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

Yan Xue[1], Avichal Mehra[3], Philip Pegion[4], Neil Barton[3], Jason Anderson[1], Kevin Garrett[1], Mark Olsen[2]

[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

NATIONAL WEATHER SERVICE

S2S Community Workshop, June 4-6, 2024, Boulder

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**.

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

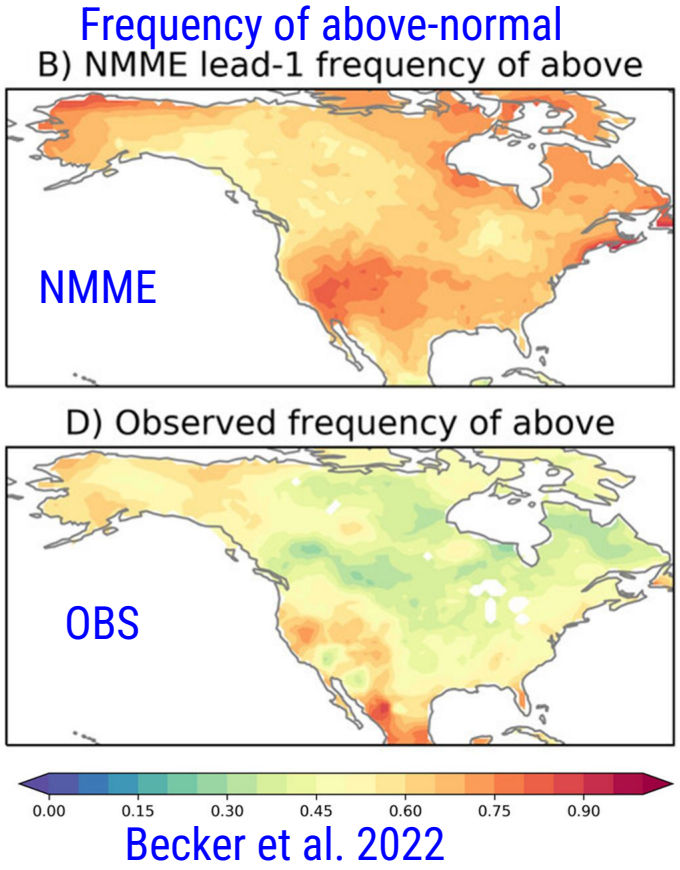
- Ensemble forecasts should provide ***best estimation of uncertainties***

- 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***

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



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.

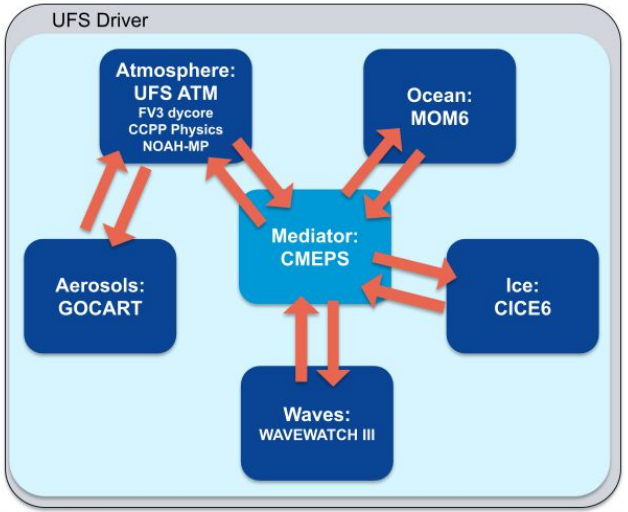
- Community components in UFS
  - Model infrastructure: ESMF, NUOPC, CMEPS
  - Atmosphere model: FV3 dycore, CCPP Physics
  - Ocean model: MOM6
  - Ice model: CICE6
  - Wave model: WW3
  - Aerosol model: GOCART
  - Land model: Noah-MP
  - Data assimilation: Joint Effort for Data assimilation Integration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

