



**Overview of Operational Modeling at NOAA's
Environmental Modeling Center (Future Modeling
and Development Center - MDC)**

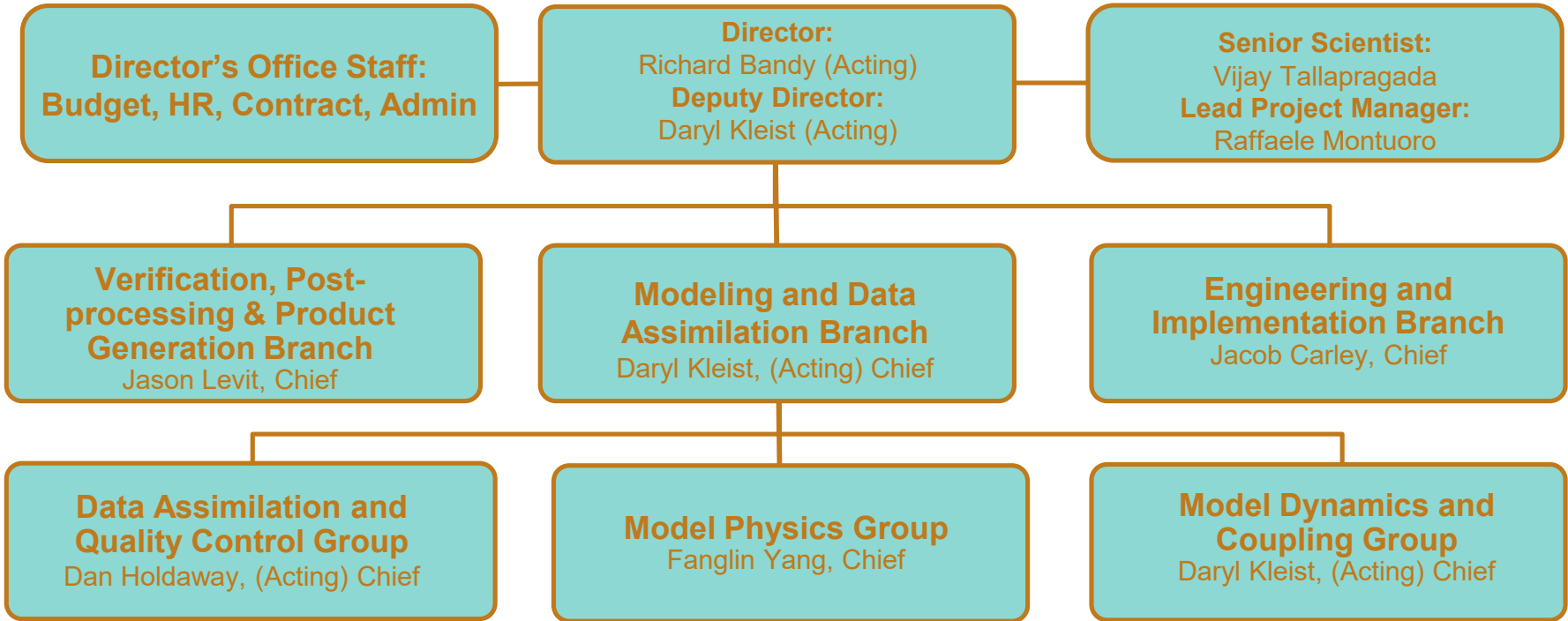
September 10, 2025

Vijay Tallapragada, Senior Scientist (ST) for MDC

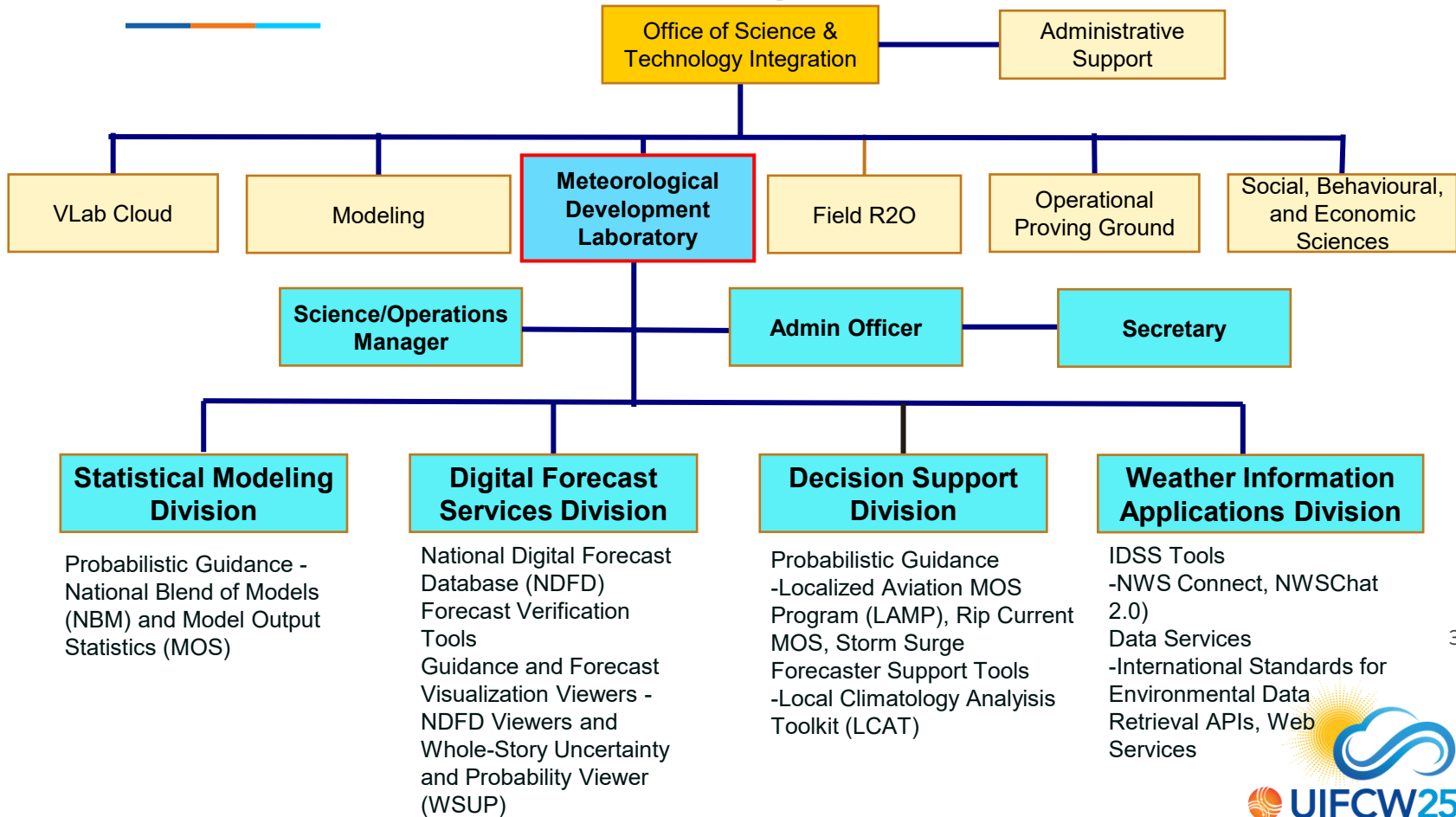
Modeling and Developmental Center
National Oceanic and Atmospheric Administration
U.S. Department of Commerce



