The Transition of Global Ensemble Forecast System to Fully Coupled Earth System Model for Sub-seasonal Predictions

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Abstract

- The Unified Forecast System (UFS)-based Global Ensemble Forecast System version 12 (GEFS v12) will be implemented in NCEP operations in September 2020. This upgraded GEFS has demonstrated great improvement of the probabilistic forecast guidance for weather, medium-range, and sub-seasonal predictions based on 31 years of reforecasts and 3 years of retrospective forecasts. The GEFS v12 will run 31 members at 25-km horizontal resolution compared to the current 21 members at 33-km horizontal resolution, and additionally extends one cycle per day into the sub-seasonal range (35 days), beyond the standard 16-day forecast. The GEFS v12 system has also added a wave component to all members, as well as adding a special atmospheric aerosol member with this upgrade.

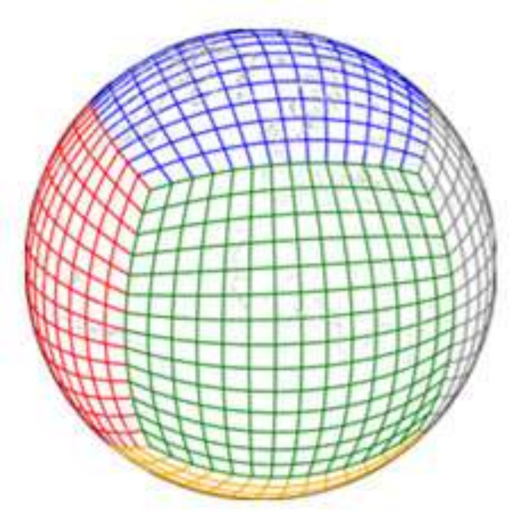
- This talk will mainly focus on forecast uncertainties of sub-seasonal predictions and plans for the transition from uncoupled GEFS v12 to fully coupled GEFS v13. The presentation will cover the following three aspects: 1) The success and highlights of GEFS v12 for weather and sub-seasonal predictions through various evaluation metrics; 2) The discussion of challenges associated with the un-coupled ensemble system, especially for sub-seasonal predictions; 3) Expectations from a fully-coupled global ensemble forecast system toward next operational implementation.

GEFS Configurations

Components	V11	V12	V13 (future)
GFS Model	Semi-Lagrangian, 2015 version	**FV3 (Finite-Vol Cubed-Sphere) GFSv15.1 version**	FV3 (GFSv17)
Physics	GFSv13 package (Zhao-Carr MP)	GFSv15.1 package (**GFDL MP**)	Advanced Physics
Initial perturbations	EnKF f06	EnKF f06	EnKF anl
Model uncertainty	STTP (Stoch. Total Tend. Pert)	**5-scale SPPT and SKEB**	SPPT, SKEB and others
Boundary forcing	SST - Climatology relaxation	**NSST + 2-tiered SST**	Full coupling (MOM6, CICE6)
Tropical storm	Relocation for all members	**No relocation**	N/A
Horizontal Resolution	T_L574 (34km)/T_L382 (55km)	**C384 (25km)**	C384/0.25d (MOM6/CICE6/Wave)
Vertical resolution	L64 (hybrid)	L64 (hybrid)	L127 (hybrid)
Daily frequency	00, 06, 12 and 18UTC	00, 06, 12 and 18UTC	00, 06, 12 and 18UTC
Forecast length	16 days	16 days, **35 days (00UTC) - Support SubX**	16 days, 35 days (00UTC)
Members	Control + 20 pert members	**Control + 30 pert members + 1 aerosol member**	EnKF anl
Output resolution	0.5^o x 0.5^o	**0.25^o x 0.25^o** and 0.5^o x 0.5^o	0.25^o (selected) and 0.5^o
Output frequency	3hly for the first 8 days; 6hly for the rest	3hly for the first **10** days; 6hly for the rest	3hly for the first 16 days; 6hly for the rest
Reforecast	EMC offline – 20 years	**30 years (1989-2018)**	Yes
Implementation	December 2, 2015	**September 23, 2020**	2024

GEFSv12: Transition from Spectral to FV3 Dycore

The Finite Volume Cubed Sphere (FV3) dynamic core

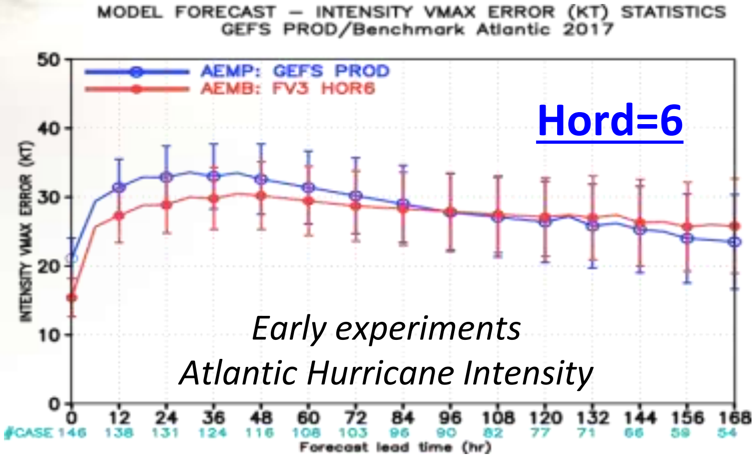


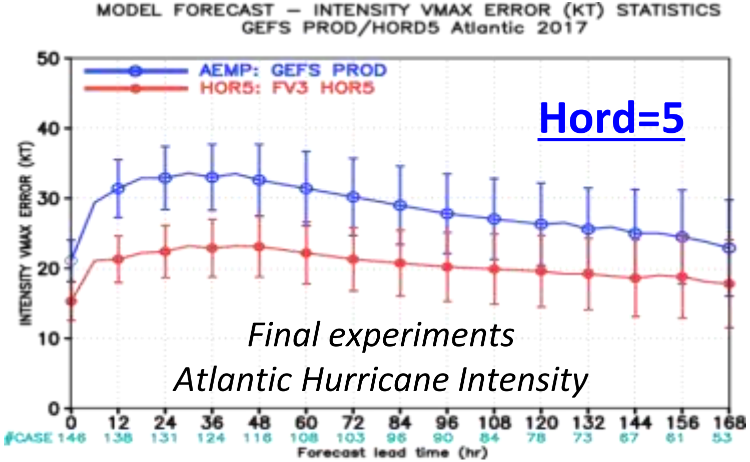
C384L64 ~ 25km resolution

Non-hydrostatic

Key parameters

- ***Time step=450s****; but use 300s for aerosol integration*
- ***ksplit=2****; for vertical mapping*
- *nsplit=****6****; for acoustic wave*
- ***<u>hord=5;</u>*** *horizontal advection scheme; see impact for TS intensity (right plot)*
- ***nord=2****; divergence damping – 6 order diffusion; impact SKEB scheme*
- ***d4_bg=0.12****; is coefficient for background higher-order divergence damping.*
- ***Vtdm4=0.02****; is coefficient for damping other-variables like vorticity, non-hydrostatic vertical velocity.*
- *Others similar to GFSv15.2*

