# Toward Initial Operational Capability: Progresses, Challenges, and Issues in Developing and Improving Hurricane Analysis and Forecast System (HAFS)


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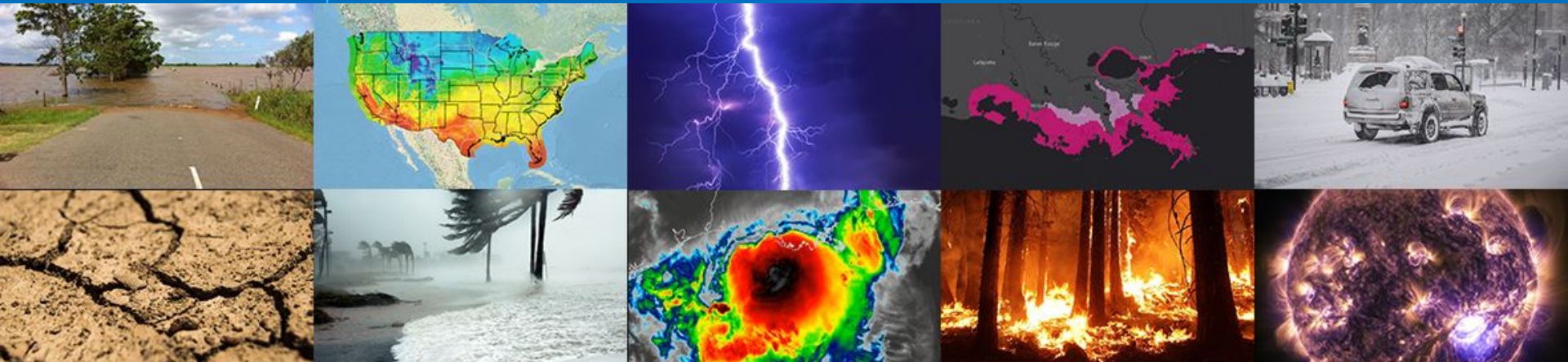

# Acknowledgement to HAFS model active developers

| Atmospheric model dynamics/configurations/workflow | Ocean/Wave coupling through CMEPS | Data Assimilation |
|---|---|---|
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| **Model Pre- and Post-processes** | **Atmospheric Physics** | **Verification/Evaluation** |
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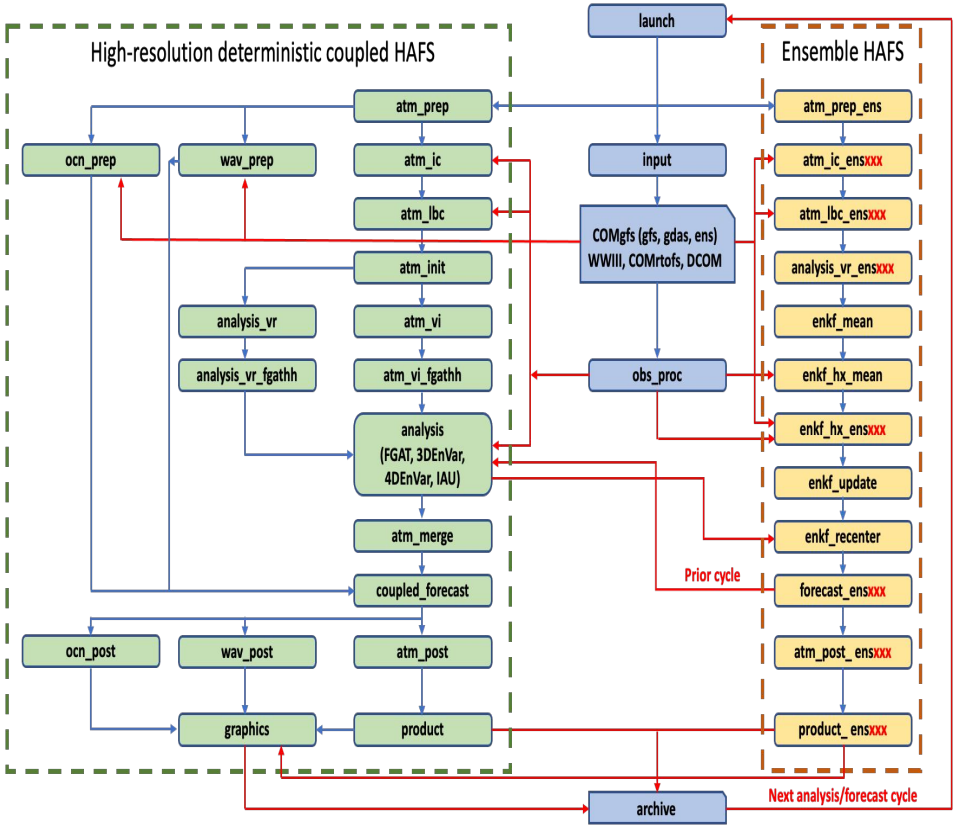
# Background