EMC Current Organizational Chart



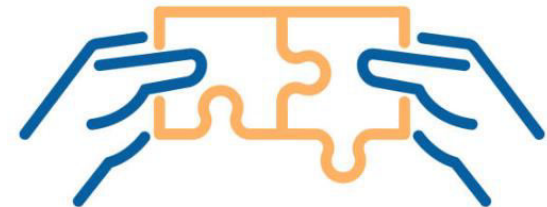
OSTI / MDL Current Organizational Chart



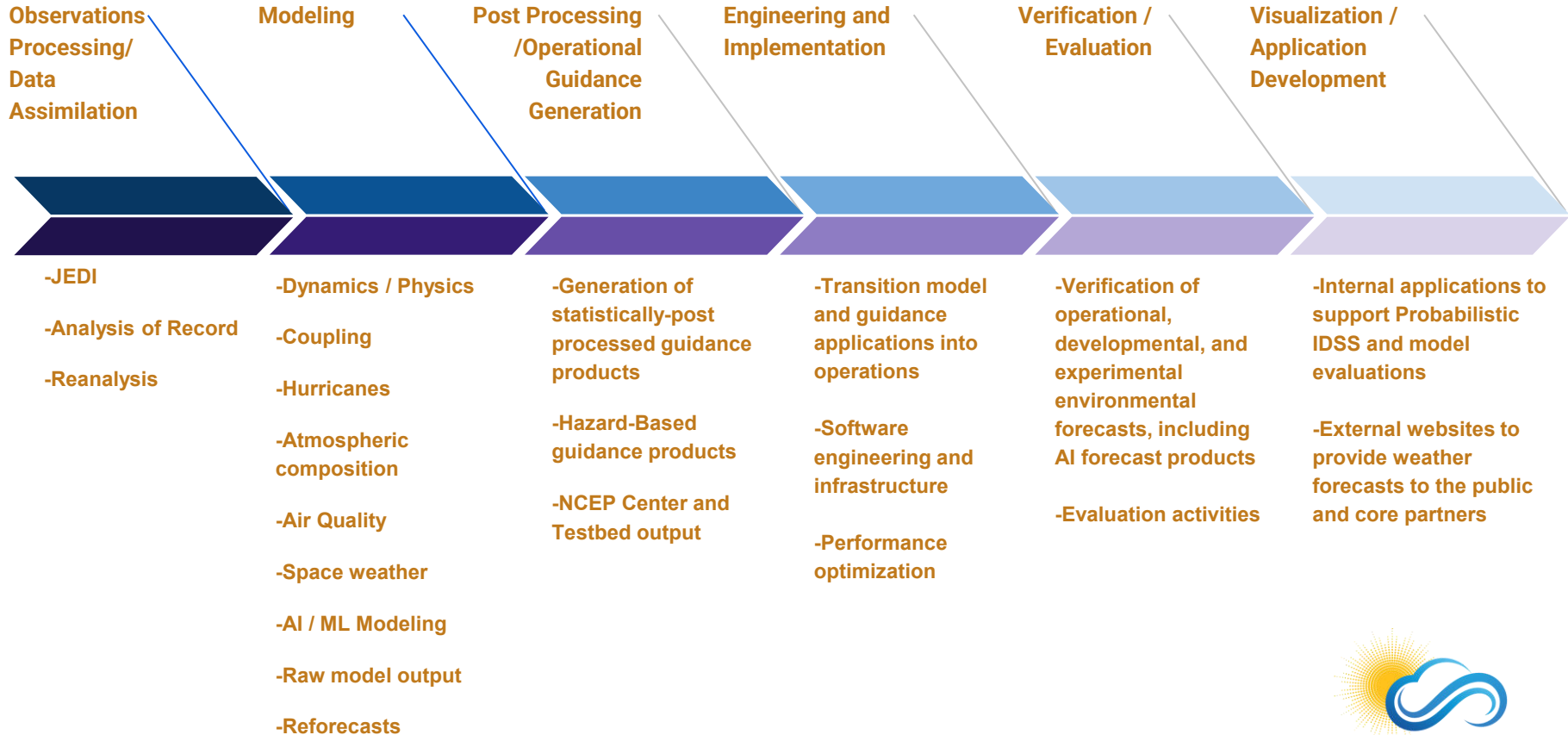
NWS Modeling and Development Center

Expertly Execute Across the Value Chain of Development and Operational Implementations

- Executing the modeling lifecycle: From observations, improvements, post-processing, value-add to verification and validation
- DSS-focused products and services including data visualization tools, data delivery, and improved web and mapping capabilities
- Direct stakeholder engagement, including a shared technical infrastructure, that enables innovation and brings closer the requirements process, effectively closing the loop on agile improvement

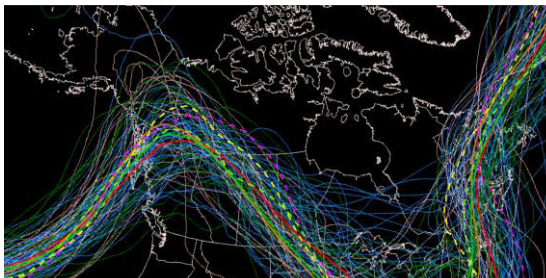


MDC Supports the Full Value Chain



Purpose of Operational Modeling

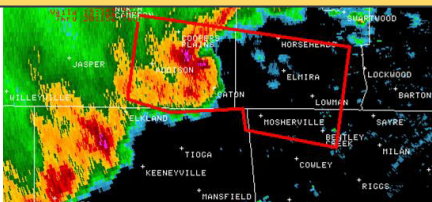
The operational modeling suite provides **ensemble-based foundational numerical guidance** that NWS scientists and forecasters rely on in providing **forecasts, warnings, and probabilistic impact based decision support services.**



Must get the science right...

to get the forecast right ...

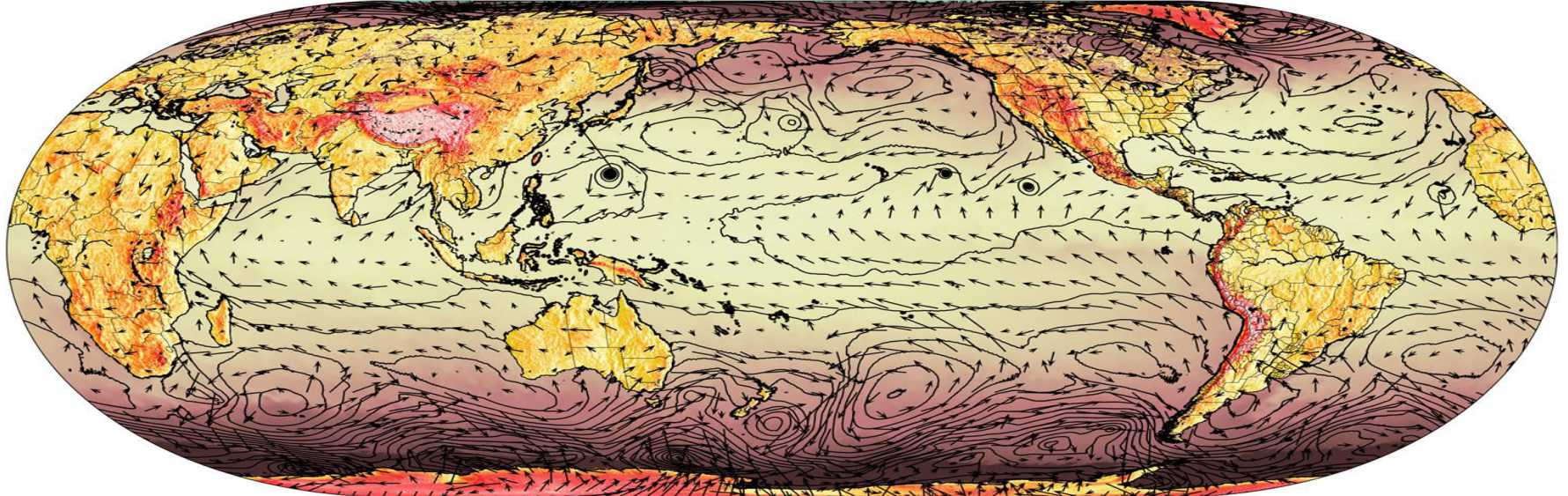
to aid the right decisions!



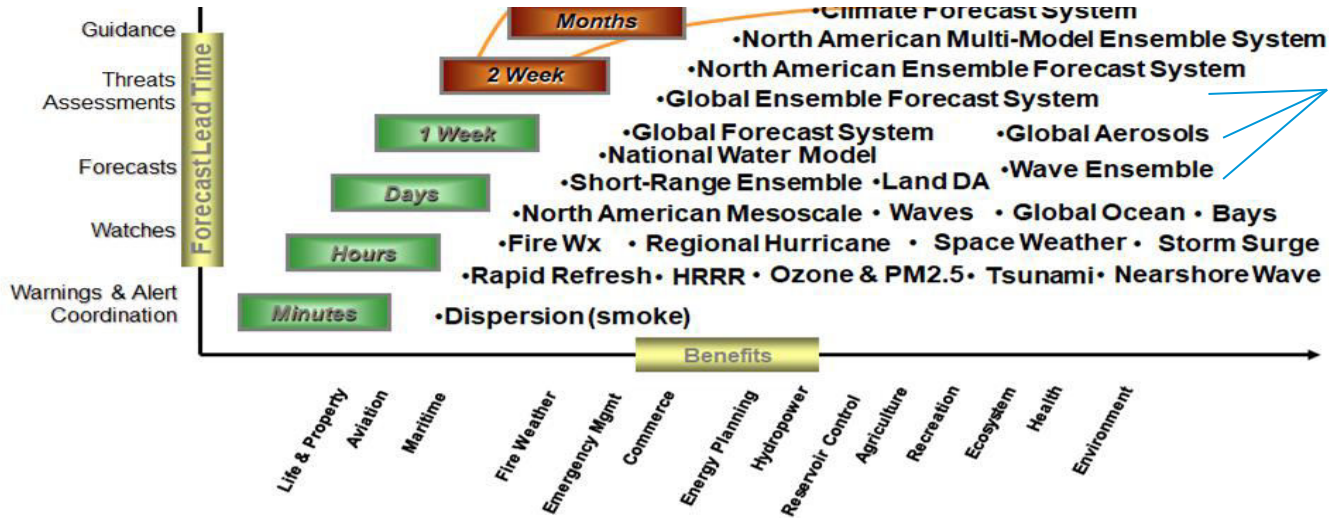
What do we do?

We develop, improve and monitor data assimilation systems and models of the atmosphere, ocean, land surface and coupled system, using advanced methods developed internally and cooperatively with scientists from universities, NOAA Labs, other government agencies, and the international scientific community.