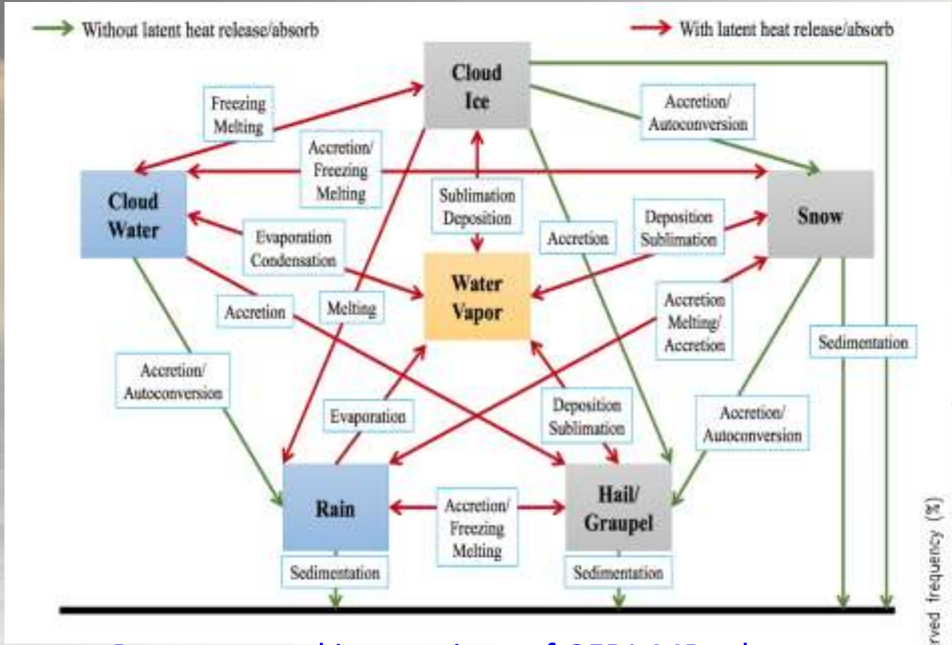




GEFSv12 Physics Changes

Replace Zhao-Carr MP with GFDL MP

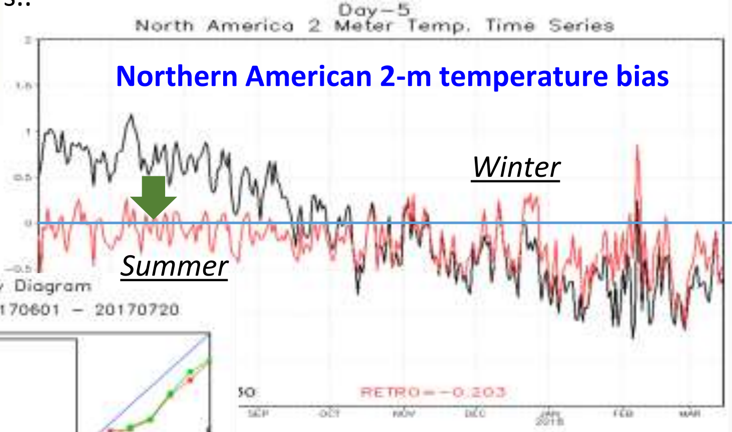
Five prognostics cloud species: Liquid, ice, snow, graupel, rain
more sophisticated cloud processes

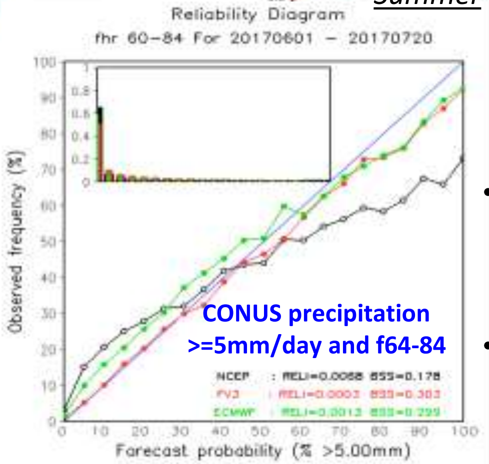


Processes and interactions of GFDL MP scheme

Tuning parameters and coefficients:

- Increase the conversion rate of ice cloud water to snow (psauto from 4.e-4 4.e-4 to ***psauto=8.e-4 8.e-4***)
- Test 5 different sets of geographic gravity wave drag and mountain block coefficients, finally to use ***cdmbgwd=1.2;1.0***
- Many others..