- HAFS is one of the UFS-R2O projects under UFS (Unified Forecast System), focusing on transitioning tropical cyclone modeling research to operation

- HAFS has been running in real time for three years (2019-2021), Initial Operational Capability (IOC) is planned in 2023, replacing HWRF/HMON

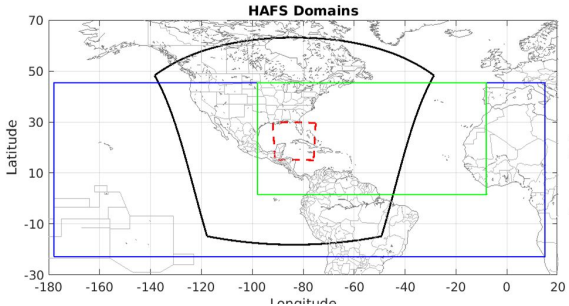
# HAFS Development Status, 2022

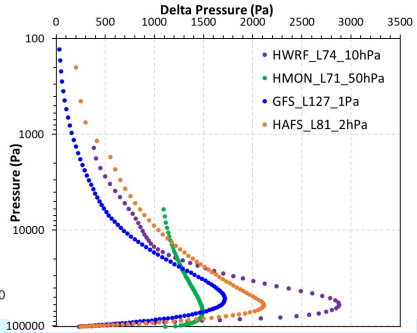
- Reproduced 2021 real-time experiment (HAFSv0.2A) results with latest GFS dynamic/physics code base
- Developed moving nest capability
- Implemented CMEPS based HYCOM coupling for moving nest
- Developed DA_tool for grids interpolation
- Implemented vortex initialization capability
- Implemented 6-hrly cycle DA system for storm-region or entire domain
- Post-process: output both parent/nest domain, all HWRF/HMON products including model satellite imagery
- Added all above components to HAFS workflow

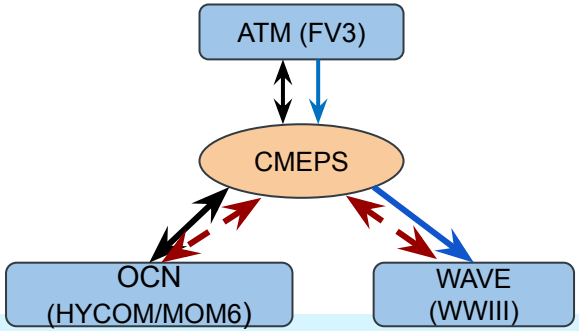


# HAFS IOC, Two Configurations

| HAFSv1.0 | Domain* | Resolution* | DA/VI | Ocean/Wave Coupling | Physics | Basins |
|---|---|---|---|---|---|---|
| **Config. 1** | Storm-centric with one moving nest, parent: ~81x81 degree, nest: ~12x12 degree | Regional (regular Gnomonic), ~6/2 km, ~L81, ~2 hPa model top | VI and 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 |
| **Config. 2** | Storm-centric with one moving nest, parent: ~81x81 degree, nest: ~12x12 degree | Regional (ESG), ~6/2 km, ~L81, ~2 hPa model top | Adaptive VI and/or DA (TBD) | Two-way HYCOM No Wave | Physics suite-2 | NHC/CPHC Max 5 Storms Replace HMON |




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

# Two Corresponding Model Physics Suites

| | Suite 1 | Suite 2 |
|---|---|---|
| Cumulus Convection (Shallow & Deep) | sa-SAS: Positive definite mass flux; Stochastic convective organization; Optimization for CAPE | sa-SAS: Positive definite mass flux; Stochastic convective organization; Optimization for CAPE, TC-specific tuning |
| Surface Layer | GFS: Sea spray, optimization | GFS: Sea spray; optimization, TC-specific. tuning |
| PBL | Modified sa-TKE-EDMF: Positive definite tracer advection; TC-Specific tuning | Modified TKE-EDMF: Positive definite tracer adv.; optimization, TC-Specific tuning |
| Gravity Wave Drag | Orographic/Convective: On/Off | ~~uGWP.v1 (TBD)~~ (may use updated GFSV16) |
| Land Surface Model | Noah LSM | NOAH MP and VIIRS veg type |
| Microphysics | GFDL MP | Thompson MP (requires ~10% more resources) |
| Radiation (LW & SW) | RRTMG (30 min) | RRTMG (30 min) |

