AGU Town Hall: Dec 15, 2023

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

## Agenda:

**Program Office:**

**William Komaromi**, IMSG: Introduction to the town hall
**Yan Xue**, NWS/OSTI: Overview of UFS MRW and S2S Applications
**Jessie Carman**, OAR/WPO: NOAA Grants for UFS S2S Applications

**Panelists:**

**Fanglin Yang**, NWS/NCEP/EMC: Global Forecast System (GFS)
**Avichal Mehra**, NWS/NCEP/EMC: Global Ensemble Forecast System (GEFS)
**Neil Barton**, NWS/NCEP/EMC: Seasonal Forecast System (SFS)
**Cristiana Stan**, George Mason University: Diagnostics and Analysis
**Wanqiu Wang**, NWS/NCEP/CPC: S2S metrics and forecast products

**Q & A**

**Town Hall Slide Deck & 3-Pager Flyer**

# Overview of UFS MRW and S2S Applications

**Dr. Yan Xue**

**Program Manager for Weeks 3-4 Program and SFS Project**

**NOAA/NWS/OSTI Modeling Program Division**

# 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.

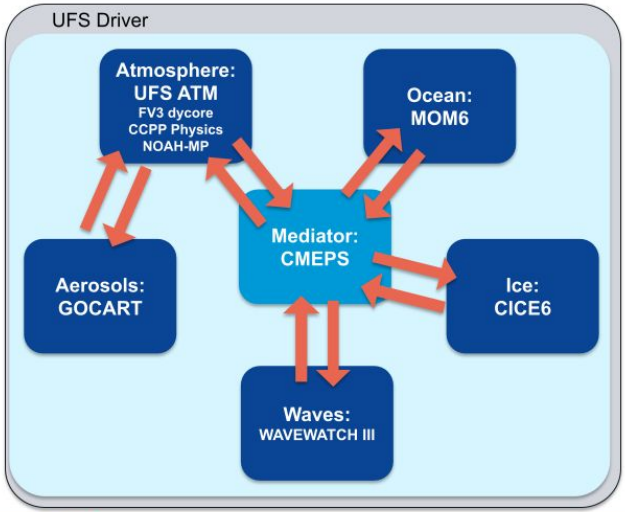
- Community components in UFS
  - Model infrastructure: ESMF, NUOPC, CMEPS
  - Atmosphere model: FV3 dycore, CCPP Physics
  - Ocean model: MOM6
  - Ice model: CICE6
  - Wave model: WW3
  - Aerosol model: GOCART
  - Land model: Noah-MP (currently)
  - Data assimilation: Joint Effort for Data assimilation 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



# Global Forecast System v17 Upgrade

## (Deterministic Forecast up to 16 days)

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

# Global Ensemble Forecast System v13 Upgrade

## (Ensemble Forecast up to 48 days)

| | GEFSv12: Implementation Sep 2020 | GEFSv13: Target Implementation Mar 2026 |
|---|---|---|
| **Model** | FV3/Noah<br>WW3/GOCART (one-way coupling) | FV3/Noah_MP<br>MOM6/CICE6/WW3/GOCART (two-way coupling) |
| **Resolution** | C384L64 (~25km, 55km top) | C384L127 (~25km, 80km top) |
| **Physics** | GFDL MP, Stochastic physics (SPPT, SKEB) | GFSv17 physics + Stochastic physics (SPPT, SKEB, ocean) |
| **Realtime** (31 members) | GSI, GLDAS<br>16 days (06Z, 12Z and 18Z), 31 members<br>35 days (00Z), 31 members | Weakly Coupled DA (GSI, JEDI Ocean/Sea Ice, JEDI Snow)<br>16 days (06Z, 12Z and 18Z), 31 members<br>48 days (00Z), 31 members |
| **31-years Reforecast** (6/11 members) | GEFSv12 reanalysis (CFSR) in 2000-2019 (1989-1999)<br>16 days, every day, 5 members<br>35 days, every Wednesday, 11 members | Replay to ERA5 Atmos, ORAS5 Ocean/Sea Ice, Noah_MP spin up, snow DA in 1994-2024<br>16 days, every day, 6 members<br>48 days, every Monday, Thursday, 11 members |

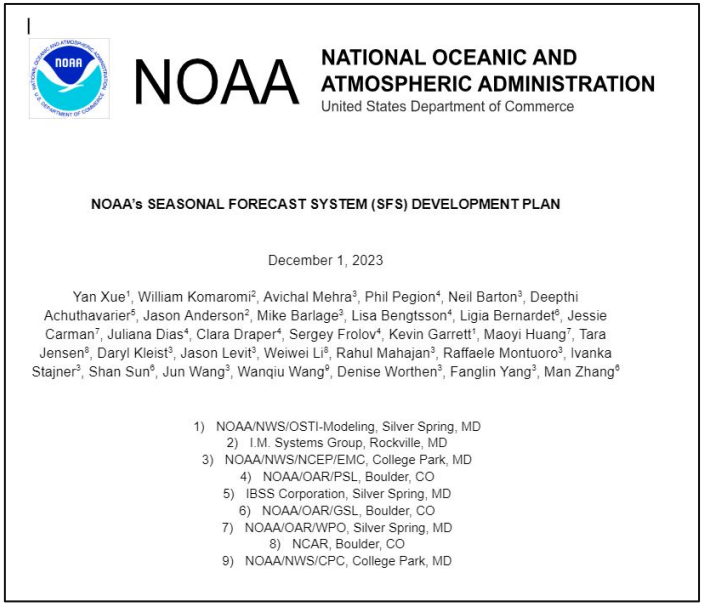
# NOAA's Seasonal Forecast System Development Plan

**GOALS:**

- Develop SFSv1 as a replacement of Climate Forecast System version 2 (CFSv2), a more-than decade-old system
- Address common errors in CFSv2 and North American Multi-Model Ensemble (NMME)
- Release reanalysis & reforecast data sets to the community