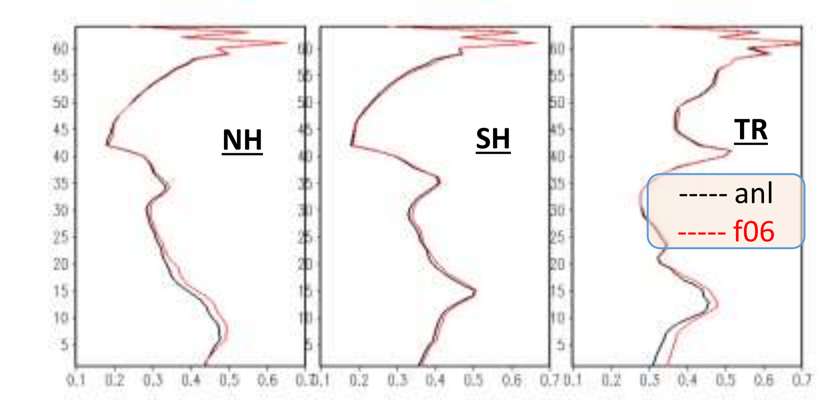




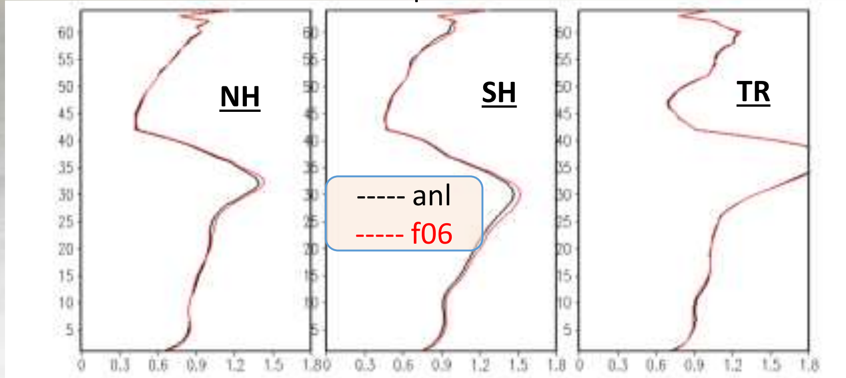
- *Top: NA 2-m temperature bias is much reduced in summer (warm) and winter (cold).*
- *Left: increase CONUS precipitation spread, and improve forecast reliability*

IC Uncertainty from EnKF 6-hr forecasts, No TSR

Example of FV3-EnKF spread vertical profile



Temperature



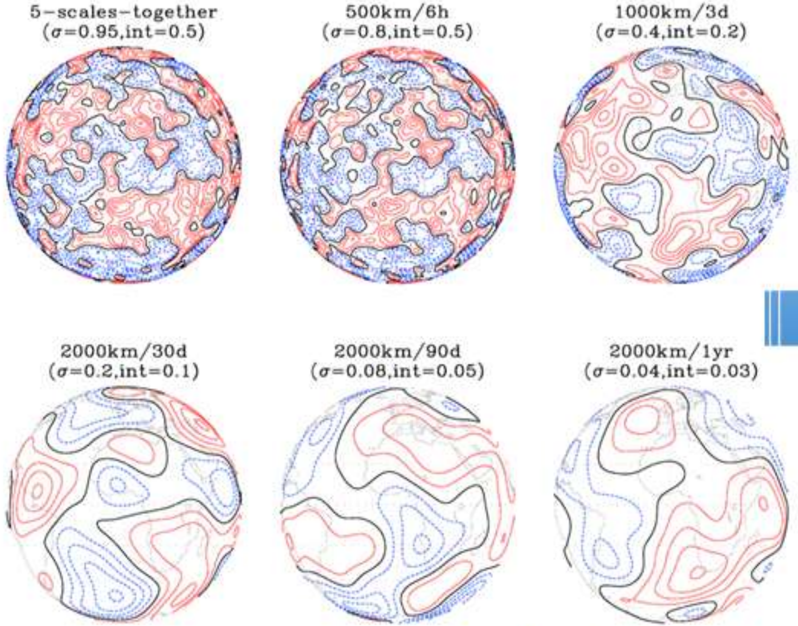
Zonal wind

- **EnKF –**
  - *Ensemble Kalman Filter is providing background error covariance to data assimilation and initial uncertainty (or perturbations)*
  - *Spread of 80 ensemble members has demonstrated its growth in 6 hours*
- **Why f06 ? –**
  - *Current EnKF is running in final hybrid DA (GDAS), it is late for GEFS initialization*
  - *There is less difference of anl and f06 in the structure (left)*
- **Re-center –**
  - *GEFS takes 1-30; 21-50; 41-70; 61-10 GDAS ensemble members for 00; 06; 12; 18 UTC respectively*
  - *Ensemble re-centering applied for selected 30 perturbations.*
- **Remove TC relocation –**
  - *Tropical storm relocation was introduced in 2006 for lower horizontal model/analysis resolution (~55km), but ~13km today, it is no longer necessary (similar to GFSv15.1)*
  - *Less impact when we take out TSR process for GEFS.*

Model uncertainty in GEFSv12: SPPT and SKEB

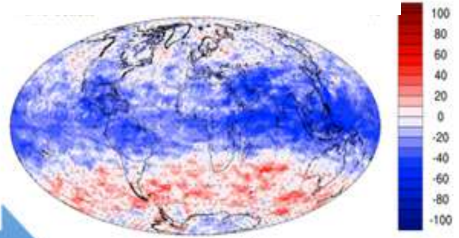
- **SKEB**: Estimate energy lost each time step and inject this energy in the resolved scales. a.k.a stochastic energy backscatter (SKEB; Berner et al. 2009)
- **SPPT and SHUM**: perturb the results from the physical parameterizations, and boundary layer humidity (Palmer et al. 2009), and inspired by Tompkins and Berner 2008, we call it SPPT and SHUM
- ***Replace STTP for GEFSv12 with SPPT and modified SKEB (amplitude reduced to 0.5 from 1.0), no SHUM***

Examples of stochastic patterns for SPPT

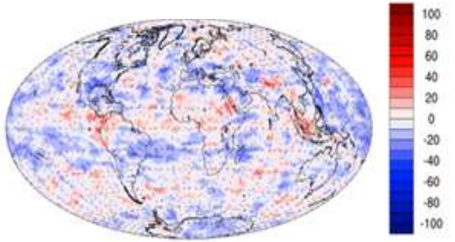


5-scale random patterns used in Stochastic Perturbed Physics Tendencies (SPPT). On the top of each plot, the numbers (except for upper left) represent the scales of spatial and temporal perturbations with the maximum amplitude and contour intervals in the parenthesis.

