



**NATIONAL
WEATHER
SERVICE**

NOAA's Seasonal Forecast System (SFS) Development Plan: A Community Modeling Approach to Increase Forecast Skill and to Meet User Needs

Yan Xue¹, Avichal Mehra³, Philip Pegion⁴, Neil Barton³, Jason Anderson¹,
Kevin Garrett¹, Mark Olsen²

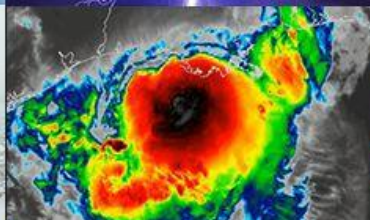
¹ NOAA NWS Office of Science and Technology Integration

² NOAA OAR Weather Program Office

³ NOAA NWS Environmental Modeling Center

⁴ NOAA OAR Physical Science Laboratory

Noah-MP Workshop, June 2-3, 2024, Boulder



NATIONAL WEATHER SERVICE

Building a Weather-Ready Nation // 1

FY23 Congressional Appropriations → Funding

\$5.0M

National Weather
Service (NWS)



- ***Development of Seasonal Forecast System (SFS)***

\$7.1M

Oceanic & Atmospheric
Research (OAR)



- ***Weather Program Office's S2S Research Program***

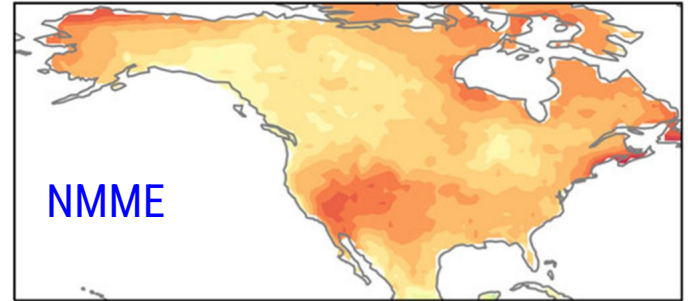
In response to the congressional appropriation, the Office of Science and Technology Integration (**OSTI**) in NOAA's NWS, and the Weather Program Office (**WPO**) in NOAA's Oceanic and Atmospheric Research (OAR) jointly established an **SFS Application Team (AT)**, composed of participants from NCEP centers, OAR labs, NCAR and academia partners. The SFS Project formally launched on **October 1, 2023**.

SFS Development Plan: Major Goals

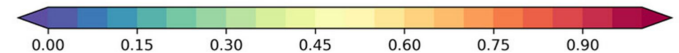
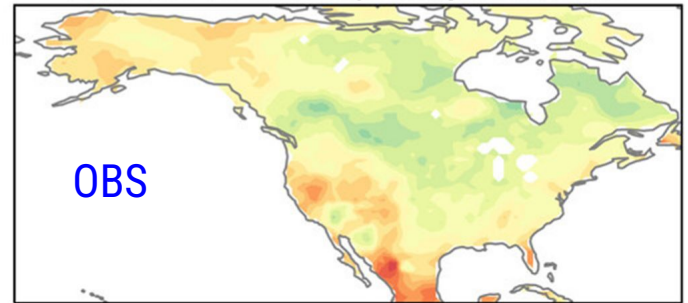
- Develop **SFSv1** as a replacement of the more than decade-old Climate Forecast System version 2 (**CFSv2**)
- **Address common errors in CFSv2 and NMME**
 - MJO propagation across Maritime Continent
 - False ENSO alarms
 - Positive SST trend errors in tropical Pacific
 - **Too frequent above-normal temperature forecast**
 - **Too infrequent below-normal temperature forecast**
- Release the coupled SFS system to the public
- Release reanalysis & reforecast data sets to the community

Frequency of above-normal

B) NMME lead-1 frequency of above



D) Observed frequency of above



Becker et al. 2022

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.

