NCEP OD Science and Decisional Brief, May 5, 2020

Implementation of Global Ensemble Forecast System - GEFS v12.0, Q4FY20

UFS Sub-Seasonal Weather Application

Presented by:

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Environmental Modeling Center

NCEP/NWS/NOAA

A Major Advancement in Probabilistic Guidance for Medium Range and Sub-Seasonal Weather Forecasts & Unification of GEFS, GWES and NGAC Applications

Acknowledgements

- **Ensemble Project Team:** Global ensemble development, ***Lead: Dingchen Hou***
- **Wave Project Team:** Wave development, unification, and support, ***Lead: Henrique Alves***
- **Aerosol Project Team:** Aerosol development, unification, and support, ***Lead: Jeff McQueen***
- **GFS Project Team:** Support for ensemble development, ***Leads: Fanglin Yang and Russ Treadon***
- **PSL DA/Ensemble Group:** Production of 20 years reanalysis and support for ensemble development including stochastic physics, ***Leads: Tom Hamill and Jeff Whitaker***
- **GSL Aerosol/Chemistry Group:** GOCART/GSL-Chemistry development and support for the atmosphere-aerosol coupled system, ***Lead: Georg Grell***
- **ARL and NESDIS: GEFSv12-Aerosol Emission Datasets**
- **Model Evaluation Group:** Evaluation of ensemble performance, coordination with the field, ***Lead: Geoff Manikin***
- **EIB:** Support for global workflow, EE2 compliance, and resource optimization, ***Leads: Walter Kolczynski, Xianwu Xue, Lin Gan***
- **NCO SPA team:** EE2 coordination and final implementation, ***Lead: Steven Earle***
- **STI staff:** Project management support and technical coordination, ***Lead: Farida Adimi***
- **CPC staff:** Evaluate ensemble performance for week-2, and weeks 3&4 (sub-seasonal), ***Lead: Matt Rosencrans***
- **Water Center:** Validate reanalysis and reforecast products, develop HEFS based on GEFSv12, ***Lead: Ernie Wells & Mark Fresch***
- **Centers and Regions and other Stakeholders:** Evaluate ensemble performance for GEFSv12
- **EMC management:** Support for the ensemble development project and NPS unification

GEFS Version 12

Status as of 5/5/20

Project Information & Highlights

Project Manager: Vijay Tallapragada

Leads: Yuejian Zhu & Dingchen Hou (EMC), Steven Earle (NCO)

Scope: Incorporate new upgrades to the NCEP GEFS to extend forecasts to weeks 3&4. This includes upgrades to stochastic physics, and unification of Global Wave Ensembles and NGAC capabilities, and increase the resolution and number of members. This development also includes efforts towards producing re-analysis datasets and reforecast (Draft project plan and charter).

Expected benefits: Extend forecasts to week 3&4 and unify with wave ensemble and GOCART

Implemented with: NA

Dependencies: Wave ensemble and GOCART development and Compute resources

G Schedule

Milestones & Deliverables	Date	Status
Freeze system's configuration	Q4FY18	Completed
Submit Product Change Notice (PNS) for retiring products	Dec 2019	Completed
Submit PNS for extending running window	3/2020	Completed
Complete full retrospective experiments	2/15/20	On track
Complete field evaluation	4/27/20	Completed
Conduct NCEP OD brief, and deliver final code to NCO	5/5/20; 5/15/20	Scheduled
Disseminate Service Change Notice (SCN)	8/3/2020	Planned
Start the 30-day evaluation and IT testing	8/3/2020	TBD
Operational Implementation	9/9/2020	Planned

EMC NCO Blue text indicates change from previous quarter

G Issues/Risks

Risk::

Mitigation:

G Resources

Staff: **2** Fed FTEs + **12** contractor FTEs including development for all components)
Funding Source: STI and OWAQ/CPO

Compute: EMC Dev: varies (x6)**; Parallels:** 500+100+40 nodes (x6); **Ops**: 421 nodes (Dell 3.5)

R Management Attention Required Y Potential Management Attention Needed G On Target

Gantt Chart for NCEP GEFSv12 T2O Plan

Implementation Plan for Global Ensemble Forecast System (GEFS V12.0)												
	Timeline	FY18			FY19				FY20			
	Component	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
GEFS											GEFS V12 in operations ◆	
(1) Dynamic Core & Model	FV3 based GEFS Development	GFS w/C384 L64 (~25km, 55km top), one-way coupled to Global Wave Ensembles and Aerosols										
(2) Ensemble configuration	Ensemble setup	31 members, 16-day forecasts at 06/12/18Z, extend forecast length to 35 days at 00Z										
(3) Physics	Stochastic Physics	GFSv15.1 Physics, SKEB and SPPT, 2-Tier SST										
(4) Reanalysis	GEFSv12 Reanalysis	~20-year reanalysis datasets using FV3GFS/GDAS (ESRL/PSL)										
(5) Reforecasts	GEFSv12 Reforecasts		~30-year reforecasts (extended to 35 days) (EMC)									
	Testing & Evaluation							3-year retrospectives, downstream validation, evaluation and transition to operations				
											Today	

Topics

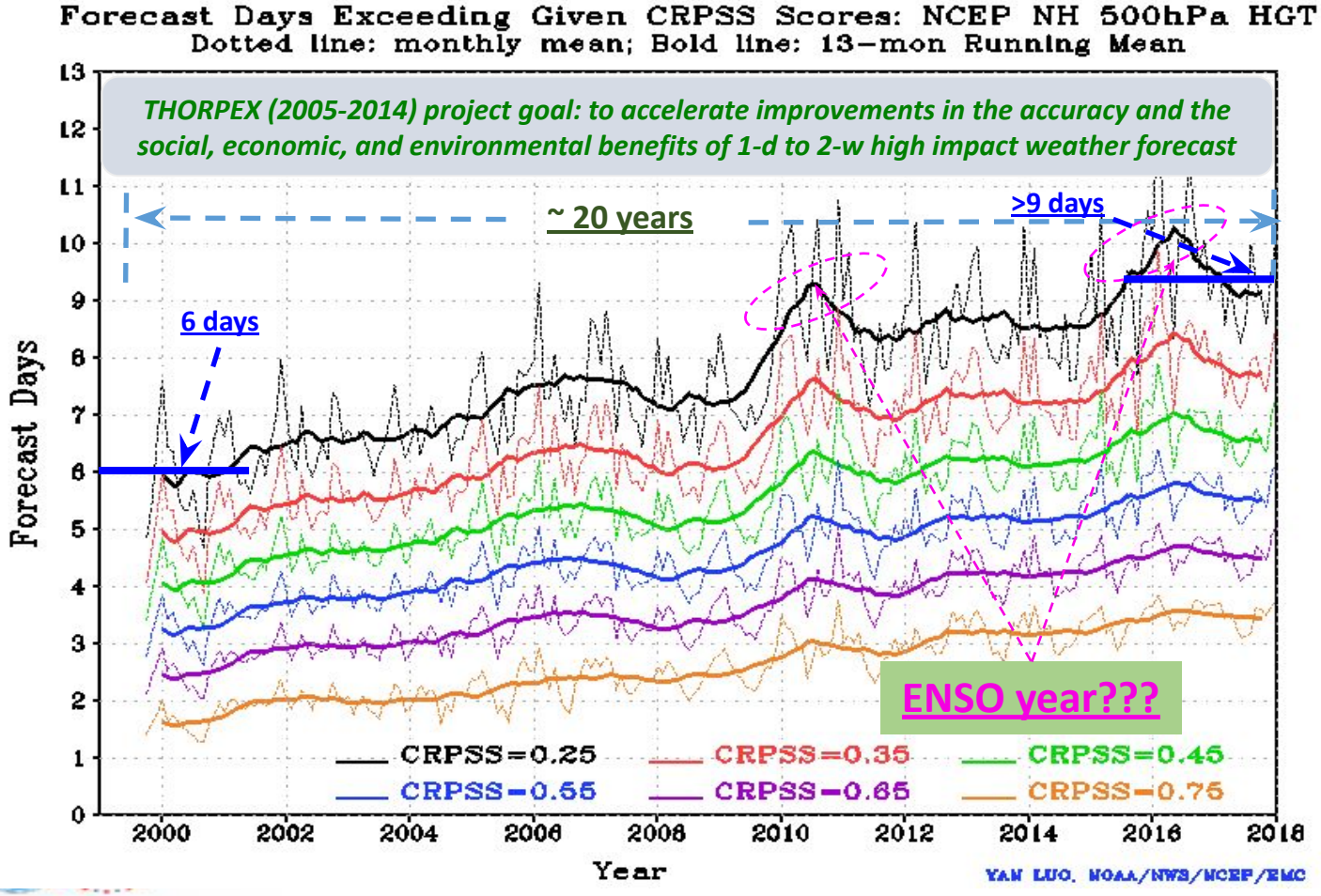
- Review of Science Changes for GEFSv12
- Statistical Evaluation of GEFSv12 (EMC Perspective)
  - GEFSv12 Medium Range Weather
  - GEFSv12 Week 2 and Weeks 3&4 Weather
  - GEFSv12 Wave Component
  - GEFSv12 Aerosol Component
- MEG and Stakeholder Evaluation of GEFSv12
- Resource Requirements

Evolution of NCEP GEFS

Version	Implementation	Initial uncertainty	TS relocation	Model uncertainty	Resolution	FCST length	Ens. size (members)	Daily frequency
V1.0	1992.12	Bred vector	None	None	T62L18 ~200km	12	2+1	00UTC
V2.0	1994.03				T62L18 ~200km	16	10+1 (00UTC) 4+1 (12UTC)	00UTC 12UTC
V3.0	2000.06							
V4.0	2001.01				T126L28(0-2.5) ~100km T62L28(2.5-16) ~200km		10+1	
V5.0	2004.03				T126(0-3.5) ~100km T62L28(3.5-16) ~200km			
V6.0	2005.08				T126L28(0-7.5) ~100km T62L28(7.5-16) ~200km			
V7.0	2006.05		TSR		T126L28 ~100km		14+1	**00UTC 06UTC 12UTC 18UTC (16 days)**
V8.0	2007.03	(BV- ETR)					20+1	
V9.0	2010.02			STTP	T190L28 ~70k			
V10.0	2012.02				T254L42 (0-8) ~50km T190L42 (8-16) ~70km			
V11.0	2015.12				TL574L64 (0-8) ~33km TL382L64 (8-16) ~50km			
V12.0*	**2020.09**	**EnKF (f06)**	**None**	**SPPT+SKEB**	**C384L64 (0-35) ~25km**	**16(35)**	**30+1+1**	**00UTC (35 days)**

**** V12 is 1st Unified Forecast System (UFS) to combine global ensemble, wave ensemble and aerosols***

History of GEFS Performance



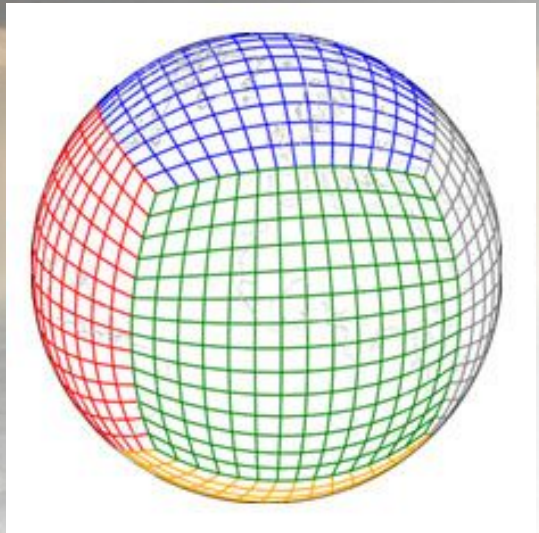
- **CRPSS** – *Continuous Ranked Probabilistic Skill Score is one of evaluation tools to measure ensemble based probabilistic forecast.*
- **Projection** – *0.25 CRPSS is very close to 0.6 AC score to estimate the days with skillful probabilistic forecast*
- **Performance** – *GEFS has provided useful skill reaching to around 10 days in recent years (typical expected improvements are 1 day per decade)*

Proposed GEFS v12 Configuration

Components	V11 (Dec. 2015)	V12 (Sept. 2020)
GFS Model	Semi-Lagrangian, 2015 version	**FV3 (Finite-Vol Cubed-Sphere) GFSv15.1 version**
Physics	GFSv13 package (Zhao-Carr MP)	GFSv15.1 package (**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) - Support SubX**
Members	Control + 20 pert members	**Control + 30 pert members + 1 aerosol member**
Output resolution	0.5^o x 0.5^o	**0.25^o x 0.25^o** and 0.5^o x 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
Reforecast	EMC offline – 20 years	**30 years (1989-2018)**
Implementation	December 2, 2015	**September 2020**

GEFSv12: Dynamic Core and Physics Changes

The Finite Volume Cubed Sphere (FV3) dynamic core



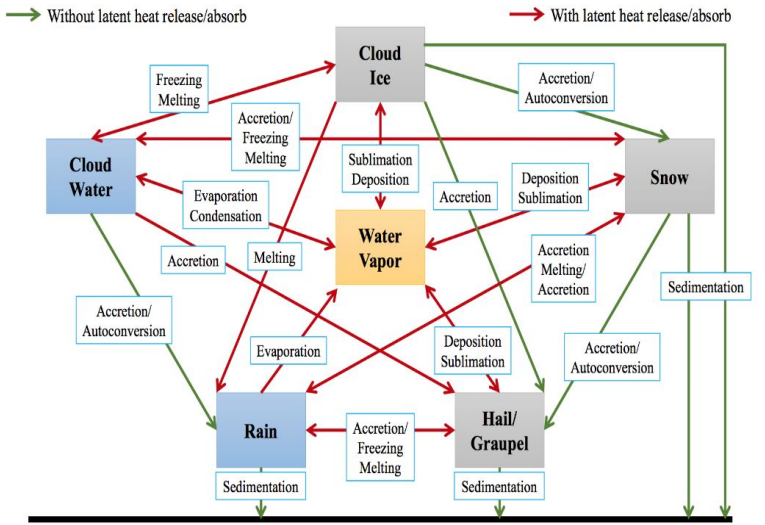
C384L64 ~ 25km resolution
Non-hydrostatic

Key parameters

- ***Time step=450s****; but use 300s for aerosol integration*
- ***hord=5;*** *horizontal advection scheme*
- *Others similar to GFSv15.2*
- *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**)*
- *gravity wave drag and mountain block coefficients set to **cdmbgwd=1.2;1.0***
- Other parameters similar to GFSv15.1

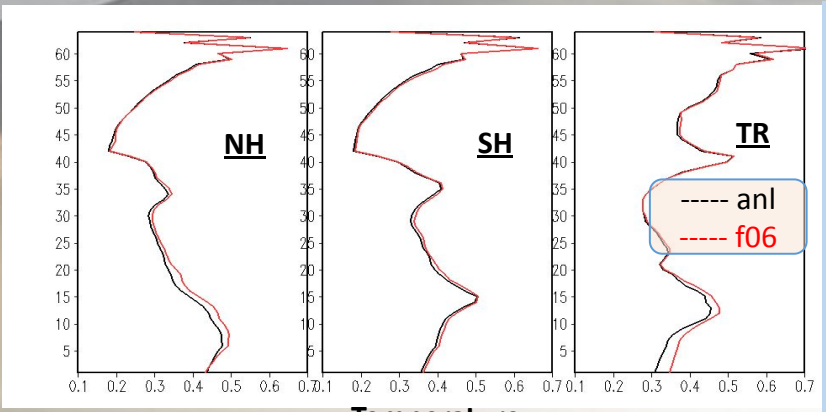
Replace Zhao-Carr MP with GFDL MP

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

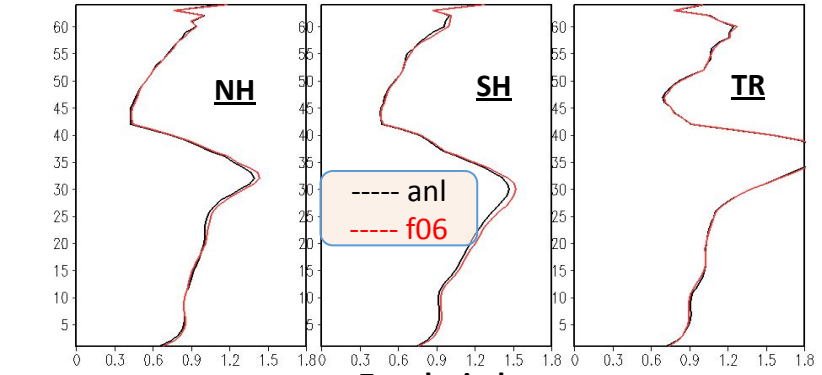


GEFSv12 IC and Model Uncertainty, No TC Relocation

Example of FV3-EnKF spread vertical profile



Temperature



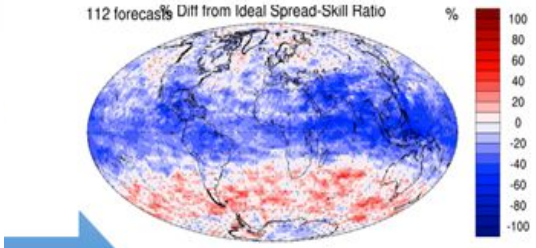
Zonal wind

- **GDAS 80-member EnKF f06 for IC perturbations:**
  - *GEFS takes 1-30; 21-50; 41-70; 61-10 GDAS ensemble members for 00; 06; 12; 18 UTC*
  - *Ensemble re-centering applied for selected 30 perturbations.*
- **Remove TC relocation –**
  - *Not* much impact on TC track forecasts, similar to GFSv15.1
- **Model Uncertainty:**
  - Considered SKEB, SPPT and SHUM
  - ***Replace STTP for GEFSv12 with SPPT and modified SKEB (amplitude reduced to 0.5 from 1.0), no SHUM***

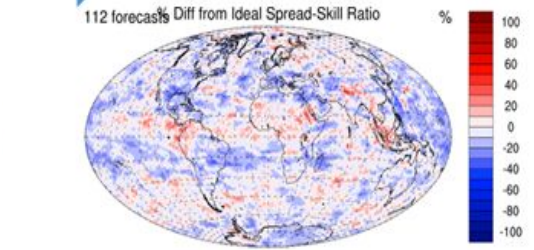
STTP vs. SKEB+SPPT

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*

- **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

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

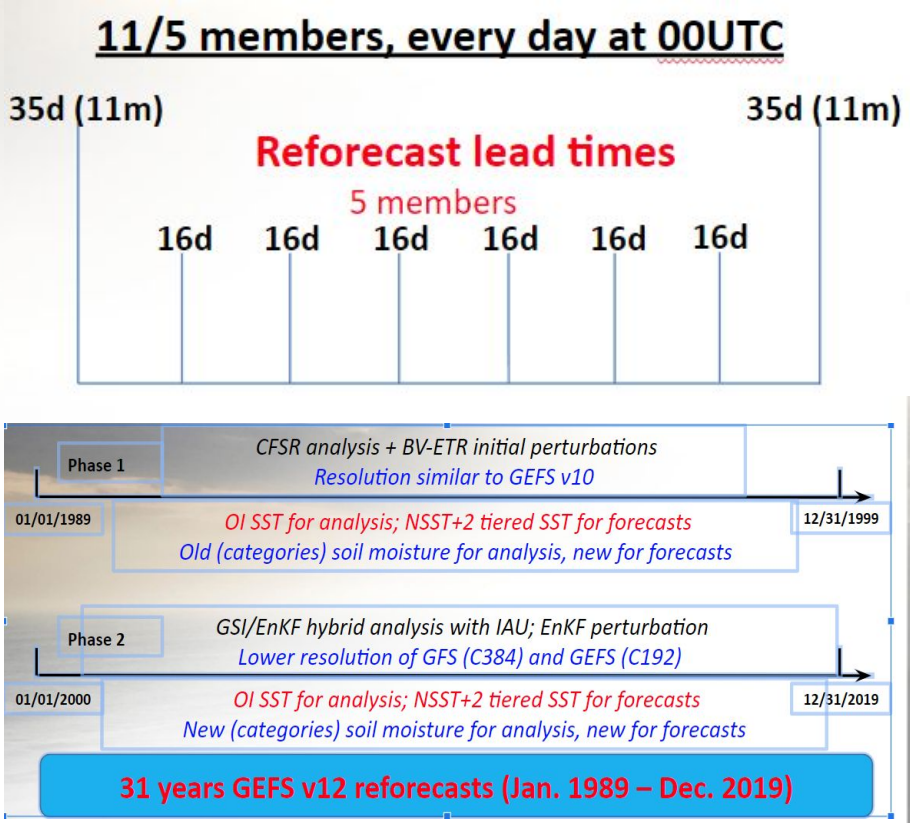
Two-tiered SST technique has been used for SubX project to provide real-time 35 days GEFS forecast to support CPC's subseasonal guidance. It has been demonstrated the value to improve tropical forecasts

GEFSv12 Reanalysis and Reforecast

to support sub-seasonal (weeks 3&4) forecasts

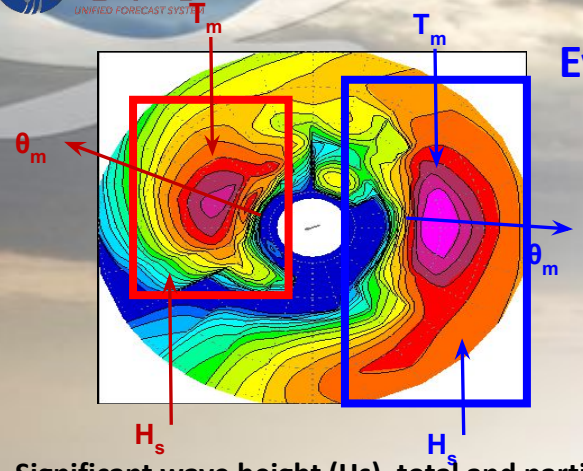
20-year Reanalysis (2000-2019), Led by ESRL/PSL
31-year Reforecast (1989-2019), Led by NCEP/EMC

