NOAA's Global Ensemble Forecast System (GEFS): Operational GEFSv12 and Development of GEFSv13

Bing Fu[1], Yuejian Zhu[1], Philip Pegion[2], Hong Guan[3], Eric Sinsky[3], Xianwu Xue[4], Fanglin Yang[1] and Avichal Mehra[1]
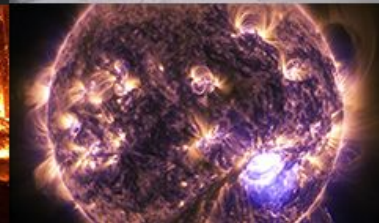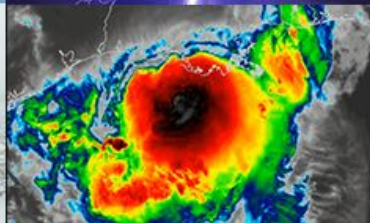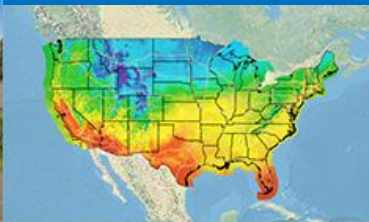
1. NOAA/NWS/NCEP/EMC
2. NOAA/OAR/ESRL/PSL
3. Lynker @ NOAA/NWS/NCEP/EMC
4. SAIC @NOAA/NWS/NCEP/EMC, (current: NOAA/NWS/ABRFC)

NOAA

**NATIONAL WEATHER SERVICE**

Outline

- Operational un-coupled GEFSv12
  - GEFSv12 configurations
  - GEFSv11 vs GEFSv12
  - Highlights of GEFSv12
- Development of coupled GEFSv13
  - GEFSv13 configurations (planned)
  - Ensemble Propotypes (EP1-EP4) targeting GEFSv13
  - Expectations of GEFSv13
- Summary

GEFSv12 Configurations

| Components	V11 (Dec. 2015)	V12 (Sept. 2020)
GFS Model	Semi-Lagrangian, 2015	**FV3 (Finite-Vol Cubed-Sphere)**
Physics	GFS13 package (Zhao-Carr MP)	GFSv15 packages (**GFDL MP**)
Initial perturbations	EnKF f06	EnKF f06
Model uncertainty	STTP (Stoch. Total Tend. Pert)	**5-scale SPPT and SKEB**
Boundary forcing	SST - Climatology relaxation	NSST + 2-tiered SST
Tropical storm	Relocation for all members	No relocation
Horizontal Resolution	T_L574 (34km)/T_L382 (55km)	**C384 (25km)**
Vertical resolution	L64 (hybrid)	L64 (hybrid)
Daily frequency	00, 06, 12 and 18UTC	00, 06, 12 and 18UTC
Forecast length	16 days	16 days, **35 days (00UTC)**
Members	Control + 20 pert members	**Control + 30 pert members**
Output resolution	$0.5^o \times 0.5^o$	$0.25^o \times 0.25^o$ and $0.5^o \times 0.5^o$
Output frequency	3h the first 8 days; 6h the rest	3h the first 10 days; 6h the rest
Reforecast	EMC offline – 20 years	30 years (1989-2018)
Implementation	December 2nd 2015	September 2020