**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 Xue[1], William Komaromi[2], Avichal Mehra[3], Phil Pegion[4], Neil Barton[3], Deepthi Achuthavarier[5], Jason Anderson[2], Mike Barlage[3], Lisa Bengtsson[4], Ligia Bernardet[6], Jessie Carman[7], Juliana Dias[4], Clara Draper[4], Sergey Frolov[4], Kevin Garrett[1], Maoyi Huang[7], Tara Jensen[8], Daryl Kleist[3], Jason Levit[3], Weiwei Li[8], Rahul Mahajan[3], Raffaele Montuoro[3], Ivanka Stajner[3], Shan Sun[8], Jun Wang[3], Wanqiu Wang[4], Denise Worthen[3], Fanglin Yang[3], Man Zhang[8]

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

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

**SFS Development Plan in revision**

# NOAA Grants in Support of UFS S2S (etc.) Applications

**Dr. Jessie Carman**

**Chief, Earth System Research and Modeling Division**

**NOAA/OAR/Weather Program Office**

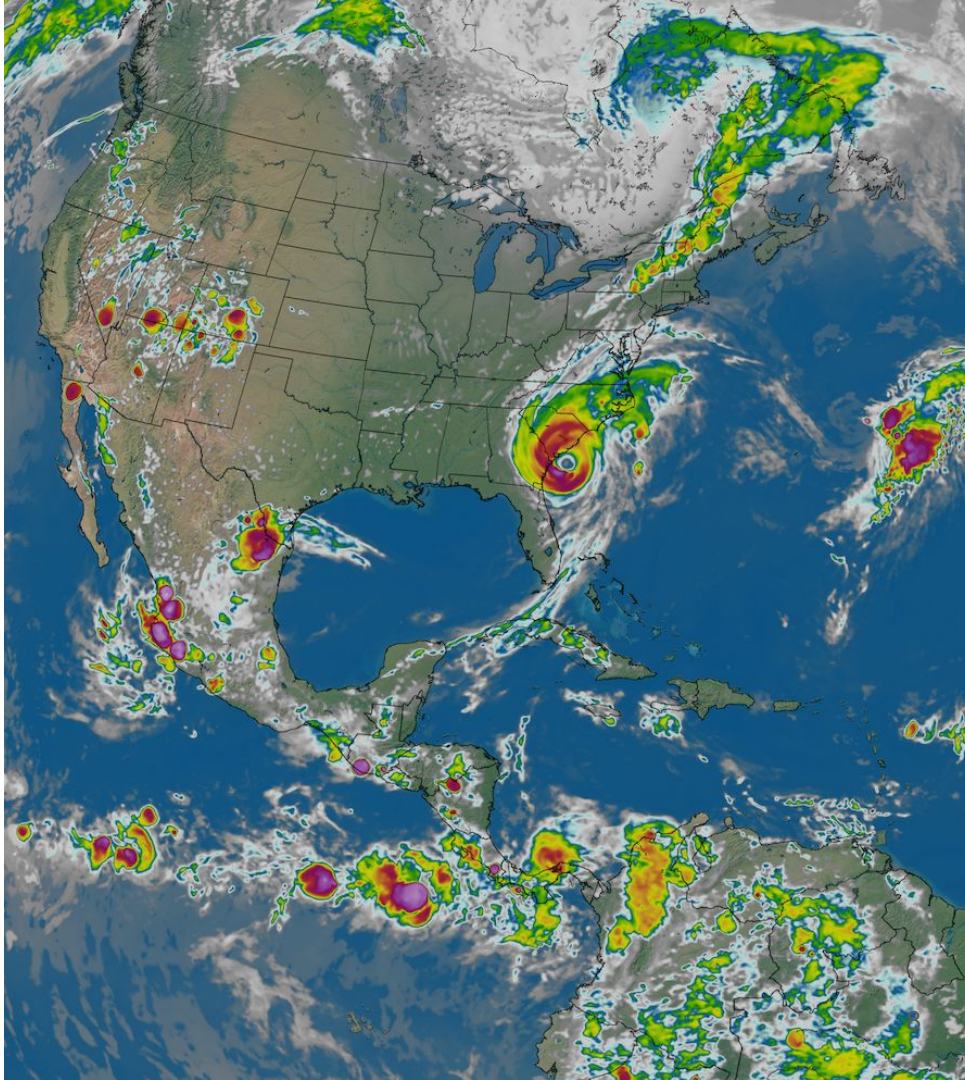
# FY24 NOFOs:

**Research NOFO: Full proposals for the FY24 competition were due November 16, 2023.**

- Climate Test Bed
- Fire Weather

**EPIC NOFO: Full proposals were due October 13, 2023 (IRA funding)**

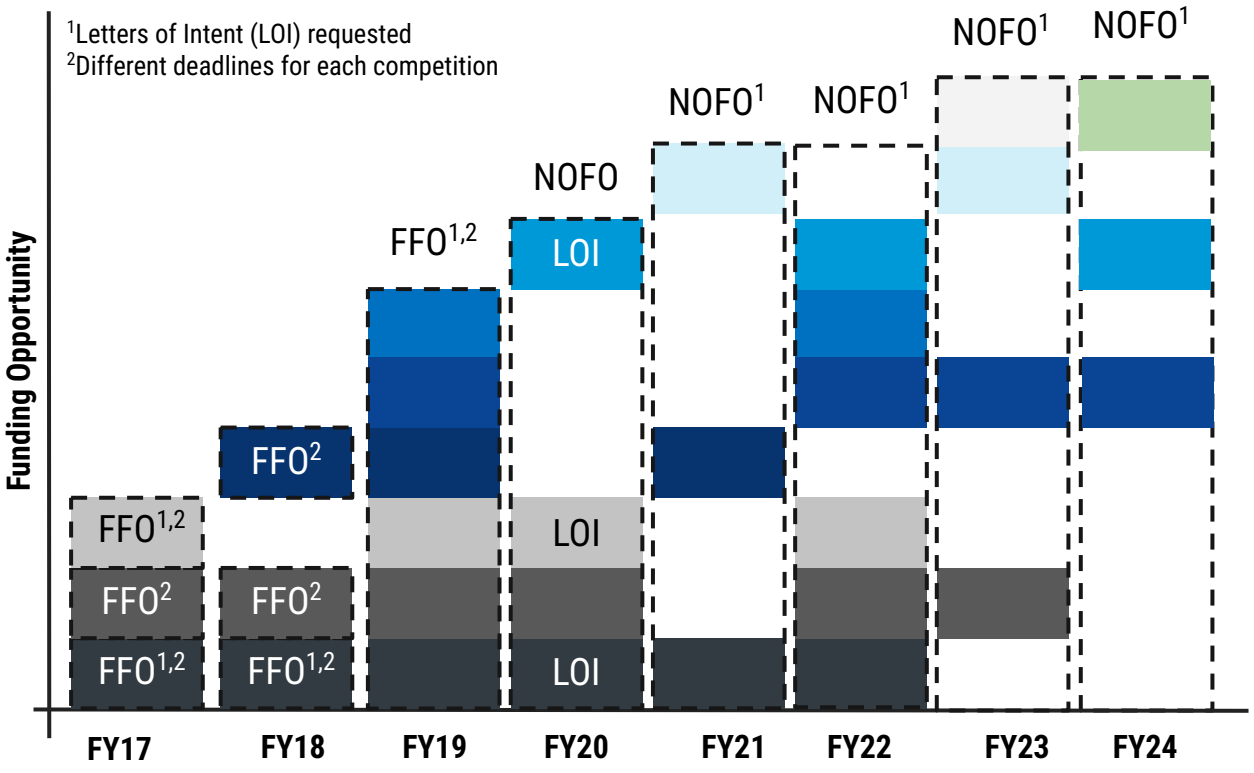
- Data Assimilation Consortium



# WPO NOFOs 2017–2024

Note: Size of boxes do not correspond to number of funded projects.

*VORTEX-USA is a National Severe Storm Laboratory funded competition coordinated by WPO.




- Innovations (FWAC + EPIC + JTTI + S2S)
- Social, Behavioral, and Economic Science (SBES)
- Climate Test Bed (CTB)
- Subseasonal to Seasonal (S2S)
- Fire Wx and Atmos. Composition (FWAC)
- Observations
- DA Consortium
- Testbeds
- VORTEX-USA*
- Joint Technology Transfer Initiative (JTTI)

# Advances and Challenges in Developing Global Forecast System

**Dr. Fanglin Yang**

**Chief, Physics and Dynamics Division**

**NOAA/NWS/NCEP Environmental Modeling Center**

# Physics/Land Advancements: GFSv16/GEFSv12 --> GFSv17/GEFSv13/SFSv1

**Items highlighted in blue color had also been included in HAFS.v1**

## Introduced

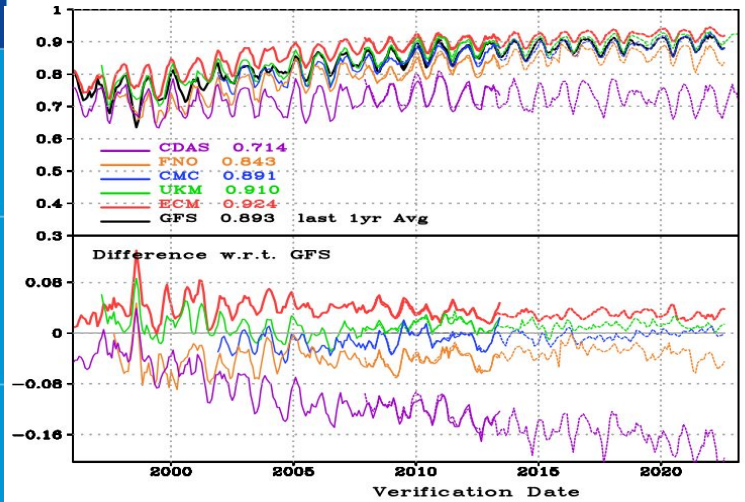
- a **two-moment cloud microphysics** scheme (GFDL MP --> **Thompson MP**)
  - Improved the cloud radiation interaction capabilities
  - Introduce Semi-Lagrangian Sedimentation for improved stability and cost
- a **new land model** (NOAH LSM --> NOAH-MP LSM )
- **new small-scale gravity wave** and **turbulent orographic form drag** parameterizations
- a **new** parameterization for **convective organization**, and a new **Prognostic**-Stochastic and Scale-Adaptive **Cumulus Convection Closure**
- **new stochastic physics** in the ocean, land-surface and the atmosphere
- a **new positive definite tracer advection (TVD)** scheme in convection and PBL
- new capability for **coupling between aerosols and physics**
- **new land/ocean/lake masks, new ice climatology, and surface composites over fractional grid**

## Improved

- **cumulus convection** schemes and **boundary layer** schemes to address model systematic biases
- **gravity wave drags and mountain blocking**
- **coupling of the land model and surface layer** schemes.

## A Historical Review of NWP Model Performances

### NH 500-hPa HGT ACC



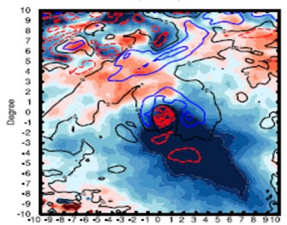

- Improvement of forecast skills for all NWP models have slowed down in the past ten years
- IFS performance is always superior to other models. GFS's rank has not changed in the past 20 years.

