-EDMF, TC-related calibration, **tc_pbl=1*, mixing length tuning**	Han et al. (2019) *Chen et al. (2022)
Microphysics	**GFDL single-moment**	**Thompson double-moment**	Lin et al. (1983) Chen and Lin (2013)
Radiation	RRTMG Calling frequency **720 s**	RRTMG Calling frequency **1800 s**	Iacono et al. (2008)
Cumulus convection (deep & shallow)	Scale-aware-SAS **calibrated entrainment**	Scale-aware-SAS	Han et al. (2017)
Gravity wave drag	Improved UGWPv1 (orographic on/convective off)	Improved UGWPv1 (orographic on/convective off)	Alpert et al. (1988)

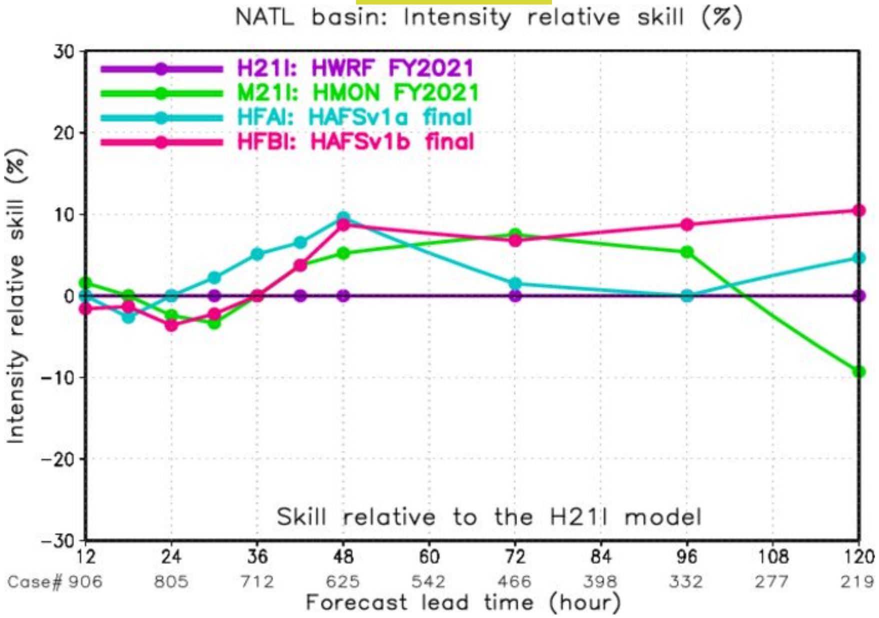
Final configurations: Track/intensity forecast skill (NATL 2020-2022)
Early Model Verification

