AGU Town Hall: Dec 9, 2024

Status of and Plan for Developing and Implementing Medium-Range Weather (MRW), Subseasonal and Seasonal (S2S) Forecast Systems Based on the Unified Forecast System at NOAA

Agenda:

Program Office:

Yan Xue, NWS/OSTI Modeling Program: Opening Remarks

Panelists:

Vijay Tallapragada, NWS/NCEP/EMC: Global Forecast System (GFSv17, Physics, Land)
Neil Barton, NWS/NCEP/EMC: Global Ensemble Forecast System (GEFSv13)
Phil Pegion, OAR/PSL: Seasonal Forecast System (SFSv1)
Clara Draper, OAR/PSL: Coupled Data Assimilation and Initialization Strategy
Jun Wang, NWS/NCEP/EMC: UFS Infrastructure and Global Workflow

Q & A

Advancing NOAA's MRW and S2S Applications through Community Modeling

Yan Xue

Program Manager for Weeks 3-4 Program and SFS Project

NOAA/NWS/OSTI Modeling Program

Acknowledgement: Steven Simon, Jason Anderson, Kevin Garrett

Unified Forecast System

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.

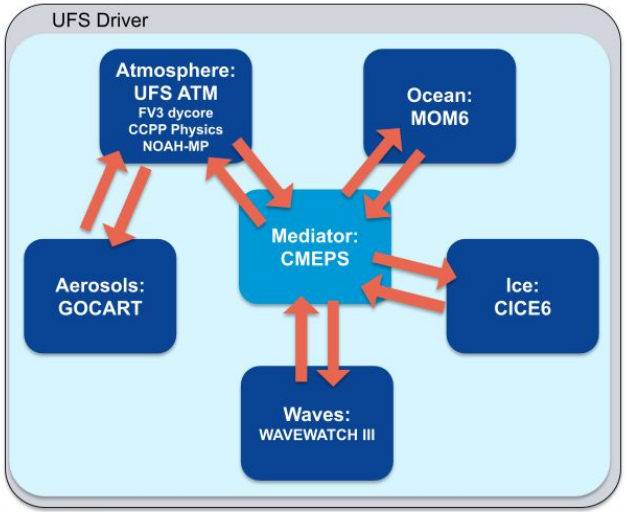
- Community components in UFS
  - Model infrastructure: ESMF, NUOPC, CMEPS
  - Atmosphere model: FV3 dycore, CCPP Physics
  - Ocean model: MOM6
  - Ice model: CICE6
  - Wave model: WW3
  - Aerosol model: GOCART
  - Land model: Noah-MP (currently)
  - Data assimilation: Joint Effort for Data Assimilation Integration (JEDI)
- Each component has its own authoritative repository.

UFS Research-to-Operations (UFS R2O) Project

Developing the next-generation global and regional forecast systems and transition to NOAA operations in FY23 and beyond

Jointly supported by NOAA NWS and OAR

MRW/S2S Applications: GFSv17, GEFSv13, SFSv1



NWS Weather, Subseasonal and Seasonal Forecast Systems

Current Systems

GFSv16 (Implemented **Mar 2021**)
Weather scales, deterministic, **no coupling with ocean/ice**. FV3 dycore

GEFSv12 (Implemented **Sep 2020**)
Weather to subseasonal, ensemble, **no coupling with ocean/ice**. FV3 cycore

CFSv2 (Implemented **Mar 2011**)
Subseasonal to seasonal, ensemble, coupled with ocean & sea ice

Future UFS Systems

GFSv17 (Target Implementation **Q3FY26**)
Weather, deterministic, **coupling with ocean, sea ice, waves with two-way interactions**, FV3 dycore, **advanced physics, new land physics, weakly coupled DA**

GEFSv13 (Target Implementation **Q3FY26**)
Weather to subseasonal, ensemble, **coupling with ocean, sea ice, waves with two-way interactions**, FV3 dycore, **advanced physics, new stochastic physics, new land physics, weakly coupled DA**

SFSv1 (Target Implementation **FY28**)

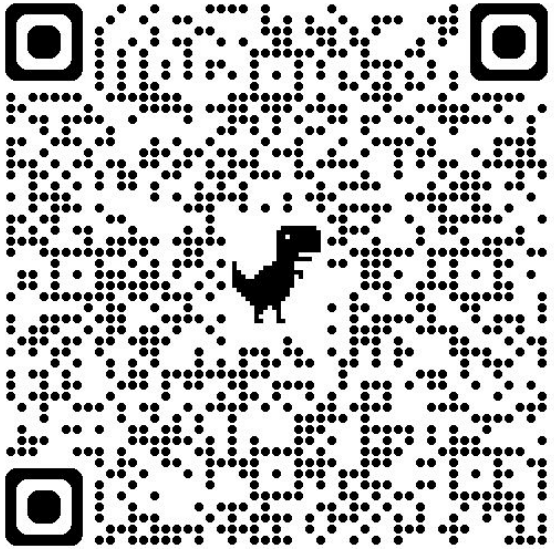
NOAA's Seasonal Forecast System Development Plan