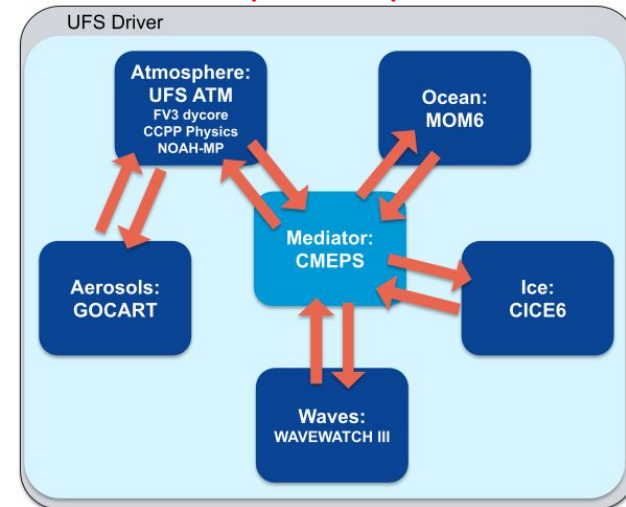
- **Community components in UFS**
 - Model infrastructure: **ESMF, NUOPC, CMEPS**
 - Atmosphere model: **FV3 dycore, CCM3 Physics**
 - Ocean model: **MOM6**
 - Ice model: **CICE6**
 - Wave model: **WW3**
 - Aerosol model: **GOCART**
 - Land model: **Noah-MP**
 - Data assimilation: Joint Effort for Data assimilation Integration (**JEDI**)
- Each component has its own authoritative repository.

UFS Research-to-Operations (UFS R2O) Project

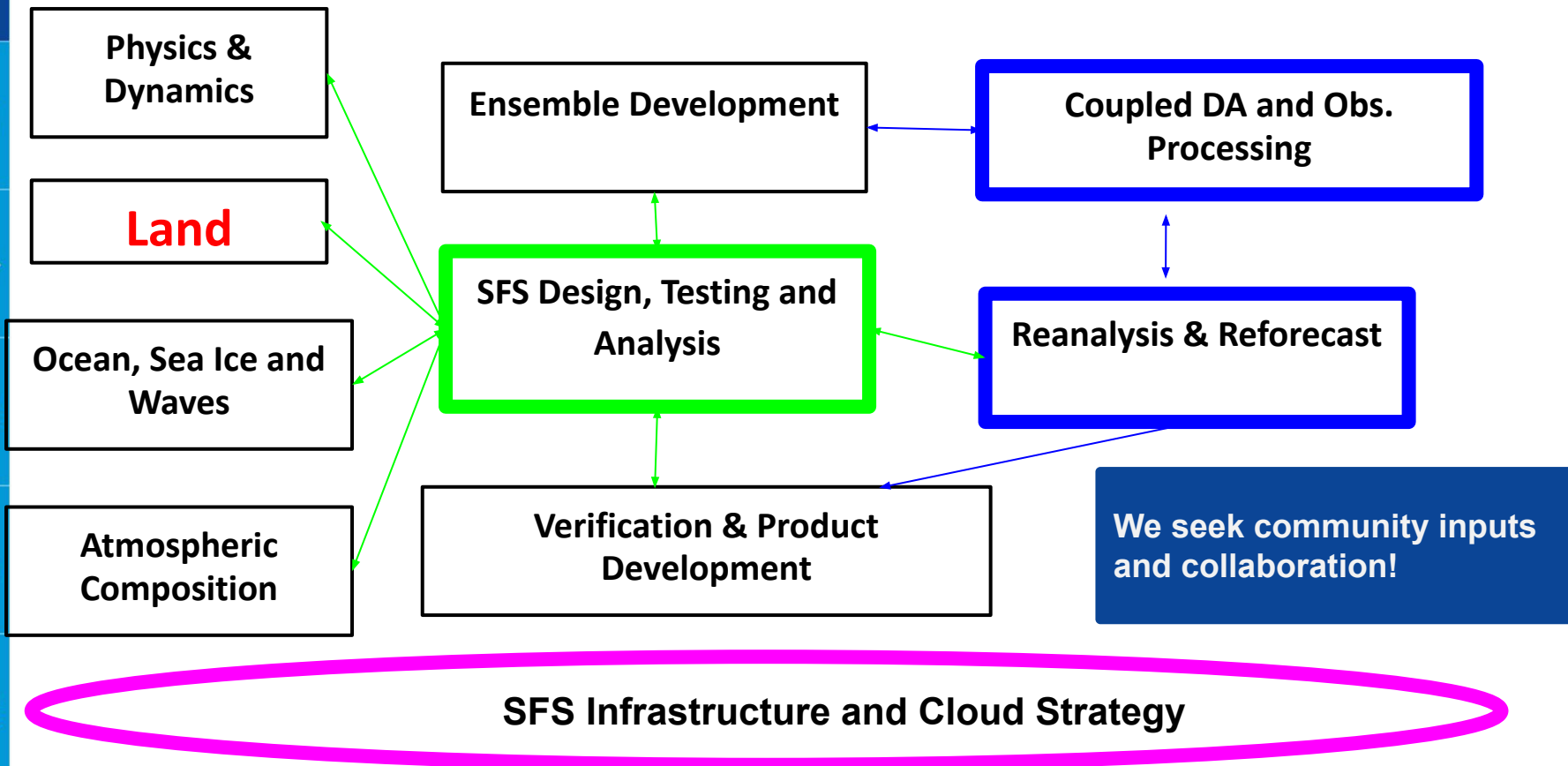
Jointly supported by NWS/OSTI and OAR/WPO

