Satellite Observations in NOAA's Operational Hurricane Model

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NATIONAL WEATHER SERVICE

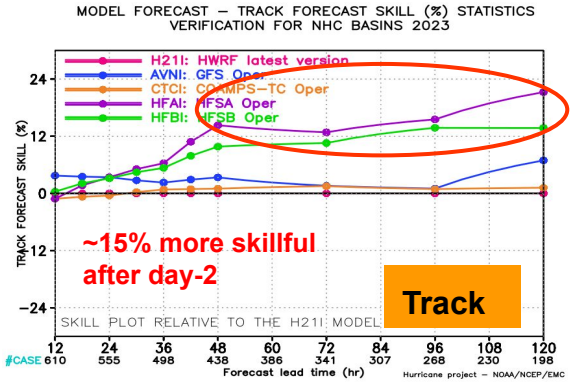
NOAA'S SATELLITE APPLICATIONS SYMPOSIUM SERIES. July 16, 2025

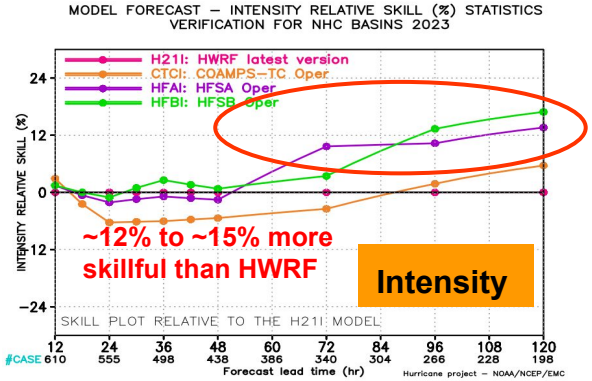
Outlines

- NOAA's Operational Hurricane Modeling System: Hurricane Analysis and Forecast System (HAFS)
- Observations Assimilated in HAFS, GOES-R meso-floater Atmospheric Motion Vectors (AMV)
- Ongoing TROPICS and Tomorrow.io projects
- Summary

NOAA's Hurricane Analysis and Forecast System

- HAFS is NOAA's next-generation multi-scale numerical model and first major UFS-based hurricane application
- HAFSv1.0 implemented in June 2023, upgraded to HAFSv2.0 in July 2024
- Successful community modeling approach for accelerated transition of research to operations
  - Cloud-allowing high resolution moving nest
  - Sophisticated vortex initialization and inner-core data assimilation with high-res. obs
  - TC-specific physics schemes
  - Two-way coupled to Ocean models
  - ~15% more skillful compared to NOAA's legacy model HWRF in terms of track/intensity forecasts





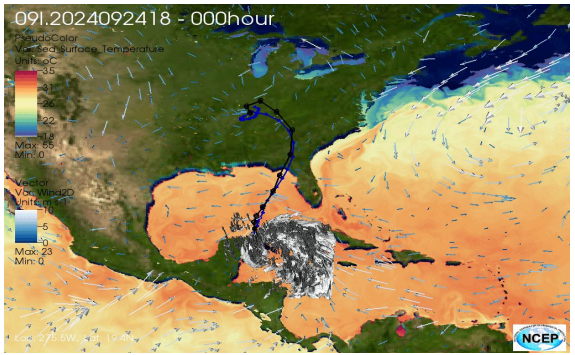
HAFSv2.1 Upgrade

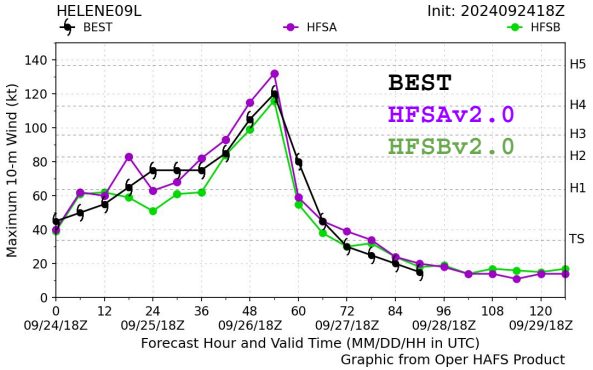
HAFSv2.1 Objectives (to be implemented on July 16, 2025)

- Use latest version of RTOFSv2.5 to initialize ocean models
- Address issues identified in 2024 hurricane season
  - Storm structure at model initial time
- Improve model track and intensity forecast skills

HAFSv2.0

Hurricane Helene 09L, initialized at 2024092418



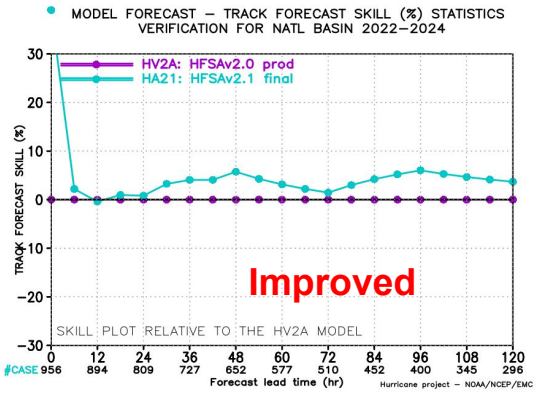


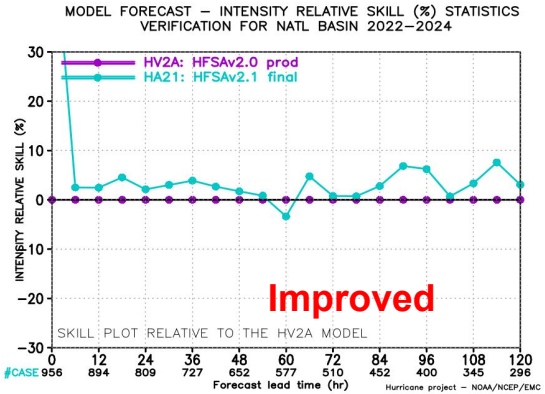
Track and Intensity Verification: NATL Basin (2022-2024), Late Model

Track Skill (%)

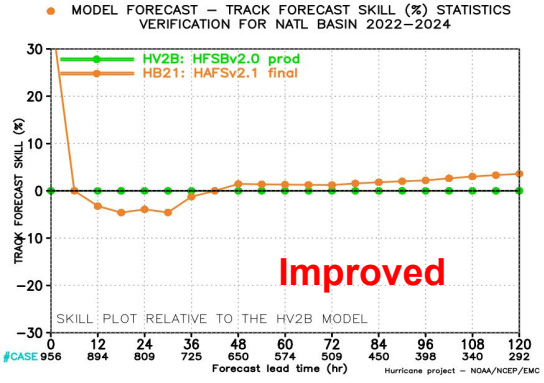
Vmax Skill (%)