GOALS:

- Develop and implement **SFSv1** as a replacement of a more than decade-old Climate Forecast System version 2 (**CFSv2**)
- Address **common errors** in CFSv2 and North American Multi-Model Ensemble (NMME)

SFS will be:

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



SFS Application Team established with participation from NWS, OAR, DTC and EPIC in **October, 2023**

NOAA's Subseasonal and Seasonal Applications Workshop

College Park, MD, Sep 4-6 2024

First NOAA's S2S Applications Workshop

- 330 registered participants; 87 oral presentations and 45 posters

Outcomes:

- Enhanced collaborations among stakeholders/users, modelers and researchers
- **Identified requirements and needs for GEFS and SFS**
- Identified urgent research and development needs and gaps
- Shared best strategies in developing S2S Applications with international and domestic modeling centers
- **Acquired community feedback on SFS Development Plan**

Community Feedback on SFSv1 Development

- **Implement SFSv1 as soon as possible**; Keep CFSv2 active so that users can compare performance of SFSv1 and CFSv2
- The generation of a reanalysis should not be rushed. Any reanalysis and model development needs to be more agile. The SFSv1 implementation should not wait until the completion of the reanalysis.
- **Consider the costs and benefits of the SFS model components in development**
- Use **deep analysis of processes**, e.g., ENSO, annual, diurnal, budget studies, and available observations
- **Engage more personnels outside of NOAA** in the SFS development

Users' Needs and Requirements for GFS/GEFS

- Support Weeks 3-4 and Monthly Temperature and Precipitation, Weekly/Monthly Drought, and Weekly/Monthly Sea Ice Outlooks
- Support Week 2 US Hazards Outlooks
- Support Global Tropical Hazards Outlooks
- Support hydrological applications (HEFS, NWM)
- Support coastal hazards (sea level, flooding) forecasts and extreme heat and wildfire outlooks
- Improve sea ice, surface winds, and waves forecasts to better support transoceanic shipping, polar routing, and cryospheric research
- Improve extreme precipitation, precipitation type, and snow level forecasts
- Reduce warm bias over Central Plains
- Improve handling of shallow cold air masses, low CAPE bias, and warm bias in heat waves
- Improve resolution to capture terrain and islands
- Improve Atmospheric River forecasts
- Improve flash drought outlook via improved land modeling and land initialization
- Expand forecast horizon for marine hazards

Users' Needs and Requirements for SFS

- Support ENSO, Seasonal Temperature and Precipitation, Seasonal Drought, Seasonal Hurricane, and Seasonal Sea Ice Outlooks
- Support coastal and lake forecasts and applications
- Support hydrologic forecasts and applications
- Support marine hazards forecasts and applications
- Reduce model biases in long-term trends, planetary boundary layer processes, tropical processes, stratospheric dynamics, and climate modes and their teleconnections
- Address ENSO false alarm forecasts, slow propagation of the MJO, and the overly frequent forecasting of warm anomalies over the CONUS
- Address the temporal discontinuities in ICs used to initialize seasonal reforecasts
- Improve ensemble and reliability including capturing of extremes
- Improve land surface model processes for drought impact prediction

Progresses and Challenges in Developing and Implementing Global Forecast System (GFSv17)

Vijay Tallapragada, Fanglin Yang

NOAA/NWS/NCEP Environmental Modeling Center

Global Forecast System (GFSv17)

(Deterministic Forecast up to 16 days)

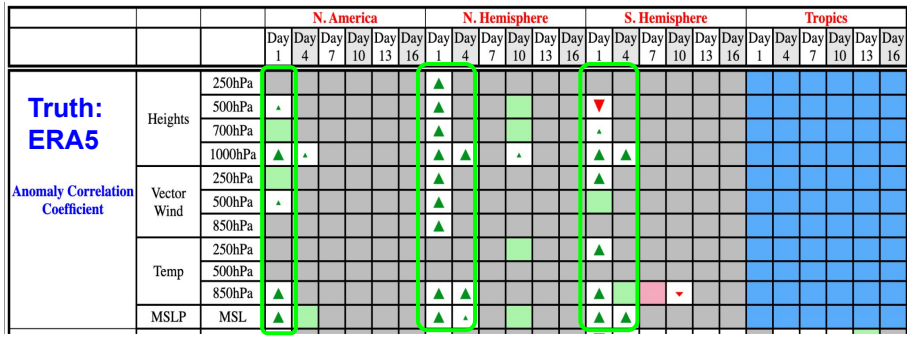
	GFSv16: Implemented in March 2021	GFSv17: Target Implementation in June 2026
Model	FV3/Noah/WW3	FV3/Noah-MP/MOM6/CICE6/WW3 (two-way coupling)
Resolution	C786L127 (13km, 80km top)	C1152L127 (9km, 80km top)
Physics	GFDL MP, sa-TKE-EDMF, non-orographic GWDs	Thompson MP, CA, UGWD, tuning of convection, surface and PBL physics schemes MERRA-2 aerosol climatology
Forecast Cadence (6 hourly)	GSI, GLDAS 16 days from 00Z, 06Z, 12Z and 18Z	Weakly Coupled DA (GSI, JEDI Ocean/Sea Ice, JEDI Snow) 16 days from 00Z, 06Z, 12Z and 18Z

