ECMWF Annual Seminar 2025

UFS-based Earth System Modeling for Research and Operational Applications at NCEP: Progress and Challenges

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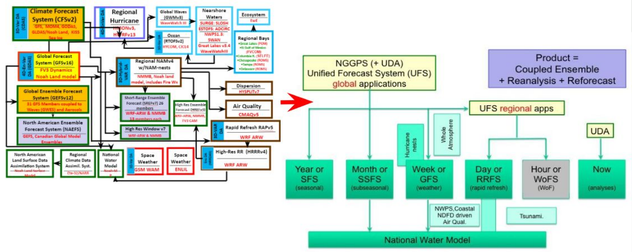
Transitioning to Unified Forecast System Applications for Operations

- **Acknowledgements**
  - All of the outstanding scientists and engineers at the Environmental Modeling Center, and Collaborators within NOAA, at other Federal agencies, International Agencies, Academia, and the Private Sector

Goal: Simplifying the NCEP Production Suite (NPS)



Recent Operational Modeling Achievements

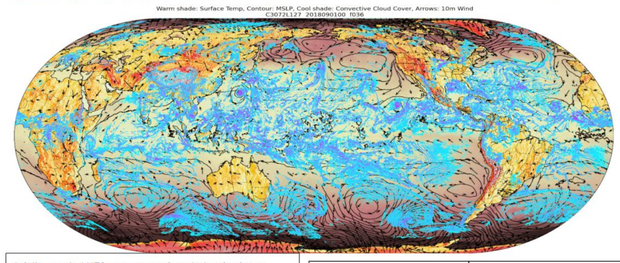
Model version#	Modeling System	Implementation date
RTMA/URMAv2.10.5	Real Time and UnRestricted Mesoscale Analysis	1/24/2023
GLWUv2	Great Lakes Waves-Unstructured Forecast System	5/9/2023
HAFSv1	Hurricane Analysis and Forecast System	6/27/2023
NAEFSv7	North American Ensemble Forecast System	12/5/2023
EVSv1	EMC Verification System	3/26/2024
AQMv7	Air Quality Model	5/14/2024
HAFSv2	Hurricane Analysis and Forecast System	7/16/2024

https://www.nco.ncep.noaa.gov/pmb/changes/ Yellow: UFS Applications

HAFS V2 - First Regional Coupled UFS Application in Operations

A Six-Way Global Coupled Unified Forecast System (UFS) -- a first for NOAA/NWS

UFS Earth System Model Components:



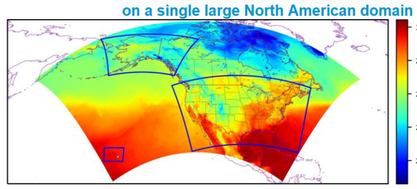
A fully coupled UFS serves as a foundation for future operational global forecast systems at NOAA/NWS/NCEP ranging from weather to subseasonal to seasonal scales.

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

Animation Courtesy: S. Moorthi and Keqin Wu, NWS/NCEP/EMC

UFS based High Resolution Short Range Weather Forecasts - AQMv7; RRFS; 3DRTMA & URMA & EVS - EMC Verification System

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



AQMv7: The next candidate for operations at 13 km resolution

- **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 the AQMv7 candidate system**

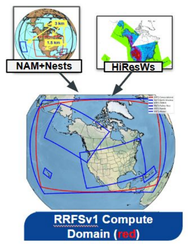
- Updated LBC (GEOS 5 + GEFS-Aerosols) and wet deposition
- Fengsha dust module
- Bias correction for ozone and PM2.5
- Post-processing for 8h ozone maximum and daily average PM2.5
- Hourly RAVE wildfire emissions over the North American domain
- Anthropogenic and biogenic emissions for this domain (NEI 2016v1 plus global)

Rapid Refresh Forecast System (RRFS)

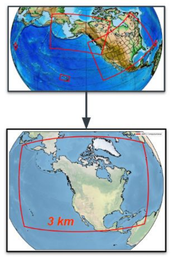
A UFS Application

- **FV3 dynamical core Limited Area Model**
- **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*



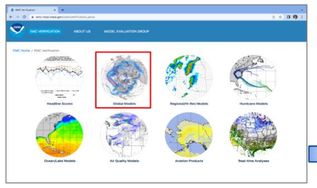
3D Real-Time & Unrestricted Mesoscale Analysis



