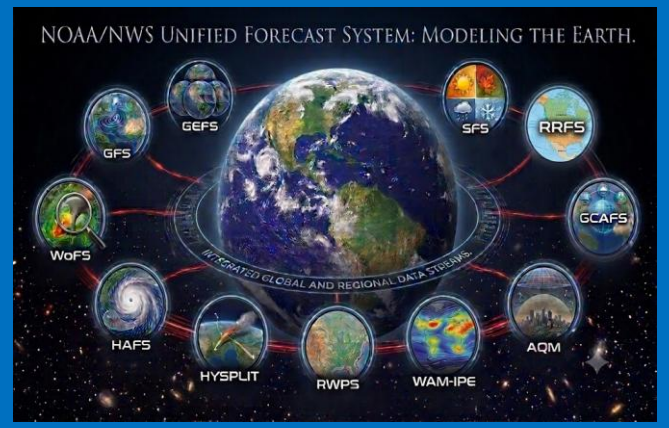
Development of the NOAA Unified Forecast System and Its Applications to Subseasonal and Seasonal Prediction

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Acknowledgment: for contributions made by Michael Barlage[2], Yangxing Yang[3], JieShun Zhu[4], Lisa Bengtsson[1], Shan Sun[5], Jiande Wang[3], Dmitry Dukhovskoy[2], Ruiyu Sun[2], Jongil Han[2], John Steffen[3], Xiao Luo[3], Santha Akella[2], Karina Asmar[3], Eric Sinsky[3], Hong Guan[3], Robert Hallberg[6], Yan Xue[1], Wanqui Wang[4]

[1]NOAA/OAR Physical Science Lab, [2]NOAA/NWS Office of Modeling and Development, [3]Lynker, [4]NOAA/NWS Weather Prediction Center, [5]NOAA/OAR Global Science Lab, [6]NOAA/OAR Geophysical Fluid Dynamics Lab



Introduction & Current State

Single Operational Coupled Global Model

Climate Forecast System, v2 (CFSv2)

- **Primary Design:** Developed as a seasonal forecast model.
- **Extended Scope:** Fills critical operational requirements for coupled Weeks 3–4 predictions.

Other Operational Models

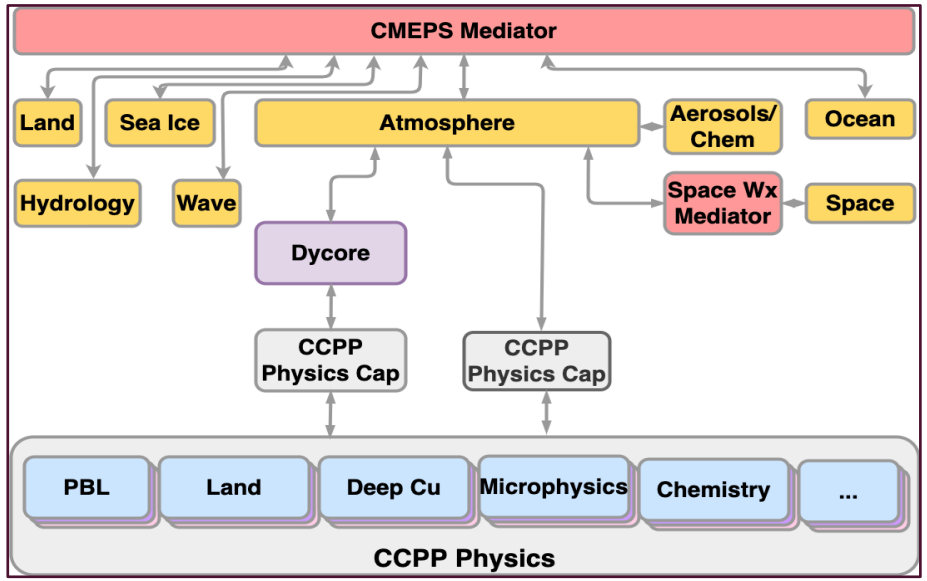
- **GFS (Global Forecast System):** Deterministic out to Day 17 (Currently uncoupled).
- **GEFS (Global Ensemble Forecast System):** 31 members out to Day 35 (Currently uncoupled).
- **HAFS (Hurricane Analysis & Forecast System):** Regional coupled model with high resolution moving nests..

Presentation Focus

An overview of upcoming global models targeted for operations in the next year or so.

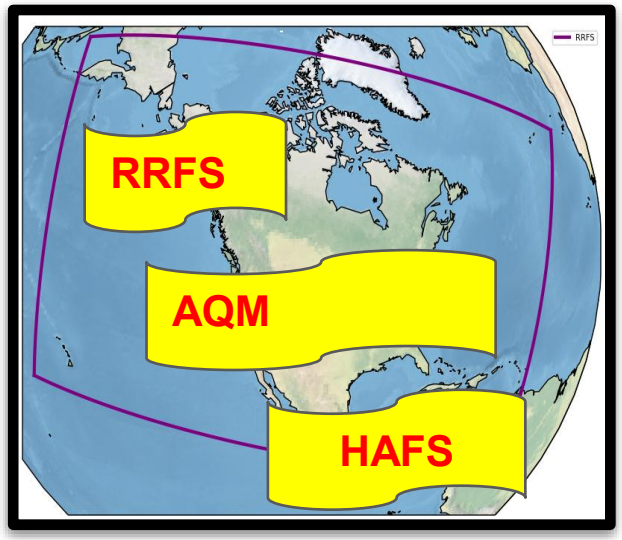
UFS
UNIFIED FORECAST SYSTEM

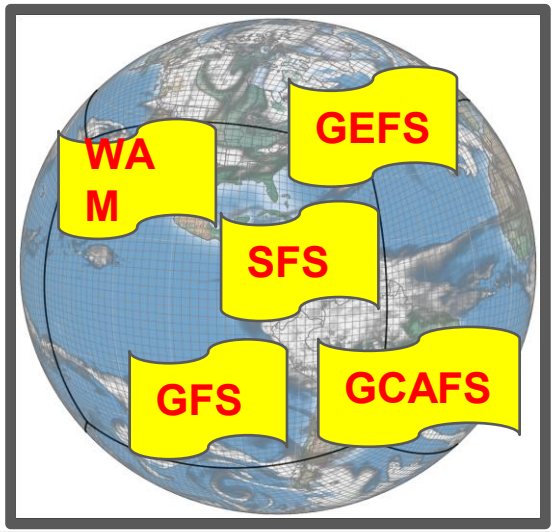
open, community-based Earth system modeling framework developed by NOAA and partner researchers to build next-generation weather and climate predictions