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
- Others

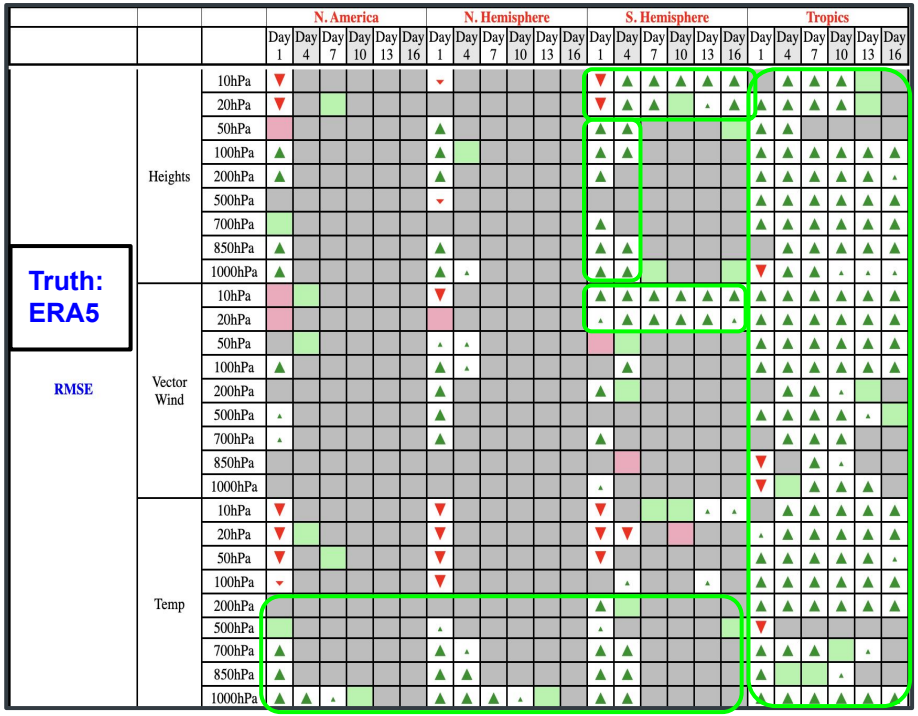
High Resolution (C1152) Prototypes: Results – ACC & RMSE

HR4 vs GFSv16 DJF



Statistically significant improvement over HR3b for days 1–7

Some challenges: tropics & stratospheric temperatures



Statistically significant improvement over GFSv16

Created by Lydia Stefanova

Weakly Coupled DA Overview

- **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)

Preliminary 3DVar Cycling Results

ATM model, ATM DA
S2S model, ATM DA
S2S model, S2S DA

500 hPa NH ACC

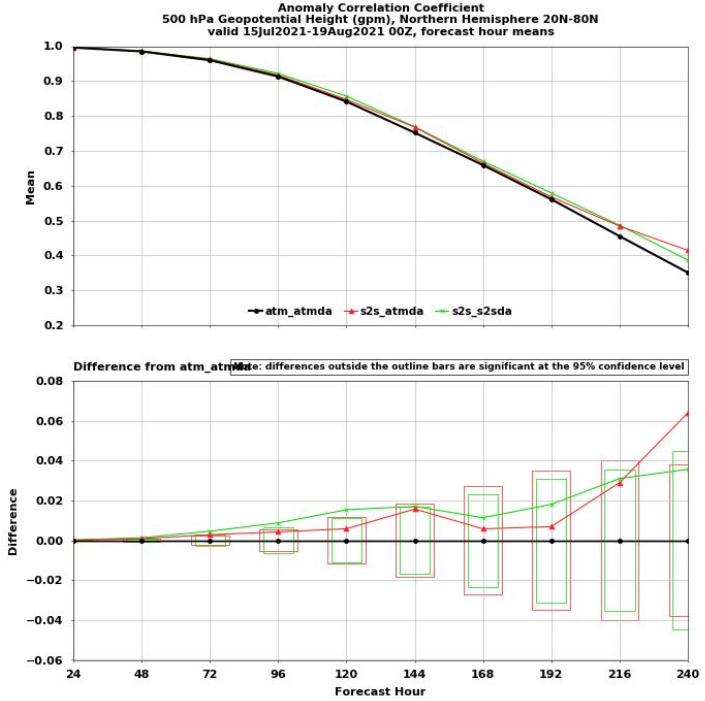
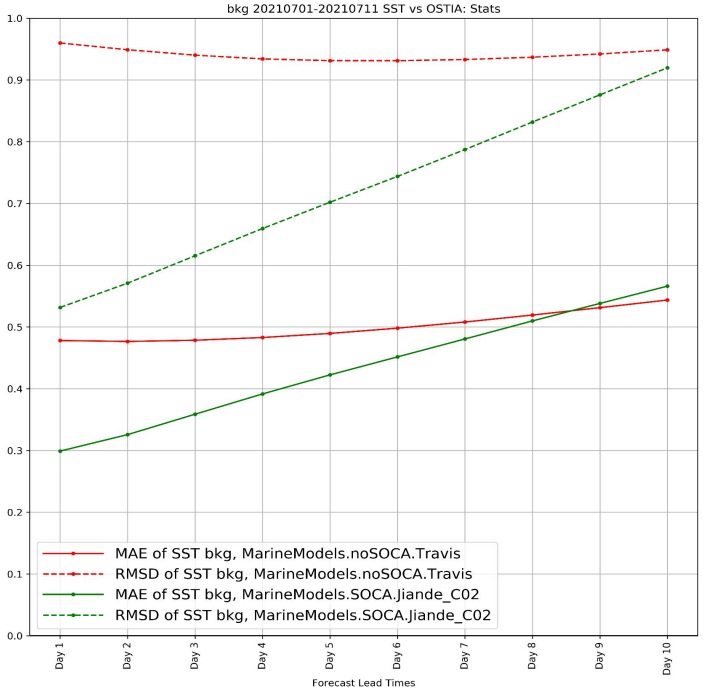


