Unified Forecast System -- Configurations towards S2S applications

NATIONAL WEATHER SERVICE

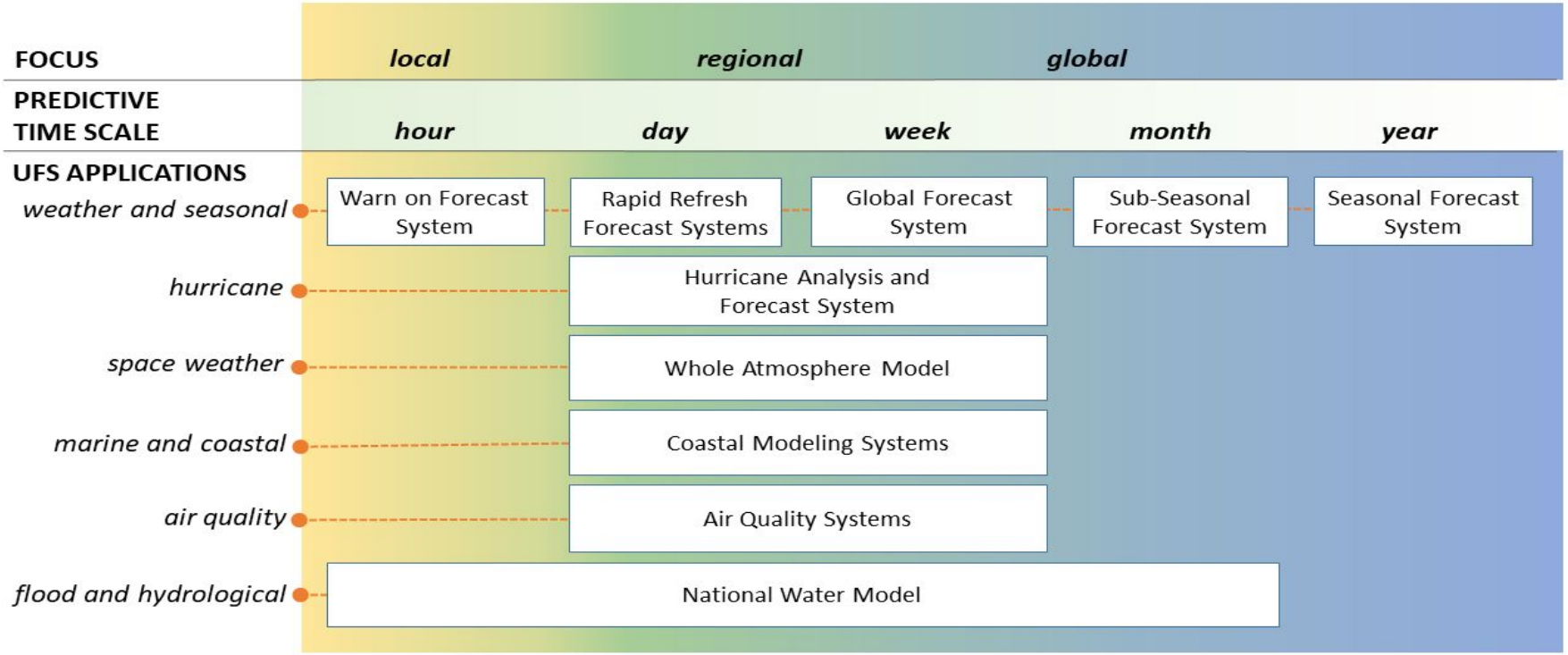
Avichal Mehra, Bing Fu, Neil Barton, Lisa Bengtsson, Fanglin Yang, Phil Pegion, Shan Sun and the UFS-MRW/S2S Team

S2S Community Workshop, June 5, 2024

Outline

- NOAA's UFS Global Coupled System: Objectives and Description
- Prototype based development of the UFS Global Coupled System
- Development of GEFS v13 (sub-seasonal scales)
- Development of SFS v1 (seasonal scales)
- Summary

NOAA's Goal: Transition to Earth System Modeling for all Operational Applications using the Unified Forecast System



Global UFS-Coupled Development Objectives

1. **Establish** forecast priorities spanning the Medium-Range (0-2 weeks) to S2S (3 weeks to 2 years) time scales, within the NOAA mission space.

2. **Identify** scientific goals that will ensure that the Medium-Range Weather(MRW) and S2S applications will meet identified forecast priorities with increased forecast skill.

3. **Design and conduct** an evaluation of MRW/S2S applications to improve performance on forecast priorities, in coordination with users and stakeholders.

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.

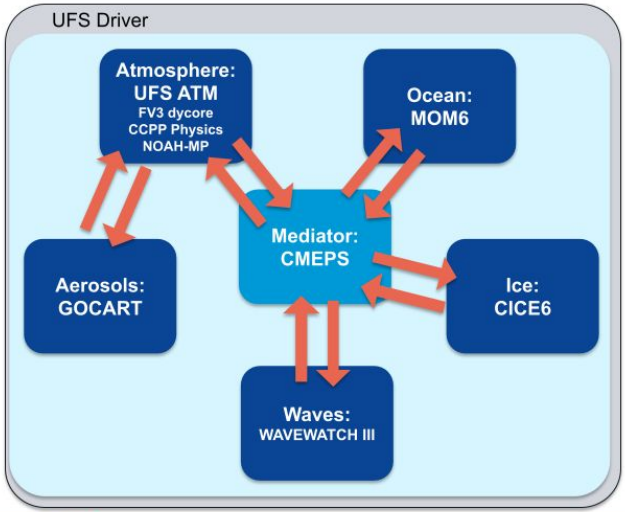
- Community components in UFS
  - Model infrastructure: ESMF, NUOPC, CMEPS
  - Atmosphere model: FV3 dycore, CCPP Physics
  - Ocean model: MOM6
  - Ice model: CICE6
  - Wave model: WW3
  - Aerosol model: GOCART
  - Land model: Noah-MP (currently)
  - Data assimilation: Joint Effort for Data assimilation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