UFS Research-to-Operations (UFS R2O) Project

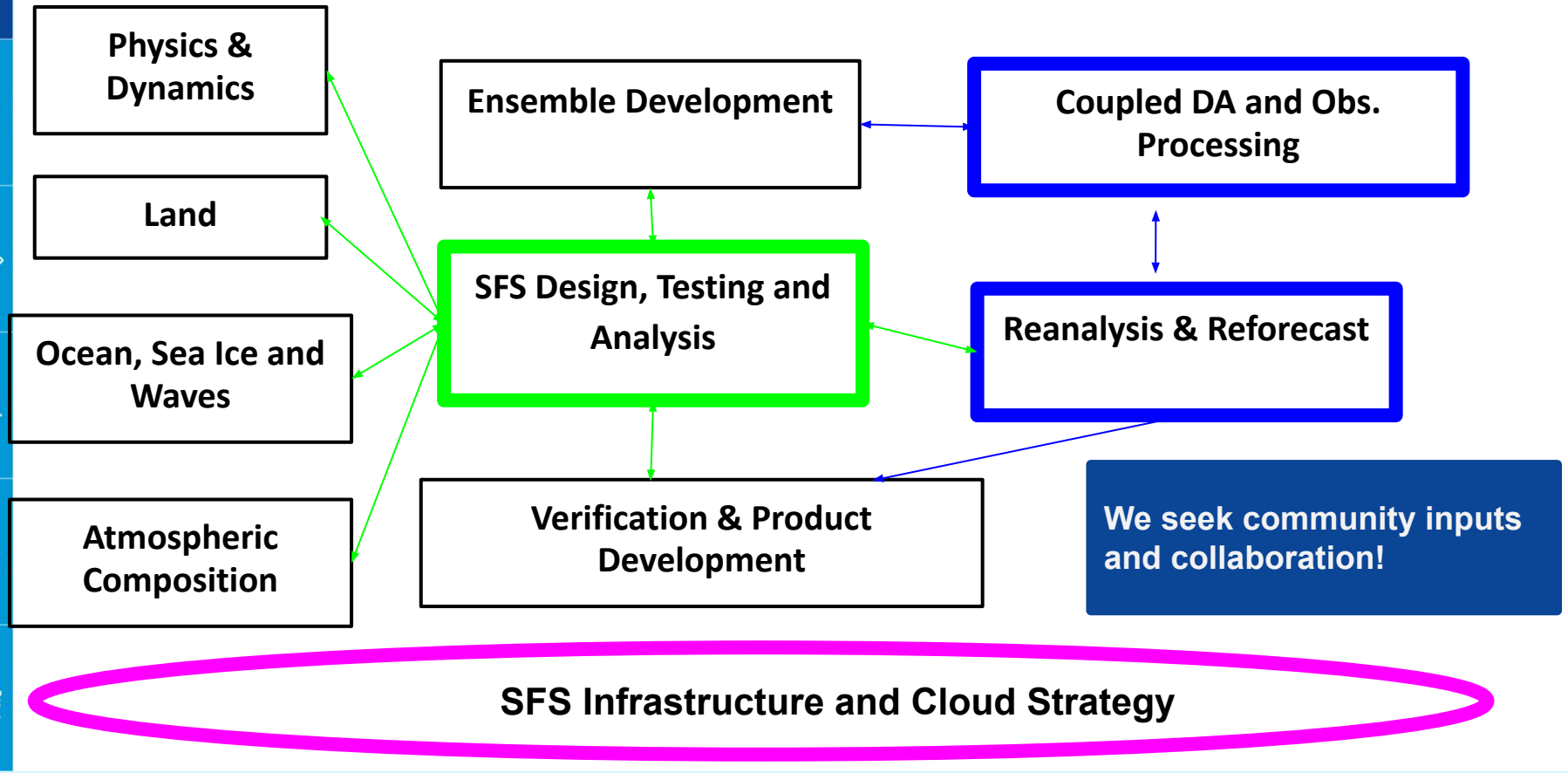
Jointly supported by NWS/OSTI and OAR/WPO

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

1) SFS Design, Testing and Analysis (Leads: Neil Barton, Phil Pegion, 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 Pegion, 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 Pegion)
9) SFS Infrastructure and Cloud Strategy (Leads: Rahul Mahajan, Jun Wang)
10) Product Developments & Verification (Leads: Wanqiu Wang, Jason Levit, Tara Jensen)

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.