500hPa zonal wind Error/Spread ratio



GEFSv11 with STTP



GEFSv12 with SPPT + SKEB

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

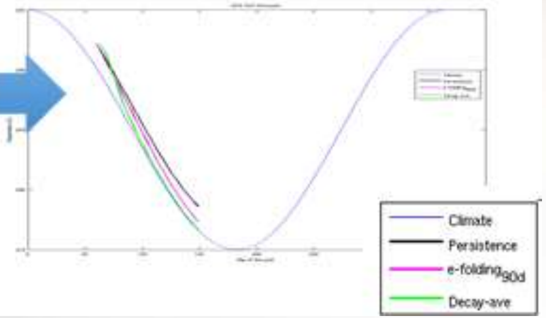
Ocean Forcing: NSST and 2-tiered SST

- **V11: Persistent + relaxation**

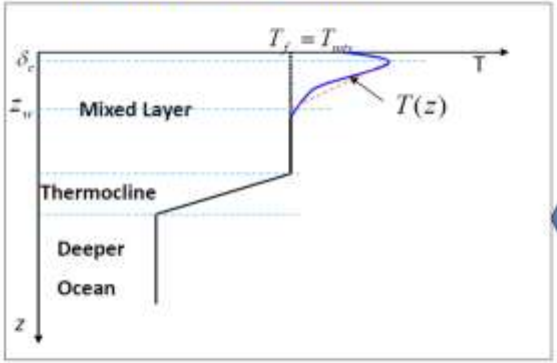
$$SST_f^t = \left[SST_a^{t_0} - SST_c^{t_0}\right] e^{-(t-t_0)/90} + SST_c^t$$

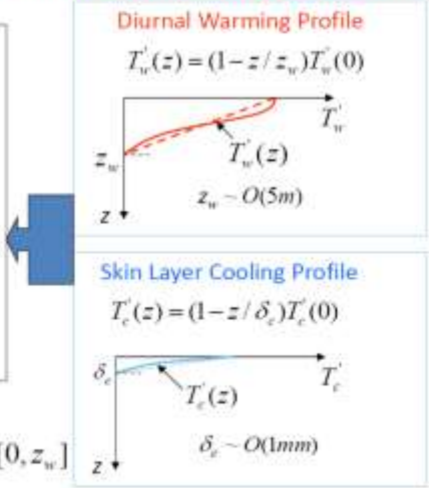
analysis - climatology at *t0* **Climatology at *t***

- *Traditional approach of SST forcing without coupling to ocean*



NSST is a **T-Profile** just below the sea surface.
Here, only the vertical thermal structure due to **diurnal thermocline layer warming** and **thermal skin layer cooling** is resolved





$$T(z,t) = T_f(z_w,t) + T_w'(z,t) - T_c'(z,t) \quad z \in [0, z_w]$$

NSST is assimilating diurnal variation of SST *Courtesy of Dr. Xu Li*

- **V12: NSST+ Two-tiered SST**

$$SST_f^t = (1-w)*\left[SST_a^{t_0} - SST_{cfsrc}^{t_0} + SST_{cfsrc}^t\right] + w*\left[SST_{cfs}^t - (SST_{cfs\_c}^t - SST_{cfsrc}^t)\right]$$

Analysis + Climatological tendency **Bias-corrected CFSv2 forecasts**

$$w(t) = \frac{(t - t_0)}{35}$$

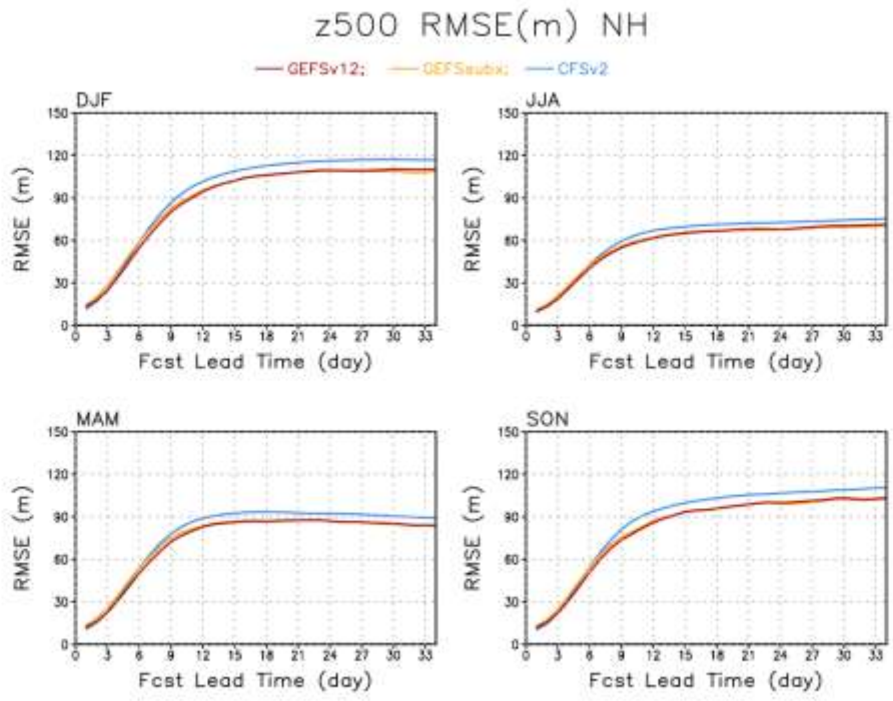
- *Two-tiered SST technique has been used for SubX project to provide real-time 35 days GEFS forecast to support CPC's subseasonal guidance. It has been demonstrated the value to improve tropical forecasts*

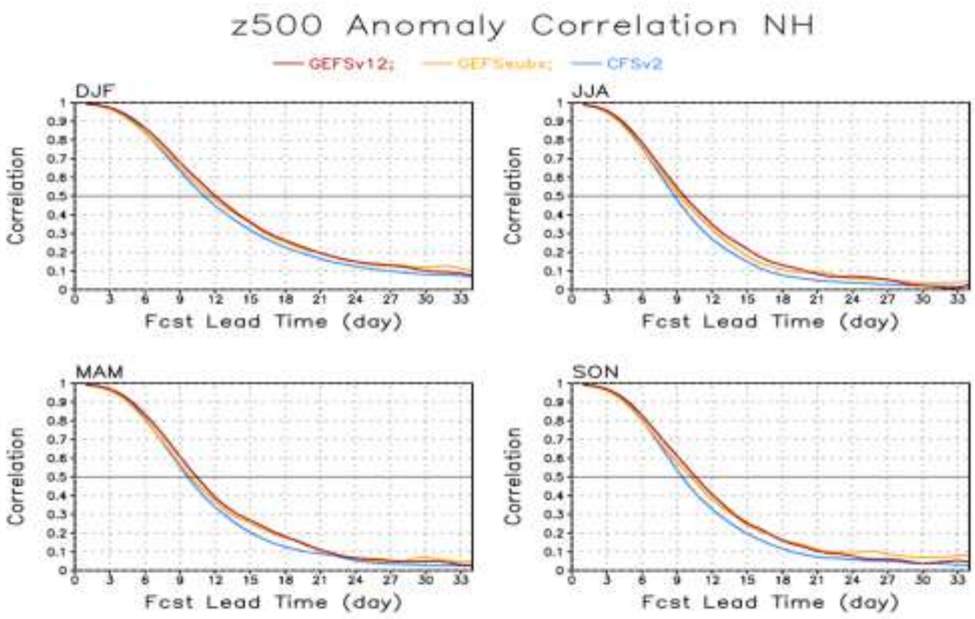
Evaluation of GEFSv12
Week-2, Weeks 3&4 Forecasts