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

MRW/S2S Applications:
GFSv17, GEFSv13, SFSv1



SFS Application Team: Ten Focus Areas



SFS Design, Testing and Analysis

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

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

The model configuration would be frozen at the end of Phase III, following which the reanalysis and reforecasts will be produced and realtime and retrospective experiments will be performed.

Land Model Improvement and Land Initialization

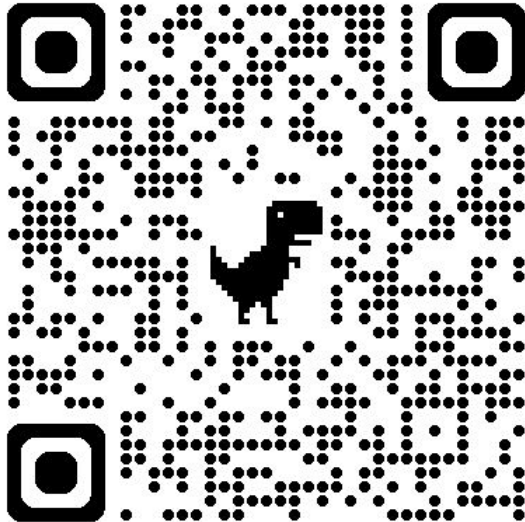
(Leads: Mike Barlage, Clara Draper)

Main Tasks:

- **Optimize existing land physics**
 - **Activate vegetation phenology and agriculture modules**
 - **Deeper soil configuration**
- **Introduce new land physics**
 - **Medium-complexity urban canopy model**
 - **Improve representation of hydrologic cycle**
- **Explore advancements in couplings**
 - **Land-atmosphere, land-composition and land-ocean**
- **Land initialization**
 - **Real-time: Operational coupled DA for GFSv17/GEFSv13**
 - **Reforecast: Offline Noah-MP forced with ERA5 bias-corrected to match the climatology of the operational GFSv17/GEFSv13 I.C. (mainly precipitation)**

SFS Development Plan

We welcome feedback
and seek collaboration!



NOAA's Subseasonal and Seasonal Applications Workshop: *Toward Increasing Collaborations among Users, Modelers and Researchers*

Workshop Date: **Sep 4-6, 2024**

Location: **College Park, MD, with
remote option available**

Abstract deadline: **June 26, 2024**

Registration deadline: **August 20, 2024**

Contact: Yan.Xue@noaa.gov



SFS Application Team (Co-Leads: **Avichal Mehra, Phil Pегion, Neil Barton**)

- 1) SFS Design, Testing and Analysis (Leads: Neil Barton, Phil Pегion, Avichal Mehra)
- 2) Physics and Dynamics Improvements (Leads: Fanglin Yang, Lisa Bengtsson, Ligia Bernardet)
- 3) Land Model and Land Initialization 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 Pегion, Neil Barton)
- 7) Coupled Data Assimilation Developments and Observation (Leads: Daryl Kleist, Sergey Frolov)
- 8) SFS Reanalysis & Reforecast (Leads: Sergey Frolov, Daryl Kleist, Jeff Whitaker, Phil Pегion)
- 9) SFS Infrastructure and Cloud Strategy (Leads: Rahul Mahajan, Jun Wang)
- 10) Product Developments & Verification (Leads: Wanqiu Wang, Jason Levit, Tara Jensen)

