

NOAA

March 27, 2024

Status and Plan in Developing and Implementing Subseasonal and Seasonal (S2S) Forecast Systems Based on the Unified Forecast System at NOAA:

Towards Meeting Stakeholders Needs and Requirements

Presenter: Jason R. Anderson¹

Yan Xue¹, Deepthi Achuthavarier¹, William Komaromi¹, Kevin Garrett¹

¹ NOAA NWS Office of Science and Technology Integration





Weeks 3-4 Program at NWS

- One of four programs within Office of Science and Technology Integration (OSTI) Modeling Program Division
- Established in 2016 as part of NOAA's initiative to improve extended-range weather outlooks
- Support the development and improvement of Weeks 3-4 forecast products at the Climate Prediction Center (CPC).
- Projects include:
 - Consolidation of Weeks 3-4 Temperature and Precipitation forecast tools
 - Drought monitoring and Forecasting
 - Global Tropical Hazard Forecast
 - Excessive Heat Outlooks
 - Arctic Sea Ice prediction
- Supported development and implementation of the sub-seasonal Global Ensemble Forecast System (GEFS) version 12 at the Environmental Modeling Center (EMC) in September 2020
- Currently supporting the development and implementation of **GEFS v13**, which is currently being developed through the **UFS-R20 Project** - <https://vlab.noaa.gov/web/ufs-r20>



*Yan Xue
Program Manager*

*Deepthi Achuthavarier
Deputy Program Manager*



*Jason Anderson
Deputy Program Manager*



SFS Development Project


FY23 Congressional Appropriations Direct NWS to Develop **Seasonal Forecast System (SFS)**; NOAA's SFS Development Plan has been drafted by a team of scientists. A **SFS Application Team (AT)** was established with participants from NWS, OAR, DTC, EPIC and academia in Oct 2023.

Goals of SFS AT:

- 1) Replace the current operational Climate Forecast System version 2 (CFSv2) with SFSv1
- 2) Address common errors in CFSv2 and NMME
- 3) Release reanalysis & reforecast data sets to the public


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 Barton³, Deepthi Achuthavari⁵, 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 Sun⁶, 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

Contact: Yan.Xue@noaa.gov





Objectives

- Provide an update on the status and expectations of the UFS S2S Applications (GEFS & SFS)
- Solicit inputs and collaboration of the research and forecast community to evaluate the UFS S2S Applications & Products
- Understand the requirements, needs, and stretch goals of stakeholders/users that will inform priorities for UFS improvement.

Global Ensemble Forecast System v13 Upgrade

(Ensemble Forecast up to 48 days)

	<u>GEFSv12</u> : Implementation Sep 2020	GEFSv13 : Target Implementation Mar 2026
Model	FV3/Noah WW3/GOCART (one-way coupling)	FV3/Noah_MP 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 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 48 days (00Z), 31 members
31-years Reforecast (6/11 members)	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, 6 members 48 days, every Monday, Thursday, 11 members

Dr. Bing Fu AMS 2024 Presentation 1B.5, Toward a Fully-Coupled Global Ensemble Forecast System (GEFSv13)



GEFSv13 Configuration (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	5-scale SPPT and SKEB	5-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		5-scale oSPPT and ePBL
Ice	Model		CICE6 (0.25°)
	Initial perturbation		SOCA-Ens
Wave	Model		WW3 (1-way) (0.5°)
Aerosol	Model	GOCART (1-way)	GOCART (2-way)

Dr. Bing Fu AMS 2024 Presentation 1B.5, Toward a Fully-Coupled Global Ensemble Forecast System (GEFSv13)



GEFSv13 Expected Improvements

- Benefits from coupled GEFS
 - Fully-Coupled configurations
 - ATM (C384L127) - OCN -ICE -WAV -CHM
- Further improvements of probabilistic forecast (PQPF, T2m, and TC)
- **New Products for Ocean & Sea Ice**
- Improvements of MJO predictions
- Improvements from two-way coupling
- 30 Years GEFSv13 reforecast for Model Calibration
- Increased forecast length to **48 days**

Dr. Bing Fu AMS 2024 Presentation 1B.5, Toward a Fully-Coupled Global Ensemble Forecast System (GEFSv13)