Figure courtesy of Xuanli Li

Mean stats per lead time for July 1-11, 2021



SST vs. OSTIA

Valid for 60°S-60°N

Figure courtesy of Katie Lukens

Evaluation is ongoing, but initial cycling results with OCN/ICE DA are encouraging.

Progresses and Challenges in Developing and Implementing Global Ensemble Forecast System (GEFSv13)

Neil Barton and Bing Fu

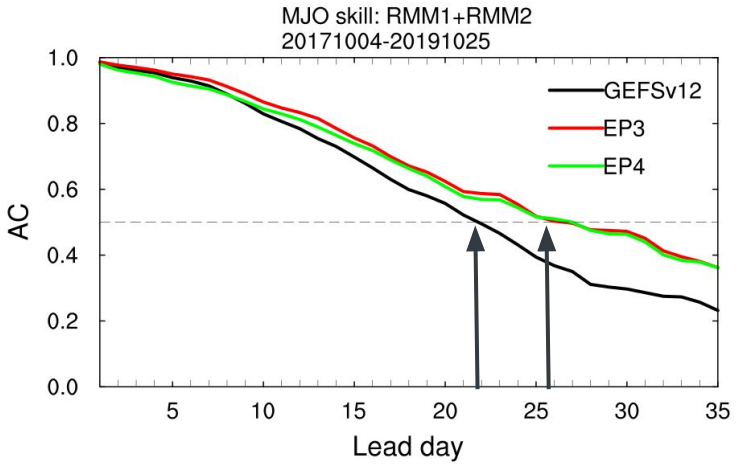
NOAA/NWS/NCEP Environmental Modeling Center

Global Ensemble Forecast System (GEFSv13)

(Ensemble Forecast up to 48 days)

	GEFSv12: Implementation September 2020	GEFSv13: Target Implementation 2026 (Summer/Fall)
Model	FV3/Noah/WW3	FV3/Noah-MP/MOM6/CICE6/WW3
Resolution	C384L64 (~25km, 55km top)	C384L127 (~25km, 80km top)
Physics	GFDL MP, Stochastic physics (SPPT, SKEB)	GFSv17 physics + Stochastic physics (SPPT, SKEB, CA, ocean)
Realtime (31 members, 6 hourly)	GSI, GLDAS 16 days (06Z, 12Z and 18Z), 31 members 35 days (00Z), 31 members	Weakly Coupled DA (GSI, JEDI Ocean/Sea Ice, JEDI Snow) 16 days (06Z, 12Z and 18Z), 31 members 45 days (00Z), 31 members
31-years Reforecast (5/11 members, daily/weekly)	GEFSv12 reanalysis (CFSR) in 2000-2019 (1989-1999) 16 days, every day, 5 members 35 days, every Wednesday, 11 members	Replay to ERA5 Atmos, ORAS5 Ocean/Sea Ice, Noah_MP spin up, snow DA in 1994-2024 16 days, every day, 5 members 45 days, every Monday, Thursday, 11 members

GEFSv13 Compared to GEFSv12



GEFSv13 testing shows higher MJO skill (RMM1+RMM2) than GEFSv12 for longer lead times at 4 to 5 days

			N. America						N. Hemisphere						S. Hemisphere						Tropics					
			Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
Anomaly Correlation Coefficient	Heights	250hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲						
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Scorecard Symbol Legend