Examples of stochastic patterns for SPPT

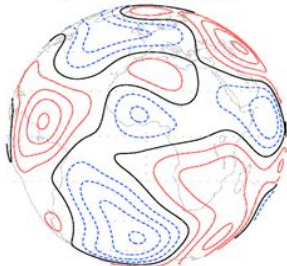5-scales-together
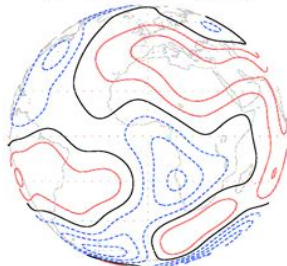($\sigma=0.95$, int$=0.5$)
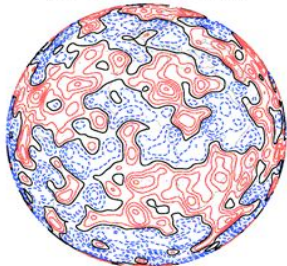
500km/6h
($\sigma=0.8$, int$=0.5$)
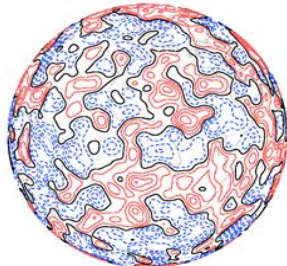
1000km/3d
($\sigma=0.4$, int$=0.2$)
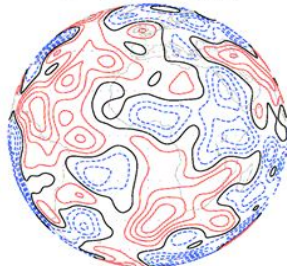
2000km/30d
($\sigma=0.2$, int$=0.1$)

2000km/90d
($\sigma=0.08$, int$=0.05$)

2000km/1yr
($\sigma=0.04$, int$=0.03$)

Fig.: 5-scale random patterns used in Stochastic Perturbed Physics Tendencies (SPPT). On the top of each plot, the numbers (except for upper left) represent the scales of spatial and temporal perturbations with the maximum amplitude and contour intervals in the bracket.
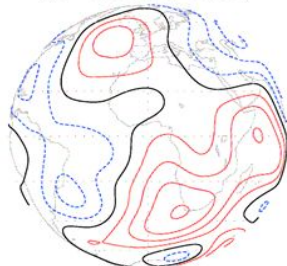
500hPa zonal wind
Error/Spread ratio
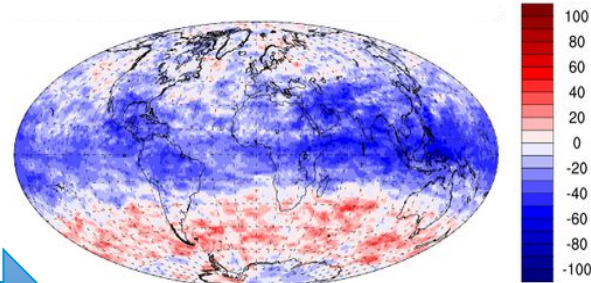
GEFSv11 with STTP

GEFSv12 with SPPT + SKEB

- No radiative perturbation for clear sky
- No perturbation under divided streamline