## Challenges

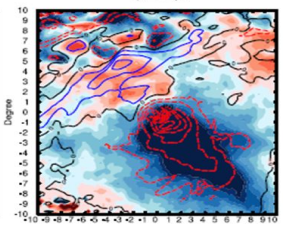
- Scale-aware physics parameterizations for UFS applications across different temporal and spatial scales.
- Different systematic biases in coupled and uncoupled models
- Should we keep increasing GFS resolution to convection permitting scale (~3km) or meger it to GEFS (~10 km) ?

**Hurricane Teddy, IC 20200913, UFS C768 132h Fcst**

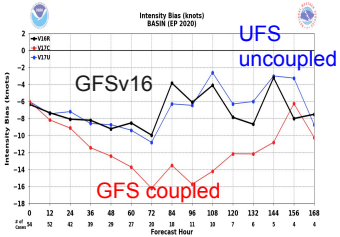
SST and SH




SST and LH




Hurricane Intensity



# Advances and Challenges in Developing Global Ensemble Forecast System

**Dr. Avichal Mehra**

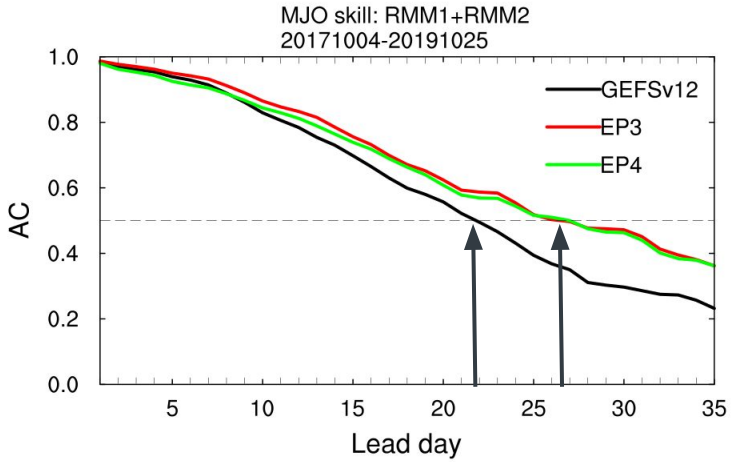
**Chief, Coupled Modeling Division**

**NOAA/NWS/NCEP Environmental Modeling Center**

# Advancements from GEFSv12 to GEFSv13

- **1st fully-coupled global ensemble forecast system including coupling between atmos-land-ocean-sea ice-aerosol-waves**
- **Model vertical resolution increase from 64 to 127 layers with a model top of 80km.**
- **Thompson microphysics scheme replacing GFDL microphysics scheme, NOAH-MP replacing NOAH LSM and other ATM physics updates**
- **Adding ocean stochastic physics to represent uncertainties from ocean prediction**
- **Forecast length increases from 35 days to 48 days**

Four Ensemble Prototypes (EP1 - EP4) completed, preliminary results are encouraging.




EP3 and EP4 both have higher MJO skill (RMM1+RMM2) than GEFSv12 for longer lead times (extend skill for 4-5 days).

# Challenges during GEFS v13 Development

- **Ensemble workflow development is lagging behind the progress of model development**
- **Limited computational resources only allow smaller ensemble size (11) to be used in our experiments which is not consistent with the ensemble size (31) of the current operational GEFSv12, and it is not affordable to run longer period experiments.**
- **As coupled data assimilation system is also under development, there are no initial conditions from coupled DA available to be used for ensemble experiments.**

- Amplitude of model perturbations can be changed significantly due to updates of model physics (via SPPT), which requires adjustments of the stochastic physics scheme to prevent model crashes.

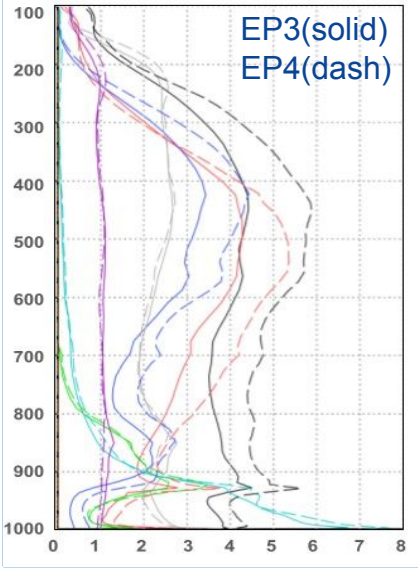



Fig. 1 Vertical profile of averaged absolute DT/Dt (1e-5) over (40E-150W,20S-20N)

Large differences in total physical tendency (black) due to updates in microphysics (red) and deep convection (blue)