▲ GEFS_EP5r2_f_m24 is better than GEFSv12 at the 99.9% significance level	▼ GEFS_EP5r2_f_m24 is worse than GEFSv12 at the 99.9% significance level
▵ GEFS_EP5r2_f_m24 is better than GEFSv12 at the 99% significance level	▾ GEFS_EP5r2_f_m24 is worse than GEFSv12 at the 99% significance level
GEFS_EP5r2_f_m24 is better than GEFSv12 at the 95% significance level	GEFS_EP5r2_f_m24 is worse than GEFSv12 at the 95% significance level
No statistically significant difference between GEFS_EP5r2_f_m24 and GEFSv12	Not statistically relevant

Dates: 20171005-20190926

Green: ~GEFSv13 better than GEFSv12

GEFSv13 Overview

Current Status of Development:

- Improvements Compared to GEFSv12
  - MJO Improvements
  - Z500 CRPS Improvements
  - U10 Bias Improvements
  - Low-level temp degradation
  - New Products for Ocean and Sea Ice!
- Targeted Implementation in 2026

GEFSv13 Reforecasting:

- GEFSv13 Re-Forecasting effort has begun
- 1994 to 2023
- 45-day 11 member forecasts on Mondays and Thursdays
- 16-day 5 member forecast on other days
- Plan to share output on AWS
- Looking forward to the community analyzing the output!

Plan and Progresses in Developing Seasonal Forecast System (SFSv1)

Phil Pegion[1], Neil Barton[2] , and Xiaqiong Zhou[2]

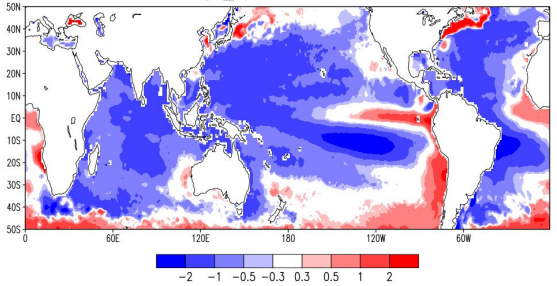
[1]NOAA/OAR/Physical Science Laboratory
[2]NOAA/NWS/NCEP Environmental Modeling Center

Challenges of Developing the SFS

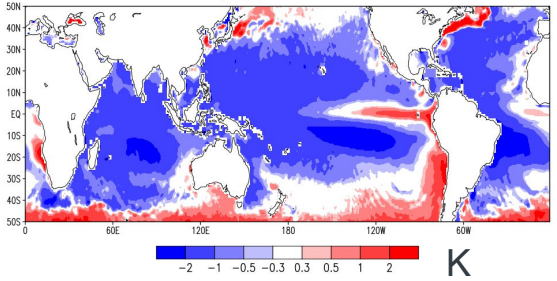
- Technical Challenges
  - Lack of dedicated computing for SFS development
  - Infrastructure has been built around weather forecasts and it not well suited for forecasts of many months
- Scientific Challenges
  - Although we are starting with the same model that has been developed for GEFSv13, there is different behavior at lower resolutions
  - We do not have our own analysis to initialize retrospect forecasts.
  - Need to correctly capture the trend

SST bias

0.5 º ATM 0.25º OCN/ICE



1 º ATM 1º OCN/ICE



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Courtesy: Kate Zhou

The Seasonal Forecast System

Progress

- Just over 1 year into focused development of SFSv1
- Development has focused on minimizing biases in the lower resolution model run for Seasonal Timescales
- Switched over to hydrostatic dynamical core in the atmosphere
- Initial testing is only with atmosphere, land, ocean, and sea-ice models at 1-degree
- Many preliminary experiments looking at the impact of different ocean initial conditions, physics tuning.
- There will be 3 phases reforecast tests

The Seasonal Forecast System

3 phases of testing

SFSv1 - Planned Baseline Experiments

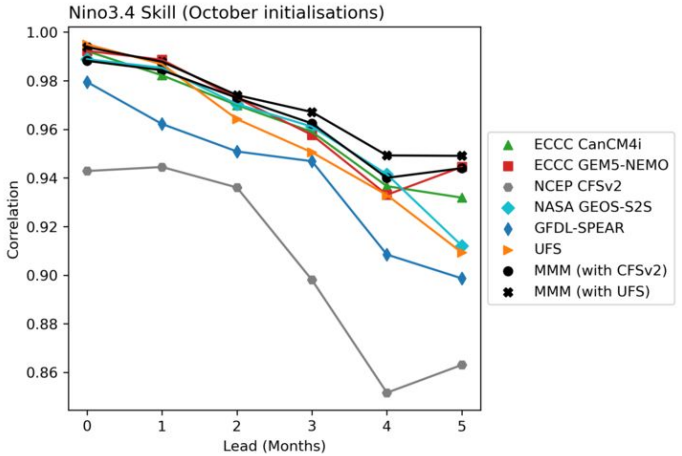
	Spatial Resolution			Ensemble	Duration		
	Atm/Land/Aerosols	Ocn/Sea Ice	Waves	Members	Time period	Starts (Month)	Forecast length
Phase I	100 kms (1 deg)	1 deg	1 deg	11	1994-2016 (2023)	2 (May, Nov)	4 months
Phase II	100 kms (1 deg)	1 deg	1 deg	21	1993-2016 (2023)	2 (May, Nov)	12 months
Phase III	50 kms (1/2 deg)	1/4 deg	1/4 deg	21	1993-2023	2 (May, Nov)	12 months

Unlike GFS and GEFS development. Idea is to have multiple institutions running Phase 1 tests.