Based 31 years reforecast

Contributors: CPC and EMC

500hPa height scores (2000-2019)

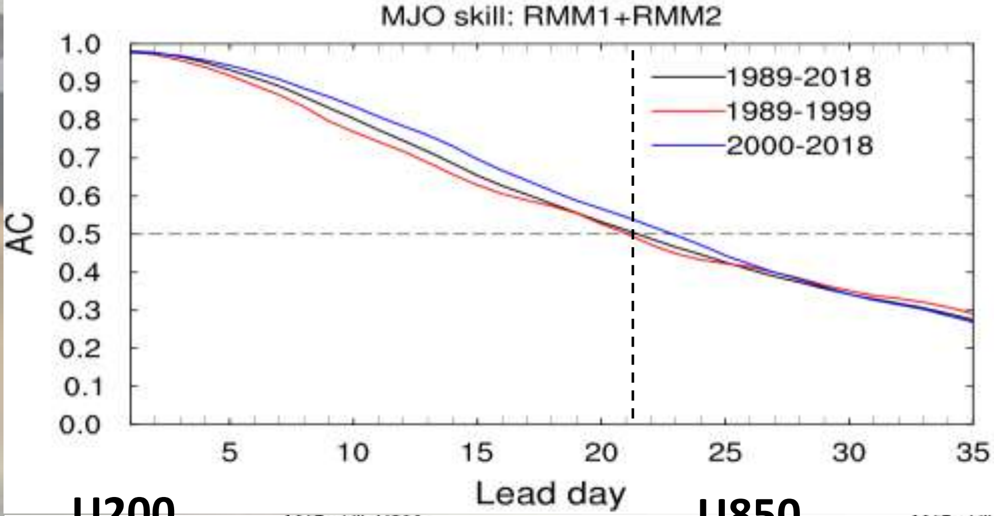




	NH				PNA			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
GEFSv12	12	10	9	10	12	10	9	10
GEFSsubx	11	9	9	10	12	9	8	10
CFSv2	11	9	8	9	11	9	8	9

Courtesy of Dr. Mingyue Chen (CPC)

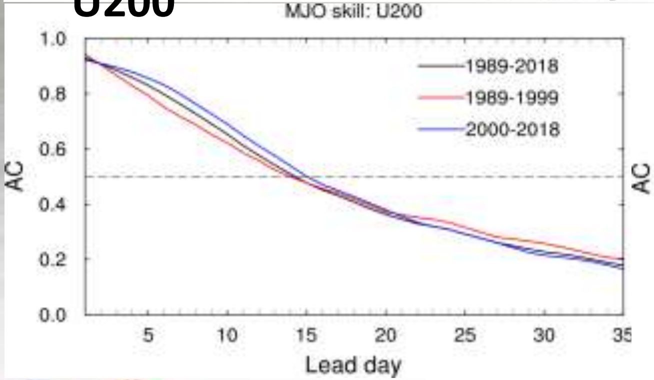
MJO RMM Skill during Different Periods



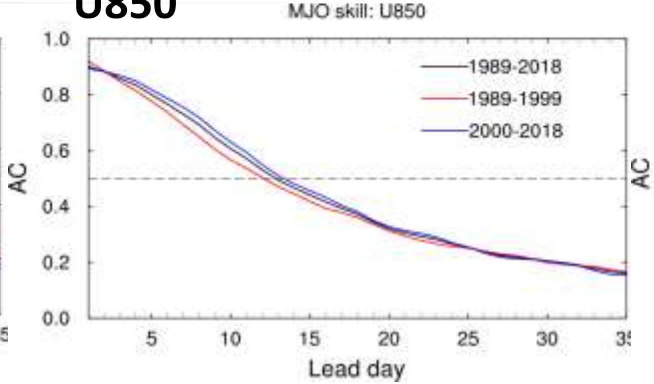
- Use dependent climatology
  - CFSR climatology (1989-1999)
  - GEFS reanalysis climatology (2000-2018)
  - GEFS reforecast climatology (1989-2018)

- MJO skill (RMM1+RMM2)
  - Latest years (2000-2018) is best
  - Early years (1089-1999) is least
  - Average scores (1989-2018) is about 21 days