# Comparison of track/intensity forecast skills (HAFSs vs HWRF)

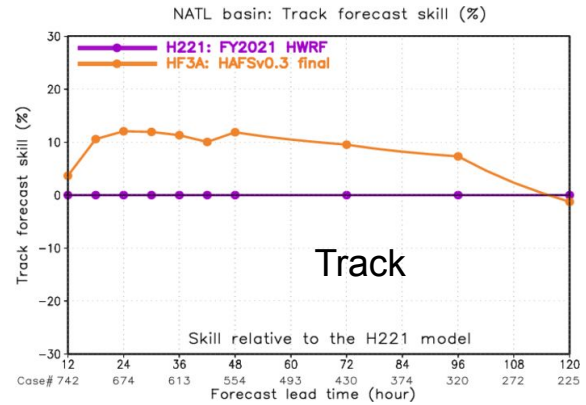
## North Atlantic, 2020-2021

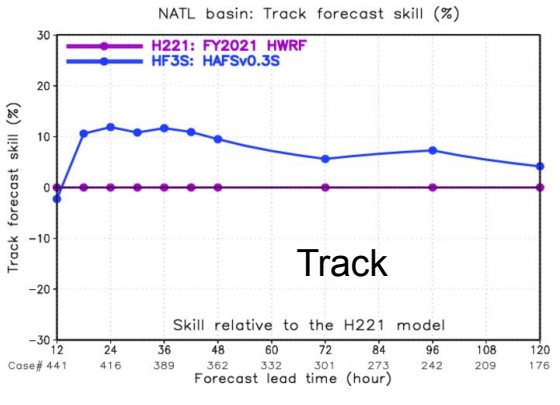
**Improvement of track/intensity forecast skills (HAFS vs HWRF)**

- H221: Operational HWRF
- HF3A: HAFS configuration 1
- HF3S: HAFS configuration 2
- Two year retrospective runs: 2020-2021 NATL
- HF3A and HF3S track forecasts are ~8-10% more skillful than HWRF at almost all forecast lead times, except for HF3A at day-5
- HF3A intensity forecast skills are mixed/comparable with HWRF, while HF3S is about ~7% more skillful than HWRF between 18 -108 h

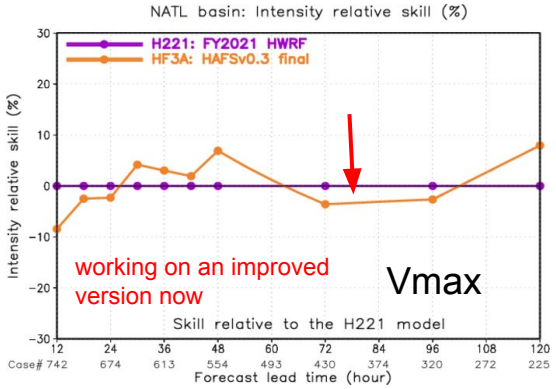
**HF3A** | **HF3S**

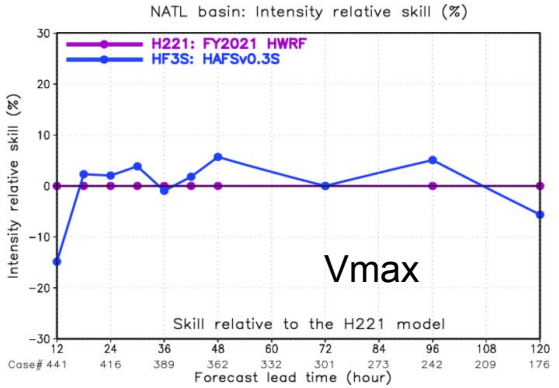
Degradation Improvement




Degradation Improvement



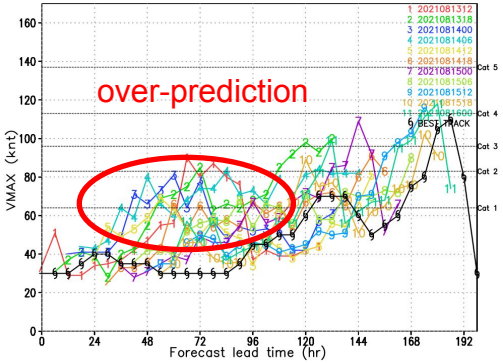



# Comparison of Composite Vmax forecasts (HAFSs vs HWRF)

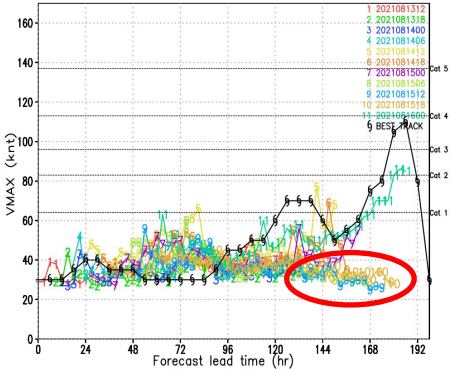
**Hurricane Grace 2021,** Both HAFSs improved over intensification, but missing few RI cycles