CRPSS of 500hPa geopotentoal height
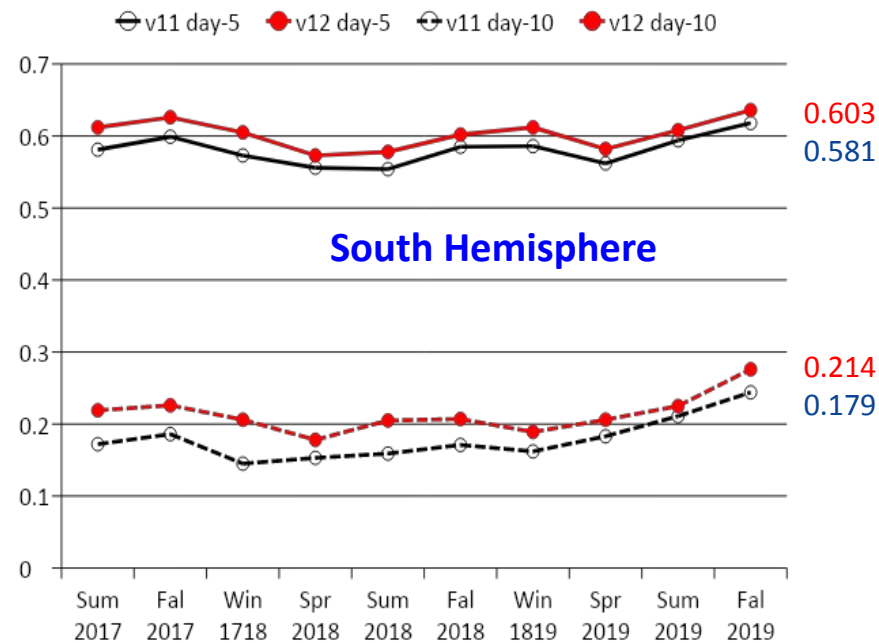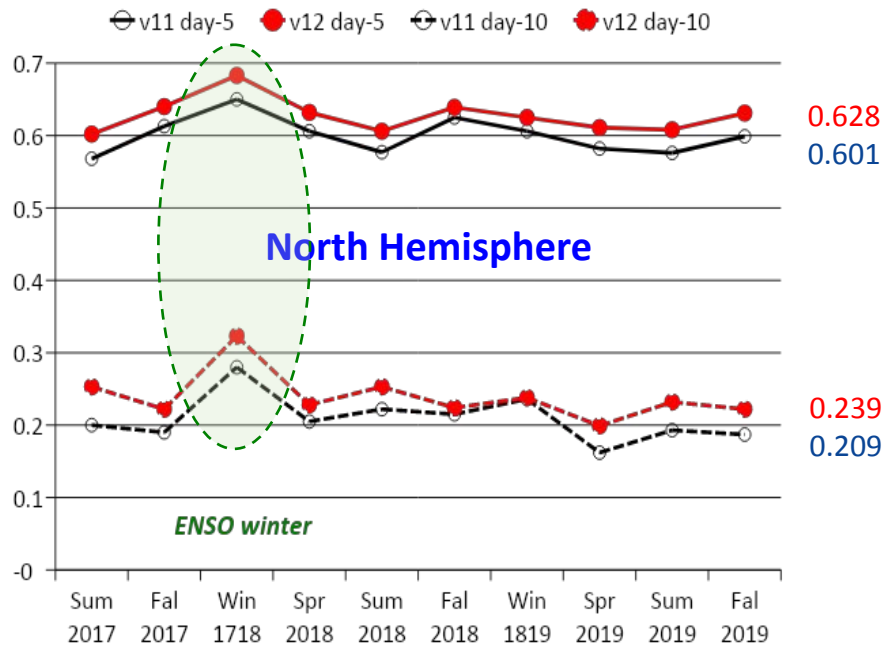
CRPSS — *Continuous Ranked Probability Skill Score is one of evaluation tools to measure ensemble based probabilistic forecast. CRPSS=1 is for perfect forecast, CRPSS=0 is for no skill from reference, CRPSS=0.25 is similar to PAC=0.6 (pattern anomaly correlation of ensemble mean). GEFSv12 has better CRPSS for both hemispheres, day-5 and day-10, all two and half years.*

