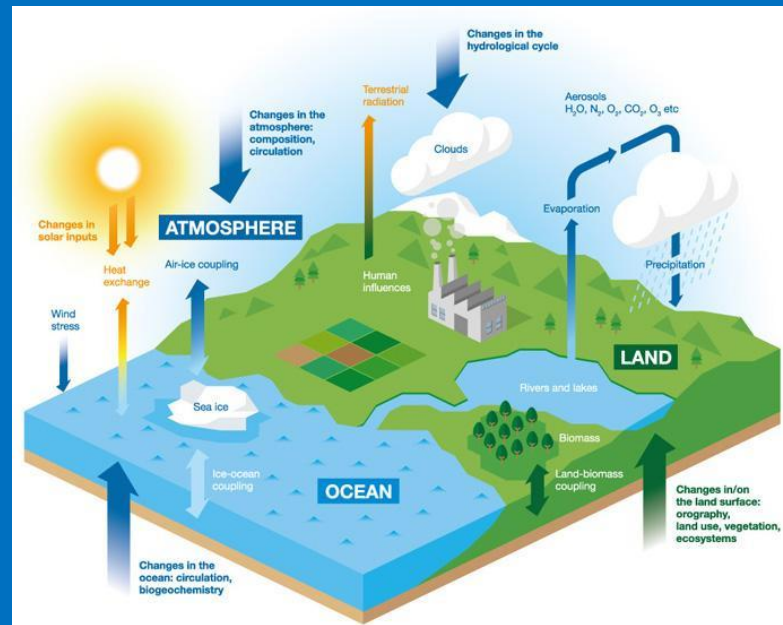




NOAA's Unified Forecast System for Research and Operational Prediction Applications

Vijay Tallapragada, Ph.D.
Senior Scientist
NOAA/NWS/NCEP/EMC

*Seamless Global Modelling workshop,
3-6 June 2025, Bristol, UK*





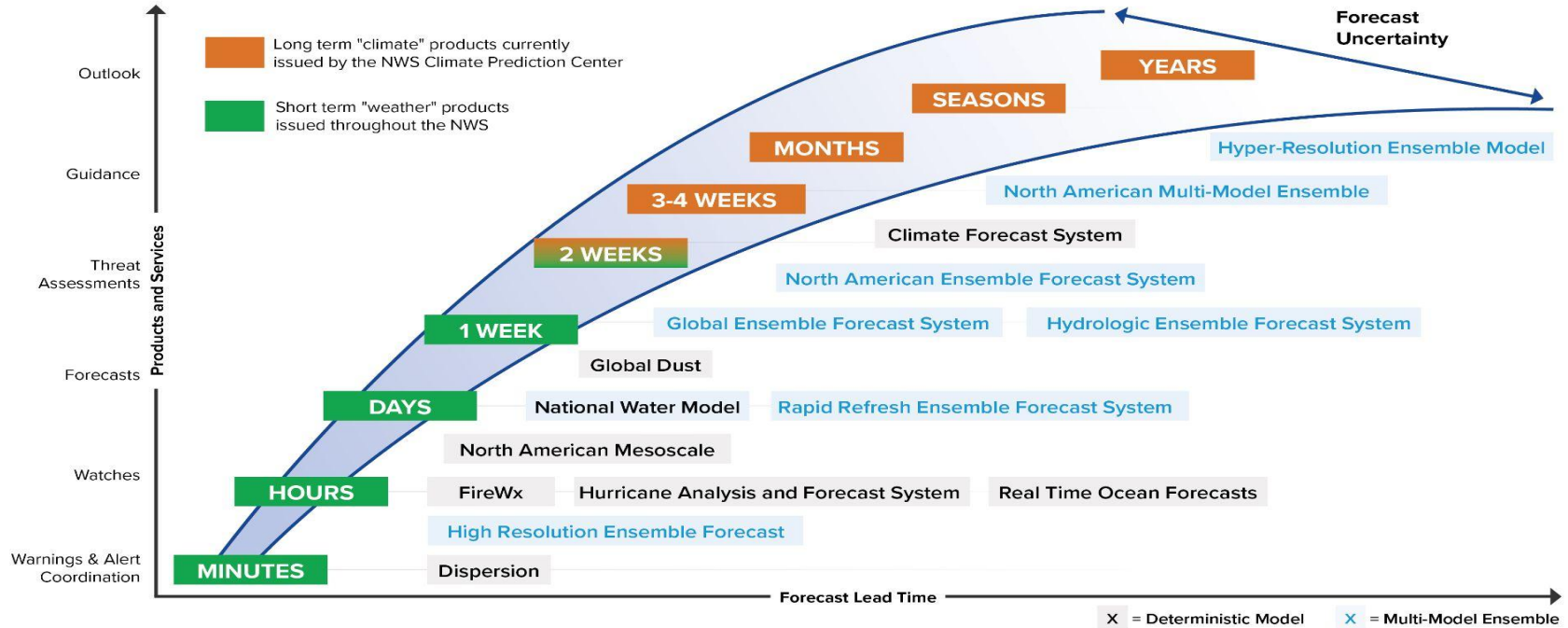
Topics

- Earth Prediction System Concept for Weather, Water and Climate Predictions and Research
- Unified Forecast System for Seamless Predictions from Sub-hourly to Seasonal Time Scales
- Modeling and Data Assimilation Horizons

Operational NWP at NOAA/NWS

Timing and Complexity of Operational Models

Spanning weather and climate, and increasingly based on multi-model ensembles



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

Uccellini, Spinrad, McClean, Lapenta, in review for BAMS



Unified Forecast System

Building better forecasts through community partnerships

The UFS is a community-based, coupled, comprehensive Earth modeling system supporting NOAA's operational weather forecasting suite and the Weather Enterprise

- Established in 2014 as part NOAA/NWS/NGGPS program
- Unify forecast “application” systems using open, community codes