Acknowledgements to the Global UFS Community Developers

Atmospheric Physics

NCEP/EMC: Jongil Han, Michael Barlage, Anning Cheng, Bing Fu, Hong Guan, Zhichang Guo, Sanath Kumar, Xu Li, Wei Li, Qingfu Liu, Eric Sinsky, Ruiyu Sun, Kevin Viner, Helin Wei, Bo Yang, Fanglin Yang, Rongqian Yang, Weizhong Zheng, Xiaqiong Zhou
ESRL/GSL: Ben Green, Joseph Olson, Tanya Smirnova, Shan Sun, Xia Sun, Michael Toy
JCSDA/UCAR: Dom Heinzeller,
ESRL/PSL: Lisa Bengtsson, Jian-Wen Bao, Clara Draper, Grant Firl, Songyou Hong, Philip Pegion, Dustin Swales
DTC: Ligia Bernardet, Weiwei Li, Man Zhang

Data Assimilation

NCEP/EMC: Catherine Thomas, Guillaume Vernieres, Daryl Kleist, Cory Martin, Andrew Collard, Jiarui Dong, Andy Eichmann, Travis Elless, Nick Esposito, Iliana Genkova, Azadeh Gholoubi, Tseganeh Gichamo, Brett Hoover, Xin Jin, Emily Liu, Haixia Liu, Hyun-Chul Lee, Xuanli Li, Ron McLaren, Dagmar Merkova, Sudhir Nadiga, Shastri Paturi, Ashley Stanfield, Steve Stegall, Andy Tangborn, Russ Treadon, Yaping Wang, Youlong Xia
CIRES/GSL: Bo Huang, Mariusz Pagowski
PSL: Clara Draper, Jeff Whitaker
JCSDA/UCAR: Kriti Bhargava, Travis Sluka

Coupled Model Component Development

NCEP/EMC: Jessica Meixner, Jiande Wang, Lydia Stefanova, Jun Wang, Yuejian Zhu, Neil Barton, Saeideh Banihashemi, Arun Chawla, Bing Fu, George Gayno, Robert Grumbine, Walter Kolczynski, Matthew Masarik, Avichal Mehra, Ali Salimi-Tarazouj, Denise Worthen
ESRL/GSL: Ben Green, Shan Sun
ESRL/PSL: Lisa Bengtsson, Phillip Pegion
GFDL: Alistair Adcroft, Rusty Benson, Stephen Griffies, Robert Halberg, Matthew Harrison, Brandon Reichl, Marshall Ward
NCAR: Alper Altuntas, Gokhan Danabasoglu, Keith Lindsay, Gustavo Marques
NRL/ESMF: Gerhard Theurich
GMU: Ben Cash, Jim Kinter, Lawrence Marx, Cristiana Stan
FSU: Alexandra Bozec, Eric Chassignet, Alan Wallcraft
NASA: Akella Santha
Univ. Alaska: Katherine Hedstrom
U. Mich.: Christiane Jablonowski
Univ. Victoria: Andrew Shao

Field Evaluation

NCEP/EMC: Alicia Bentley, Mallory Row, Shannon Shields
NWS Regional SSDs
NCEP Centers

Products

NCEP/EMC: Hui-Ya Chuang, Wen Meng, Andrew Benjamin, L. Gwen Chen, Yali Mao, Bo Cui

Atmospheric Composition

NCEP/EMC: Partha Bhattacharjee, Jeff McQueen, Raffaele Montuoro, Li Pan, Ivanka Stajner
ARL: Barry Baker, Patrick Campbell, Rick Saylor
ESRL/GSL: Georg Grell, Shan Sun, Li (Kate) Zhang
CSL: Gregory Frost, Jian He, Stuart McKeen, Siyuan Wang
NESDIS/STAR: Ethan Hughes, Shobha Kondragunta, Xiaoyang Zhang