- History
  - 2DVar RTMA/URMA in operations since 2006
    - The official NWS Analysis of Record
    - *Analysis only - designed to fit obs very closely*
  - 3D RTMA began in 2017 as a joint effort between EMC and NOAA/GSL
- Progress
  - Hybrid En3DVar Algorithm
  - *RRFS* for atmospheric background and Ens **B**
    - Unification of many disparate domains
  - GFS/WW3 background for waves
  - Dynamic downscaling
  - Automated Obs-QC for mesonet and aircraft obs
  - Bias correction for mesonet winds
  - Non-variational cloud analysis - assimilates dBZ
  - Ceiling & Visibility diagnosed from 3D analysis fields
  - Gridded estimate of analysis uncertainty
  - Adjoint-based Real-Time Quality Monitoring
  - Proposed to replace SPC's Mesoanalysis product

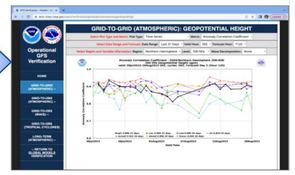
EMC Verification System

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



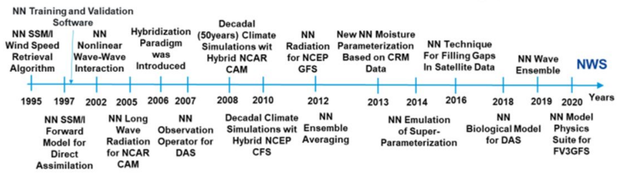
- Model Evaluation Group: statistical evaluation, evaluation of high impact events, weekly presentations

- **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



Machine Learning Applications at EMC

EMC Developments in ML for NWP and Climate

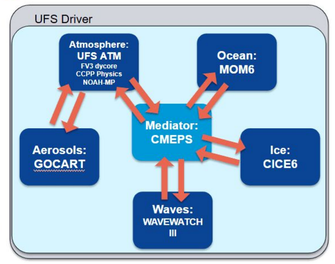


UFS for Medium Range, Sub-Seasonal and Seasonal Applications (MRW/S2S)

MRW/S2S System Overview

Coupled system resolutions
- Atmosphere/land:
  - Forecast: C1152 L127
  - Analysis/DA Ensemble: C384 L127
- Ocean
  - ¼° tripolar
  - 75 layers
- Sea ice
  - ¼° tripolar
- Waves
  - Unstructured grid
- Aerosol
  - Included in GDAS deterministic forecast
  - No aerosol-radiation interaction

GFS and GEFS infrastructure will be as unified as possible with implementation planned for the same day



Weakly Coupled DA for MRW/S2S Using JEDI

- Atmosphere
  - GSI-based hybrid 4DEnVar deterministic analysis
  - GSI-based 4D-LETKF ensemble analysis
  - Additional early cycle ensemble analysis for GEFS initialization (if resources allow)
- Marine
  - Sea-ice Ocean and Coupled Analysis (SOCA): ocean and sea ice are strongly coupled
  - JEDI-based hybrid 3DEnVar for deterministic analysis
  - JEDI-based 3D-LETKF for ensemble analysis
- Land
  - JEDI-based 2DVar for snow
  - GSI-based 4D-LETKF for soil moisture and soil temperature (strongly coupled with atmosphere)
- Aerosol
  - JEDI-based 3DVar
  - Initializes central analysis only (no ensemble perturbations)

ATM Physics

- Updated Cumulus Convection:
  - positive definite mass flux; optimization; improved MJO prediction with prognostic closure; improved CAPE forecast; improved hurricane forecasts
- Updated Planetary Boundary Layer (PBL):
  - positive definite mass flux; optimization; improved CAPE forecast; improved hurricane forecasts
- Land Surface Model (LSM):
  - replacing Noah LSM with **Noah-MP LSM.** Noah-MP uses multiple options for key land-atmosphere interactions
- Microphysics (MP):
  - replacing GFDL MP scheme with **Thompson MP scheme,** a hybrid double moment scheme
- Gravity wave drag (GWD):
  - small-scale gravity wave drag; turbulent orographic form drag; updates of orographic GWD, mountain blocking
- Aerosol:
  - replacing OPAC data with MERRA2 aerosol climatology