- WAVEWATCH III wave
- CICE6 sea-ice
- GOCART aerosols
- CMAQ air quality

- CMEPS mediator
- FV3 dycore
- CCPP physics
- MOM6 ocean
- Noah-MP LSM





Regional:

HAFS - Hurricane Analysis and Forecast System (~4km/2km)

RRFS - North America Rapid Refresh Forecast System (3km)

AQM - North American Air Quality Model (12km)

Global:

GFS - Medium-Range Deterministic Weather Forecast Model (9km)

GEFS- Global Ensemble Sub-Seasonal Forecast System (25km)

GCAFS- Global Chemistry and Aerosol Forecast System (25km)

SFS - Seasonal Forecast System (50km)

WAM - Whole Atmospheric Model (up to 500 km; 100km)

Overview of current GFS



- Global deterministic model: GFSv16
  - FV3 dycore, C768 (~13 km), L127 (~80 km)
  - One-way coupled with wave model
- Run 4 times a day out to 16 days
  - Hourly output for first 120 hours
  - 3 hourly for days 6-16
- Global Data Assimilation System (GDAS)
  - GSI-based Hybrid 4DEnVar + 4D-LETKF
  - 80 ensemble members: FV3 dycore, C384 (~25 km), L127
- Provides initial and/or boundary conditions for multiple downstream forecast systems:
  - Global Ensemble Forecast System (GEFS), HAFS, AQM, RTOFS, etc.
  - Waves provides ICs & BCs to HAFS waves and ICs to NWPS

Global Forecast System (GFS) v17 forecast model

NOAA's First Fully Coupled Earth System Model for Medium-Range Weather Prediction

Forecast Model

Atmosphere: FV3 dynamical core

- **13 km → 9 km** horizontal resolution
- Fractional land-sea mask
- new Microphysics: GFDL → Thompson Microphysics
- Updates in Convection, PBL, and GWD, etc
- new land model: Noah → Noah-MP

Wave Model: WAVEWATCH III

- Unstructured grid (~15km)
- Feedback to ATM & OCN

New Components:

- **Ocean: MOM6** (¼° tripolar, 75 hybrid layers)
- **Sea-ice: CICE6** (¼° tripolar)
- **Coupler: Community Mediator for Earth Prediction Systems (CMEPS)**

Global Forecast System (GFS) v17 Data Assimilation

NOAA's First Fully Coupled Earth System Model for Medium-Range Weather Prediction

Data Assimilation

- Control member has a 9 km resolution in atmosphere, 25 km in marine components
- 80-member ensemble is at 25 km in all components
- Weakly coupled data assimilation with a 6-hour DA window

Atmospheric Data Assimilation

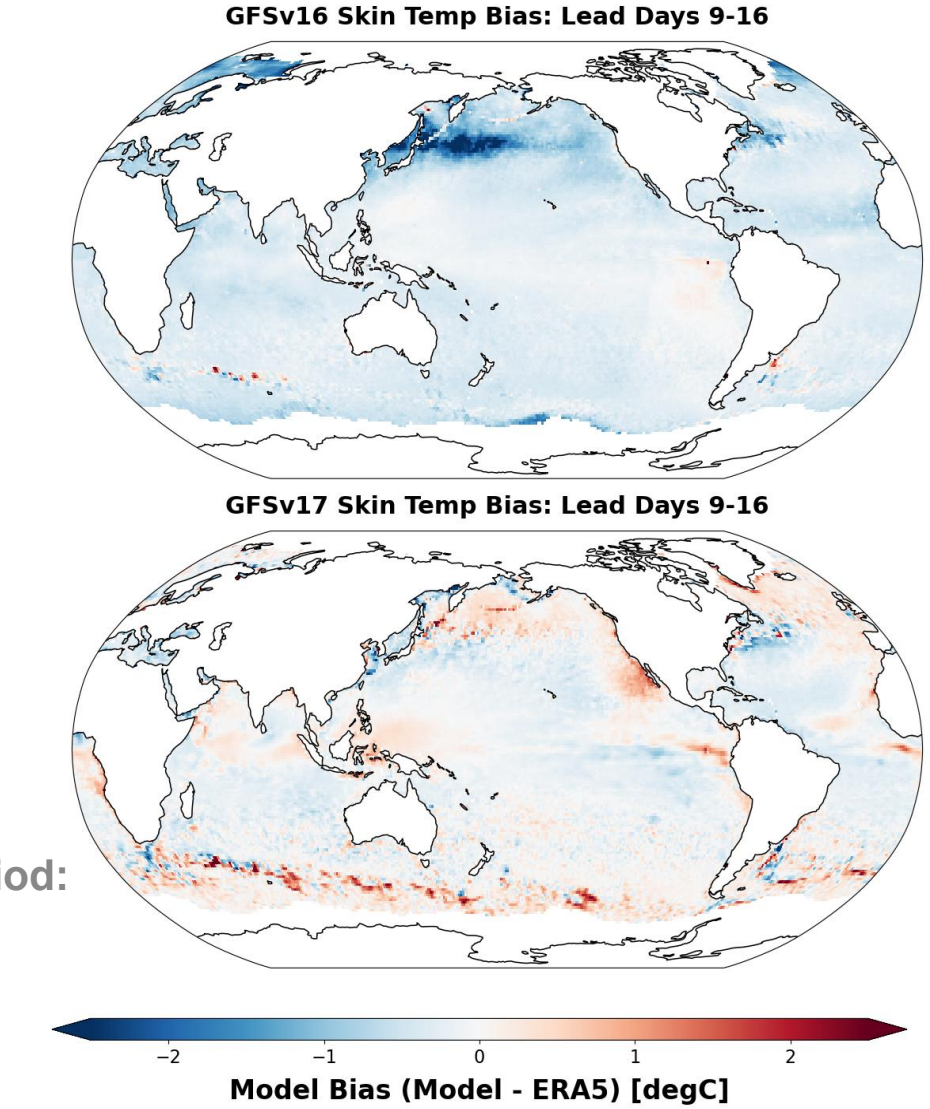
- **Continue using GSI-based algorithms**
  - *Deterministic analysis:* Hybrid 4-DEnVar with new multiscale DA.
  - *Ensemble analysis:* 4D-LETKF.
- **Scale-dependent localization** - SDL
  - *Buehner and Shlyaeva 2015, Tellus; Huang et al. 2021, MWR; Yokota et al 2024, JAMES*
  - Unified scheme has now been implemented into GSI for use in global and regional applications (*Sho Yokota, OU MAP*)
- **NOAA's first global soil moisture and soil temperature analysis**
  - Strongly coupled,EnKF
  - The GSI-based EnKF control vector is expanded to include soil moisture and soil temperature in the top 50 cm (2 layers)
  - adds the assimilation of T2m and q2m obs into the land and atmosphere