Brier Skill Scores of the CONUS PQPF

Ensemble Precipitation Verification for CONUS
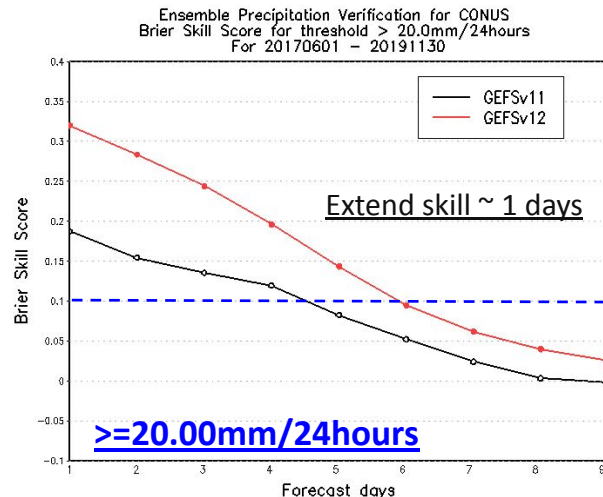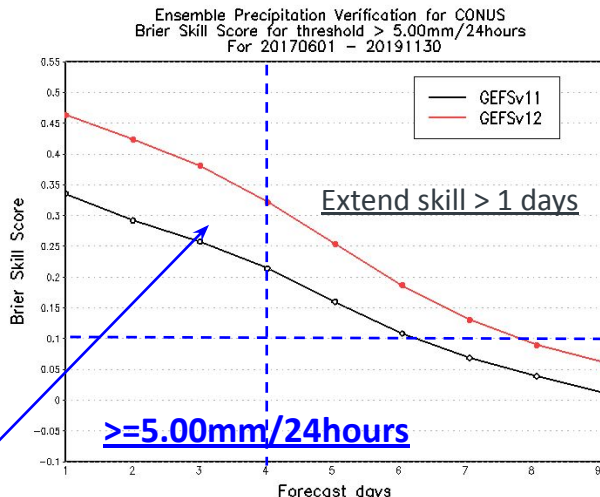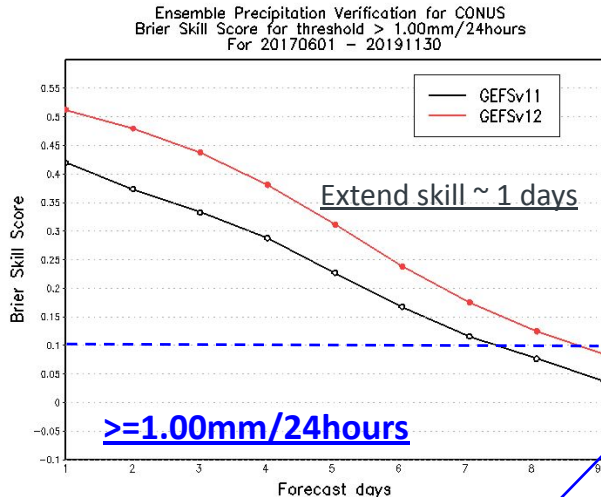Brier Skill Score for threshold > 1.00mm/24hours
For 20170601 − 20191130

Extend skill ~ 1 days

>=1.00mm/24hours

Ensemble Precipitation Verification for CONUS
Brier Skill Score for threshold > 5.00mm/24hours
For 20170601 − 20191130

Extend skill > 1 days

>=5.00mm/24hours

Ensemble Precipitation Verification for CONUS
Brier Skill Score for threshold > 20.0mm/24hours
For 20170601 − 20191130

Extend skill ~ 1 days

>=20.00mm/24hours

Reliability Diagram
fhr 108−132 For 20170601 − 20191130

GEFSv11: RELI=0.0055 BSS=0.158
GEFSv12: RELI=0.0010 BSS=0.253

Brier Score — *Brier score is a very popular verification tool to evaluate (probabilistic) forecast performance. It is easy to decompose to three components (resolution, reliability and uncertainty). BSS=1 is for perfect forecast, BSS=0 is for no skill from reference of climatology. GEFSv12 probabilistic Quantitative Precipitation Forecast (PQPF) is over performance than GEFSv11 for all forecast categories, all forecast lead-time. Statistically, GEFSv12 has extended one more day(s) probabilistic forecast skills over GEFSv11. The forecast is much reliable (left plot) than GEFSv11.*

Spatial and Time-Lag Correlation of equatorial OLR and U850 centered in Indian ocean
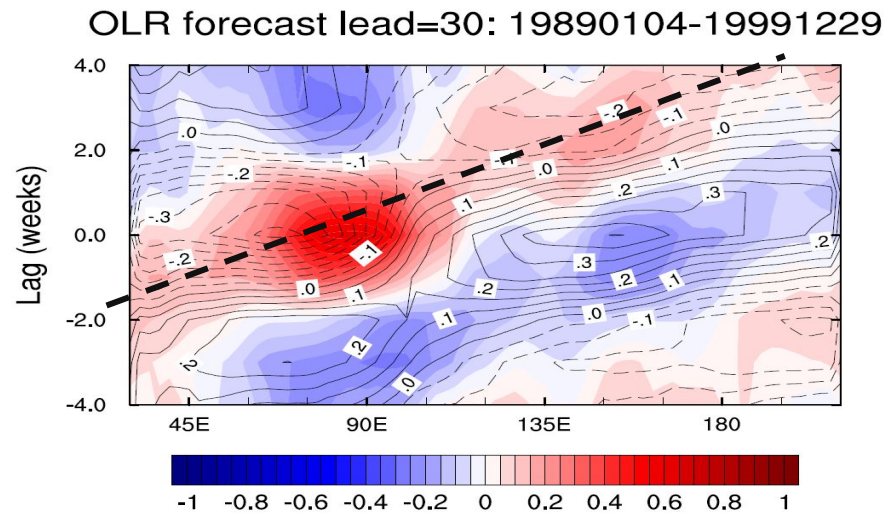