Track



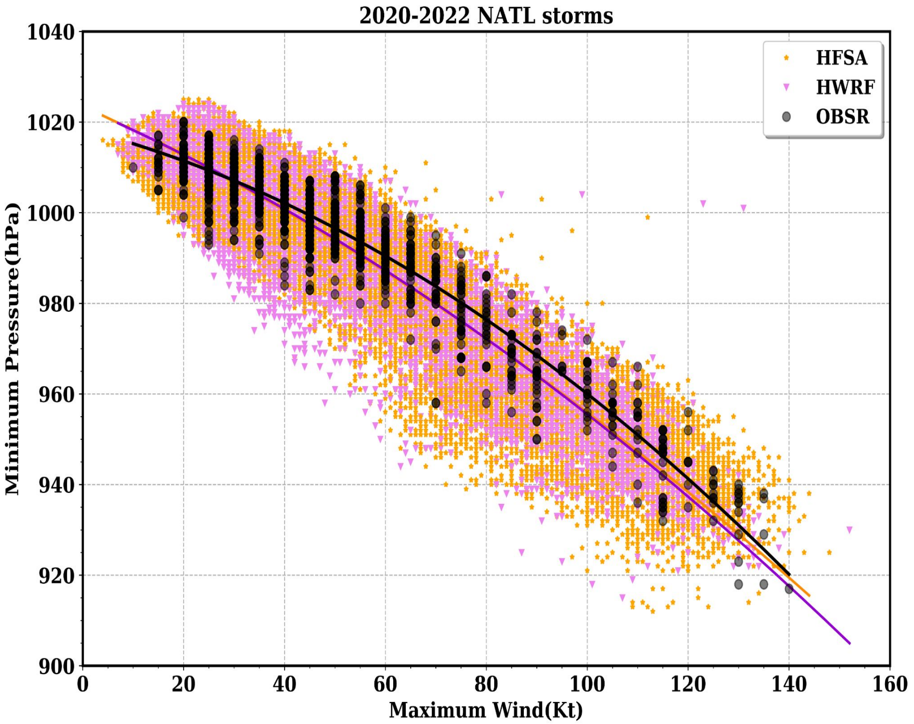
~10% max improvement

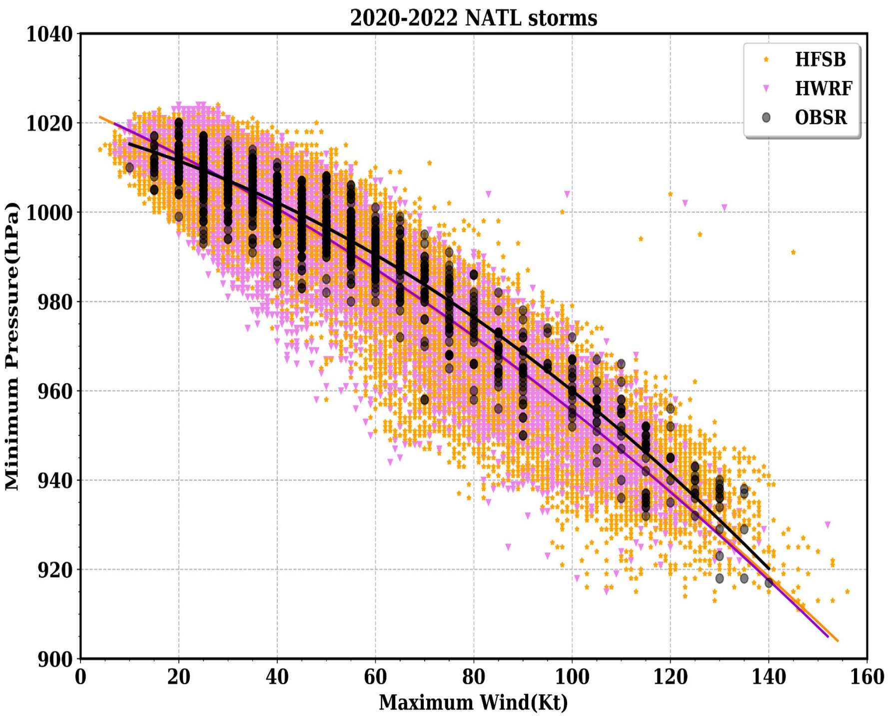
Intensity



~10% max improvement

Pressure/Wind relationship: NATL Basin

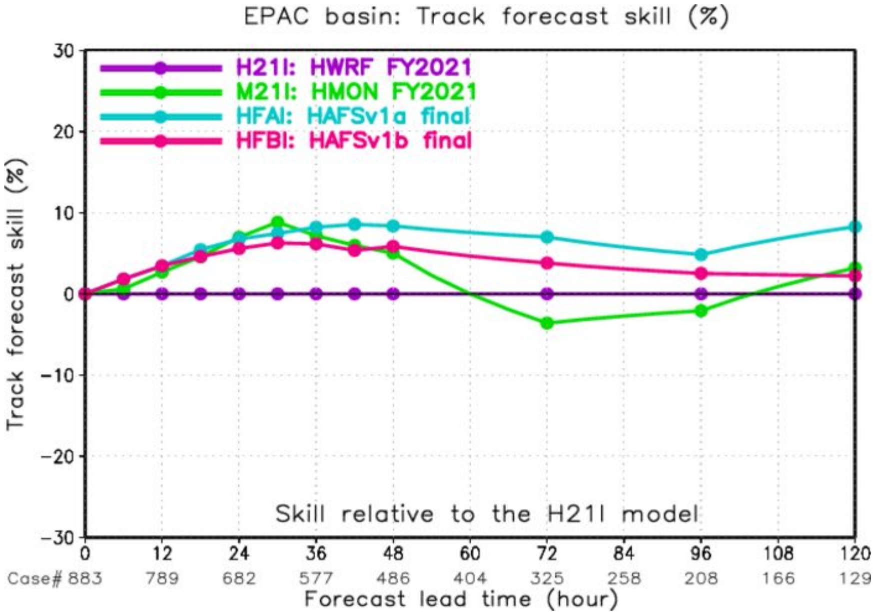




Both HAFS-A and HAFS-B have very similar results to HWRF for the North Atlantic Basin.