# Advances and Challenges in Developing Seasonal Forecast System

**Dr. Neil Barton**

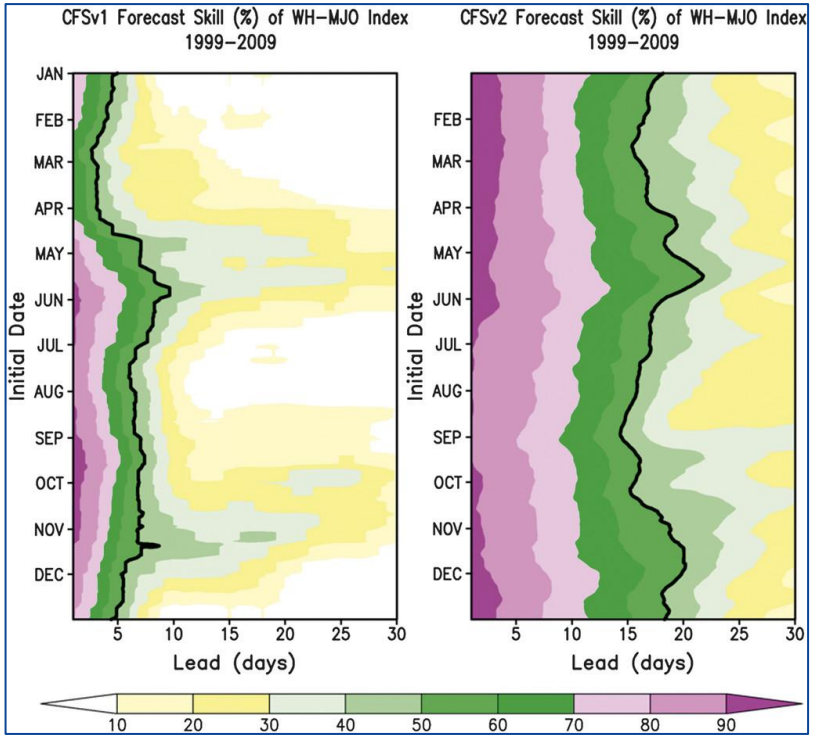
**NOAA/NWS/NCEP Environmental Modeling Center**

**Phil Pegion**

**NOAA/OAR/Physical Science Laboratory**

# SFSv1 to replace CFSv2

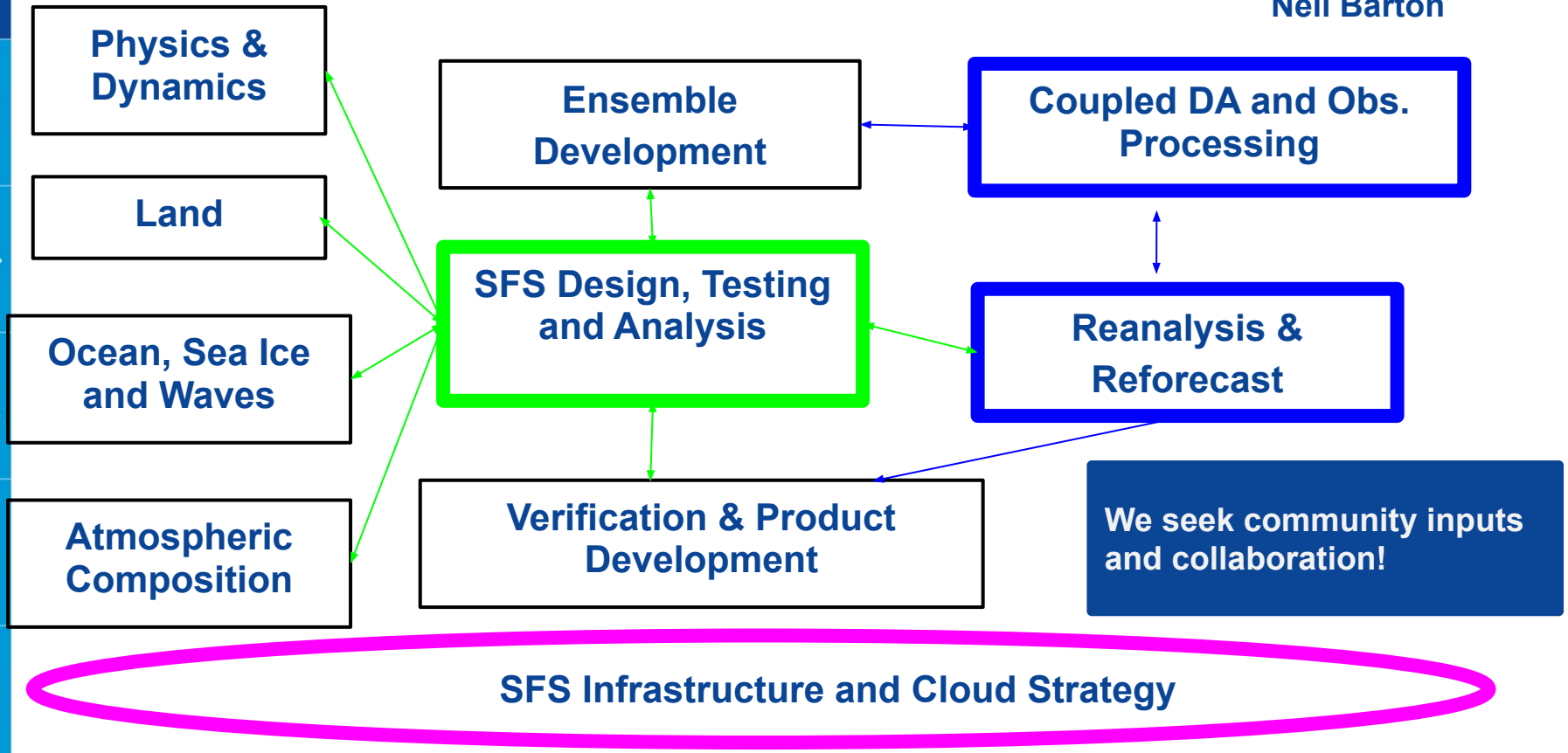
- Develop SFSv1 as a **replacement** of Climate Forecast System version 2 **(CFSv2)**, a decade-old system
- **Address common errors** in CFSv2 and NMME
  - MJO propagation across Maritime Continent
  - False ENSO alarms
  - Positive SST trend errors in tropical Pacific
  - Too frequent above-normal temperature forecast
  - Too infrequent below-normal temperature forecast
- **Community Model**
  - Code to be on github through UFS system
  - Release reanalysis-reforecast data sets to the community