Scan to get SFS experimental data

Opportunities

- Target implementation is several years away
- Incorporation of the Wave and Aerosol models will be tested
- Use of common infrastructure (global workflow) for experiments allows for cleaner experiments to be run in different institutions.
- Sharing of experimental data in the cloud will allow for broader community feedback in the development process.
- Early tests show the UFS is competitive with NMME models



Courtesy: Jonathan Beverley

Weakly Coupled DA and Initialization Strategy for Seasonal Forecast System (SFSv1)

Clara Draper[1], Sergey Frolov[1], Daryl Kleist[2]

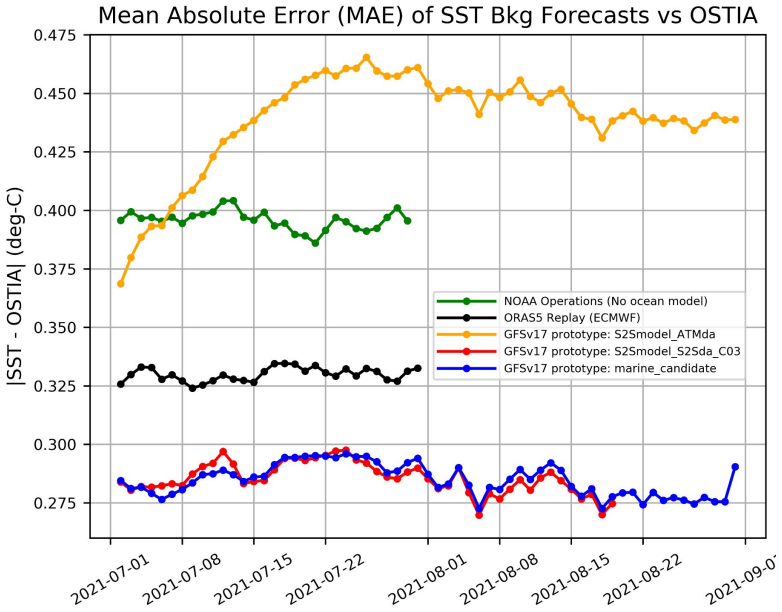
[1]NOAA/OAR/Physical Science Laboratory
[2]NOAA/NWS/NCEP Environmental Modeling Center

Initialization and Data Assimilation of the SFS Forecasts and Hindcasts

Real time SFS forecasts will be initialized from the operational weather model (GFSv17) DA cycle

For GFSv17, the DA will be:

- **Atmosphere: Hybrid 4DEnVar**
  - **Includes strongly coupled updates to the soil states**
  - **Weakly coupled 2DVar snow DA in JEDI**
- **Ocean/Sea ice: Weakly coupled Hybrid 3DEnVar in JEDI**
  - **Assimilating sea ice concentration, SST, SSH, and in situ T and S**
- **Aerosols: Weakly coupled 3DVar DA in JEDI**
  - **Assimilating VIIRS AOD**



Above: Weakly coupled ocean/atmos DA (red, blue) significantly improves SST.

Initialization of SFS Hindcasts

Very important to initialize hindcasts with states that are consistent with the states used to initialize the real time system (GFSv17)

- NOAA does not have a recent reanalysis for generating hindcast initial conditions
  - Long term plan is to generate a reanalysis, but this is a major (scientific and computing) effort, will not be ready for SFSv1

- Instead for SFSv1, use UFS-Replay (nudged to ERA-5 and ORAS5) and adjust for systematic differences with GFSv17 DA
  - Corrections will be calculated using an interim short reanalysis with the GFS model (1-6 years, depending on computational resources)
  - Adjustment methodology currently being developed
- Atmosphere:
  - UFS Replay (replay of GFS model to ERA-5/ORAS5, from 1979 onwards)
- Land:
  - Land-only spin-up forced by ERA-5 atmosphere, adjusted to GFSv17 climatology
- Ocean:
  - UFS Replay, with a climatological adjustment to GFSv17