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

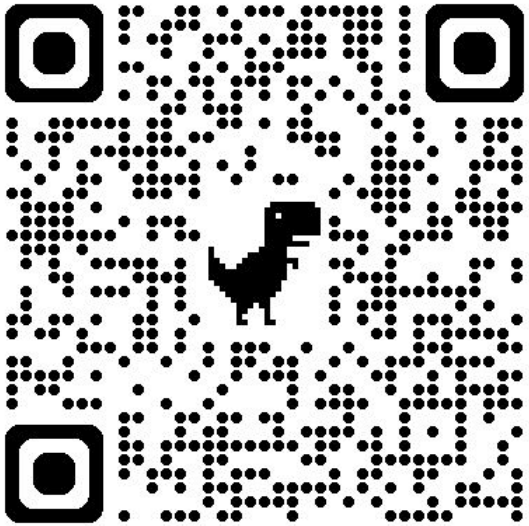
Land Model Improvement and Land Initialization (Leads: Mike Barlage, Clara Draper)

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

Global Forecast System v17 Upgrade

(Deterministic Forecast up to 16 days)

	GFSv16: 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)

	GEFSv12: 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

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

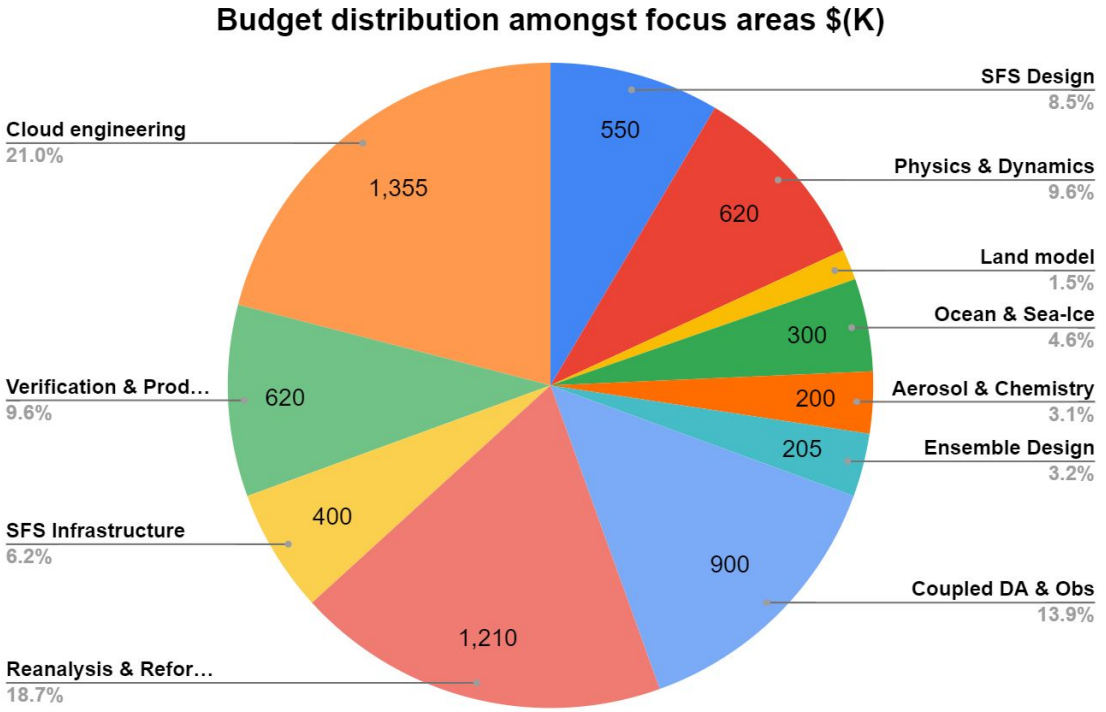
Global-Workflow Infrastructure

- 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

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

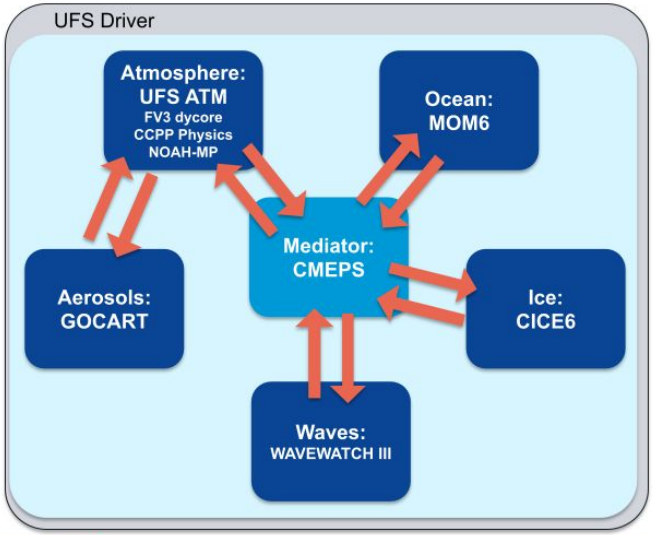
Future UFS Systems