Ocean and Ice Data Assimilation

- Sea-Ice Ocean and Coupled Assimilation (SOCA)
- Algorithm
  - *Deterministic analysis:* **JEDI-based 3DVar-FGAT**
  - *Ensemble analysis:* **No ensemble ocean/ice DA.** Ensemble forecast will be coupled and **recentered** about the deterministic forecast.
  - *6 hour DA window:* For SST retrievals, drifters, and sea-ice concentration
  - *2 days overlapping DA window:* Looking up to 2 days in the past for Argo profiles and altimeters
- Observations
  - In-situ temperature and salinity observations
  - Satellite data includes along-track sea surface height, sea surface temperature, sea ice concentration.

Ocean Component: MOM6

- Developed primarily at NOAA/GFDL with input from MOM6 community
- Coupled with ice, atmosphere and wave models to simulate 3D ocean temperature, salinity, currents and surface height with state-of-art OM4 Physics package [Adcroft, 2019]
- Provides SST to atmospheric model which calculates a near-sea-surface temperature (NSST).

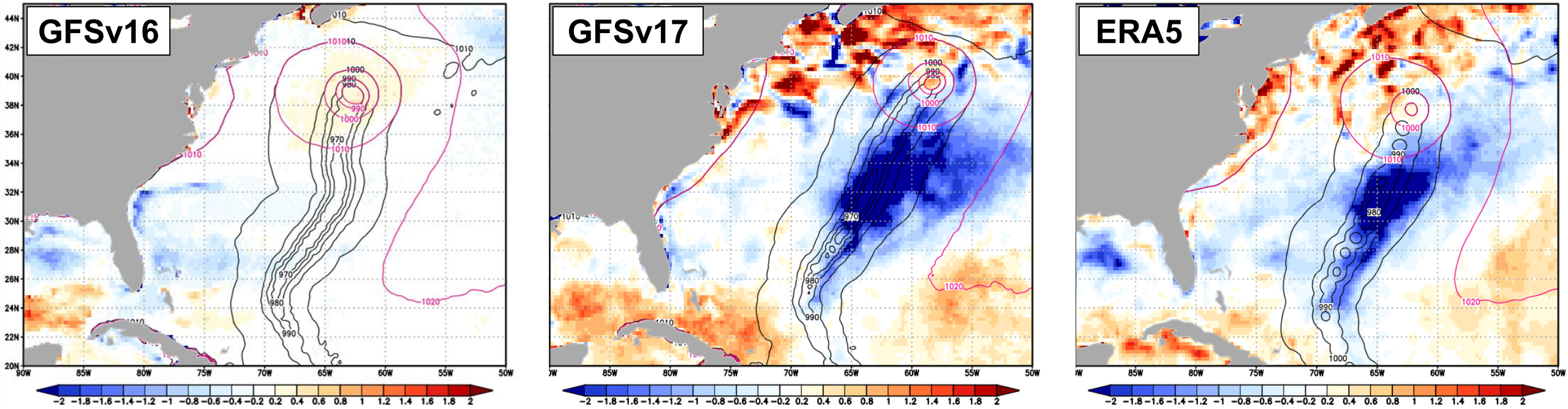


Time Period:
JJA

Reduced SSTs after TC Passage (Cold Wakes)

Initialized: 0000 UTC 8/14/24 (F120)

Valid: 00Z 8/19/24



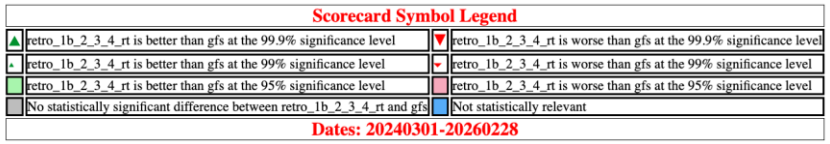
Minimum MSLP Trace (contours) and SST change (shaded)

- **GFSv17** is a coupled model, so the passage of a TC (accompanied by strong winds and mixing) can lower SSTs and result in reduced latent heat fluxes
- Example: There was almost no change in SSTs in **GFSv16** after the passage of TC Ernesto (2024), with a considerable reduction in ERA5