**Hurricane Ida 2021,** Both HAFSs Improved RI intensity forecasts, HF3A had intensity phase shift issues due to landfilling timings

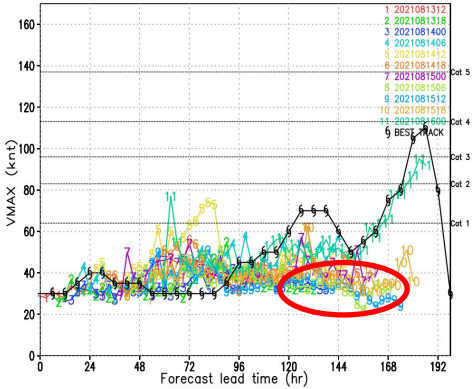
HWRF

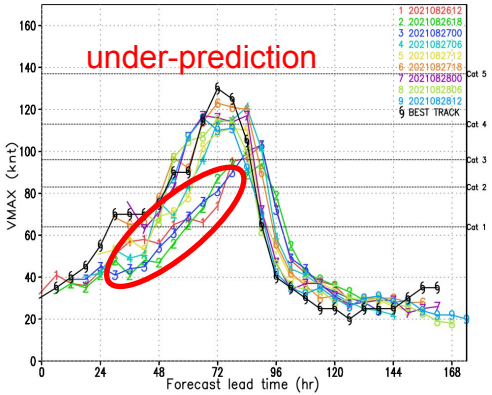


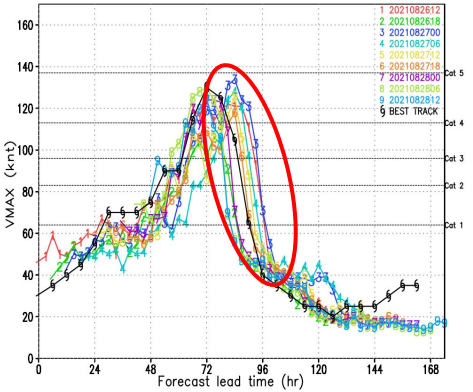

HF3A

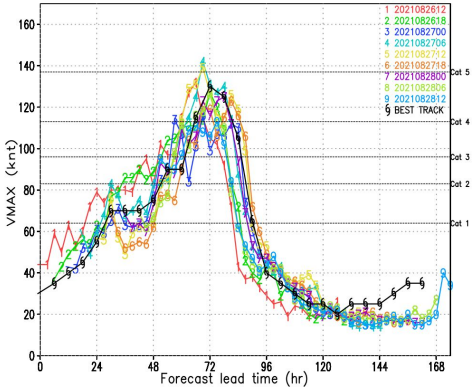



HF3S



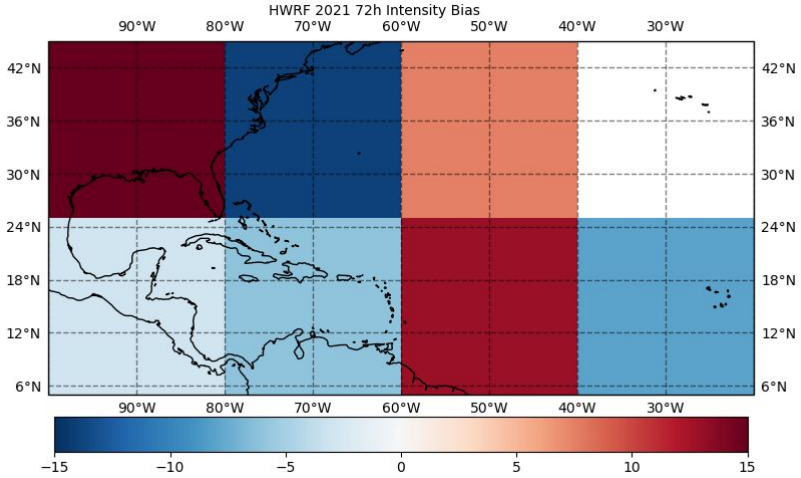