Saha *et al.* 2014 (*J. Climate*)
Comparing CFSv1 to CFSv2

# Seasonal Forecast System Application Team

Co-Leads: Avichal Mehra, Phil Pegion, Neil Barton



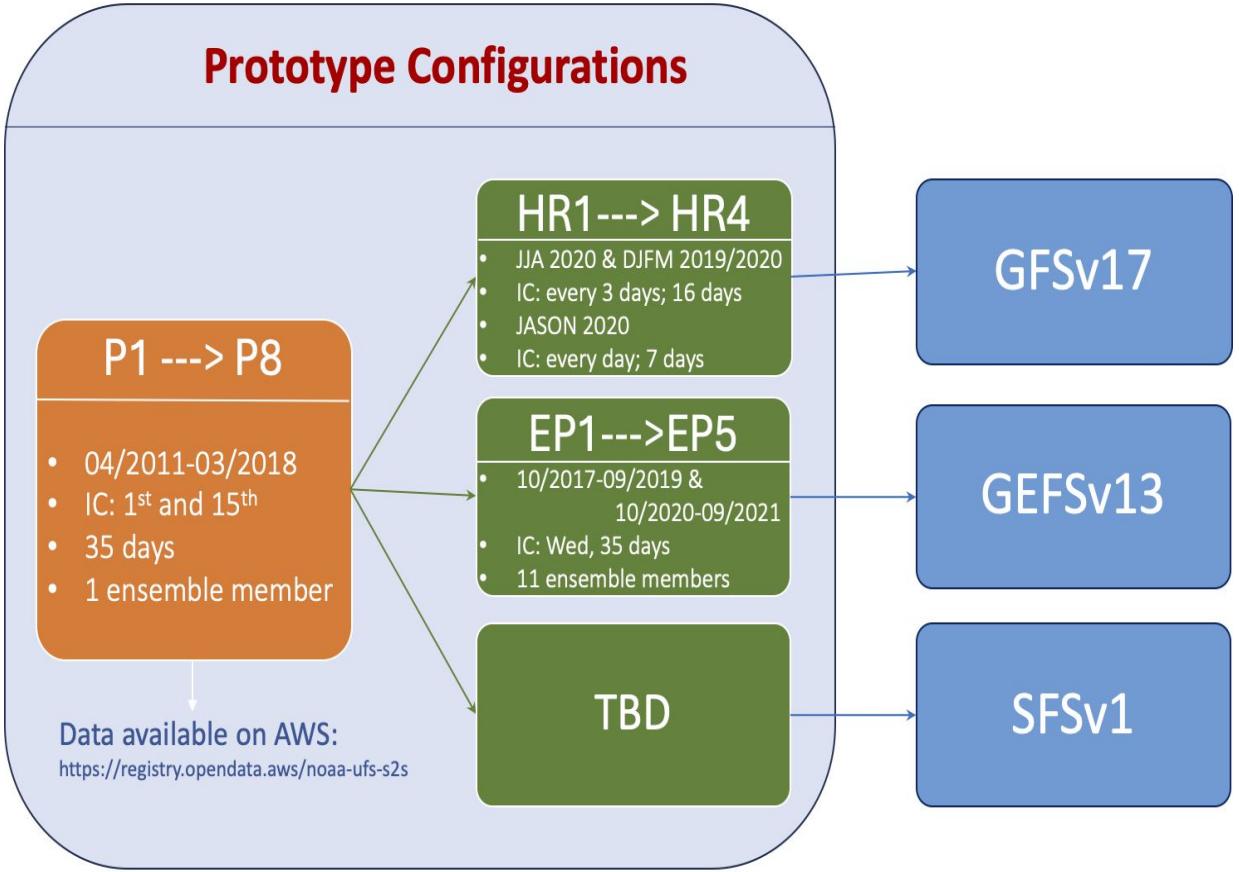
# Advances and Challenges in Diagnostics and Analysis

**Dr. Cristiana Stan**

**Department of Atmospheric, Oceanic and Earth Sciences**

**George Mason University**

# MRW/S2S Applications Evaluation during the Development



# MRW/S2S Applications Evaluation and Remaining Challenges

## Accomplishments

- P1-P8 evaluated with respect to: *mean biases and anomaly correlation* (for each model component); *tropical variability* (MJO, Indian monsoon); *troposphere-stratosphere coupling*, *impact of tropical SST biases on ENSO*, *land-atmosphere interactions.* **P1-P7 results published in a NOAA Technical Report.**
- P5: extremes in *precipitation* & *temperature* (T2m, T2m min & T2m max)
- P5 & P6: *MJO-teleconnections* (impact of number of vertical layers)
- P6 and P8: impact of *tropical SST biases* on forecast skill of *surface weather* over CONUS

## Challenges

- Ocean, sea-ice and aerosol variability underexplored
- Impacts of aerosol on the S2S forecast skill
- Impact of initial conditions (various datasets) on the error growth
- **Diagnosing and understanding sources of model errors with *sensitivity experiments***
- **Limited statistical significance of results: need of longer experiments and larger ensemble size**