NOAA's SFS Development Plan

GOALS:

- Coupled reanalysis should provide ***balanced initializations*** across interfaces between coupled model components that maximize source of ***long-term predictability***, e.g. from ***ocean, sea ice and land***
- Coupled model should ***minimize systematic drift*** from initial conditions and ***minimize false alarms for extreme events***, e.g. overconfident in El Nino forecast
- Ensemble forecasts should provide ***best estimation of uncertainties***
- Improvements in physics/dynamics and model components should ***reduce systematic biases and improve forecast skill***
- ***SFS infrastructure*** should provide critical support to model coupling, testing, evaluation and eventual transition to operations on both ***on-premise and cloud***







Physics and Dynamics Improvements

(Leads: Fanglin Yang, Lisa Bengtsson, Ligia Bernardet)



Main Tasks:

- **Assess the suitability of hydrostatic dycore option for SFS**
 - **Reduce cloud and radiation biases in the tropics**
 - **Improve the MJO, QBO, ENSO, polar jet streams and stratosphere/troposphere coupling**
 - **Improve the boundary layer processes and shallow cumulus**
 - **Improve the mixed-phase clouds and radiation balance in the Arctic**
 - **Develop aerosol-cloud interaction algorithm and improve aerosol-radiation interactions**
 - **Update historical trace gas (e.g. CO₂) and volcanic background aerosol datasets**
 - **Improve O₃ and water vapor predictions in the upper atmosphere**
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Global Forecast System v17 Upgrade

(Deterministic Forecast up to 16 days)

	<u>GFSv16</u> : Implementation Mar 2021	GFSv17 : Target Implementation Mar 2026
Model	FV3/Noah WW3 (one-way coupling)	FV3/Noah_MP 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 (See Slide 10 for details)
Forecast Cadence	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

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







Ocean and Sea-Ice Model Improvements

(Leads: Shan Sun, Neil Barton, Wanqiu Wang)



Main Tasks:

- Test sensitivities of SFS skill to different ocean and sea ice initial conditions
 - Increase near surface vertical resolution in the ocean model to reduce SST biases
 - Mitigate deficiencies in oceanic circulations (e.g. Atlantic Meridional Overturning Circulation)
 - Improve coupling between CICE6 and MOM6 by adopting the C-grid
 - Add the ability to couple aerosols to CICE; Test different melt-pond schemes in CICE
 - Explore economical alternatives to the costly wave model
 - Examine and mitigate deficiencies in moisture and energy conservation in the whole system
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Coupled Data Assimilation and Reanalysis (Leads: D Kleist, S Frolov, J Whitaker, P Pegion)

- Completion of **30 year replay** to ERA5 and ORA5 reanalysis from 1993-2023
 - Balanced coupled initial conditions for GEFSv13 reforecast
 - Dataset publicly available at NODD
<https://noaa-ufs-gefsv13replay-pds.s3.amazonaws.com/index.html>
- Development of a **50+ year publicly available observational database** for coupled reanalysis
- Low resolution "scout run" in progress (in preparation for upcoming full resolution ensemble coupled reanalysis)

SFS Infrastructure and Cloud Strategy

(Leads: Rahul Mahajan, Jun Wang)

Coupled Model Infrastructure

- Expand the exchange grid capability for calculating atmosphere-ocean fluxes
- Improve computational performance

Global-Workflow Infrastructure

- Extending GFSv17 and GEFSv13 in global-workflow to SFSv1 configurations
- Porting of the infrastructure to various cloud platforms; **AWS, GCP, Azure**
- Support for reanalysis, reforecasts, retrospective and real-time experiments