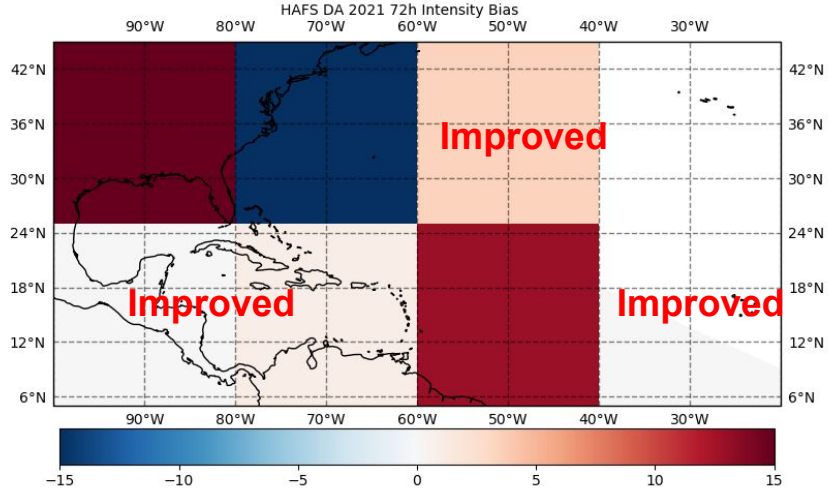



# Spatial Intensity Forecast Error Variability

**HWRF**



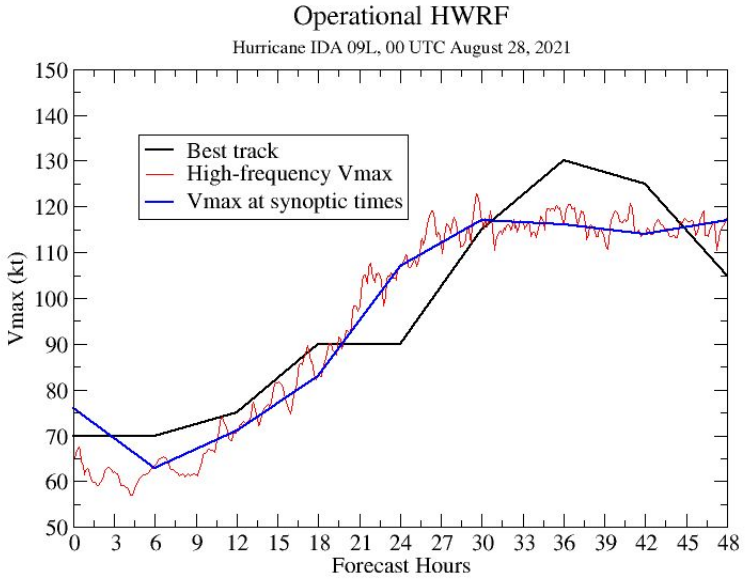

**HF3A**



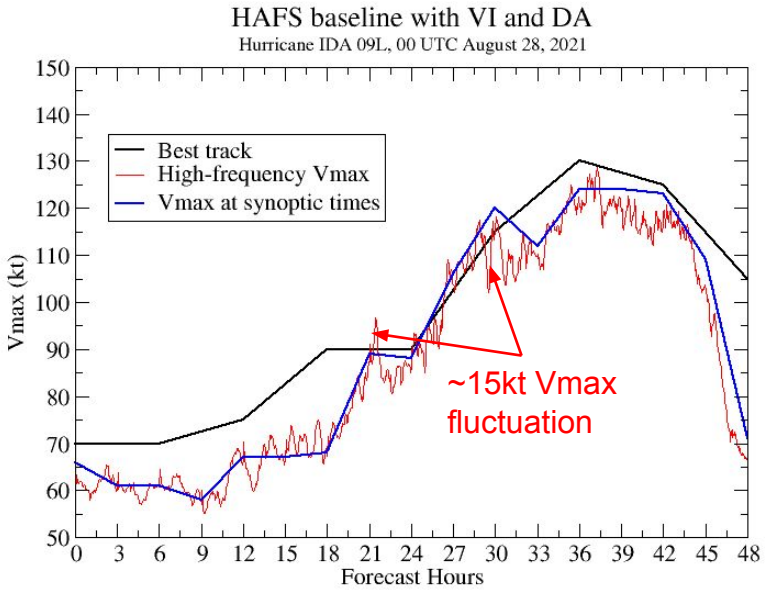

Samples are based on Hurricanes Grace 07L, Henri 08L, Ida 09L, Larry 12L, Peter 16L, Sam 18L
Will re-evaluate when more samples are available.