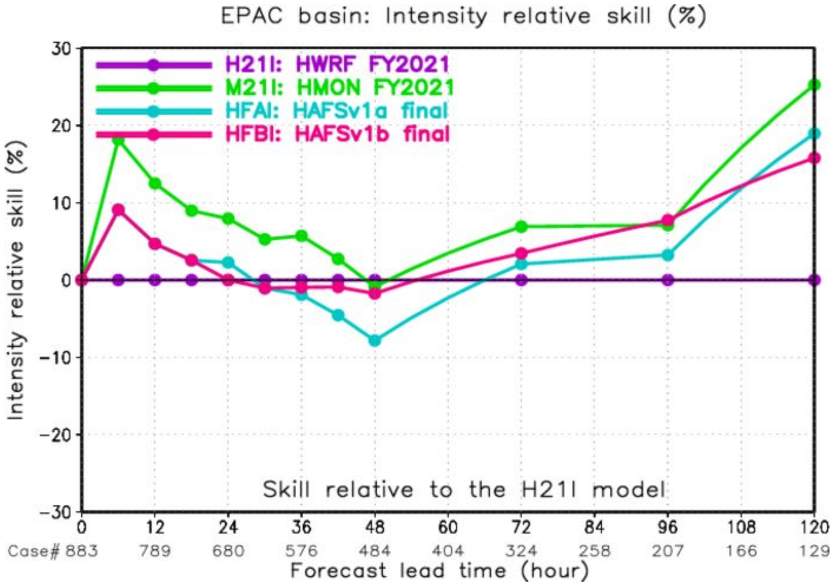
Final configurations: Track/intensity forecast skill (EPAC 2020-2022) Early Model Verification