Community engagement opportunities

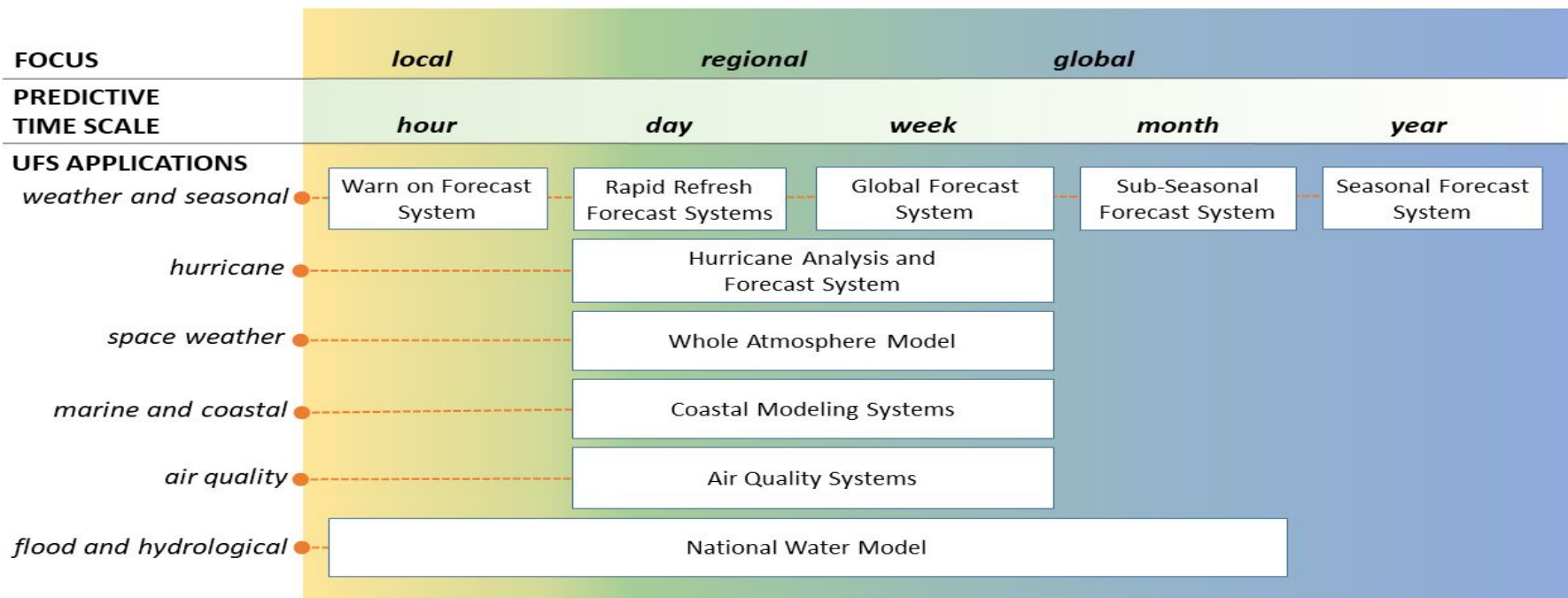
- Model releases, graduate student tests
- Annual user tutorials and workshops
- Website, newsletter, webinar series



<https://ufscommunity.org>



Scope of UFS



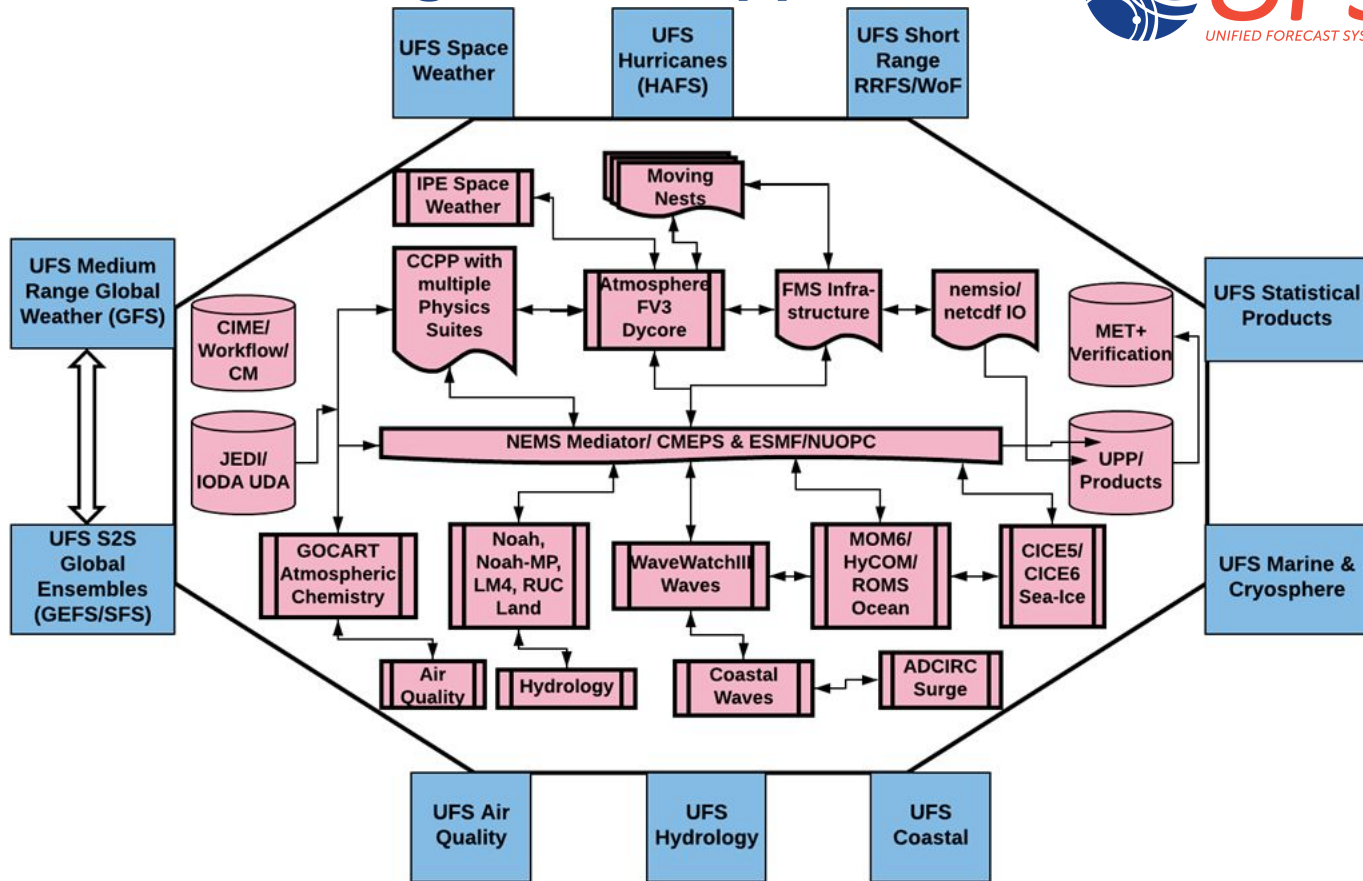
UFS applications span predictive timescales (less than an hour to more than a year) and focus on multiple spatial scales (local to global).

NPS Transitioning 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.”