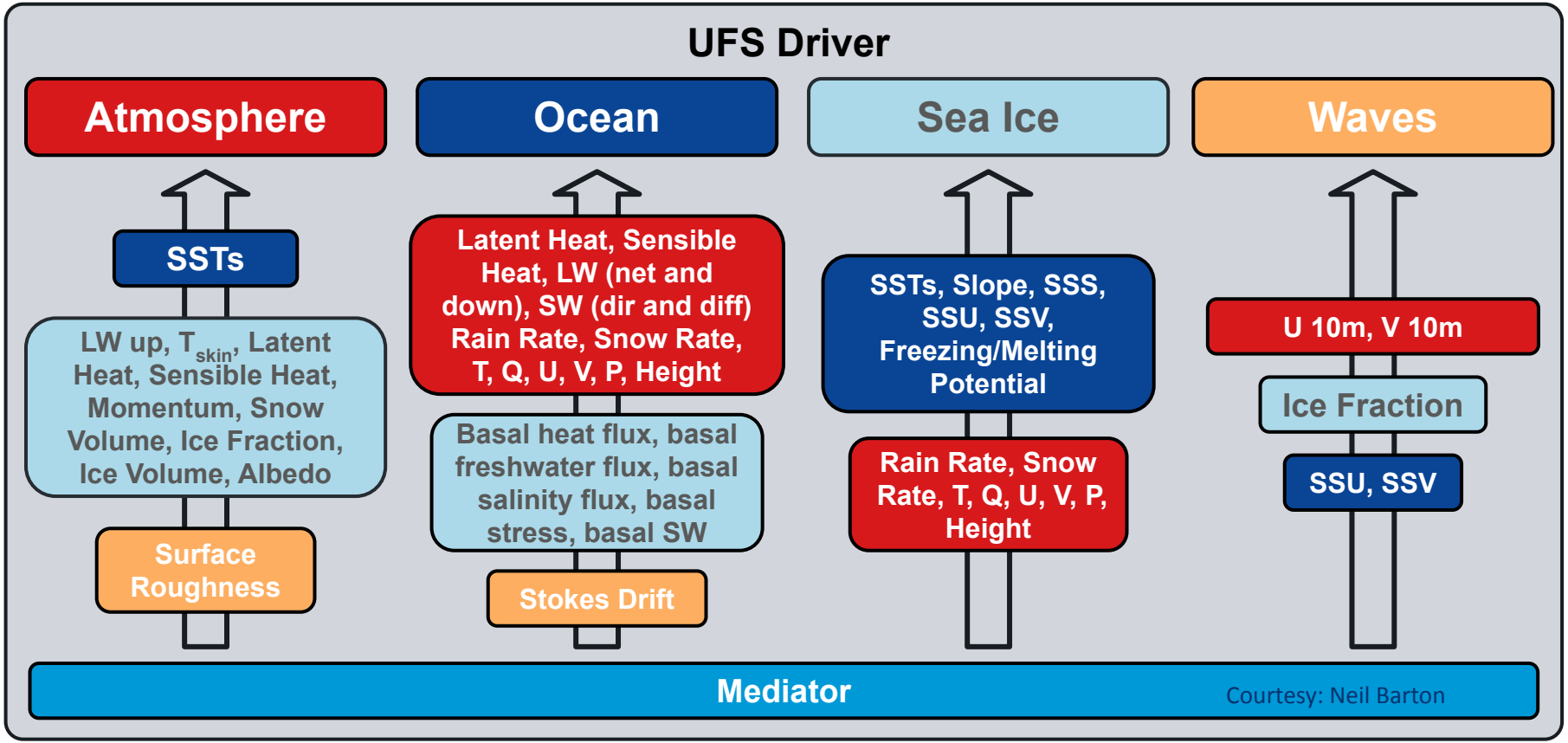
Infrastructure

NCEP/EMC: Rahul Mahajan, Jun Wang, Kate Friedman, Lin Gan, George Gayno, Ed Hartnett, Dusan Jovic, Walter Kolczynski, Hang Lei, Terry McGuinness, Alex Reichert, Mallory Row, Edward Stafford, Henry Winterbottom, Jack Wollen, Denise Worthen
Redline Performance: David Huber

Coupled Model Evaluation

NCEP/EMC: Lydia Stefanova, Jiande Wang, Michael Barlage, Neil Barton, Partha Bhattacharjee, Zhichang Guo, Robert Grumbine, Wei Li, Avichal Mehra, Ghazal Mohammadpour, Jiayi Peng, Sulagna Ray, Huug van den Dool, Helin Wei, Youlong Xia, Weizhong Zheng
CPC: Laura Ciasto, Yanyun Liu, Wanqiu Wang, Jieshun Zhu
ESRL/PSL: Chris Cox, Maria Gehne, Juliana Dias, Zachary Lawrence, Amy Solomon
GMU: V. Krishnamurthy, Eunkyo Seo, Cristiana Stan

UFS Coupling Schematic



Benchmark Runs for Prototype Evaluation

Deterministic 35-day free forecasts

Strategy: Include a variety of distinct cases, yet keep short enough to be run multiple times. Compromise between computational resources and need for large enough sample for statistically meaningful metrics.

- April 2011 to March 2018 (Includes both El Niño and La Niña events, and years of very low ice extent)
- Initialized from the 1st and 15th of each month
- 7 years, 168 forecasts

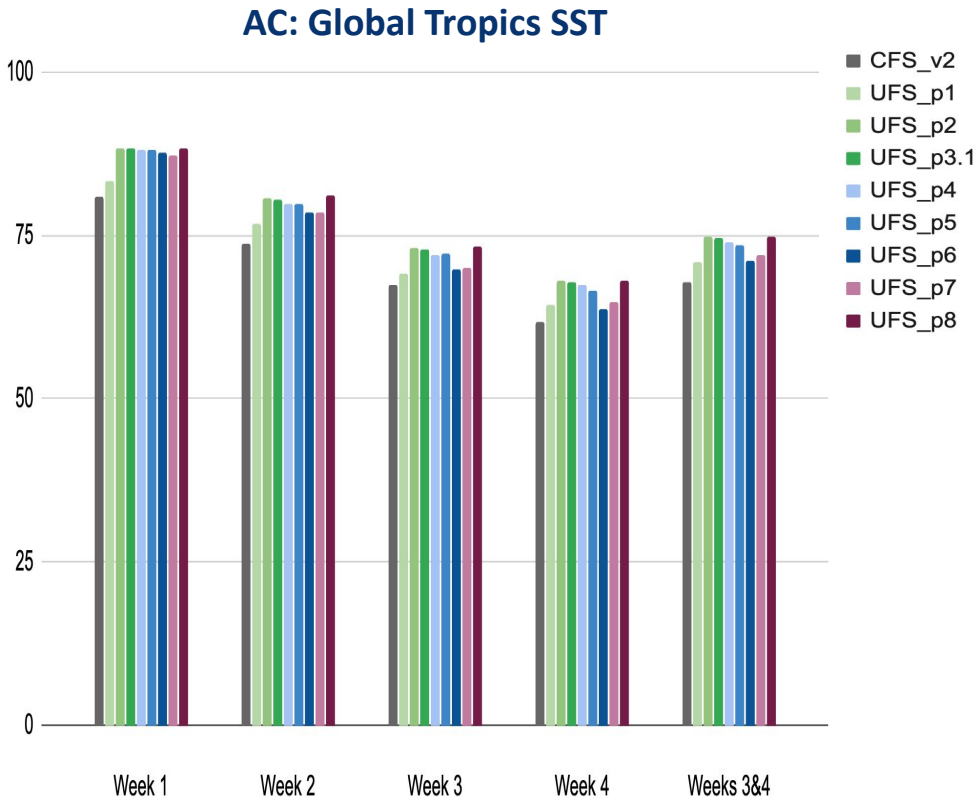
Evaluated with fixed metrics & code against fixed reference data