- **Model configuration**: Same as GEFSv12 (C384L64)
- **Period of retrospective**: 31 years (1989 – 2019)
  - 1989 – 1999 (11 years) CFS analysis
  - 2000 – 2019 (20 years) Hybrid FV3 GFS/EnKF/IAU reanalysis (ESRL/PSL)
- **Frequency and ensemble size**
  - Initialized at 00UTC for every day; 5 members out to 16 days, except for 11 members out to 35 days once a week
- **Output data (Grib2 format, 590 variables)**
  - 3 hrly out to 10 days at 0.25o resolution
  - 6 hly beyond 10 days at 0.5o resolution
  - Selected 77 variables on disk for CPC, MDL and NWC
  - PSL converting Grib data to NetCDF for public access



GEFSv12-Wave Component

Evolution of NCEP's Global Wave Ensemble



Version	Implementation	Resolution	FCST length	Forcing Stride	Ens. size (members)	Daily frequency
V1.0	2004	1°x1.25°	5.5 days (126h)	6h	10+1	00, 06, 12, 18 UTC
V2.0	2008	1°x1°	10 days (240h)	6h	20+1	00, 06, 12, 18 UTC
V3.0	2014	0.5°x0.5°	10 days (240h)	6h	20+1	00, 06, 12, 18 UTC
V3.0	2014	0.5°x0.5°	10 days (240h)	3h	20+1	00, 06, 12, 18 UTC
GEFSv12	**2020**	**0.25°x0.25°**	**16 days (384h)**	**1h**	**30+1**	**00, 06, 12, 18 UTC**

Significant wave height (Hs), total and partitions

Peak and Mean wave periods (Tp, Tm), total and partitions

Peak and mean wave directions (θp, θm), total and partitions

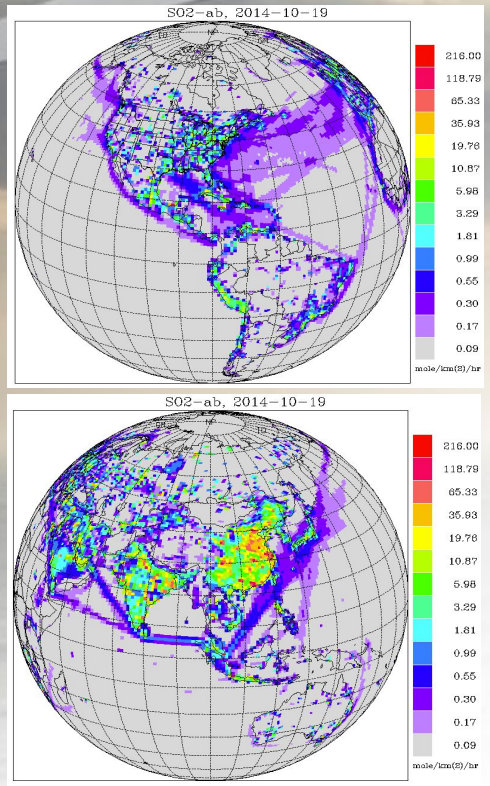
GWES→GEFSv12-Wave

- **"The first global-scale UFS coupled system at NCEP"**
- Integration of wave model to GFS global-workflow,
- Improved source-terms;
- Objective optimization with hourly GFS surface-wind forcing

- Additional (third) swell partition in gridded outputs
- Increased ensemble membership (21→31),
- Increased spherical grid resolution: ½° to ¼° global,
- Extended forecast range: 240h to 384h (16 days).

Courtesy: Jose-Henrique Alves

GEFSv12-Aerosol member



CEDS-2014 SO2 emissions

- **One additional member of GEFSv12 for aerosols**
- Replace operational NGACv2
- GFS meteorology (based on GFSv15) at C384 (~25 km), 64 levels, to 120 hrs, 4x/day
- Inline aerosol representation based on GOCART (GSD-Chem)
- Sulfate, Organic Carbon, Black Carbon, Dust, Sea Salt
- **Emissions**: CEDS-2014 (SO2, PSO4, POC, PEC), GBBEPx biomass burning, FENGSHA dust, GEOS-5 sea salt, marine DMS
- **Initial conditions**: cycled for aerosols, but from GFSv15 analysis for meteorology
- **Smoke plume rise**: Wind shear dependent 1-d cloud model to simulate tilt of plume. Fire Radiative Power is used to calculate convective heat flux and determine injection height

Tracer transport and wet scavenging are included in Simplified Arakawa-Schubert (SAS) scheme. Fluxes are calculated positive definite. Scavenging coefficient is α=0.2 for all aerosol species.

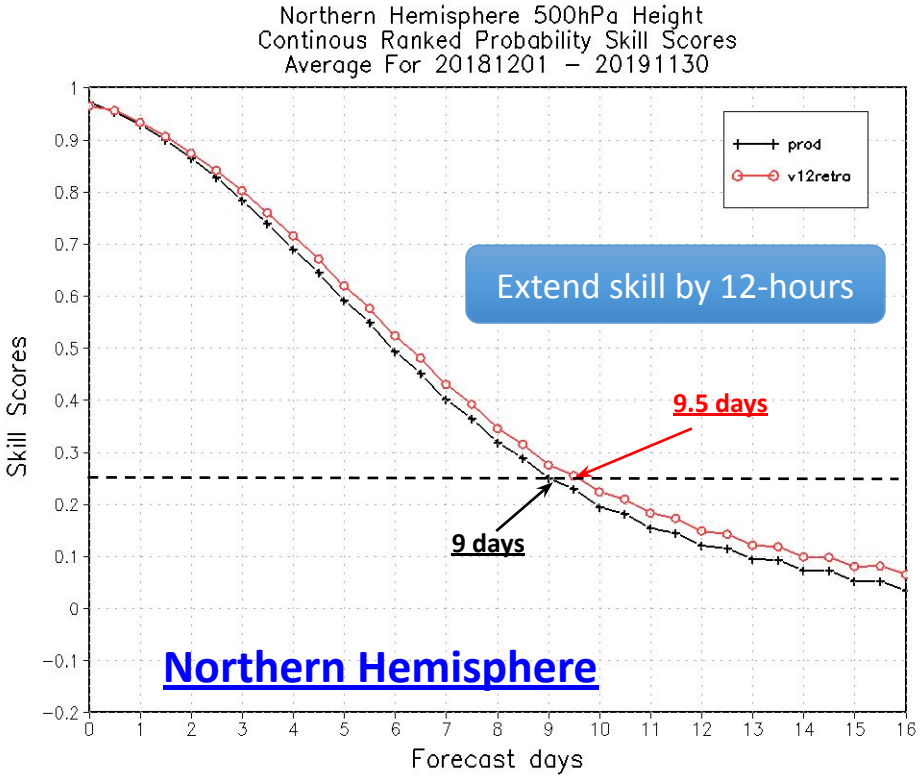
Courtesy: Jeff McQueen/Ivanka Stajner

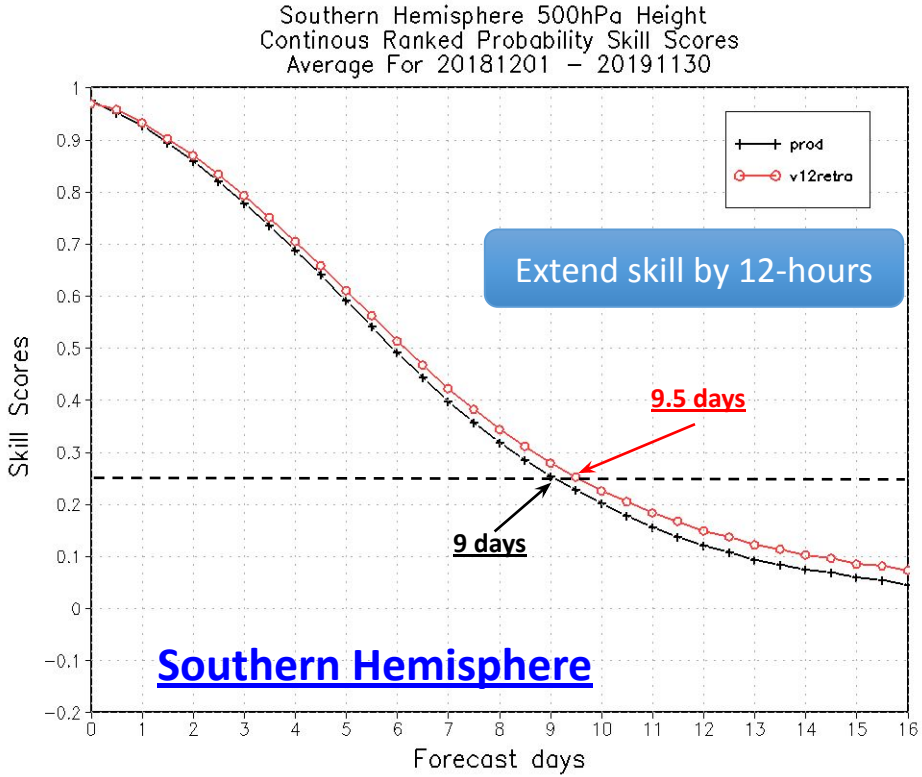
Statistical Evaluation of GEFSv12-Atmosphere Medium Range Weather

based on 2.5 yr retrospective forecasts (June 2017 – Nov. 2019)

EMC Perspective

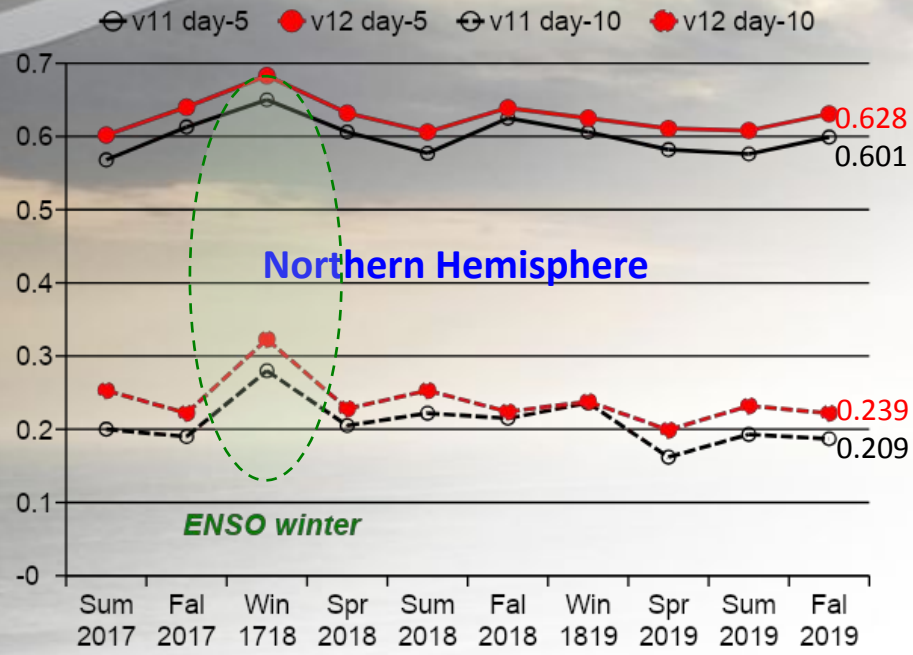
CRPS Skill of 500hPa geopotential height

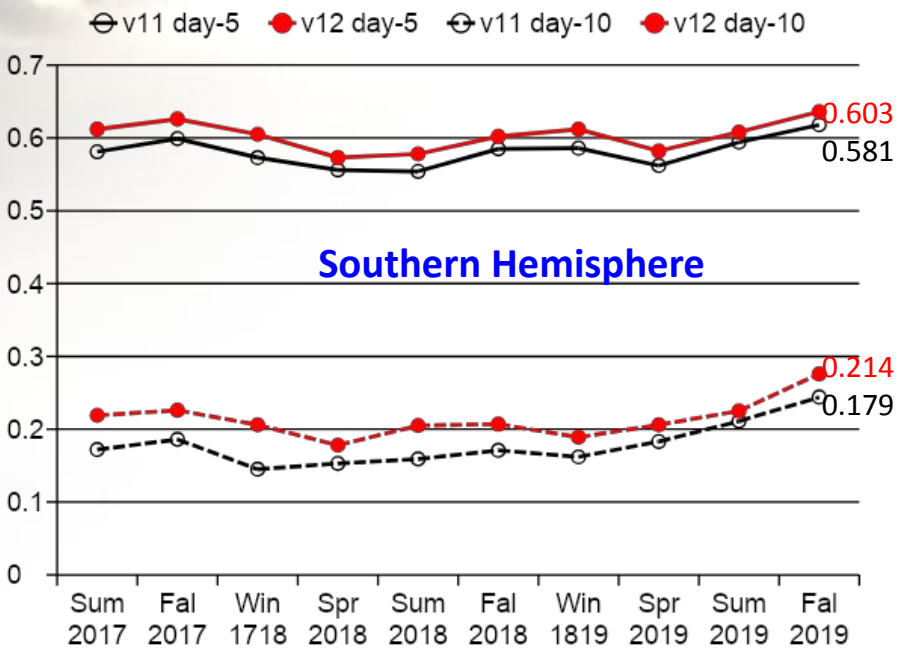




CRPSS – *Continuous Ranked Probabilistic Skill Score is one of evaluation tools to measure ensemble based probabilistic forecasts. CRPSS=1 is for perfect forecast, CRPSS=0 is for no skill from reference (climatology), CRPSS=0.25 is similar to PAC=0.6 (pattern anomaly correlation of ensemble mean).* ***GEFS v12 has better CRPSS for both hemispheres of 500hPa heights.***

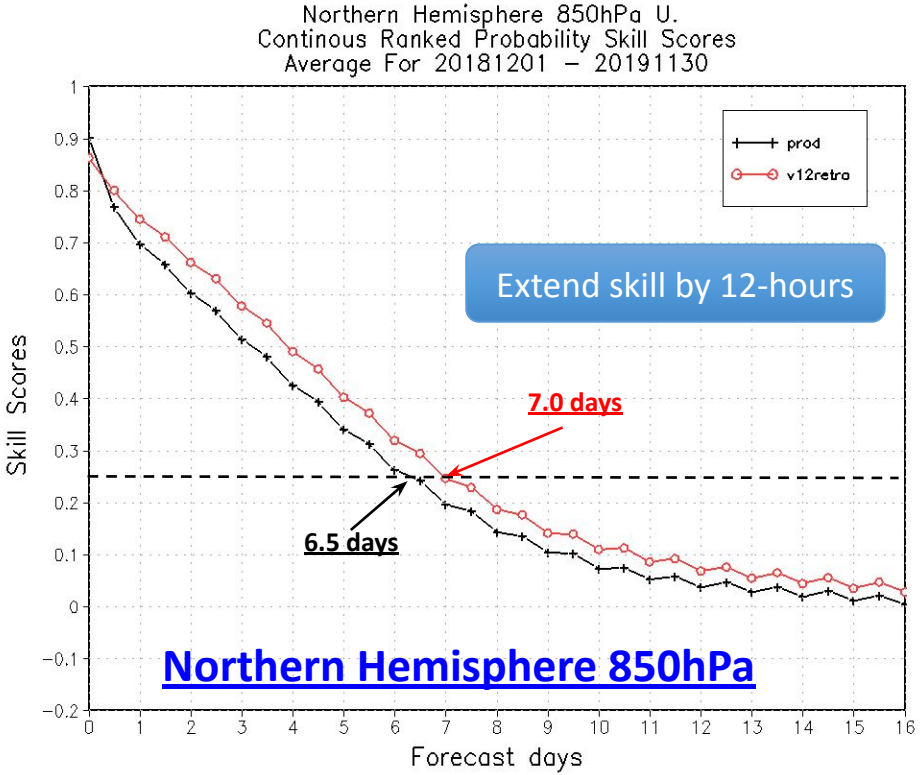
CRPS Skill of 500hPa geopotential height

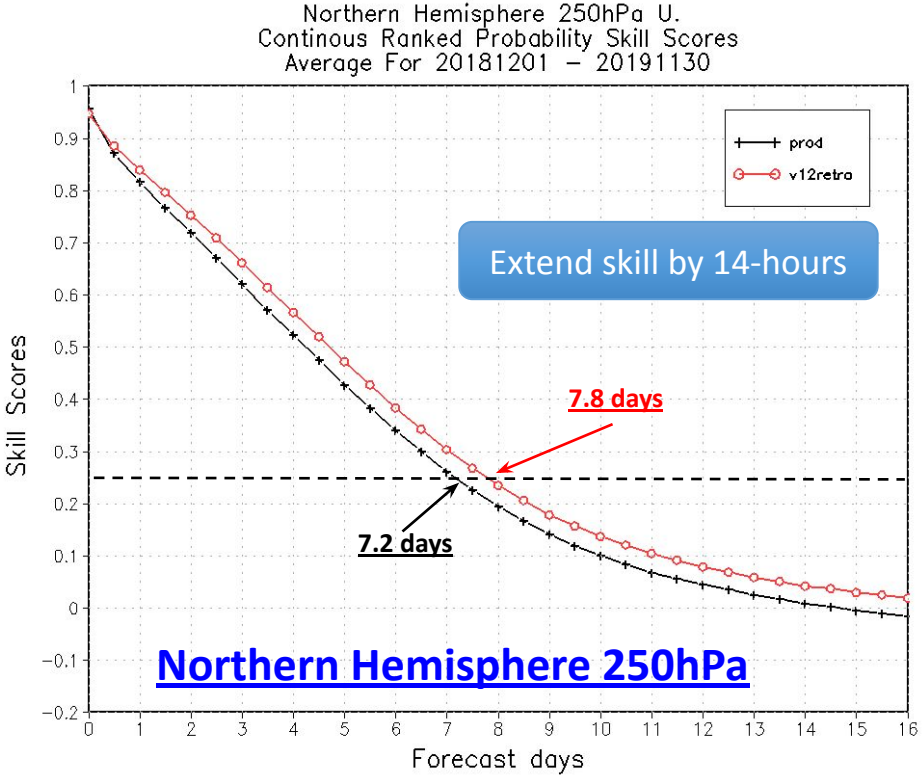




GEFS v12 has better CRPSS for 500hPa heights for both hemispheres, day-5 and day-10, all two and half years.

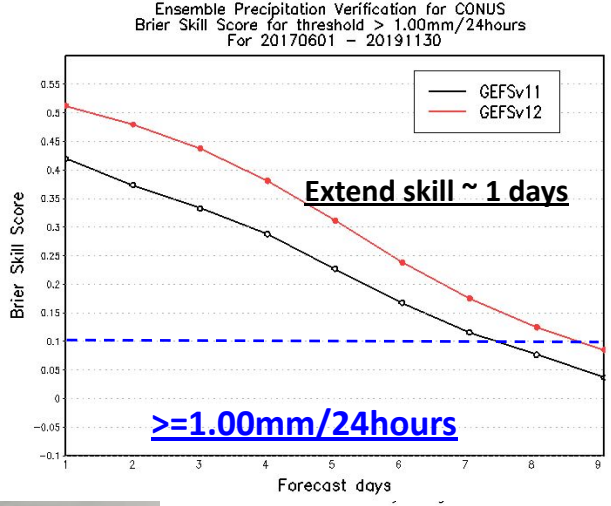
CRPS Skill of 850hPa and 250hPa zonal winds

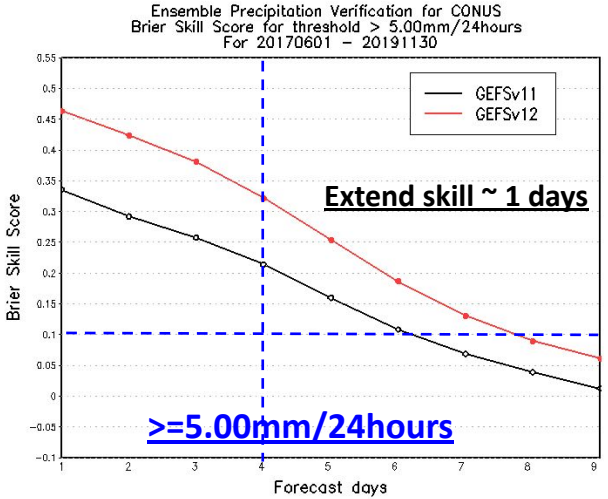


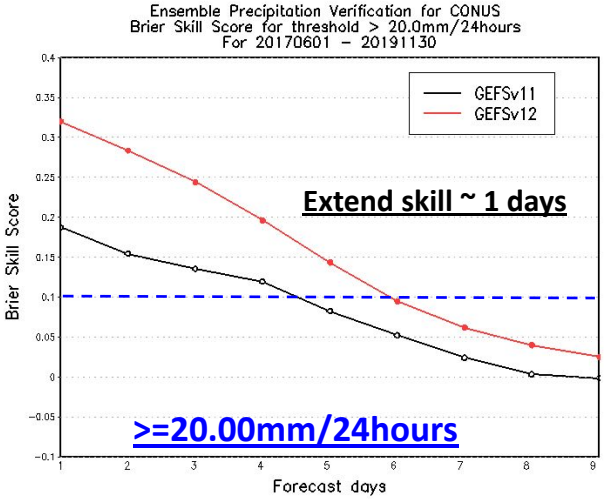


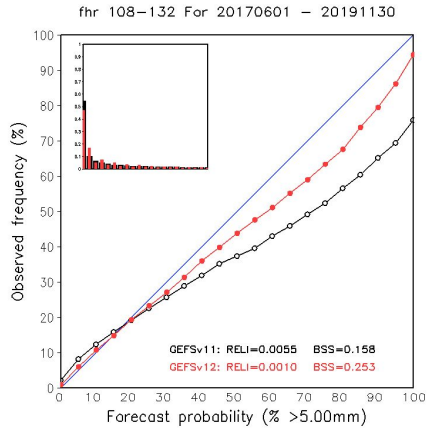
GEFS v12 has better CRPS for both Northern Hemisphere 850hPa and 250hPa zonal winds.