Track



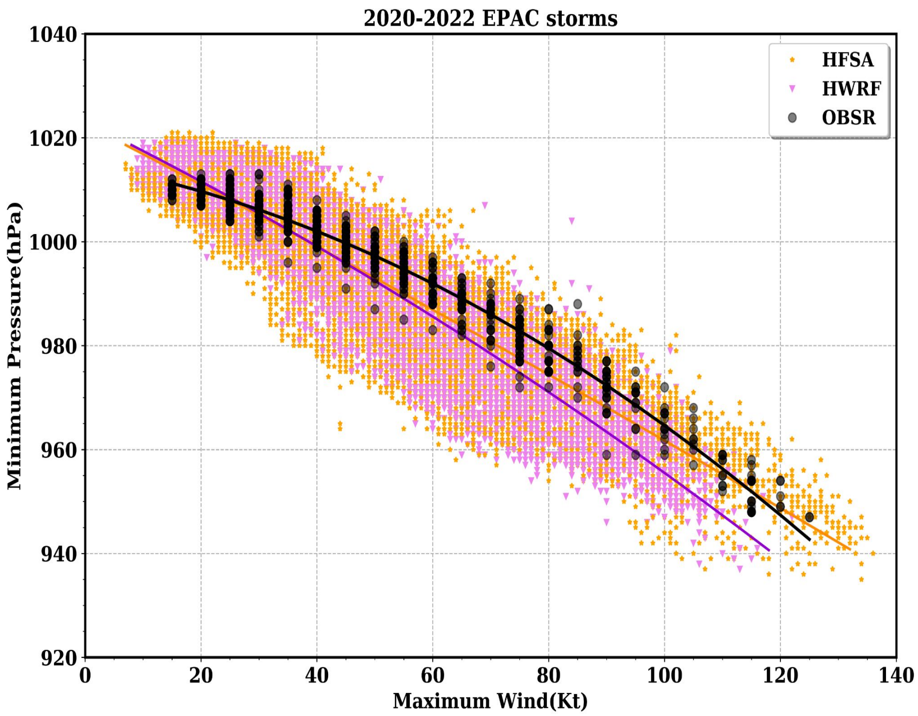
~5-10% improvement

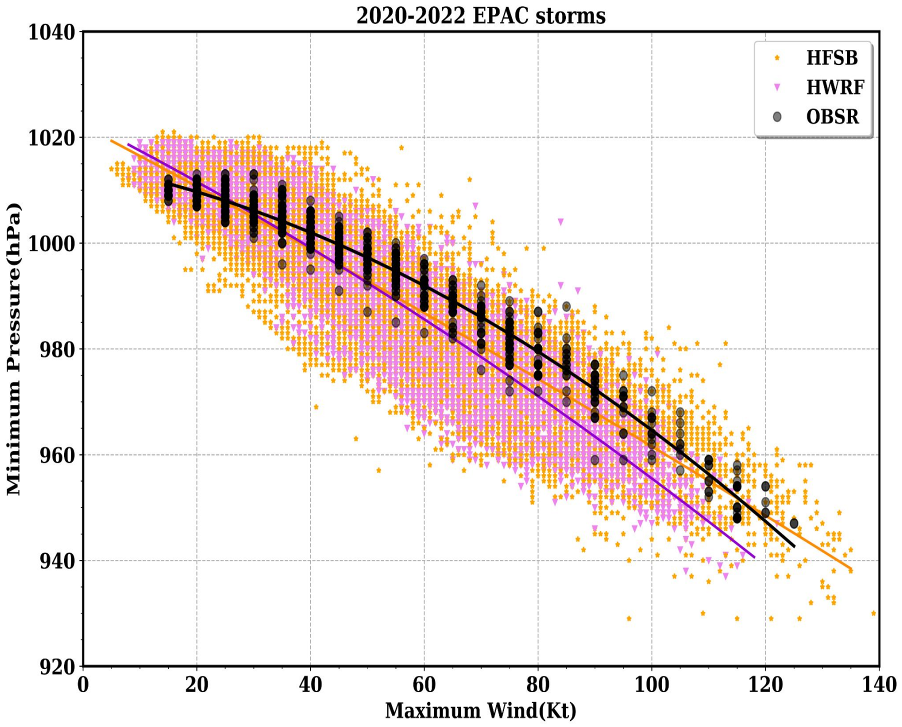
Intensity



HFSB: neutral to positive at later lead times
HFSA: Positive impact except for 72 h

Pressure/Wind relationship: EPAC Basin

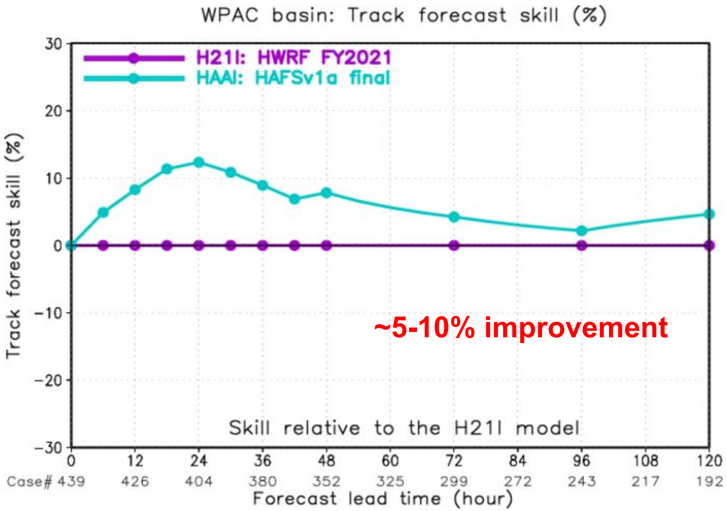




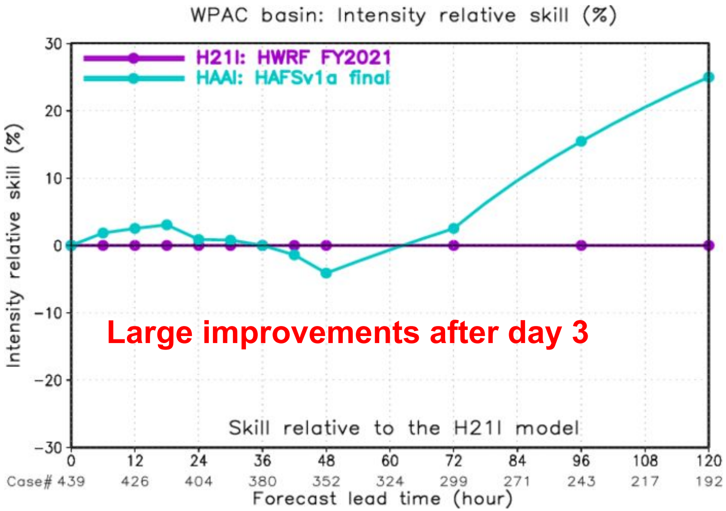
Both HAFS-A and HAFS-B show improvements over HWRF for the East Pacific Basin.