GFSv17 vs. GFSv16 Scorecard (3/1/24–2/28/26)

- The **GFSv17** vs. **GFSv16** Scorecard (right) highlights the statistically significant improvement over **North America** and the **Northern Hemisphere** at all pressure levels and at most lead times

- Some statistically significant degradation in mid-level geo. height and low-level vector wind over the **Southern Hemisphere** and **Tropics** at shorter lead times, but much more improvement overall



Implementation in FY27

RMSE

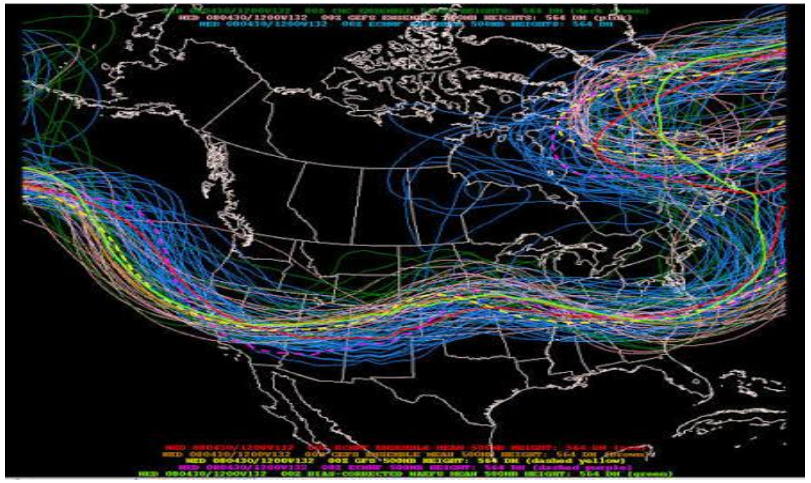
		N. America						N. Hemisphere						S. Hemisphere						Tropics					
		Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
Geo. Height	10hPa	▲	▲	▲				▲						▲						▲	▲	▲	▲	▲	
	20hPa	▲	▲	▲	▲			▲	▲	▲	▲			▲	▲	▲	▲			▲	▲	▲	▲	▲	▲
	50hPa	▲	▲	▲	▲			▲	▲	▲	▲	▵		▲	▲	▲	▵		▵	▲	▲	▲	▲	▲	▲
	100hPa	▲	▲	▲	▲	▵		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▵	▲	▲	▲	▲	▲	▲
	200hPa	▲	▲	▲	▵			▲	▲	▲	▲	▲	▵	▲	▲			▵		▲	▲	▲	▲	▲	▲
	500hPa	▲	▲	▲	▲			▲	▲	▲	▲	▵		▼	▵			▵		▼	▲	▲	▲	▲	▲
	700hPa	▲	▲	▲	▲			▲	▲	▲	▲	▵		▼						▼	▼	▲	▲	▲	▲
	850hPa	▲	▲	▲	▲			▲	▲	▲	▲	▵		▲	▲					▼		▲	▲	▲	▲
	1000hPa	▲	▲	▲	▲			▲	▲	▲	▲	▵		▲	▲	▲	▲	▵	▵	▼	▲	▲	▲	▲	▲
Vector Wind	10hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	20hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	50hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	100hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	200hPa	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	500hPa	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	700hPa	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▵	▲	▲			▵	▵	▲	▲	▲	▲	▲	▲
	850hPa	▲	▲	▵				▲	▲	▲	▲			▼	▼	▼				▲	▲	▲	▲	▲	▲
	1000hPa	▲	▲					▲	▲	▲	▲			▼	▼	▼	▼	▾		▼	▼	▲	▲	▲	▲
Temperature	10hPa	▲	▲	▲	▲	▵		▲	▲	▵				▲	▲	▲	▵			▲	▲	▲	▲	▲	▲
	20hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▵	▲	▲	▲	▲	▲	▲
	50hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	100hPa	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	200hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	500hPa	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	700hPa	▲	▲	▲	▲	▵	▵	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	850hPa	▲	▲	▵	▵			▲	▲	▲	▲	▵		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	1000hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲

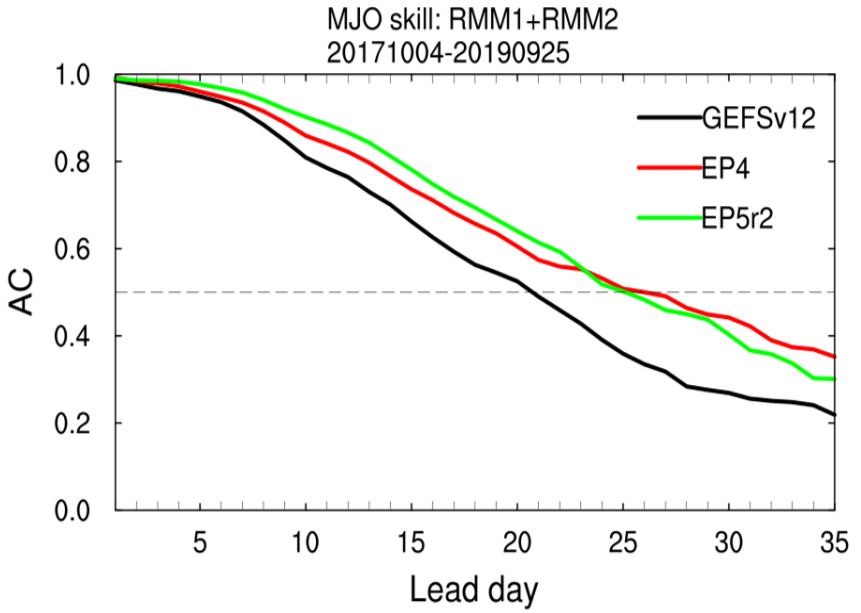
Subseasonal to Seasonal Systems

- Both the Seasonal and Subseasonal coupled forecasts system are also targeted to go into operations soon.
  - Medium range to month 1 : GEFSv13
  - Seasonal to month 12: Seasonal Forecast System (SFSv1)
- Real-time initialization: Interpolated GFS analysis.
- Reforecast initialization: replay to existing reanalyses.