Courtesy of George Alvey

# Comparison of High Frequency Vmax



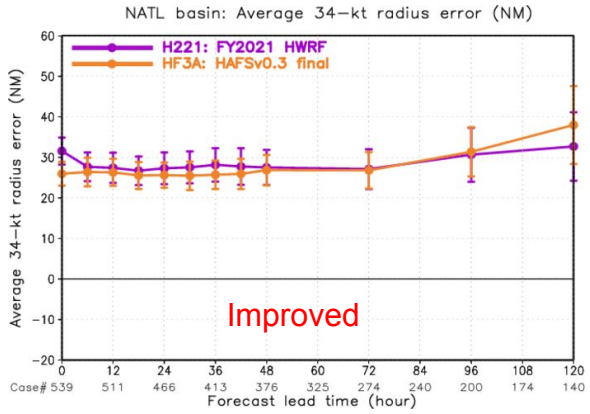

HWRF

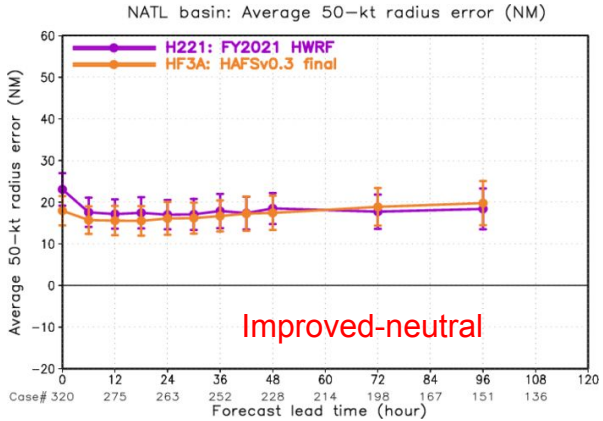


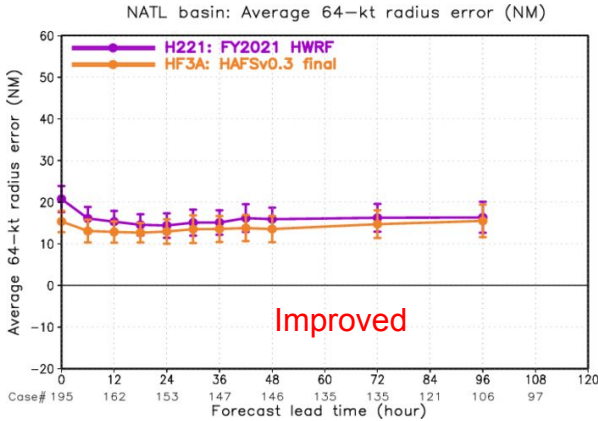

HF3A

# Comparison of storm structure forecast errors (HAFSs vs HWRF)

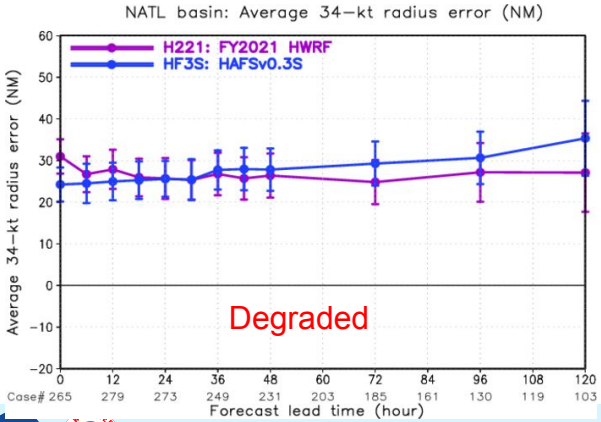
**HF3A**

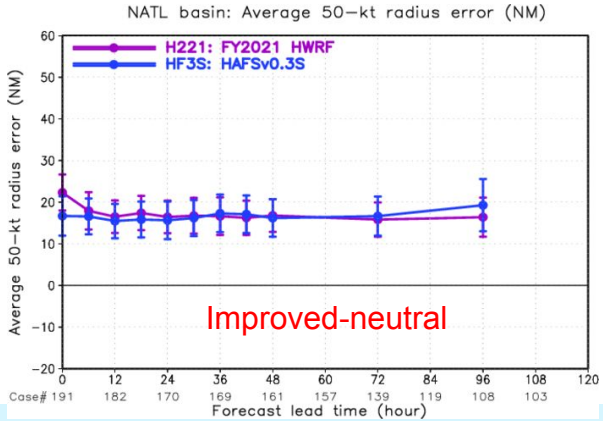


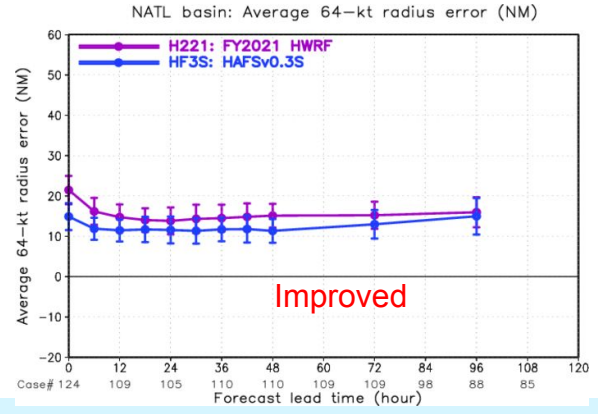