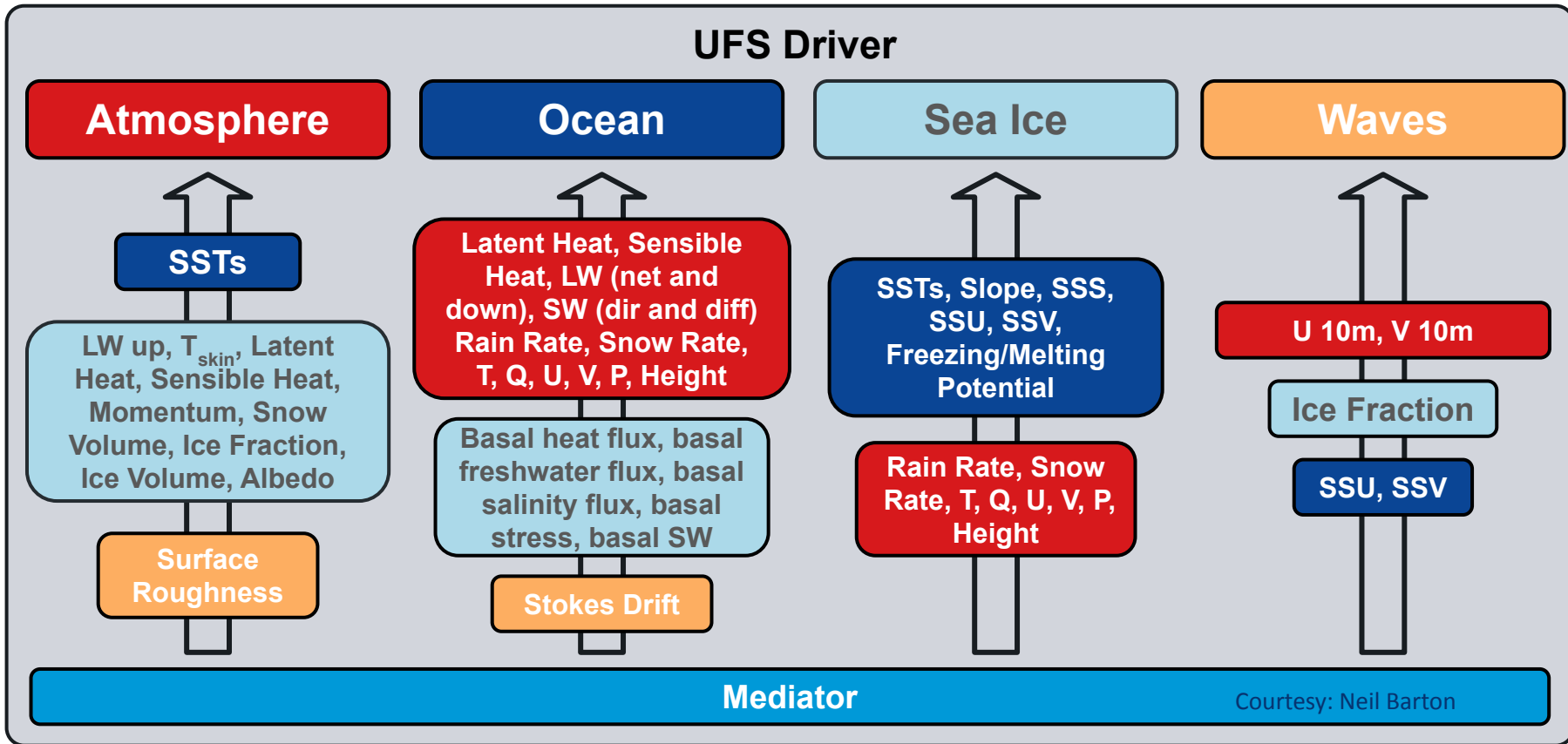
Conceptual UFS applications in production covering all NPS applications, maintaining the dependencies between the applications and products.



Major Forecast Systems Within UFS

- **Global Medium Range Weather (MRW) and Sub-seasonal to Seasonal (S2S):** Global Ensemble Forecast System (GEFS), Global Forecast System (GFS) and Seasonal Forecast System (SFS)
 - Six-way (atmosphere-ocean-ice-waves-land-aerosols) coupled Modeling System with coupled data assimilation
- **Hurricane Analysis & Forecast System (HAFS)**
 - Regional high-resolution system; Atmosphere, ocean, waves, weakly coupled DA
- **Air Quality System**
 - In-line regional Air Quality Predictions using RRFs-CMAQ
 - Global Aerosol Predictions using GEFS-Aerosols
- **Regional Short Range Weather (SRW):** Rapid Refresh Forecast System (RRFS)
 - Convective scale ensemble data assimilation; replaces legacy regional systems
- **Space Weather**
 - FY25 FV3 deep atmospheric dynamics; Ionosphere-Plasmasphere-Electrodynamics (IPE) Space weather with data assimilation

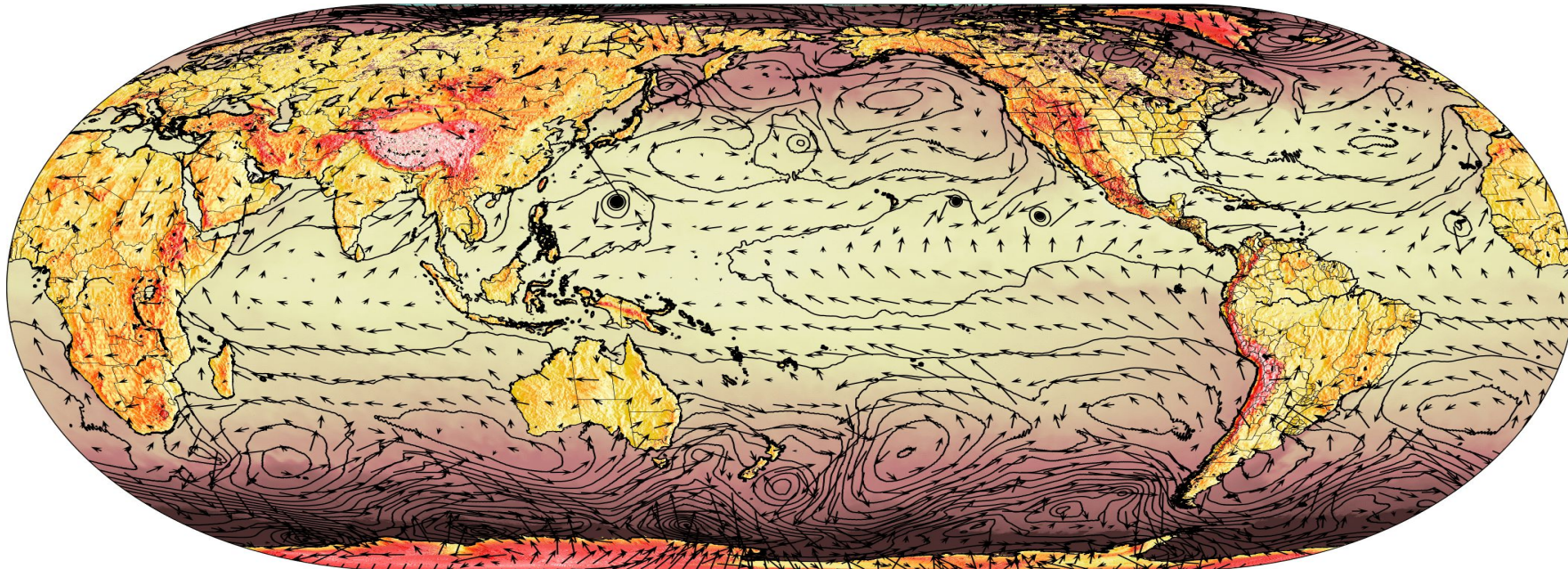
UFS Coupling Schematic



A Six-Way Global Coupled Unified Forecast System (UFS)

a first for NOAA/NWS

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



A fully coupled UFS serves as a foundation for future operational global forecast systems at NOAA/NWS/NCEP ranging from weather to subseasonal to seasonal scales.