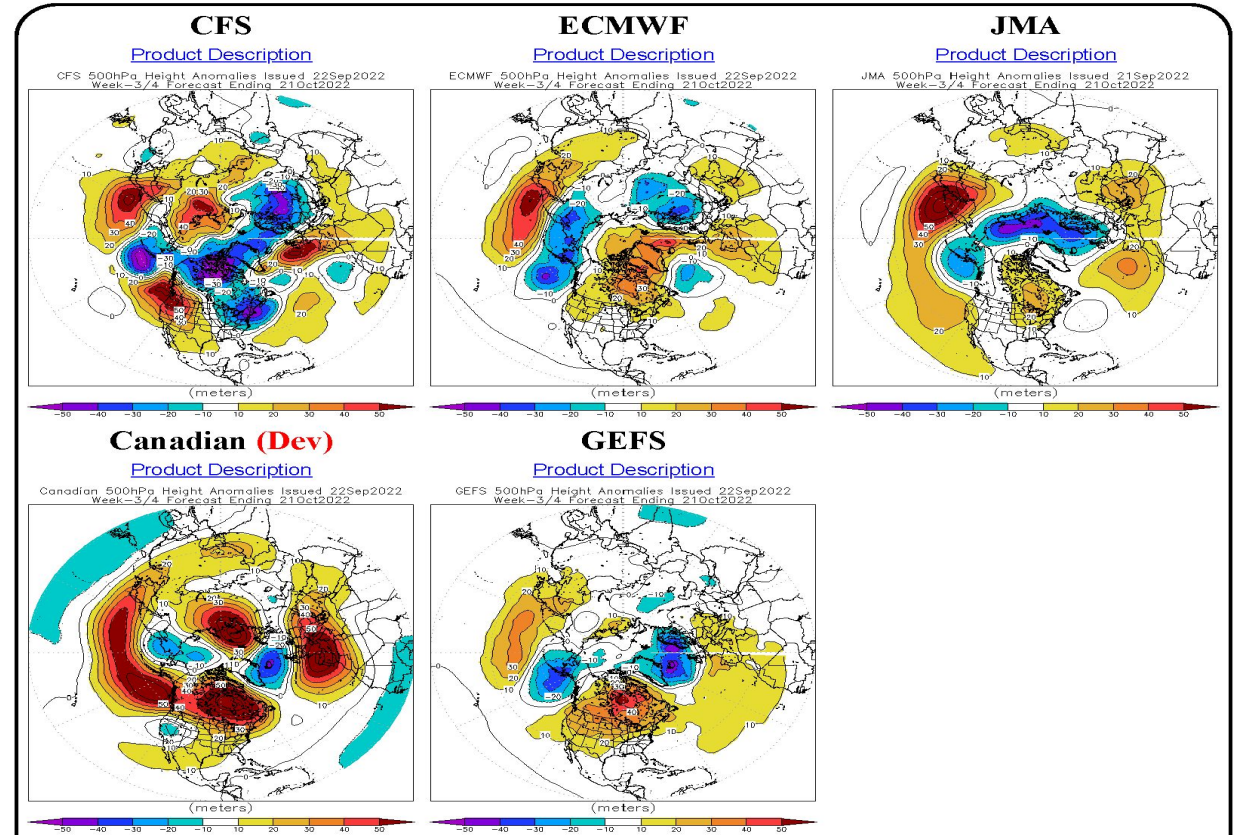
Stakeholders of GEFS

- OSTI is working to identify and reach out to multiple stakeholders/users of GEFS data
 - Focused on Real-Time and Reforecast products
 - What are the requirements from these users/products?
- Users we need to connect with
 - NHC
 - EMC
 - CPC
 - PSL
 - MDL
 - WPC
 - OPC
 - SPC
 - OCLO/FSTS
 - NWS Regional
 - Fisheries
 - Other Users

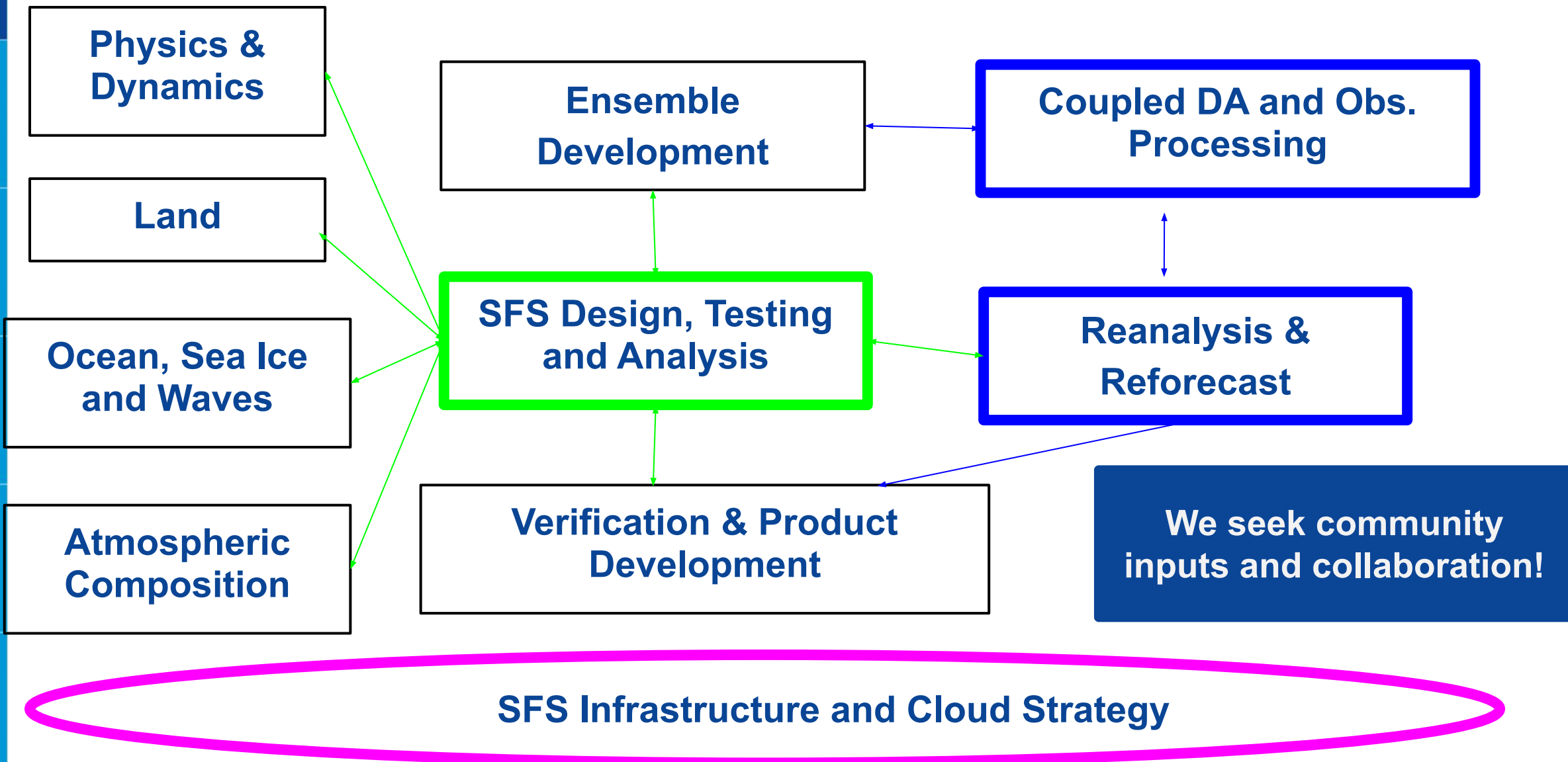


CPC's Requirements for GEFS and SFS

- Systematic errors or low skills in the forecasts from the current forecast systems (CFS and/or GEFS)
 - Soil moisture
 - Stratospheric sudden warmings
 - Tropical cyclone
 - MJO propagation
 - Tropical SST trend
 - ENSO false alarms
- Discontinuities in CFS Initialization
 - Soil moisture
 - Ocean
 - Sea ice



