

# **State of the Earth Prediction Innovation Center and the Unified Forecast System**

**Session Chair:** John Ten Hoeve

**Speakers:** Maoyi Huang, Saeed Moghimi, Kevin Garrett, Vijay Tallapragada,



# Unified Forecast System

## WHAT

An Earth System Modeling framework developed by the science community to better predict weather and climate. The UFS aims to simplify NOAA's operational suite from 21 standalone forecast systems to 8 by 2025.

## WHY

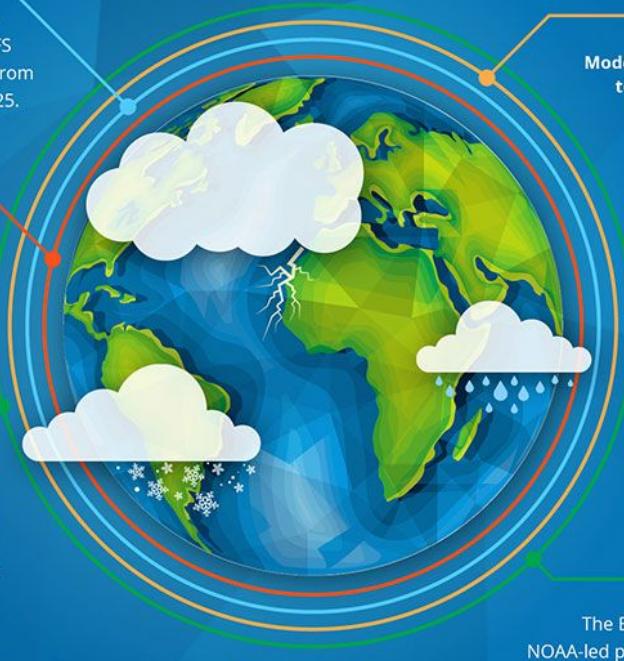
We can't control the weather, but we need to be able to **predict and adapt** to it. The UFS harnesses the **power of community** to build next-generation, operational weather and climate prediction systems.

## PARTNERS



NOAA supports the UFS in partnership with the research and development community.

Innovation through community



## INITIATIVES

Modeling applications spanning local to global scales and sub hourly to seasonal predictions



Configurable infrastructure



Community webinars



Research-to-Operations and Operations-to-Research thrusts



## UFS AND EPIC

The Earth Prediction Innovation Center (EPIC) is a NOAA-led program that fuels the UFS via **user support, hands-on training, and community engagement**.



# Simplifying NOAA's Operational Forecast Suite

Reducing the 21 Stand-alone Operational Forecast Systems into Eight Applications

## 21 Independent Stand-alone Systems

Global Weather, Waves & Global Analysis - GFS/ GDAS

Global Weather and Wave Ensembles, Aerosols - GEFS

Short-Range Regional Ensembles - SREF

Global Ocean & Sea-Ice - RTOFS

Global Ocean Analysis - GODAS

Seasonal Climate - CDAS/ CFS

Regional Hurricane 1 - HWRF

Regional Hurricane 2 - HMON

Regional High Resolution CAM 1 - HiRes Window

Regional High Resolution CAM 2 - NAM nests/ Fire Wx

Regional High Resolution CAM 3 - RAPv5/ HRRR

Regional HiRes CAM Ensemble - HREF

Regional Mesoscale Weather - NAM

Regional Air Quality - AQM

Regional Surface Weather Analysis - RTMA/ URMA

Atmospheric Transport & Dispersion - HySPLIT

Coastal & Regional Waves - NWPS

Great Lakes - GLWU

Regional Hydrology - NWM

Space Weather 1 - WAM/IPE

Space Weather 2 - ENLIL

## Unified Forecast System (UFS)



## UFS Applications

Medium Range & Subseasonal

Marine & Cryosphere

Seasonal

Hurricane

Short-Range Regional HiRes CAM & Regional Air Quality

Air Quality & Dispersion

Coastal

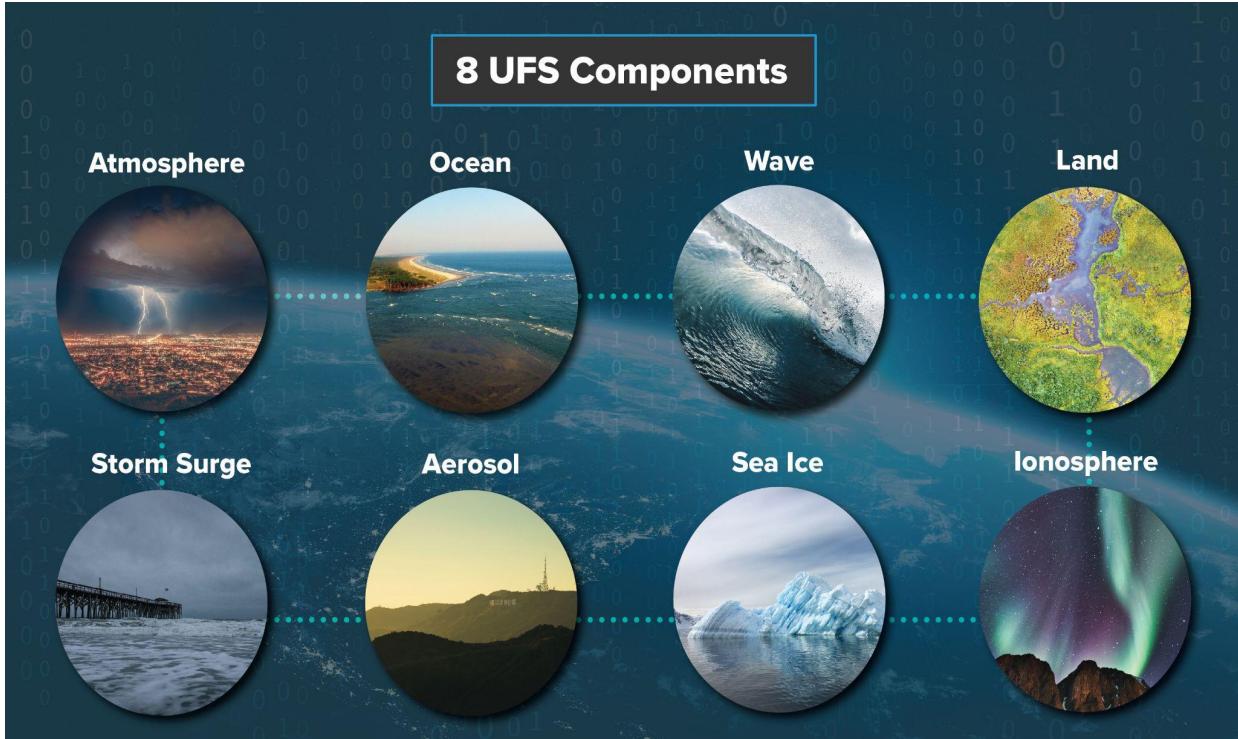
Lakes

Hydrology

Space Weather

# Unified Forecast System (UFS)

- The Unified Forecast System (UFS) is a **community-based coupled Earth modeling system**, designed to support the Weather Enterprise and also be the **source system for NOAA's operations**.
- UFS applications share agreed-upon numerical forecast system elements.
- Unified infrastructure at the application level allows for coupled interactions among components.