OLR anal: 19890203-20000128

OLR forecast lead=30: 19890104-19991229
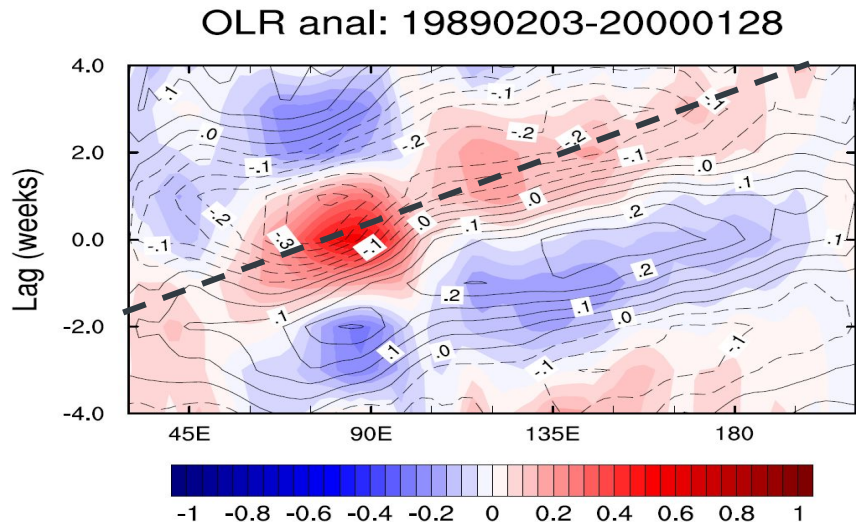
Figure: *Spatial and time correlation (anomaly) between Centre* **India Ocean** *and different longitudes/time-lag of 11 years analysis (CFSR; left) and 30-day forecast (GEFS ensemble mean; right). The correlation coefficient of OLR is in shaded and 850 zonal wind is in contours.*

The statistics indicate that there is a very good eastward propagation of signal (or MJO) from Indian Ocean. However, it is really a challenge to capture northward propagation of India Ocean (Not show).

Highlights of GEFSv12

- Weather -
  - Improved probabilistic forecast skill and predictability
  - Improved PQPF and T2m
  - Improved TC tracks and spread
- Week-2; Weeks 3&4 -
  - An improvement for temperature, precipitation, 500 hPa heights tropical cyclone and stratosphere.
- Wave -
  - Reduce bias and RMSE; An improvement of wave spread.
- Aerosol (control member only) -
  - Improvement in the dust predictions (signals and errors)
- 31-year Reforecasts
  - Support forecast calibration and validation of hydrometeorological application

GEFSv13 Configurations (planned)

Components		V12 (Oct. 2020)	V13 (Q2FY25)
Atmos	Dynamics	**FV3 (Finite-Vol Cubed-Sphere) GFSv15**	FV3 (Finite-Vol Cubed-Sphere) GFSv17
	Physics	**saSAS, GFDL-MP, K-EDMF, oroGWD**	**saSAS, Thompson-MP, sa-TKE-EDMF, uGWD**
	Initial perturbation	**EnKF f06 (previous cycle)**	EnKF f00 (early cycle)
	Model uncertainty	**5-scale SPPT and SKEB**	5-scale SPPT, SKEB, **SPP, CA**
	Boundary (ocean surface)	**NSST + 2-tiered SST**	NSST
	Resolutions	**C384L64 (25km)**	**C384L127 (25km)**
Land	Model	NOAH-LSM	**NOAH-MP**
	Initial perturbation	N/A	Soil moisture
Ocean	Model	N/A	**MOM6 (0.25°L75)**
	Initial perturbation	N/A	**SOCA-Ens**
	Model uncertainty	N/A	**5-scale oSPPT and ePBL**
Ice	Model	N/A	**CICE6 (0.25°)**
	Initial perturbation	N/A	**SOCA-Ens**
Wave	Model	WW3 (1-way) (0.5°)	**WW3 (2-way) (0.25° lat/lon grid)**
Aerosol	Model	GOCART (1-way)	**GOCART (2-way)**