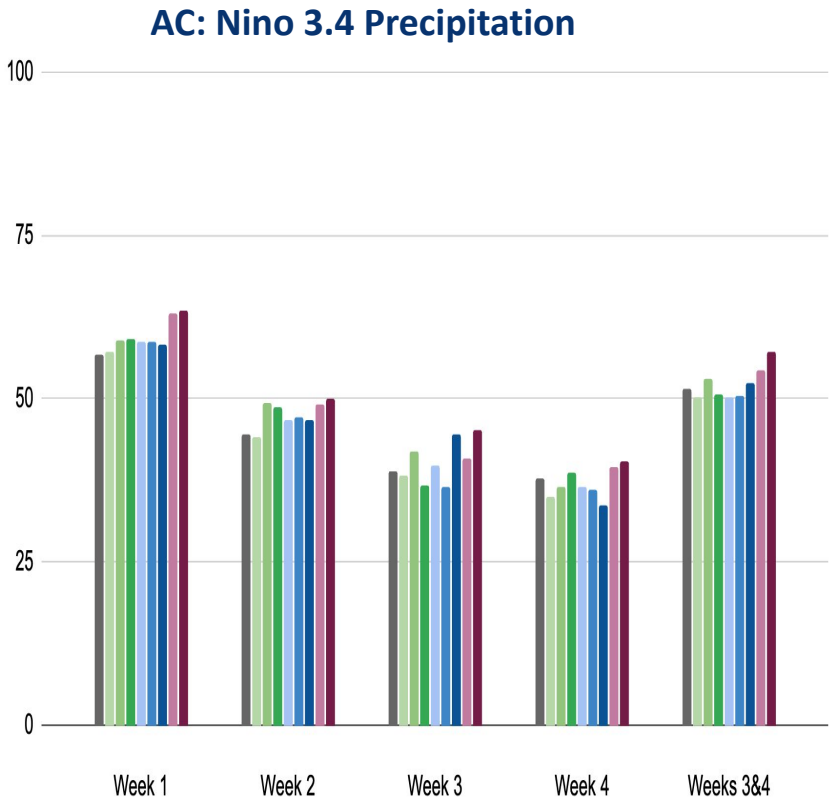
Coupled UFS Prototypes 1–8

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)

Anomaly Correlations in Benchmark UFS Prototypes (P1–P8)





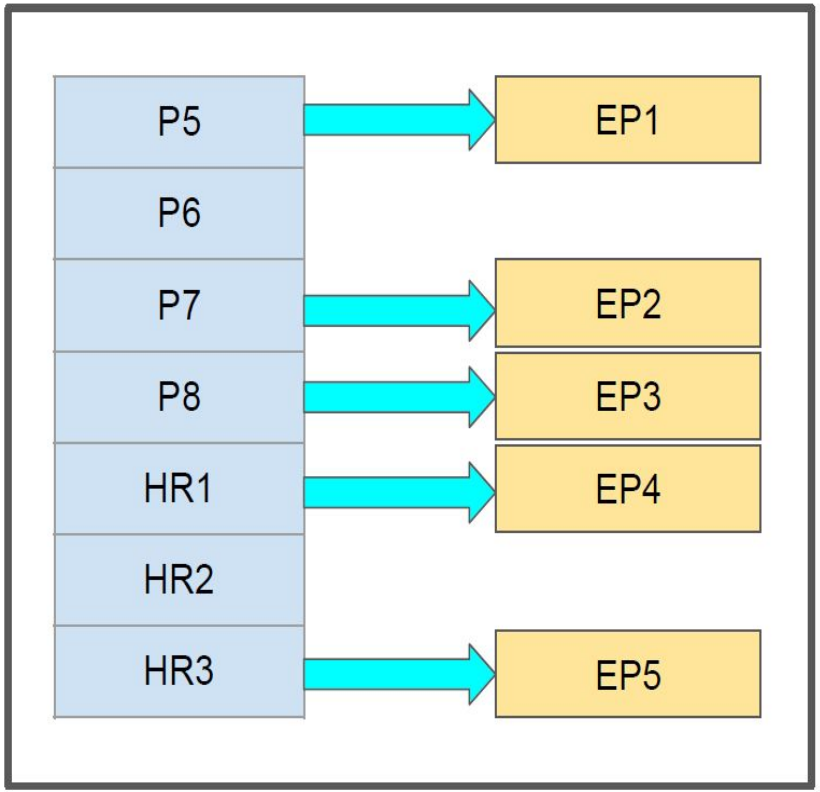
Evolution of Physics Configurations for recent UFS Experiments

Experiment	PBL	Microphysics	Deep Convection	Shallow Convection	Radiation	Gravity Wave Drag
P8	TKE-EDMF Positivie definite massflux scheme, reduced entrainment rate	Thompson MP + Semi-Lagrangian Sedimentation + refined ice microphysics	saSAS Cellular automata convective org scheme. Positivie definite massflux scheme	saMF Positivie definite massflux scheme	RRTMG	GWDv0
HR1	TKE-EDMF	Thompson MP Improve radiative fluxes and cloud cover	saSAS Prognostic closure	saMF Prognostic closure	RRTMG Couple convective cloud to radiation	GWDv0
HR2	TKE-EDMF wind shear effect and TKE dependent entrainment. CONUS CAPE enhancement	Thompson MP Reduce stratus and downwelling rad. fluxes	saSAS wind shear effect and TKE dependent entrainment	saMF	RRTMG	GWDv0
HR3	TKE-EDM	Thompson MP	saSAS	saMF	RRTMG Address excessive large net SW net to ocean at low sun angle	GWDv1

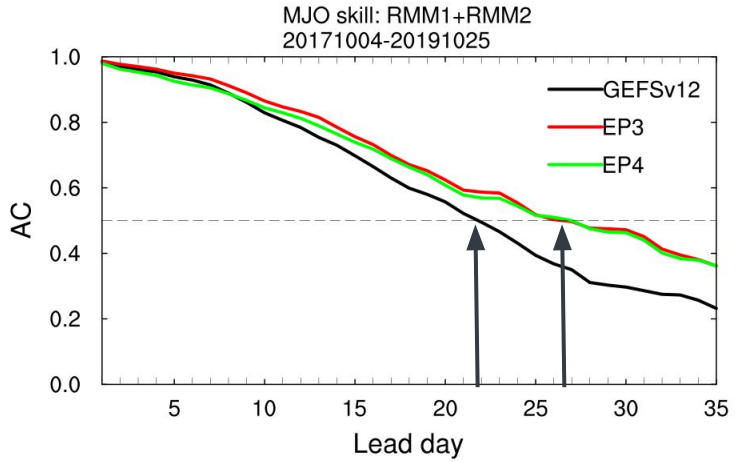
Global Ensemble Forecast System v13 Upgrade