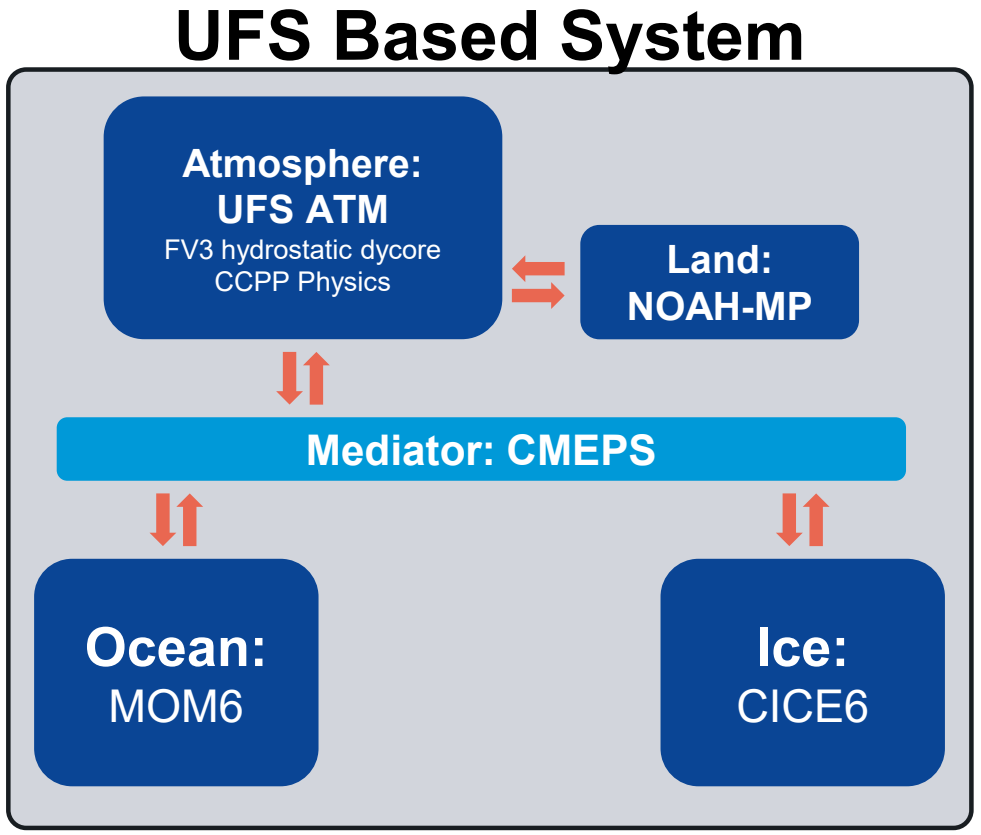
Global Ensemble Forecast System (GEFSv13)

- NOAA's first fully coupled ensemble subseasonal prediction system.
- Uses the same system components and atmospheric physics suite as GFSv17, but at **25-km resolution**.
- Reforecasts are initialized by replaying ERA5/ORAS5 analyses, while real-time forecasts use GFSv17 initial conditions.
- Approximately 50% of the reforecast dataset had been completed as of September 22, 2025.
- However, due to computing resource limitation and the reprioritization of OMD projects, GEFSv13 development has slowed. The timeline for its operational implementation has not yet been determined.





SFSv1 to Replace CFSv2



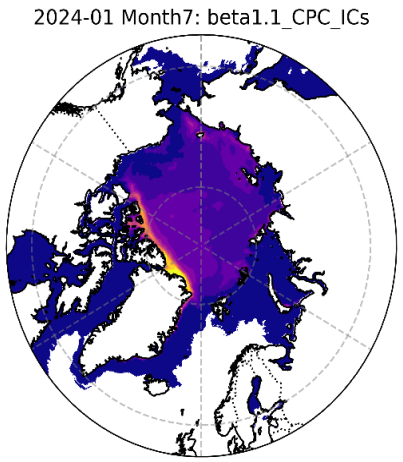
Targeted Implementation in late 2027

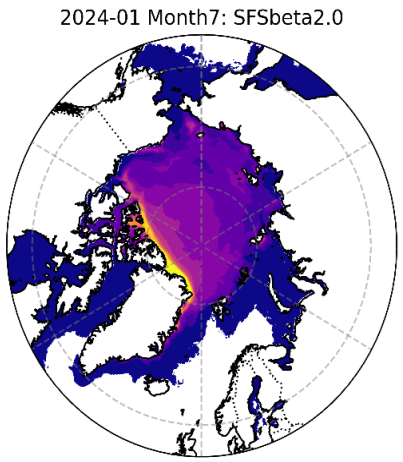
	CFSv2	SFSv1
Atmos	T126 (~100km) /L64 (~55km), GSM	C192 (~50km) L127 (~80km), FV3
Land	Noah (4 levels)	Noah-MP (4 levels)
Ocean	MOM4 (0.25°-0.5°, tripole grid, 40 layers)	MOM6 (0.25° tripole grid, 75 layers)
Sea Ice	SIS1 (0.5° tripole grid, 5 ice thickness categories)	with CICE6 (0.25° tripole grid, 7 ice thickness categories)