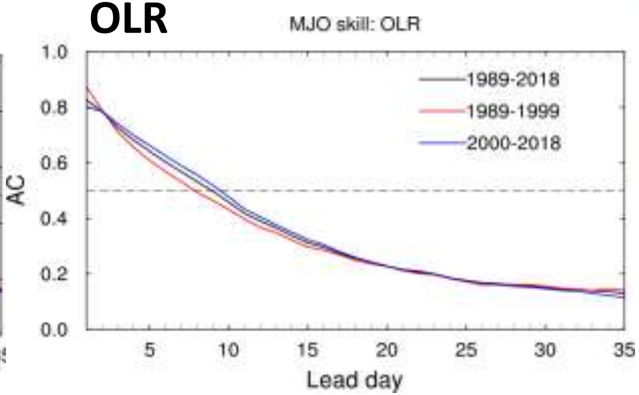
U200



U850



OLR

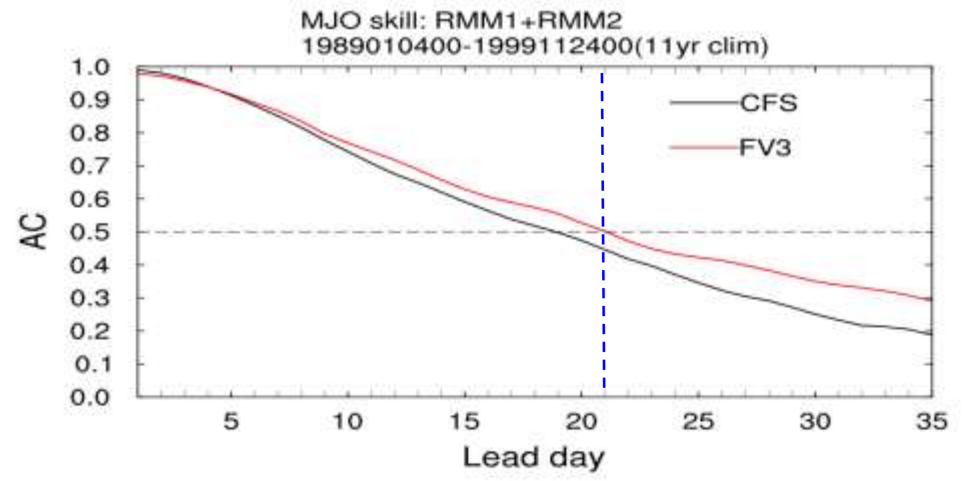


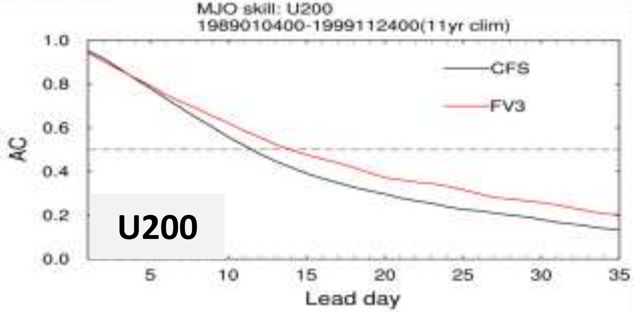
Courtesy of Dr. Wei Li (EMC)

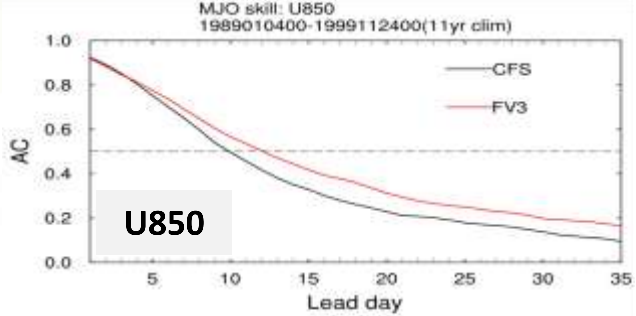
MJO skills comparison (1989-1999)

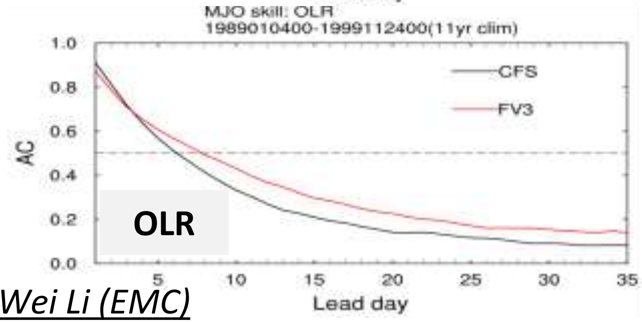
GEFSv12 vs. CFSv2

MJO RMMs ACC









MJO Components

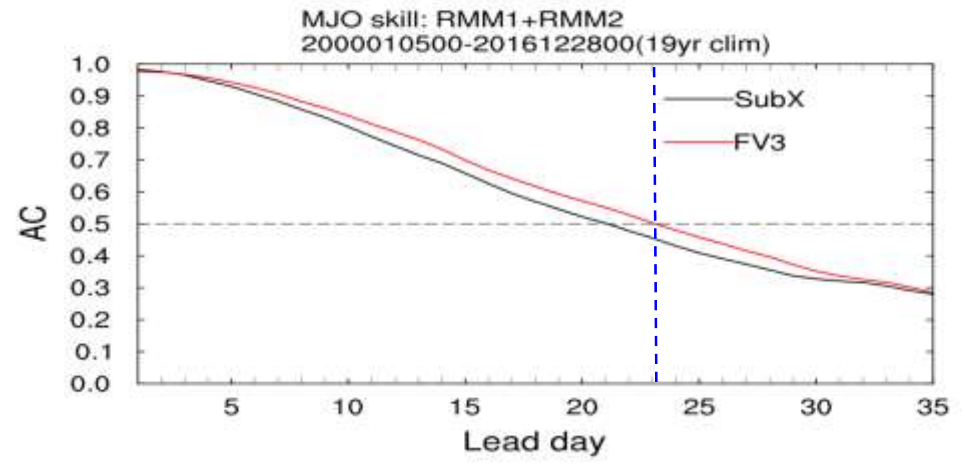
- *Both MJO skills are lower, but GEFSv12 is better than CFSv2 about 2 days*
- *The same for MJO components skill, GEFSv12 is better than CFSv2*

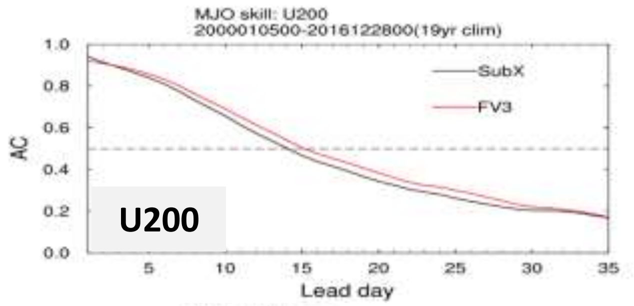
Courtesy of Dr. Wei Li (EMC)