new

Updated stochastic physics

- Cellular Automata (CA)

  - stochastic parameterization of cumulus convection

- OCN_SPPT:

  - temperature,salinity,layer thickness

- OCN_ePBL:

  - generation and destruction of ePBL

- SPP (perturb cloud fraction)

- SPPT/SKEB tuning

Ensemble Prototypes targeting GEFSv13

	EP1(p5) (C384L64, OCN_L75)	EP2(p7) (C384L97,OCN_41)	EP3(p8) (C384L97,OCN_41)	EP4(HR1+) (C384L127,OCN_75)
phy	Hybrid-EDMF Sa-SAS GFDL-MP GWD (stationary oro) NOAH-LSM …	Sa-TKE-EDMF Sa-SAS GFDL-MP GWD (stationary oro) NOAH-MP NSST …	Sa-TKE-EDMF Sa-SAS Thompson-MP uGWDv0+GSL NOAH-MP NSST …	Sa-TKE-EDMF Sa-SAS Thompson-MP uGWDv0+GSL NOAH-MP NSST …
stoch	SPPT (25% off) SKEB (0.7)	SPPT(30% off) SKEB (0.7) CA pert_mp, radtend ocnSPPT(100%) ePBL(100%)	SPPT (25% off) SKEB (0.8) CA pert_mp, radtend ocnSPPT(100%) ePBL (100%)	SPPT (30% off) SKEB (0.8) CA pert_clds ocnSPPT(100%) ePBL (100%)

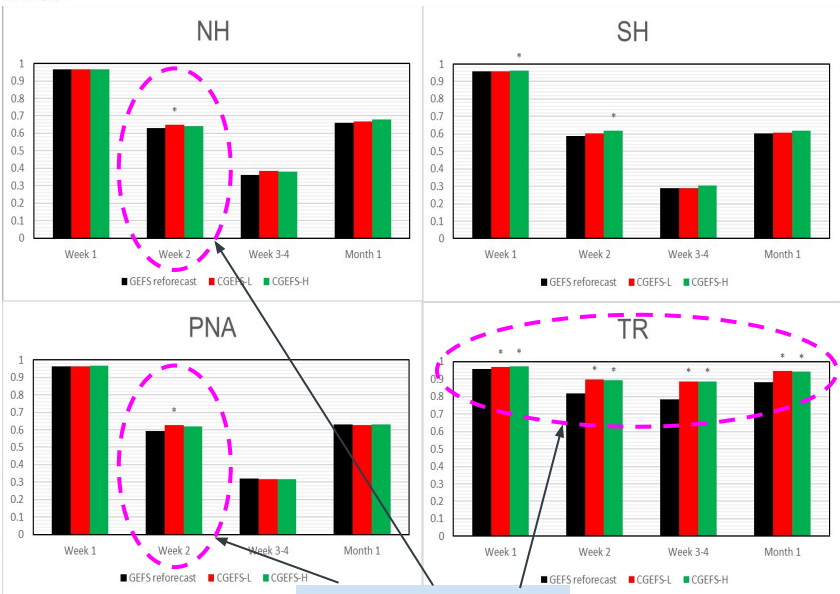# GEFSv13 Prototype Experiments - EOS highlights