# S2S Metrics, Forecast Products and How Forecasters Contribute to Development of UFS S2S Applications

**Dr. Wanqiu Wang**

**Chief, Operational Monitoring Branch**

**NOAA/NWS/NCEP Climate Prediction Center**

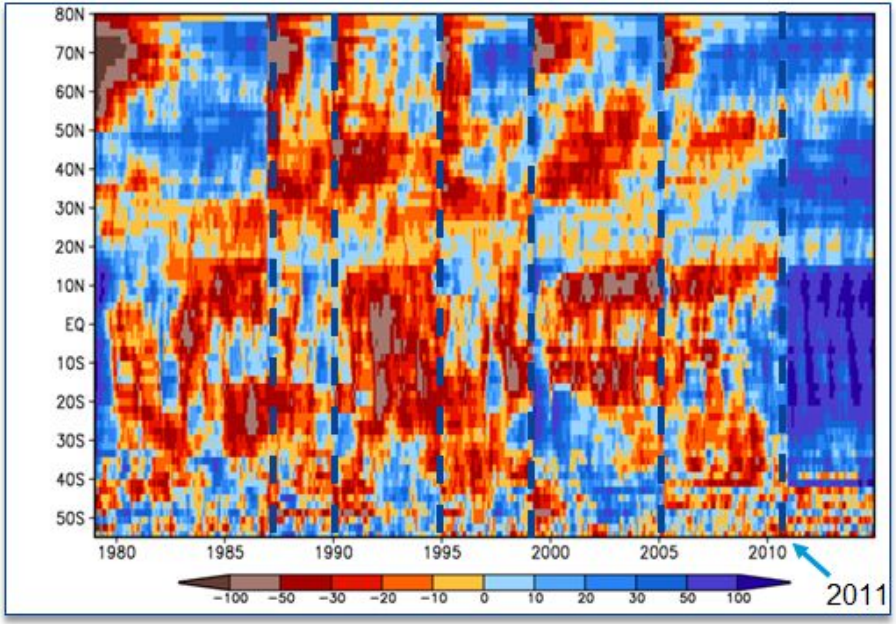
# Forecast Products, Dynamical Models and S2S Metrics at NWS

| Forecast Products | Dynamical Models | Major S2S Metrics |
|---|---|---|
| **Temperature, Precipitation Outlooks** | GEFSv12, CFSv2, NMME | HSS, RPSS |
| **Drought Outlooks** | GEFSv12, CFSv2, NMME | Hit Rate (Raw score minus persistence score) |
| **MJO Outlooks** | GEFSv12, CFSv2 | ACC, phase error |
| **ENSO Outlooks** | CFSv2, NMME | ACC, RPSS |
| **Tropical Hazards Outlooks** | GEFSv12, CFSv2 | HSS, CSI (Critical Success Index) |
| **Hurricane Outlooks** | CFSv2, NMME | Hit Rate, ACC |
| **Sea Ice Outlooks** | UFS-P5 | HSS |

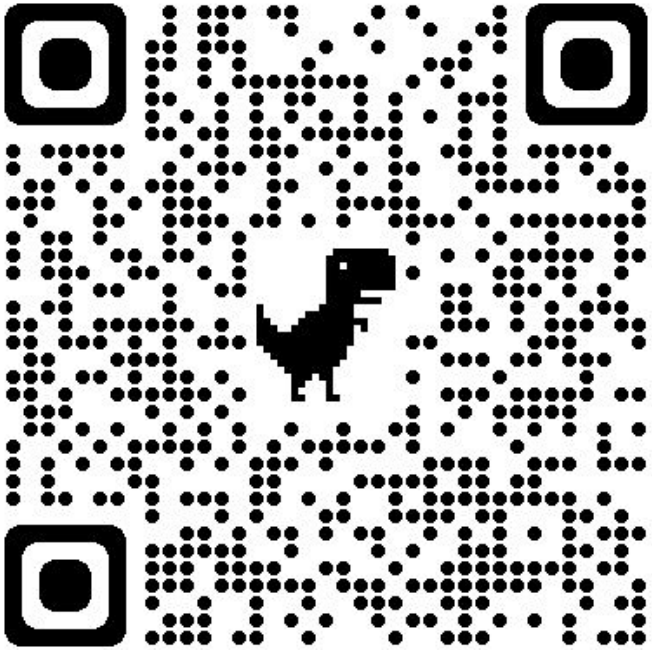
# Forecaster's Needs

- METplus-based verification and diagnostics package for UFS S2S Applications
- Artificial intelligence and machine learning algorithms for post-processed products
- Minimizing temporal discontinuities in initial conditions (soil moisture, ocean, sea ice)
- Reducing SST trend errors in the Tropics
- Reducing biases in surface temperature forecast (too frequent above-normal)
- Reducing occurrence of ENSO false alarms
- Reducing tropical cyclone false alarms
- Improving predictions of MJO propagation across Maritime Continent