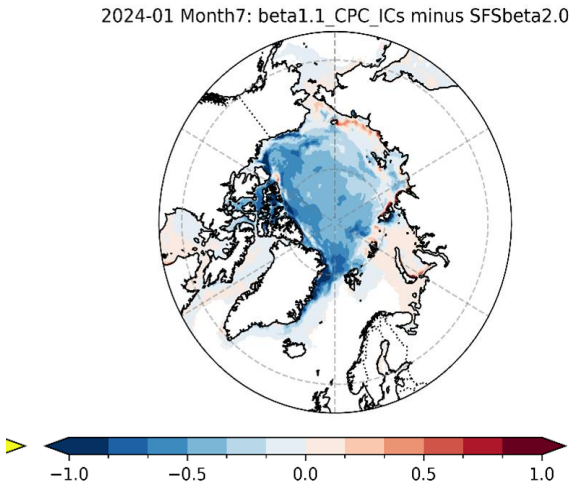
SFS related development

- **Hydrostatic** FV3 dynamics (up to a 40% reduction in computational cost).
- **ECMWF nonstationary gravity wave** scheme for improved QBO simulation.
- Updated McCormack (2015) ozone parameterization, **restoring the Antarctic ozone hole.**
- Total turbulent energy (**TTE**)-based eddy-diffusivity mass-flux (**EDMF**) vertical mixing scheme.
- Tuned **atmospheric physics** and **MOM6 background gustiness** to reduce systematic SST biases.
- Sliding 6-year averaged MERRA-2 **aerosol climatology**.
- Refined SKEB and SPPT schemes to improve SST **ensemble spread**.
- Reduced **sea-ice** analysis and prediction **biases**, particularly the underestimation of Arctic sea-ice coverage during the warm season.