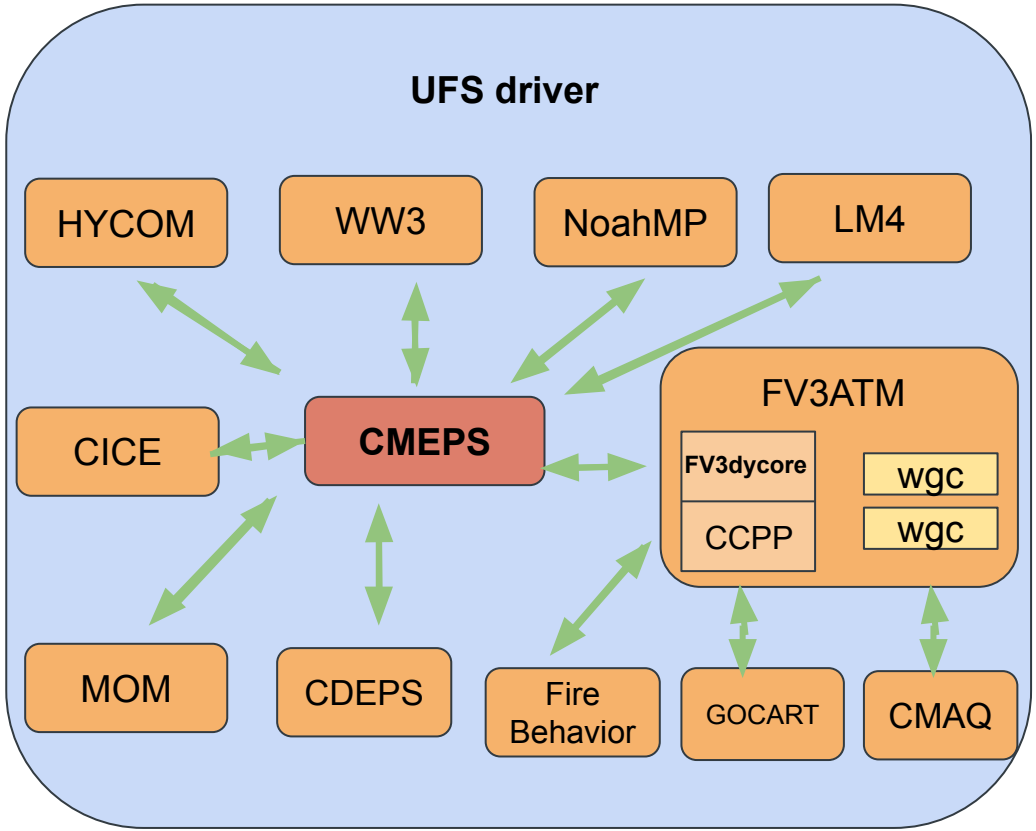
UFS Infrastructure and Global Workflow

Jun Wang, Rahul Mahajan, Jacob Carley

NOAA/NWS/NCEP Environmental Modeling Center

Fully Coupled UFS Weather Model Overview

- The UFS weather model is **open source** software supporting both **research and operational** developments. It contains:
  - **19 authoritative** repositories
  - **11 major flagship** model components
  - **Community mediator** and 11 **sharable** NUOPC caps
- **Model infrastructure** has been developed as the foundation to build the unified system:
  - Coupling is built upon **ESMF/NUOPC/FMS**
  - Coupling through direct exchange field **redistrition with interpolation** or **through mediator** where coupling fields are collected, accumulated and redistributed
  - Supports **GFSv17**, **GEFSv13**, **SFSv1**, **RRFSv1**, **AQMv7-8**, **HAFSv1-2**



UFS Weather Model Infrastructure

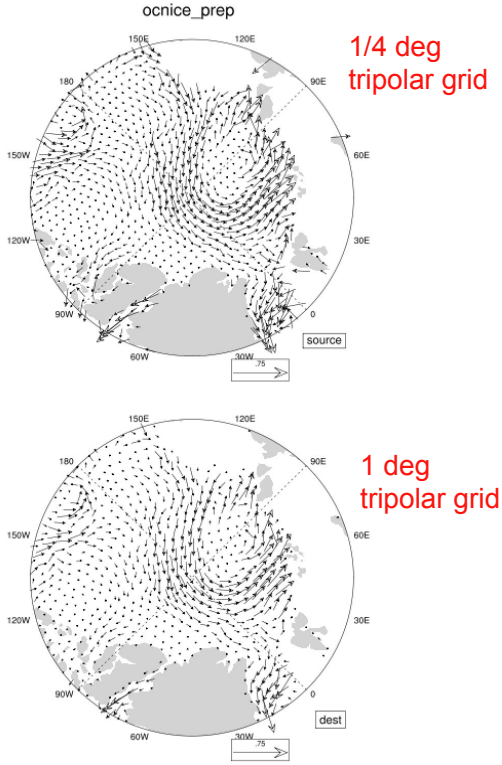
Goal:

To enhance earth components coupling capability, improve computational performance, build consistent testing framework and diagnostic tools

Achievements and on-going work:

- Improve model IO, load balance, scalability
- Develop testing framework that supports all the UFS supported applications
  - Develop testing capability for atmosphere only experiments in coupled mode with data ocean and data ice components
- Develop utilities to generate different resolution ocean and ice ICs
- Extend the mediator diagnostic capabilities to analyze air sea interactions and global conservations in the Earth modeling system
- Implement exchange grid with mediator computed fluxes for atmosphere and ocean interaction.