SFS Development Project: Ten Tasks



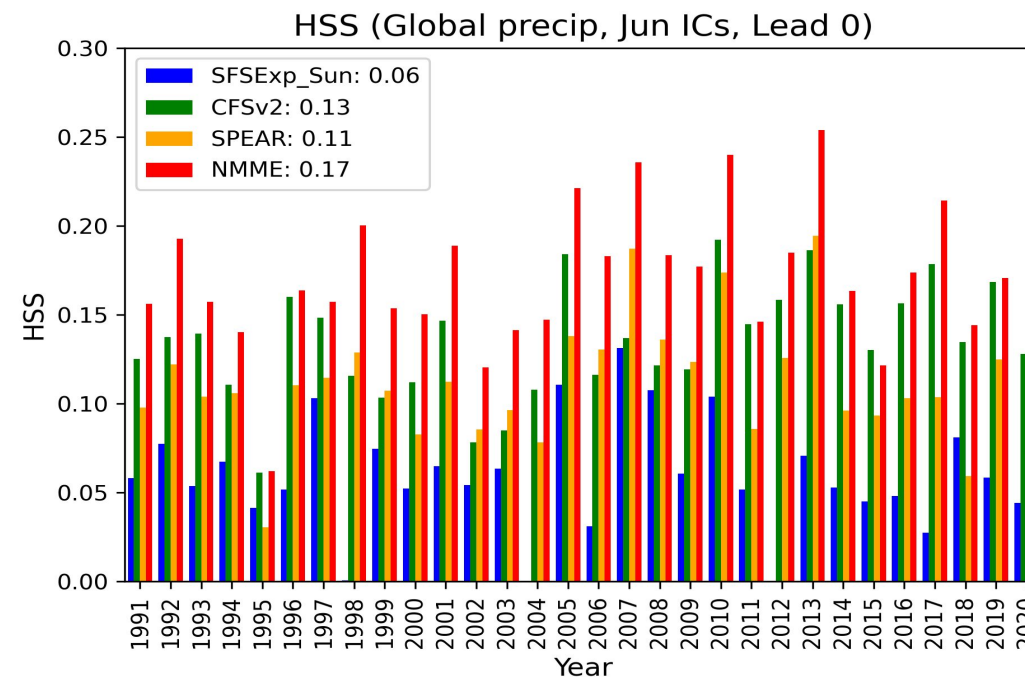
Task 10: Product Developments & Verification

(Leads: W. Wang, J. Levit, T. Jensen, J. Dias)

Variables and Metrics at CPC

Field	Domain	Metrics
SST	Global, tropics, 2D	ACC, trend, bias, RMSE
SST indices	Nino indices, IOD	ACC, false alarms, RPSS, RMSE
Prec	Global, tropics, 2D	ACC, trend, bias
	US, 2D	ACC, HSS, trend, bias
T2m	Global land, 2D	ACC, trend, bias
	US, 2D	ACC, HSS, trend, bias
Soil Moisture	US, 2D	ACC, trend, bias
Sea Ice Con.	NH, 2D	HSS, IIEE, bias, trend
NAO, PNA Indices	NH, 1D	ACC

METplus-based Verification



AMS Presentations

John Opatz: Examining Successes of R2O Implementation in the METplus Verification System

Johnna Infanti: Generating a Flexible Verification System for Precipitation by Assessing Precipitation Skill in the Unified Forecast System (UFS) and North American Multi-Model Ensemble (NMME) via Model Evaluation Tools (METplus)

Gwen Chen: Real-Time Ocean Forecast System Verifications Using METplus

Alicia Bentley: An Overview of Global Verification at the Environmental Modeling Center

Jason Levit: The EMC Verification System: Real-time Verification of Unified Forecast System (UFS) models



SFS Stakeholder Needs (NOAA)



Surface temperature, precipitation, ENSO, MJO, teleconnections, Arctic sea ice, soil moisture, snow cover, QBO, SSW events



Multi-week to seasonal temperature anomalies, precipitation anomalies, soil moisture



Lake ice cover, lake water temperature, air temperature, cloud cover, surface water currents, water levels, surface wind, waves