## PARTNERING WITH THE COMMUNITY FOR THE BENEFIT OF THE NATION

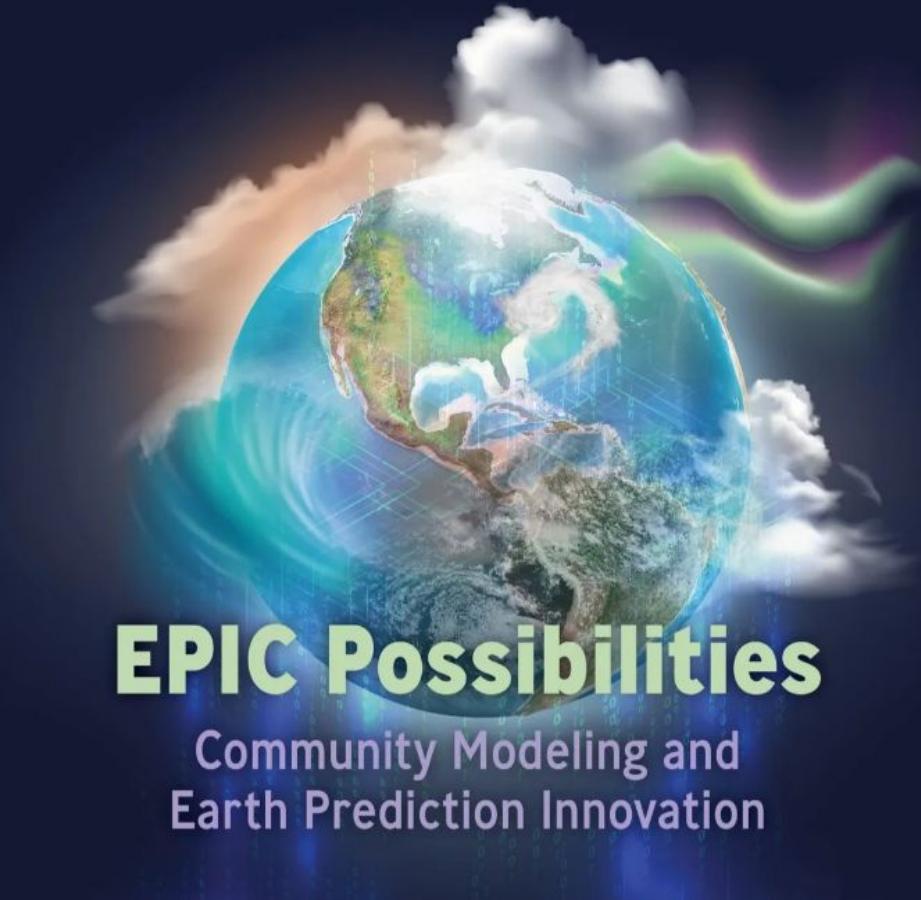
### Vision

To enable the most accurate and reliable operational numerical forecast model in the world.

### Mission

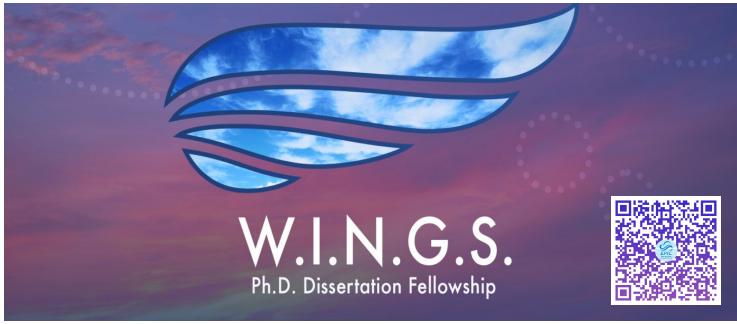
To be the catalyst for community research and modeling system advances that continually inform and accelerate advances in our nation's operational forecast modeling systems.

(2024) *Bulletin of the American Meteorological Society*, 105 (2)  
<https://journals.ametsoc.org/view/journals/bams/103/10/BAMS-D-21-0061.1.xml>



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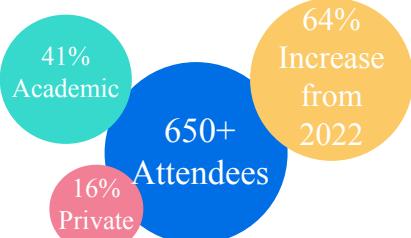
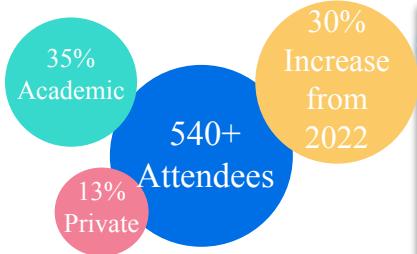
# Community



VOLUME 8  
SEPTEMBER 2025

**UFS Insights**

A QR code is located to the right of the text.



# Infrastructure for Community

## Code + Support



### Short-Range Weather (SRW) Application

The SRW App targets predictions of atmospheric behavior on a limited spatial domain and on time scales from minutes to several days. Access user support, documentation, and developer info [here!](#)

### UFS Weather Model (WM)

The UFS WM is a prognostic model that can be used for short- and medium-range research and operational forecasts. It can be run in atmosphere-only mode or coupled with additional components, such as wave or ocean models.

### Unified Post Processor (UPP)

The UPP software package generates useful products from raw model output. UPP output can be used directly by visualization, plotting, or verification packages and in further downstream post-processing (e.g., statistical post-processing).

### Land Data Assimilation (DA) System

The Land DA System is an offline version of the Noah Multi-Physics land surface model used in the UFS Weather Model. It uses JEDI DA software to apply the LETKF-OI algorithm for snow DA.

### Unified Workflow (UW) Tools

UW Tools help automate common tasks in standard numerical weather prediction (NWP) workflows. The *uwtools* software package also includes drivers to automate the configuration and execution of UFS components.

### Stochastic Physics

Stochastic physics is a component of the UFS Weather Model (WM) and contains a variety of stochastic schemes. The schemes add valuable scientific and numerical impact by addressing dynamical effects of unresolved scales in the UFS WM forecast system.

### Artificial Intelligence (AI)

EPIC and the NOAA Artificial Intelligence for Numerical Weather Prediction Applications (AI4NWP) Working Group support a community-based, comprehensive Earth modeling system. NOAA's operational model suite for numerical weather prediction (NWP) is quickly broadening to include artificial intelligence-based models.

### Hierarchical System Development (HSD)

HSD facilitates community collaboration and development toward improving numerical weather prediction models. Integration of HSD into the UFS provides a tool for users to test the impact of their code innovations on forecast skill and model performance through the implementation of simplified configurations, process isolation, and idealized/realistic test cases.

# Training Resources

## Videos



12 Videos

New Users:

[GitHub Tutorial: Part 1. Contributing to UFS/EPIC Repositories](#)

[GitHub Tutorial: Part 2. Contributing to UFS/EPIC Repositories](#)

[UFS Weather Model Test Case Walkthrough](#)

[Land DA Workflow Demo](#)

[Building and Running the Containerized Global-Workflow](#)

[SRW App Tutorial 1: Containerized SRW App v3.0.0 Walkthrough](#)

[SRW App Tutorial 2: SRW App v3.0.0 Plots and Postprocessing Walkthrough](#)

Cloud Tutorials:

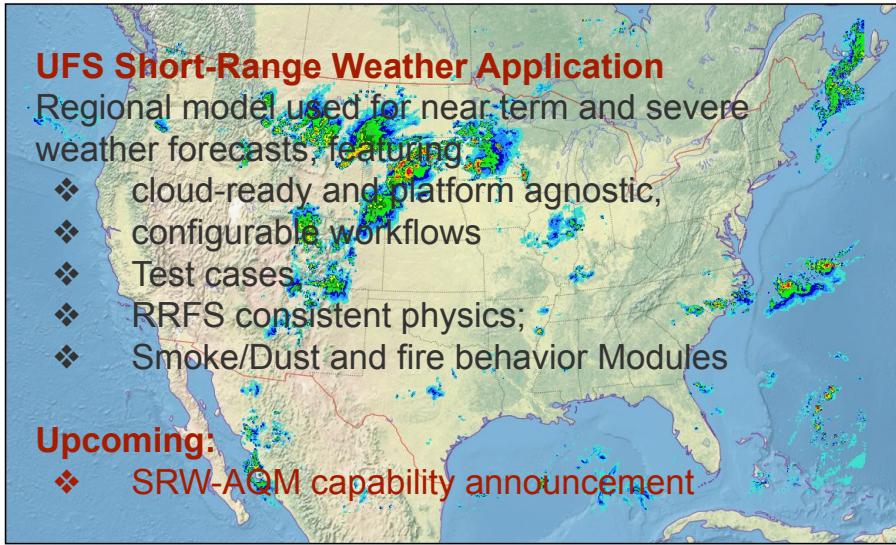
[Creating a Base Image on Amazon Web Services \(AWS\)](#)