Brier Skill Scores of the CONUS PQPF







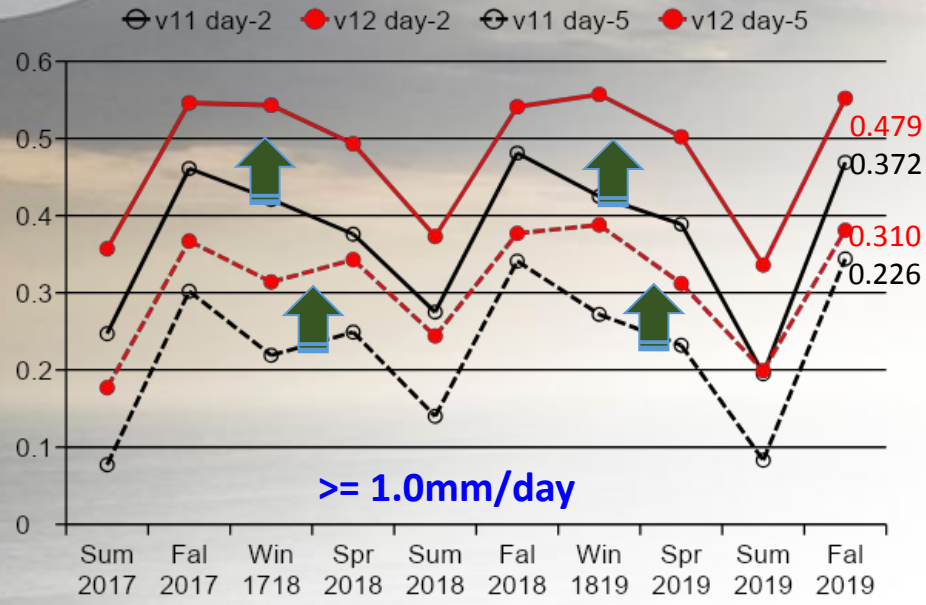


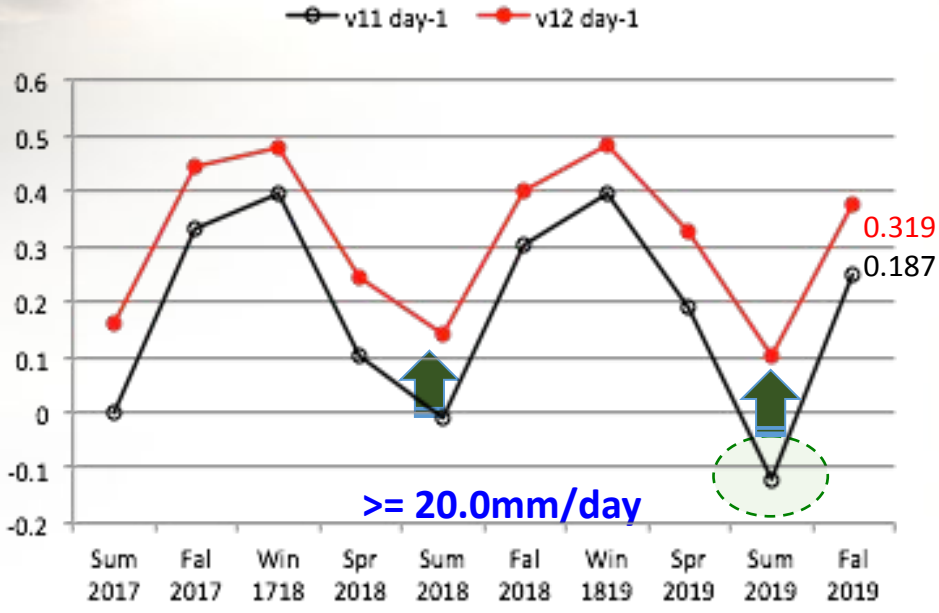
Brier Skill Score: *BSS=1 is for perfect forecast, BSS=0 is for no skill from reference climatology.*

Statistically, GEFSv12 has extended one additional day of useful probabilistic forecast skill over GEFSv11.

The forecast is more reliable than GEFSv11.

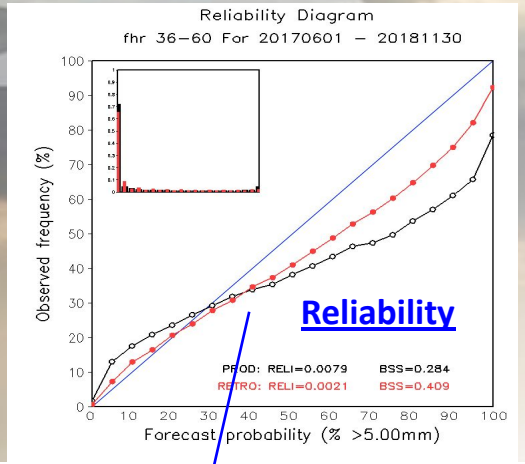
Brier Skill Scores of the CONUS PQPF

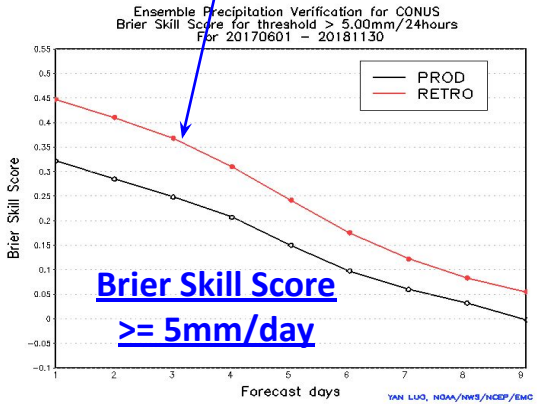




- ***GEFSv12 probabilistic Quantitative Precipitation Forecast (PQPF) performs better than GEFSv11 for all forecast categories, at all forecast lead-times.***
- ***Statistically, PQPF has higher skills in the winter period, and less skills in the summer.***
- ***The PQPF skills are more challenging for heavy precipitation (>20 mm/day).***

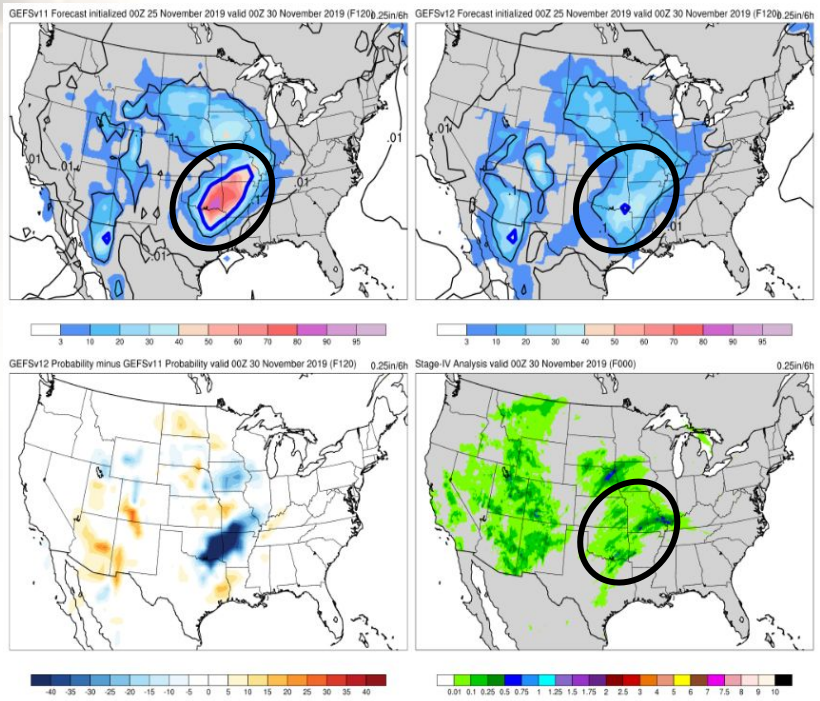
Probabilistic Quantitative Precipitation Forecast





Significant improvement of Probabilistic Quantitative Precipitation Forecast (PQPF) for all categories in terms of reliability and Brier Skill Score

GEFS v11 **GEFSv12**

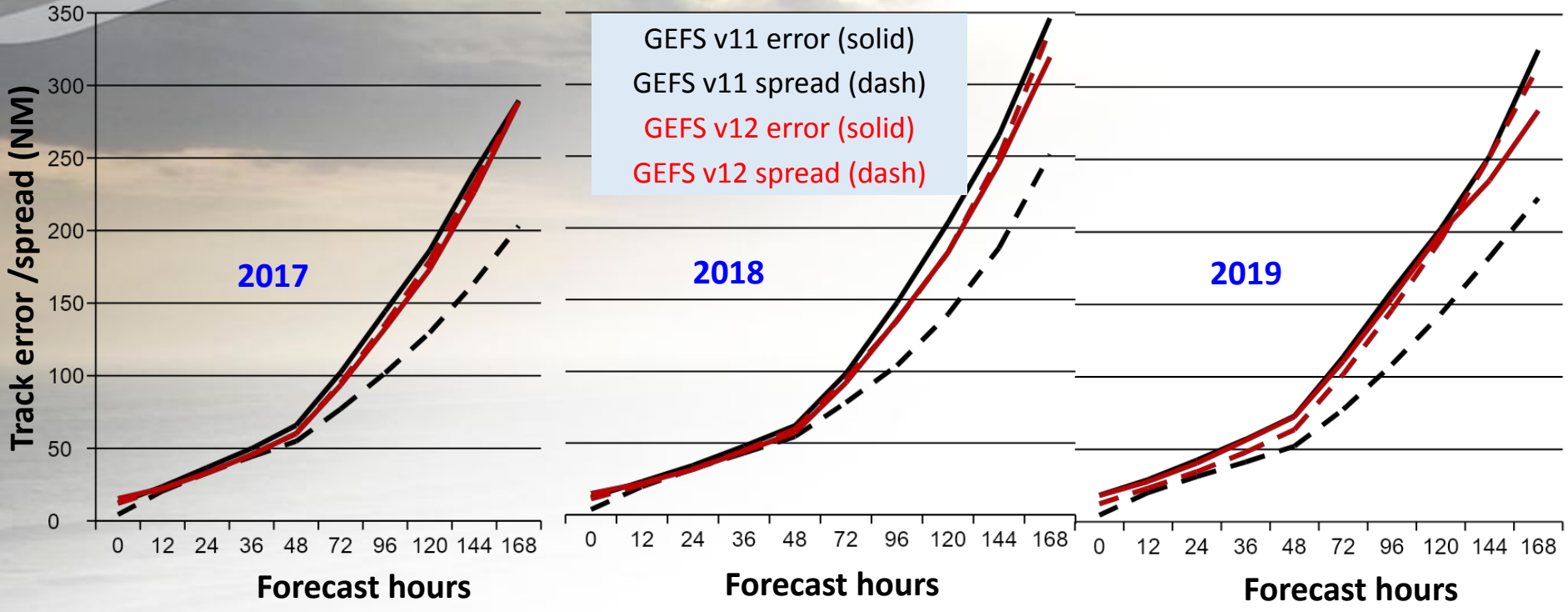


Diff **OBS**

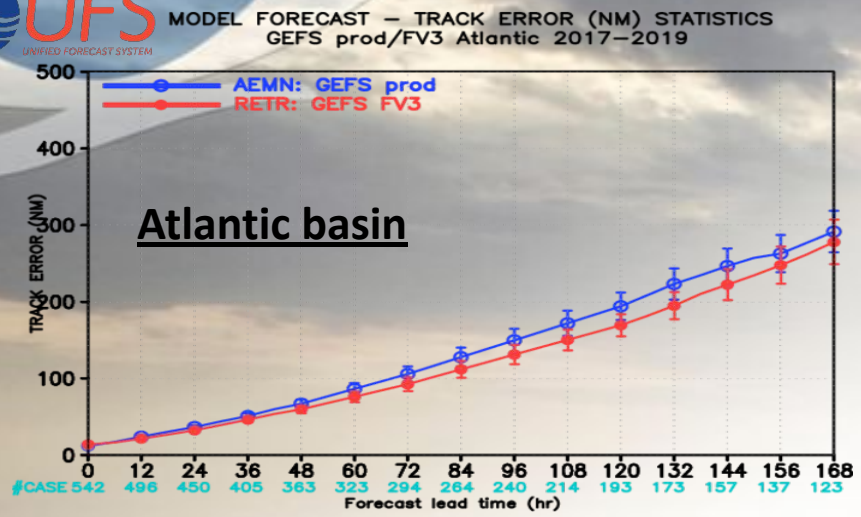
GEFS v11 is extremely overconfident here in a rainfall event (PQPF >=0.25 inch/24 hours of 120-hour forecast), while GEFSv12 has more reasonable (day 5) probabilities due to increased spread

Hurricane track forecast error and spread

Include WNP/EP/ATL (all retrospective cases)



GEFSv12 shows increasing the track spread (significantly) and reducing error for all three years (2017, 2018 and 2019).

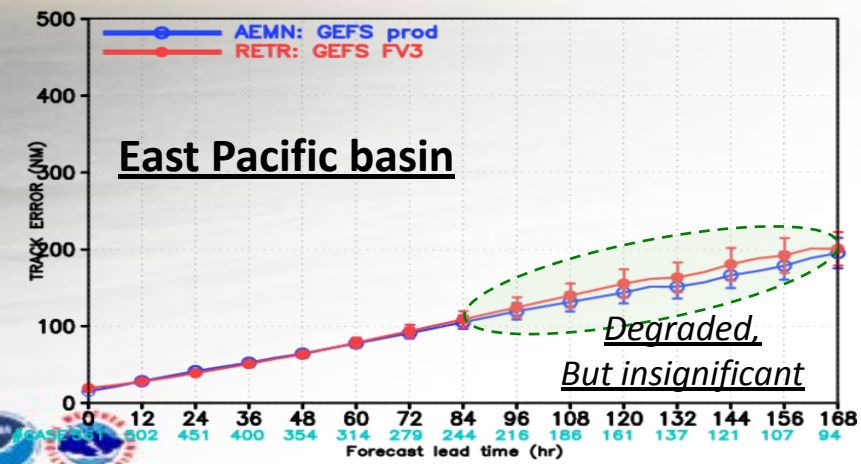


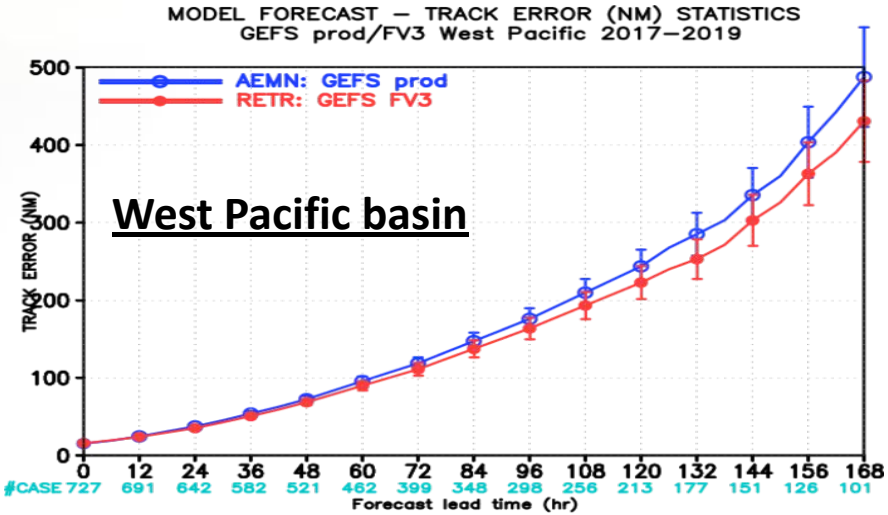
TC track verification

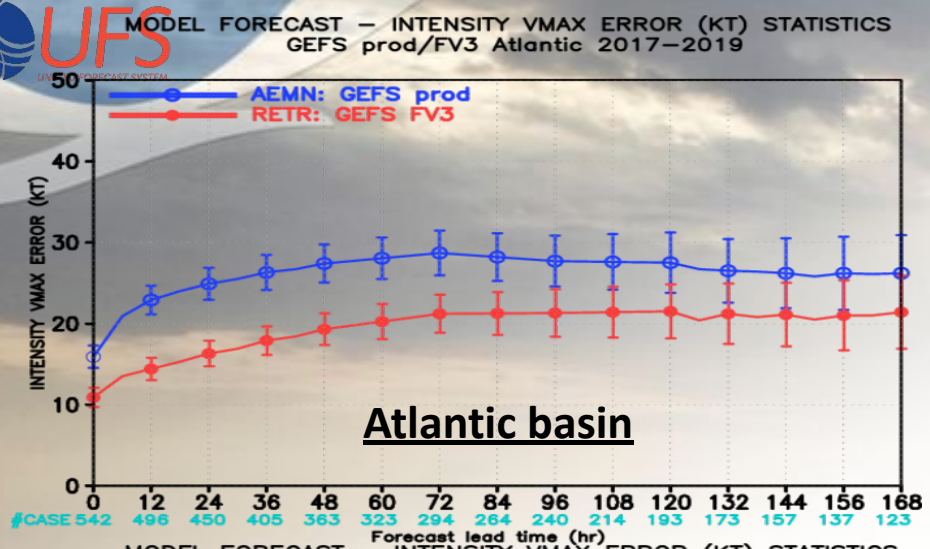
2017: 00Z 06/01----11/30 ; 12Z 07/01----10/31

2018: 00Z 05/01----11/30; 12Z 07/01----10/31

2019: 00Z 05/01----11/30; 12Z 07/01----10/31







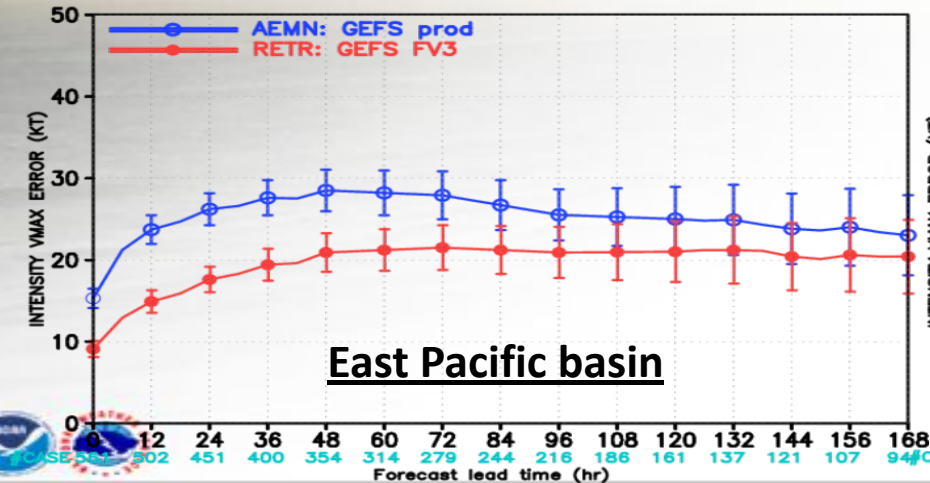
Atlantic basin

TC intensity verification

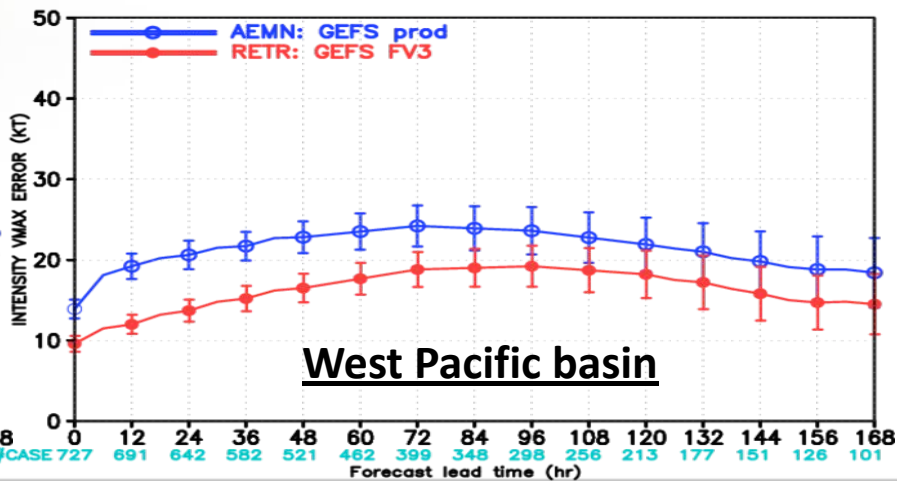
2017: 00Z 06/01----11/30; 12Z 07/01----10/31