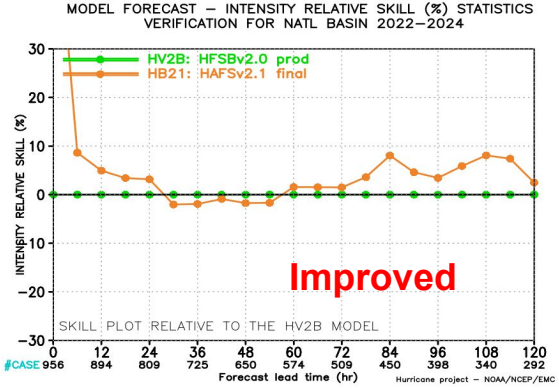
HFSA





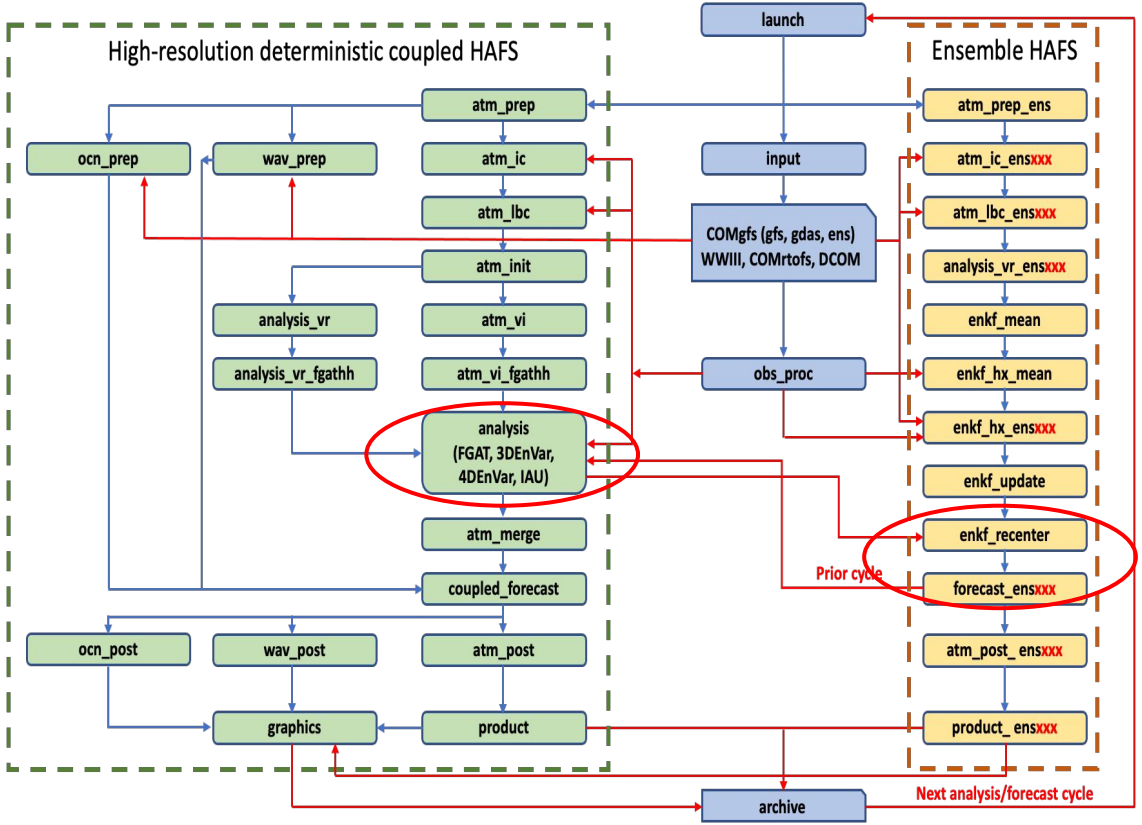
HFSB





- **HV2A/H2AI: Late/Early models of current operational HAFS-Av2.0**
- **HV2B/H2BI: Late/Early models of current operational HAFS-Bv2.0**
- **HA21/A21I: Late/Early models of proposed HAFS-Av2.1**
- **HB21/B21I: Late/Early models of proposed HAFS-Bv2.1**
- **Total 1048 cycles with 956 verifiable cycles**

HAFS Workflow and DA Capabilities (Clear-Sky only)



DA Options

- Vortex Initialization
- FGAT, SDL, 3DIAU (new after HAFSv2.1)
- 3DVar/3DEnVar/4DEnVar/EnKF/Var-EnKF Hybrid
- 3DEnVar/4DEnVar:
  - GDAS ensemble
  - HAFS ensemble
  - GDAS/HAFS ensemble combined

Options for DA domains

- Nest domain only, and use GFS analysis elsewhere
- Parent domain only
- Self-cycled DA for nest using dual-res. approach, highRes. deterministic and lowRes HAFS EnKF
- Self-cycled static DA domain for parent only

No ocean DA

No DA for JTWC TCs

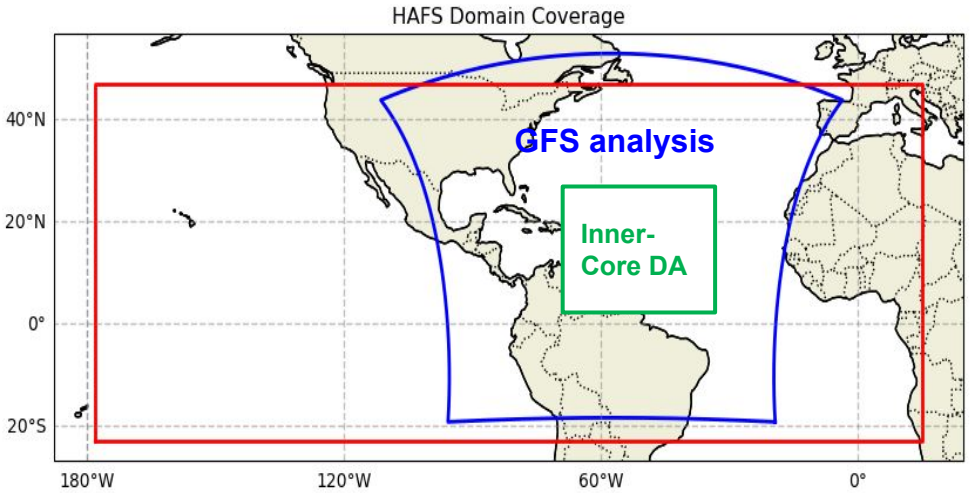
Observations Assimilated in HAFS

All observations assimilated in GFS

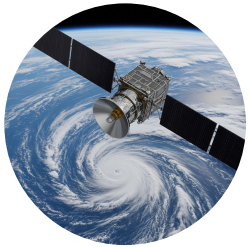
- Conventional obs
- Recon
- **Satellite derived winds**
- **Satellite radiance**
- TCVitals

HighRes. Obs.