Warm shade: Surface Temp, Contour: MSLP, Cool shade: Convective Cloud Cover, Arrows: 10m Wind
C3072L127 2018090100 f000

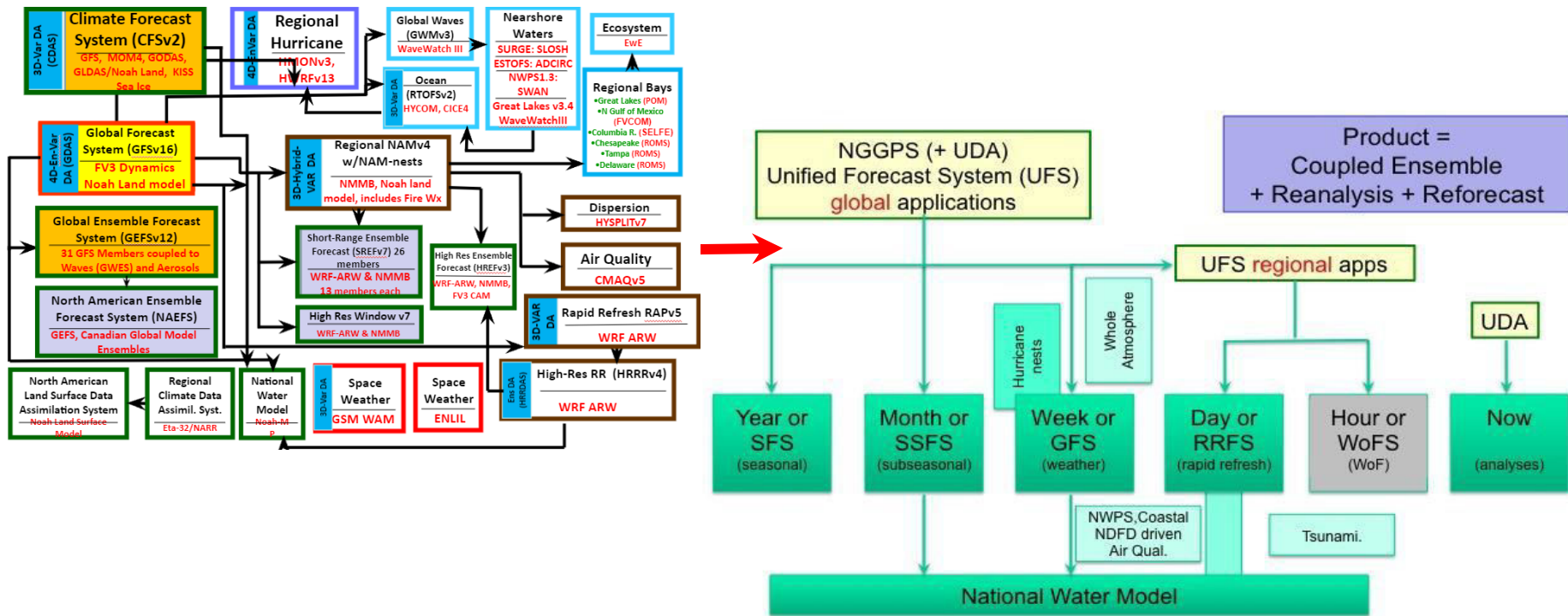


NCEP Production Suite (Modeling)



EMC develops and implements the prediction systems that provide operational numerical guidance, spanning weather and climate, for use across the NWS and its worldwide partners.

Goal: Simplifying the NCEP Production Suite (NPS)



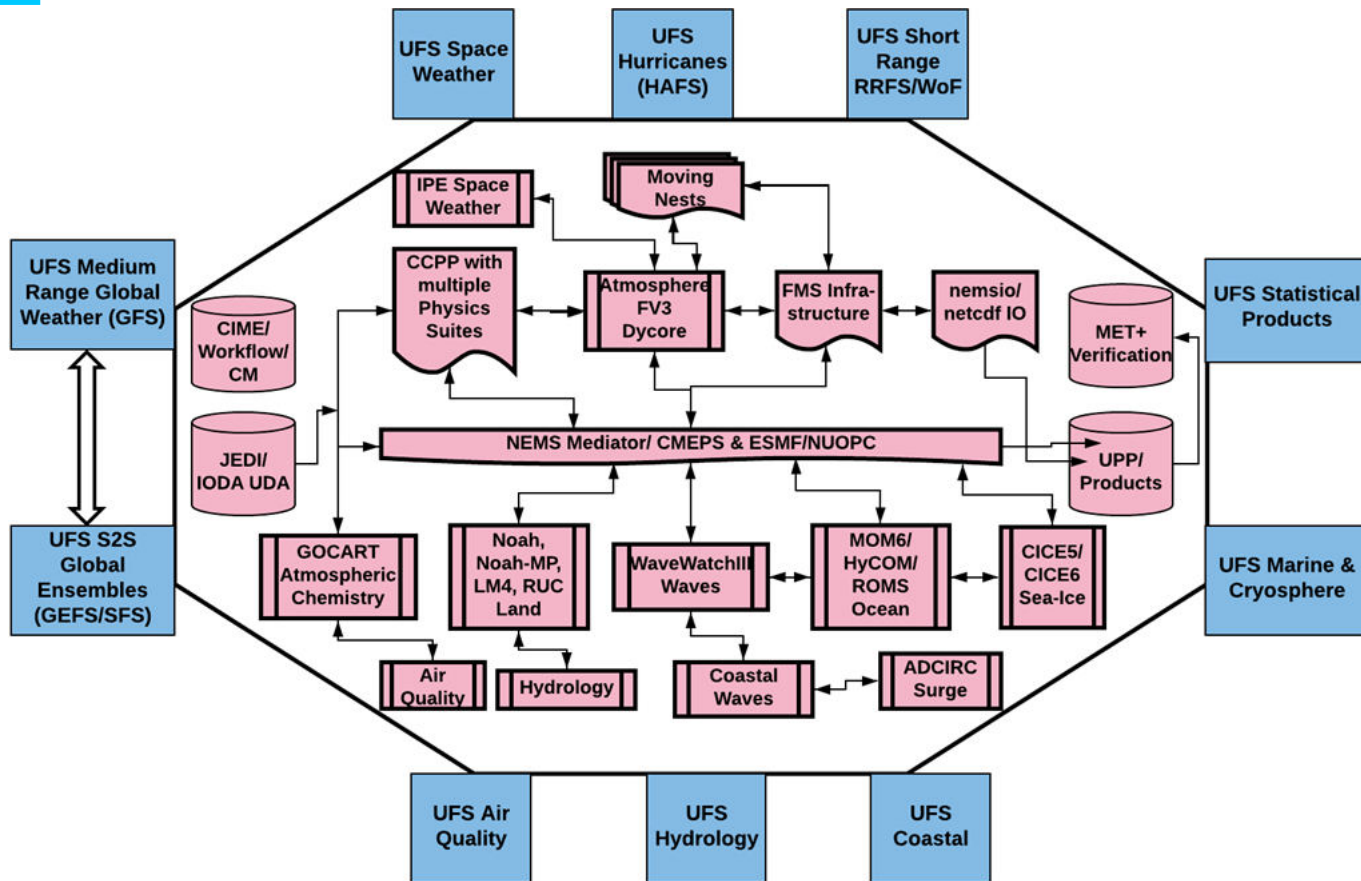
UDA: Unified Data assimilation
 SFS: Seasonal Forecast System
 SSFS: Subseasonal Forecast System

GFS: Weather Forecast System
 RRFs: Rapid Refresh Forecast System
 WoFS: Warn on Forecast System

Transitioning NPS to UFS Applications

“UFS is configurable into multiple applications that span local to global domains and predictive time scales from less than an hour to more than a year.”

Conceptual UFS applications in production covering all NPS applications, maintaining the dependencies between the applications and products.



Recent/Planned Operational Model Upgrades

Model version#	Operational System	Implementation date
EVSv1	EMC Verification System	3/26/2024
AQMv7	Air Quality Model	5/14/2024
HAFSv2	Hurricane Analysis and Forecast System	7/16/2024
RTOFSv2.4	Real-Time Ocean Forecast System	9/13/2024
GFSv16.4	Global Forecast System	July 2025
HAFSv2.1	Hurricane Analysis and Forecast System	July 2025
RTOFSv2.5	Real-Time Ocean Forecast System	July 2025
GCAFSv1	Global Chemistry & Aerosol Forecast System	Q3FY2026
RRFSv1	Rapid Refresh Forecast System	Q2FY2026
GFSv17	Global Forecast System	Q1FY2027
GEFSv13	Global Ensemble Forecast System	Q2FY2027
SFSv1	Global Seasonal Forecast System (Beta)	Q3FY2027

By FY27, 80% of NCEP Production Suite is expected to be UFS based

Yellow:
UFS Applications



Global Model Development Priorities

GFSv17

- Coupled forecast model (atmosphere, land, ocean, ice, wave)
- Improved DA with marine JEDI
- Physics improvements including Noah-MP land model, PBL, convection, gravity waves, and Thompson Microphysics
- Unstructured Wave grids w/2-way coupling
- Higher resolution (9-km)

GEFSv13

- Have the same model configuration as of GFSv17
- Early cycle EnKF analysis for ensemble initial perturbations
- Advanced model stochastics for all component models
- 30 years reforecast to support forecast calibration (and training)
- Extend forecast length to 48 days

Joint Effort for Data assimilation Integration

Infrastructure for Unified Data Assimilation



GSI in operations since 2007, but portions of the code are 30+ years old
JEDI is a project within the Joint Center for Satellite Data Assimilation (JCSDA)

JEDI provides a software infrastructure for DA that:

1. is model agnostic (but requires an interface to models!)
2. is generic and portable
3. does not impose specific methodologies or algorithms
4. allows to share efforts (new observation types, etc.) across different orgs.

