Improving NWS Subseasonal-to-Seasonal Forecast with Unified Forecast System: Highlights of Modeling and Analysis Results

NATIONAL WEATHER SERVICE

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47th CDPW, Logan, UT, 25-27 Oct 2022

Motivation

- The NWS issues global forecasts at three time scales – weather (GFS), subseasonal (GEFS) and seasonal (CFSv2)
- Since 2016, NWS has been in the process of upgrading its operational modeling suite using a new atmospheric dycore (FV3)
- NWS is using this opportunity to upgrade and unify its modeling capability across different scales using Unified Forecast System

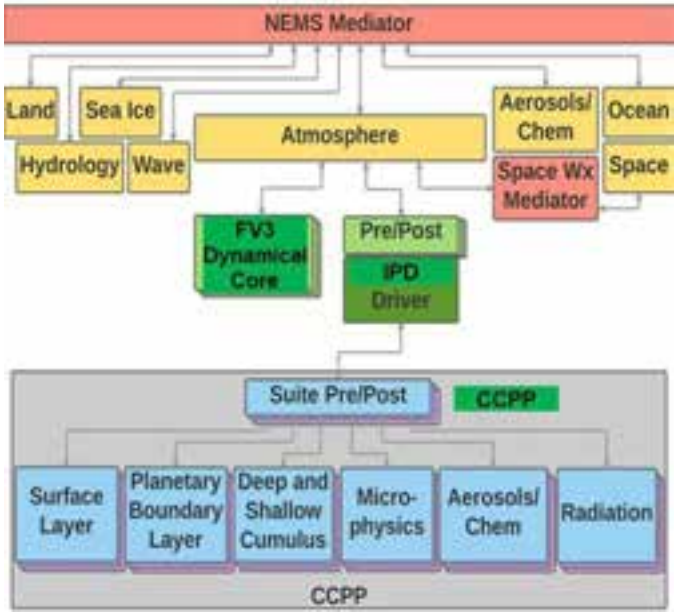
Unified Forecast System

https://ufscommunity.org

UFS
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.



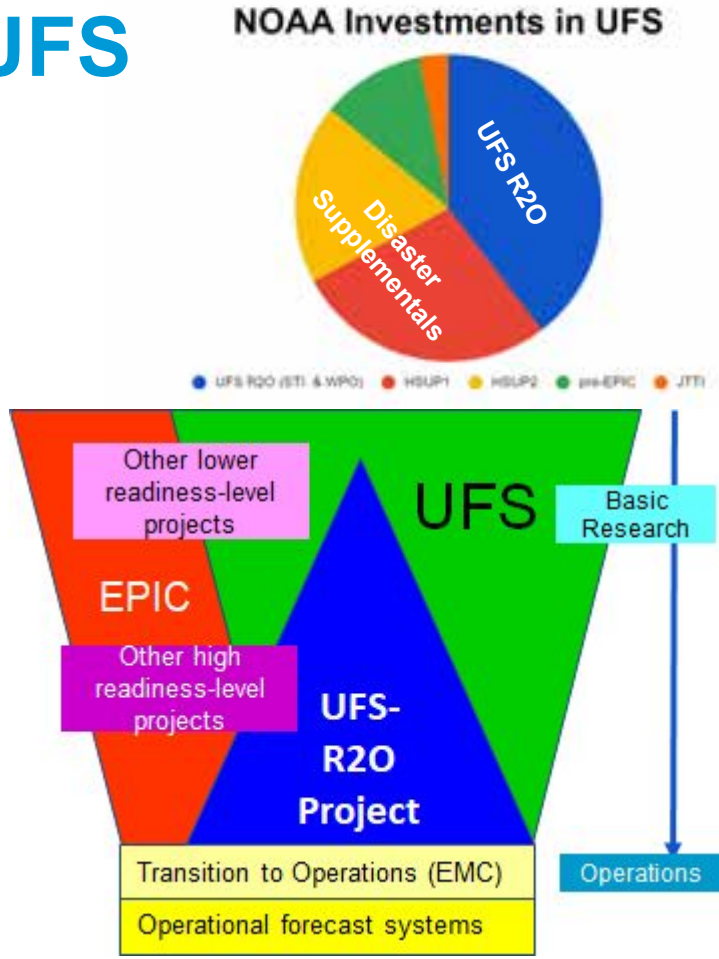
NOAA Investments in UFS

Unified Forecast System (UFS)