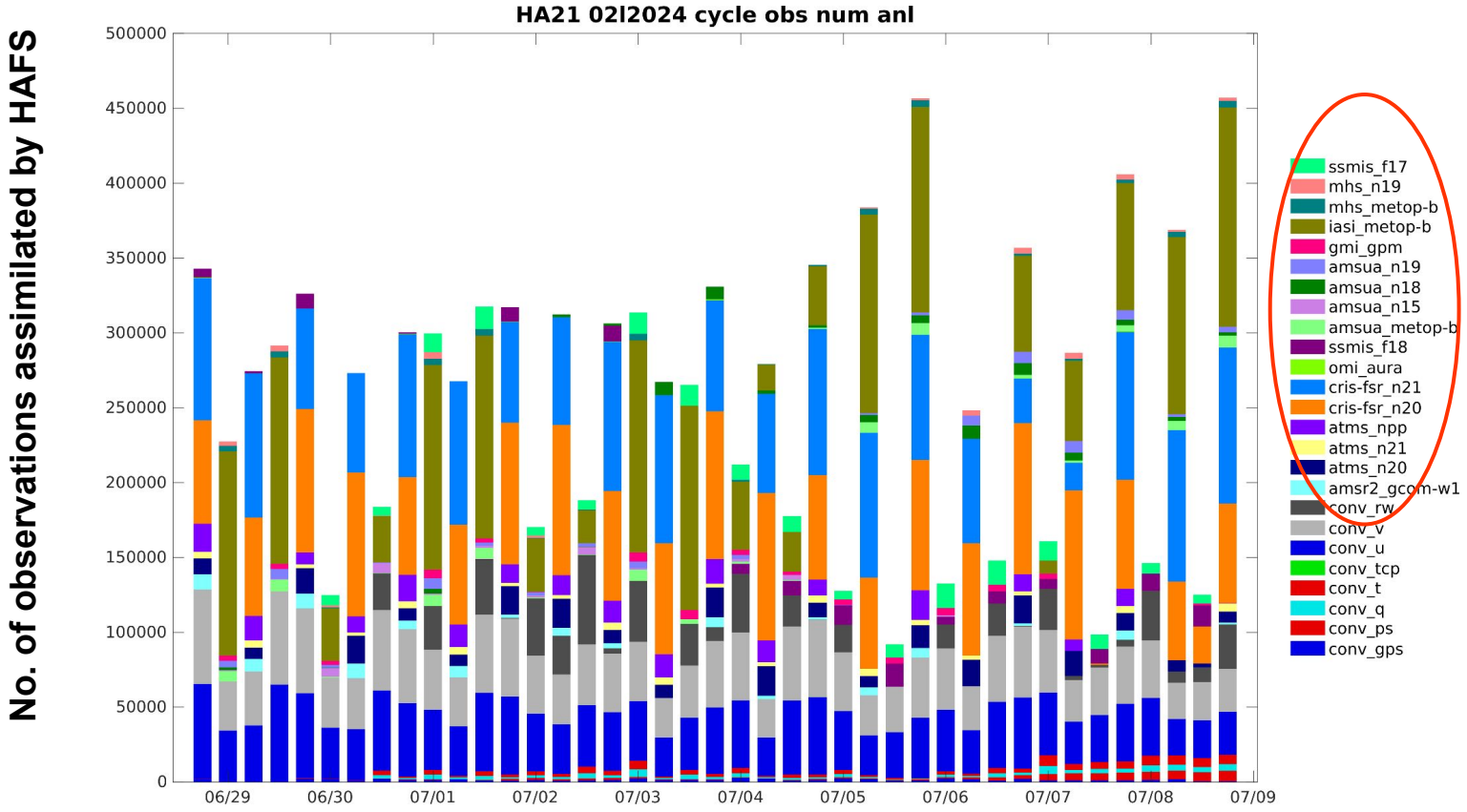
- Recon: Tail Doppler Radar (TDR) and High Density Observations (HDOB)
- NEXRAD
- Dropsondes with drift corrections
- METAR observations
- **Meso-floater High resolution GOES-R AMVs**



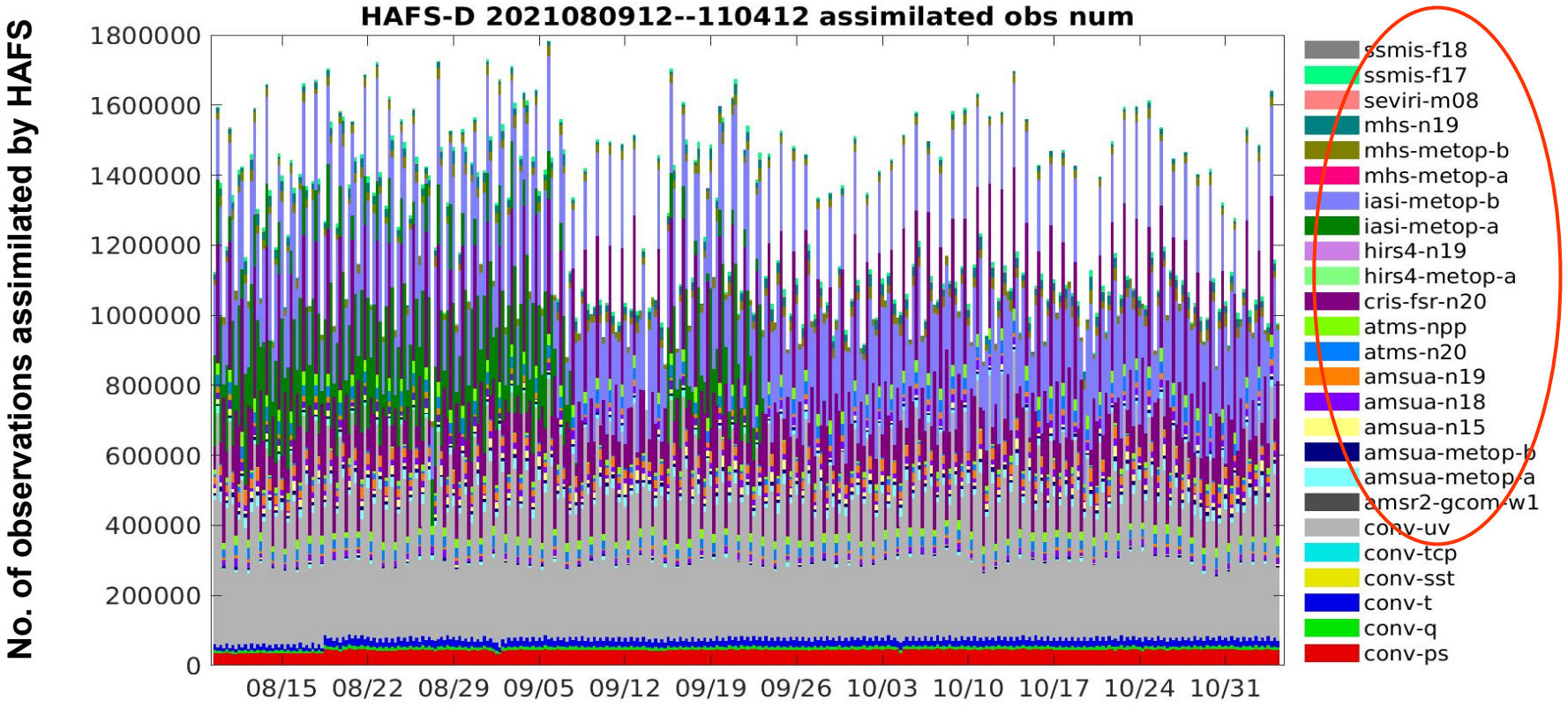
Atmos: Parent/storm-following nested domains
Ocean model: fixed domain