UFS Earth System Model Components:

- | | |
|--------------------|---------------------|
| • FV3 (Atmosphere) | • WW3 (Waves) |
| • MOM6 (Ocean) | • NOAH-MP (Land) |
| • CICE6 (Sea Ice) | • GOCART (Aerosols) |



Global Model Development Priorities

GFSv17

- Coupled forecast model (atmosphere, land, ocean, ice, wave)
- Improved DA with marine JEDI (more later)
- 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
- Include interactive aerosols in all ensemble 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

GFSv17 Development | Operational Target Configuration

Resolution

- ATM & Land : C1152 (9km), 127L (top at 80km)
- MOM6 & CICE6: 0.25 deg; WW3: unstructured uniform grid

Physics

- HR5, including Noah MP LSM (to be finalized in January 2025)

Initial Conditions

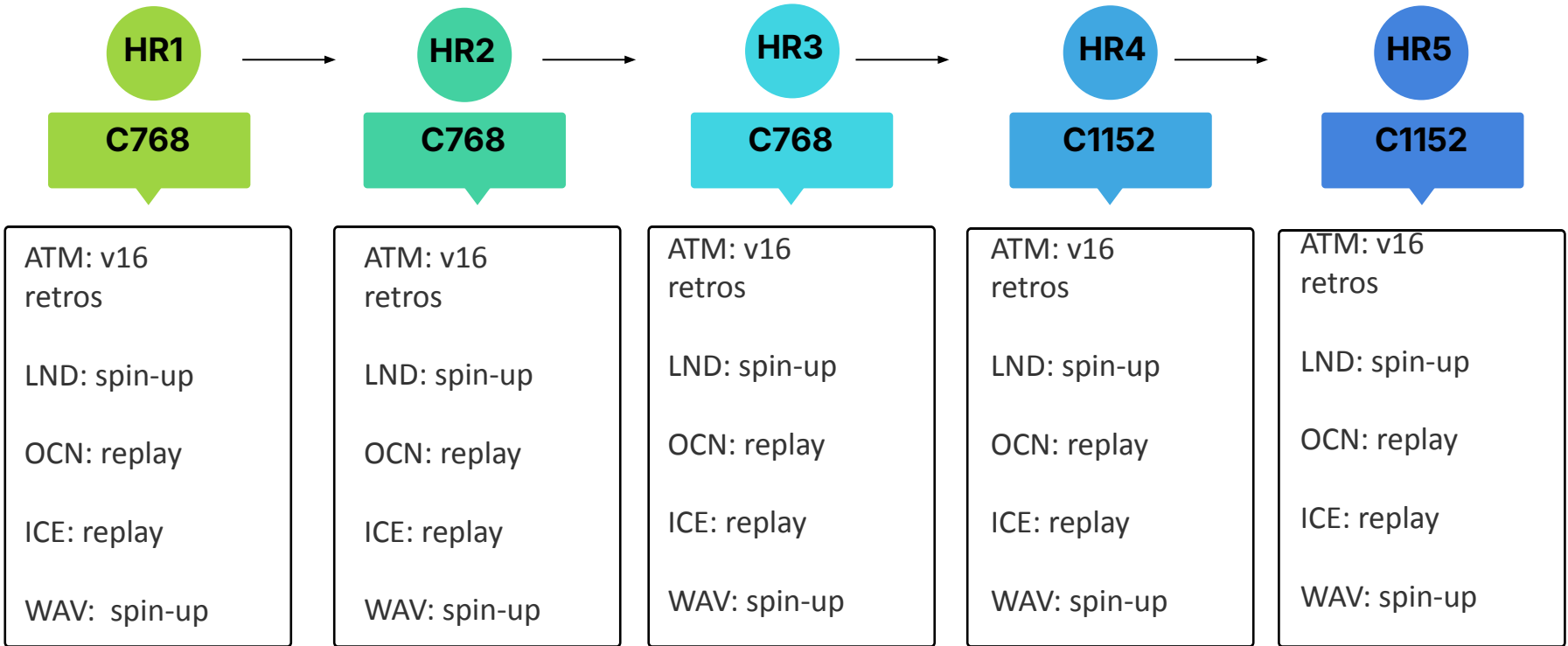
- Weakly Coupled Data Assimilation

Ensembles

- deterministic single member

Operational implementation target: Q3FY26 (notional)

GFSv17 Development | Runs | Initial Conditions



GEFSv13 Development | Operational Target Configuration

Resolution

- ATM & Land : C384L127 (0.25 deg)
- MOM6 & CICE6 & WW3: 0.25 deg (New in GEFSv13)

Physics

- HR4
- GOCART aerosol: only in one member

Initial Conditions

- Real-time: Weakly coupled data assimilation
- Re-forecast: replay

Ensembles

- Real-time: 30 members + one aerosol member
- Re-forecast: 30 years (1994- 2023, 5 members, out to 16 days at each 00 UTC initial time; 11 members, out to 48 days at Mon & Thur

Operational implementation target: Q3FY26 (notional)

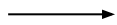




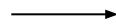
GFSv13 Development | Runs | Initial Conditions