- NOAA programs that support the UFS: NGGPS, Weeks 3&4, HFIP, JTTI, EPIC, and Hurricane and Disaster Supplementals

UFS Research to Operations (UFS R2O) Project

- Three year project (FY20-23) with 5-year vision
- Developing the next-generation global and regional forecast systems for NOAA's operations by **FY24**
- NOAA's largest investment in the UFS: **$13M/yr**, jointly supported by NOAA Operations (NWS) and Research (OAR)
- Community team (NOAA, NCAR, JCSDA, Universities)
- Website: https://vlab.noaa.gov/web/ufs-r2o



NWS Weather to Seasonal Forecast Systems: Current and Future Systems

Current Systems

GFSv16 (since March 2021)
Weather scales, deterministic,
no coupling with ocean/ice. FV3

GEFSv12 (since September 2020)
Weather to subseasonal, ensemble,
no coupling with ocean/ice. FV3

CFSv2 (since March 2011)
Subseasonal to seasonal, ensemble,
coupled with ocean & sea ice.
Spectral Atm/MOM4 Ocean/SIS1 Sea ice

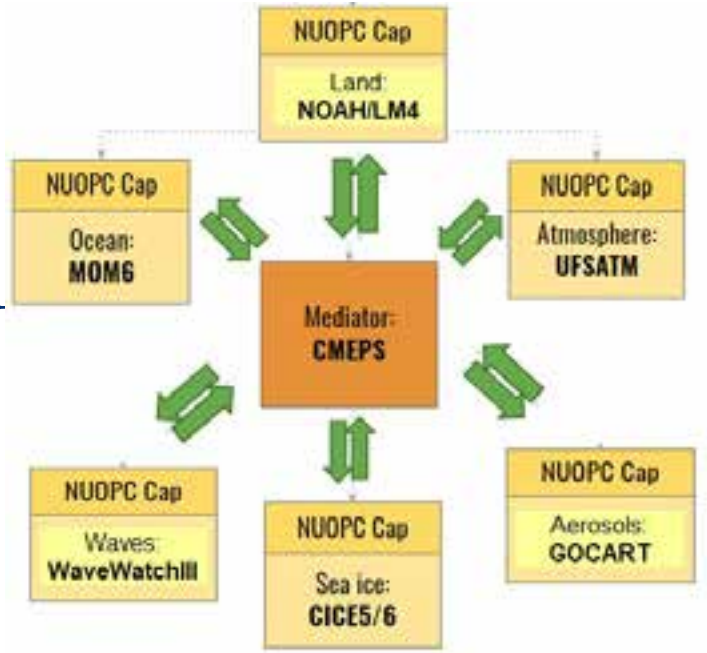
Future UFS Systems

GFSv17 (FY 2024)

GEFSv13 (FY 2024)

SFSv1 (FY 2027+)

UFS System Configuration



Coupled Prototypes: Testing Framework

Strategy for testing

Compromise between computational resources and need for large enough sample for statistically meaningful metrics. Repeat for each prototype.

- **April 2011 to March 2018**
  - Includes both El Niño and La Niña events
  - Includes years of very low ice extent
- Initialized on the 1st and 15th of each month
- 7 years, 168 forecasts
- Deterministic 35-day free forecasts

Evaluation

- Fixed metrics: biases, anomaly correlations and RMSE, MJO skill
- Ad-hoc evaluations as needed; more detailed evaluations for later prototypes.
- **Details on the prototypes' evaluation, see Lydia's presentation at the UFS S2S All-Hands Meeting here.**

Coupled UFS Prototypes 1–8

Prototype	Atmospheric Model C384 (~0.25 degree) horizontal resolution			Ocean Model Tripolar ~0.25 degree horizontal resolution	Wave Model Regular lat/lon 0.5 degree grid	Ice Model Tripolar ~0.25 degree horizontal resolution	Mediator
	Dynamical Model	Physics Settings & Driver	Land Model				
P1	FV3 64 layers, Non-Fractional grid (model top at 54km)	GFSv15.2, IPD driver	Noah LSM	MOM6	N/A	CICE5	NEMS
P2							
P3.1							
P4		GFSv15.2, CCPP driver			WW3		
P5						CICE6 (Mushy TD not turned on)	CMEPS
P6	FV3 127 layers, Fractional grid (model top at 80km)	GFSv16					
P7		Modified GFSv16	Noah-MP LSM			CICE6 (Mushy TD turned on)	
P8		Further Modified GFSv16	Modified Noah-MP LSM				