Observation Data Assimilated by HAFS DA Nested Domain in June 29 - July 29, 2024

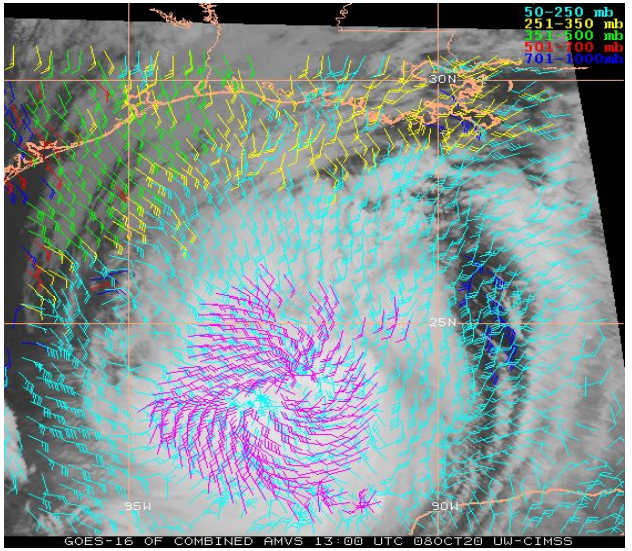


Observation Data Assimilated by HAFS DA Single Domain in 2021 Real time Experiment



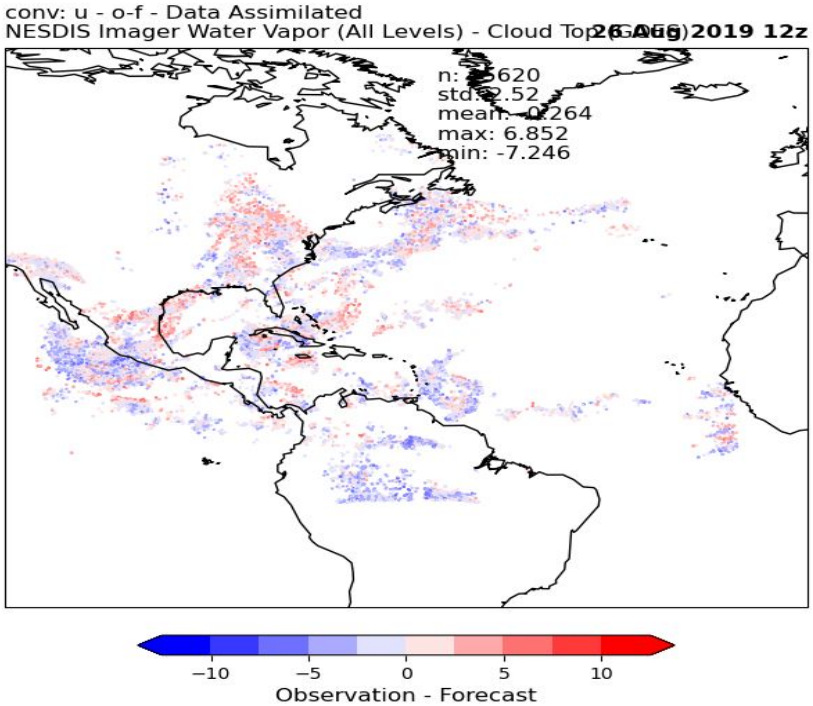
Enhanced Atmospheric Motion Vectors

- The high-res. AMV dataset are generated from rapid-scan GOES-16 and GOES-18/19 imagery.
- The Advanced Baseline Imager (ABI) onboard the GOES-16 and GOES-18/19 satellites have 2 flexible mesoscale scans for targeting limited domains in one-minute intervals.
- Moveable “meso sector” , focus on a Tropical Cyclone center with 10x10 domain, requested by NHC
- Using a specially tailored automatic algorithm to produce enhanced, high resolution AMVs during targeted TC event.
- GOES-R AMVs developed by Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison (CIMMS)

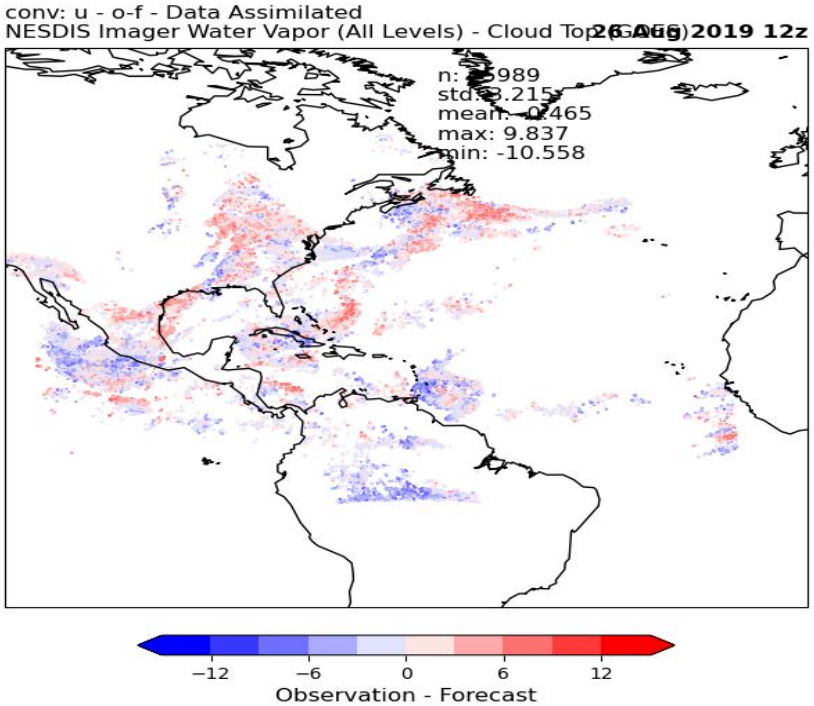


Example: Hurricane Delta AMV fields at 15-min. intervals. Optical Flow vectors (50-150 mb) in magenta.
Meso-scale AMVs was tested in HWRF and earlier version HAFS, and was assimilated in the HAFSv2.0, 2024