History & Current Status

Current State of Data Assimilation Capabilities at NOAA/NWS/NCEP/EMC

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
National Centers for Environmental Prediction
5830 University Research Court
College Park, MD 20740-3818

Office Note ###
<https://doi.org/10.25923/#####>

Current State of Data Assimilation Capabilities at NOAA's National Weather Service / National Centers for Environmental Prediction / Environmental Modeling Center

Daryl Kleist, Jacob R. Carley, Andrew Collard, Emily Liu, Shun Liu, Cory R. Martin, Catherine Thomas, Russ Treadon, Guillaume Verrieres
NOAA/NWS/NCEP Environmental Modeling Center
College Park, Maryland
April 2023

Data Assimilation Strategy for NOAA/NWS/NCEP/EMC

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
National Centers for Environmental Prediction
5830 University Research Court
College Park, MD 20740-3818

Office Note ###
<https://doi.org/10.25923/#####>

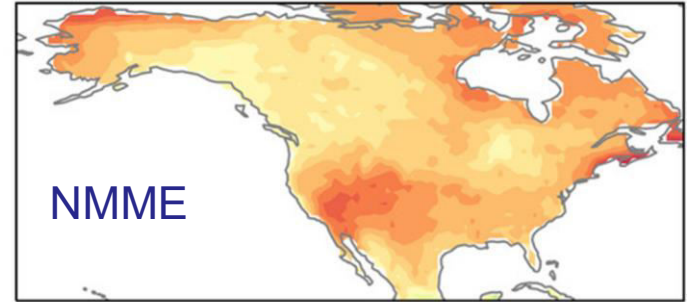
Data Assimilation Strategy for NOAA's National Weather Service National Centers for Environmental Prediction Environmental Modeling Center

Daryl Kleist, Jacob Carley, Andrew Collard, Emily Liu, Shun Liu, Cory R. Martin, Catherine Thomas, Russ Treadon, Guillaume Verrieres
NOAA/NWS/NCEP Environmental Modeling Center
College Park, Maryland
February 2023

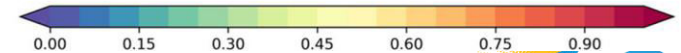
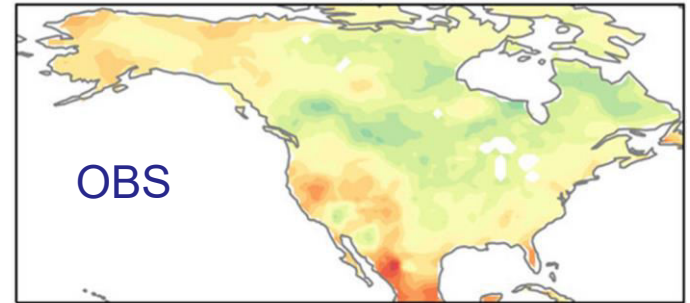
SFS Development Plan: Goals and Objectives

- Develop SFSv1 as a replacement of Climate Forecast System version 2 (CFSv2), a more than decade-old system
- **Address common errors in CFSv2 and NMME**
 - MJO propagation across Maritime Continent
 - False ENSO alarms
 - Positive SST trend errors in tropical Pacific
 - Too frequent above-normal temperature forecast
 - Too infrequent below-normal temperature forecast
- Release the coupled SFS system to the public
- Release reanalysis & reforecast data sets to the community

Frequency of above-normal
B) NMME lead-1 frequency of above



D) Observed frequency of above



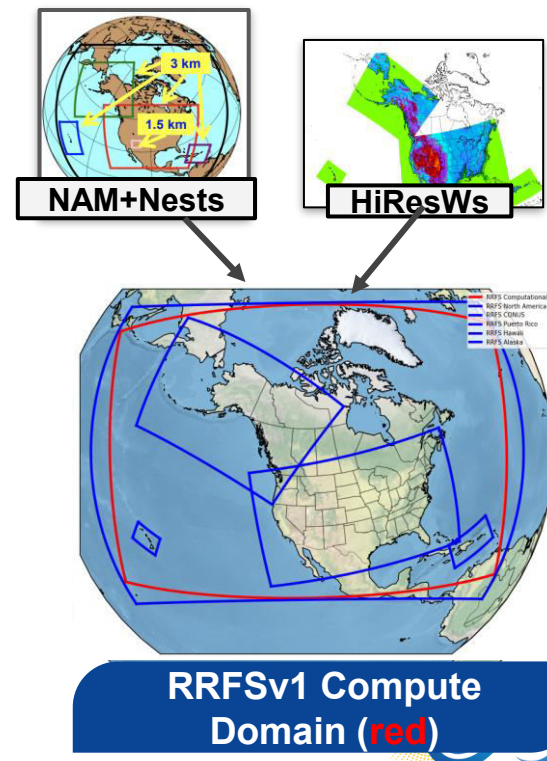
Becker et al. 2022



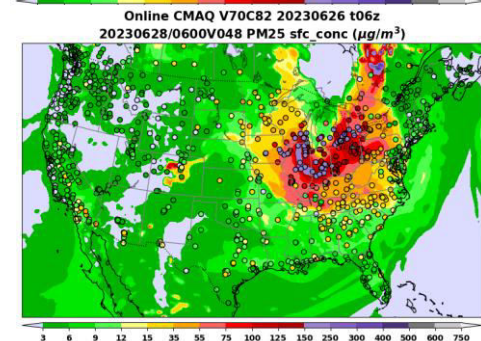
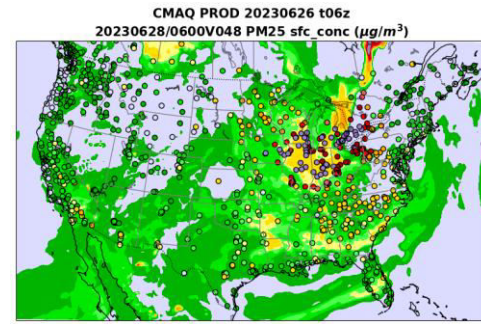
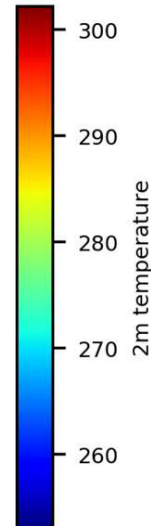
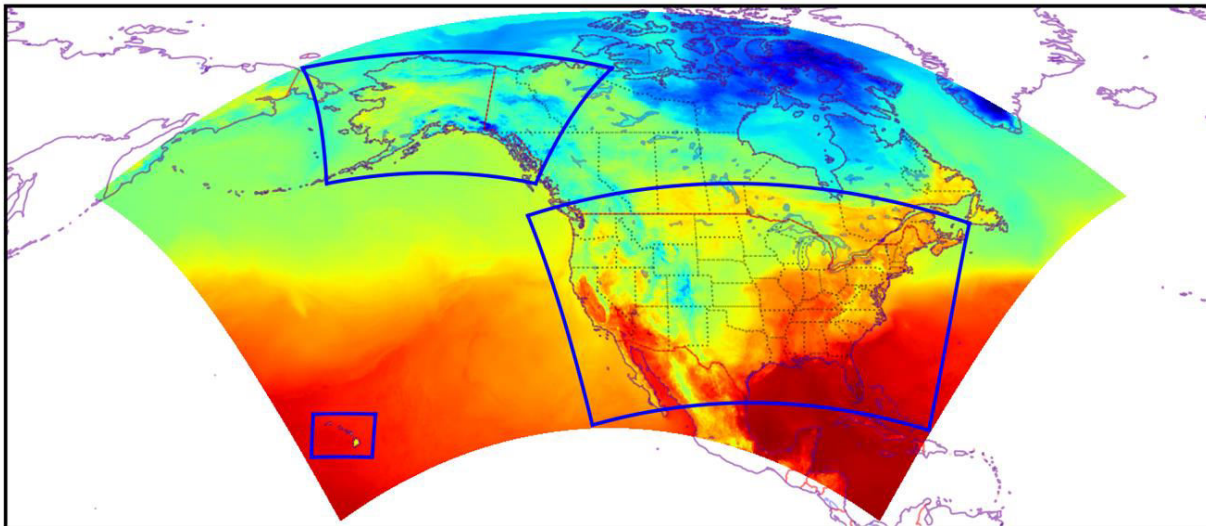
Rapid Refresh Forecast System (RRFS)