**HF3S**



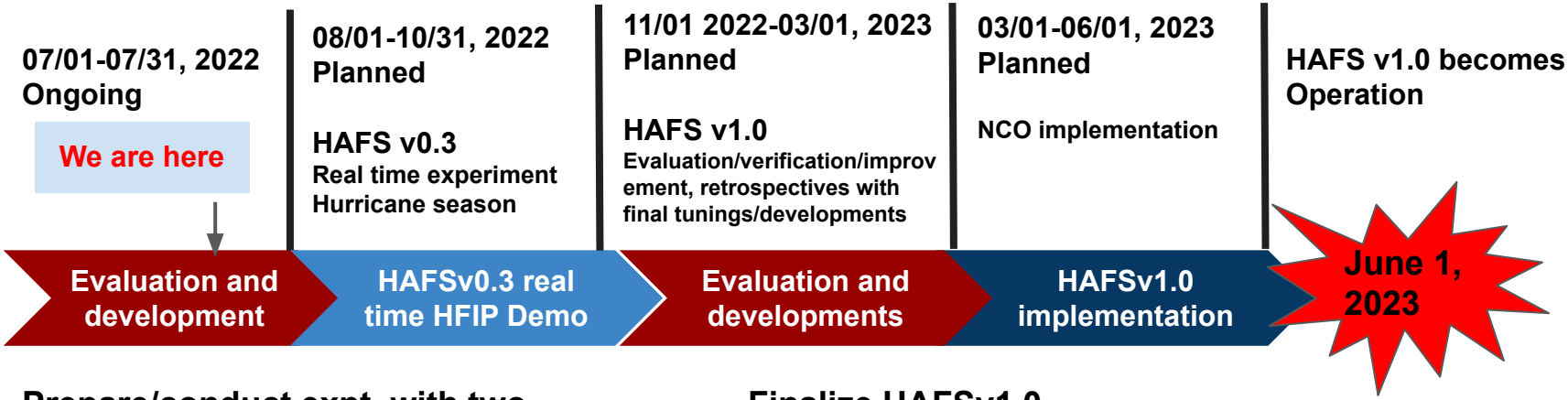



# Challenges ahead

- Improve runtime to fit operational time window
- Improve two physics suites
- HAFS T&E for other basins (non-NHC)
- HAFS IOC operational transition to NCO
- Develop HAFS/MOM6 coupling capability
- Flexible parent-nest ratio for moving nest
- Multiple moving nests in basin-centric domain
- Advanced DA system and vortex initialization scheme
- GSI to JEDI transition