	GEFS v12 to GEFSv13
Model	FV3/Noah_MP MOM6/CICE6/WW3/GOCART (two-way coupling)
Resolution	C384L127 (~25km, 80km top)
Physics	GFSv17 physics + Stochastic physics (SPPT, SKEB, ocean)
Ensemble Forecast - Realtime	GSI (Atmos, Soil), JEDI Ocean/Sea Ice, JEDI Snow 16 days (06Z, 12Z and 18Z), 31 members 48 days (00Z), 31 members
Ensemble Forecast - 31-years Reforecast	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
Evaluation	Weather/hurricane/waves: 2.5 year retrospective experiments Subseasonal: 31-year reforecasts

Fully Coupled Global Ensemble Forecast System (GEFSv13)



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

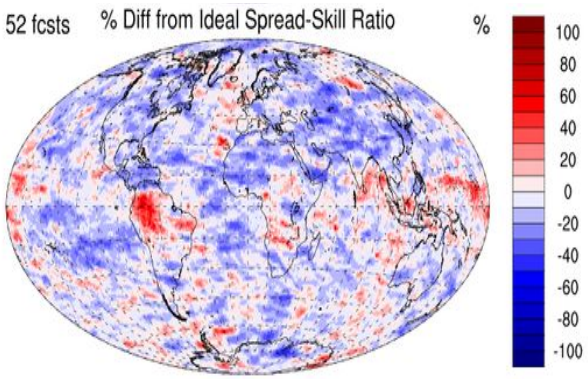


EP3 and EP4 both have higher MJO skill (RMM1+RMM2) than GEFSv12 for longer lead times (extend skill for 4-5 days).

Courtesy: Bing Fu

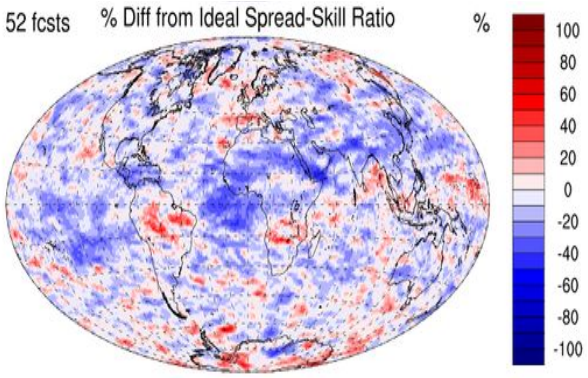
Ensemble spread changes in different EPs

% diff from ideal spread-skill ratio for winter cases at 7-day forecast



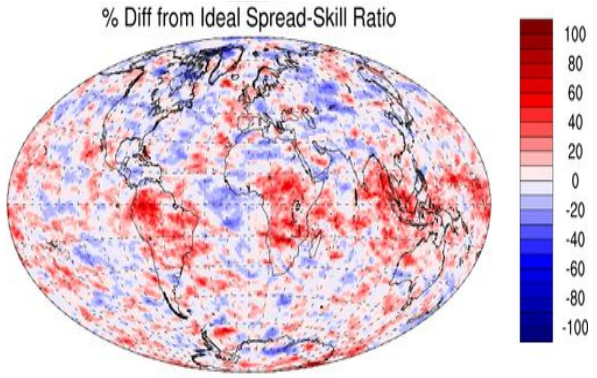
EP1

SPPT: 25% off GEFSv12
SKEB: 0.7



EP2

SPPT: 30% off GEFSv12
SKEB: 0.7



EP3

SPPT: 25% off GEFSv12
SKEB: 0.8

- Stochastic physics has to be adjusted to obtain a better representation of model uncertainty

Courtesy: Bing Fu

Physical tendency changes with physics updates

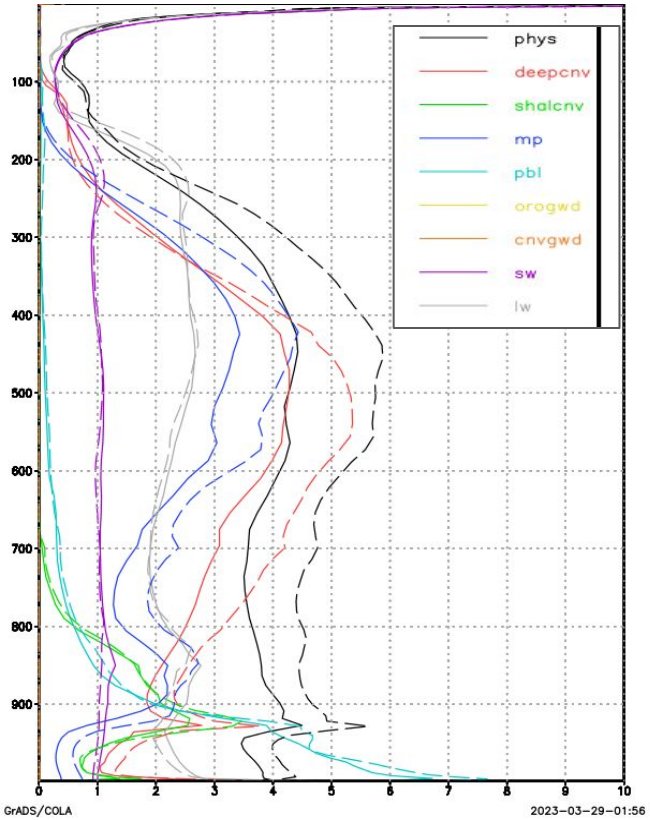
Physical tendency comparison:
EP3 (solid) vs EP4 (dash)

(p02: 20171004 00Z 252h forecast)

Averaged absolute DT/Dt (1e-5)
Over (40E-150W,20S-20N)