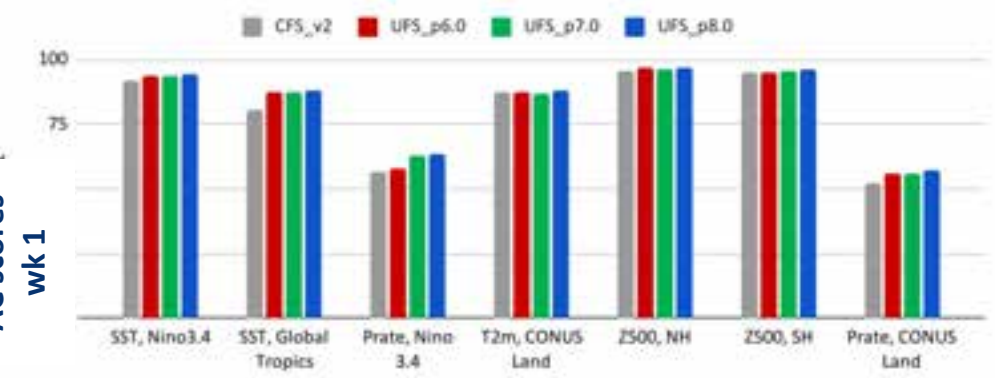
(P8 includes one-way coupled aerosols)

Changes from Prototype 7 to Prototype 8

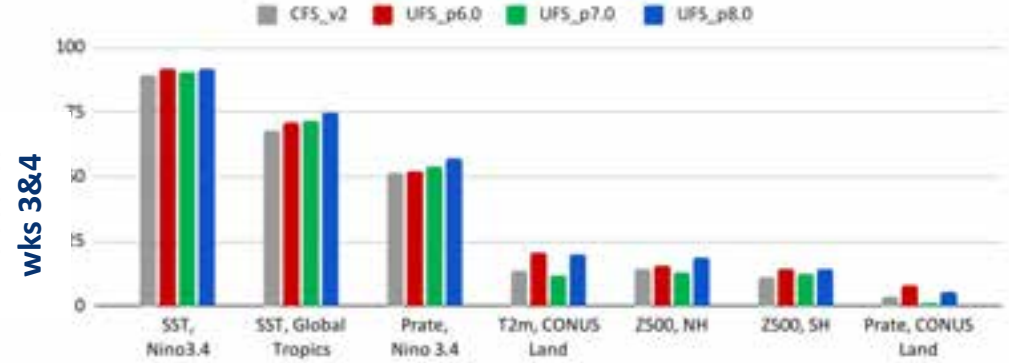
Prototype 7	Prototype 8:
GFSv16 physics Noah-MP land surface scheme	**Physics updates to GFSv16, including:** - **Thompson microphysics** - PBL and Convection updates - **Stochastic parameterization of tropical convection using cellular automata** - **Noah-MP parameterization updates (snow, coupling, roughness length, sub-grid tiling) to correct P7 shortcomings** - Reverting gravity wave drag parameterization to P6 (uGWD.v0) to reduce winter high latitude warming; orographic gravity drag deactivated
Snow ICs from **GEFSv12**. Soil ICs from spin up with Noah-MP using **GDAS** forcing	**Snow and Soil ICs** from spin up with updated Noah-MP using **NASA GLDAS** forcing (**GSWP3/GDAS** for Antarctica) and new land/lake mask
	GOCART aerosol