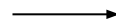
EP1



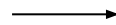
EP2



EP3



EP4



EP5/
EP6

C384

C384

C384

C384

C384

ATM: GFSv15

LND: Noah LSM

OCN: CFSR

ICE: CPC

WAV: v15 forcing

ATM: GFSv15

LND: Noah LSM

OCN: ORAS5

ICE: CPC

WAV: v15 forcing

ATM: GFSv15

LND: Noah MP

OCN: ORAS5

ICE: CPC

WAV: v15 forcing

ATM: GFSv16

LND: Noah MP

OCN: ORAS5

ICE: GEFSv12

WAV: v15 forcing

ATM: replay

LND: replay

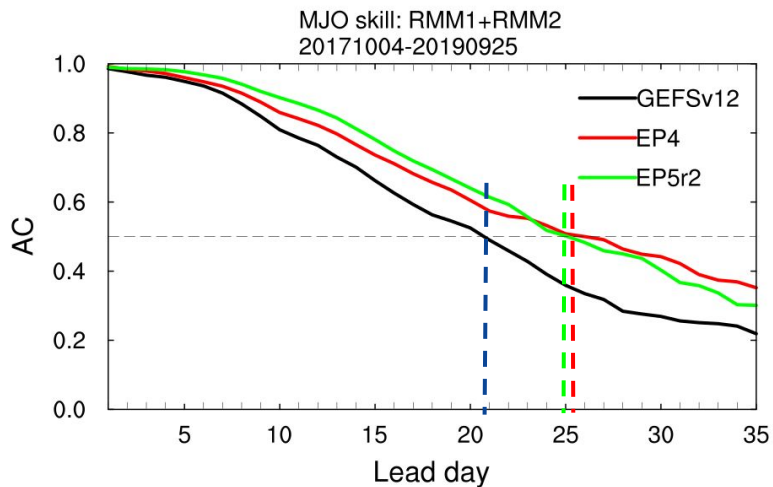
OCN: replay

ICE: replay

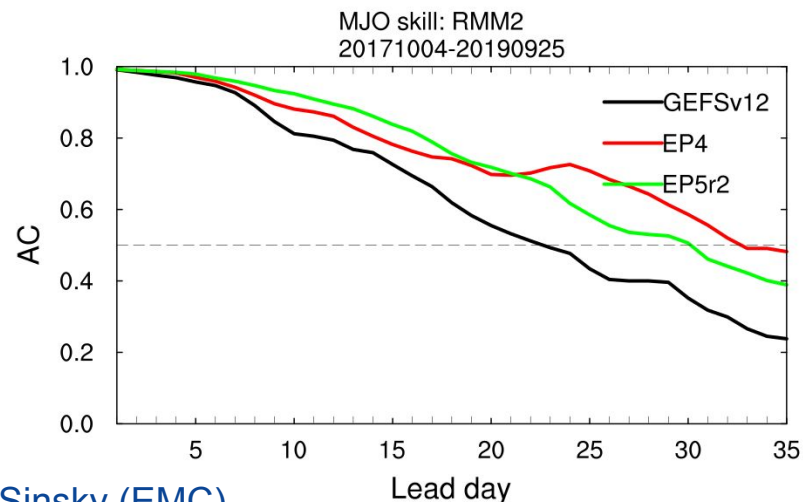
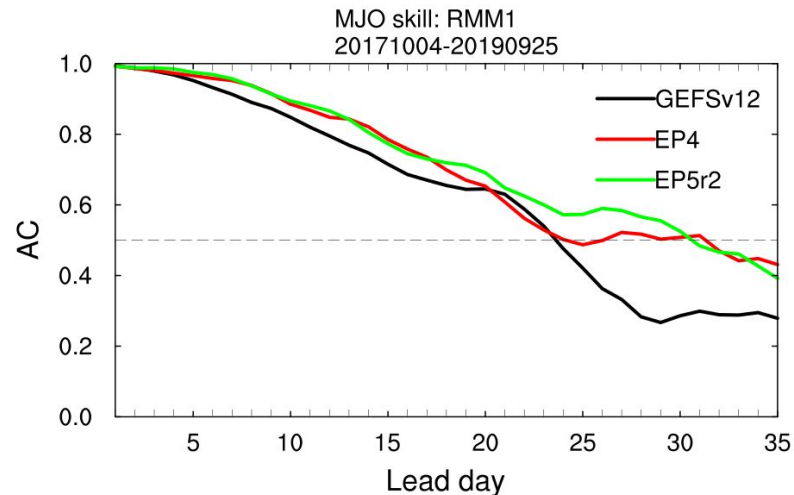
WAV: replay



MJO skills of the RMMs



- EP5r2 performs better than EP4 for first 3 weeks and is consistently better than GEFSv12
- For GEFSv12, MJO skill remains useful for about 21 days
- For EP4, MJO skill remains useful for about 26 days
- For EP5r2, MJO skill remains useful for about 25 days
- MJO skill of EP5r2 and EP4 both remain useful for about 25-26 days, and are both better than GEFSv12 by about 4 days



NOAA's Seasonal Forecast System Development Plan

GOALS:

- **Balanced initializations across interfaces**
- **Minimize systematic drift from initial conditions**
- **Best estimation of uncertainties in ensemble forecasts**
- **Reduce systematic biases and improve forecast skill**
- **SFS infrastructure should provide critical support**

SFS will be:

- **Enabled to run in the cloud**
- **Incorporated into UFS repositories**
- **Provided to community through the Earth Prediction Innovation Center (EPIC)**



NOAA

**NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION**
United States Department of Commerce

NOAA'S SEASONAL FORECAST SYSTEM (SFS) DEVELOPMENT PLAN



December 1, 2023

Yan Xue¹, William Komaromi², Avichal Mehra³, Phil Pegion⁴, Neil Barton⁵, Deepthi Achuthavari⁶, Jason Anderson², Mike Barlage³, Lisa Bengtsson⁴, Ligia Bernardet⁶, Jessie Carman⁷, Juliana Dias⁴, Clara Draper⁴, Sergey Frolov⁴, Kevin Garrett¹, Maoyi Huang⁷, Tara Jensen⁸, Daryl Kleist³, Jason Levit³, Weiwei Li⁸, Rahul Mahajan³, Raffaele Montuoro³, Ivanka Stajner³, Shan Sun⁸, Vijay Tallapragada¹, Jun Wang³, Wanqiu Wang⁹, Denise Worthen³, Fanglin Yang³, Man Zhang⁶

- 1) NOAA/NWS/OSTI-Modeling, Silver Spring, MD
- 2) I.M. Systems Group, Rockville, MD
- 3) NOAA/NWS/NCEP/EMC, College Park, MD
- 4) NOAA/OAR/PSL, Boulder, CO
- 5) IBSS Corporation, Silver Spring, MD
- 6) NOAA/OAR/GSL, Boulder, CO
- 7) NOAA/OAR/WPO, Silver Spring, MD
- 8) NCAR, Boulder, CO
- 9) NOAA/NWS/CPC, College Park, MD



Progress in SFSv1 Development: Prototype T&E

(Leads: Neil Barton, Phil Pegion, Avichal Mehra)

- Use GEFSv13 as baseline for testing

[Toward a Fully-Coupled Global Ensemble Forecast System \(GEFSv13\)](#), Fu et al., Monday, UFS-R2O Session

- Testing resolutions

Phase I, II: C96 atmos, 1deg ocean/ice

Phase III: C192 atmos, 0.25deg ocean/ice

- Testing lengths & ensembles

Phase I: 4 months, 11 members

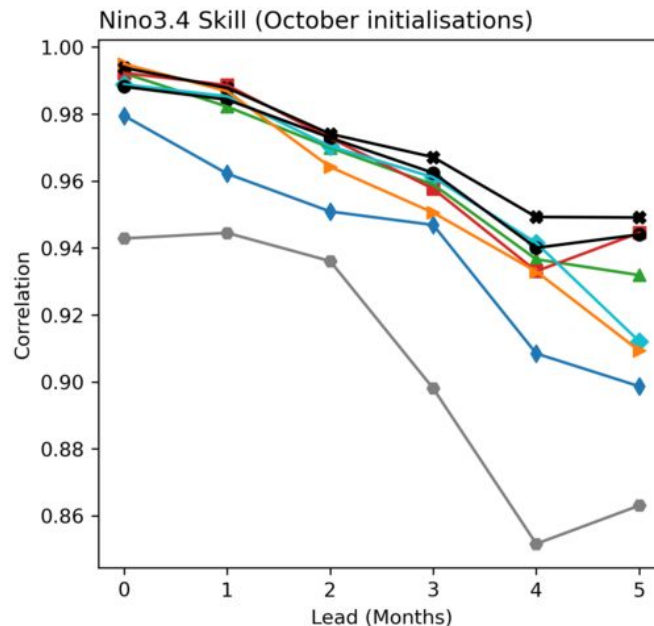
Phase II, III: 12 months, 21 members

- Reforecast:

Start month: May & Nov

Period: 1994-2023 (extending to 1980-2023 later)

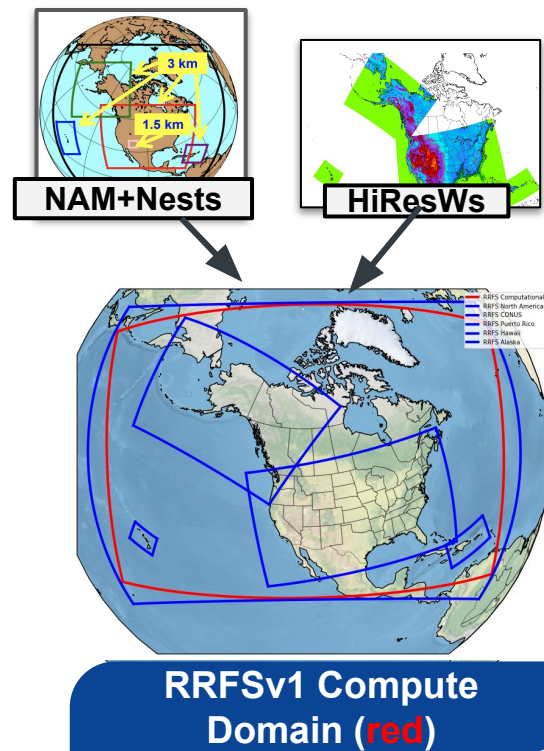
SFS one-degree “Proof-Concept” Reforecasts



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 3DENvar assimilation (30 members)
- Includes Smoke & Dust
- Deterministic forecasts to *at least* 18h every hour
- Deterministic & Ensemble forecasts to 48+h every 6 hours
- RRFSv1 Beta Evaluation Completed
- RRFSv2
 - Transition from FV3 dynamical core to MPAS
 - *Adding American Samoa and Micronesia Support to improve service to underserved communities*