2018: 00Z 05/01----11/30; 12Z 07/01----10/31

2019: 00Z 05/01----11/30; 12Z 07/01----10/31



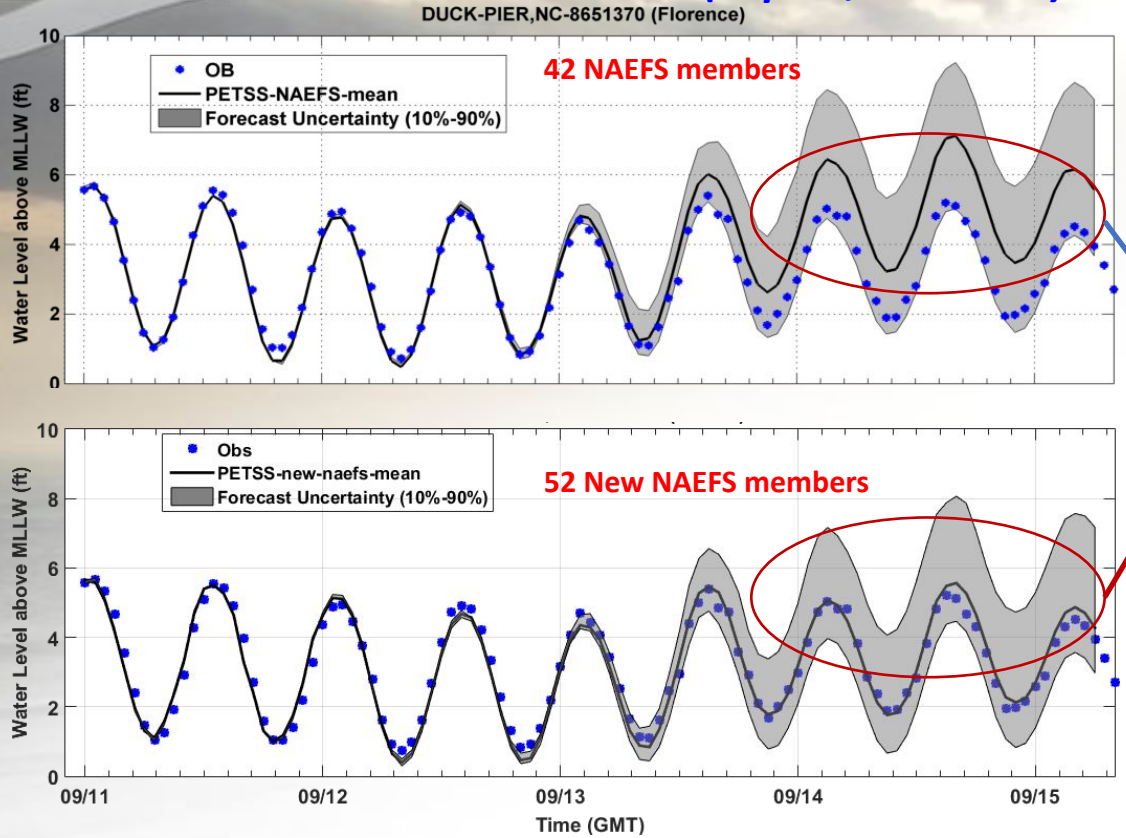
East Pacific basin



West Pacific basin

Downstream Application - Hurricane Florence

(Sep 11, 2018 00Z)



P-ETSS v1.1 Wind (52 New NAEFS members) Improvements

Ensemble mean guidance is significantly improved

Courtesy: Huiqing Liu and Peter Arthur (MDL)

More Evaluation ……

- **GEFS retrospective verification (includes 45 specific case studies selected by MEG)**
  - https://www.emc.ncep.noaa.gov/users/meg/gefsv12/verif/
- **Presentations**: https://www.emc.ncep.noaa.gov/users/meg/gefsv12/
  - FV3 Dynamical Core Information - Developed by GFDL
  - Kickoff to the GEFSv12 Official Evaluation - Presented by Geoff Manikin (2/27/20 MEG Meeting)
  - GEFSv12 Official Evaluation Webpages - Presented by Alicia Bentley (2/27/20 MEG Meeting)
  - Overview of GEFSv12 Verification Statistics - Presented by Alicia Bentley (3/12/20 MEG Meeting)
  - GEFSv12 Retrospective Case Studies: Excessive QPF - Presented by Shannon Shields (3/12/20 MEG Meeting)
  - GEFSv12 Retrospective Case Studies: Winter Storms - Presented by Alicia Bentley (3/19/20 MEG Meeting)
  - GEFSv12 Retrospective Case Studies: Tropical Cyclones - Presented by Shannon Shields/Alicia Bentley (3/26/20 MEG Meeting)
  - GEFSv12 Retrospective Case Studies: Severe Weather - Presented by Logan Dawson (4/2/20 MEG Meeting)
  - GEFSv12 Retrospective Case Studies: Low Skill/Dropouts - Presented by Shannon Shields (4/2/20 MEG Meeting)
  - GEFSv12 Retrospective Case Studies: Cold-Air Outbreaks - Presented by Geoff Manikin (4/2/20 MEG Meeting)
  - GEFSv12 SOO Team Evaluation Overview - Presented by NWS SOO Team (4/16/20 MEG Meeting)
  - The MEG GEFSv12 Evaluation Overview - Presented by Alicia Bentley/Geoff Manikin (4/23/20 MEG Meeting)
  - GEFS v12 Field Evaluations (Waves/Aerosols/Weeks 2-4) – Presented by Henrique Alves/Deanna Spindler/Jeff McQueen/Shannon Shields (4/30/20 MEG Meeting)
  - GEFS v12 Field Evaluations (Days 1-10 Weather)- Presented by Alicia Bentley (4/30/20 MEG Meeting)
  - GEFS v12 EMC CCB - Presented by Yuejian Zhu and Geoff Manikin (5/1/20)

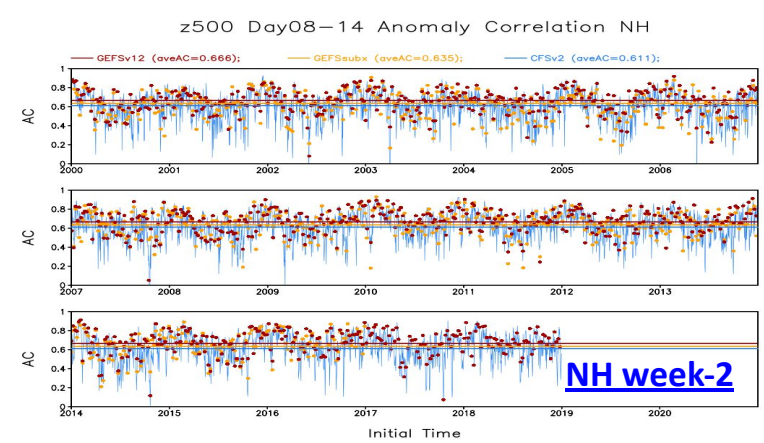
Statistical Evaluation of GEFSv12-Atmosphere

Extended Range and Sub-Seasonal Weather (Week-2, Weeks 3&4 Forecasts)

based on 2.5 yr retrospective (June 2017 – Nov. 2019) and 30-year reforecasts (1989-2019)

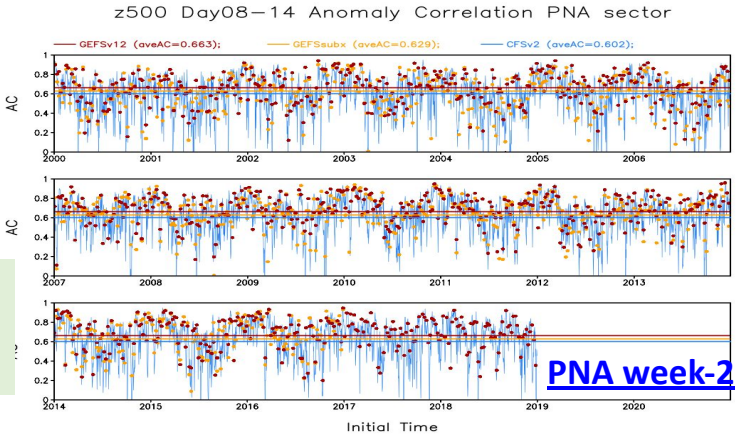
EMC and CPC Perspective

500hPa height PAC scores (2000-2019)



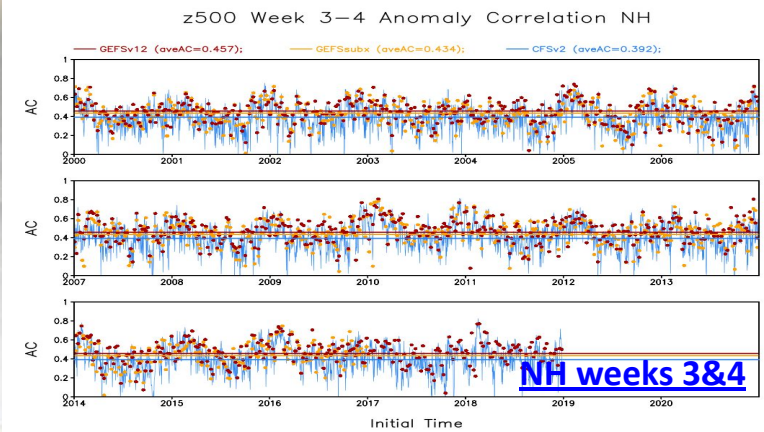
GEFSv12 – 0.666
SubX – 0.635
CFSv2 – 0.611

NH week-2



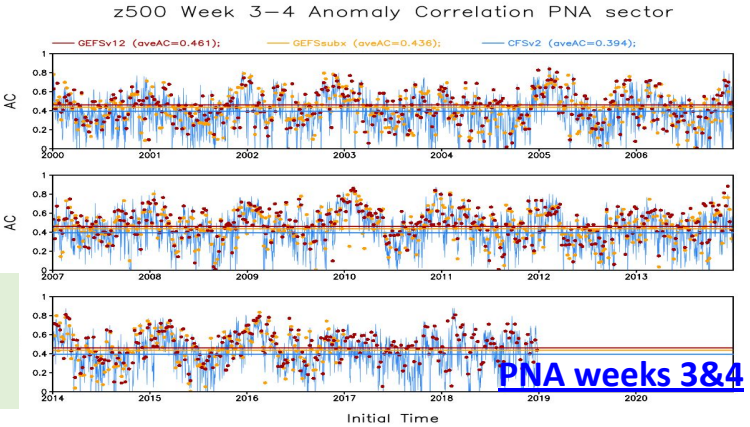
GEFSv12 – 0.663
SubX – 0.629
CFSv2 – 0.602

PNA week-2



GEFSv12 – 0.457
SubX – 0.432
CFSv2 – 0.394

NH weeks 3&4



GEFSv12 – 0.461
SubX – 0.439
CFSv2 – 0.394

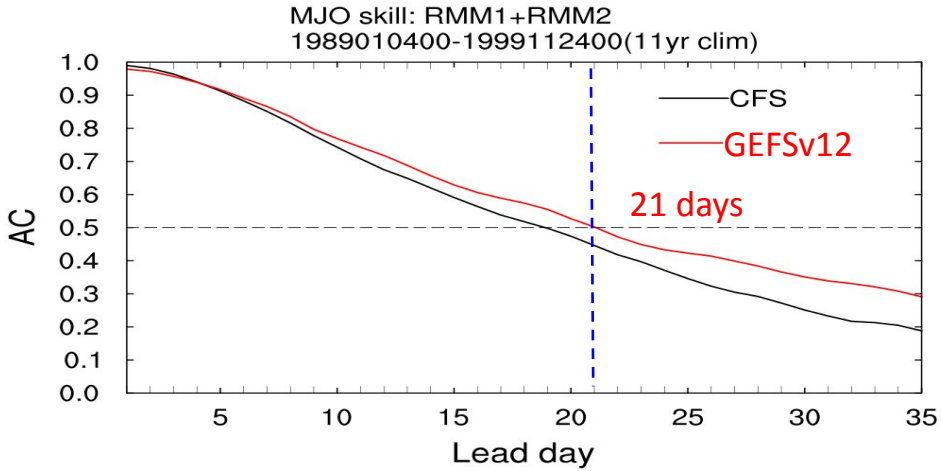
PNA weeks 3&4

Courtesy: Mingyue Chen (CPC)

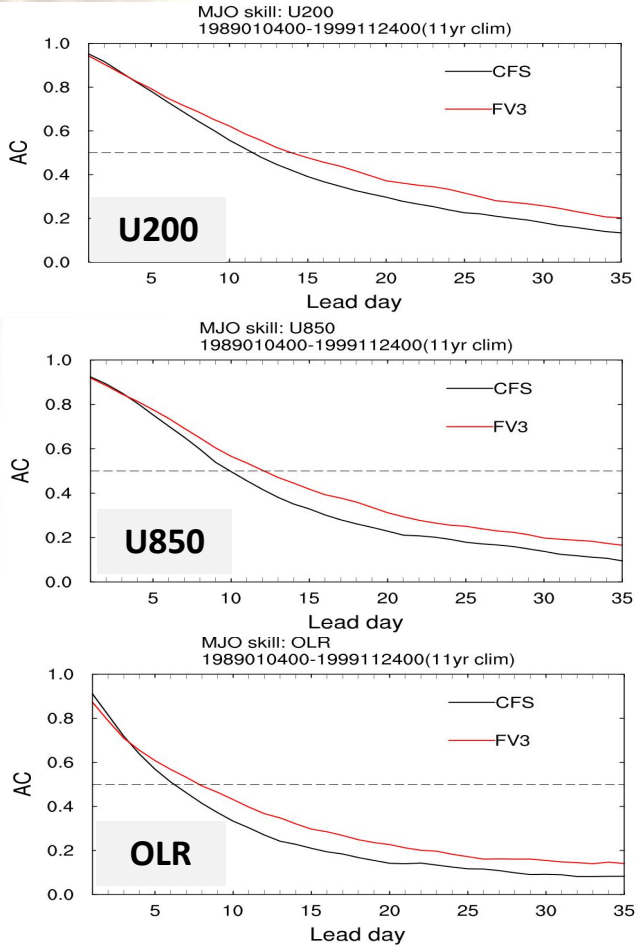
MJO skills comparison (1989-1999)

GEFSv12 vs. CFSv2

MJO RMMs ACC



- *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*

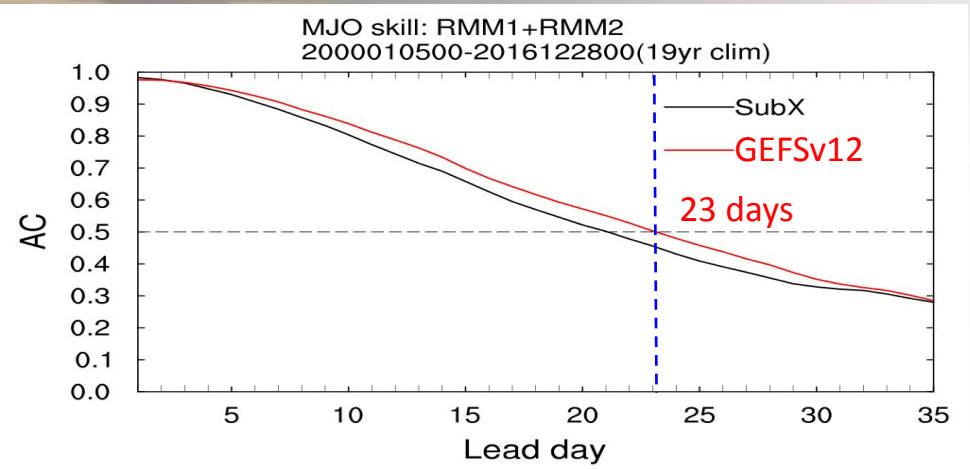


MJO Components

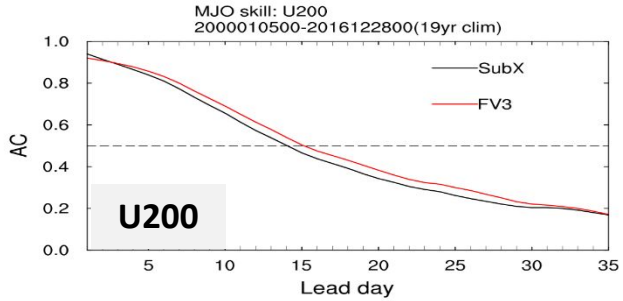
MJO skills comparison (2000-2016)

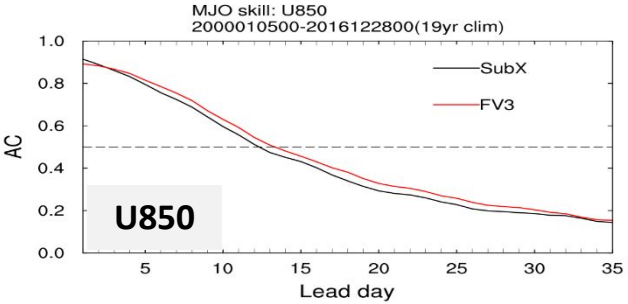
GEFSv12 vs. SubX

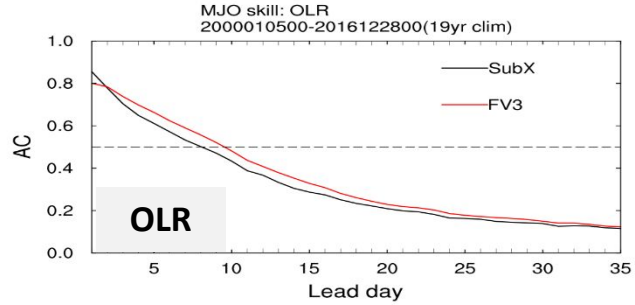
MJO RMMs ACC



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



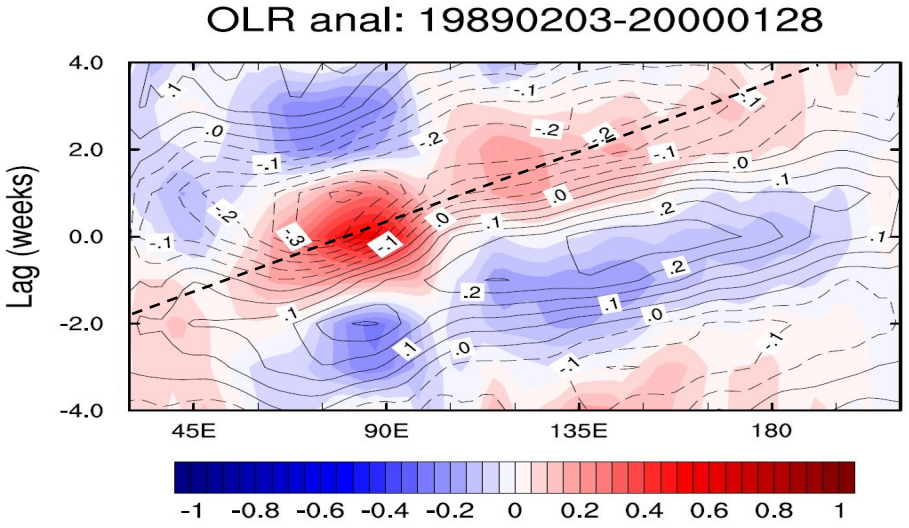


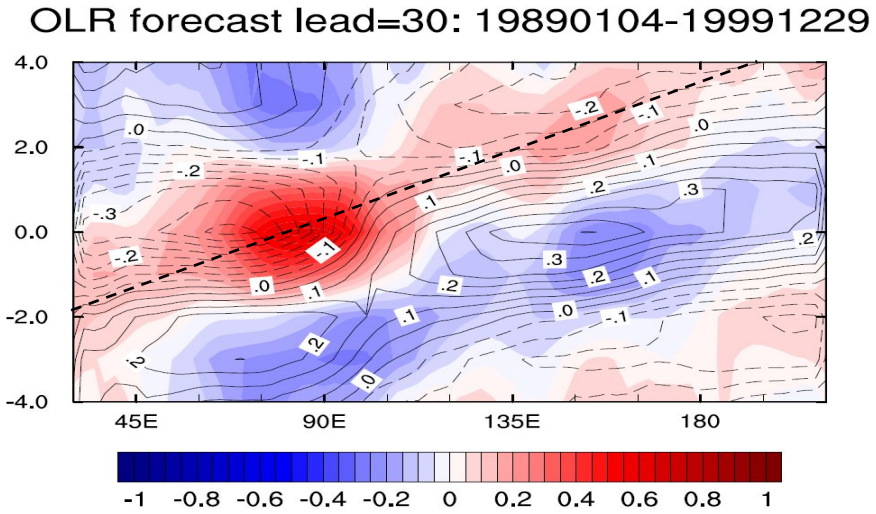


MJO Components

Propagation of MJO in GEFSv12

1989 - 1999



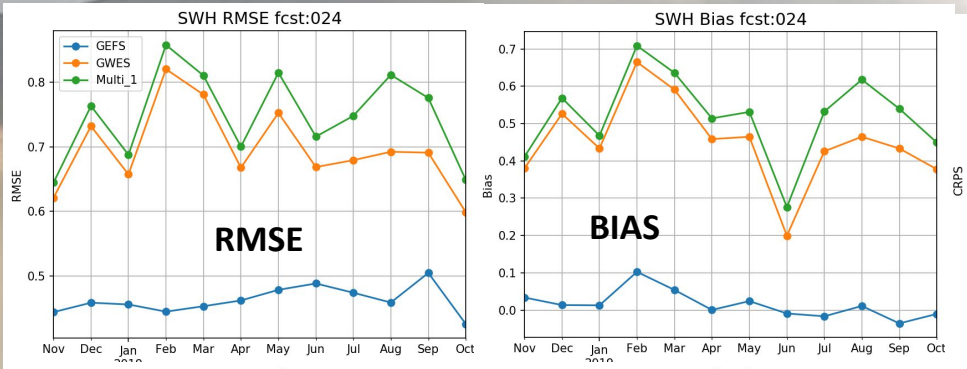


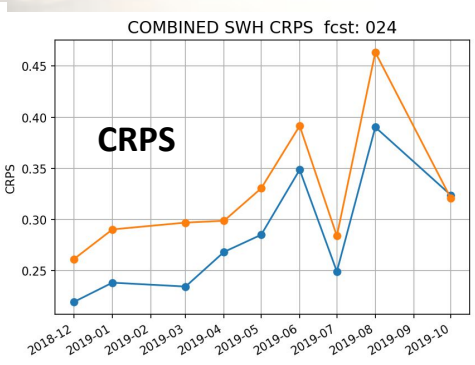
*Spatial and time correlation (anomaly) in the **Central Indian Ocean** /time-lag of 11 years analysis (CFSR; left) and 30-day forecast (GEFSv12 ensemble mean; right). The correlation coefficient of OLR is in shaded and 850 zonal wind is in contours. The statistics indicate that there is a very good eastward propagation of signal (or MJO) from India Ocean. However, it is challenging to capture northward propagation of Intra-Seasonal Oscillations.*