CICE6 Updates in Snow Physics, Melt Ponds, and Albedo

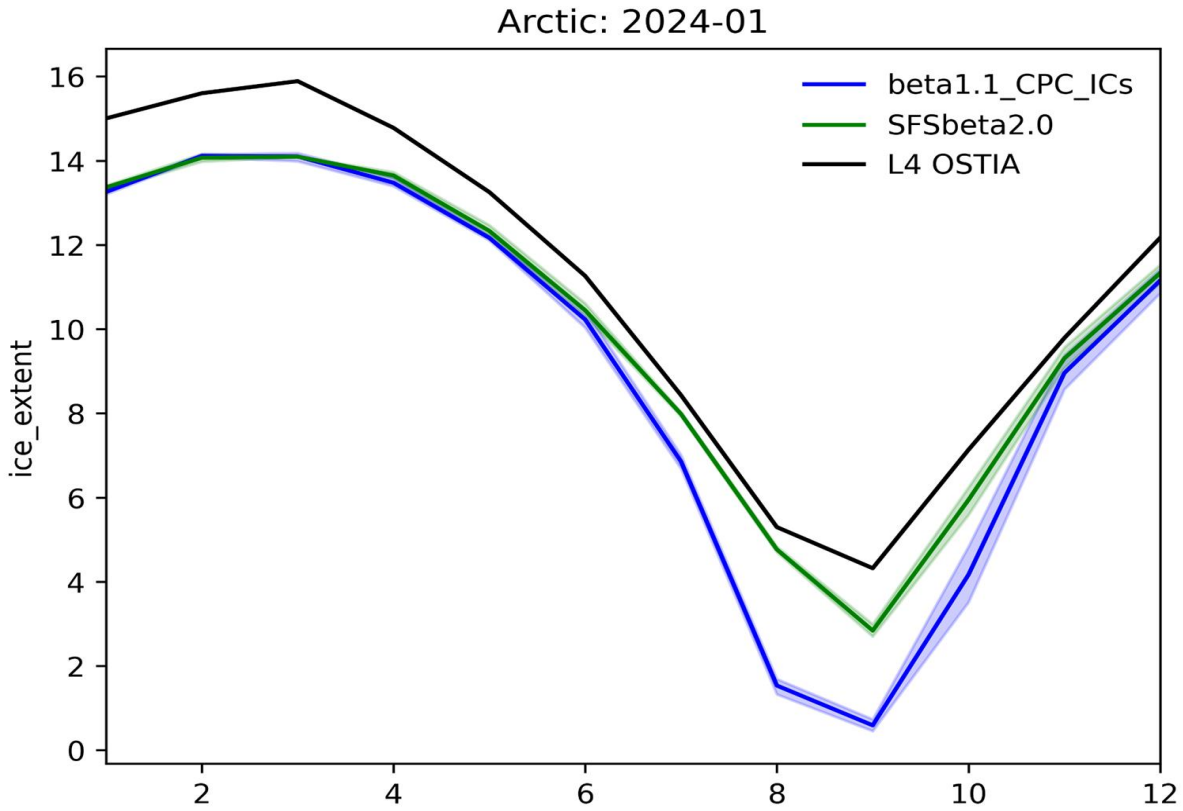






Thicker sea ice by almost a meter 7 months into the forecast

Improved sea ice extent at longer lead times

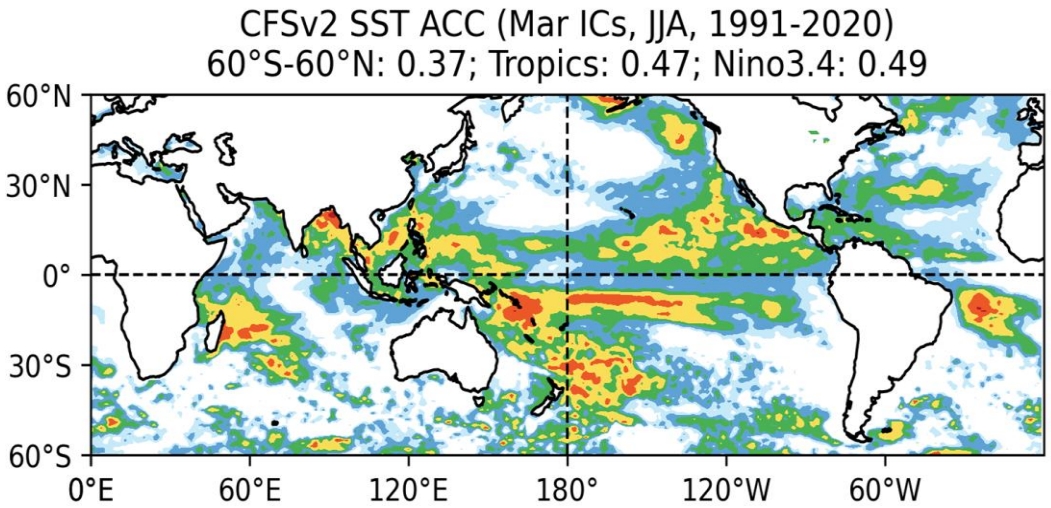


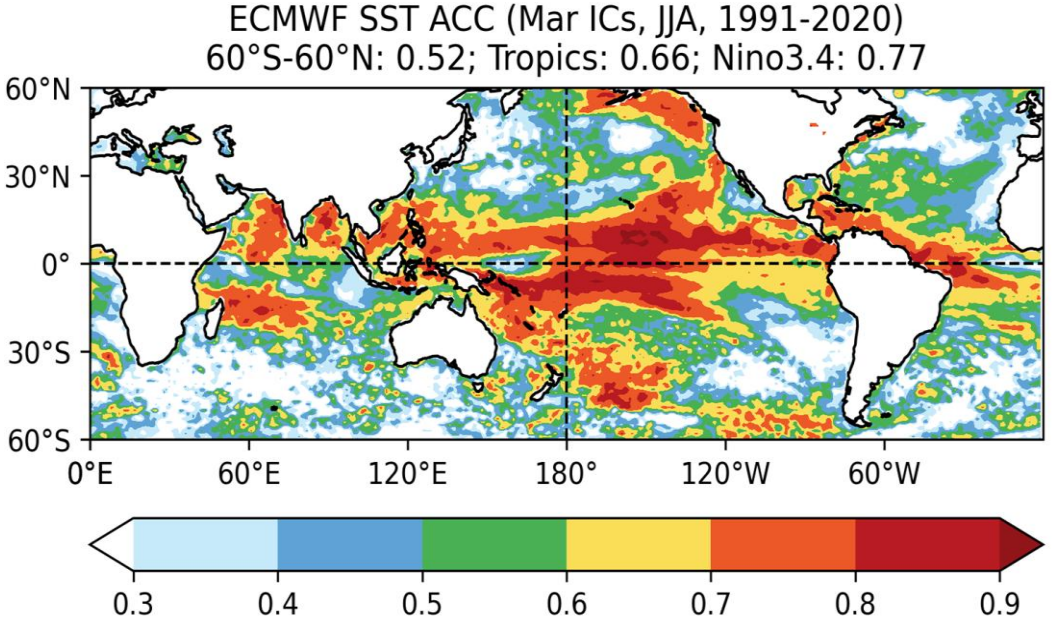
Current State of SFS Development

- Near Real-Time Experiments
  - Started in March 2026
  - Forecasts Once a Month
  - Forecast Length of One Year
  - 31 members
- On-the-fly Reforecasting
  - reforecasting of forecast month is produced before the near-real-time runs begin
  - 11 members
  - 1991–2025
- Used experimentally by NCEP / WPC (CPC)
- Accelerated implementation timeline: direct deployment on new operational computer by the end of 2027.
- CFSv2 will not be ported to new platform and will be retired when WCOSS2 is decommissioned.

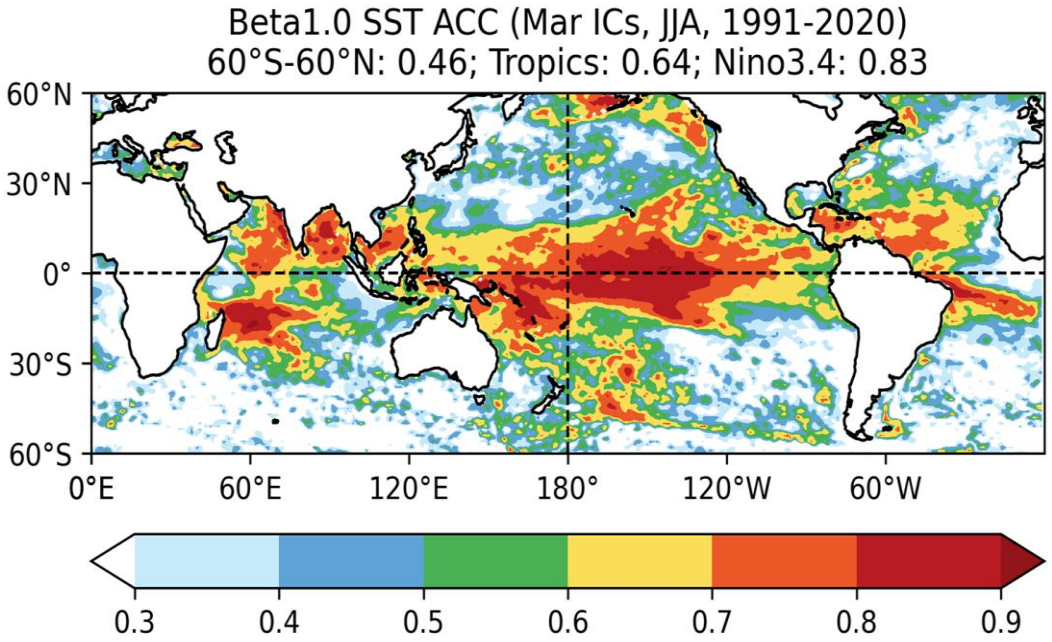
SFS Beta output link on SFS webpage

JJA SST ACC (Mar ICs, 1991-2020)