[Launching a PCluster Image to run SRW on Amazon Web Services \(AWS\)](#)

[Building and Running Containerized Land Data Assimilation \(DA\) Workflow on Amazon Web Services \(AWS\)](#)

Unified Workflow:

## 2 Infrastructure for Community Innovation



### SRW Contributors (in alphabetical order)

ARL, CIESRDS, CIRA, CIWRO, DTC, EMC, EPIC, GFDL, GSL, NCAR, NESDIS, NSSL, PSL, SDSU

### Computing & Data:

NOAA RDHPCS, NCAR-CISL, NODD

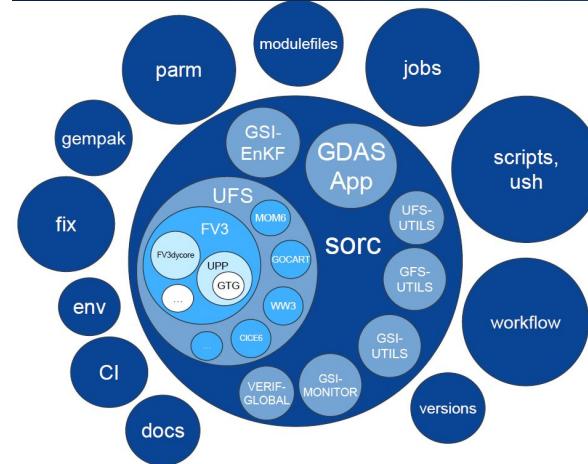
**Spackstack:** EMC, NRL, JCSDA, EPIC

### Funding:

OAR/WPO/EPIC, FWx & AQ, JTTI Programs

NWS/OSTI modeling programs

NOAA DRSA Program

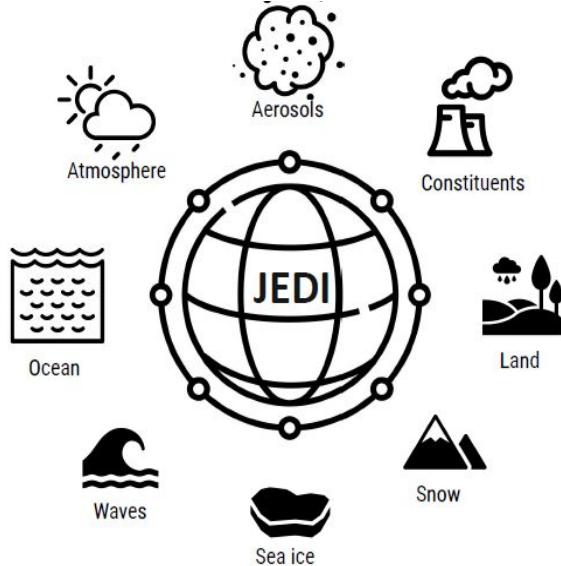


Courtesy:  
Rahul Mahajan (EMC)  
and the Global  
Workflow team

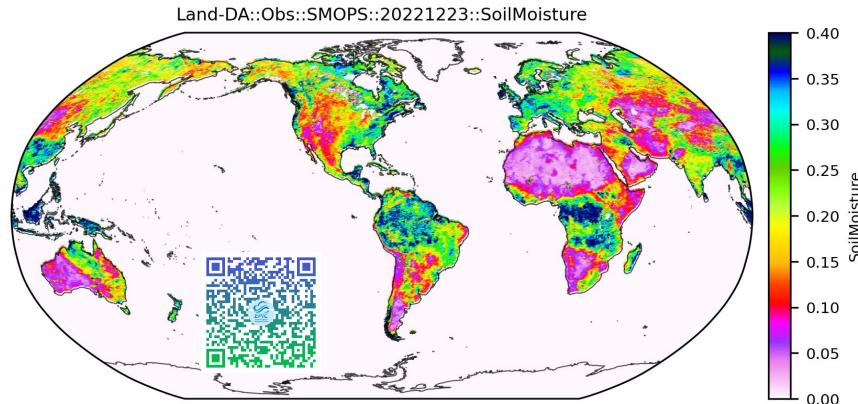
### Planned release (Jan-April 2026):

- Community friendly with extensive documentation and user support
- Containerized version that could be run on NOAA and Non-NOAA platforms
- Port data needs to EPIC supported platforms and cloud
- Forum for communication/collaboration and support
- **Community inputs will be solicited! Send us an message at [support.epic@noaa.gov](mailto:support.epic@noaa.gov)**

- Provide NOAA Base Funding to the Joint Center for Satellite Data Assimilation to establish and maintain **Joint Effort for Data assimilation Integration (JEDI)**
- **Supported the created of NOAA NASA Joint Archive (NNJA) of Observations for Earth System Reanalysis**



## UFS Community DA system Land DA System as a Prototype



- Three releases between May 2023 and November 2024;
- Started engaging NESDIS and CADRE developers since the UFS Land DA 2.0 release;
- Seek to maintain consistency across Noah-MP model config, JEDI Configuration Builder, and JEDI versions to ensure a R2O2R transitions;
- **Welcome inputs/contributions from the land modeling and DA communities. Send us an message at [support.epic@noaa.gov](mailto:support.epic@noaa.gov)**

# Innovation with NOAA AI4NWP Team

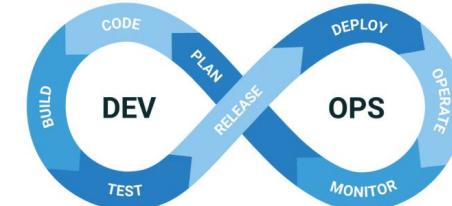


## Upcoming:

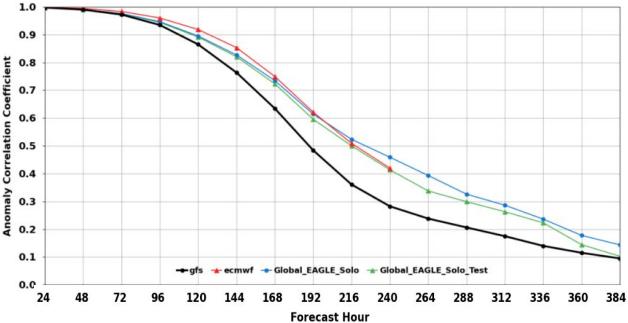
- Migrate to a unified modeling infrastructure (Anemoi):
- Release of the verification pipeline
- Addition of new AI systems:
  - HRRRCast, WofSCast, Nested-EAGLE, Coupled Model...
- Moving toward a DevOps paradigm

## Learn more about EAGLE:

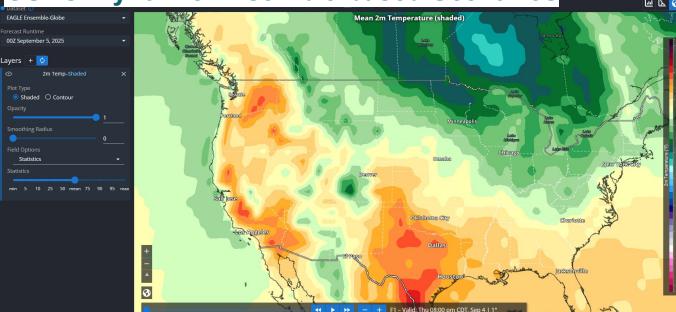
Wednesday 3:30 pm | Emerging Technologies: Artificial Intelligence / Machine Learning



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



## GSL's Dynamic Ensemble-based Scenarios



# EPIC v2.0 - What will be different over the next few years



Expand role into the provision of community modeling infrastructure to support AI model development (AI4NWP)



Cultivate partnerships that will provide stepwise advancements in NOAA's modeling capabilities (e.g. NCAR, JCSDA, ECMWF, startups, big tech, etc.)