GFSv17 Development Priorities

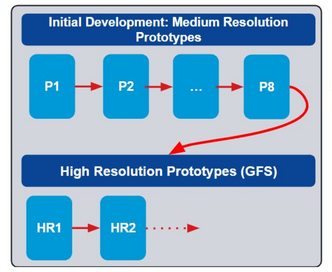
- **Coupled forecast model (atm, land, ocn, ice, wav)**
- **Improved DA with marine JEDI (more later)**
- **Physics improvements including Noah-MP land model, PBL, convection, gravity waves, and Thompson Microphysics**
- **Unstructured Wave grids w/2-way coupling**
- **Higher resolution (9-km target)**
- **Improve on known issues in GFSv16**
- **Consolidation of NCEP production suite**
  - GODAS combined in Coupled GDAS
  - Retirement of NAM and RAP

GEFSv13 Configurations (planned)

Components		V12 (Sep 23, 2020)	V13 (targeting FY26)
Atmos	Dynamics	FV3 (Finite-Vol Cubed-Sphere) GFSv15	FV3 (Finite-Vol Cubed-Sphere) GFSv17
	Physics	saSAS, GFDL-MP, K-EDMF, orogWD	saSAS, Thompson-MP, sa-TKE-EDMF, uGWD
	Initial perturbation	EnKF f06 (previous cycle)	EnKF f00 (early cycle)
	Model uncertainty	S-scale SPPT and SKEB	S-scale SPPT, SKEB, SPP, CA
	Boundary (ocean surface)	NSST + 2-tiered SST	NSST
	Resolutions	C384L64 (25km)	C384L127 (25km)
Land	Model	NOAH-LSM	NOAH-MP
	Initial perturbation	N/A	Soil moisture
Ocean	Model	N/A	MOM6 (0.25°L75)
	Initial perturbation		SOCA-Ens
	Model uncertainty		S-scale oSPPT and ePBL
Ice	Model		CICE6 (0.25°)
	Initial perturbation		SOCA-Ens
Wave	Model	WW3 (1-way) (0.5°)	WW3 (2-way) (0.25° lat/lon grid)
Aerosol	Model	GOCART (1-way)	GOCART (1-way)

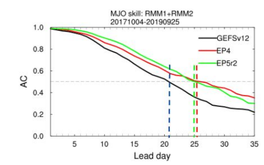
UFS Prototypes for Accelerated Development

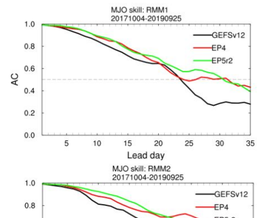
UFS Prototype Development



- ***Iterative development***: Discrete system prototypes with gradually increasing complexity defined and evaluated. Findings used to inform subsequent development.
- ***Medium Resolution Prototypes (1-8):*** Deterministic, 35-day fcsts, med. resolution. **P8**: all system components in. → Starting point for High Resolution prototypes
- ***High Resolution Prototypes*:** Target GFSv17: Deterministic, 16-day fcsts, high resolution, tuning

MJO skills of the RMMs





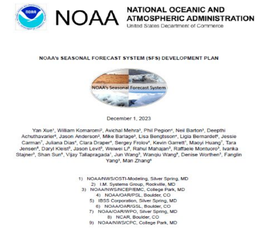
- EP5r2 performs better than EP4 for first 3 weeks and is consistently better than GEFSv12
- For GEFSv12, MJO skill remains useful for about 21 days
- For EP4, MJO skill remains useful for about 26 days
- For EP5r2, MJO skill remains useful for about 25 days
- MJO skill of EP5r2 and EP4 both remain useful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

Courtesy: Eric Sinsky (EMC)

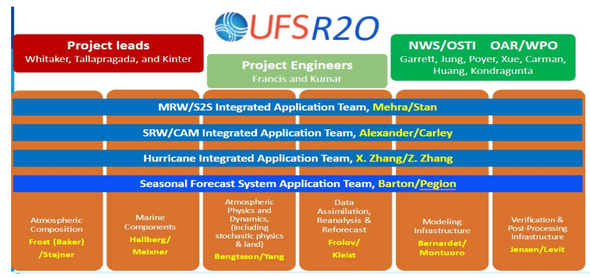
NOAA's Seasonal Forecast System Development Plan

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)**



UFS-R2O Project Leading the Innovations



Future Plans for UFS-R2O

- **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.**