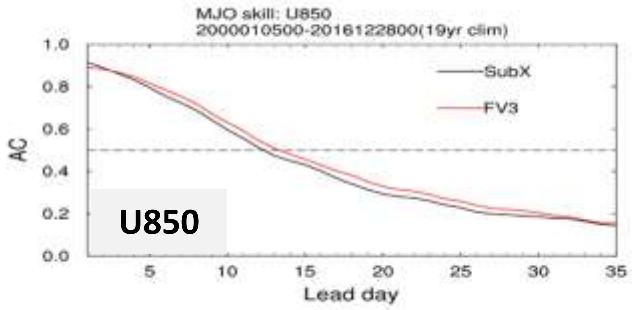
MJO skills comparison (2000-2016)

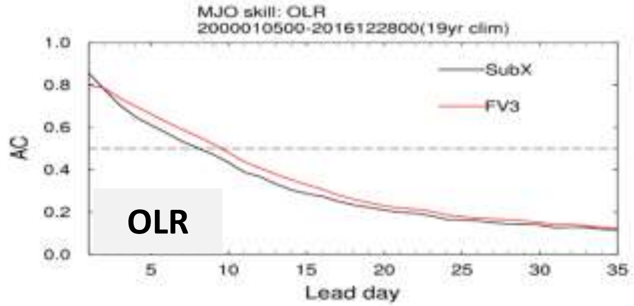
GEFSv12 vs. SubX

MJO RMMs ACC









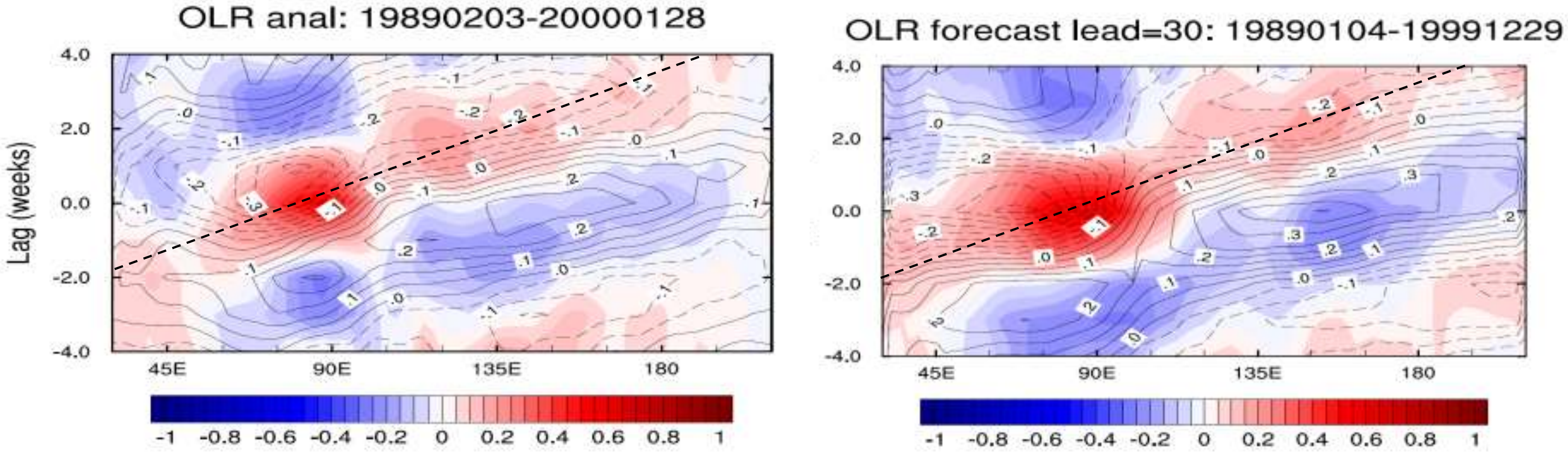
MJO Components

- *For MJO RMM skill (bias corrected), GEFSv12 (23+ days) > SubX GEFS for ~ 2 days*
- *For MJO components skill, GEFSv12 > SubX GEFS*

Courtesy of Dr. Wei Li (EMC)

Propagation of MJO in GEFSv12

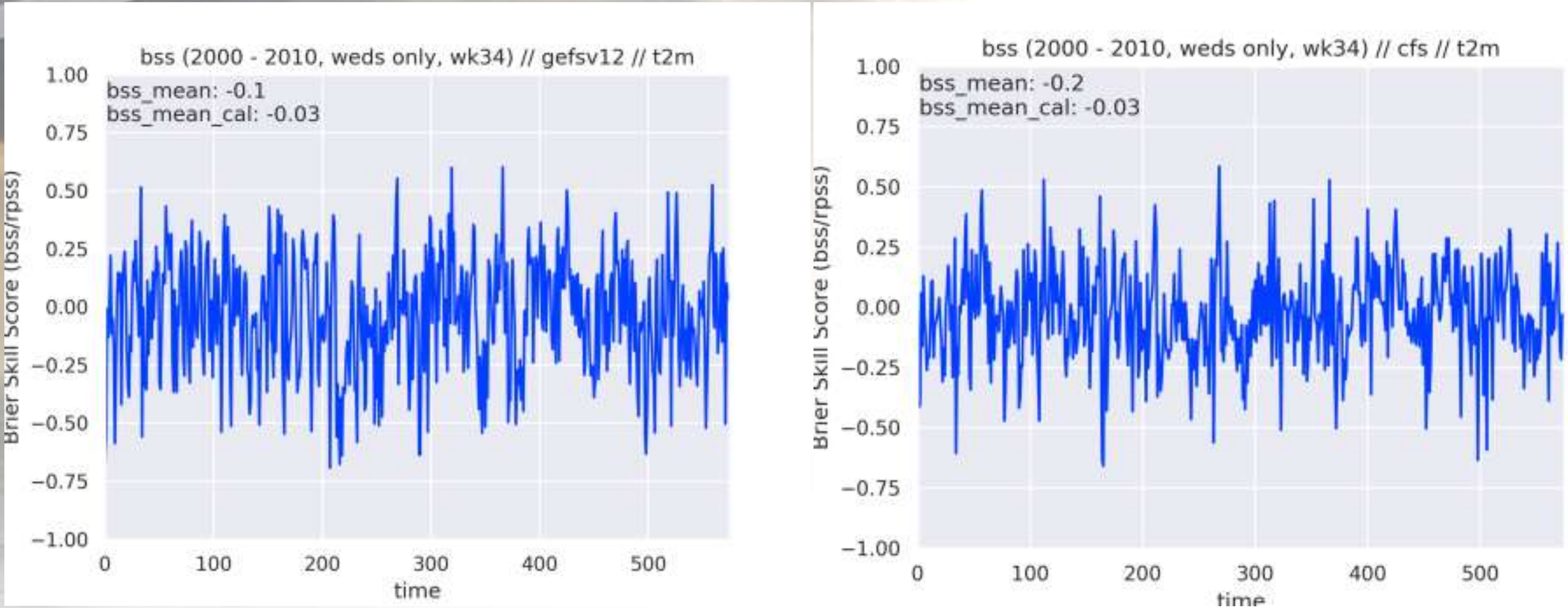
1989 - 1999



*Spatial and time correlation (anomaly) in the **Central Indian Ocean** /time-lag of 11 years analysis (CFSR; left) and 30-day forecast (GEFSv12 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 India Ocean. However, it is challenging to capture northward propagation of Intra-Seasonal Oscillations.*