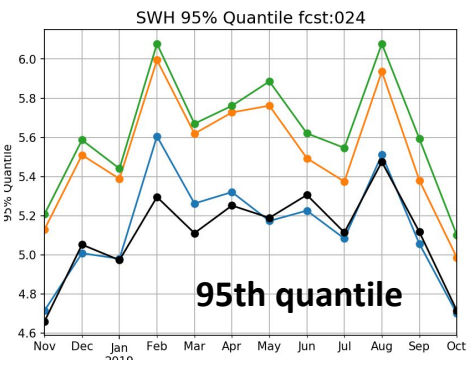
Statistical Evaluation of GEFSv12-Waves

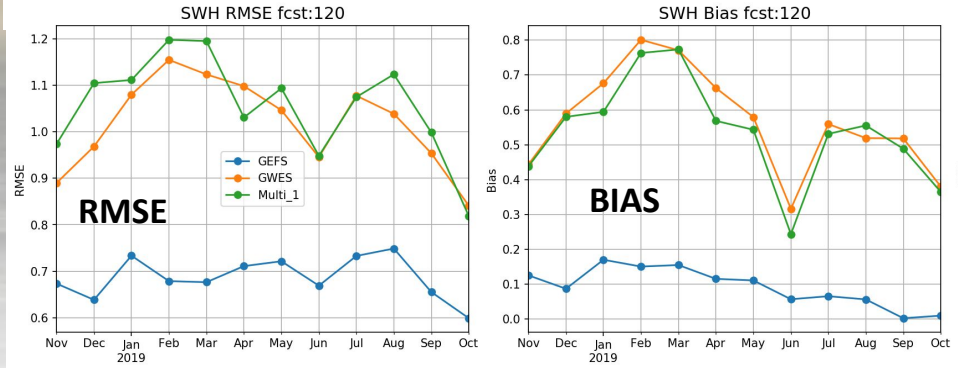
based on one year retrospective forecasts (Dec 1, 2018 - Nov 30, 2019)

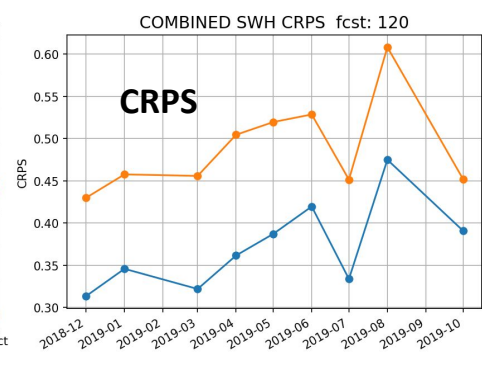
Monthly Hs Statistics - Days 1 & 5 - Altimeters

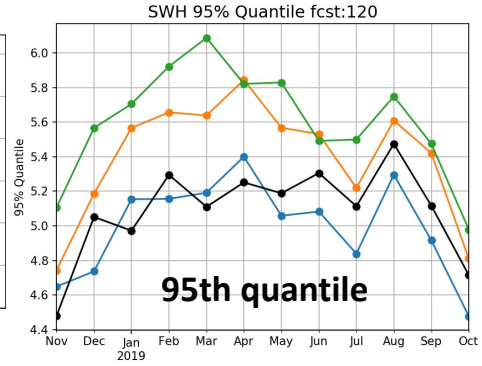










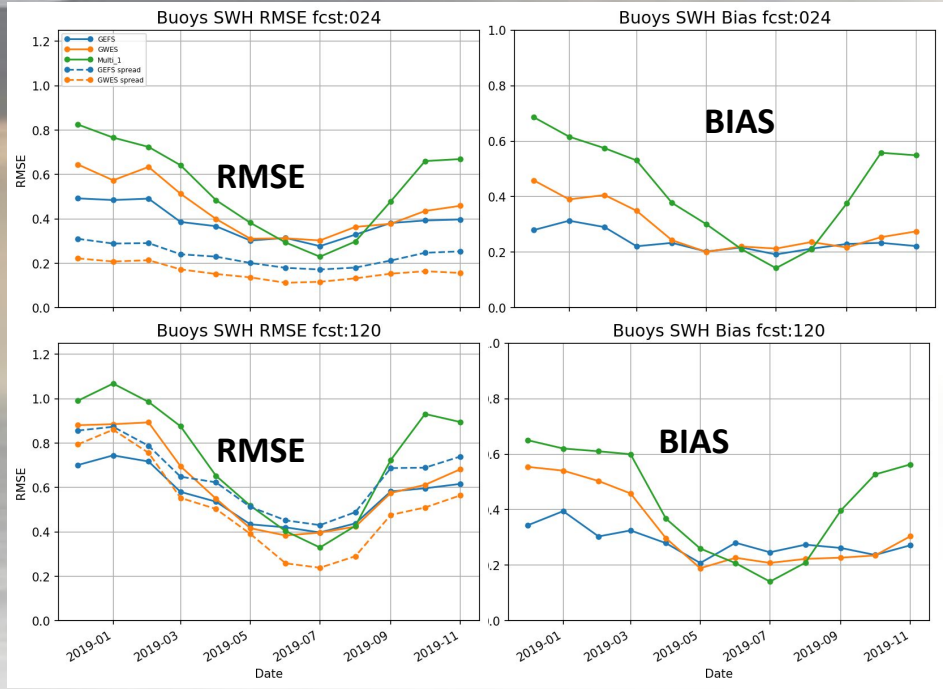


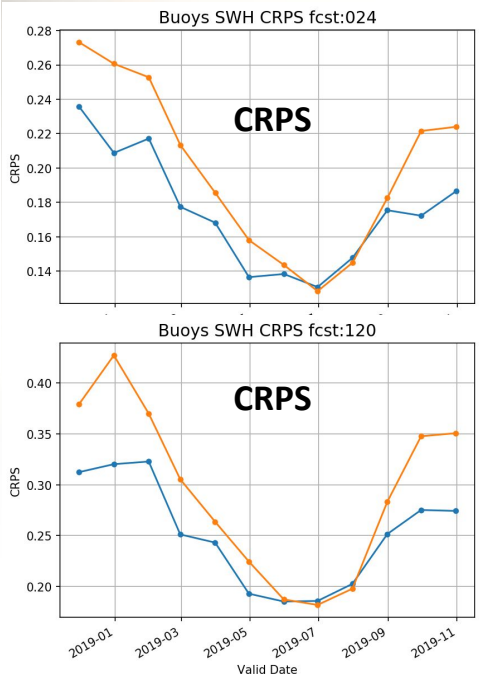
Significantly reduced Hs error and bias consistently in short and long fcst ranges

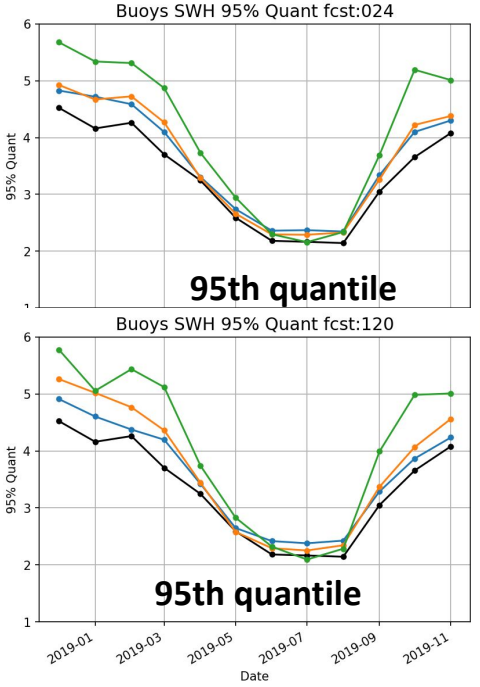
Ensemble wave-heights from GEFSv12 have higher accuracy and predictability.

Storm waves better predicted through year in short and long fcst ranges

Monthly Hs Statistics - Days 1 & 5 - Buoys







Buoy data confirms altimeter validation: significantly reduced Hs error and bias. Also note larger spread, and closer relationship between RMSE and spread.

Hs ensemble from GEFSv12 is more accurate, provides higher predictability.

Storm waves better predicted in short and long fcst ranges.

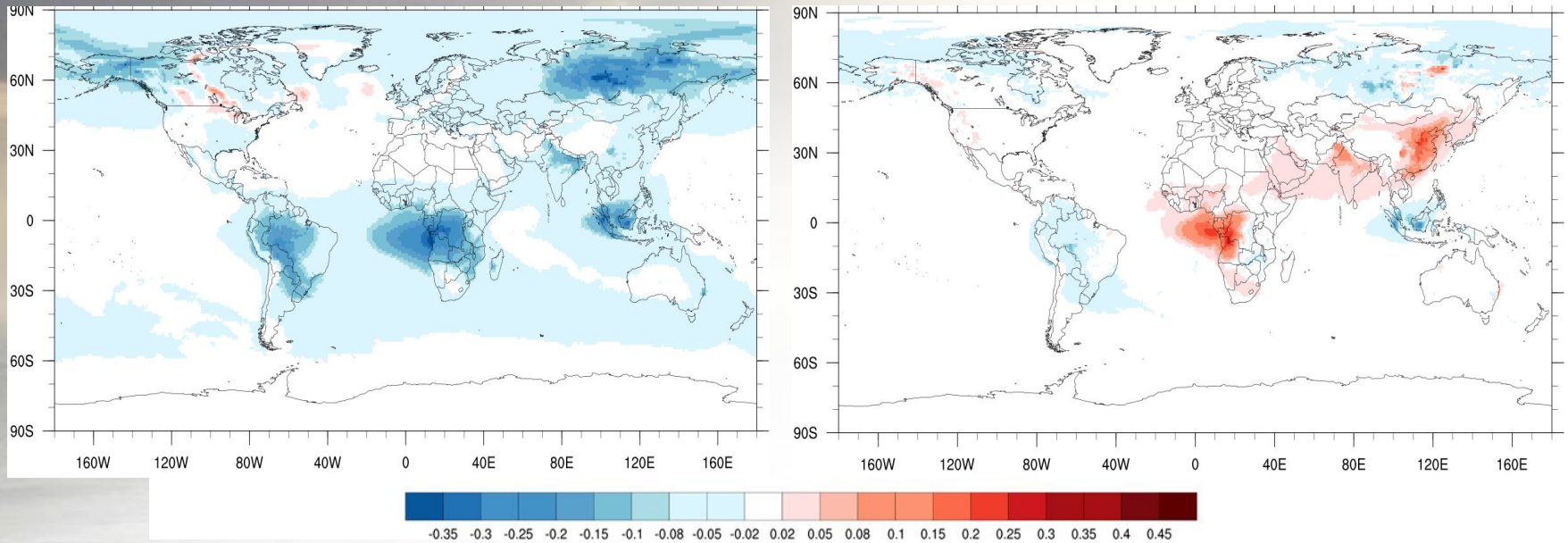
Statistical Evaluation of GEFSv12-Aerosols

based on 9-month retrospective forecasts (July 2019 – March 2020)

Mean behavior: Organic carbon AOD bias

NGAC day 1 prediction – GEOS-5 analysis
550 nm AOD, 7/5/19-11/30/19

GEFS-Aerosol day 1 prediction – GEOS-5 analysis
550 nm AOD , 7/5/19-11/30/19

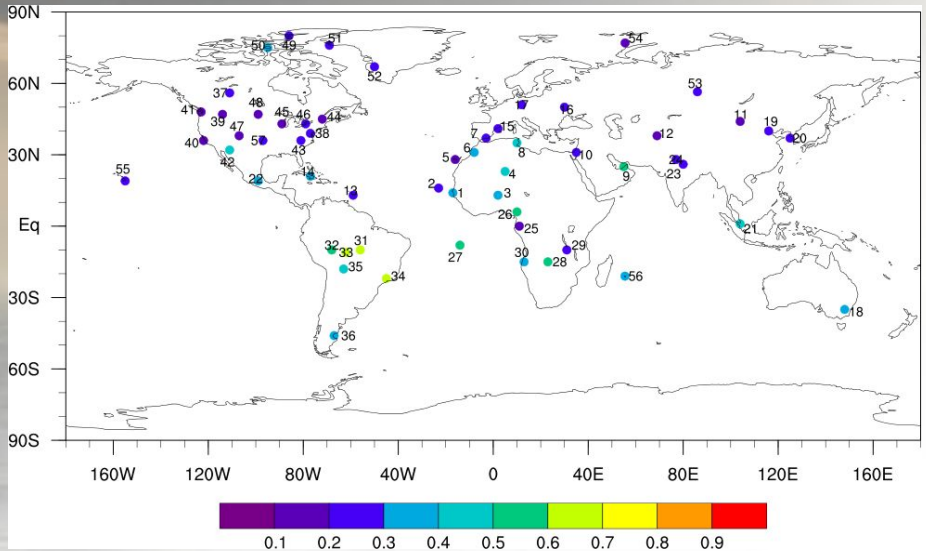


- **Organic carbon AOD (Aerosol Optical Depth) biases with respect to GEOS-5 analyses are smaller for GEFS-Aerosols (right) than those for NGAC (left).**
- **Same is true for dust and sulfate (not shown).**

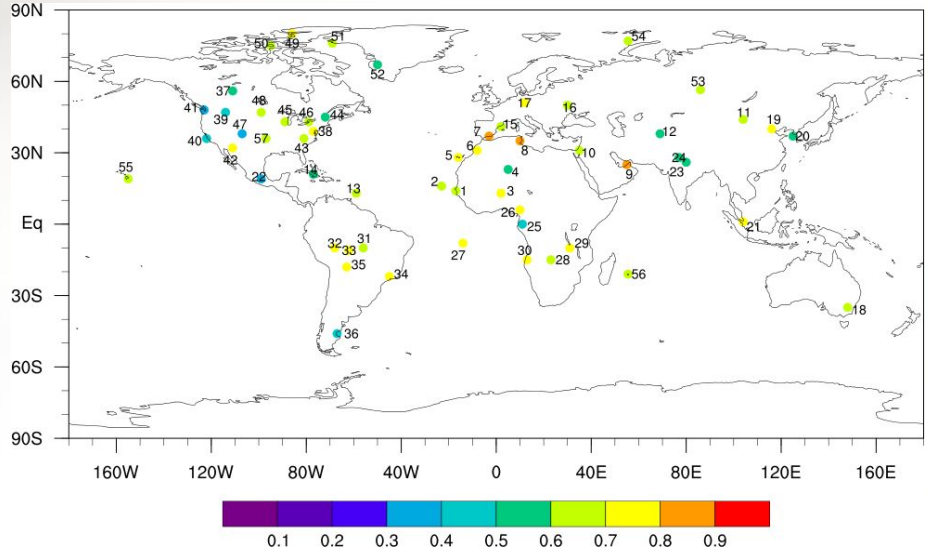
Courtesy of Dr. Ivanka Stajner

AOD Forecasts compared to AERONET Observations

Correlation (R) based on Day 1 forecast of NGACv2 and AERONET

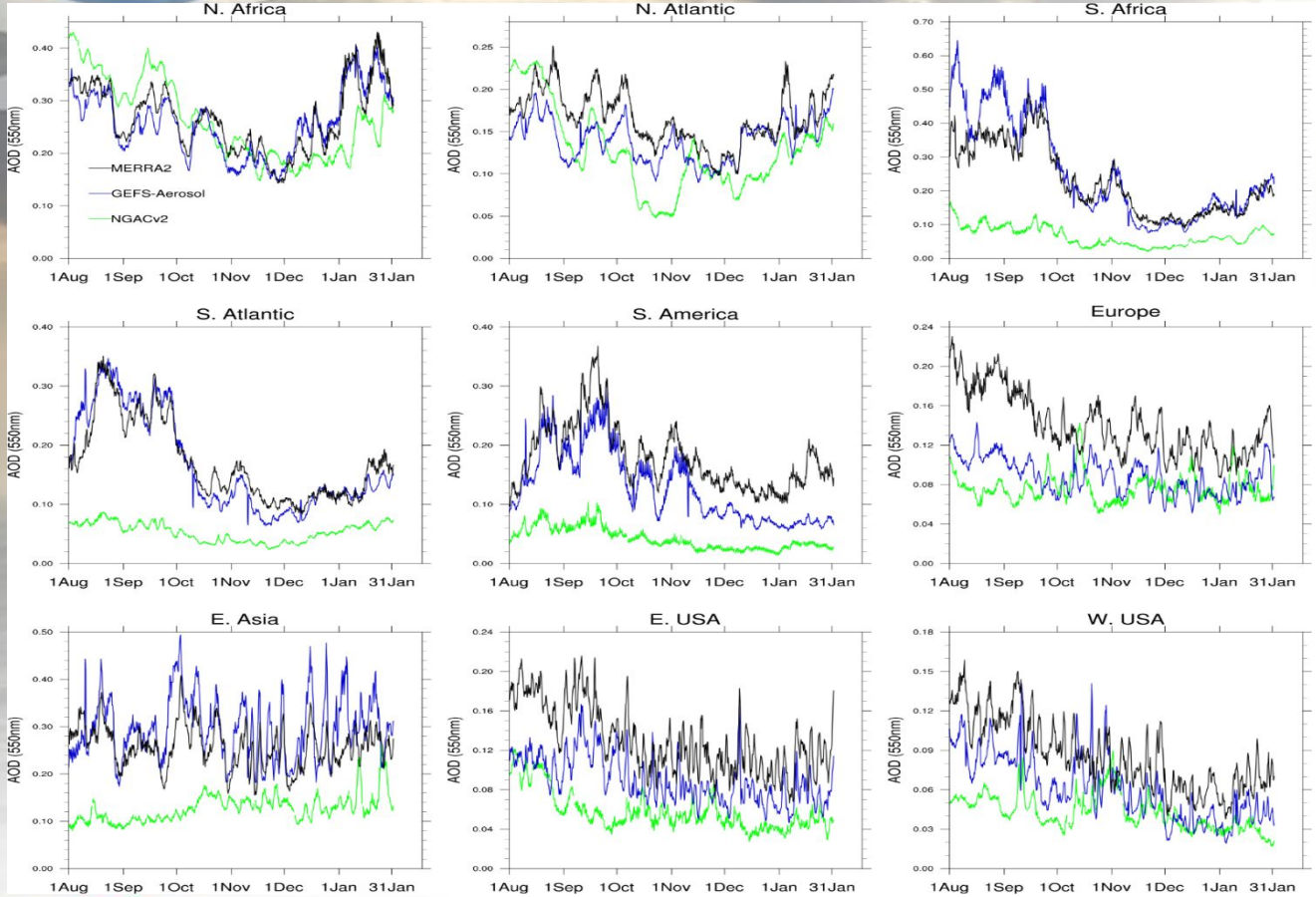


Correlation (R) based on Day 1 forecast of GEFSv12-Aersol and AERONET



Significant improvement in aerosol forecasts from GEFSv12-Aerosol

AOD forecasts compare to MERRA2 reanalysis



Black – MERRA2 reanalysis

Green – NGACv2

Blue – GEFSv12

Major global regions
(from top left to bottom right)

- *N. Africa*
- *N. Atlantic*
- *S. Africa*
- *S. Atlantic*
- *S. America*
- *Europe*
- *E. Asia*
- *E. USA*
- *W. USA*

An improvement is over all major global regions. A significant improvement is for S. Africa, S Atlantic, S America and E. Asia.