GFS v17 (T2O Phase)

GEFS v13 (T2O Phase)

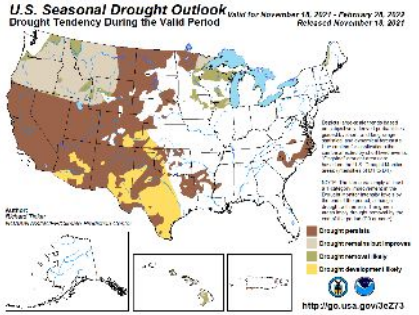
SFS v1 (R2O Phase)

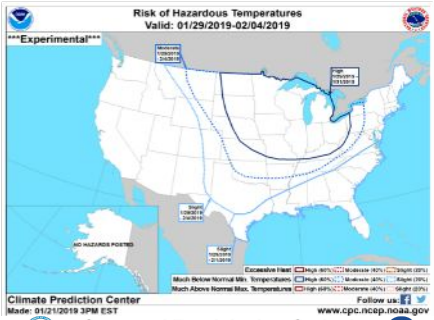
UFS System Configuration

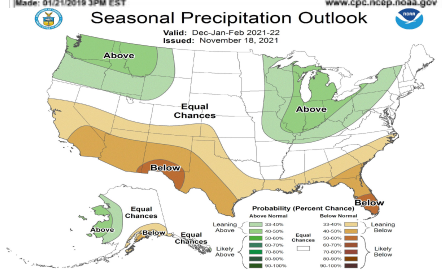


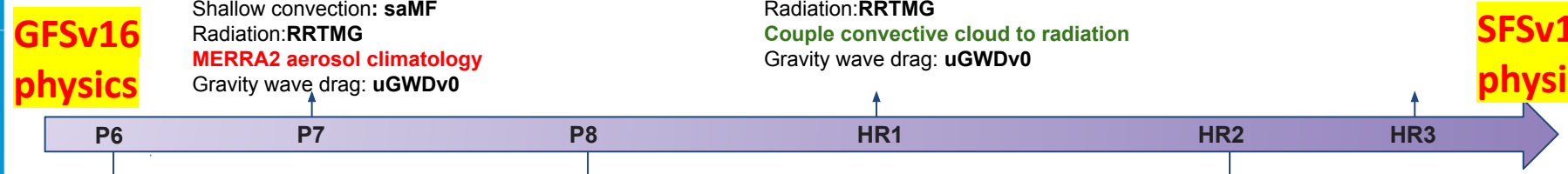
NWS Subseasonal-to-Seasonal Forecast

- **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









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

UFSR2O physics/dynamics development coordination
Fanglin Yang, Lisa Bengtsson

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

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

Acknowledgement to ALL UFS coupled/infrastructure/physics/dynamics/DA developers, application/workflow leads, and level 1/2 PIs!