GOES Water Vapor Cloud top AMV

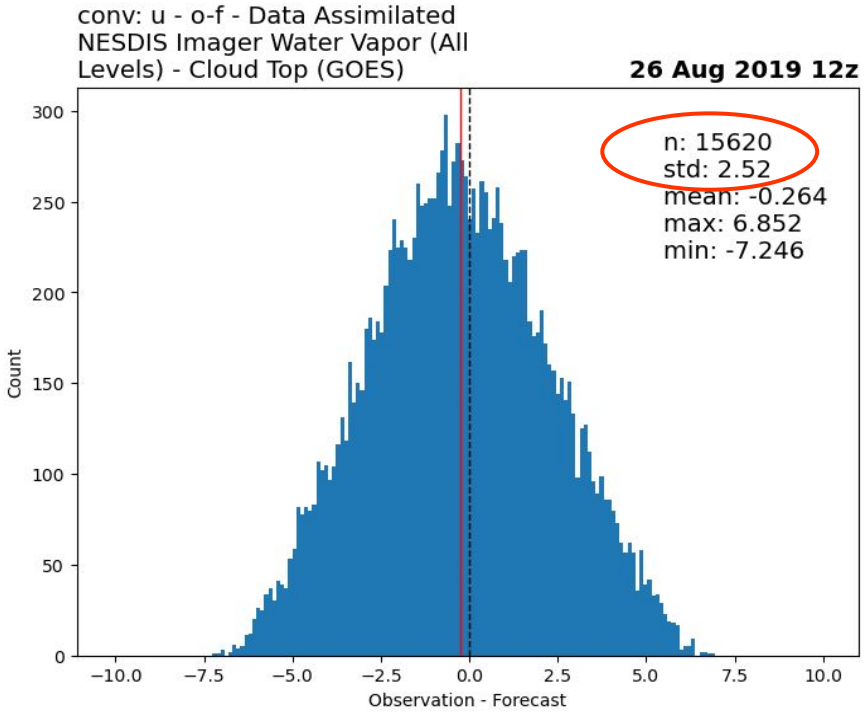


NESDIS AMVs

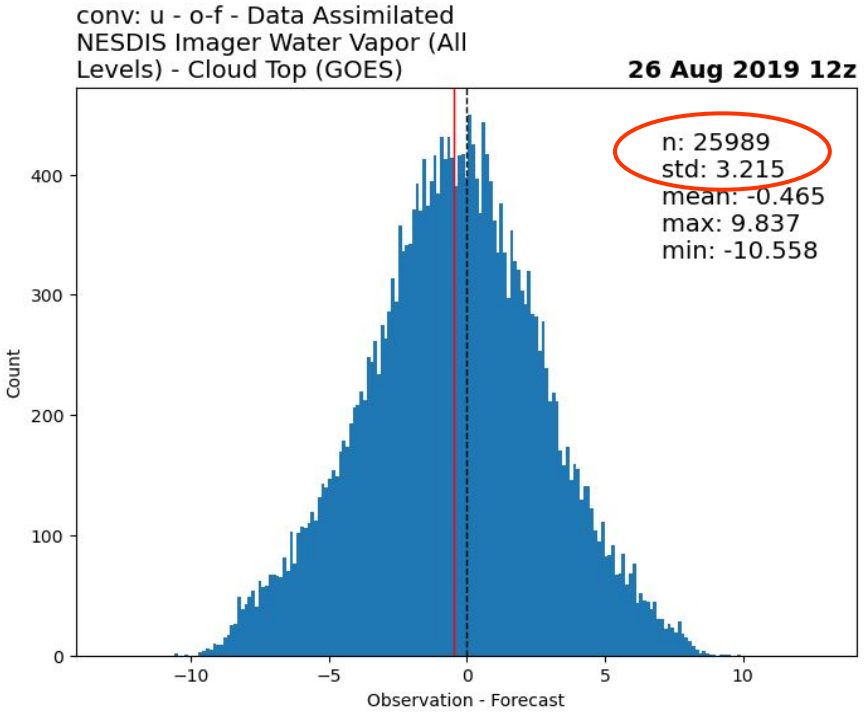


Enhanced meso-floator AMV + NESDIS AMVs

GOES Water Vapor Cloud top AMV



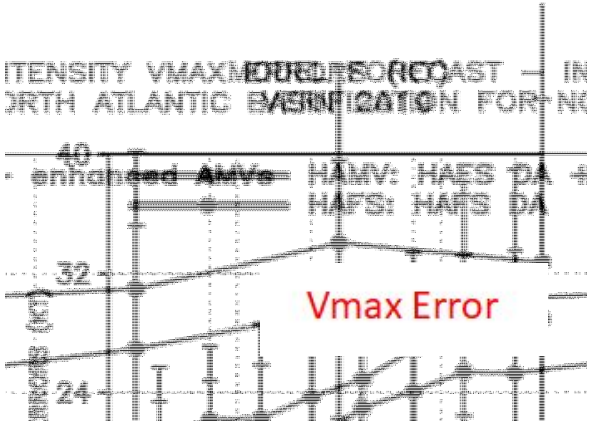
NESDIS AMVs

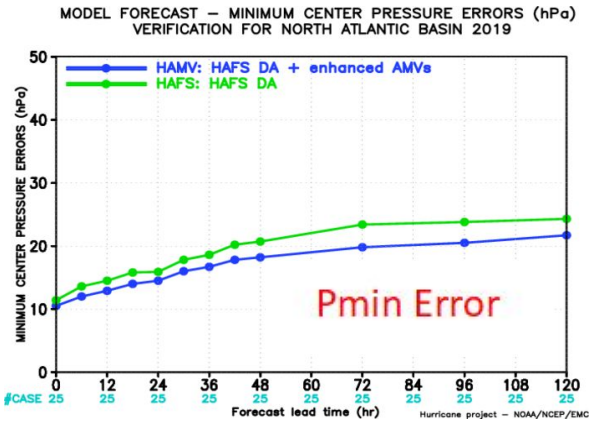


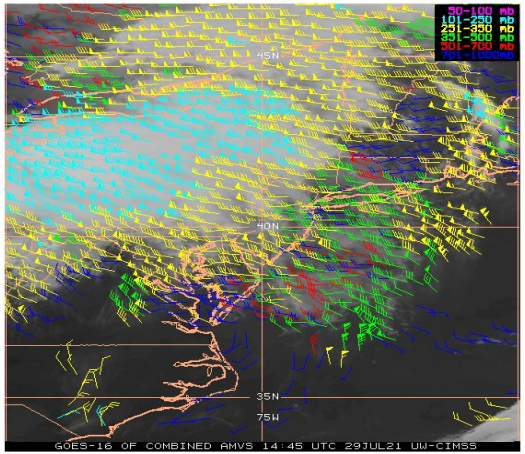
Enhanced meso-floator AMV + NESDIS AMVs

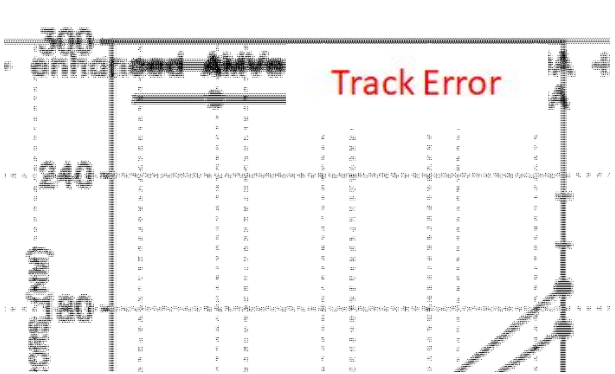
Impact of the Enhanced GOES-16 AMVs, HAFSv0.2, 2019

- Assimilating ultra-high-density AMVS products derived from GOES-16 meso scans in HAFS DA workflow
- Receive enhanced AMVs production from CIMSS every 15 mins.
- Bring in 40% more obs for each cycle.
- Real-time ingestion into HAFS DA starting from **2021072500**
- Impressive intensity improvement from retrospective run (Hurricane Dorian, 2019).