A UFS Application

- Currently based on FV3 dynamical core Limited Area Model
- Hourly updated
- 3 km grid spacing over North America
- 65 vertical layers
- Hybrid 3D EnVar assimilation (30 members)
- Includes Smoke & Dust
- Deterministic forecasts to *at least* 18h every hour
- Deterministic & Ensemble forecasts to 48+h every 6 hours
- **RRFSv1 Field Evaluation Completed - potential transition into operations in February 2026**
- **RRFSv2**
 - Transition from FV3 dynamical core to MPAS
 - *Adding American Samoa and Micronesia Support to improve service to underserved communities*



AQMv7: Online-CMAQ in UFS on a single large North American domain



- **Near-real-time online-CMAQ** has run since July 2022 over the North American large domain that covers all 3 current operational product domains: CONUS, AK and HI.
- Updates have been integrated into this near-real-time run to build **AQMv7 candidate system**
- Updated LBC (GEOS 5 + GEFS-Aerosols) and wet deposition
- Fengsha dust module; Bias correction for ozone and PM2.5
- Post-processing for 8h ozone maximum and daily average PM2.5

- Hourly RAVE wildfire emissions over the North American domain
- Anthropogenic and biogenic emissions for this domain (NEI 2016v1 plus global)

Hurricane Modeling at EMC

HAFSv1.0 implemented in June 2023, upgraded to HAFSv2.0 in July 2024

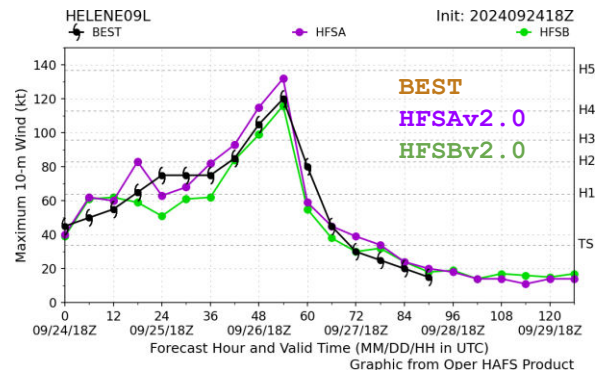
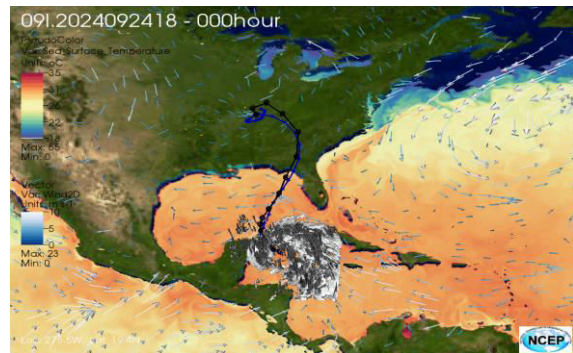
HAFSv2.0 Highlights

- Increased horizontal resolutions,
- improved model efficiency and stability
- Improved Vortex Initialization
- Improved inner-core data assimilation system
- Introduced new ocean model MOM6

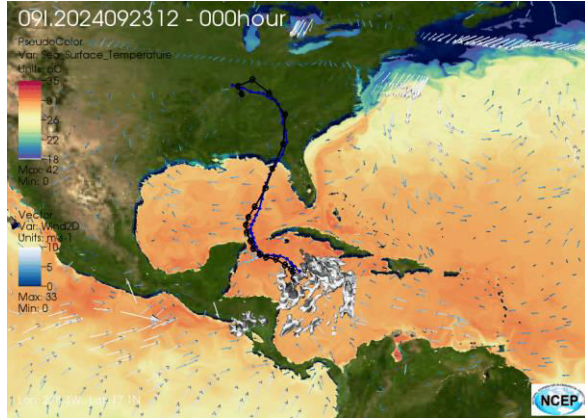
HAFSv2.1 to be implemented on July 31, 2025

- Use latest version of RTOFS (v2.5, July 2025) to initialize ocean models
- Address issues identified in 2024 hurricane season
 - Storm structure at model initial time
- Improve model track and intensity forecast skills

Hurricane Helene 09L, initialized at 2024092418



Helene

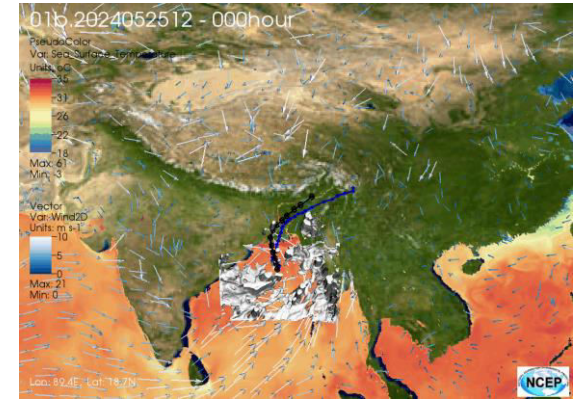


Milton

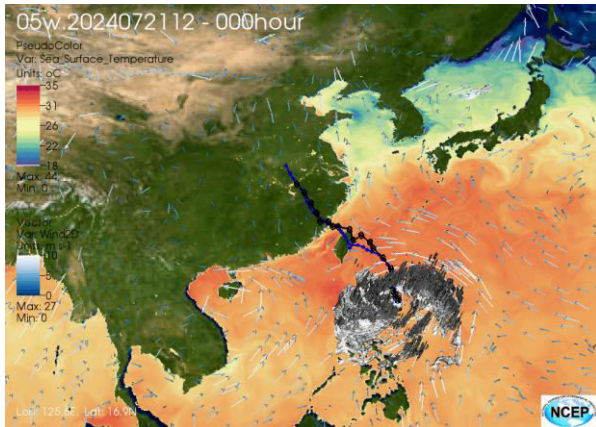


HAFSv2 Real-Time Forecasts 2024

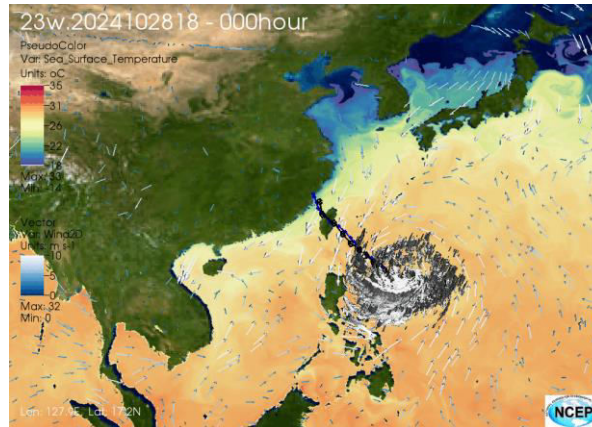
Remal



Gaemi



Kong-Rey

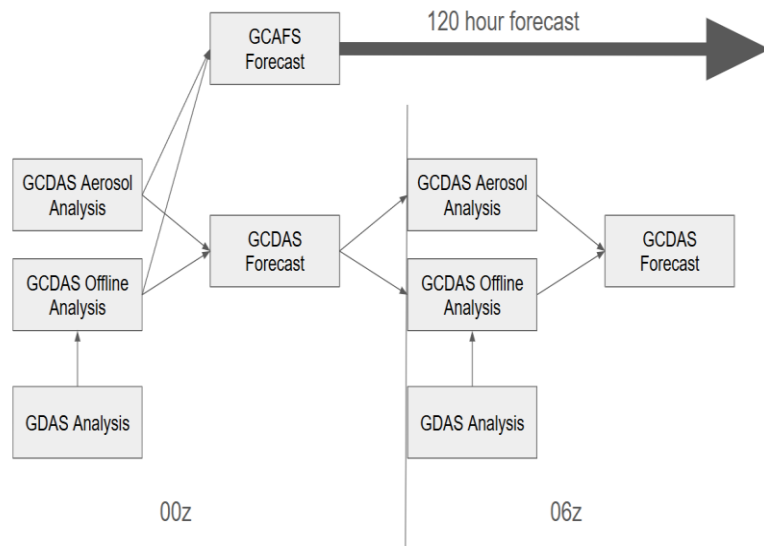


Global Chemistry and Aerosol Forecast System (GCAFS)

v1

Barry Baker, Cory Martin, Fanglin Yang

- **Replaces/retires GEFS aerosol member**
 - Provides 120 hour aerosol forecasts 2x a day
 - Updates to more recent model configuration (L127; physics to match GFSv17, etc.)
- **Adds aerosol data assimilation**
 - **JEDI-based system**
 - aerosol optical depth from polar orbiting satellites (VIIRS)
- **First step towards a comprehensive chemistry/aerosol forecast and analysis system**
 - Currently just using GOCART - aerosols but longer term vision is more tracers/gas phase chemistry/possibly to include regional air quality in a nest