UFS utility to create ocean/ice ICs



UFS Global Workflow

Goal:

Develop global workflow to support Global Applications spanning the development and deployment of GFS, GEFS, and SFS

Milestones:

- Develop an initial prototype configuration management system to enable and explore model, data assimilation developments within the scope of global applications
- Deploy initial configurations of the Global Workflow on the Cloud.
  - Global Workflow on the Cloud (AWS, Google, Azure) in forecast-only mode
  - Migration from CentOS to Rocky8 images and containers in progress
  - Adding and expanding CI testing as resources allow
  - Documentation on Global Workflow Readthedocs is available here (In progress)

Documentation on Global Workflow

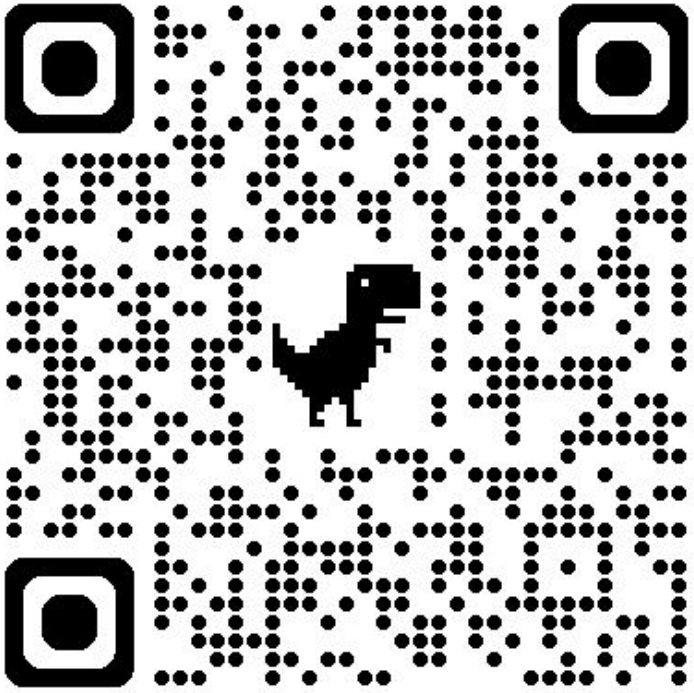
Q & A

- Do you have any questions and recommendations on the science and technology incorporated and to be incorporated in GFS, GEFS and SFS?
- Do you see any urgent needs and gaps in research & development?
- Have the achievements and challenges been communicated to the community clearly?
- How do we enhance collaboration and contribution from the community for advancements of those modeling systems?

AGU Talks/Posters

(relevant to GFS, GEFS, SFS)

Town Hall Web Site



We welcome feedback and seek collaboration!

nws_modeling_pmo@noaa.gov

Extra slides

SFS Application Team (Co-Leads: Phil Pegion, Neil Barton, Kate Zhou)

1) SFS Design, Testing and Analysis (Leads: Neil Barton, Phil Pegion)
2) Physics and Dynamics Improvements (Leads: Fanglin Yang, Lisa Bengtsson, Ligia Bernardet)
3) Land Model Improvement (Leads: Helin Wei, Clara Draper)
4) Ocean, Waves and Sea-Ice Model Improvements (Leads: Shan Sun, Neil Barton)
5) Aerosol and Atmospheric Composition Improvements (Lead: Fanglin Yang)
6) Coupled Ensemble Strategies, Design and Development (Leads: Philip Pegion, Neil Barton)
7) Coupled Data Assimilation Developments and Observation (Leads: Daryl Kleist, Sergey Frolov)
8) SFS Reanalysis & Reforecast (Leads: Sergey Frolov, Daryl Kleist, Phil Pegion)
9) SFS Infrastructure (Leads: Jacob Carley, Rahul Mahajan, Jun Wang)
10) Product Developments & Verification (Leads: Wanqiu Wang, Jason Levit, Michelle Harrold)

Investing in the UFS

NOAA Programs that Support UFS

- **NWS/OSTI Modeling Programs:** NGGPS, Weeks 3&4, HFIP
- **OAR/WPO Programs:** EPIC, JTTI, S2S, Atmospheric Composition
- **Disaster Supplementals FY18, FY19, FY22 and Bipartisan Infrastructure Legislation FY22**

UFS Research-to-Operations (UFS R2O) Project

- **UFS R2O Phase I (FY21-23) with 5 year vision**
- **UFS R2O Phase II (FY24-26) including Transition to Operation**
- Developing the next-generation global and regional forecast systems and transition to NOAA operations in **FY23 and beyond**
- Jointly supported by **NOAA NWS and OAR**
- Community team (NOAA, NCAR, JCSDA, Academia)
- Website: https://vlab.noaa.gov/web/ufs-r2o