HWT Spring Forecasting Experiment

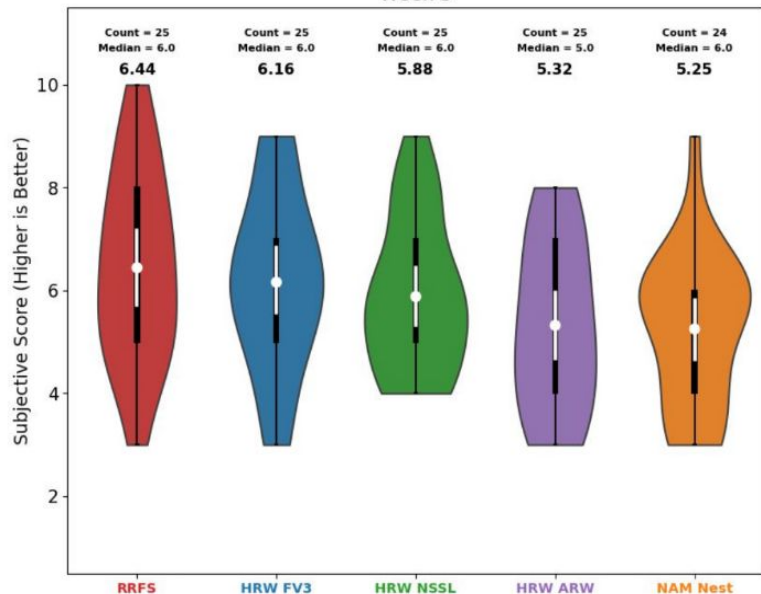
2025 Week 5 Wrap-Up Discussion



Group 3: D4 Week 5

00Z RRFs vs. Op CAMs: Composite Reflectivity & UH

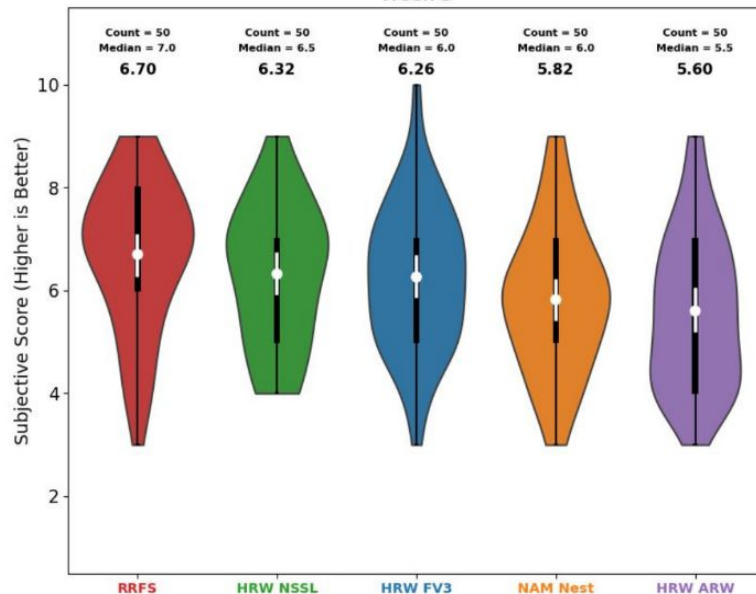
Week 5



Updated 20250530 14:31:21 UTC

00Z RRFs vs. Op CAMs: All Environment Fields

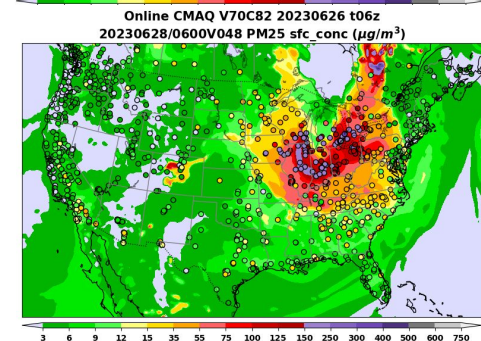
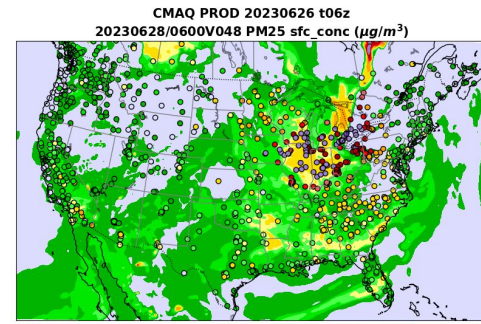
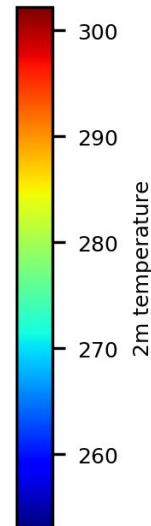
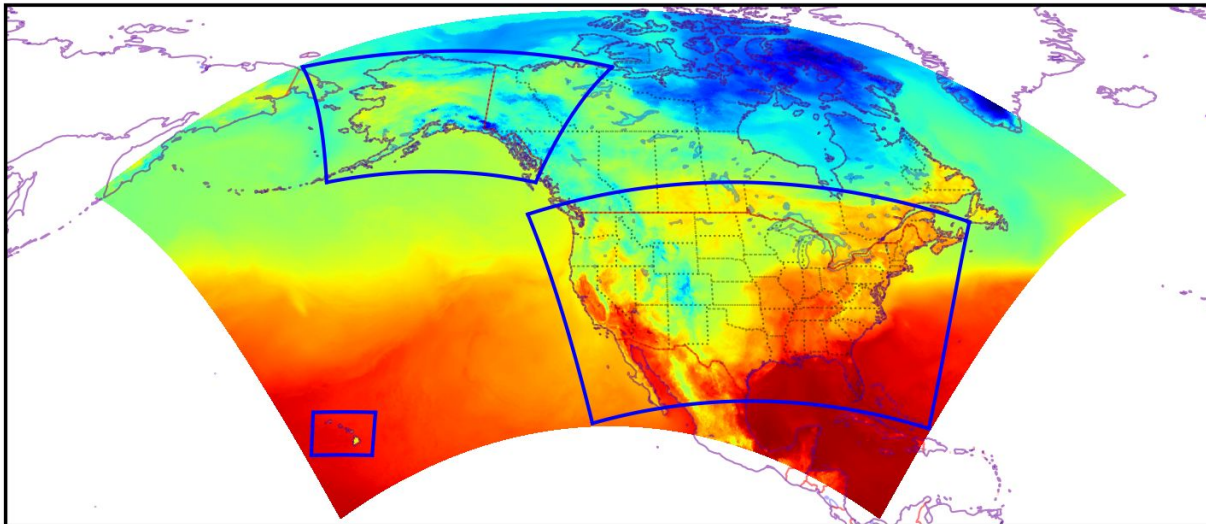
Week 5



Updated 20250530 14:31:23 UTC



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)

UFS for Hurricane Applications

HAFSv1.0 implemented in June 2023, upgraded to HAFSv2.0 in July 2024; will be upgraded to HAFSV2.1 in July 2025

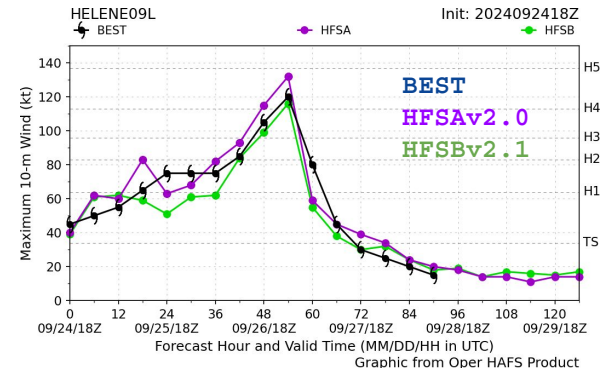
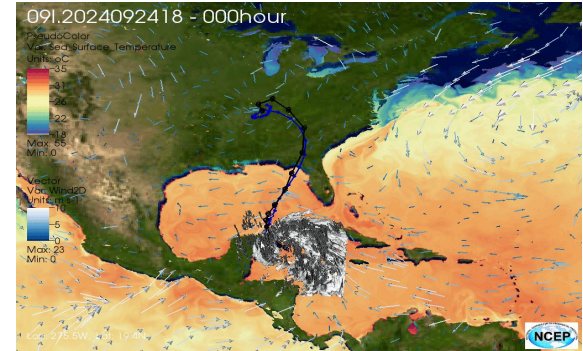
HAFSv2.0 Highlights

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

HAFSv2.1 Highlights

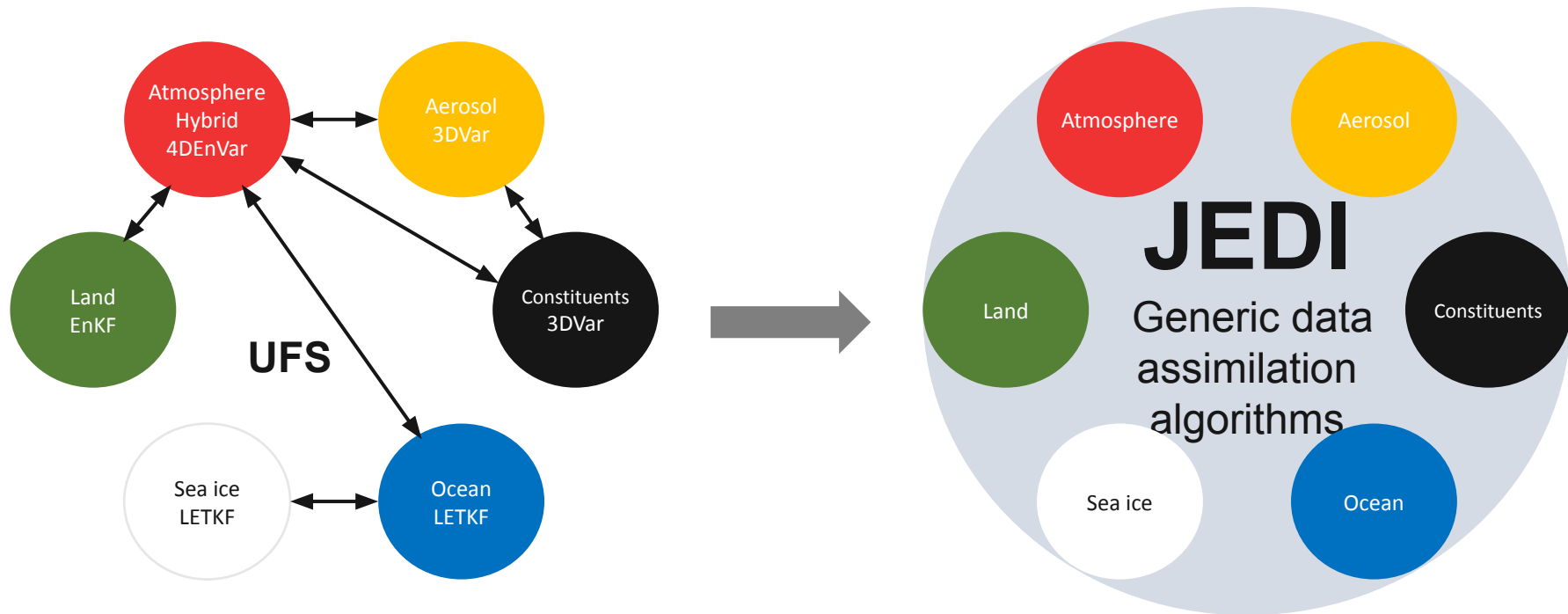
- Use latest version of RTOFS (v2.5, July 2025) to initialize ocean models
- Address issues identified in 2024 hurricane season
 - Storm structure at model initial time
- Improve model track and intensity forecast skills