HAFS Baseline, WPAC (some 2021-2022 Storms)

Track



Intensity



- HFSA will be run for all global basins, Data Assimilation will be turned off, generate IC from GFS analysis.
- TCs included: 2022: 12W, 14W, 16W, 18W, 20W, 23W, 26W; 2021: 06W, 09W, 10W, 16W, 19W, 20W.
- HFSA has improved track skill over HWRF for all lead times.
- Intensity forecast skills is also largely improved especially after Day 3.

Timeline for HAFS Transition to Operations

08/01, 2019 to 07/31, 2022
Complete

HAFS v0.0 to HAFS v0.2 real time experiments & evaluation

08/01-10/31, 2022
Complete

HAFS v0.3 real time Experiments

11/01-01/15, 2023
code development - code freeze
01/16-03/30, 2023
3-year retros and NHC evaluation

Evaluation and developments

03/31-06/30, 2023
Planned

HAFSv1.0 implementation

~July 1, 2023

Testing two configurations (HAFS v0.3):

- High resolution moving nest
- Improving model physics
- Vortex initialization and Inner-core data assimilation
- T&E to select optimal configurations

Finalize HAFS v1.0

- ESG grids with dynamic core diffusion tuning
- Vortex initialization threshold
- 4DEnVar using GDAS ensemble
- Enhanced GOES-R and GOES-18 AMVs
- VIIRS Veg Type
- Ocean coupling bug fix
- Code modernization and optimization
- Model efficiency and stability
- JTWC basins T&E

NCO implementation

Development Roadmap for Hurricane Modeling System

Annual Upgrade after IOC

HAFSv1/IOC

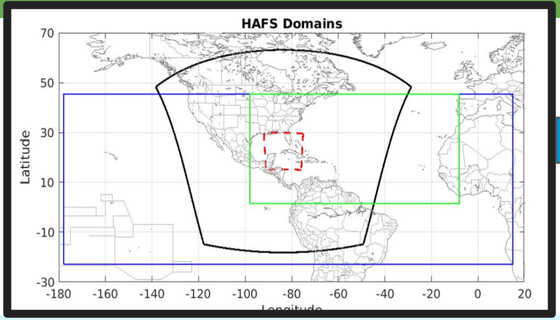
- Storm-centric with one moving nest
- Ad-hoc Vortex initialization
- Flight-level obs. for priority storms
- 4DEnVar using GDAS ensemble
- TC-calibrated Physics based on UFS physics suites
- HAFS/HYCOM Coupled System, one-way Wave

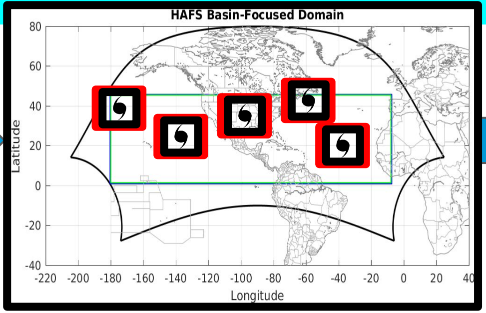
Near future plans

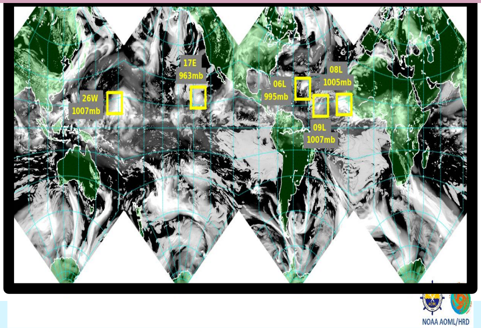
- Multiple moving nests in a basin-centric domain
- Sophisticated VI, GSI and/or AI and/or dynamics-based VI
- High-frequency, self-cycled 4DEnVar, weakly coupled Atmos/Ocean DA, All-sky, explore JEDI-based DA
- Scale-aware model Physics suitable for high res. model
- Three-way HAFS/MOM6/WW3 coupling