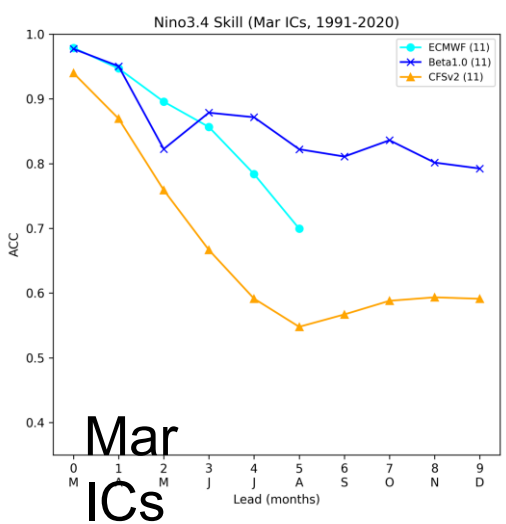
CFSv2, ECMWF: ens=11

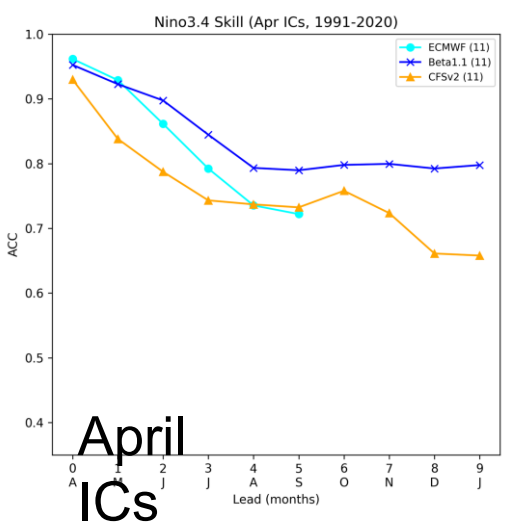


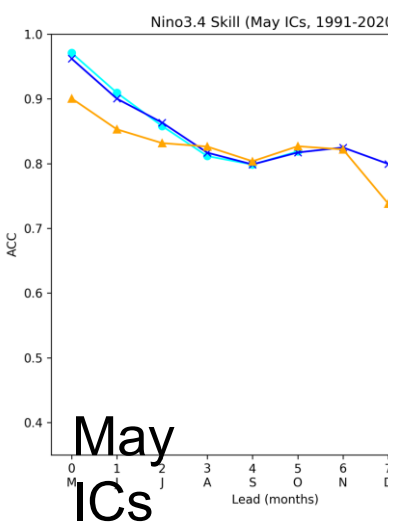
- **JJA season from Mar ICs**
  - **Beta1.0 shows improved skill over CFSv2**

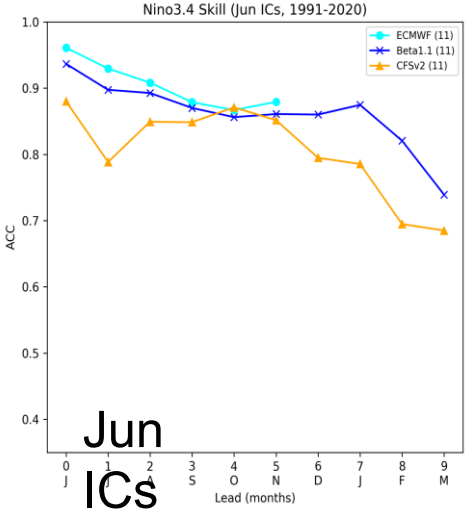
Figure provided by WPC

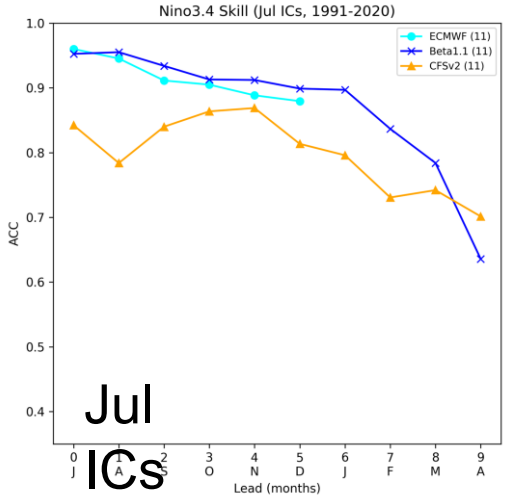
SFS-beta1 evaluation: Nino3.4 ACC comparison

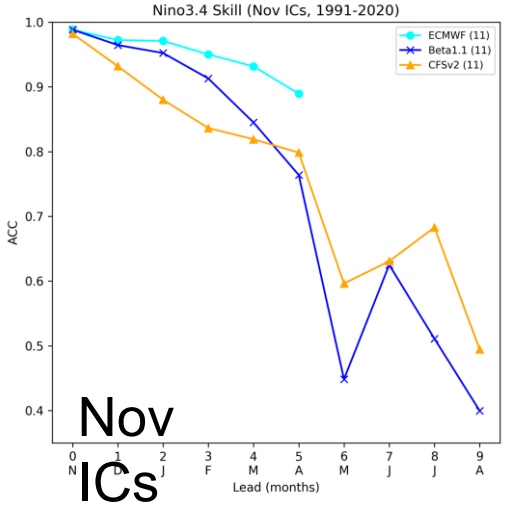












Yellow: **CFSv2**

Green: **ECMWF**

Blue: **SFS-beta**

- Mar-Jul
  - SFS shows improved skill for March-July ICs, especially for March and April
  - SFS is overall comparable to SEAS5
- Nov
  - SFS shows improved skill for the first 5 months
  - SFS becomes less skillful after April

Provided by NCEP/WPC Wanqiu Wang

Summary

- NOAA is nearing implementation of a fully coupled GFS (9km atmosphere, 25km ocean/sea-ice), its first major upgrade since 2021.
- The S2S systems depend on GFS analysis and will follow its implementation.
- SFS targets a fall 2027 operational launch, replacing CFSv12 (operational since 2011).
- GEFSv13 lacks a target date due to resource constraints (last upgraded in 2020).
- Rapid advancements in ML-forecast models create uncertainty for the future of NOAA's global coupled models.