Editor's highlights - JGR Atmosphere (2023) --- Zhu, Y., B. Fu, B. Yang, H. Guan, E. Sinsky, W. Li, J. Peng, X. Xue, D. Hou, X.-Z. Liang and S. Shin, 2023: Quantify the Coupled GEFS Forecast Uncertainty for the Weather and Subseasonal Prediction.
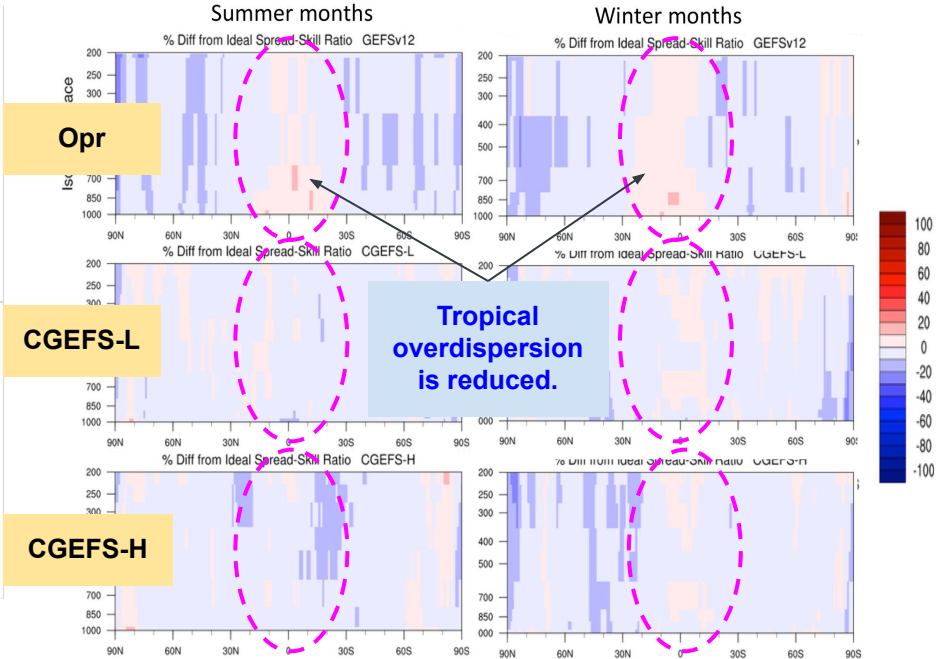
Figure 9: The vertical cross section of the ratio for boreal summer six months (left column) and boreal winter six months (right column) of zonal wind from surface (1000hPa) to 200hPa in vertical, for 144 hours (6 days) forecasts, and for the GEFSv12 reforecast (top), CGEFS-L (middle) and CGEFS-H (bottom).

GEFSv13 ensemble prototype performances

OPS
GEFSv12 (Winter)

EP1
CGEFS-a (Winter)

EP3
CGEFS-b (Winter)