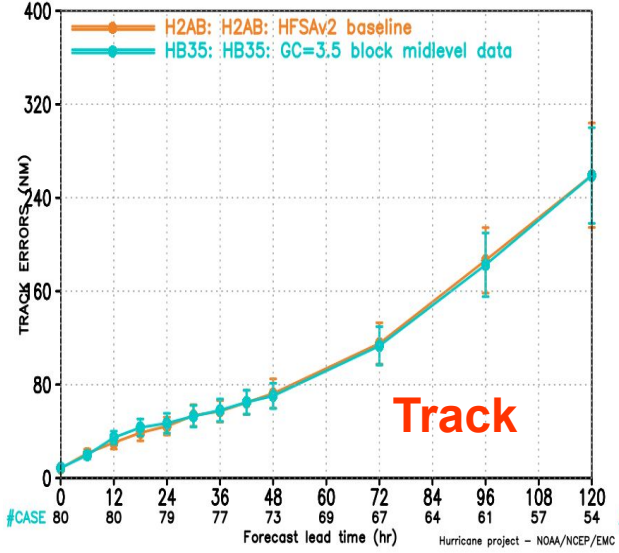


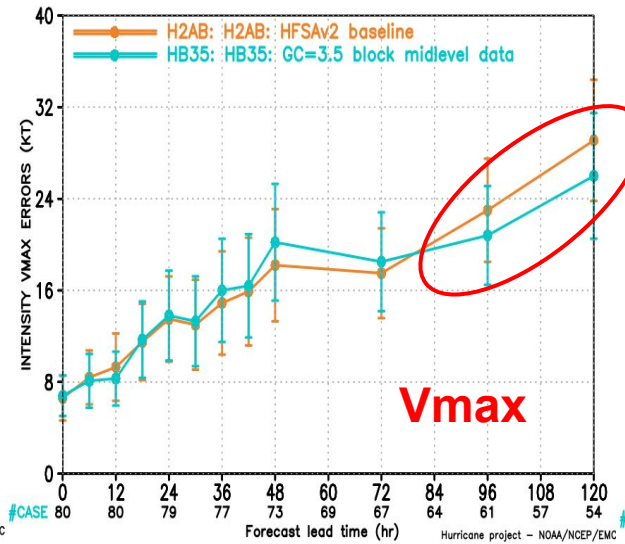


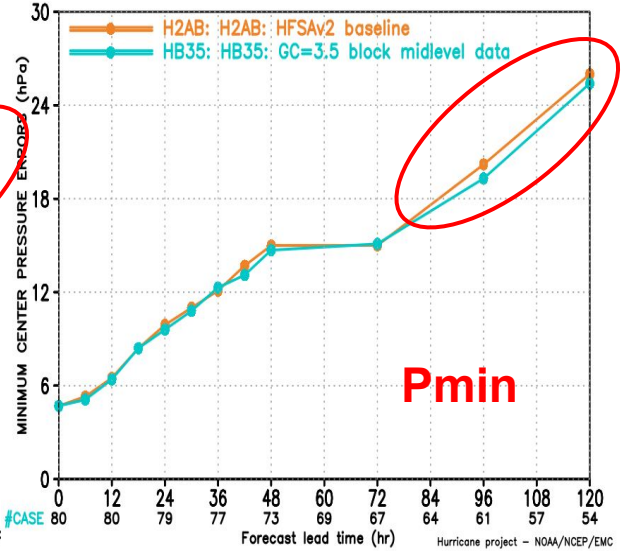




Impact of Enhanced Meso-sector GOES-R AMVs on HAFSv2

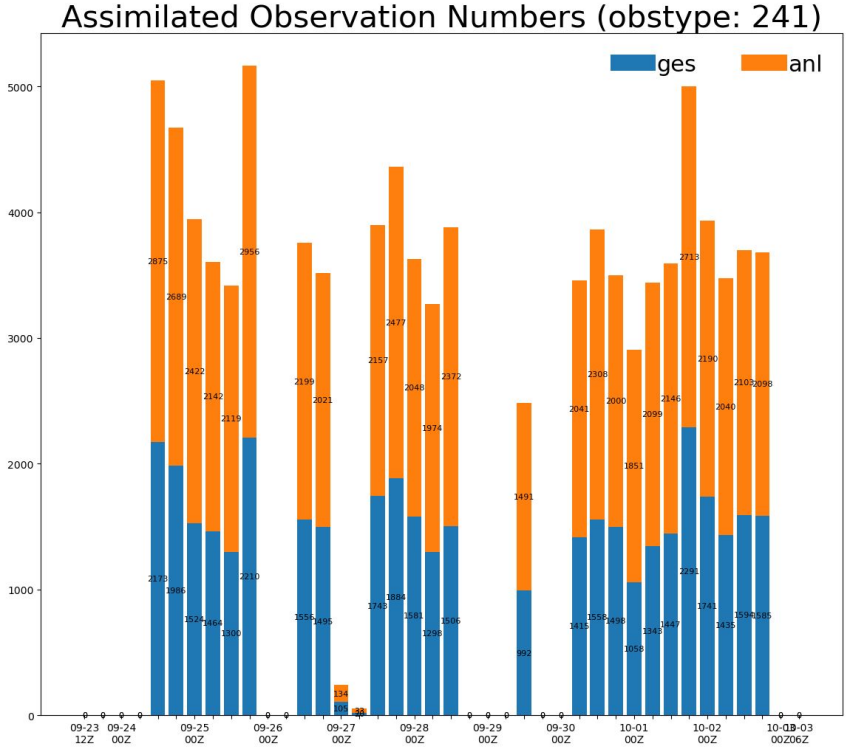


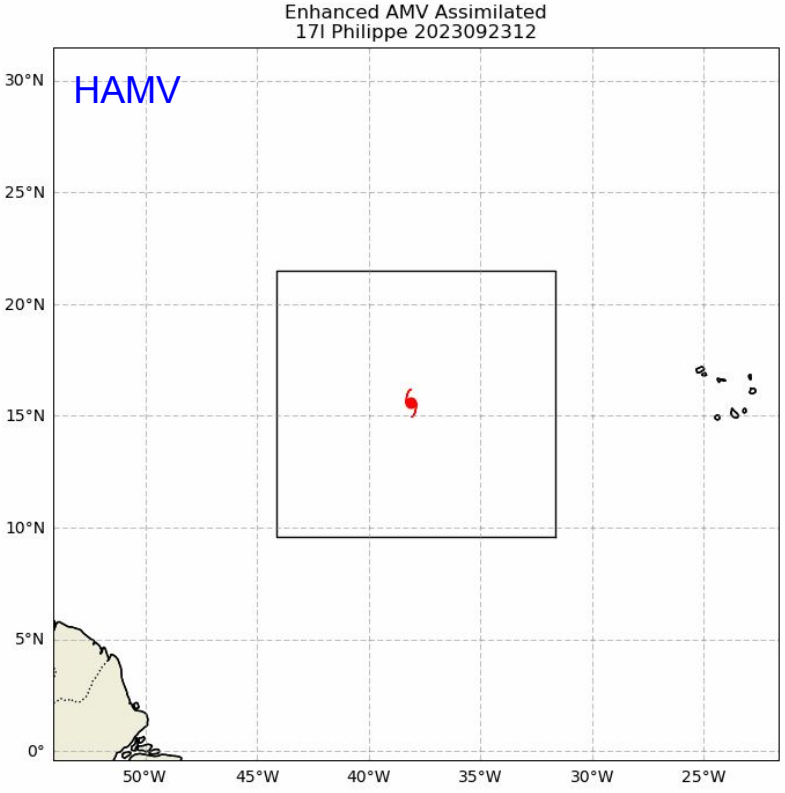




Assimilation of enhanced semo-sector AMVs has neutral impact of track forecast skills, but positive on intensity forecast skills, especially on the longer forecast lead times.

Observation assimilated in 2023 Hurricane Philippe

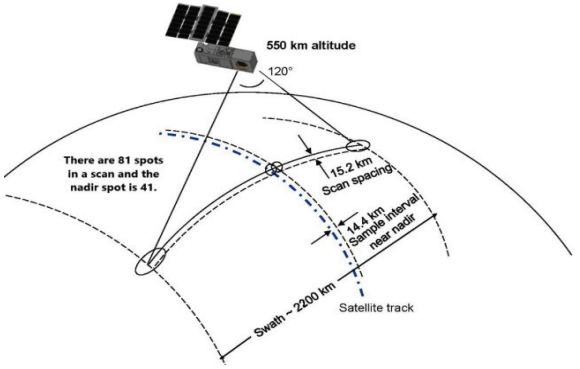