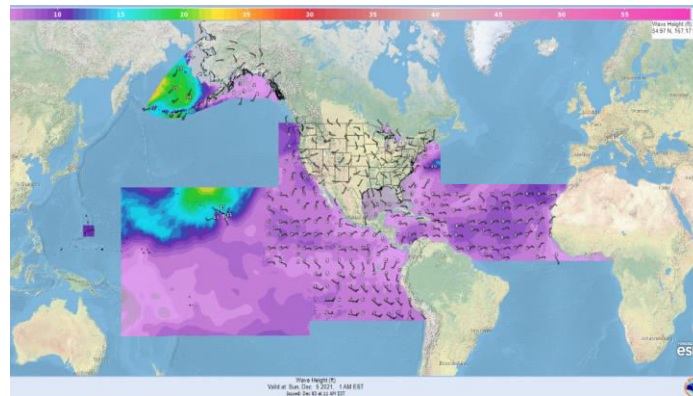


Implementation: Q2FY26

Regional Wave Prediction System (RWPS)

Jessica Meixner

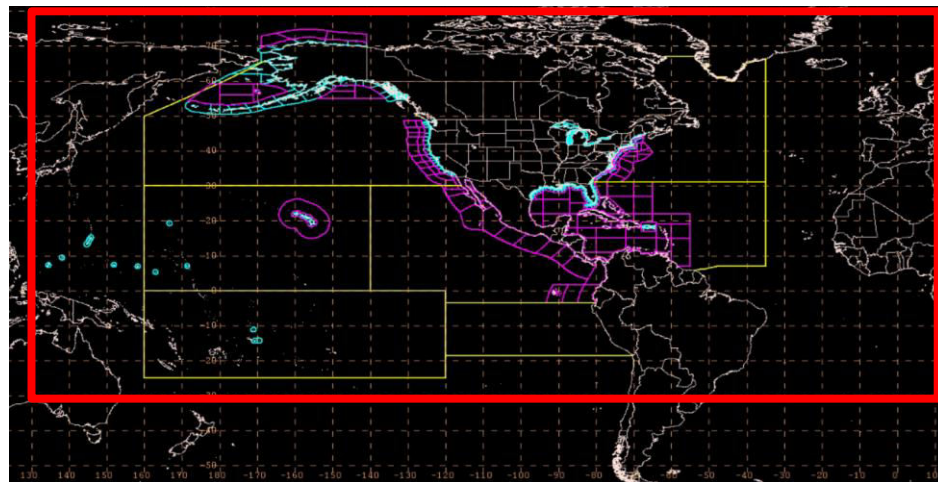
- Addresses [CaRDS 17-005](#) – capability similar to Nearshore Wave Prediction System (NWPS) for Offshore and High Seas areas
- Facilitate
 - Efficient grid production across NWS coastal and ocean areas
 - Full spectrum of wave parameters (not just significant wave height)
 - Addresses the challenges of TCs including consistent wave fields across all waters
 - Consistent tracking of wave systems from generation to coastal threats/impacts
 - Output – point forecasts – Gerling-Hanson plots across all waters
- Address Nearshore Wave Prediction System (NWPS) requirements
 - Consistency across NWS boundaries
 - No overlapping domains
 - Nearshore needs met under UFS



NDFD Oceanic Domain – significant wave height

Regional Wave Prediction System

- Single large Oceanic Domain
 - Lower left
 - 30.42S - 129.91E
 - Upper right
 - 79.99N - 10.71E
- Synergies with Unified Forecast System (UFS)
 - Use WAVEWATCH III (WW3)
 - Framework for future coupling



Proposed domain for RWPS (red) covering the Oceanic NBM domain and NWS marine responsibility. High Seas zones are in yellow, offshore waters in magenta, and coastal and Great Lakes in cyan.

Tentative: Implementation in 2028

Product Generation and Post-Processing

Product Systems

- **North American Ensemble Forecast System (NAEFS)**
- Combined NCEP/FNMOC Wave Ensemble (**NFCENS**)
- North American Rapid Refresh Ensemble - Time Lagged (**NARRE-TL**)
- Ensemble Tropical Cyclone Tracker (**ENS_Tracker**)
- Extra Tropical Cyclone Tracker (**ETC_Tracker**)
- Climatology Calibrated Precipitation Analysis (**CCPA**)
- Precipitation Analysis (**pcpAnalysis**, **pcpRTMA**, **pcpURMA**)
- **World Area Forecast System (WAFS)**
- Dozens of “operational” **websites** and **FTP data services**

9 Product Systems + WAFS + Websites

NAEFS v7 implemented December 5th, 2023
WAFS/ICAO product upgrade January 22, 2024

Legacy Products to UFS

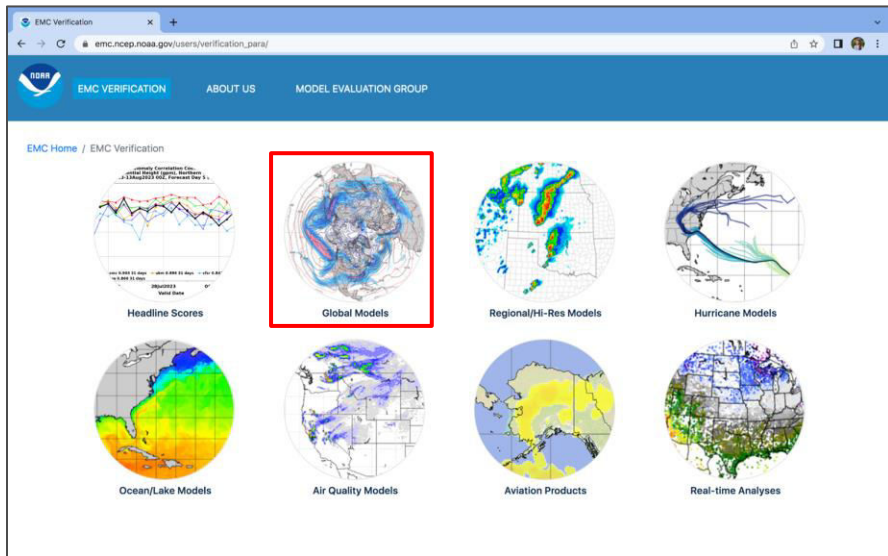
- NAM/RAP/SREF -> **GFS/GEFS**
- HRRR/HiresW/HREF/NAM Nest/NARRE-TL -> **RRFS**

Research Projects

- JTTI **snowfall** products
- **RRFS** aviation variables

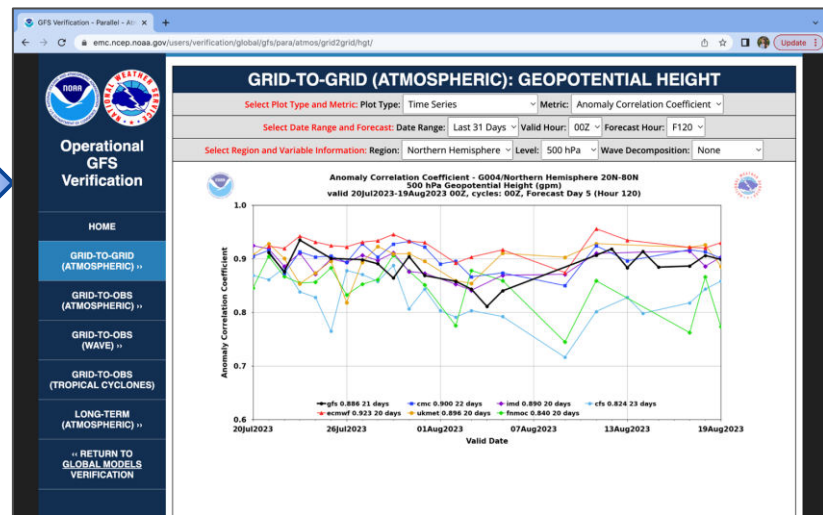
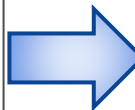
Verification System

<https://www.emc.ncep.noaa.gov/users/verification/>

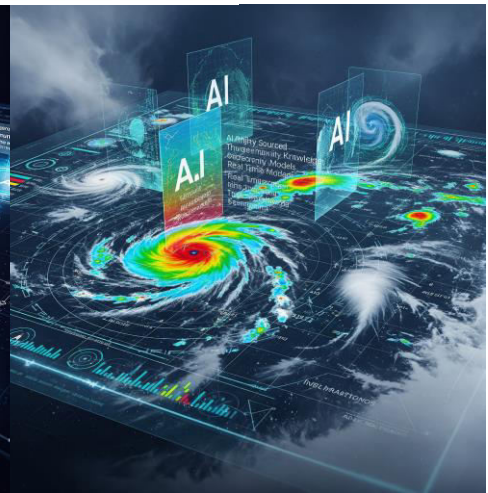


- **New software tool** to evaluate EMC **real-time** ESMs
- **Organizes** and consolidates EMC verification software
- Uses the **Model Evaluation Tools (METplus)** library
- Utilizes results of 2021 DTC **Metrics Workshop**
- Implemented on March 26, 2024