Explore new funding mechanisms to drive innovation (e.g. prize challenges)



Foster a new DevOps framework across NOAA, utilizing containers and the cloud



Initiate a stronger community-driven process to receive feedback and determine EPIC's future priorities (e.g. code releases, tiers of user support, requests for funding proposals, etc)



Establish UFS ambassadors to teach and engage others (i.e., UFS Ambassador Program)

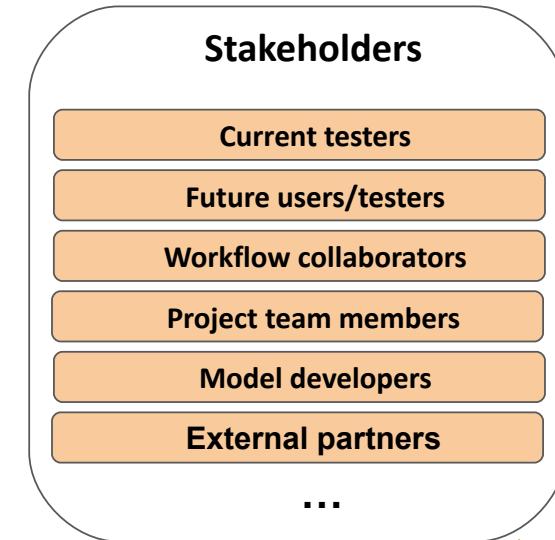
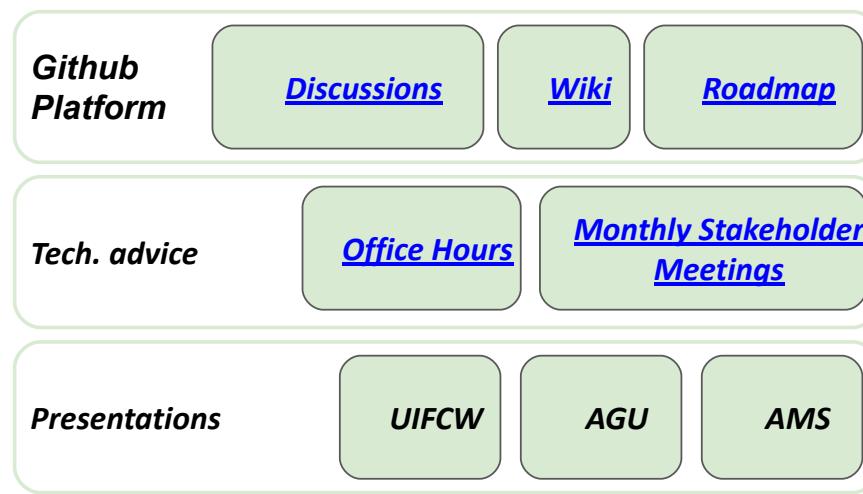


Lead Agile management of cross-NOAA modeling projects (e.g. MPAS, AI4NWP)



# UFS-Coastal: A community-centric project

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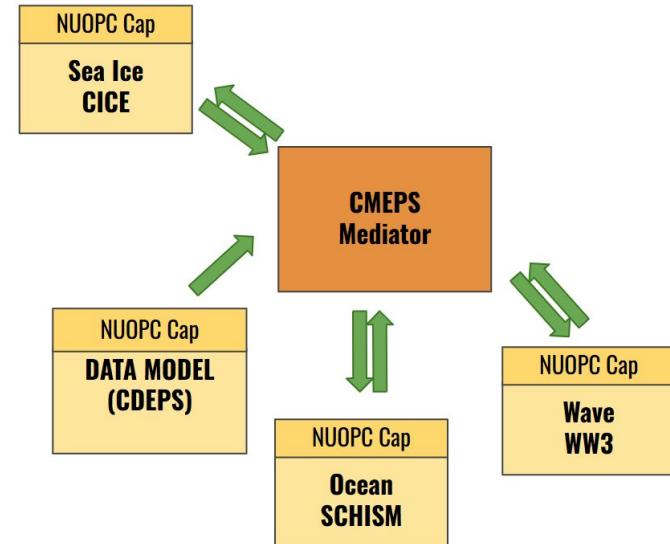
*NOS' next-generation coastal ocean modeling infrastructure for integration into the Unified Forecast System portfolio*



POC: [Saeed.Moghimi@noaa.gov](mailto:Saeed.Moghimi@noaa.gov)

# Advances in UFS-Coastal Model

- ADCIRC, FVCOM, SCHISM and ROMS ocean components are tested regularly through the EPIC's CI/CD pipeline
- New co-processing component - GeoGate
  - Prototyping ADCIRC and SCHISM output to S-104 and S-111 navigation support file formats
- Successful testing of new configurations (e.g. DATM+SCHISM+CICE6 for Bering Sea)
- Community support:
  - Regular meetings for troubleshooting issues
  - Modifying existing RTs to create new configurations



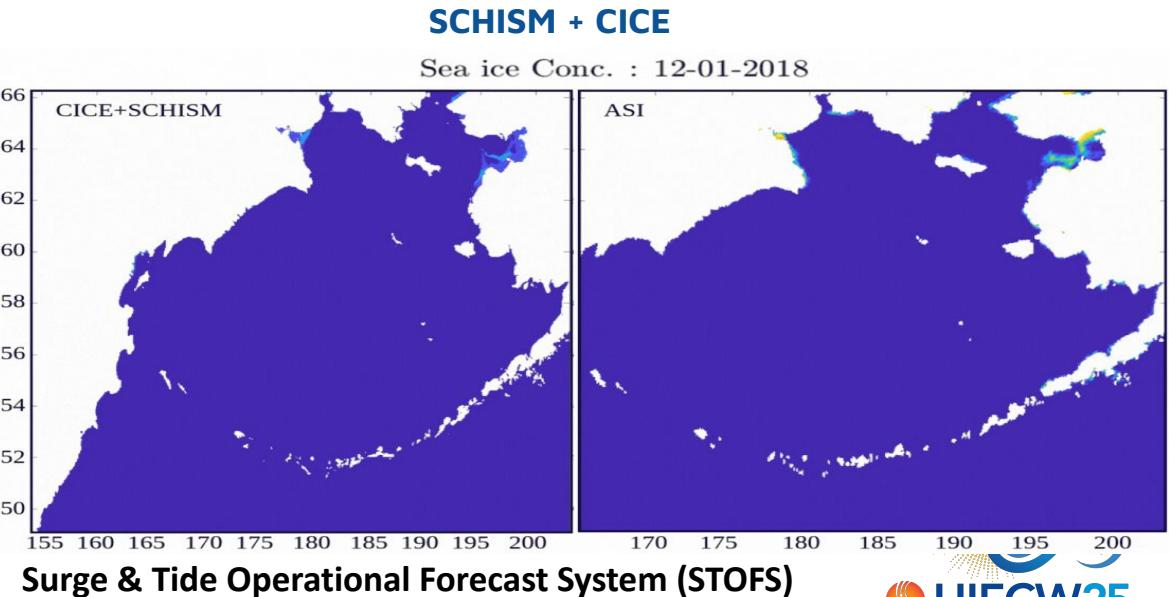
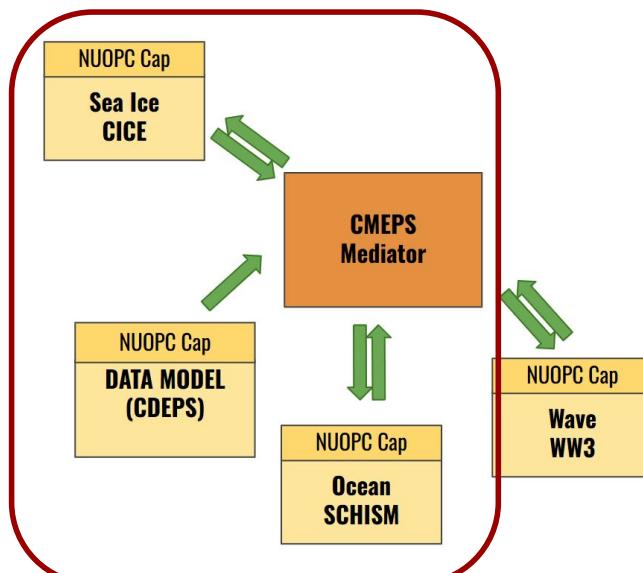
Partners: OCS, NCAR, CO-OPS, EPIC, EMC, Academic partners, ...  
See Moghimi et al, Wed Sep 10, 11:15pm – 12:00pm  
and Turuncoglu et al on Fri Sep 12, 10:45am – 11:15am