SST anomalies, salinity, pH, nutrients, biogeochemistry

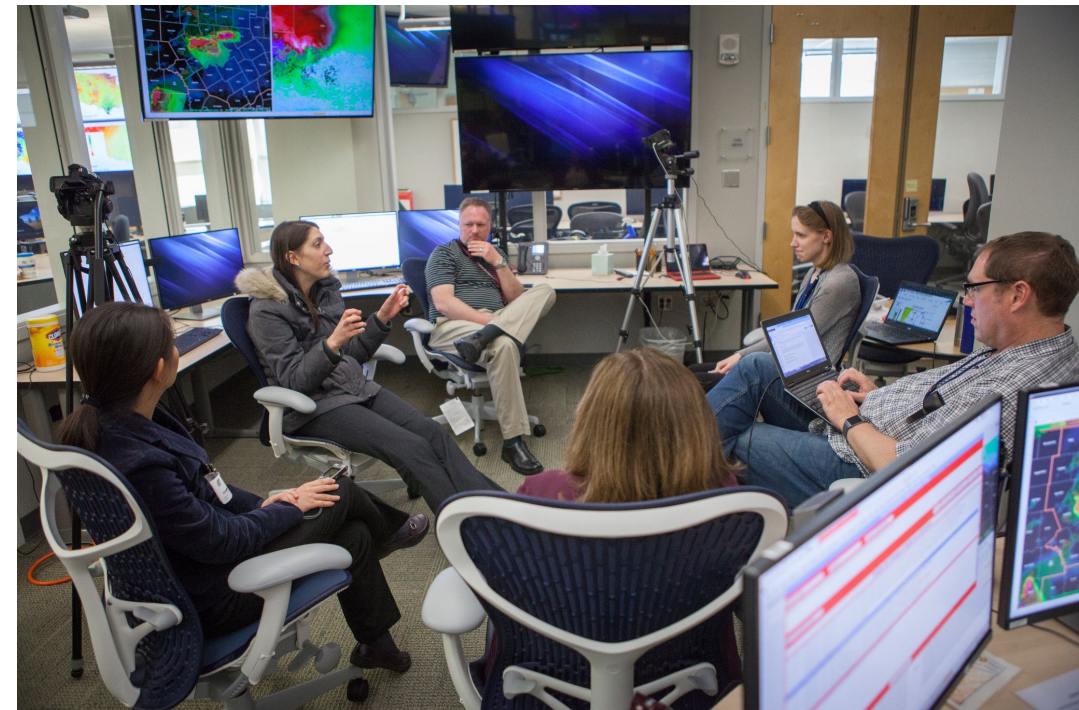


Mean sea level anomalies, hourly non tidal water levels, 500-m coastal grid resolution



Future Workshops & Outreach

- **“UFS S2S Applications Workshop”** scheduled on Sept 4-6, 2024, NCWCP Auditorium, College Park, Maryland
 - Looking for Speakers
 - Stakeholders & Users
- Need to hear from our stakeholders & users
 - Requirements
 - Product Improvements
 - New Products
- Build a regular cadence of communication with the user community



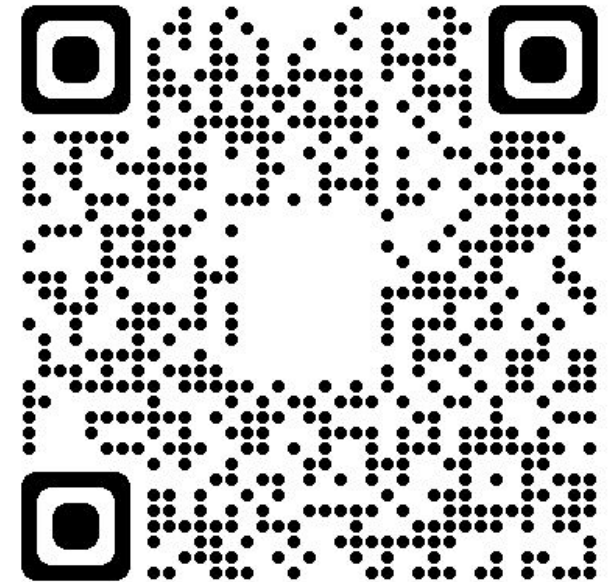
Thank You!!!

Reach out to us:

Jason.R.Anderson@noaa.gov

Yan.Xue@noaa.gov

Deepthi.Achuthavarier@noaa.gov





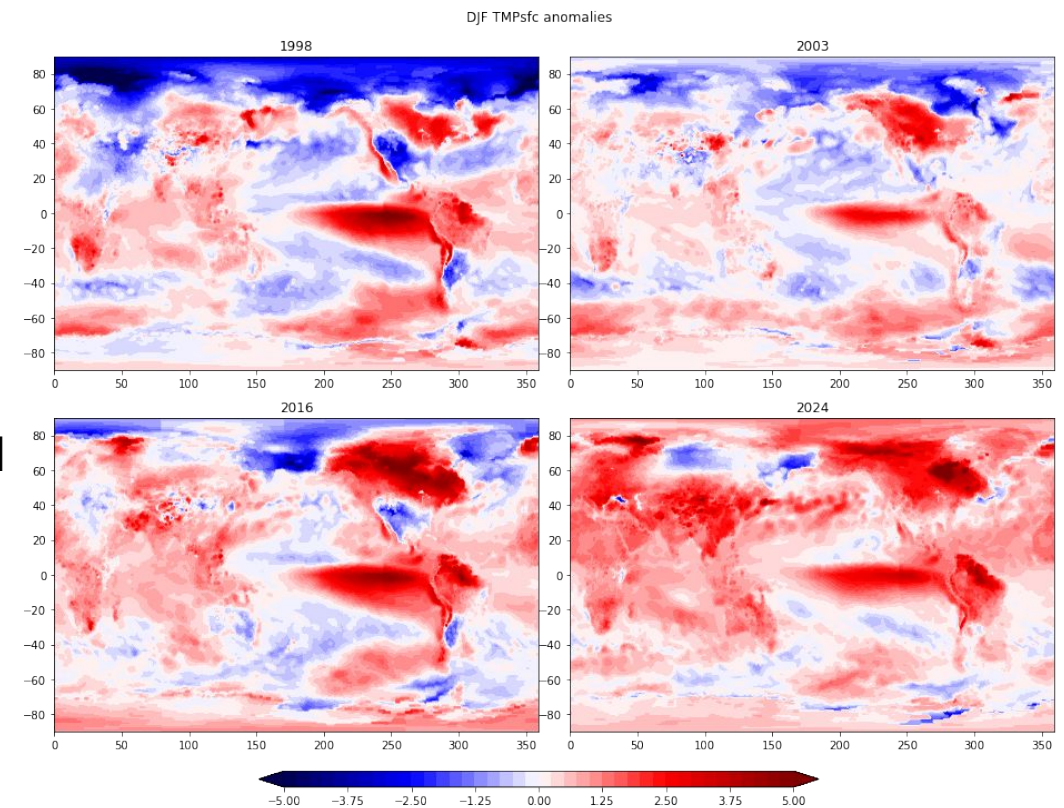
Backup Slides

SFS & UFS

The Climate Forecast System version 2 (CFSv2) has not been upgraded since implementation in 2011. CFSv2 was competitive for its time, but has since fallen behind in recent years. As such, NOAA's National Weather Service (NWS) and Oceanic and Atmospheric Research (OAR) have drafted a plan to develop and implement a new Seasonal Forecast System (SFS v1).