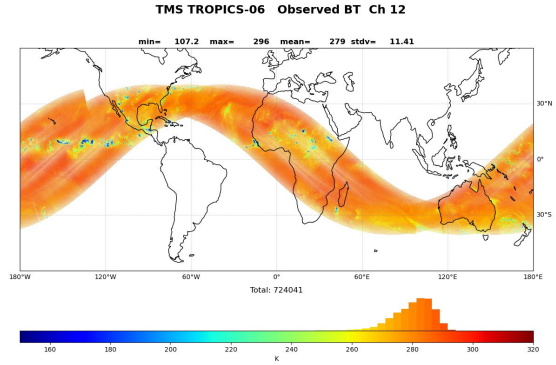


Ongoing Efforts

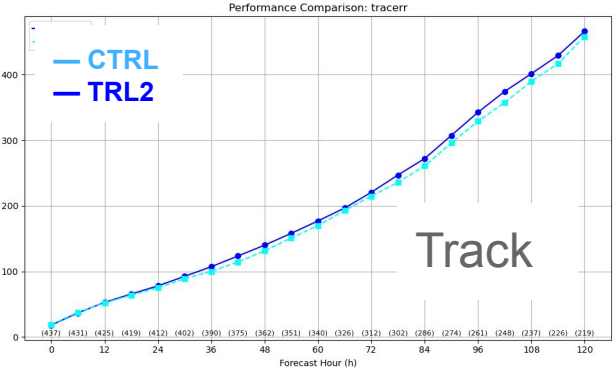
Assimilation of the TROPICS and Tomorrow.io

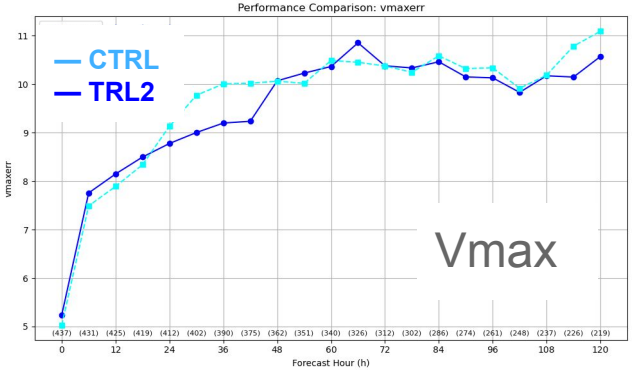
- **T**ime-**R**esolved **O**bservations of **P**recipitation structure and storm **I**ntensity with a **C**onstellation of **S**mallsats
- TROPICS L2 in HASF
  - Completed Data Evaluation
  - Optimal thinning 30 km, 200 hPa
- TROPICS L1 in GFS and HAFS
  - Completed Data QA/QC Evaluation
  - Bias correction from GFS
- Tomorrow.io in GFS and HAFS