# Advances in UFS-Coastal Applications

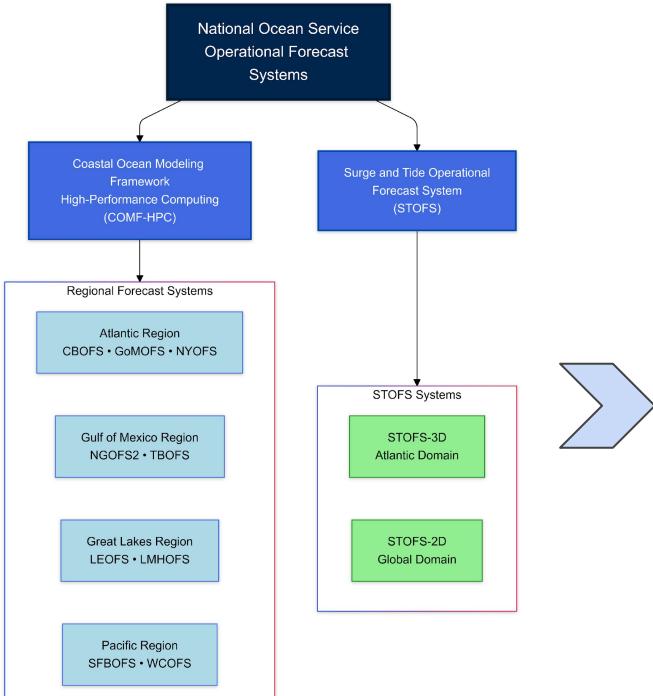
**STOFS-3D-Alaska:** DATM+SCHISM+CICE+WW3 (DRSA / NOS Water team)

Coupled CICE-SCHISM computation: technical task accomplished but more work is needed to improve solution quality and computational efficiency

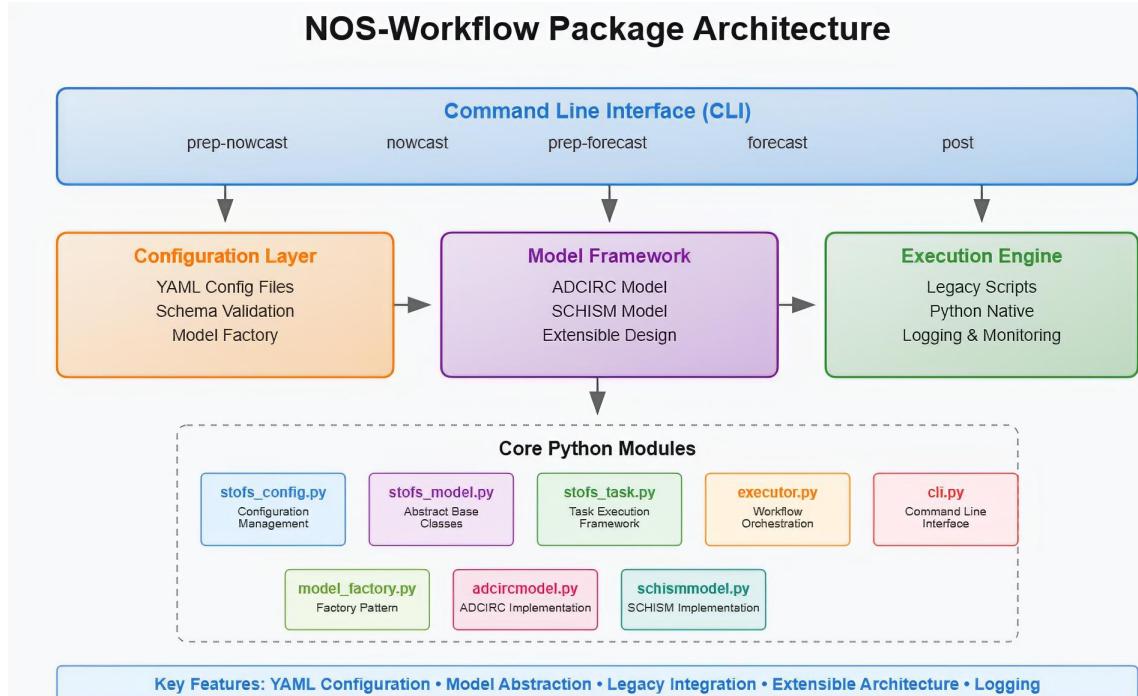


Partners: OCS, Oregon State University, NCAR and VIMS

# NOS Unified Operational Workflow



Disjointed operational workflows currently exist across NOS Operational Systems.

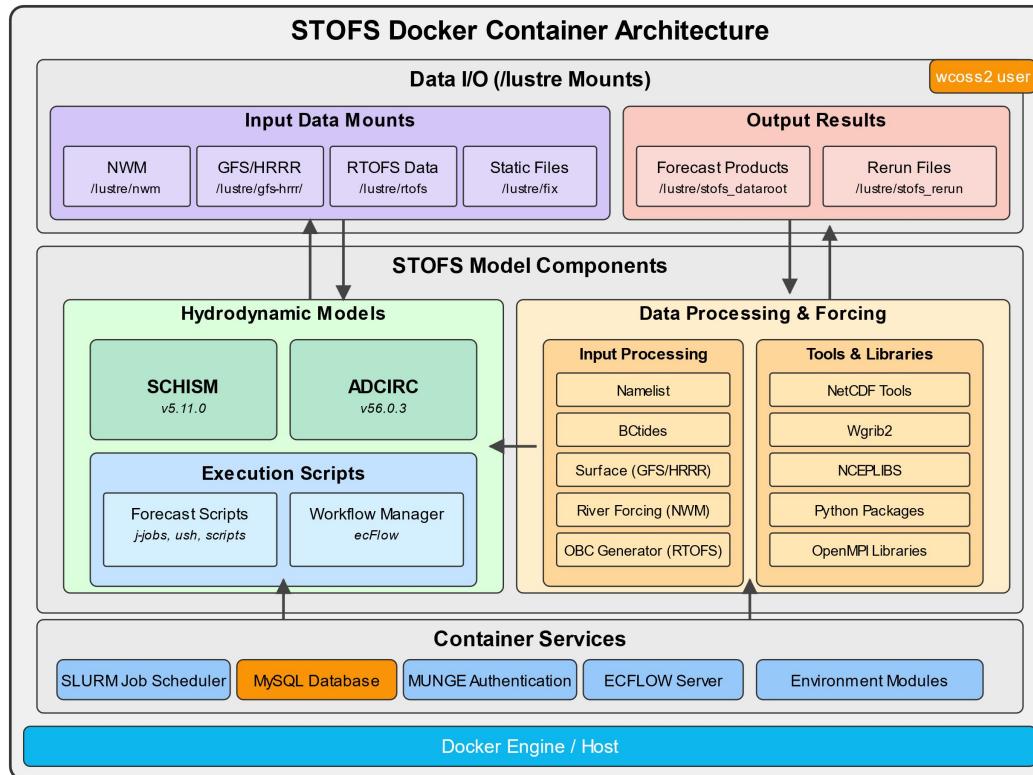


Unified Python Workflow Manager (Architecture)