Field/MEG evaluations of GEFSv12

Acknowledgements

VPPGB Chief: Jason Levit

Model Evaluation Group: Geoff Manikin, Alicia Bentley, Shannon Shields, and Logan Dawson

Waves Coordination: Henrique Alves and Deanna Spindler

Aerosols Coordination: Jeff McQueen and Partha Bhattacharjee

Weeks 3-4 Coordination: Matt Rosencrans (CPC)

The MEG Evaluation of GEFSv12

1) Constructed formal evaluation plan
2) Conducted 7 webinars covering different components of the GEFSv12 evaluation
3) Generated GEFSv11 vs GEFSv12 comparison graphics for 45 different retro cases covering a variety of challenging/high-impact cases; with no real-time parallel, this was the only way for the field to visualize the changes
4) Led a national SOO team to complement the evaluation
5) Gathered and organized all evaluations covering the atmospheric, aerosol, and wave components of GEFSv12

Summary of GEFSv12-Atmosphere Metrics (Days 1-10)

PARAMETER	SKILL	SPREAD	BIAS
250-hPa winds (NH)	Improved	Improved	Somewhat Improved
500-hPa height (NH)	Improved	Improved	Somewhat Degraded
850-hPa winds (NH)	Improved	Improved	Neutral
850-hPa temp. (NH)	Improved	Improved	Somewhat Degraded
1000-hPa height (NH)	Improved	Improved	Somewhat Degraded
10-m winds (NH)	Improved	Improved	Neutral
2-m temp. (NH)	Improved	Improved	Improved
Precipitation (NH)	Improved	Improved	Degraded (higher amts)
TC Tracks (N. Atlantic)	Somewhat Improved	Improved	Degraded (across track)
TC Tracks (E. Pacific)	Somewhat Degraded	Improved	Degraded (across track)

Summary of GEFSv12-Atmosphere Metrics (Days 1-10)

PARAMETER	SKILL	SPREAD	BIAS
250-hPa winds (SH)	Improved	Neutral	Somewhat Improved
500-hPa height (SH)	Improved	Neutral	Somewhat Degraded
850-hPa winds (SH)	Improved	Somewhat Improved	Somewhat Degraded
850-hPa temp. (SH)	Improved	Somewhat Improved	Degraded
1000-hPa height (SH)	Improved	Somewhat Improved	Somewhat Degraded
10-m winds (SH)	Improved	Improved	Neutral
2-m temp. (SH)	Improved	Improved	Improved
250-hPa winds (Tropics)	Improved	Considerably Improved	Neutral
850-hPa winds (Tropics)	Improved	Considerably Improved	Somewhat Improved
10-m winds (Tropics)	Improved	Considerably Improved	Somewhat Degraded

Summary of GEFSv12-Waves Metrics

Metric	Significant Wave Height	Peak Wave Period	
		Windseas	Swell
Skill	Improved	Neutral	Neutral
Reliability	Improved	N/A	N/A
RMSE	Improved	Neutral	Neutral
Spread	Improved	Improved	Improved
Bias	Improved	Slightly Improved	Neutral
95% Quantile	Improved	N/A	N/A

Summary of GEFSv12-Aerosol Metrics

Bias for Day 1 Aerosol Optical Depth (AOD) forecast (July 2019 – March 2020)

Event	Period	Bias	Comment
African Dust	Full	Improved	
African Biomass Burning	Summer	Neutral	NESDIS GBBEPx adjustment
South America Biomass Burning	Summer	Improved	
Asian Sulfate	Fall/Winter	Neutral	Strong overprediction (COVID related)
North America	Full	Improved	Overpredict ag fires
Ocean sea-salt	Full	Neutral	Wet scavenging likely too low

National SOO Team Ratings: Overall Utility of GEFSv12

	Mean Rating -3 to +3	% of Cases Rated as Good or Better than v11	% of Cases Rated Worse than v11
Day 10	0.18	82	18
Day 9	0.14	74	26
Day 8	0.23	70	30
Day 7	0.32	70	30
Day 6	0.23	74	26
Day 5	0.30	74	26
Day 4	0.44	74	26
Day 3	0.53	82	18
Day 2	0.58	84	16
Day 1	0.44	95	5

Mean rating favors v12 at all forecast lengths

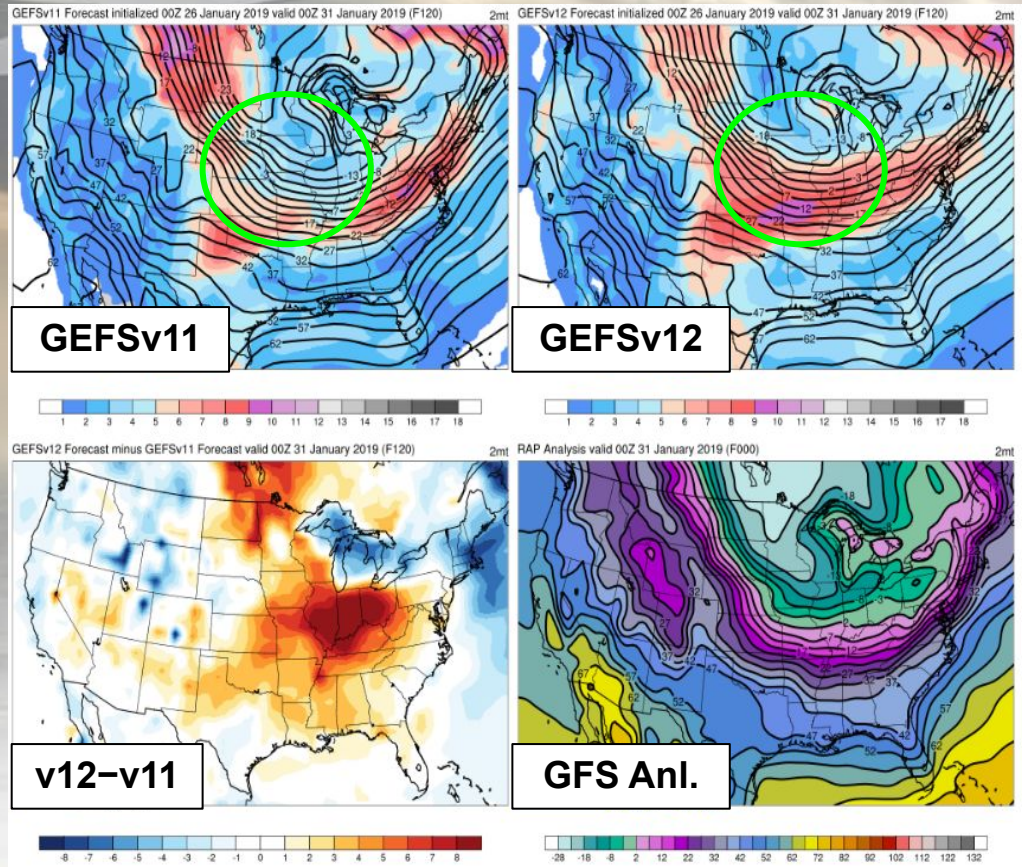
Some clear utility in the short range

In the aggregate, the SOO team clearly found GEFSv12 to be as good or better than GEFSv11

Common Positive Themes in MEG and Field GEFSv12-Atmospheric Evaluations

1) Higher 500-hPa AC scores and improved synoptic predictability
2) Increased ensemble spread (improved ensemble dispersion), with spread located in meaningful areas
3) Improved TC tracks, spread, and location of precip. maxima
4) Better handling of deepening extratropical cyclones
5) More reliable precipitation forecasts
6) Improved representation of weather events near topography
7) Mitigation of exaggerated offshore QPF maxima

Increased and More Useful Spread



Arctic Air Outbreak 2019
Init: 00Z 1/26/19 F120

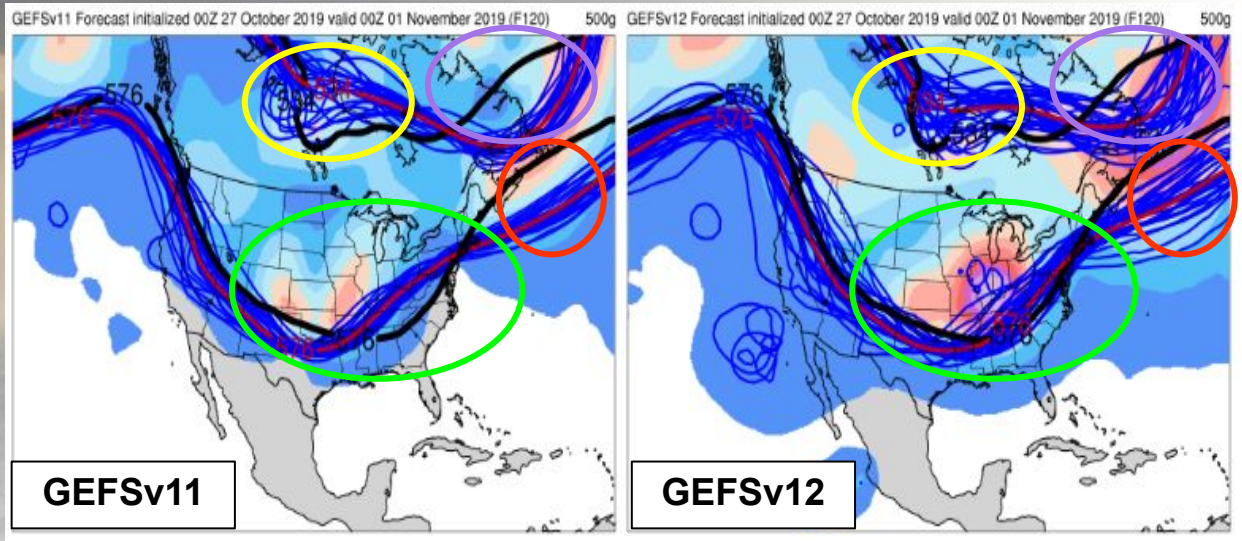
GEFSv12 is better & GEFSv11 is too aggressive w/ the cold dome into the Great Lakes & OH Valley

v11 is overconfident in its temps; v12 has more spread all along the tight baroclinic zone

SOO Team Finding: GEFSv12 often exhibited quality spread in highlighting areas of uncertainty (e.g., baroclinic zones, noses of low level jets/moisture plumes)

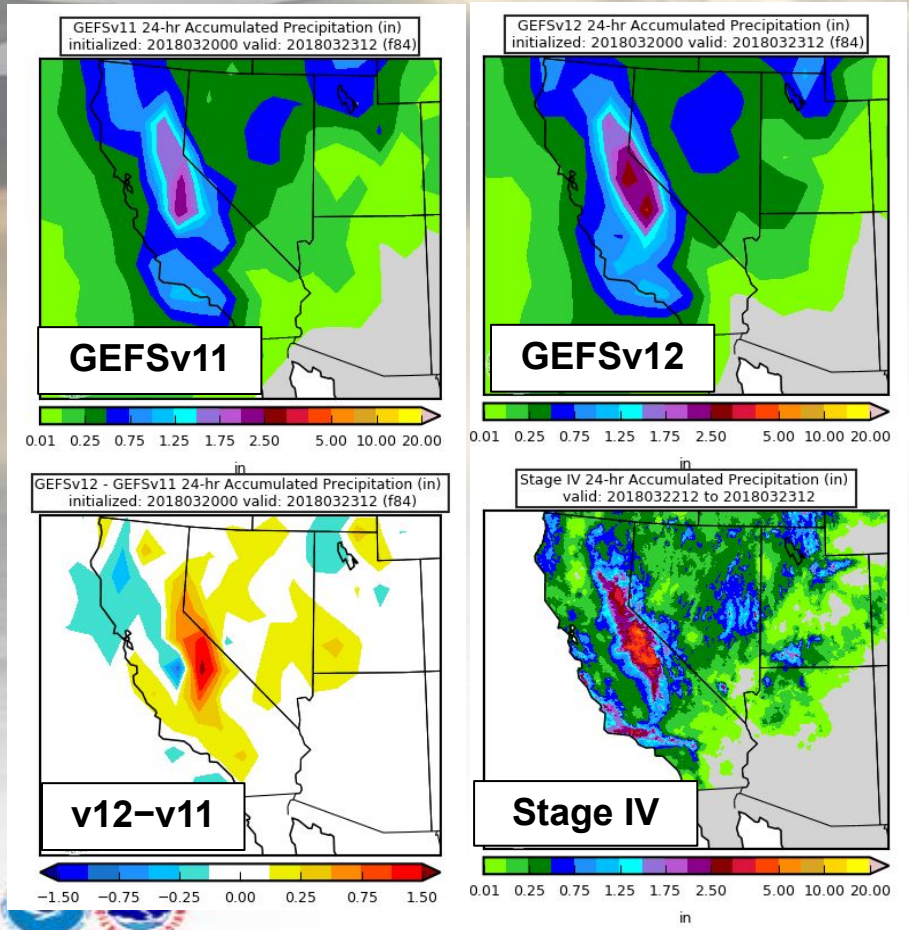
Increased and More Useful Spread

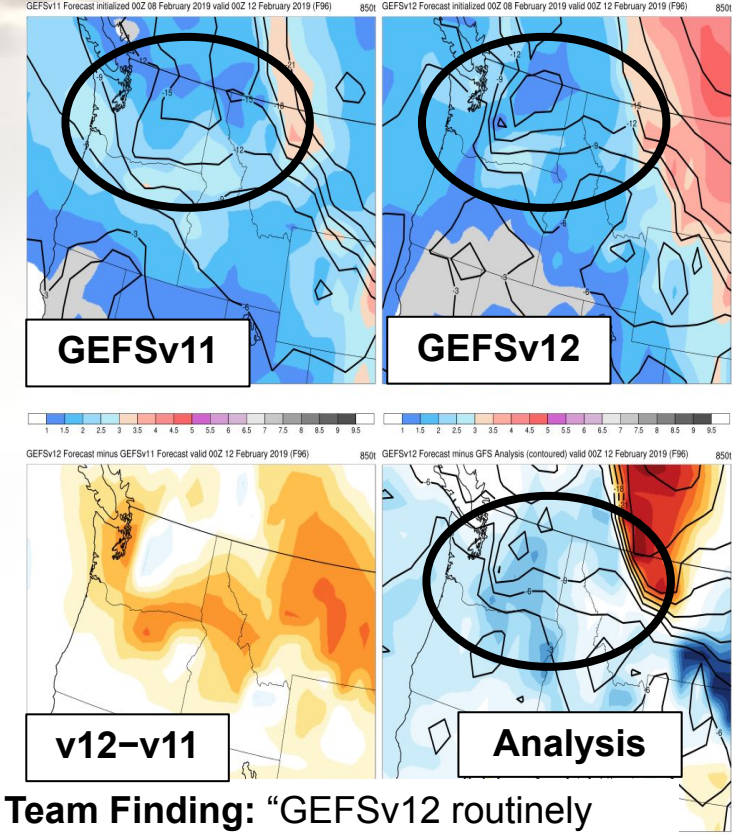
120-h fcst valid at 00Z 1 Nov 2019



Numerous cases in which GEFSv12 had greater spread and captured the eventual solution, which was outside the envelope of the GEFSv11 members

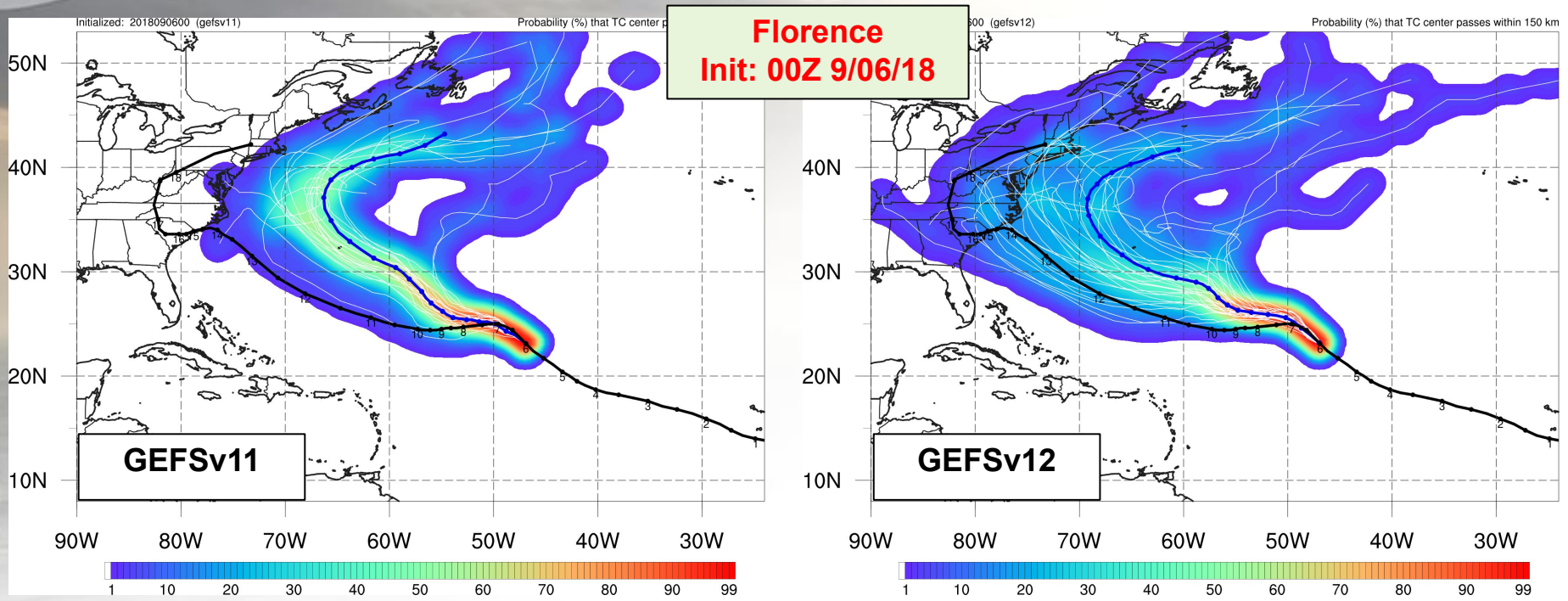
Improved Representation of Terrain-influenced Events





SOO Team Finding: "GEFSv12 routinely captured details in complex terrain better than GEFSv11"

Improved TC Tracks and Spread



GEFSv11 indicates a high probability of Florence recurving well before reaching the east coast, while Best Track (no recurvature) is well within the GEFSv12 envelope of possible solutions

Common Concerns for Atmospheric GEFSv12 Evaluations

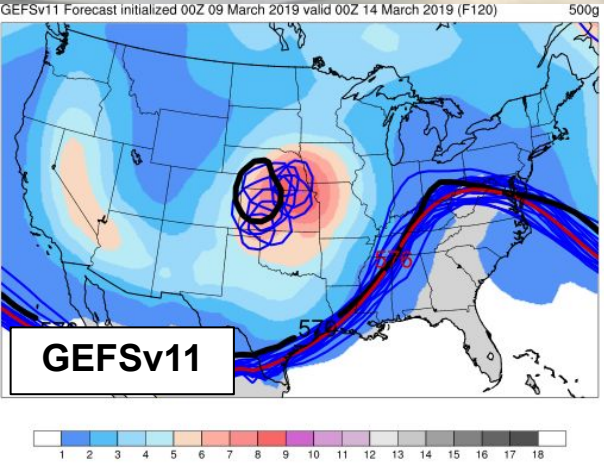
1) Progressiveness of some upper troughs
2) Right of track bias for tropical cyclones
3) Low QPF bias at higher thresholds
4) Spread is occasionally too large
5) Issues with West Coast performance
6) Handling of Arctic air masses at extended ranges
7) Reduced instability
8) Overmixing in the PBL along moisture gradients

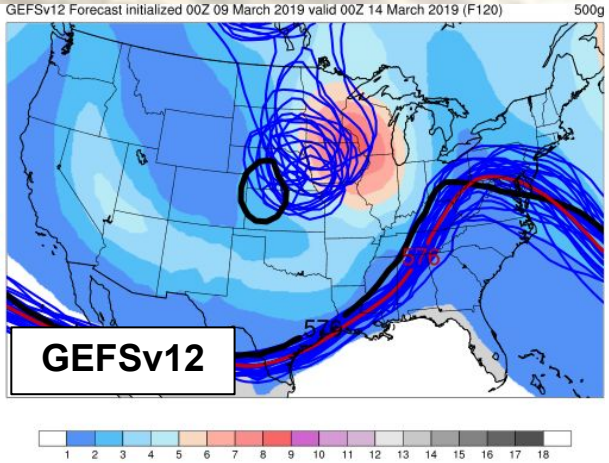
Issues Related to FV3 Configuration

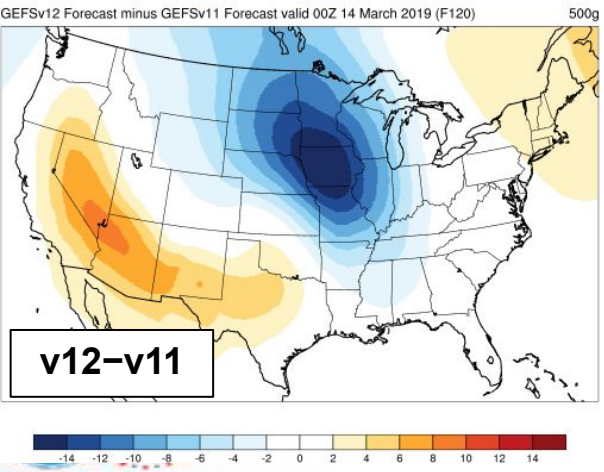
Some issues are being inherited by GEFSv12 from the GFSv15 configuration