AC Scores for Wk1 and Wks 3-4

AC scores wk 1

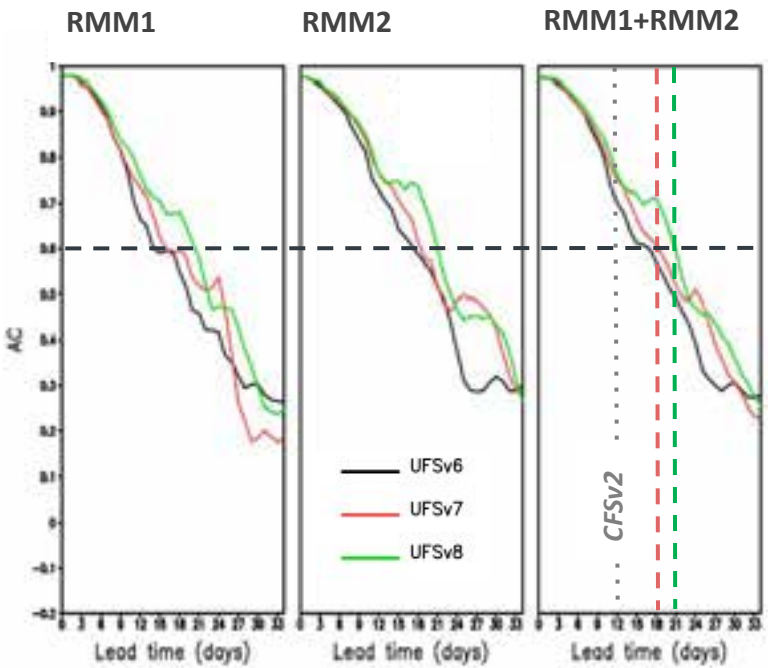


AC scores wks 3&4



POC: Lydia Stefanova

AC scores for MJO



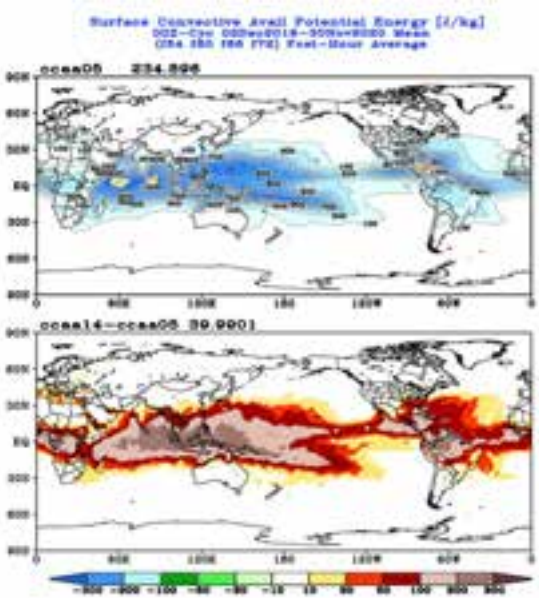
Courtesy of Wei Li, EMC

- Benchmark AC scores clearly improved in P8
- MJO skill is highest of all prototypes

MRW/S2S: Atmosphere Physics Development

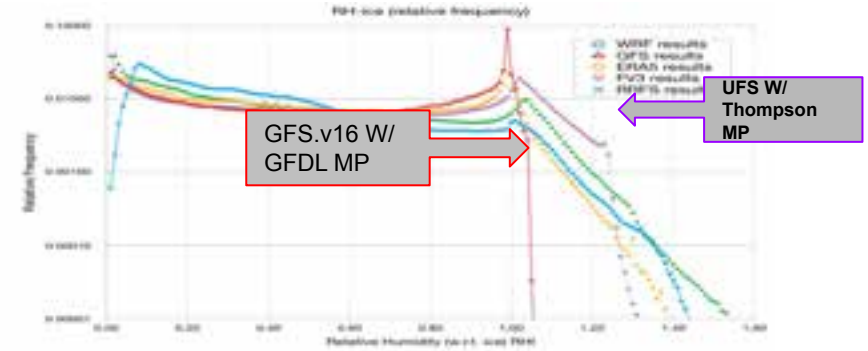
Physics update:

- Microphysics:
  - GFDL → Thompson
- Convection:
  - sa-SAS, stochastic convective organization, optimization for CAPE
- PBL/turbulence:
  - K-EDMF → sa-TKE-EDMF
- NSST is turned on
- Aerosol climatology:
  - OPAC → MERRA2



Negative biases in Surface Convective Available Potential Energy (CAPE) were reduced in the Tropics