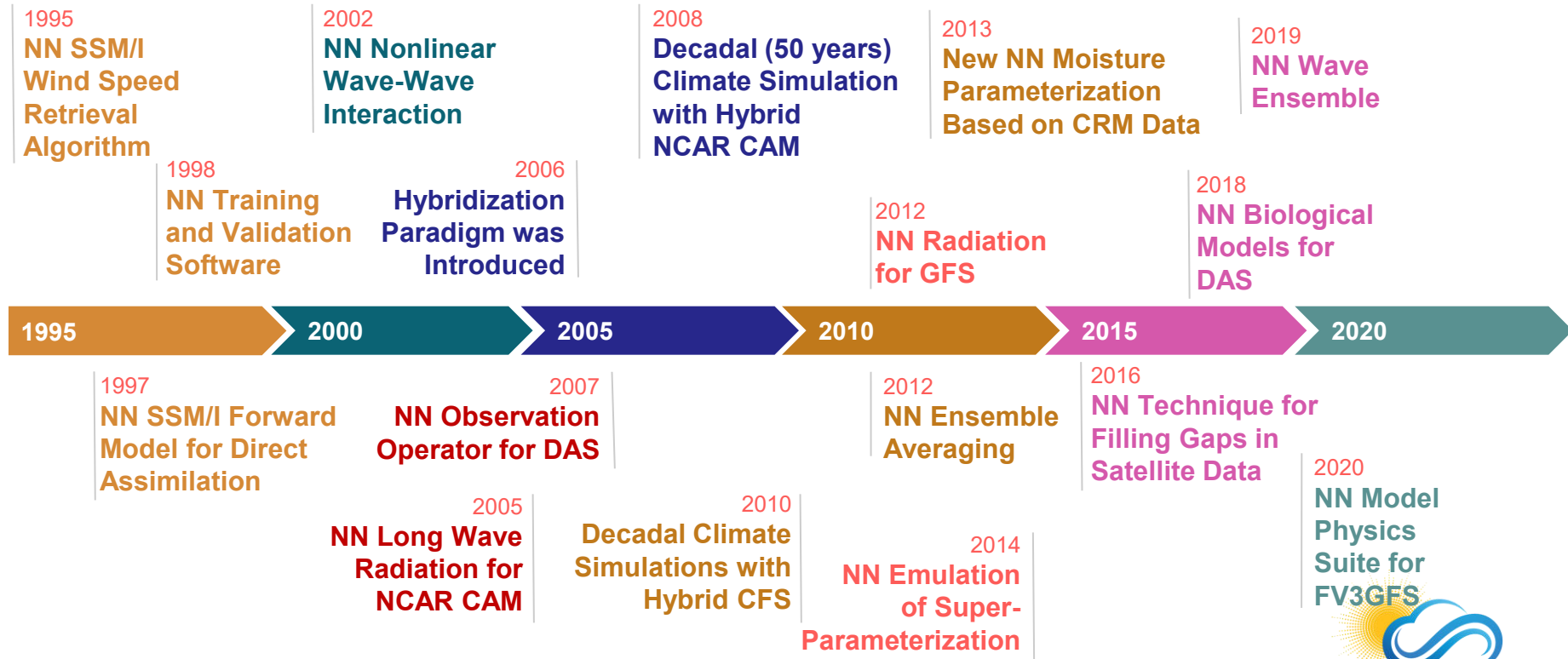
- **Model Evaluation Group:** statistical evaluation, evaluation of high impact events, weekly presentations



Future of Operational Prediction Systems Enabled through Rapid Advancements in AI/ML for NWP



Developments in ML for NWP and Climate



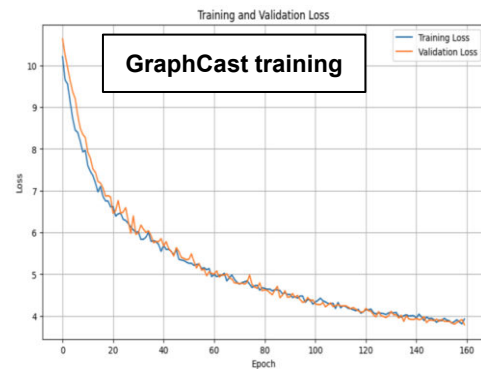
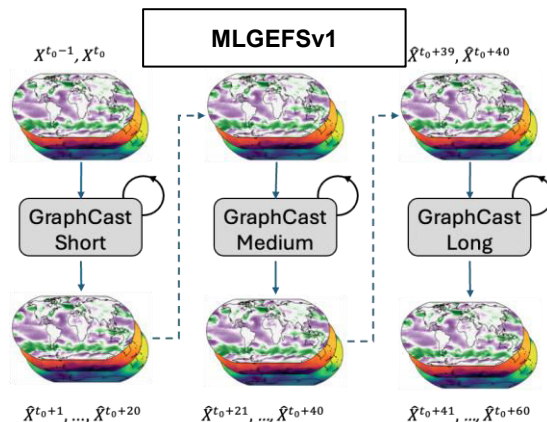
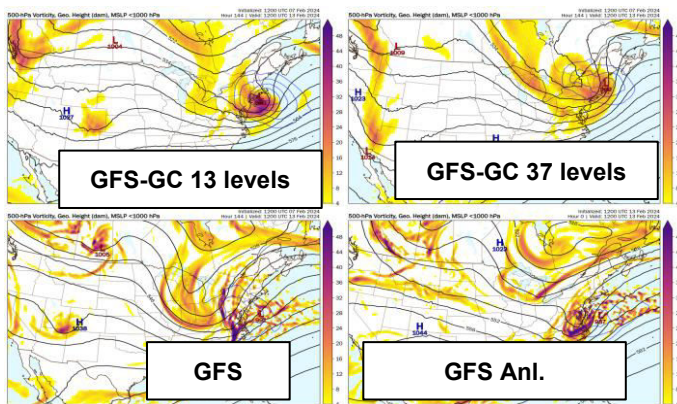
Develop data driven Machine Learning Weather Prediction models

Leverage the latest MLWP models and the advanced training techniques to develop the MLWP models for global weather and climate prediction

Global-EAGLE-Solo is a demonstration environment for “deterministic” models that are initialized from a single GFS initial condition.

Global-EAGLE-Ensemble is a demonstration environment for ensemble forecast systems initialized with the ensemble of GEFS initial conditions.

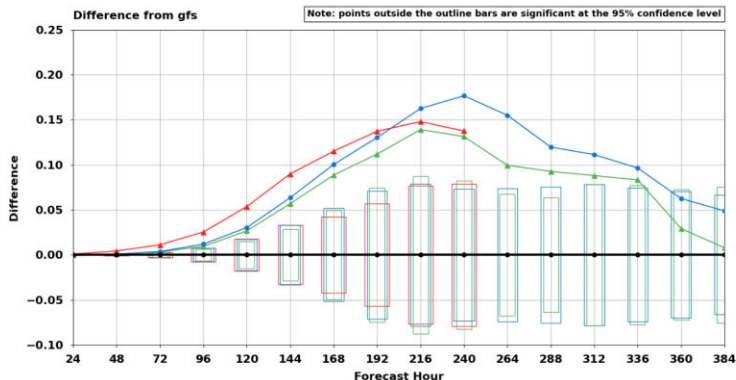
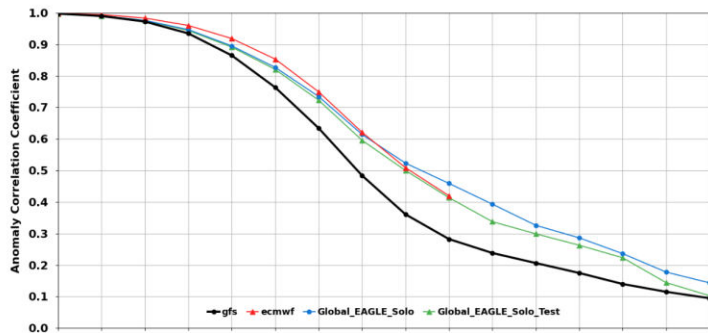
- Built GraphCast and FourCastNet with ERA5 data and GDAS data on NOAA cloud and R&D HPC platforms; setup the real time experimental GraphCastGFS on NODD: <https://noaa-aws-graphcastgfs-pds.s3.amazonaws.com/index.html>
- Fine tuning GraphCast with GFS input using GFS analysis data
- Developing autoencoder ML models to correct biases of GFSv16 products
- Created the first prototype of MLGEFSv1 with GraphCast model with GEFS 30 member ensembles
- Develop hybrid ensemble hurricane forecast system and ML2Ops system to support MLWP operational implementation