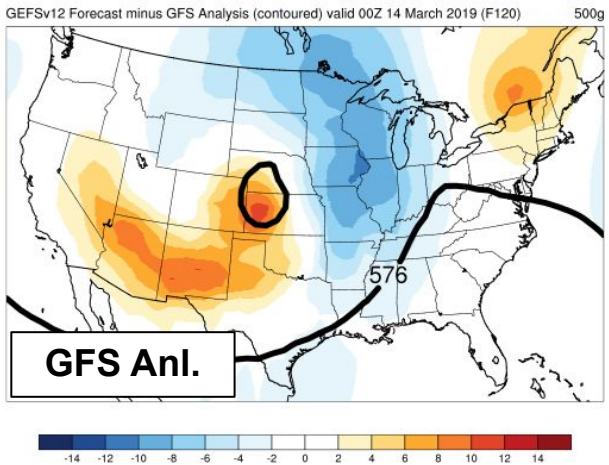
1) Progressiveness of some upper troughs
2) Low QPF bias at higher thresholds
3) Handling of Arctic air masses at extended ranges
4) Reduced instability

Progressiveness





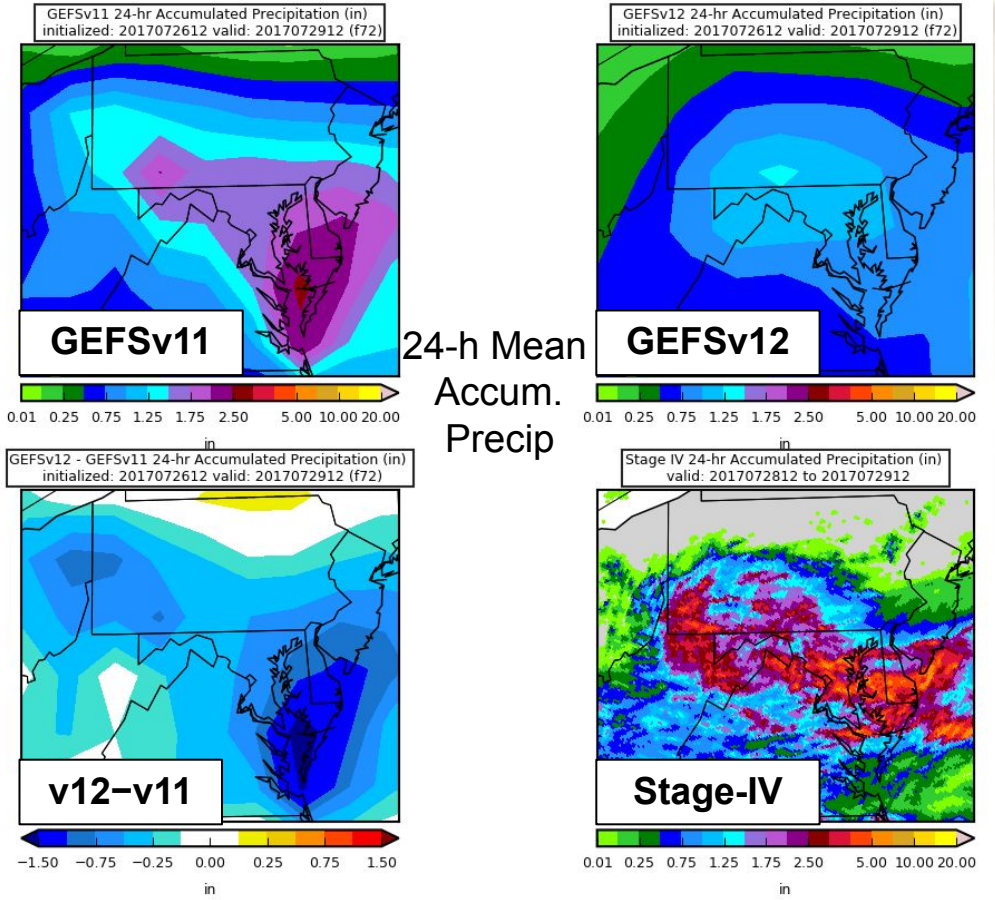




Cutoff lows trying to rapidly rejoin the midlatitude waveguide is a **known bias of the FV3-based global models** (i.e., progressive)

*Example of 500-hPa spaghetti plots (also available online), with **analyzed 576-dam and 534-dam contours (black)**, ensemble mean (red), and ensemble members (blue)*

Low QPF Bias at Higher Thresholds



Some of the low bias for higher amounts of mean QPF is clearly due to the increased spread, with the means being muted

The mean is widely used, so forecasters will need to be prepared for the change in the character of mean QPF. Products like probability-matched mean are recommended for future versions.

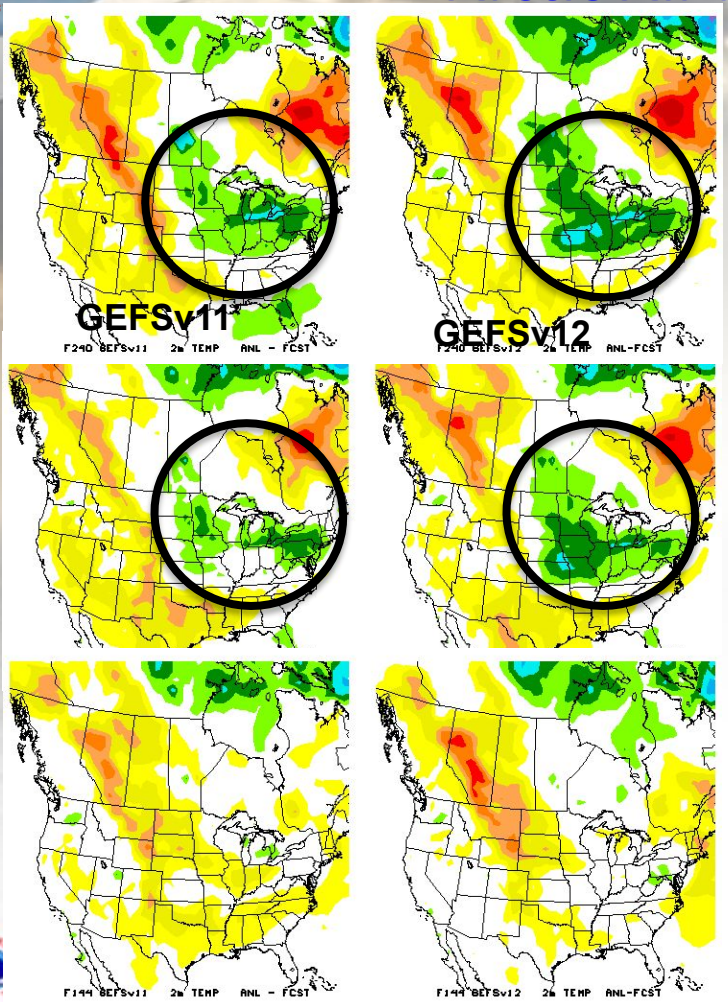
But the issue is also partially driven by a low bias for higher amounts associated with the global configuration, as seen during the evaluation of GFSv15

Arctic Air Mass Intrusions

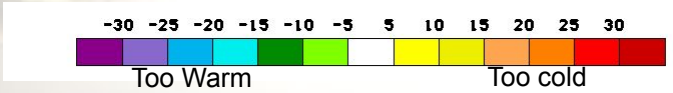
F240

F192

F144

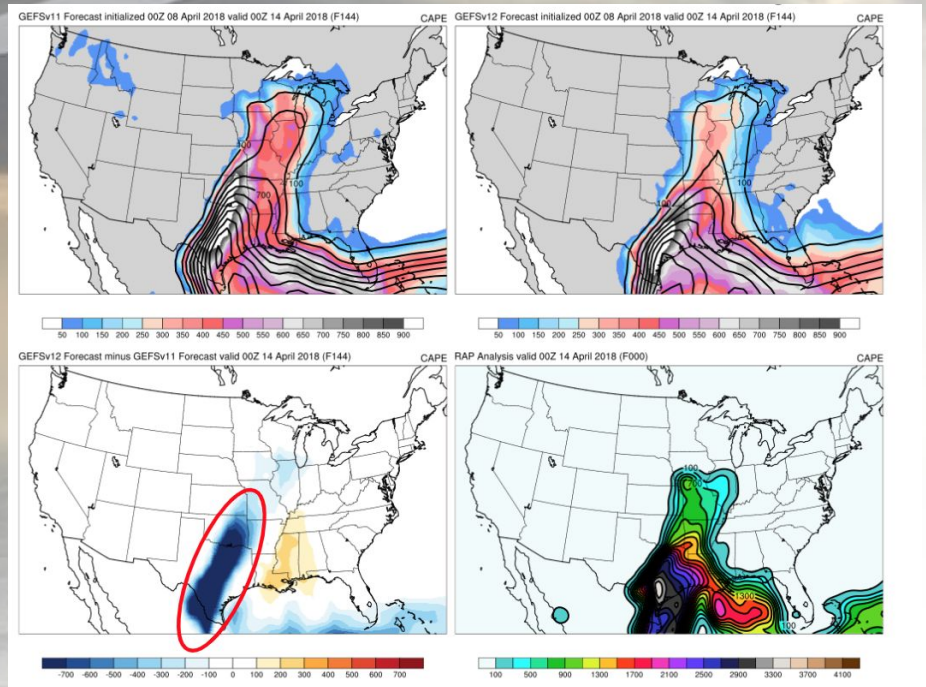


2m TEMP ERRORS (ANALYSIS – FORECAST)

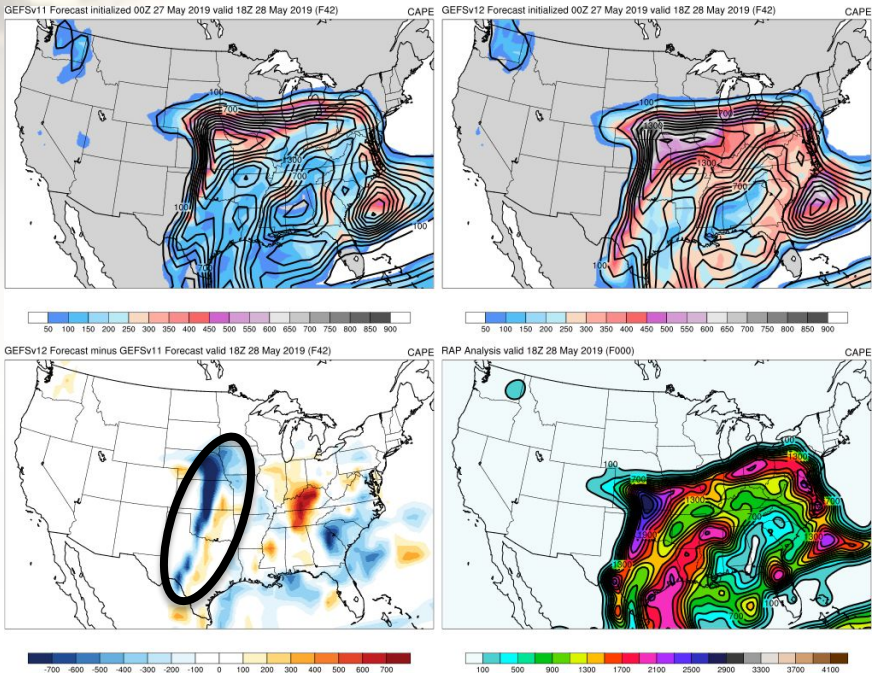


- GFSv15 has a clear low-level cold bias that grows with forecast length and is most pronounced in winter
- GEFSv12 shows this cold bias at 850 mb in stats
- But the cold bias is not seen at 2m, potentially due to some land-sfc changes
- 2m temps are clearly warmer in v12, which is an overall positive, but a clear warm bias was seen at longer forecast ranges in multiple arctic air intrusions
- The warm bias in these cases was typically resolved between day 4 and 6

Instability / PBL Mixing

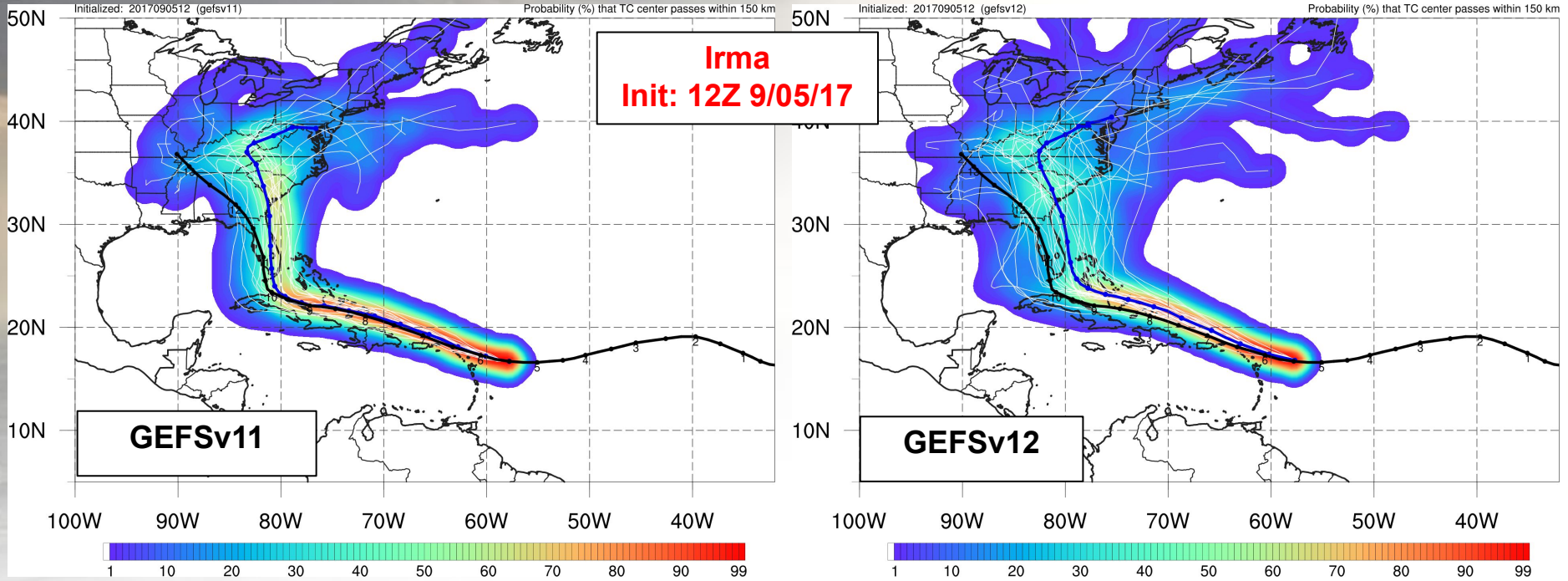


Numerous cases with reduced instability forecasts in v12



Dryline can be forecasted too far east due to overly aggressive PBL mixing

TC Right-of-Track Bias



GEFSv11 is in good agreement with Best Track at shorter lead times, but becomes right of Best Track at longer lead times. GEFSv12 is further right than GEFSv11 at all lead times.

Summary of GEFSv12-Atmosphere Field Evaluations

Region	Recommendation	Key Remarks
Eastern Region	**Implement**	GEFSv12 had significantly better synoptic performance. Improved spread in TC tracks, with increased right-of-track bias.
Central Region	**Implement**	GEFSv12 outperformed GEFSv11 synoptically. Improved spread, which better encapsulated the envelope of potential solutions and highlighted important gradients. Improved performance in areas of complex terrain.
Southern Region	**Implement**	A noticeable step forward in ensemble modeling. Overall improved spread in nearly all fields.
Western Region	**Implement**	Overall improvements in AC scores, dispersion, terrain resolved features, etc. Concerned with the performance of a few of the cases in the West showing long-range forecast degradation.
Alaska Region	**Implement**	GEFSv12 shows definite benefits over GEFSv11, mainly due to its increased spread. GEFSv12 can have a progressive bias.

Summary of GEFSv12-Atmosphere Field Evaluations

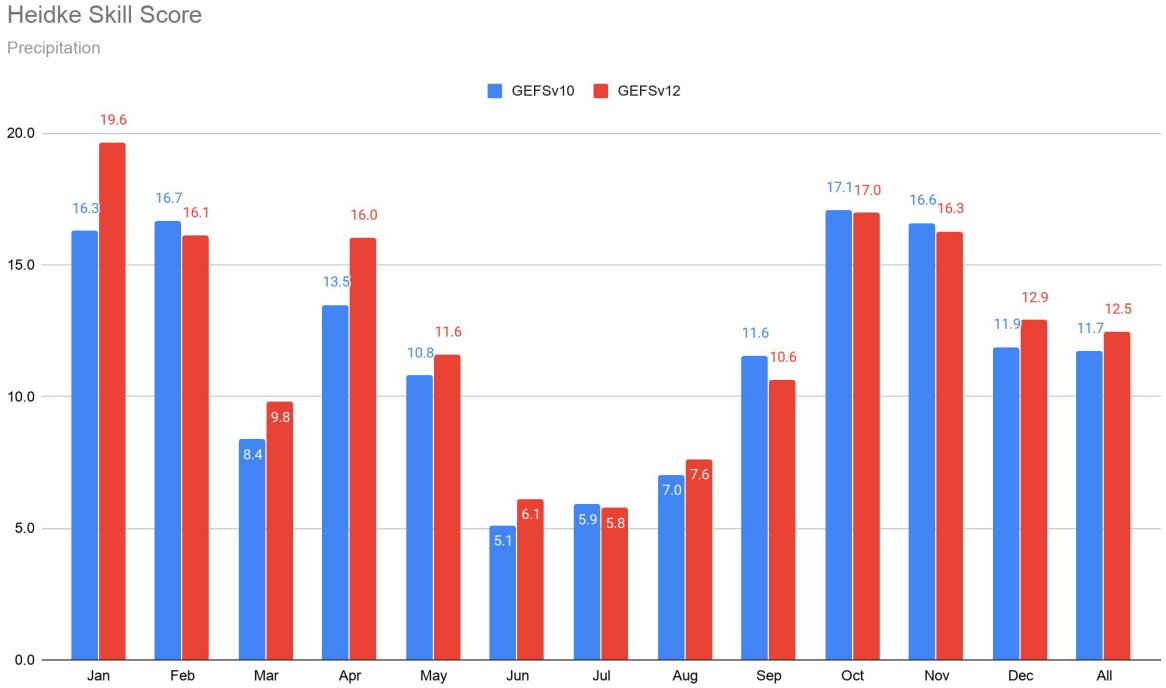
Center	Recommendation	Key Remarks
Pacific Region	**Implement**	No concerns.
WPC	**Implement**	Major improvements in QPF reliability and over complex terrain. Probabilistic fields will provide more useful guidance. Concerned about the low mean QPF bias at moderate to heavy amounts. Increased spread (particularly in regions with tight gradients), provides better uncertainty information to forecasters.
SPC	**Implement**	Impressive general statistical improvement. Systematic biases: progressive shortwave troughs and overmixing in the PBL along and near moisture gradients. Improved dispersion, probabilistic thunderstorm proxy forecasts, and 2-m dewpoint z-scores.
NHC	**Implement**	Large improvements in hurricane intensity skill. Hurricane track forecasts are improved in the NATL and degraded in EPAC. Right-of-track track bias gets worse at longer lead times. Larger spread in GEFSv12 better captures range of potential tracks.