Improved Supercooled Cloud Water



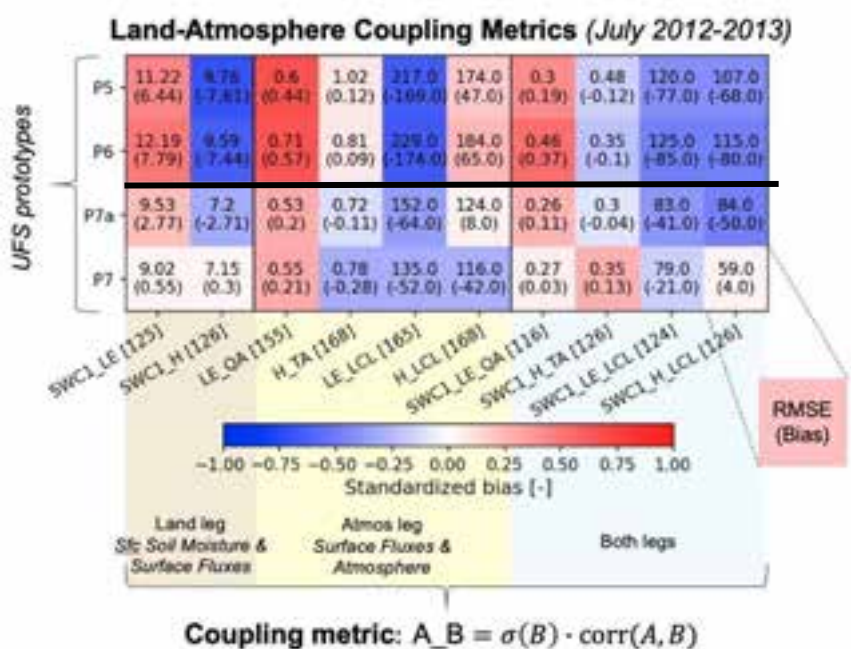
POC: Fanglin Yang, Lisa Bengtsson

MRW/S2S: Land Model Development

- **Transition from Noah LSM to Noah-MP LSM includes**
  - sub-grid tiles for vegetation and bare soil;
  - separate canopy structure;
  - groundwater transfer and storage;
  - prognostic vegetation

- **Hierarchical testing approach includes**
  - land-only model to single column model to fully-coupled system;
  - land-atmosphere coupling metrics to diagnose problem areas in the model process chain (figure right)

POC: Michael Barlage



Improvement in L-A coupling metrics (see description of the method here) from P6 to P7 (lower RMSE & bias in metrics across 171 global flux tower sites); atmosphere is responding more realistically to land anomalies (namely soil moisture). Courtesy of Paul Dirmeyer

MRW/S2S: Atmospheric Composition Development

Motivation: Incorporating aerosols improves prediction of weather for weeks 3 and 4 in ECMWF model (*Benedetti and Vitart, 2018*)

Key goal: Improved representation of global aerosol distribution and inclusion of aerosol interactions with radiation on S2S timescales for GEFS v13

Major tasks:

- Global aerosol **emissions processing system** based on HEMCO
- **Biomass burning emissions** for S2S timescales
- Improved **dust predictions**
- Quality control, bias correction, and improved aerosol speciation and vertical profile representations for **AOD data assimilation**
- Assess meteorological impacts of **aerosol-radiation interactions**

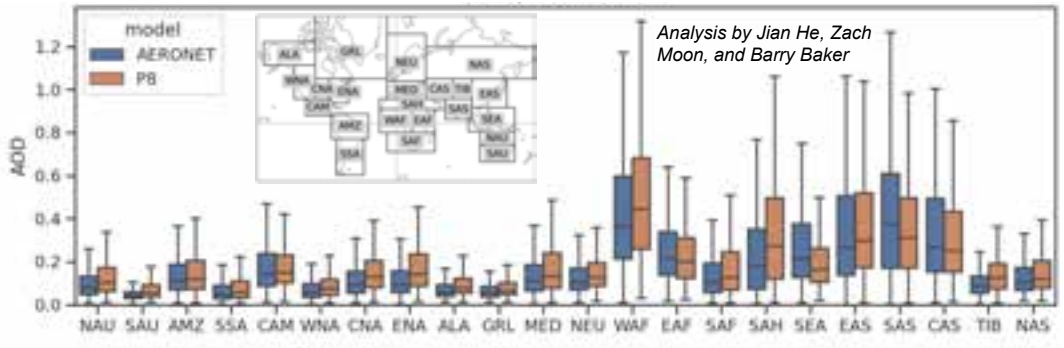
Benefits:

- Improved aerosol process descriptions
- Realistic aerosol spatial distributions and temporal variability
- Realistic representation of aerosol radiative impacts on meteorology

Code base for aerosol processes: NASA's **GOCART** repository

POCs: Greg Frost, Ivanka Stajner

Regional comparisons of **P8 Weeks 1-4 UFS-Aerosols** AOD to **AERONET** AOD



Weakly Coupled Data Assimilation for Initialization of MRW/S2S Applications

Plans:

- Weakly coupled initialization for GFSv17 and GEFSv13 (~2024) with hybrid data assimilation methods.
- Weakly coupled reanalysis (1981-present) to support SFSv1 reforecasts.
- Transition to full JEDI-based data assimilation.