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

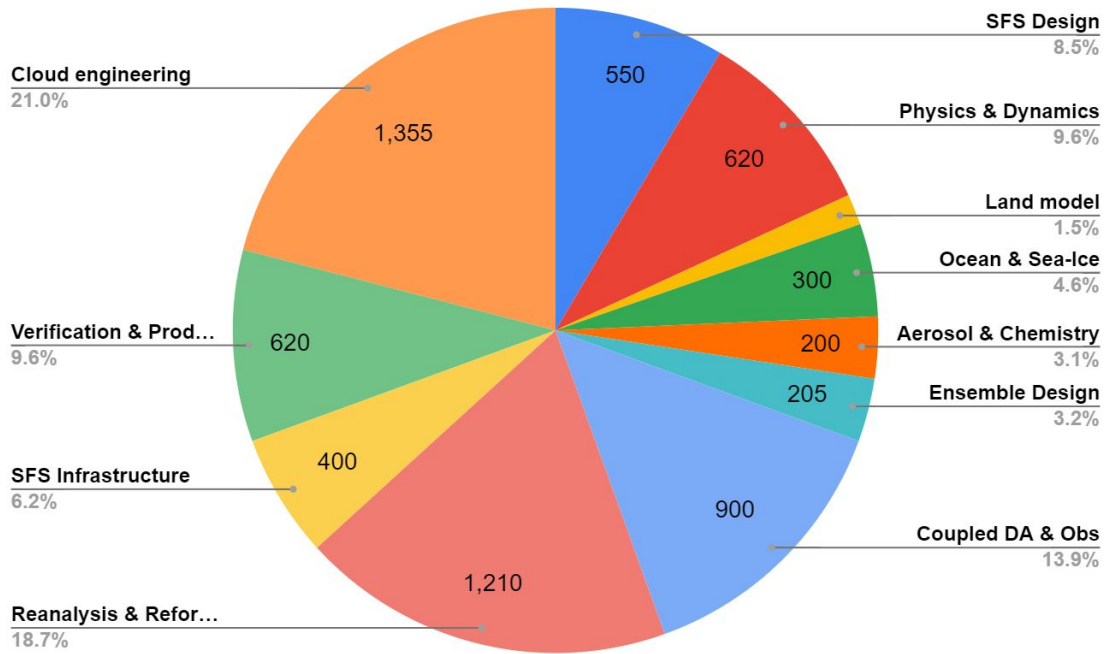


Budget distribution amongst focus areas \$(K)

FY23 Budget for SFS Development:

\$5.0M (NWS)

\$1.46M (OAR)



OFFICE OF SCIENCE & TECHNOLOGY INTEGRATION



WEATHER PROGRAM OFFICE



EMC



CPC



NWS Weather, Subseasonal, Seasonal Forecast Systems: Transition to Global Coupled UFS-based Systems

Current Systems

GFS v16 (since March 2021)
Weather (0-14 days),
deterministic, **no coupling with
ocean/ice**. FV3

GEFS v12 (since September 2020)
Subseasonal (0-35 days),
ensemble, **no coupling with
ocean/ice**. FV3

CFS v2 (since March 2011)
Seasonal (0-9 months), ensemble,
coupled with ocean/ice. Spectral
Atm/MOM4 Ocean/SIS1 Sea ice

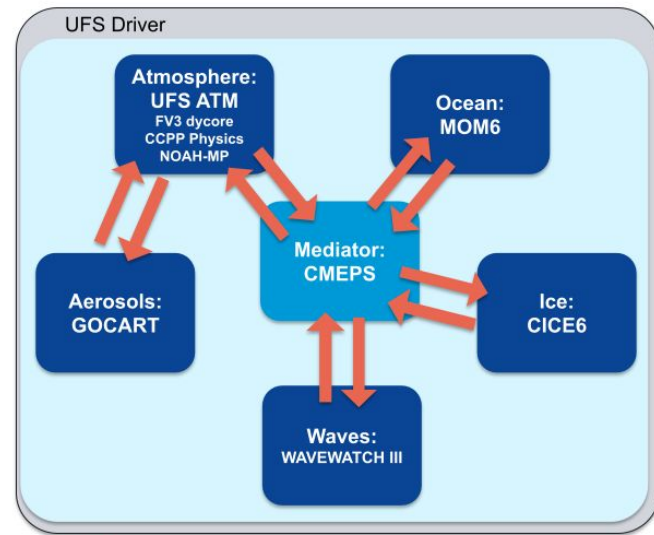
Future UFS Systems

GFS v17
(T20 Phase)