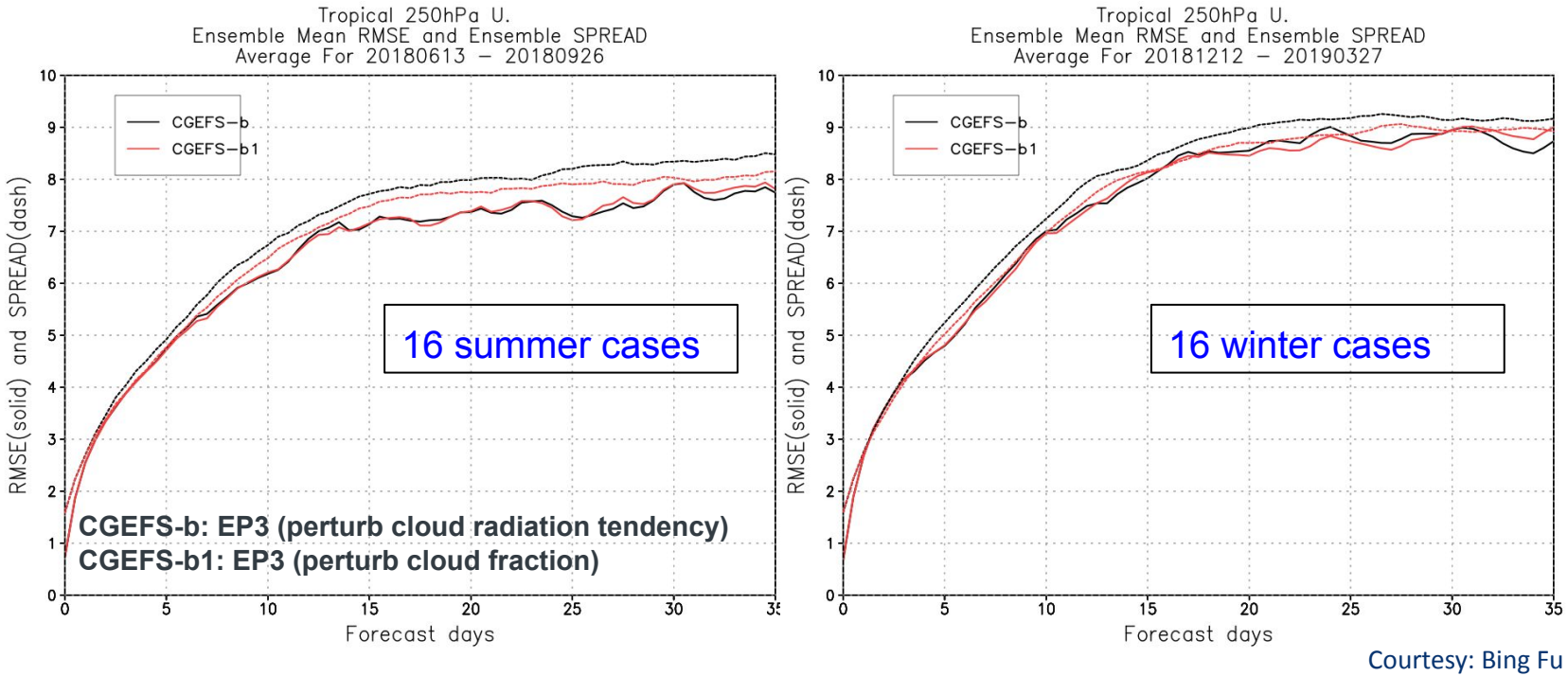
Physics tendency increases from EP3 to EP4 which led to additional reduction of SPPT.

EP3: 25% off SPPT from GEFSv12
EP4: 30% off SPPT from GEFSv12



Courtesy: Bing Fu

Perturbation method adjustment to reduce overdispersion of tropical winds



Courtesy: Bing Fu

- Switching from cloud radiation tendency perturbation to cloud fraction perturbation to reduce over-dispersion of 250 hPa tropical winds without impact on model RMSE

NOAA's Seasonal Forecast System (SFS) to replace CFS

GOALS:

- **Balanced initializations across interfaces**
- **Minimize systematic drift from initial conditions**
- **Best estimation of uncertainties in ensemble forecasts**
- **Reduce systematic biases and improve forecast skill**
- **Enhanced infrastructure for future needs**

SFS will be:

- **Enabled to run on the cloud**
- **Incorporated into UFS repositories**

- 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

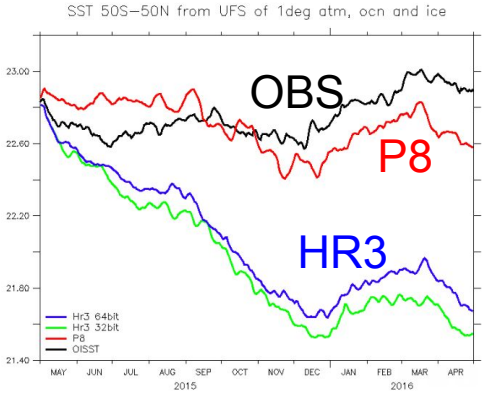
Example of scale dependent challenges seen in SFS

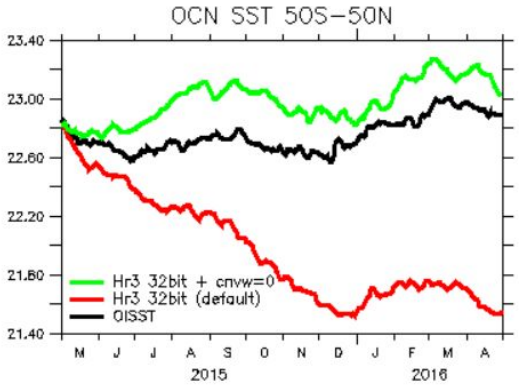
L. Bengtsson (PSL), S. Sun (GSL), W. Li (DTC), F. Yang, J. Han, R. Sun (EMC), X-W Quan (PSL)