**Partners:** NOS/OCS, NOS/CO-OPS, Water Institute  
See Dr. Jisan presentation on FRI, SEP 12; 10:45am - 11:15am;



# Container for Emulating WCOSS2 Environment



## Objectives

- Emulate WCOSS2 operational environment to support STOFS workflow development and testing.
- Incorporate NCO software stack to mirror production.
- Facilitate collaboration with external partners involved in upgrading STOFS workflows.

## Progress Highlights

- Successfully tested the STOFS Atlantic preprocessing workflow within containerized environment.
- Integrating and testing a new YAML-driven command-line configuration system for STOFS3D-Atlantic within the container.



Partners: NOS/OCS, NOS/CO-OPS, Water Institute

See Dr. Jisan presentation on FRI, SEP 12; 10:45am - 11:15am;



**UFCW25**  
A UFS Collaboration Powered by EPIC

# Challenges & Risks

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## Architecting a Unified Future

- We're proactively working with our partners to envision a unified modeling framework for UFS-WM and UFS-Coastal.
- The UFS Governance framework will provide clear guidance for a streamlined and collaborative approach.

## Advancing R2O Through Strategic Partnerships

- Support from the EPIC Program is vital for accelerating the development of UFS-Coastal.
- This partnership is key to defining a clear Research to Operation (R2O) pipeline, providing a path for new capabilities to become operational.
- **Artificial Intelligence and Machine Learning in Operational Forecasting:**
  - NOAA's National Ocean Service (NOS) is working towards aligning its AI/ML operational development and implementation with broader NOAA-wide modeling and data processing initiatives.



# NWS Modeling - State of the UFS



Finalize GFSv17/GEFSv13

Initial cycled JEDI  
prototype for  
GFSv17

RRFSv1 field evaluation

Development of RWPS v1



Initiate the  
GEFSv13  
reforecast

Development of GCAFSv1



Update HAFS to v2.1  
with coupled MOM6

Enhanced experimental  
HAFS Ensemble

10-year HFIP strategy,  
project and governance

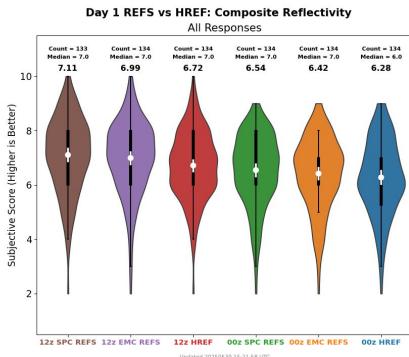


Update of AQM to v7 with  
online coupled atm-chem

NAQFC Design Review and  
10-year roadmap

- Leveraging UFS for global and regional coupled modeling and DA addressing broad mission needs
- Developing programmatic objectives and priorities to inform UFS development and create new opportunities

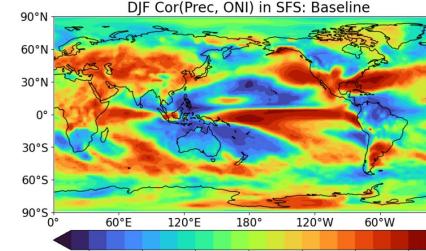
# NWS Modeling - State of the UFS



UFS-R2O in its 6th year

Focus on completing coupled global model and RRFSv1 implementation

RRFSv1 extends CAM coverage to OCONUS and enables retirement of legacy systems (except HRRR)



Courtesy Xiao-Wei Quan

Seasonal Forecast System

SFSv1 implementation plan drafted

Prototypes based on GEFSv13 configuration

Desired baseline implementation prior to WCOSS3 upgrade



NWS Warn-on-Forecast Demonstration Project

STI/Vlab supporting real-time WoFS guidance on request

Exploration beyond severe wx



# Challenges & Risks

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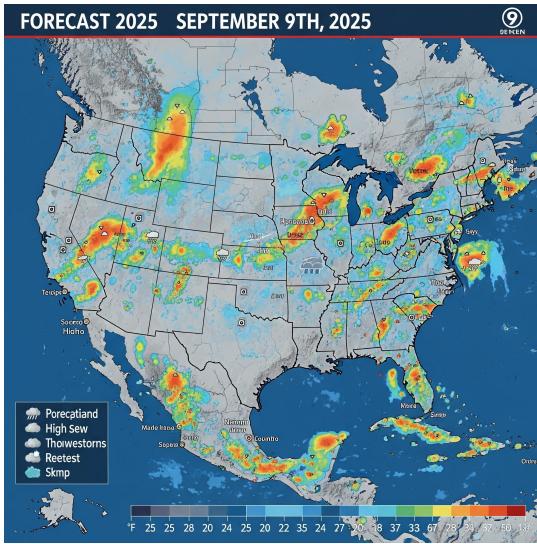
- Resources and planning/timelines
- Complexity of modeling systems/performance
- Number of applications
- Operational HPC capacity
- Transition/implement operational models in the cloud
- Development/T&E/Implementation cycles
- Research and Operations divergence
- Governance