Long term plans

- Multiple moving nests with cloud-resolving resolutions in a global model framework
- Multi-scale, coupled DA
- High temporal and spatial resolution of in-situ atms/ocn obs
- AI-based sub-kilometer model physics
- Hurricane Ens. Prediction System
- High res. products, tornadoes, inundation and flooding



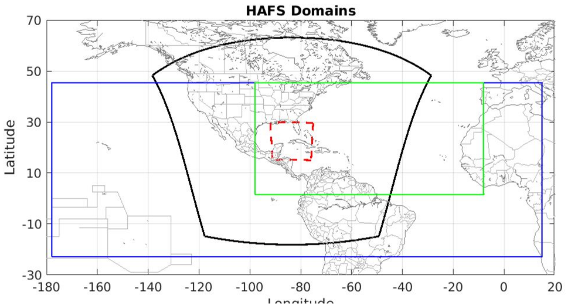


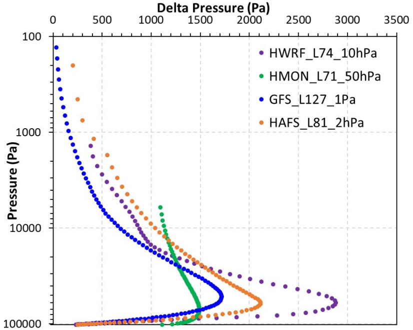


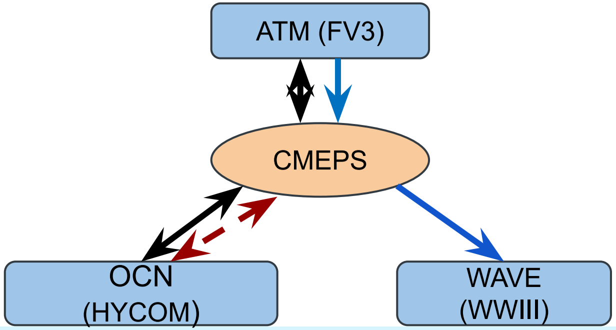
Thank you!

Two Configurations for HAFS IOC

HAFSv1.0	Domain*	Resolution*	DA/VI	Ocean/Wave Coupling	Physics	Basins
Config. 1	Storm-centric with one moving nest, parent: ~78x75 degree, nest: ~12x12 degree	Regional (ESG)), ~6/2 km, ~L81, ~2 hPa model top	VI and DA	Two-way HYCOM, one-way WW3 coupling for NHC AOR	Physics suite-1 (GFDL MP)	All global Basins NHC/CPHC/JTWC Max 7 Storms Replace HWRF
Config. 2	Storm-centric with one moving nest, parent: ~75x75 degree, nest: ~12x12 degree	Regional (ESG), ~6/2 km, ~L81, ~2 hPa model top	Adaptive VI and/or DA	Two-way HYCOM No Wave	Physics suite-2 (Thompson MP)	NHC/CPHC Max 5 Storms Replace HMON