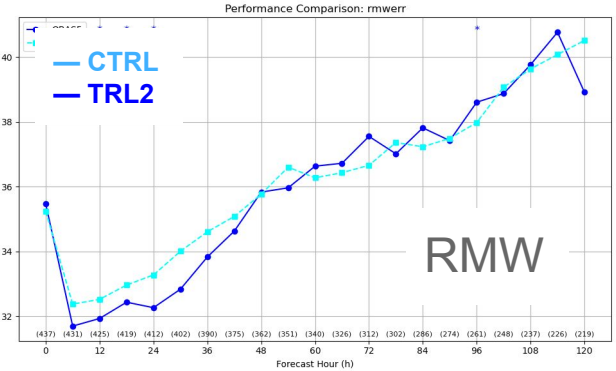


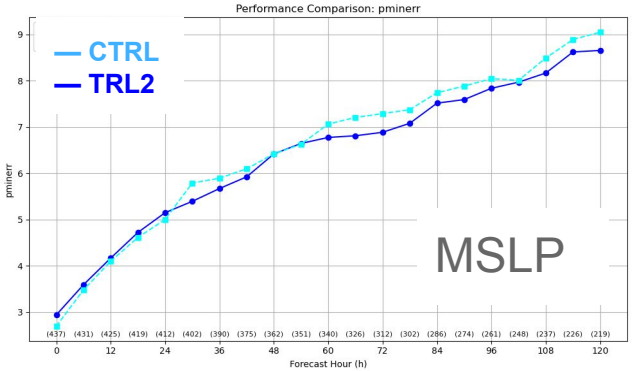


Impact of TROPICS L2 on HAFSv2







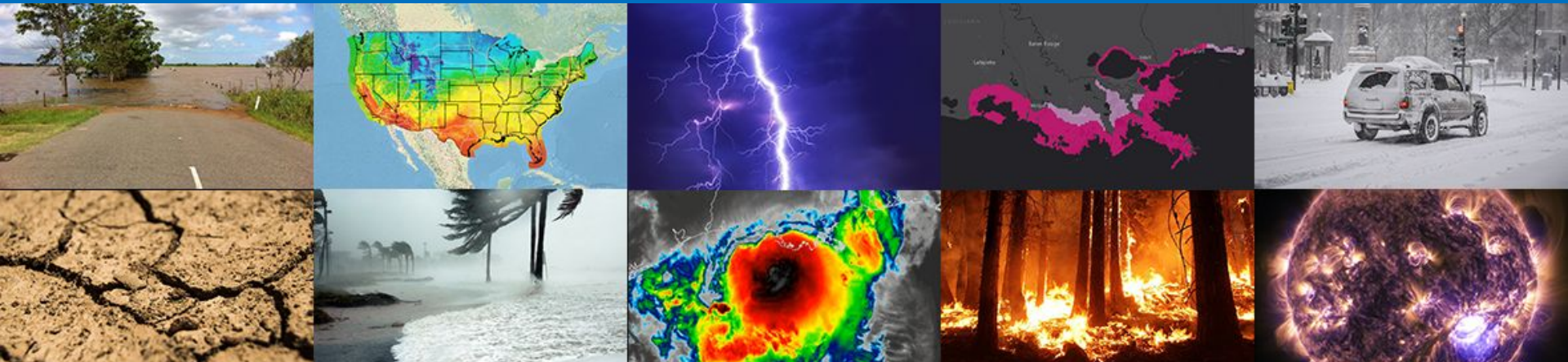


- Thinning 30 km, 200 hPa + SDL
- CTRL: No TROPICS L2 DA
- TRL2: CTL + TROPICS L2 DA
- 2023 named storms
- Neutral impact on track forecasts
- Improvements mid-to-long term Vmax/MSLP predictions and RMW and

Summary

- HAFS model benefits from satellite observation data, parent domain through GFS analysis, nest domain through high-res GOES AMVs
- High temporal and spatial resolution observation data, such TROPICS, Tomorrow.io, will be included in future versions of HAFS
- DA is planned to be conducted in the parent domain to take advantage of more satellite observations
- AI/ML approaches are being explored for inner-core data assimilation to incorporate both high-resolution satellite observations and flight reconnaissance data.

Thank you!



Future Plan for HAFS DA System

Future HAFS-DA

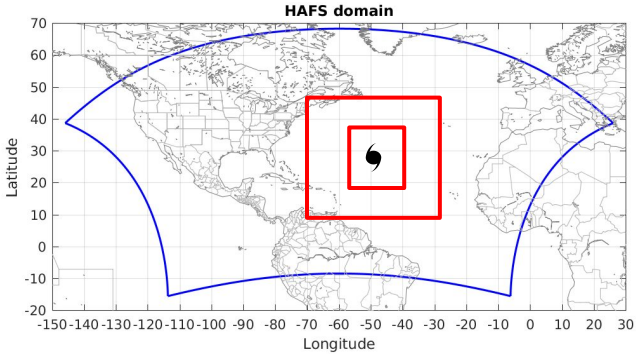
- Transition to JEDI based atmospheric DA
- Implement MOM6 3DVAR
- High frequency DA for atmosphere
- Coupled atmosphere/ocean DA
- Self-cycled flow-dependent background error covariance on either static or storm-centric domain
- Assimilate more high temporal and spatial resolution obs., such TROPICS, Tomorrow.io, IWRAPS
- Large DA domain
- Introduce DA for TCs in JTWC basins
- Explore AI/ML based TC inner-core DA

HAFSv2.2

- Upgrade, GFSv17 downstream impact (2026)

HAFSv3.0+ (2026/2027 and beyond)

- HFSAv3: Storm-Centric configuration with telescopic higher resolution moving nest (~1 km)
- HFSBv3: Multiple moving nests in basin-scale domain
- HAFS based hurricane ensemble
- AI/ML based deterministic an ensemble forecast system



TROPICS & Tomorrow Microwave Sounder - Channel Info

Sensor		TROPICS Microwave Sounder		Tomorrow.io Microwave Sounder	
CH	Band	Center Freq. (GHz)	Bandwidth (GHz)	Center Freq. (GHz) (S1-S6)	Bandwidth (GHz) (S1-S6)
1	W	91.65 +/- 1.4	1	91.65	2
2	F	114.5	1	115.25	1
3	F	115.95	0.8	116.125	0.75
4	F	116.65	0.6	118.75±1.875	0.75
5	F	117.25	0.6	118.75±1.25	0.5
6	F	117.8	0.5	118.75±0.75	0.5
7	F	118.24	0.38	118.75±0.375	0.25
8	F	118.58	0.3	118.75±0.125	0.25
9	G	184.41	2	184.41	2
10	G	186.51	2	186.51	2
11	G	190.31	2	190.31	2
12	G	204.8	2	204.8	2