SFS v1 will build upon and extend capabilities of NOAA Global Ensemble Forecast System (GEFS), building upon GEFS v13, currently in development and testing, for extended range forecasting. GEFSv13 coupled model will be part of NOAA's Unified Forecast System (UFS), consisting of: FV3 dynamical core for the atmosphere, Common Community Physics Package (CCPP) for atmospheric physics, MOM6 for ocean, GOCART for aerosols, CICE6 for sea-ice, Noah-MP for land, WW3 for waves.

Proof-of-concept 1-degree SFS prototype ensemble mean reforecast DJF surface temperature anomalies ($^{\circ}$ C) for selected El Nino years



EMC's Requirements

- EMC seeks to implement GEFsV13 to improve forecast guidance for the atmosphere, ocean, sea ice, waves, and aerosols out to 3 to 4 weeks.
 - Expected improvements include:
- Improve probabilistic forecast skill of surface temperature over the continent area, precipitation for CONUS of week-1, week-2, weeks 3&4
- Reduced TC track and intensity error and improved TC ensemble spread
- Extended NH 500hPa height AC/CRPS day-to-day forecast skills (based on 60% of AC and 30% of CRPS)
- Extended NH 500hPa height weekly average AC scores, particular for week-2; weeks 3&4.
- Improve MJO prediction including propagation, intensity and each components
- Addition of two-way coupling between the atmosphere and waves, and two-way coupling between the ocean and wave models.
- Coupling time steps between the wave and atmosphere changed to 30 minutes from the 1 hour coupling time step in GEFsV12.
- Subseasonal forecasts of ENSO will be available.
- Sea ice extent and area predictions will be available on the S2S time-scales.
- Two-way aerosol-atmosphere coupling will likely occur in one member/configuration of GEFsV13.

OCLO/FDTD's Requirements

- Creation of reforecast dataset within GEFS would allow calculations for comparisons on how a current model forecast compares to past model forecasts, specifically to create datasets like the Extreme Forecast Index and Shift-of-Tails (EFI/SoT). By adding a GEFS M-climate (potentially re-running the v12 data through the v13 code to extend the length of runs), users of the data would be able to compare how extreme or not the current GEFS data is to its past model run climatology and add another layer of situational awareness to the forecast process.
- Update the Ensemble Situational Awareness Table comparisons for the GEFS Model Climate. This reanalysis dataset ends in 2019 so the v12 M-Climate dataset is missing several significant weather events in the M-Climate record to today, potentially resulting in poor comparisons with the latest GEFS model runs.
- The Cooperative Institute for Precipitation Studies (CIPS) Analog-Based Severe Probability Guidance are also outdated and missing many events since 2017 that an updated set of GEFS reforecasts could help build better analogs. This would allow users to see the potential for winter weather and/or severe weather patterns 8-10 days out. This would be both a real-time use but also a case for being able to use the reforecast data to run through machine learning and artificial intelligence tools.
- Unfortunately I'm not aware of any evaluation or verification being performed on the reforecast datasets to see how they would verify against observed meteorological conditions but would be something that could be an area of research and product creation in the future.

Jason Jordan & Kevin Scharfenberg



Use of CFS and GEFS for CPC's S2S products

- Operational

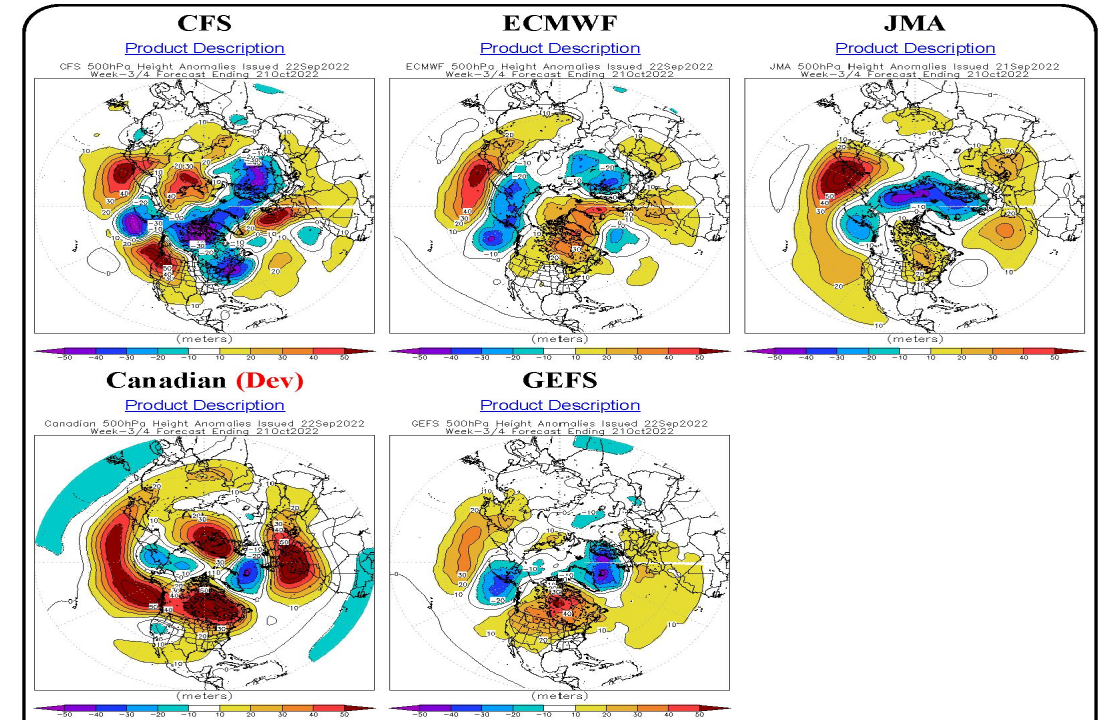
- Temperature and Precipitation Outlooks (CONUS, AK, HI):
- Monthly and Seasonal Drought Outlooks (CONUS, AK, HI)
- US Hazards Outlook
- Global Tropics Hazard Outlook:
- Seasonal Hurricane Outlook
- ENSO Prediction