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**

P8 → **HR1**

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**





Examination by Shan Sun, GSL

This drift is only seen at 100 km res simulations

Remove conv. cloud from radiation-cloud interaction

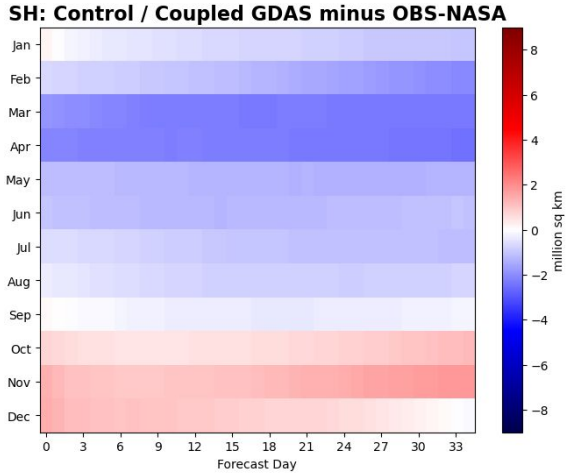
Include conv. cloud from radiation-cloud interaction

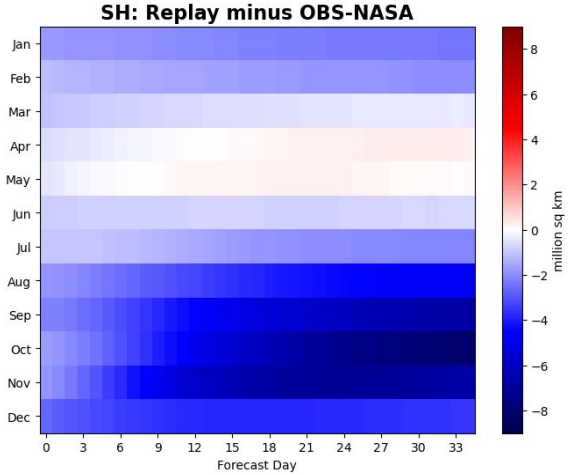
Courtesy: Lisa Bengtsson

Sea Ice Biases in Initial Replay

- Southern Hemisphere sea ice forecasts from the initial replay had larger biases compared to the coupled GDAS initial conditions

- Initial replay analysis did not include routines to update the sea ice



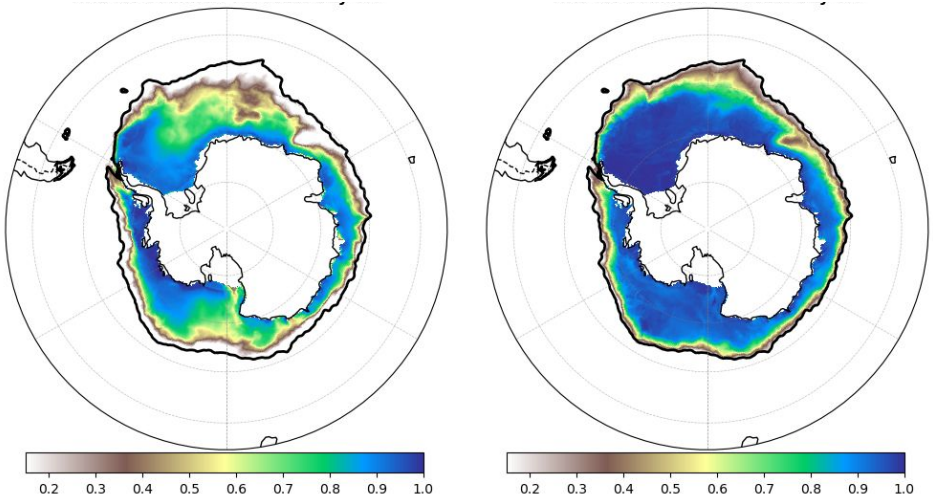


Courtesy: Neil Barton

Rerun Replay Sea Ice Updates

- JEDI SOCA Sea Ice Updates Used
  - Variables: ice concentration, ice thickness, snow depth

Sea Ice Concentrations at Initialization (31 dates)