EAGLE-Solo Results

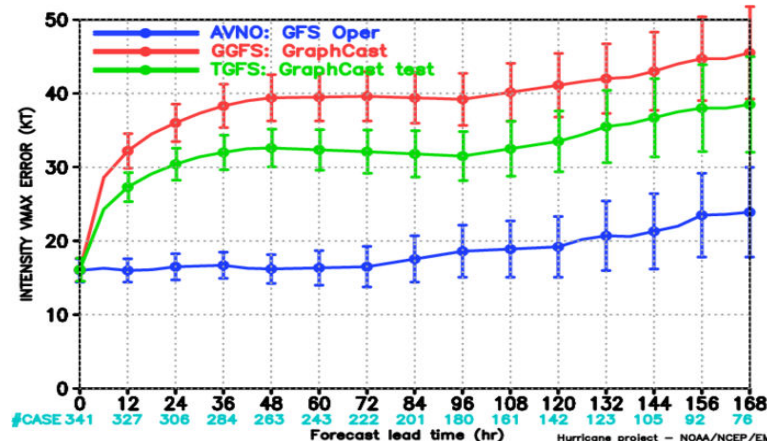
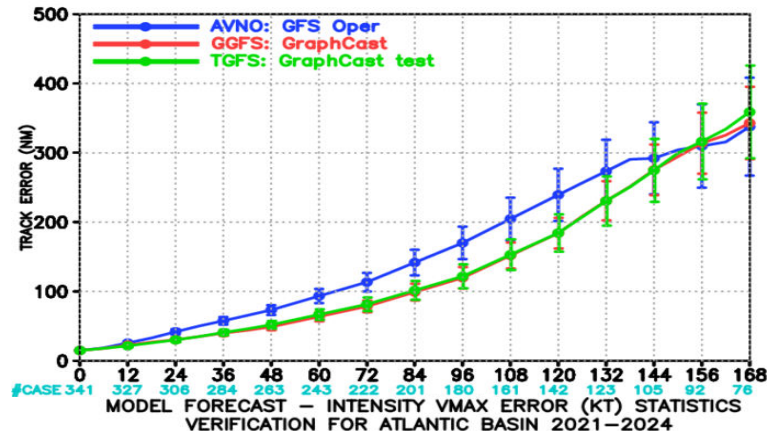


Anomaly Correlation Coefficient - G004/Northern Hemisphere 20N-80N
500 hPa Geopotential Height (gpm)
valid 12Apr2025-12May2025 00Z, init. hours: 00Z

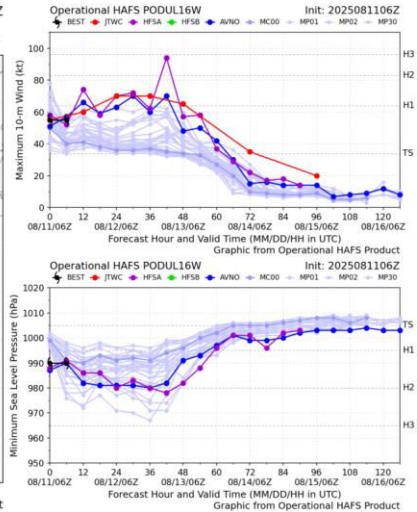
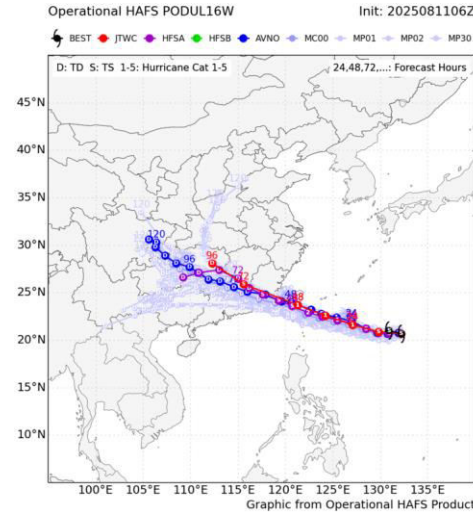
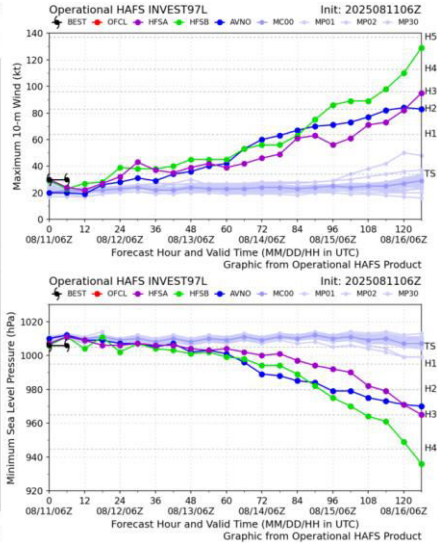
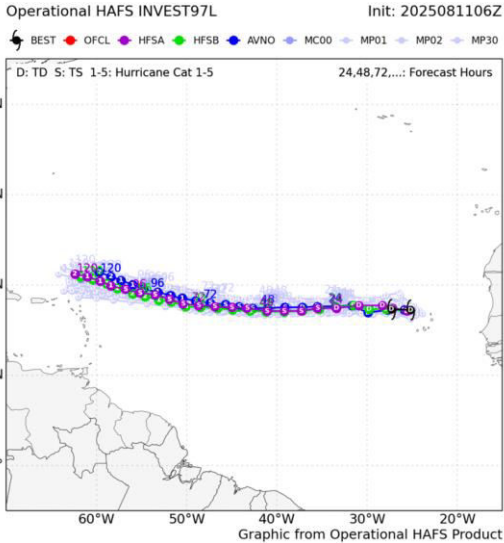


Note: All the models were compared against ERA5 Climatology data

MODEL FORECAST – TRACK ERROR (NM) STATISTICS
VERIFICATION FOR ATLANTIC BASIN 2021–2024

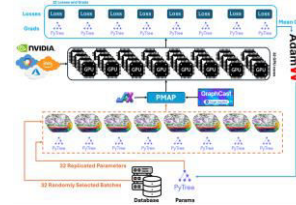


EAGLE Ensembles: Erin 05L/Podul 16W

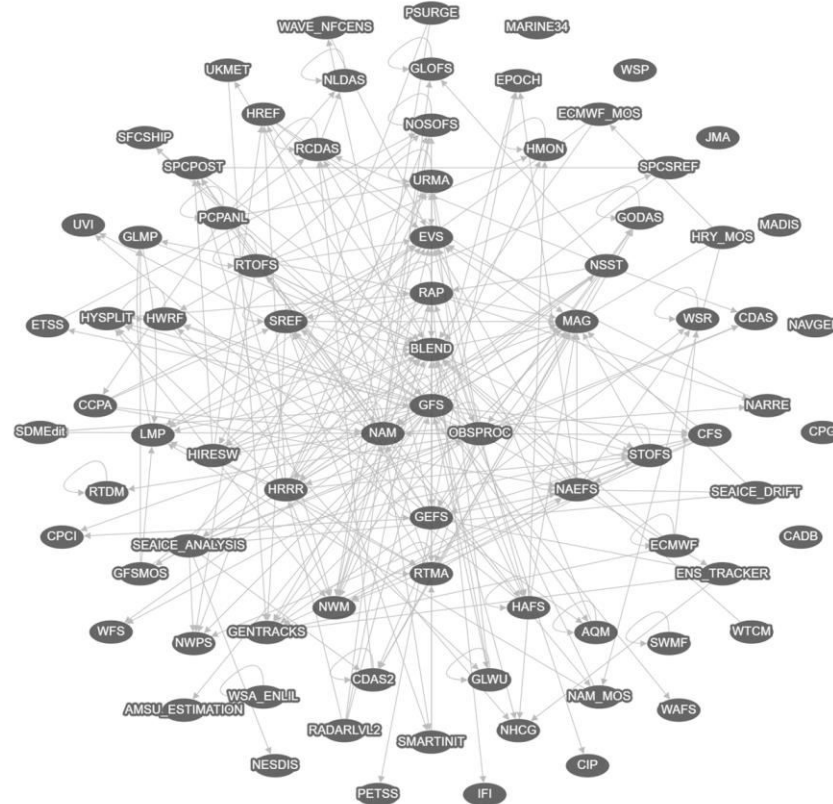


Major Ongoing AI/ML Activities

- **Prototype Global systems#**
 - GFS, GEFS, hybrid ML + Classical GEFS, SFS
- **ML Bias Correction#**
- **Direct from Observations with OCELOT@**
 - Prediction of future observations from past conventional and radiance observations
- **End-to-End Data Driven Forecast Models (including cycling)@**
- **AI data readiness@**
 - Provide operational data for AI/ML community
- **Generative AI**
 - NOAA Pilot Project Approval to explore use for scientific software development
- **Collaboration with AI4NWP, NOAA Research Labs, and Private Sector**
- **Plan move toward Anemoi framework**



Production Suite Dependencies



Challenges & Risks

- Limited Resources (HPC & Human) & Limited Expertise (AI/ML, DA, Software Engineering, Cloud architecture)
- Increased complexity of UFS, workflows and associated support on heterogeneous computing environments
- Competing priorities between physical model advancements and data driven AI/ML models
- High-Resolution (Coupled) Reanalysis for AI/ML training
- Retiring legacy systems from operations - nearly impossible to implement new applications on WCOSS
- CI/CD and DevSecOps for all applications - seamless R2O/T2O

Acknowledgement

All of the outstanding scientists and engineers at the Environmental Modeling Center (EMC), Meteorological Development Laboratory (MDL), collaborators within NOAA, at other Federal agencies, Academia, the Private Sector, and international operational and research centers.