Hurricane Helene 09L, initialized at 2024092418

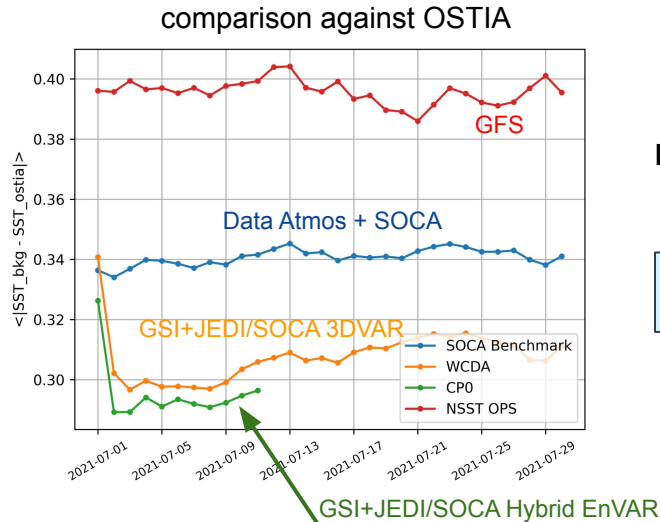


Towards Coupled Data Assimilation

Up to now data assimilation systems have been developed in parallel for the different models, with various levels and approaches for coupling between data assimilation and model components.

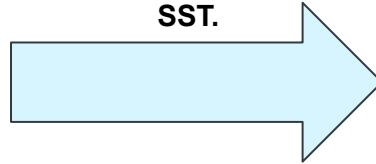


Advances in JEDI based Weakly Coupled Data Assimilation

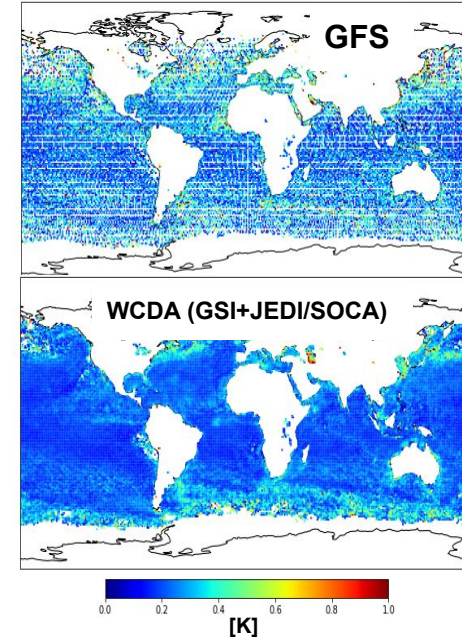


cp0: Status as of 07-11-2023.
Ocean & sea ice hybrid EnVAR
with 30 offline members

Better estimate of the
foundation temperature
leads to better simulation
of radiances sensitive to
SST.



AVHRR NOAA-18, channel 3 $\langle |\text{Obs} - \text{Bkg}| \rangle$ from

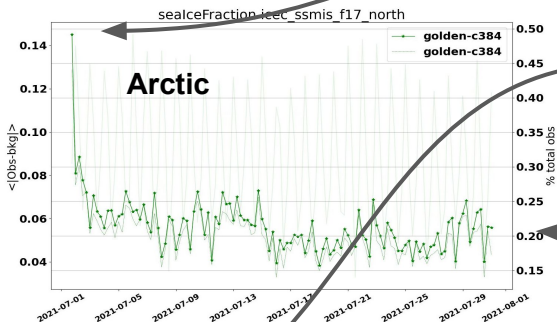


- More obs passed the GSI QC
- Smaller O-B almost everywhere

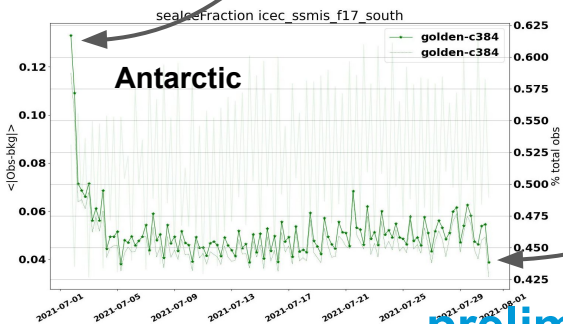
Weakly Coupled Data Assimilation preliminary
results: SST

Advances in JEDI based Weakly Coupled Data Assimilation

Sea ice concentration OMB statistics

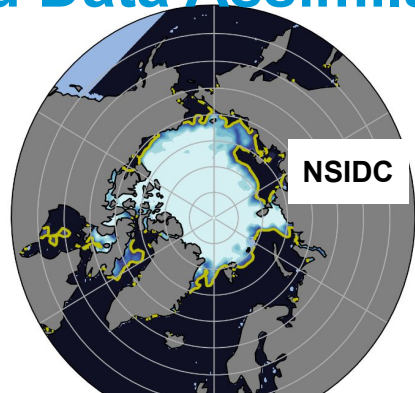


Started from a benchmark SOCA based short reanalysis (~6 months)

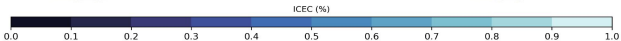
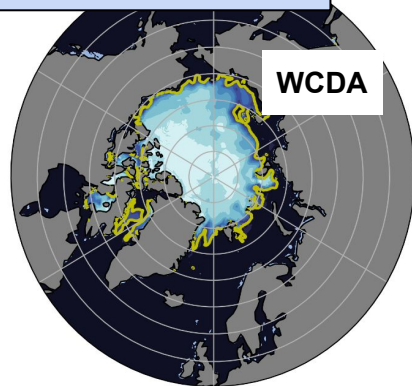
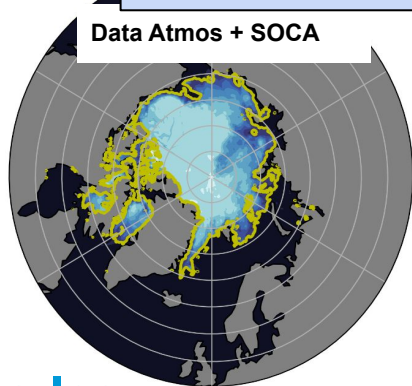


Significant error reduction in the WCDA system

preliminary results: Sea-Ice



Better sea ice extent in the WCDA prototype



Future Plans for UFS

- **Continue to accelerate the transfer of innovations from the research community into UFS applications so they can be evaluated for potential operational implementation. Require:**
 - **more streamlined/seamless engagement with lower RL activities from the rest of the UFS community.**
 - **(A lot) more HPC for T&E.**
- **Incorporate new applications (space-weather, coastal....).**
- **Coordinate with EPIC to provide easy access to portable workflows, diagnostic/verification packages and datasets so community partners can more easily work with end-end systems.**



Thanks for your attention

Questions?