# Planning for Year 3 activities



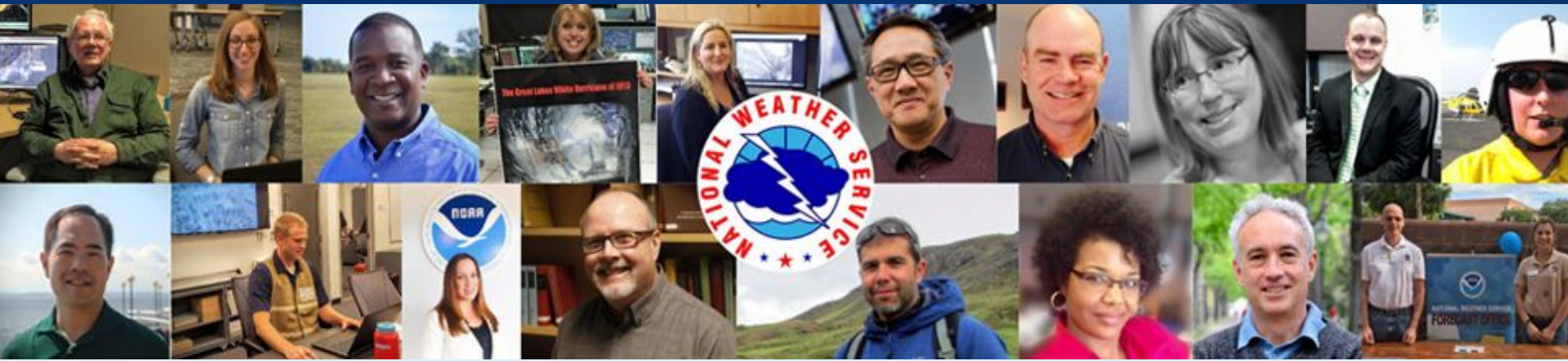

**Prepare/conduct expt. with two configurations (HAFSv0.3):**

- High resolution moving nest
- Updated model physics
- Vortex initialization
- Inner-core data assimilation
- Test & Evaluation
- Select optimal configurations

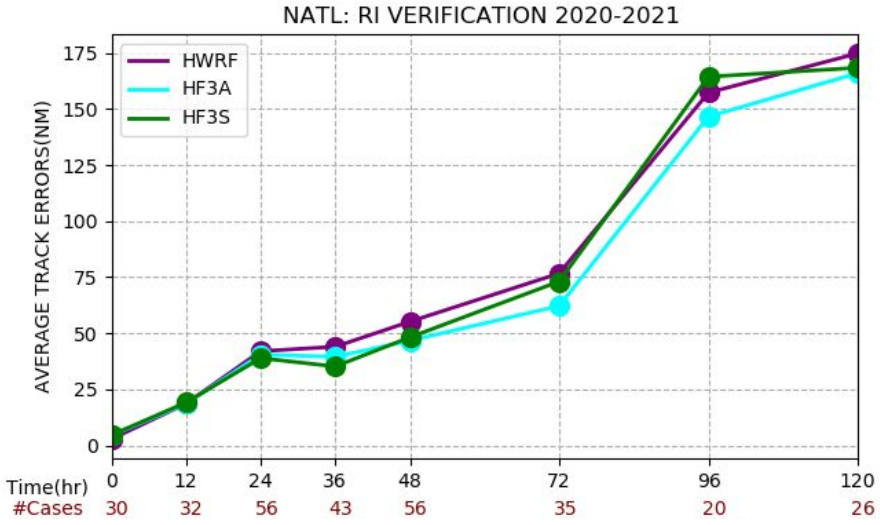
**Finalize HAFSv1.0**

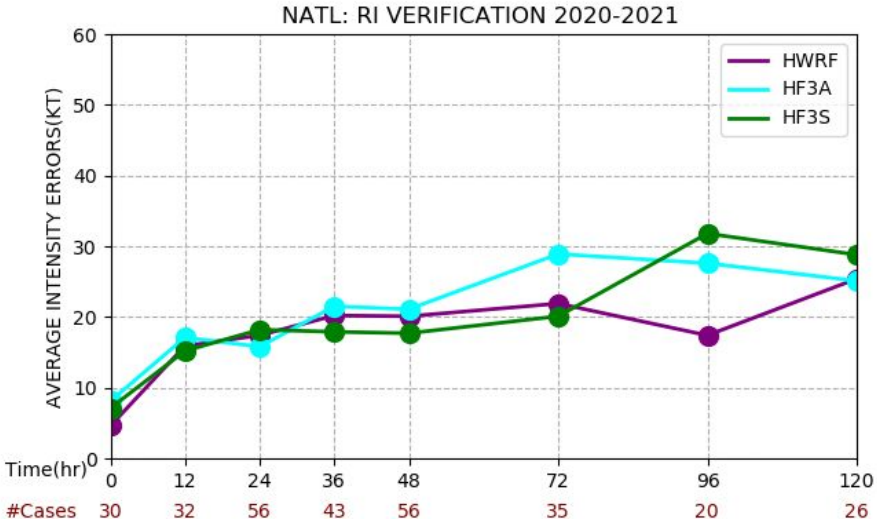
- Fine tune the system
- 3-year retrospectives
- Stakeholders approval
- Code optimization and compliance with NCO standard
- Hand off system to NCO

# Thank you!



# Track/intensity verification for RI cycles only




**Track:** improved track, compared to HWRF at all forecast lead times for both config., except for HF3S at day-5

**Intensity:** HF3S outperformed HWRF up to day-3, HF3A similar to HWRF before day-2. Both configurations have relatively larger intensity errors than HWRF after day-3