Courtesy of Dr. Wei Li (EMC)

T2m: GEFSv12 vs CFS for 2000-2010

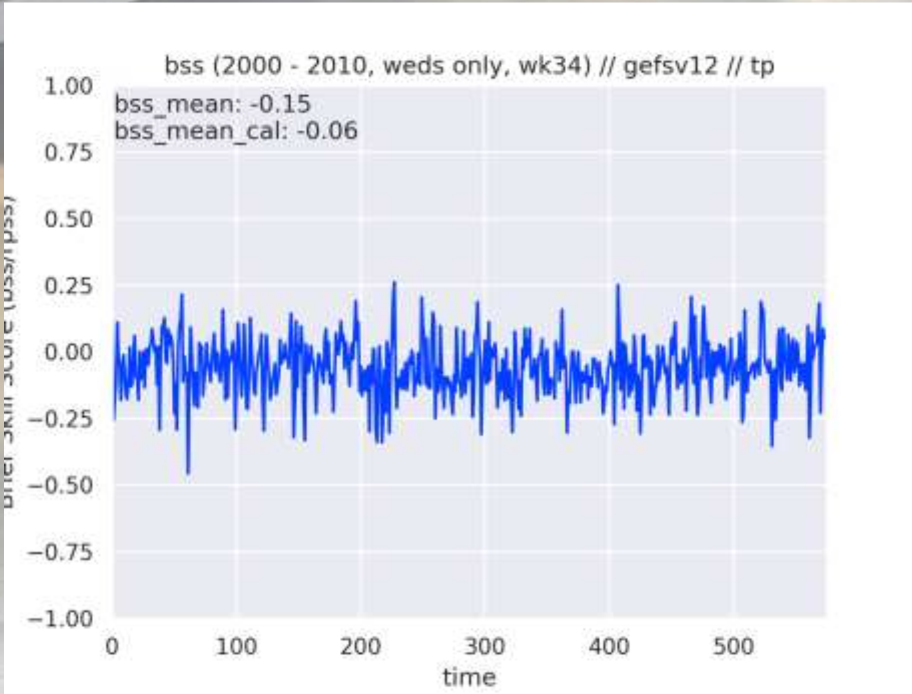


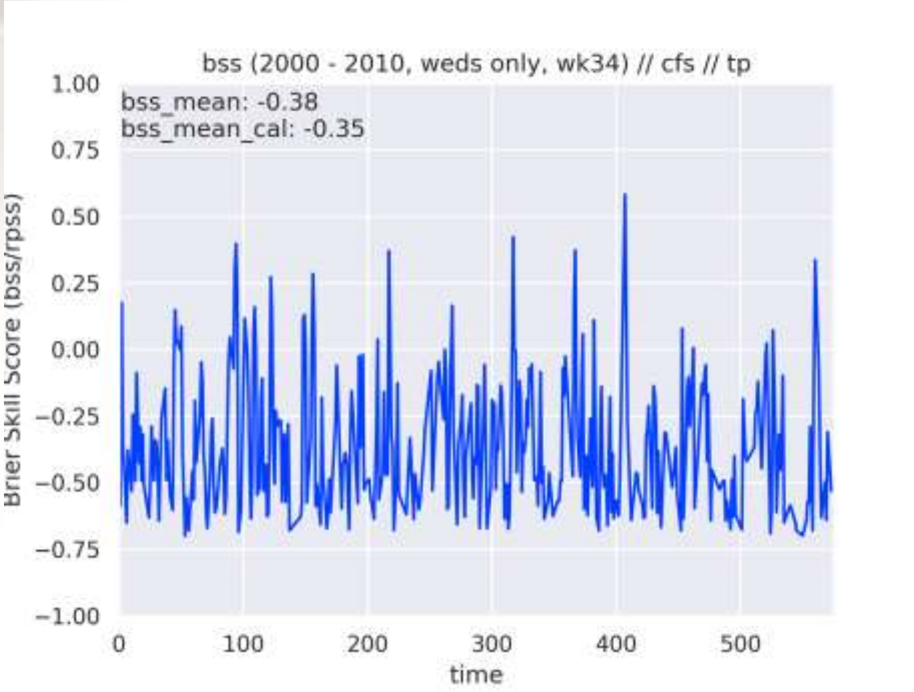
Summary:

- The GEFSv12 is slightly better uncalibrated, and identical when calibrated.

Courtesy of Dr. Kyle MacRitchie

Precip: GEFSv12 vs CFS for 2000-2010





Summary:

- The GEFSv12 has higher BSS than the CFS and less variance.

Courtesy of Dr. Kyle MacRitchie

Benefits from GEFSv12 implementation (9/23/2020)

- GEFSv12 is much improved from GEFSv11:
  - Higher 500-hPa AC and CRPS scores to extend skillful forecast more than 12 hours.
  - Increased ensemble spread to better present forecast uncertainty.
  - Improved TC tracks, spread, and location of QPF maxima
  - Better handling of deepening extratropical cyclones
  - Extend about 1 day PQPF skill and more reliable precipitation forecasts
  - Improved representation of weather events near topography

- GEFSv12 is improved from SubX (GEFSv11+) and CFS of subseasonal forecast
  - GEFSv12 has demonstrated an extension of MJO skill by 2-3 days compared to GEFS SubX version.
  - GEFSv12 shows much better scores than GEFS SubX version and CFSv2 for 500hPa height PAC scores of NH and PNA.