- Experimental and in-development

- Arctic Sea Ice
- Week 2 fire weather
- Week 2, Week 3-4 severe weather
- Week 2, Week 3-4 storminess
- Water year outlook
- Marine heat wave outlook
- S2S drought forecasts

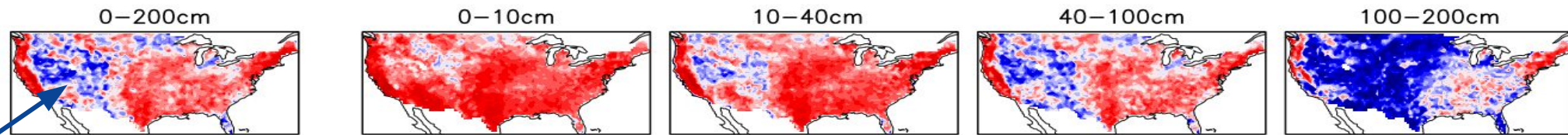
- CPC International Desks Prediction Products

- Africa, Central Asia, South Asia, Central and Caribbean



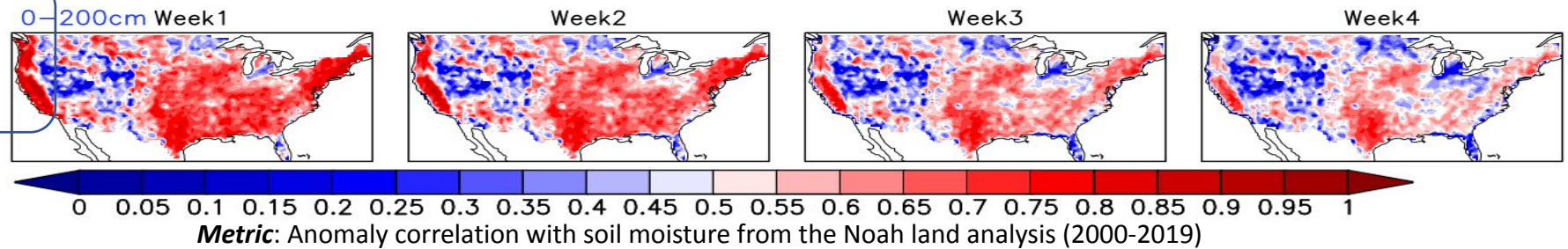
Evaluation of GEFSv12 Subseasonal Reforecasts for Soil Moisture

Accuracy of GEFSv12 Reforecast Initialization



- i) Precipitation bias
- ii) Spin-up too short

Evaluation of GEFSv12 EnsMean Reforecasts



Observational References

A Noah land analysis, produced by driving Noah offline with NLDAS-2 atmospheric forcings, with a sufficient spin-up

Evaluation

Initial soil moisture anomalies contribute substantially to the soil moisture forecast skill, owing to their intrinsic memory on subseasonal timescales. **The GEFSv12 soil moisture initialization** shows low accuracy in the western interior U.S., which adversely impacts soil moisture forecasts in these regions.

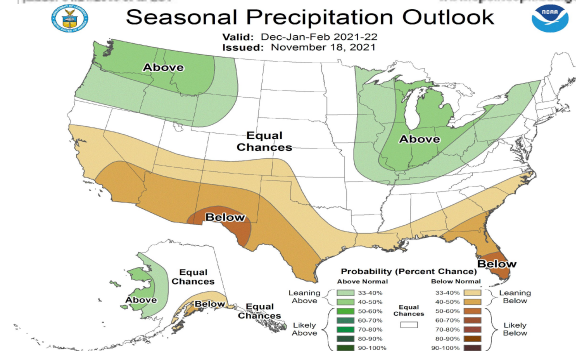
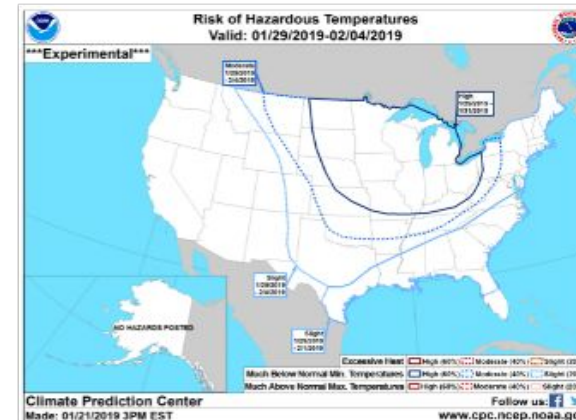
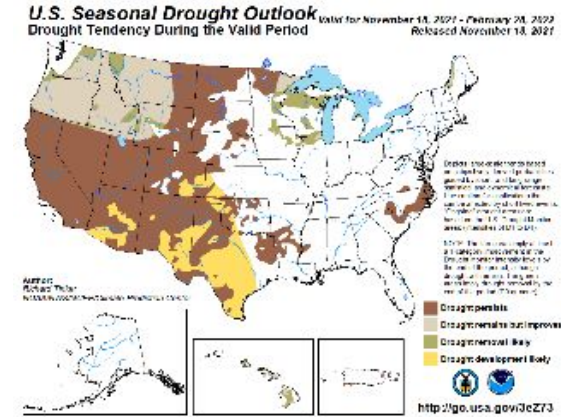
CPC production of subseasonal soil moisture forecasts: The forecasts are being produced by driving Noah/Noah-MP offline with bias-corrected and calibrated GEFSv12 meteorological forecasts, initialized using the Noah/Noah-MP land analysis.