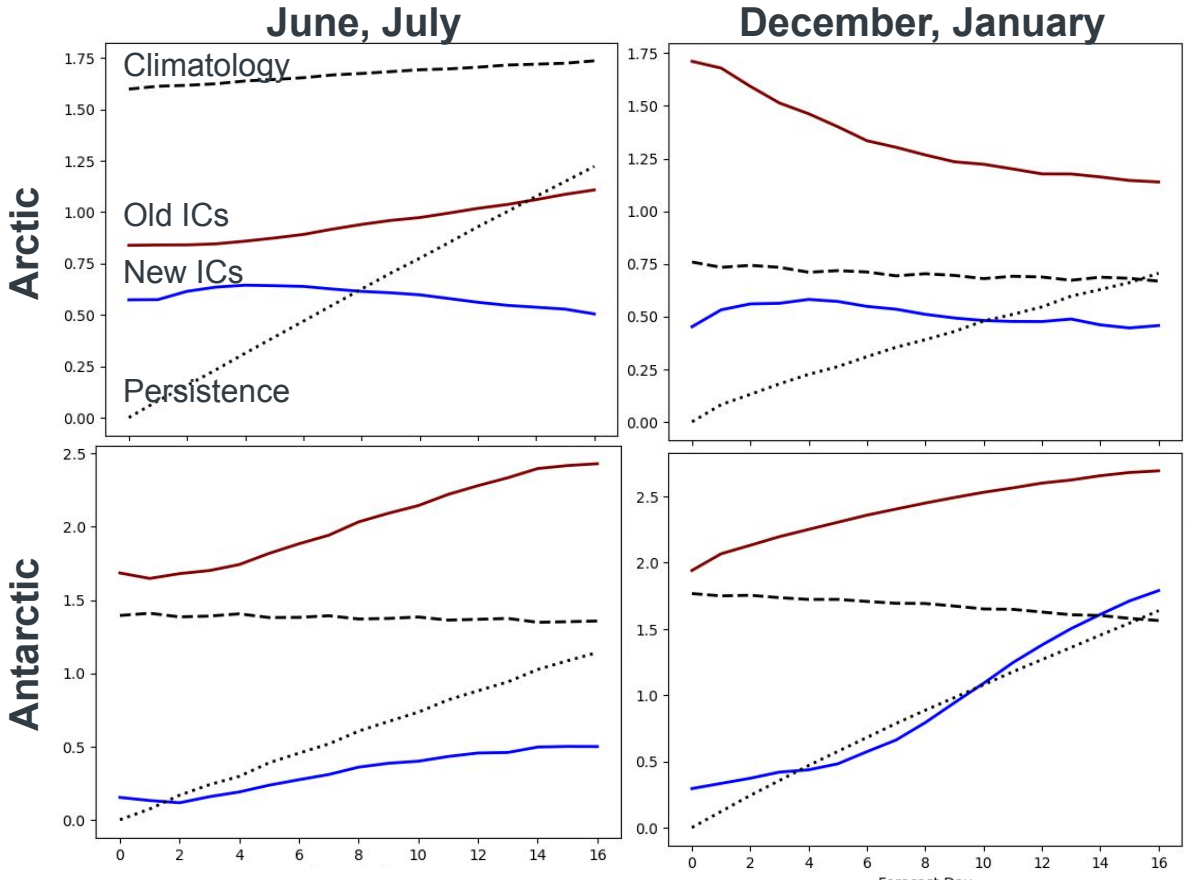


Initialized through replay process with atmos and ocean updated

Initialized through replay process with atmos, ocean, and **sea ice** updated

Courtesy: Neil Barton

Integrated Ice Edge Errors (IIEE)



Runs with updates CICE ICs produce results closer to observations throughout the forecasts

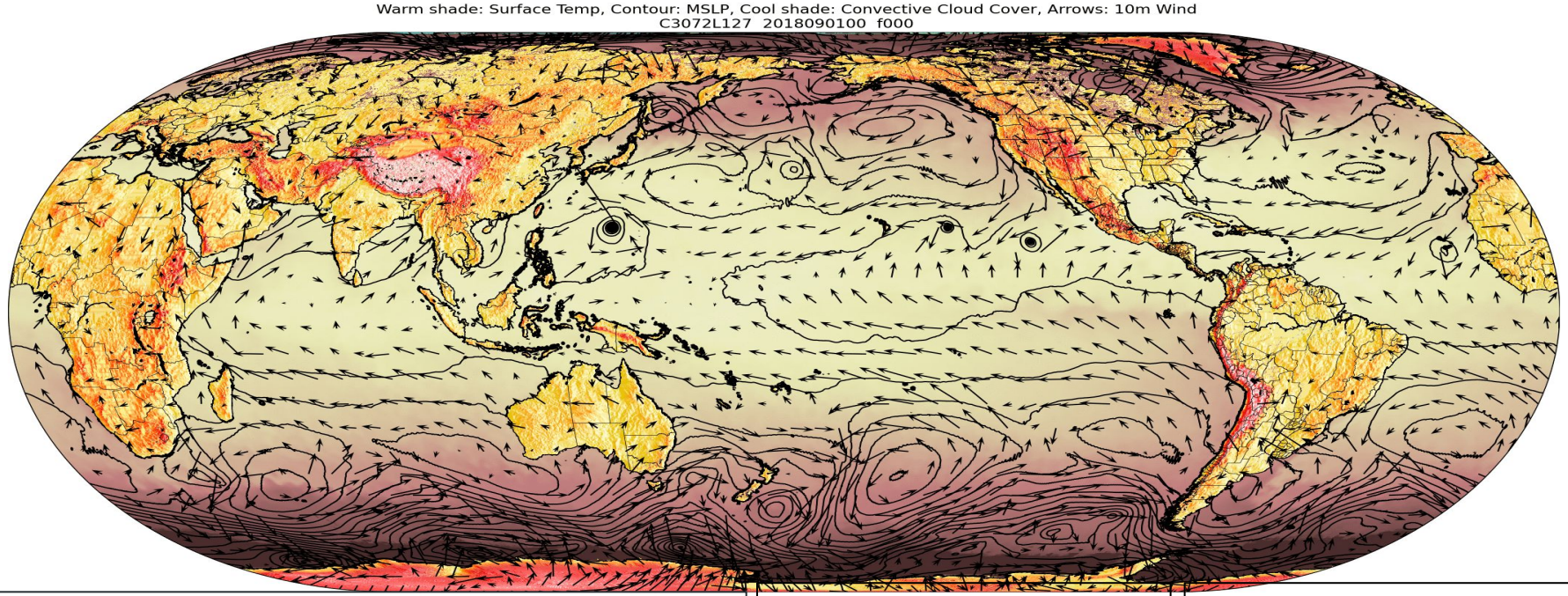
Courtesy: Neil Barton

Summary

- Coupled UFS Applications are being targeted for future global operational implementation at NWS/NCEP.
- There are many contributions from the UFS-community including for the component Earth System Models, atmospheric physics, coupling of models, data assimilation/initializations, infrastructure, and more.
- NCEP and the community are actively conducting prototype experiments which target applications at S2S time scales and seeking improvements.
- NCEP/EMC looks forward to these continued collaborations with the broader community as we advance towards our operational goals.

A Six-Way Global Coupled Unified Forecast System (UFS) -- a first for NOAA/NWS

UFS Earth System Model Components:



A fully coupled UFS serves as a foundation for future operational global forecast systems at NOAA/NWS/NCEP ranging from weather to subseasonal to seasonal scales.

- FV3 (Atmosphere)
- MOM6 (Ocean)
- CICE6 (Sea Ice)

- WW3 (Waves)
- NOAH-MP (Land)
- GOCART (Aerosols)

Animation Courtesy: S. Moorthi and Keqin Wu, NWS/NCEP/EMC

Questions?

Extra slides

Global Forecast System v17 Upgrade

	GFSv16 to GFSv17
Model	FV3/Noah_MP MOM6/CICE6/WW3 (two-way coupling)
Resolution	C786L127 or C1152L127 (13km or 9km, 80km top)
Physics	Thompson MP, CA, UGWD, tuning of convection, surface and PBL physics schemes, MERRA-2 aerosol climatology
Deterministic Forecast (up to 16 days)	GSI (atmos, soil), JEDI Ocean/Sea Ice, JEDI Snow 16 days from 00Z, 06Z, 12Z and 18Z
Evaluation	2 year retrospective and real-time runs MEG Group, Field evaluation focusing on hurricane, winter storms, severe weather, extreme temp and prec., waves, sea ice, ocean Evaluation of impacts on downstream models

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.