Image courtesy Google  
Slides/Gemini

# Looking to the Future

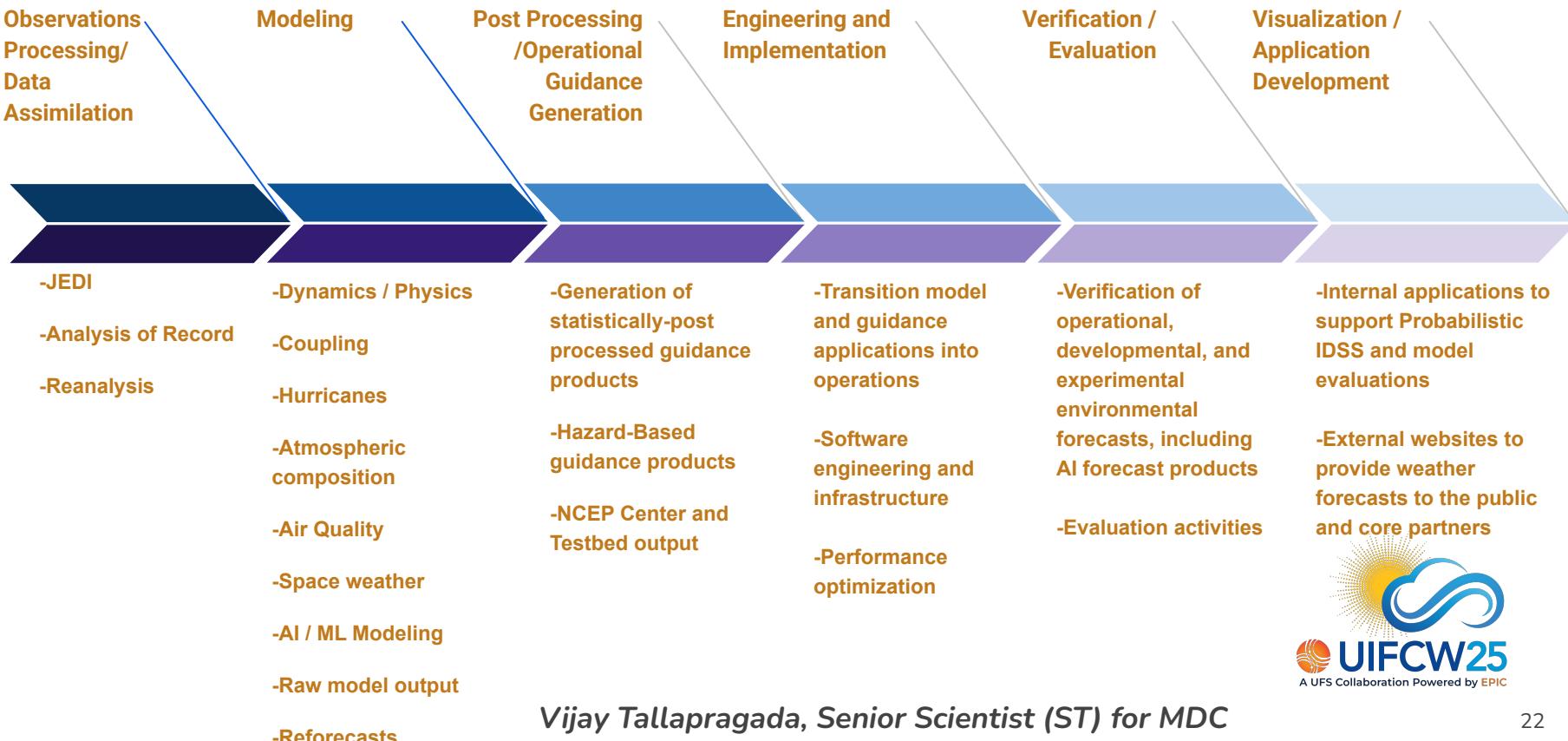
- Making progress on new UFS Governance
- UFS-R2O Phase III (strong community focus)
- AI/EAGLE
- Reanalysis/Reforecast
- FY26/27 modeling suite upgrades, JEDI
- WoFS transition to operations, UFS integration
- MPAS Integration
- New ensemble systems (HAFS, SFS)
- 10-year vision for operational model configurations



5-day forecast generated in  
Google Slides/Gemini



# NWS Modeling: EMC+MDL = MDC: Supporting the Full Value Chain



Vijay Tallapragada, Senior Scientist (ST) for MDC



# 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

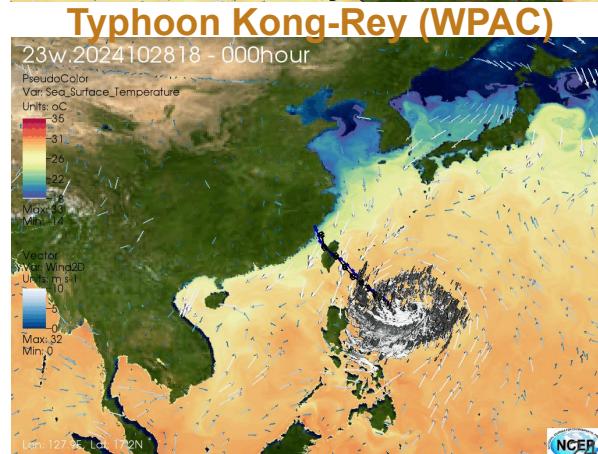
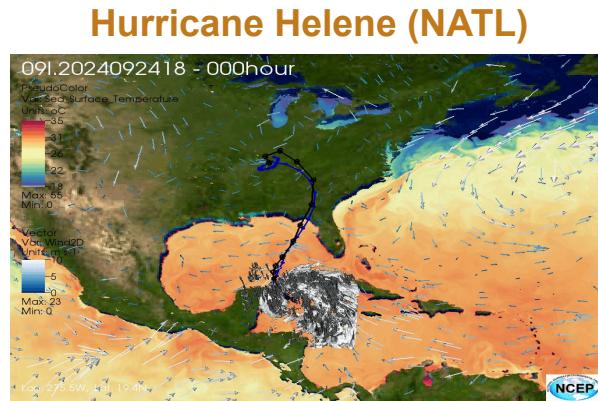
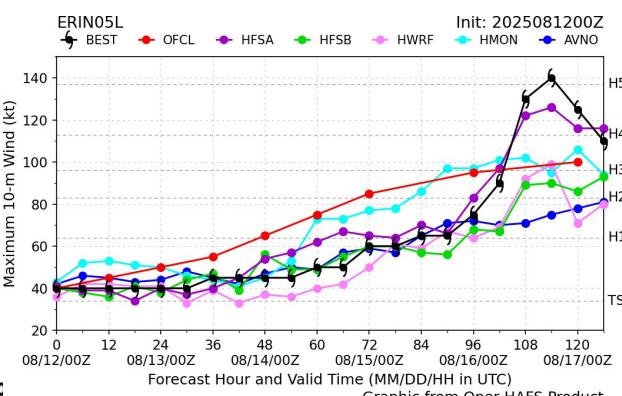
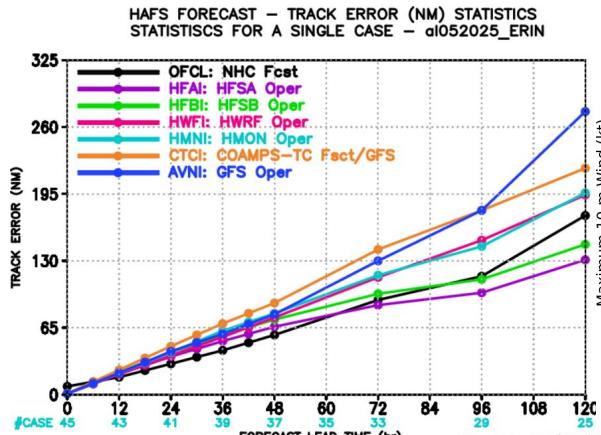


# Hurricane Modeling: A Success Story for UFS

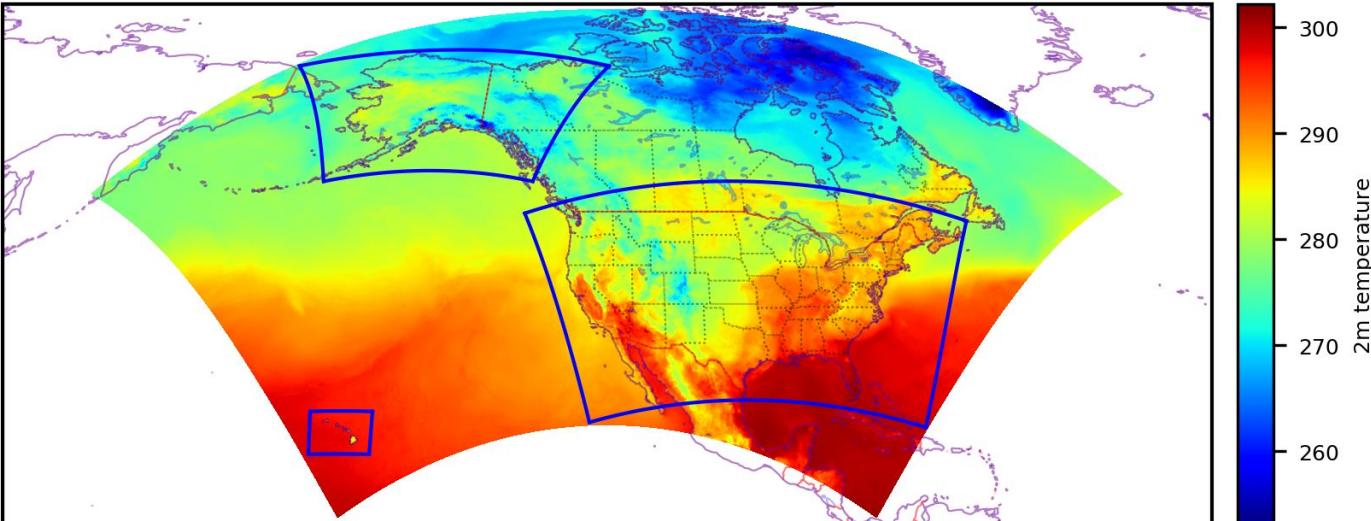
HAFSv1.0 implemented in June 2023, upgraded to HAFSv2.0 in July 2024