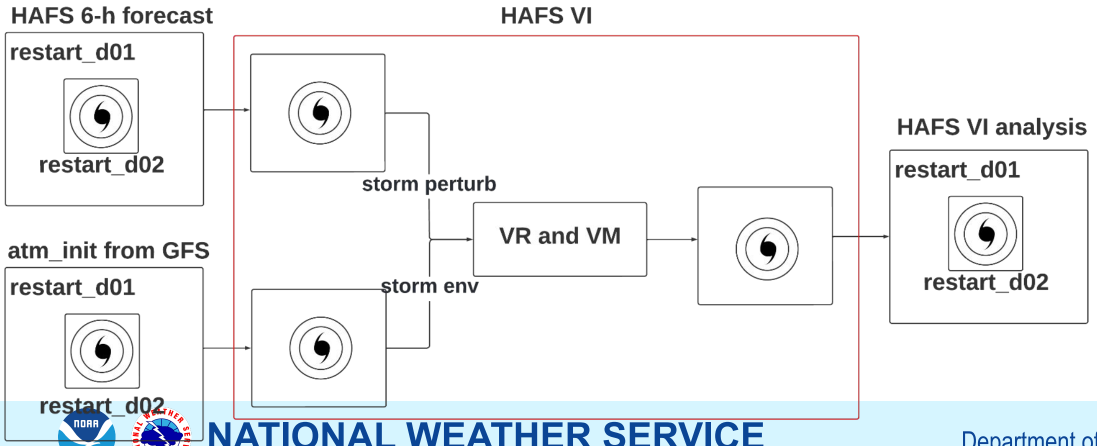


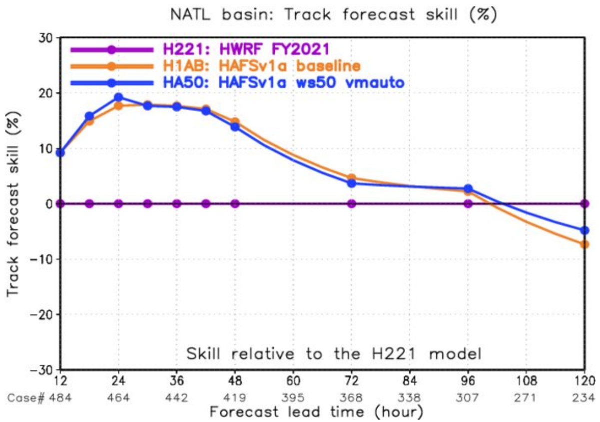
*Subject to change based on T&E and available computer resources

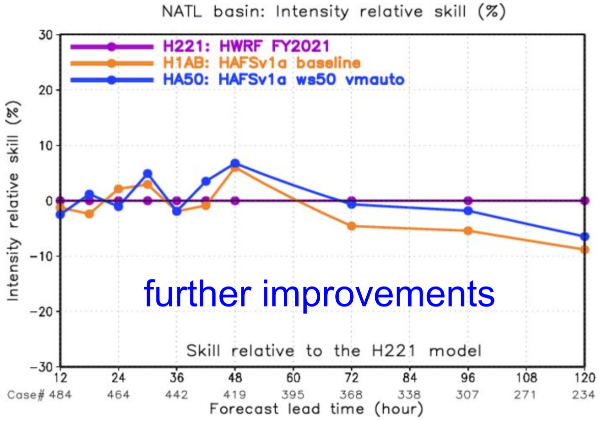
Vortex Initialization Improvements

Sophisticated Vortex Initialization technique modernized and leveraged from operational HWRF and HMON

- Vortex Relocation and Vortex Modification
- Cold-start from GFS analysis if vmax < 20 m/s
- Warm-start by combining GDAS 6-h forecast storm perturbations with GFS environment if vmax => 20 m/s vmax < 50 m/s
- Warm-start by combining HAFS 6-h forecast storm perturbations with GFS environment if vmax => 50 m/s
- Cycling storm region only







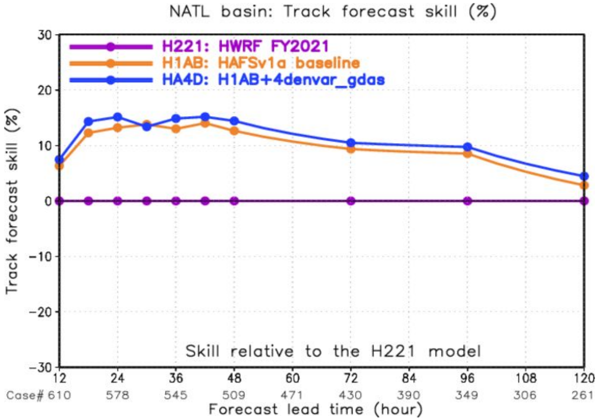
VI Threshold tuning

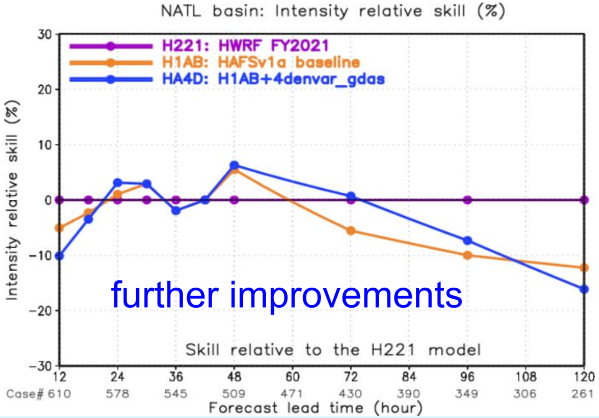
Data Assimilation Improvements

- 6-hourly DA cycling in nested domain region, and use GFS analysis elsewhere in the parent domain
- +/- 3-hour FGAT window
- 3DEnVar to 4DEnVar with GDAS ensembles
- Leverage obs. used in GFS
- Additional meso-scale obs.