(Courtesy: H. Wang)



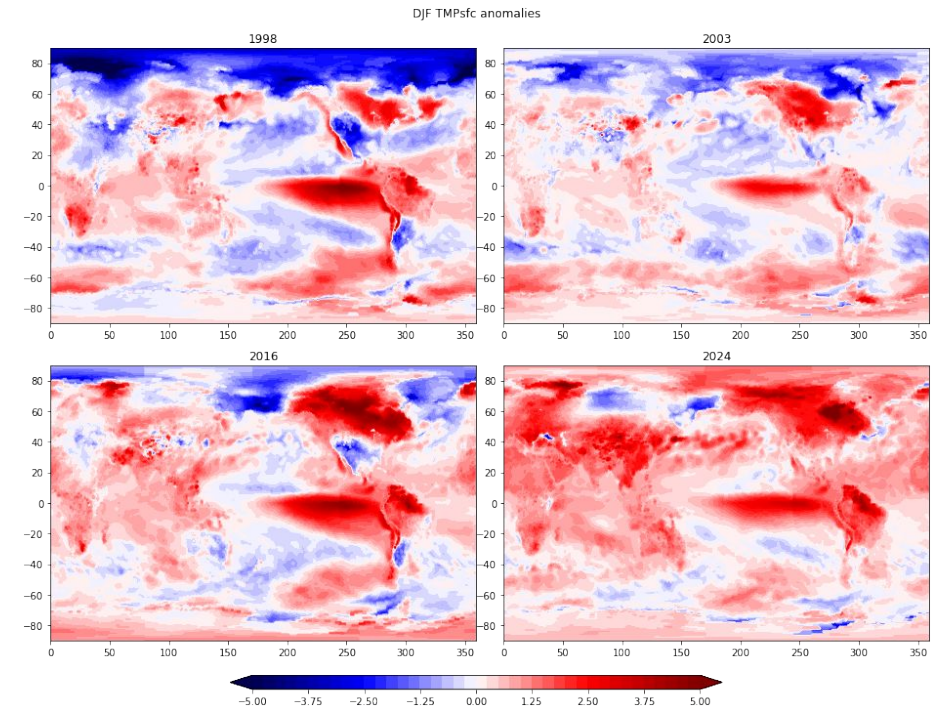
NWS Subseasonal-to-Seasonal Forecast

- **Temperature and Precipitation Outlooks** (CONUS, AK, HI)
 - Week 2, Week 3-4, Monthly, and Seasonal
- **Monthly and Seasonal Drought Outlooks** (CONUS, AK, HI)
- **US Hazards Outlook**
 - Week 2 extremes of temperature, precipitation, and wind
- **Global Tropics Hazard Outlook**
 - Weeks 2-3 extremes of temperature and precipitation, and potential of tropical cyclones
- **Seasonal Hurricane Outlook**
- **ENSO Prediction**
- **Arctic Sea Ice Prediction**
 - Weeks 1-6, Monthly, and Seasonal



SFS Development Plan: Goals and Objectives

- Develop SFSv1 as a replacement of Climate Forecast System version 2 (**CFSv2**), a more than 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**
- Release the coupled SFS system to the public
- Release reanalysis & reforecast data sets to the community

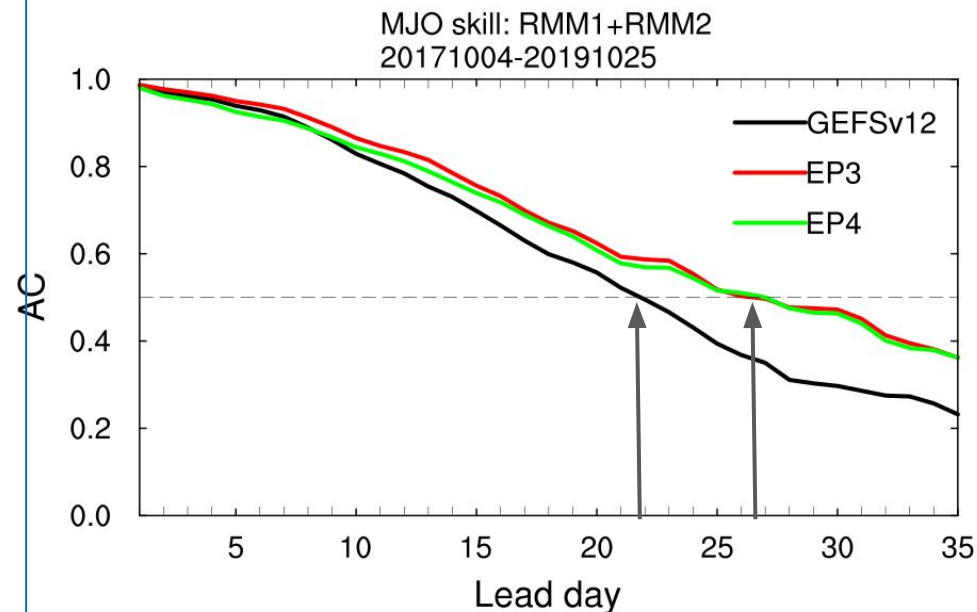


Proof-of-concept 1-degree SFS prototype ensemble mean reforecast DJF surface temperature anomalies (°C) for selected El Niño years

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.