Current status:

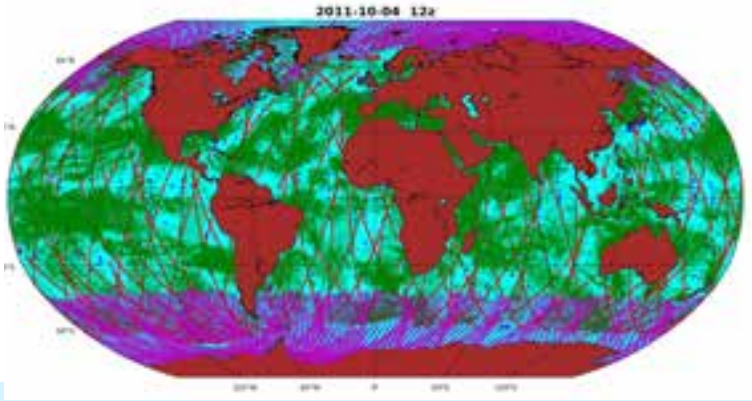
- Weakly coupled 3DVAR system for testing:
  1° UFS (FV3GFS+MOM6+CICE6)
  GSI for atm., JEDI-SOCA for ocean/sea ice
  - Upgrade to 1/4° ocean/sea ice, 1/2° atm
  - Upgrade to ensemble system

POC: Daryl Kleist and Sergey Frolov

Next Generation Global Ocean Data Assimilation System (NG-GODAS):

Co-developed by JCSDA, EMC and CPC

- Interim ocean reanalysis: 1-deg, 40 year (1979 ~2020)
- Near-real-time production for CPC ocean monitoring



Planned GEFSv13 Implementation in FY24

GEFSv13 Ensemble Configuration:

- 6-way coupled system: C384L127 Atmospheric Model, ¼ degree MOM6 with 75 levels, unstructured grids for WW3, CICE6, Noah-MP and GOCART*
- Stochastic physics in atmos, ocean and land
- Perturbations in initial conditions
- 31-member* ensemble out to 35 days+
- Weakly coupled DA
- 3-year full resolution retrospectives prior to operational implementation in FY24

- *Possible to increase ensemble size
- +Extend forecast length to 45 days
- *Decision on coupling to aerosols will be done soon

POC: Vijay Tallapragada and Jeff Whitaker

Reanalysis (Replay) & Reforecast:

- CPC/OWP requires 30-year reforecast data (1991-2022) for calibration and validation
- Reforecast will be initialized by a replay of UFS to ERA5 atmos. and ORAS5 ocean, CPC sea ice analysis, Noah-MP spin up, snow DA
- Every Monday and Thursday, 35 days, 11 ensemble members
- Every day, 16 days, 6 members
- To ensure a smooth transition from reforecast to operation, a test dataset of reforecasts initialized by the replay will be run and used to assess its similarity with reforecasts initialized from a prototype pre-operational weakly coupled ensemble DA system.

UFS S2S Application Team (AT)

https://vlab.noaa.gov/web/ufs-r2o/ufs-s2s-applications-team

UFS S2S AT Co-Leads

Cristiana Stan, GMU; **Fanglin Yang**, NWS/EMC; **Lucas Harris**, OAR/GFDL; **Wanqiu Wang**, NWS/CPC

S2S AT - Goals

- Collect and prioritize **forecast objectives** working with NWS forecasters and model users in general
- Establish **scientific goals** for the model development and ensure that they meet the NWS forecast priorities
- Promote or conduct **model evaluations** and comparisons in order to stay abreast on model performance and deficiencies