CFSR Soil Moisture Anomaly Zonal Mean



**Town Hall Slide Deck & 3-Pager Flyer**



***We welcome feedback and seek collaboration!***

nws_modeling_pmo@noaa.gov

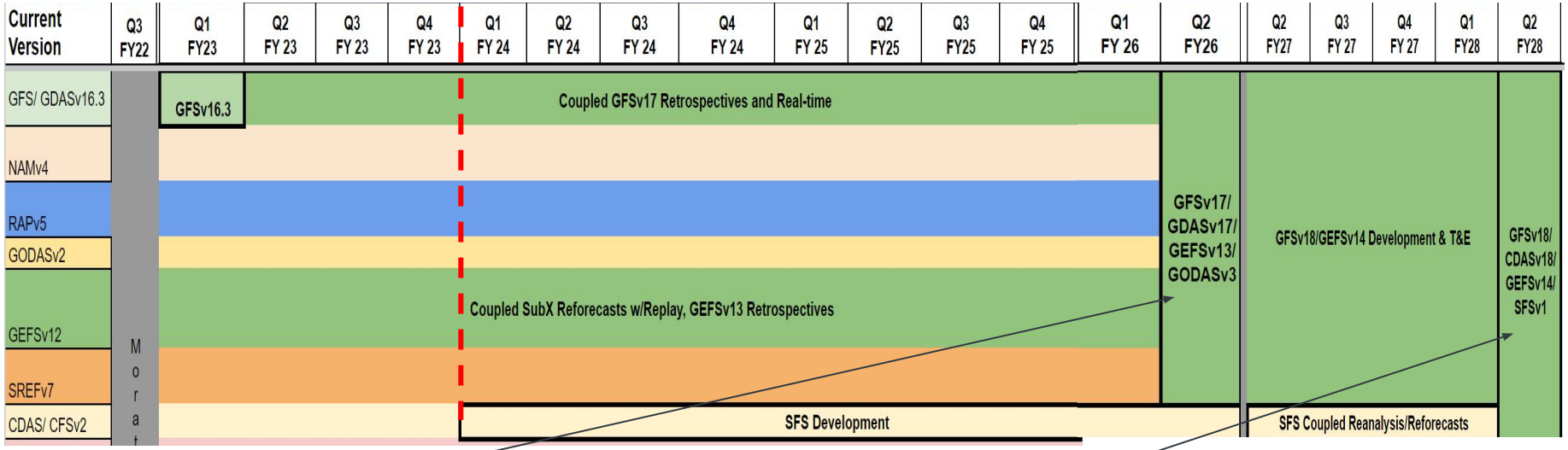
# Extra slides

# SFS Application Team (Co-Leads: Avichal Mehra, Phil Pegion, Neil Barton)

1) SFS Design, Testing and Analysis (Leads: Neil Barton, Avichal Mehra, Phil Pegion)
2) Physics and Dynamics Improvements (Leads: Fanglin Yang, Ligia Bernardet, Lisa Bengtsson)
3) Land Model Improvement (Leads: Mike Barlage, Clara Draper)
4) Ocean, Waves and Sea-Ice Model Improvements (Leads: Shan Sun, Neil Barton)
5) Aerosol and Atmospheric Composition Improvements (Lead: Ivanka Stajner)
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 and Cloud Strategy (Leads: Rahul Mahajan, Jun Wang)
10) Product Developments & Verification (Leads: Wanqiu Wang, Jason Levit, Tara Jensen)

# Transitioning to UFS-based Applications

## EMC Implementation Plan FY23-27




**Q2FY26:**

**GFSv17: Deterministic forecast (0-16 days)**

**GEFSv13: Ensemble forecast (0-48 days)**

**Q2FY28:**

**GFSv18: Deterministic forecast (0-16 days)**

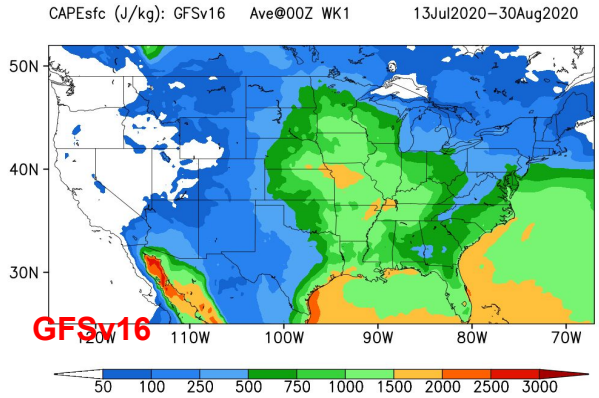
**GEFSv14: Ensemble forecast (0-48 days)**

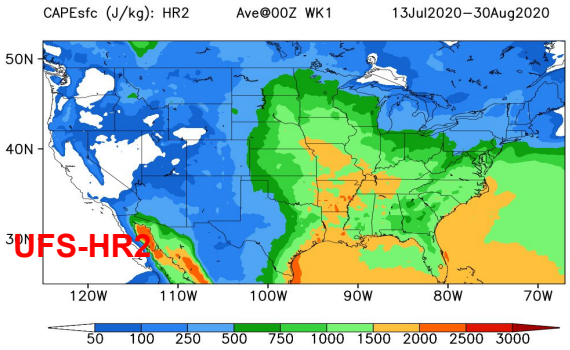
**SFSv1: Seasonal Forecast System (0-12 months)**

# Major Goals for GFSv17 Update

- Enhance predictability through improved atmospheric physics, improved land model, and improved representation of interactions across model components
- Enhance predictability through improved initialization with a weakly coupled data assimilation
- Desired improvements compared to GFSv16:
  - MJO propagation and intensity
  - **Low bias in CAPE,** low-level inversions,10m wind speed bias
  - Mixed-phase clouds and supercooled liquid clouds
  - Hurricane track errors and false alarm rate

**CAPE**

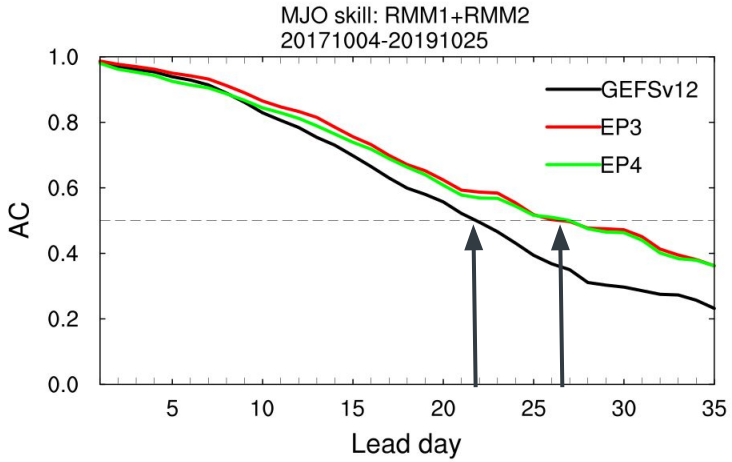


# Major Goals for GEFSv13 Update

- Desired improvements compared to GEFSv12:
  - **MJO** propagation and intensity, extend useful skill by 5-10 days
  - CRPS skill extended; brier skill scores of CONUS PQRF extended
  - West coast and Arctic air mass forecast improved
  - Hurricane track and intensity forecast improved
  - Forecast of Z500, T2m, Prec, tropical cyclone improved
  - Forecast of Sudden Stratospheric Warming improved

**Four Ensemble Prototypes (EP1 - EP4) completed, preliminary results are encouraging.**




EP3 and EP4 both have higher MJO skill (RMM1+RMM2) than GEFSv12 for longer lead times (extend skill for 4-5 days).

# 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 (FY20-23) 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**