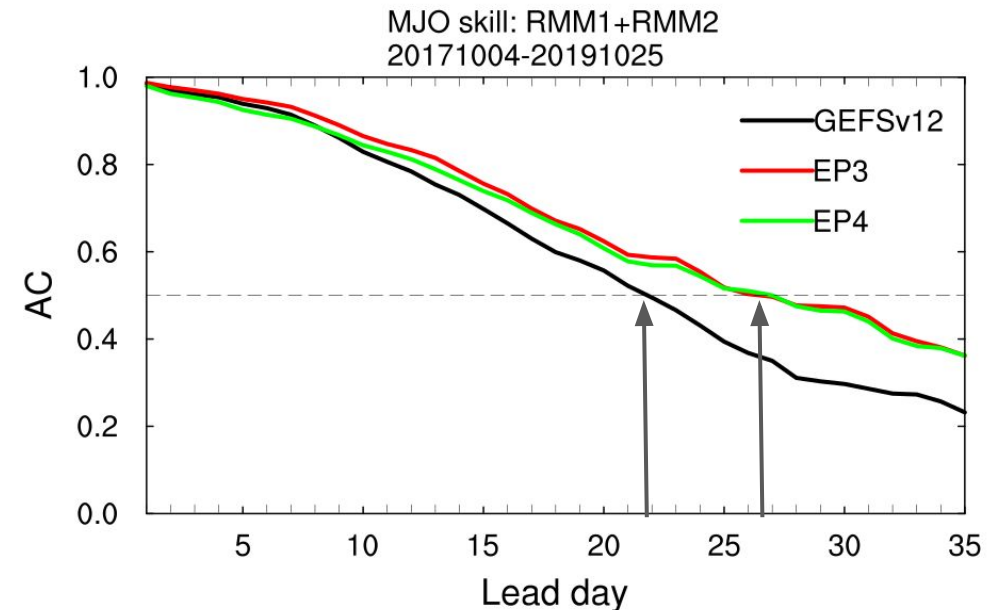


EP3 and EP4 both have higher MJO skill (RMM1+RMM2) than GEFsv12 for longer lead times (extend skill for 4-5 days).

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 PQRFB 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).

Priorities and Gaps

Near-term:

- Implement HAFSv2 into operations June 2024
 - MOM6 coupling, high-density meso AMVs DA, improved vortex relocation, improved physics
- Retirement of HWRF & HMON pending HAFSv2 retrospective/NHC eval
- 2024 HREx (HAFS Ensemble closer to HAFSv2 configuration)

Gap: *Current HPC capability does not fully support development & real-time evaluation needs. Operational HPC becomes constrained as new HAFS versions come online*

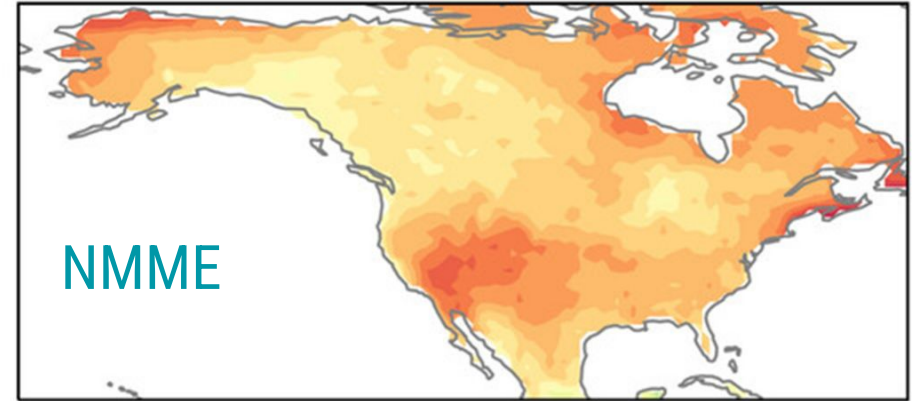
Operational Impact: NHC loses HWRF & HMON with potential reduction in official forecast track and intensity skill; delayed moving nests inhibits NHC capability to recognize high risk situations

SFS Development Plan: Goals and Objectives

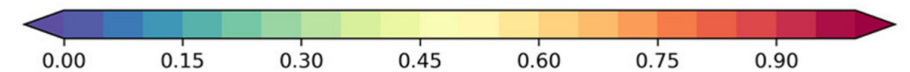
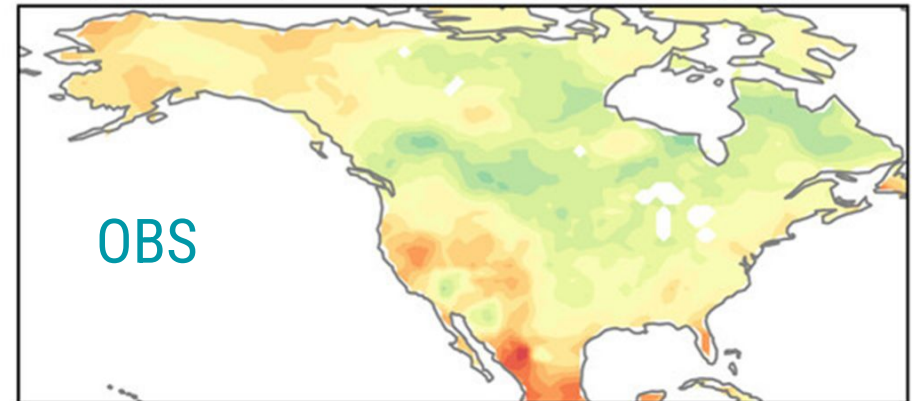
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Frequency of above-normal

B) NMME lead-1 frequency of above



D) Observed frequency of above



Becker et al. 2022