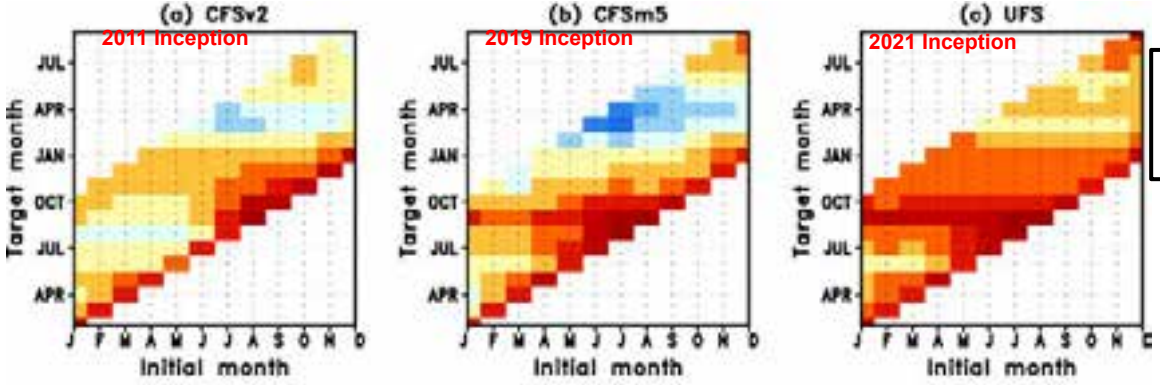
UFS S2S AT All-Hands Monthly Meetings

- **Model Evaluation** on S2S Time Scales including prediction skill of the UFS and other models
- **New diagnostics** designed to advance the understanding of Earth system variability in the S2S timescale
- **Identify projects** that can be spun up to **fill the gap** in the model evaluation
- Meeting format will be informal presentations and discussions
- Sign-up link

UFS Coupled model prototype data sets are available on the **AWS S3 Bucket** **for community access**. Community volunteers are invited for model evaluations, diagnosis and comparisons with other models.

Arctic Sea Ice Prediction Based UFS Prototype 5 (MOM6/CICE6)

(Improving Experimental Sea Ice Prediction System at NCEP/CPC)



Heidke Skill Score for Sea Ice Extent (2007-2020, 9 month hindcasts)

Users: NWS Alaska and Alaska Center for Climate Assessment and Policy (ACCAP)

UFS (MOM6/CICE6) has higher skill than CFSv2 (MOM4/SIS) and CFSm5 (MOM5/SIS) starting from all initial months.

POC: Wanqiu Wang

Thanks!

Yan.Xue@noaa.gov

UFS MRW/S2S Applications

Global Forecast System (GFS v17)
(0 – 16 days)

- Fully coupled UFS
- C768 (~13km), 127 levels
- ¼ degree ocean and sea ice
- Weakly coupled DA
- FY24: Implement GFS v17

Seasonal Forecast System (SFS v1)
(0 – 12 months)

- Fully coupled UFS
- Weakly coupled DA
- Reanalysis and reforecast (1981-present)
- FY27: Implement SFS v1

Sub-Seasonal Forecast System (GEFS v13)
(0 – 35 or 45 days)

- Fully coupled UFS
- C384 (~25km), 127 levels
- ¼ degree ocean and sea ice
- Weakly coupled DA
- 30 yr replay & reforecast (1993-2022)
- FY24: Implement GEFS v13

Coupled UFS Prototypes 1–8: Initial Conditions

Prototype	Initial Conditions Source					
	FV3			MOM6	CICE	WW3
	Atm	Soil	Snow			
P1	CDAS1			CDAS1/MOM4	CDAS1/SIS1	n/a
P2				CPC 3Dvar Analysis		
P3.1					CPC-CSIS Analysis	
P4						Generated with CFSv2 forcings
P5						
P6						
P7	GEFSv12 reanalysis	Spin up of Noah-MP with GDAS forcing	GEFSv12 reanalysis			Generated with GEFSv12 forcings
P8		Spin up of updated Noah-MP with NASA GLDAS forcing				

(P8 aerosols initialized with interpolated MERRA-2 aerosol mixing ratio values. Uptake of dust and sea salt is dynamically predicted during model integration, while anthropogenic, biogenic, wildfire, and volcanic emissions are continuously prescribed.)

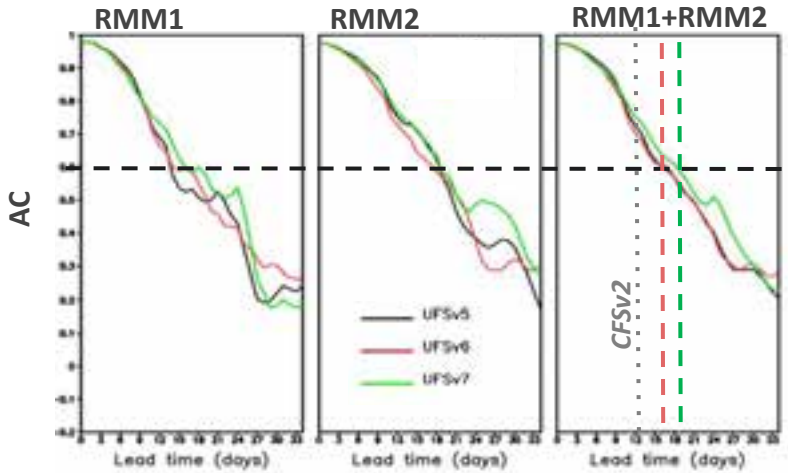
Prototype 7: Updated GFSv16 physics, Noah MP Land