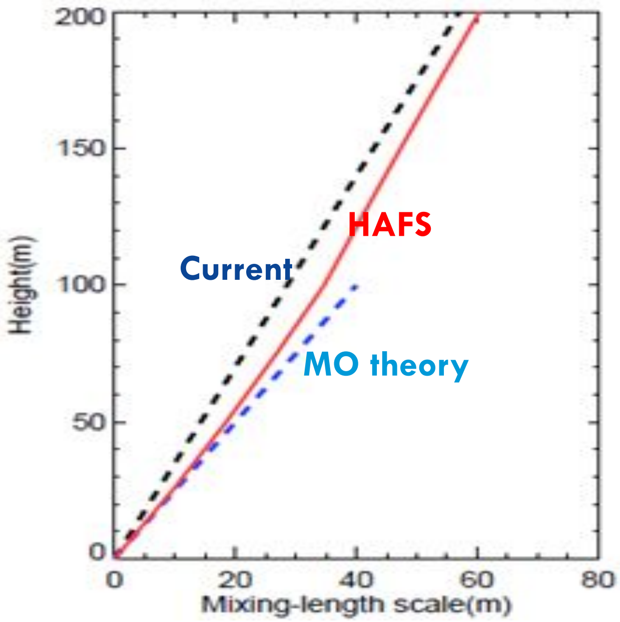
Additional obs. assimilated in HAFS/HWRF

- Tail Doppler Radar (TDR)
- Next Generation Weather Radar (NEXRAD)
- Corrected drift for Dropsondes
- Metar observations
- High resolution GOES-16 AMVs

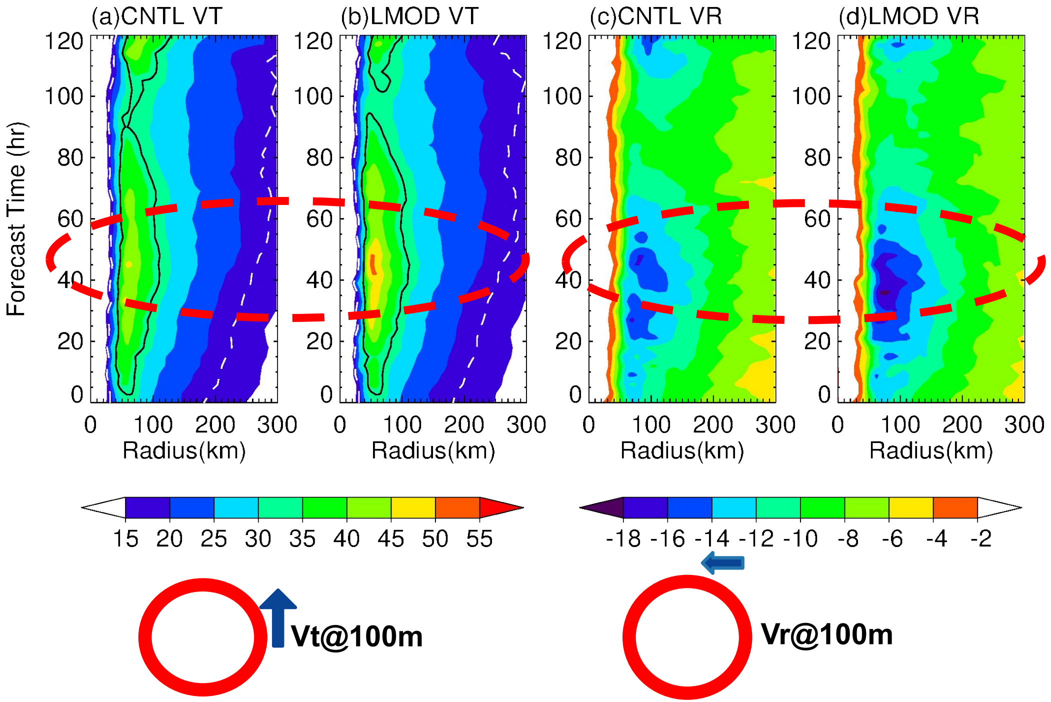




Model Physics Improvements



- HAFS uses a modified mixing length scale (Red) near the surface, closer to MO theory (blue).



Slide courtesy of Weiguo Wang, EMC