Outliers are reduced for winter time

GEFSv12 (Summer)
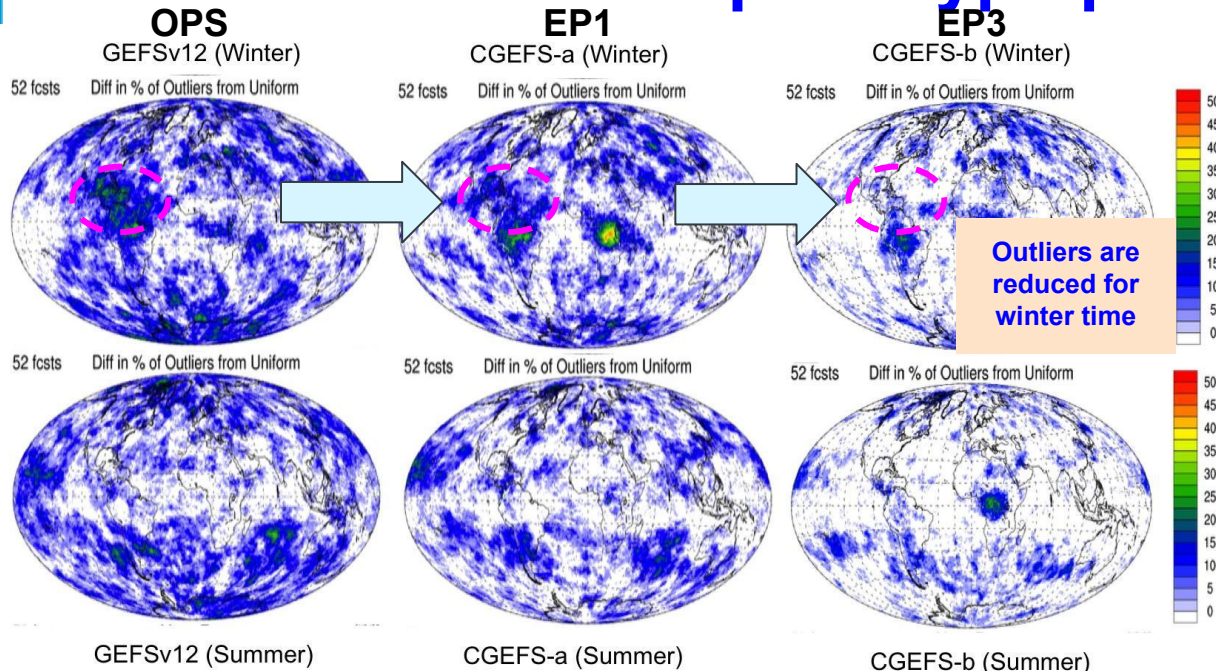
CGEFS-a (Summer)

CGEFS-b (Summer)

Figure 3. Distribution of the ratio of 500 hPa height 120h forecast outliers from uniform (in percentage) in GEFSv12 (left), CGEFS-a (middle) and CGEFS-b (right) for summer (bottom) and winter (top).

Figure 11. The MJO index for the GEFSv12 (black), CGEFS-a (red) and CGEFS-b (green).The MJO forecast skill is defined as the bi-variate anomaly correlation between the analysis and forecast real-time multivariate MJO index 1 and 2

27 days
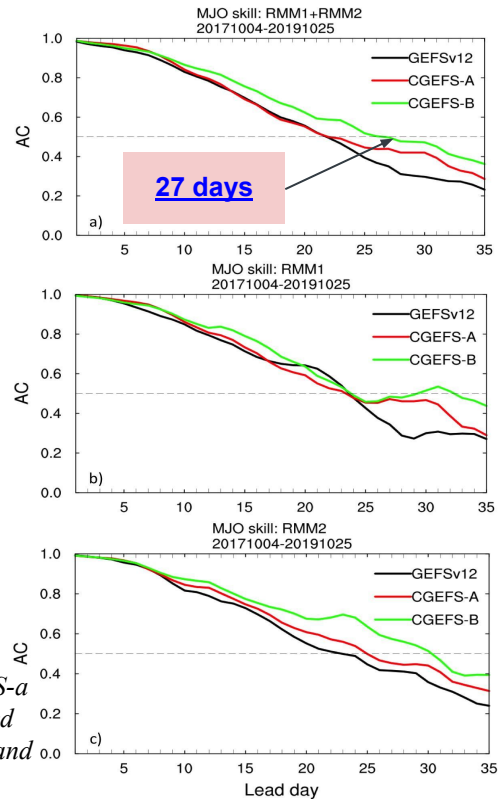
Bing Fu et al. 2023: Weather to subseasonal prediction from the UFS coupled Global Ensemble Forecast System

GEFSv13 Expectations

- The benefits from coupled GEFS

- Further improvement of probabilistic forecast (PQPF, T2m and TC)

- Improvement of MJO predictions (propagation, intensity and skill)

- Improvement from two-way coupling

- New products for the ocean and sea ice

- 30 years GEFSv13 reforecast for model calibration.

Summary

- GEFSv12

  - Configurations: (1-way coupled)

    - ATM (C384L64) - WAV - CHM

  - Implementation: (September 23, 2020)

- GEFSv13

  - Configurations: (fully-coupled)

    - ATM (C384L127) - OCN - ICE - WAV - CHM

  - Planned implementation time:

    - Q1FY26 - GEFSv13 implementation