Annually aggregated benchmark AC scores [%]. Green=Best overall (through P7), Red=Worst overall, ✓=Better than CFSv2, ✗=Worse than CFSv2

Week 1 AC	P6	P7
SST, Nino3.4	94.0 ✓	*93.8* ✓
SST, Global Tropics	87.6 ✓	*87.2* ✓
Prate, Nino 3.4	58.2 ✓	**63.0** ✓
T2m, CONUS Land	87.3 ↕	**86.8** ✗
Z500, NH	**96.7** ✓	96.2 ✓
Z500, SH	95.3 ✓	**96.0** ✓
Prate, CONUS Land	55.8 ✓	56.2 ✓

Week 2 AC	P6	P7
SST, Nino3.4	91.7 ✓	*91.3* ✓
SST, Global Tropics	78.6 ✓	*78.5* ✓
Prate, Nino 3.4	46.8 ✓	49.1 ✓
T2m, CONUS Land	**47.9** ✓	46.1 ↕
Z500, NH	56.6 ✓	53.3 ✓
Z500, SH	50.2 ✓	**54.3** ✓
Prate, CONUS Land	19.8 ✓	18.3 ✗

Weeks 3&4 AC	P6	P7
SST, Nino3.4	91.8 ✓	*90.9* ✓
SST, Global Tropics	71.2 ✓	*71.9* ✓
Prate, Nino 3.4	52.4 ✓	**54.4** ✓
T2m, CONUS Land	20.7 ✓	12.1 ✗
Z500, NH	15.4 ✓	**13.4** ✗
Z500, SH	14.6 ✓	12.5 ✓
Prate, CONUS Land	**8.4** ✓	**1.5** ✗



- **Improvements**: e.g. Nino 3.4 precipitation, first two weeks SH Z500, MJO
- **Degradations**: e.g. week 3&4 CONUS T2m and precipitation, all leads NH Z500

- **The skill degradations likely related to increased land temperature biases.**

Suggested Timelines for GEFSv13

Timelines:

- **Freeze/finalize replay reanalysis configuration using P8 as a baseline: September 30, 2022**
- **Finalize Ensemble Prototypes (EP3/EP4): Q1FY23**
- **Freeze/finalize reforecast configuration: Q1FY23**
- **Prepare workflows, secure resources: Q1FY23**
- **Final reforecast production: Q2FY23-Q1FY24**
- **Connect weakly coupled DA to GEFS Retrospectives: Q32023**
- **2.5 year Retrospectives: Q4FY23-Q1FY24**
- **Stakeholder and Field Evaluation: Q2FY24**
- **Code hand-off to NCO: March 1, 2024 (planned)**

MRW/S2S: Land Model Development

- **Transition from Noah LSM to Noah-MP LSM includes**
  - sub-grid tiles for vegetation and bare soil;
  - separate canopy structure;
  - groundwater transfer and storage;
  - prognostic vegetation

- **Hierarchical testing approach includes**
  - land-only to single column model to fully-coupled system;
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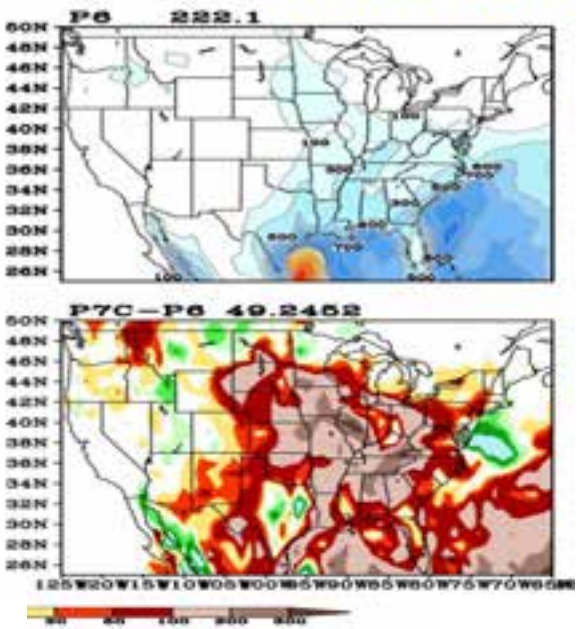
POC: Michael Barlage



CAPE was improved in UFS P8 with spin-up land initial conditions and updated land physics