GEFS v13
(T20 Phase)

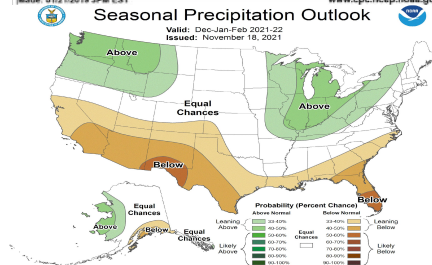
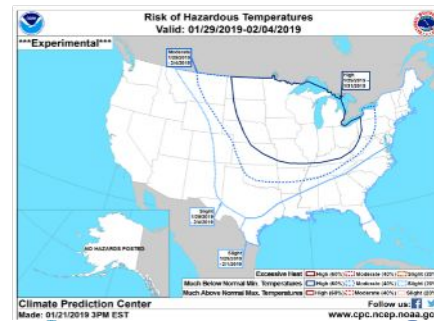
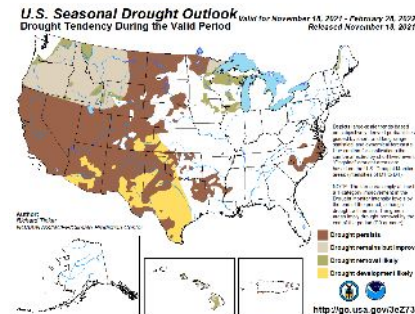
SFS v1
(R20 Phase)

UFS System Configuration



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





GFSv16 physics

Land: **Noah-MP +**
Compositing surface layer variables, albedo/emissivity
 PBL: **TKE-EDMF**
Reduced background diffusivity, limit PBL updraft overshoot.
 Microphysics: **GFDL MP**
 Deep convection: **saSAS**
Stricter trigger criteria, reduced entr. rate, reduced rain evap. rate
 Shallow convection: **saMF**
 Radiation:**RRTMG**
MERRA2 aerosol climatology
 Gravity wave drag: **uGWDv0**

Land: **Noah-MP**
Bug-fixes
 PBL: **TKE-EDMF**
 Microphysics: **Thompson MP**
Improve radiative fluxes and cloud cover
 Deep convection: **saSAS**
Prognostic closure
 Shallow convection: **saMF**
Prognostic closure
 Radiation:**RRTMG**
Couple convective cloud to radiation
 Gravity wave drag: **uGWDv0**

Land: **Noah-MP**
 PBL: **TKE-EDMF**
 Microphysics: **Thompson MP**
 Deep convection: **saSAS**
 Shallow convection: **saMF**
 Radiation:**RRTMG**
Address excessive large net SW net to ocean at low sun angles
Gravity wave drag: uGWDv1

SFSv1 physics



Land: **Noah**
 PBL: **TKE-EDMF**
 Microphysics: **GFDL MP**
 Deep convection: **saSAS**
 Shallow convection: **saMF**
 Radiation:**RRTMG**
 Gravity wave drag: **uGWDv0**

Land: **Noah-MP**
Tuning, use CICE albedo in atm, new ice climatology, VIIRS based land/lake mask, spun up land IC's.
 PBL: **TKE-EDMF**
Positive definite massflux scheme, reduced entrainment rate
Microphysics: Thompson MP +
 Semi-Lagrangian Sedimentation + refined ice microphysics
Deep convection: saSAS
Cellular automata convective org scheme
Positive definite massflux scheme
 Shallow convection: **saMF**
Positive definite massflux scheme
 Radiation:**RRTMG**
 Gravity wave drag: **uGWDv0**

Land: **Noah-MP**
Bug-fixes
PBL: TKE-EDMF
wind shear effect and TKE dependent entrainment.
CONUS CAPE enhancement
 Microphysics: **Thompson MP**
Reduce stratus and downwelling rad. fluxes
 Deep convection: **saSAS**
wind shear effect and TKE dependent entrainment
 Shallow convection: **saMF**
 Radiation:**RRTMG**
 Gravity wave drag: **uGWDv0**

UFSR20 physics/dynamics development coordination
Fanglin Yang, Lisa Bengtsson