HAFSv2.1 implemented on July 30, 2025

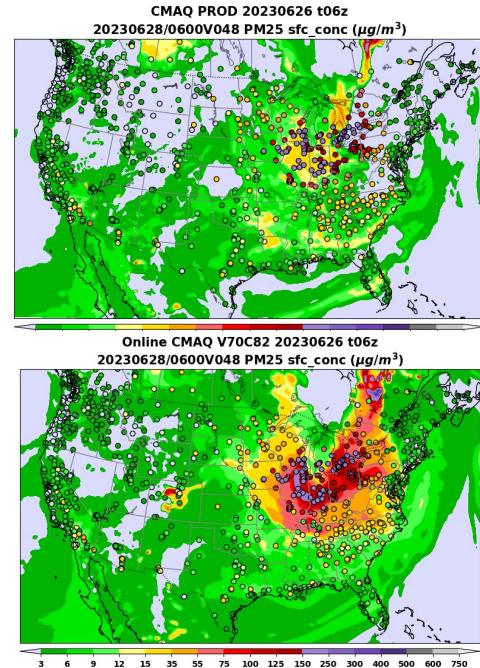
- Use latest version of RTOFS (v2.5, July 2025) to initialize ocean models
- Address issues identified in 2024 hurricane season
  - Storm structure at model initial time
- Improve model track and intensity forecast skills



# AQMv7: Online-CMAQ in UFS



- **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

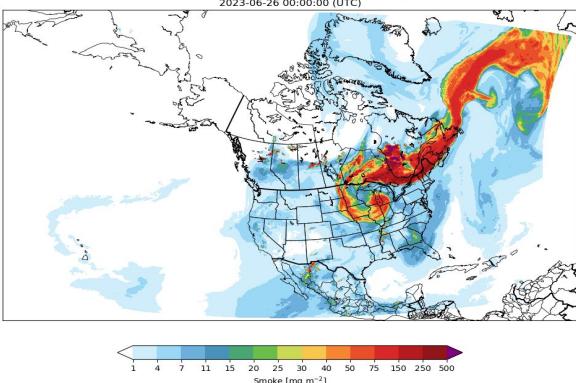


- Hourly RAVE wildfire emissions over the North American domain
- Anthropogenic and biogenic emissions for this domain (NEI 2016v1 plus global)

# Rapid Refresh Forecast System (RRFS): A UFS Application

- FV3 dynamical core Limited Area Model
- 3 km grid spacing, 65 vertical layers
- Hourly updated, Hybrid 3DEnVar DA (30 members)
- Deterministic forecasts to 18h every hour, 84h every 6 hours; Ensembles 60h every 6 hours
  - RRFSv1 Field Evaluation Completed - potential transition into operations in Q2FY2026
  - RRFSv2: Transition from FV3 dynamical core to MPAS

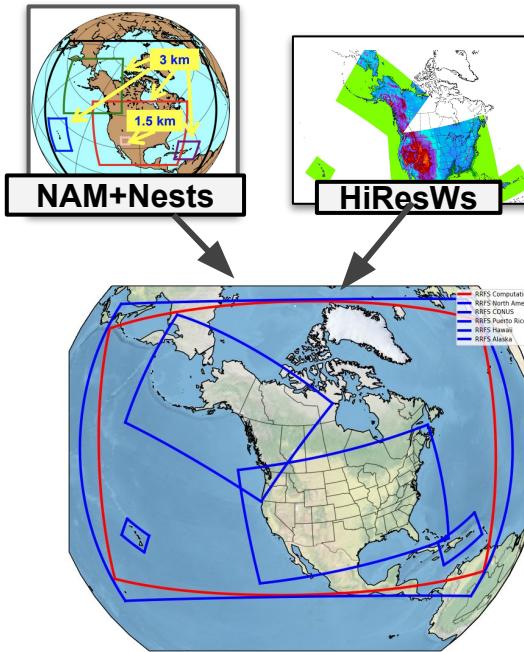
Includes Smoke and Dust



## REFS:

Ensemble spread from:

- EnKF ICs; GEFS LBCs
- Multiple physics options
- Time lagging
- Stochastic and fixed parameter perturbations



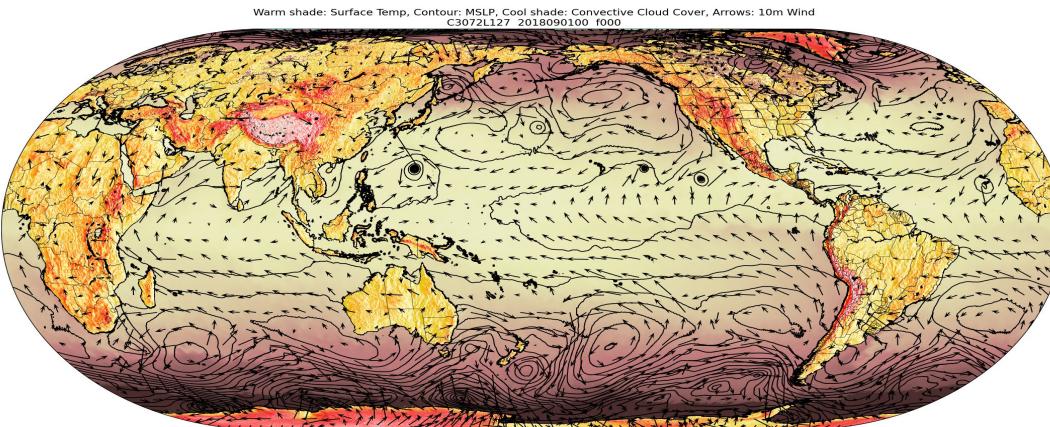
RRFSv1 Compute  
Domain (red)



# FY26-27: GFS, GEFS and SFS to go fully coupled

## 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)

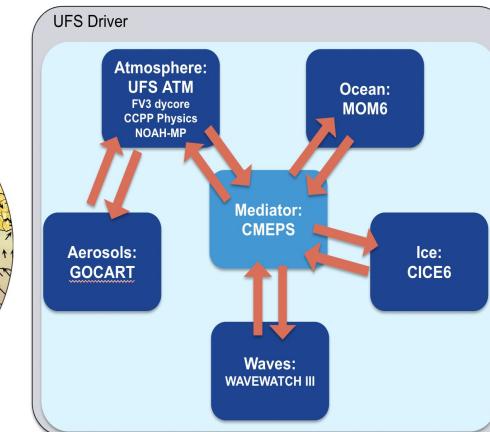


## GEFSv13

- Have the same model configuration as of GFSv17 except for C384 resolution, 31 members
- 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

## SFSv1

- Have the same model configuration as of GEFSv13 except for C192 resolution, 31 members
- ICs: GLORe for Ocean/Sea Ice
- ICs: CORe for Atmosphere and Land
- 30 years reforecast to support forecast calibration (and training)



# Challenges & Risks

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- 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

# Looking to the Future

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



Global:  
ML-GFS and  
ML-GEFS in  
operations by  
Q1FY26

Severe Wx:  
HRRRCast  
WoFSCast  
HAFSCast

Future:  
AI DA  
DOP: Ocelot  
Hybrid  
Emulators