Summary of GEFSv12-Atmosphere
Week 2 and Weeks 3-4 Evaluation (CPC)

- The parallel version is an improvement over GEFSv10 in week 2 and over GEFSv11 and CFSv2 in weeks 3 and 4
- GEFSv12 was an improvement for temperature and 500 hPa heights during weeks 2, 3, and 4; there was also some likely improvement in precipitation
- GEFSv12 was an improvement over CFSv2 for week 2 tropical cyclone forecasts and similar to the ECMWF; GEFSv12 was an improvement at weeks 3 and 4 for tropical cyclones, but all models struggle
- GEFSv12 was largely an improvement in the stratosphere (improved T and u), but there is much room for improvement

- Supports proposed implementation of GEFSv12

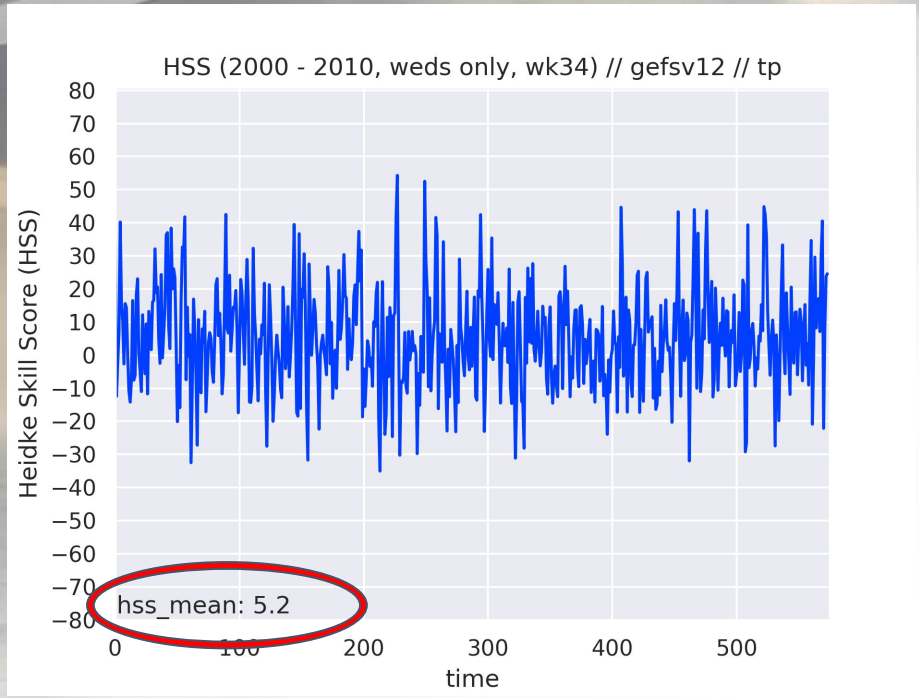
Average Heidke Skill Score

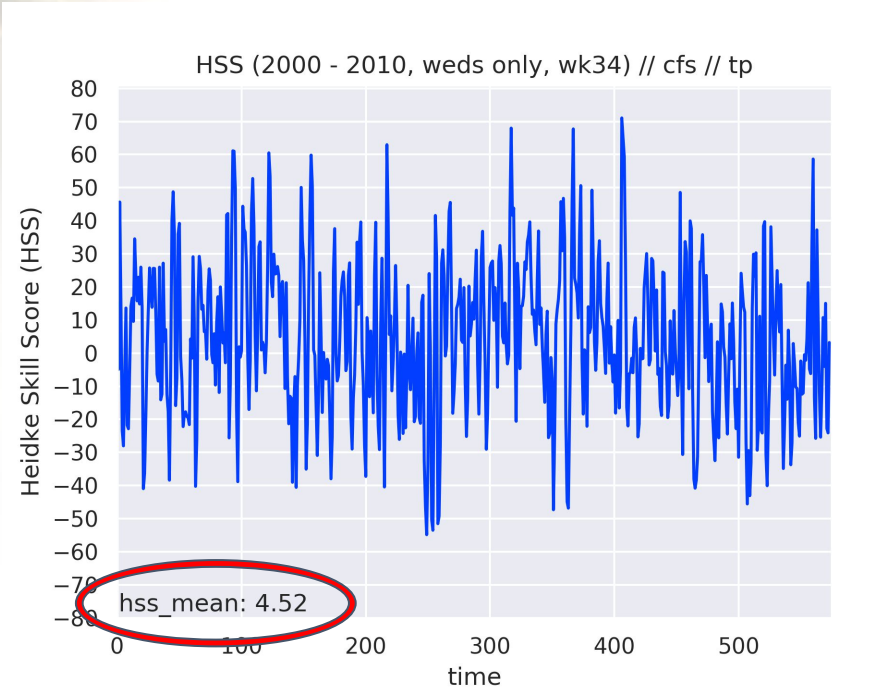


- GEFSv12 HSS higher 8 out of 12 months
- Overall GEFSv12 skill higher than GEFSv10

Precipitation

precip: GEFSv12 vs CFS for 2000-2010

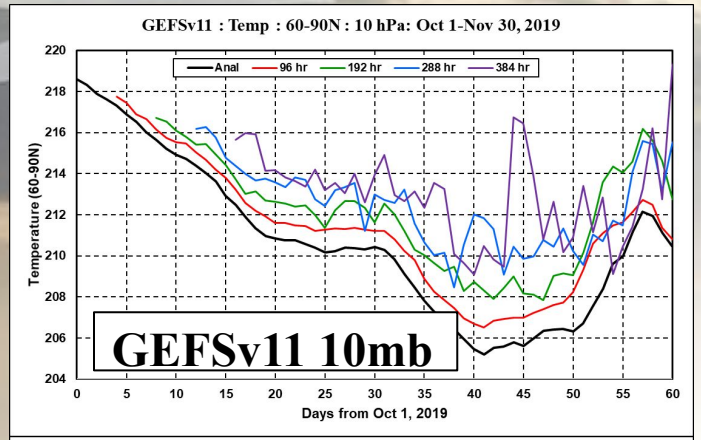


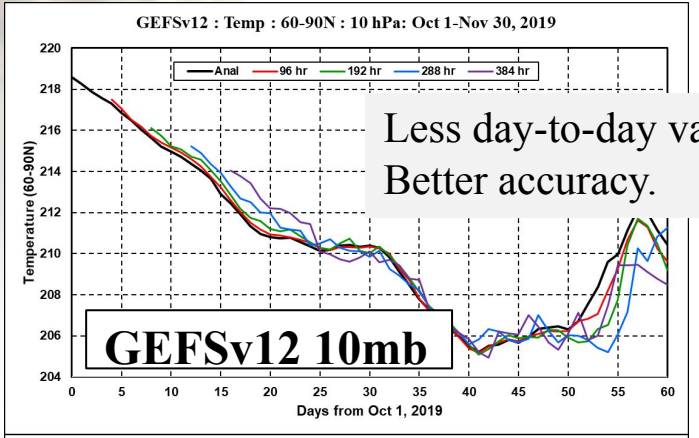


Summary:

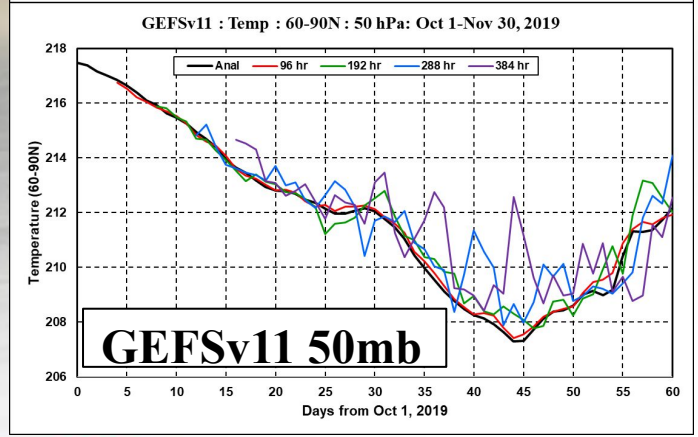
- The GEFSv12 is slightly better than the CFS over this time period.
- The difference between these means **<u>does not</u>** pass a t-test at 95%.

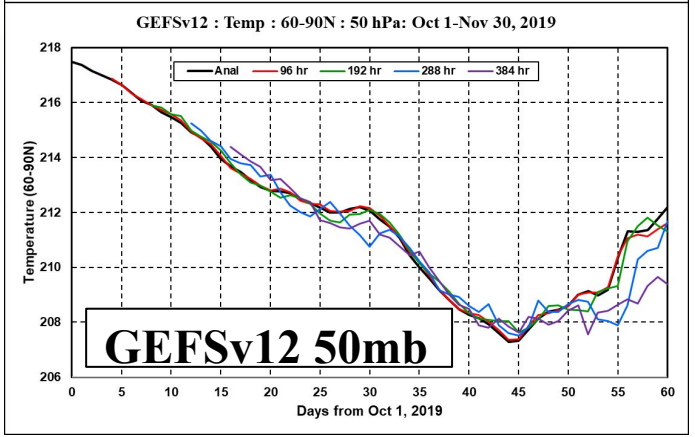
Retrospectives : Temperature : 60-90N





Less day-to-day variability.
Better accuracy.





"Vast" improvement of GEFv12 12 & 16 day fcsts wrt GEFSv11

Summary of GEFSv12-Waves Field Evaluations

Region	Recommendation	Key Remarks
Ocean Prediction Center	**Implement**	For all time steps GEFS-Wave is showing reduced bias and lower RMSE. A clear improvement. The increased resolution, extension of the forecast range to 384 hours, increasing the number of members from 21 to 31, and adding a third swell partition are significant upgrades.
Alaska Region	**Implement**	The bias is significantly lower during the typically difficult to forecast winter season. This has important implications for Alaska - which often experiences intense and difficult to forecast storms in the winter. Skill is particularly apparent on the day 7 where forecast skill typically depreciates. It seemed that especially for the Gulf of Alaska that the spread would often be quite high and above the final verification.
Canadian Meteorological Center - ECCC	**Implement**	The most noticeable improvement is in spread. RMSE and bias of the ensemble mean appear to have improved in the North Hemisphere winter, this is notable considering the operational ensemble was already good with respect to this. No systematic degradation was noticed. Forecast extension potentially allows for NAEFS-like wave collaboration.
National Hurricane Center	**Implement**	There are substantial upgrades to the overall system. Significant wave height verification is greatly improved for the ensemble mean while peak period is more neutral. Extended forecast range a plus. The model improvements and verification statistics more than support implementation.

Common Themes in GEFSv12-Waves Evaluations

- Overall, the parallel version is an improvement over the operational GWES. All participating evaluators support the proposed implementation.

Alaska Region Concern:

- Overdispersive in Gulf of Alaska

Common Positives:

- Reduced bias & lower RMSE, especially during the winter season
- Improved reliability in forecasts of ocean waves
- Overall larger and more meaningful spread in GEFS-Wave
- Extension of forecast range to 16 days and the new swell partition

Summary of GEFSv12-Aerosols Field Evaluations

Region	Recommendation	Key Remarks
Western Region	**Implement**	Not a huge amount of wildfire cases to examine, regarding smoke in the West. The few cases looked at, however, as well as Aug. 2019 stats, indicated improvement over NGAC.
Air Resources Laboratory	**Implement**	GEFS-Aerosol model gave superior input than that from NGAC for National Air Quality Forecasting Capability. Model-simulated elemental carbon and black carbon fields showed more accurate signals from the GEFS-Aerosol system than the NGAC system.
Southern Region	**Implement**	It appears there is indeed ample reflection of the higher-resolution aerosol information provided in the GEFSv12 data. Comparing errors of GEFSv12 vs NGAC relative to MERR/IMME (observed), GEFSv12 appears to have smaller errors; almost always in area, and often in magnitude as well. Improvement seems to be even better in the dust forecasts, vs the Total AOD views.
Alaska Region	**Implement**	Greatest strength for long-term transport events; does not seem to detect local fire and smoke events due to lower resolution. Appears to hold promise to help our aviation forecasters handle ash resuspension events. In case study of greatest concern, the correct smoke did not occur, but this may have been due to unavailability of GBBEPx emissions.

Summary of GEFSv12-Aerosols Field Evaluations

Region	Recommendation	Key Remarks
U.S. Naval Research Laboratory	**Implement**	Significant biases still exist, but overall GEFS-Aerosols member looks much better than NGAC. With improved biomass burning, GEFS-Aerosols would likely also be improved. However, in some places like Africa, the bias is only shifting signs. Big improvement in dust prediction.
Climate Prediction Center	**Implement**	Aerosol forecasts will improve UV Index forecasts; current product uses seasonal climatology that does not capture smoke at all. Higher resolution in GEFS-Aerosols. Expect smoke to be advected better than in NGAC.
Connecticut Dept of Energy and Environmental Protection	**Implement**	Wildfire smoke prediction will be a major improvement, especially when 1-day old fire data can be used. Higher resolution is a big improvement.
NESDIS	**Implement**	Mode predictions are very encouraging. Comparisons with VIIRS AOD show that model is slightly underpredicting.

Common Themes in GEFSv12-Aerosol Evaluations

- **Overall, the parallel version is an improvement over the operational NGAC. All participating evaluators support the proposed implementation.**

Alaska Region Concern:

- GEFS-Aerosols member did not seem to detect local fire and smoke events

Common Positives:

- 5 out of 8 evaluators saw overall improvement in the dust prediction of GEFS-Aerosols compared to NGAC (3 did not assess)
- More accurate signals and smaller errors in GEFSv12-Aerosols compared to NGAC

Call For Comments from Evaluators

Summary of GEFSv12 Evaluation: Benefits

- **Benefits:**
  - **GEFSv12 is much improved from GEFSv11/GWESv3/NGACv2:**
    - Higher 500-hPa AC scores and improved synoptic predictability
    - Increased ensemble spread (improved ensemble dispersion)
    - Improved TC tracks, spread, and location of QPF maxima
    - Better handling of deepening extratropical cyclones
    - More reliable precipitation forecasts
    - Improved representation of weather events near topography
    - Mitigation of exaggerated offshore QPF maxima
    - For sub-seasonal forecasts, 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.
    - GEFSv12-Waves significantly reduced Hs error and bias in short and long fcst ranges
    - Hs forecasts from GEFSv12 are more accurate and provide higher predictability.
    - GEFSv12 10-day (16-day) forecasts are equivalent in skill to current operational 5-day (10-day) forecasts
    - Significant improvement in AOD forecasts from GEFSv12-Aerosol in all global regions

Summary of GEFSv12 Evaluation: Concerns

- **Issues and concerns for future improvement:**
  - Temperature bias – adding low-level cold bias, as seen in GFSv15 (although surface is overall exempt, save for being too warm for longer range arctic air intrusions) - ***reforecasts can help to reduce the bias and advance the skill through bias correction and calibration.***
  - Progressiveness*:* Some upper troughs (especially cutoff lows) are considerably too progressive – challenging issue related to model dynamics and physical parameterizations
  - Intensity and position of heavy (or convective) precipitation – could be a challenging issue related to model dynamics and physical parameterizations.
  - Cross-track bias of hurricane tracks for longer lead-times – could be related to model dynamics, the intensity and position of westerly jet streams and storm internal structure.
  - Reduced instability – need improvement in PBL scheme
  - Extreme weather? – improve ensemble spread to better represent the tail of distributions
  - Weak MJO amplitude? – looking for further improvement from coupling and convective schemes
  - GEFSv12-Aerosol may have made things worse for spring biomass burning in Africa (AOD initialization issues/lack of DA?)

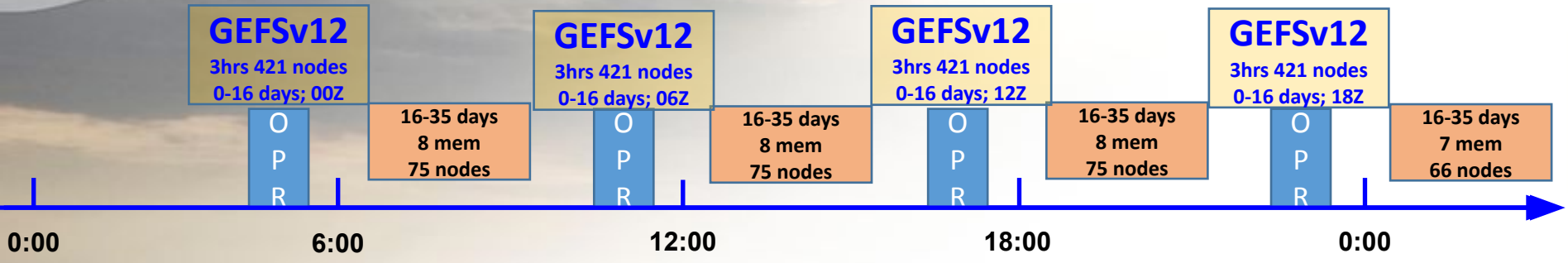
New Products from GEFSv12

To Support Stakeholders and Community

- High resolution (25 km) data (selected 35 variables).
- Top 5 pressure levels (stratosphere) data included in the ensemble mean and spread to support (and development) stratospheric applications.
- Station time series BUFR data for all 31 ensemble members and ensemble mean to show ensemble plumes at observation locations (2082 stations).
- Daily mean products to support sub-seasonal guidance, **we could stop GEFS SubX experiments after GEFS v12 is implemented.**
- Wave ensemble provides higher grid resolution (25km) to stakeholders and community (10 additional members, 50% increase of data). Grib2 data is updated to latest WMO wave products tables and third swell partition is added to the output.
- Aerosol 25km 2d data of all species will provide much higher resolution to the community

GEFSv12 forecast timeline and HPC requirements

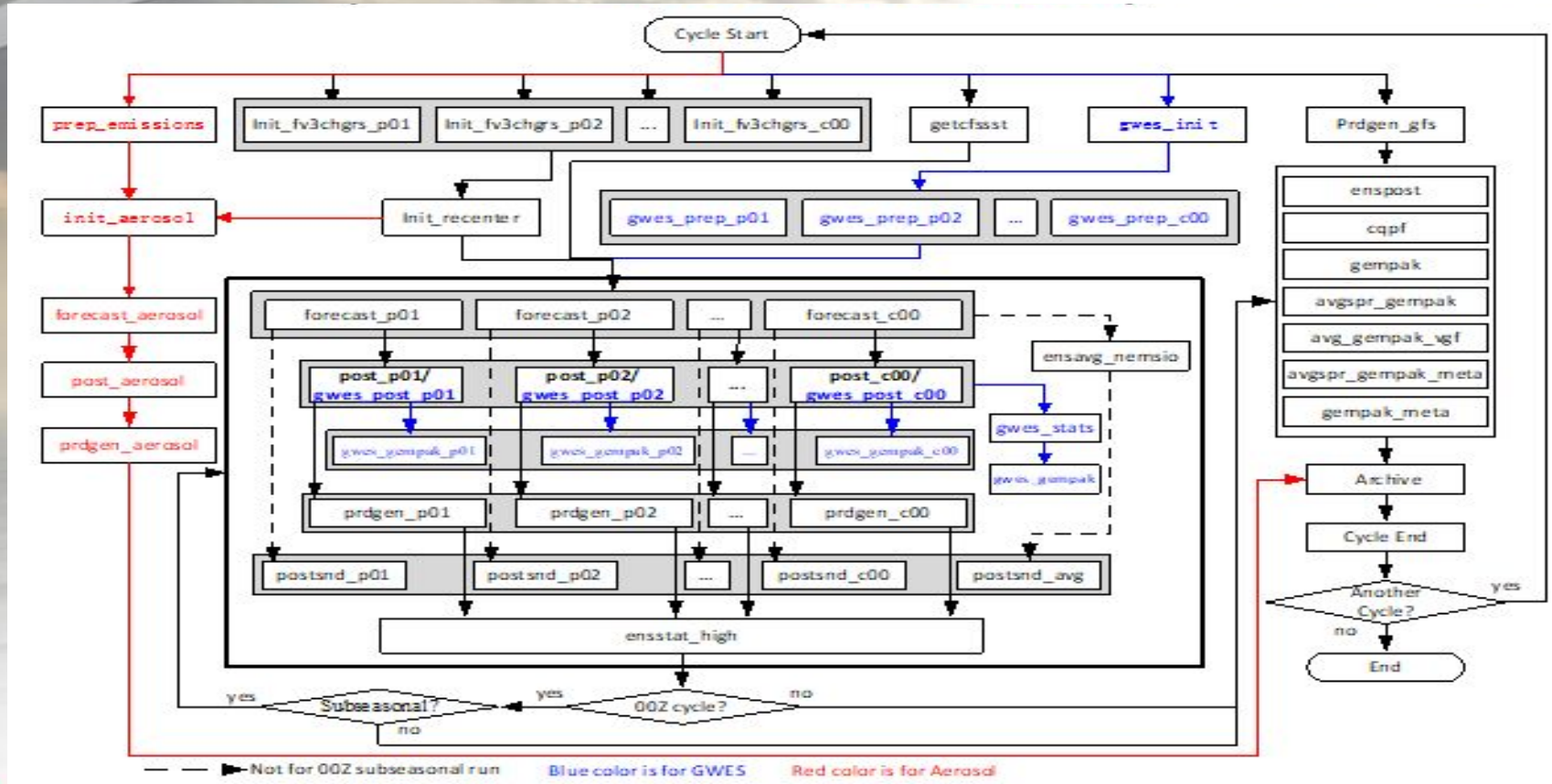
GEFSv12 nodes usage for 24 hours cycling window compared to GEFSv11 (Opr)



Summary of Operational Resource Requirements for GEFSv12

	Atmosphere		Wave		Aerosol		Total	
	GEFSv11	GEFSv12	GEFSv11	GEFSv12	GEFSv11	GEFSv12	GEFSv11	GEFSv12
WCOSS (node)	200n/60m	421n/3h 80n/3h	N/A	Included	N/A	Included	200n/60m	421n/3h 80n/3h
WCOSS (disk)	7,000GB	68,000GB	220GB	1,040GB	66GB	1,800GB	7,286GB	70,840GB
ftp/nomads (days)	1,500GB	4,000GB	100GB	240GB	12GB	200GB	1,612GB	4,440GB
HPSS total	1,600GB		60GB		66GB	90GB (?)	1,726GB	1,800GB*

GEFSv12 Atmosphere-Wave-Aerosol Workflow



Public Notifications for Changes

- Scientific advancements and benefits associated with the GEFSv12 upgrade along with changes in the timelines of GEFS product availability are described in the PNS issued on March 4, 2020: https://www.weather.gov/media/notification/pns20-07gefs.pdf
  - *No feedback received.*

- Certain forecast products from GEFS v11.3 will be discontinued as described in the PNS issued on Dec. 2, 2019: https://www.weather.gov/media/notification/pns19-37gefs_product_removal.pdf
  - *No feedback received.*

- Certain forecast products from Global Wave Ensemble System (GWES) described in the PNS issued on April 7, 2020: https://www.weather.gov/media/notification/pns20-20gwes_removal.pdf
  - *No feedback received.*

MDC Decision/Recommendation for GEFSv12 implementation: TBA

GEFSv12 Development and T2O Timeline

- Freeze GEFS-Atmosphere configuration for reanalysis/reforecast - **Q1FY19**
- Freeze GEFS-Atmosphere configuration for retrospectives - **Q3FY19**
- Freeze GEFS-Wave configuration/code for retrospectives - **Q4FY19**
- Freeze GEFS-Aerosols configuration/code - **Q2FY20**
- Produce 20 years reanalysis datasets (ESRL/PSD): **Q1FY20**
- Produce 30 years reforecast extended to 35 days: **Q1FY20**
- Produce 2.5 years retrospectives for atmosphere: **Q2FY20**
- Produce one year retrospectives for wave ensemble: **Q2FY20**
- Produce 9-month retrospectives for aerosol: **Q2FY20**
- **Final IT and EE2 compliance - 4/23/2020**
- EE2 process and coordination with NCO: **Q4FY20**
- Deliver PNS to HQ: **PNS1 (12/2019)**, **PNS2 (04/2020)**, **PNS3-Wave (5/2020)**, **SCN (30 days before)**
- Field evaluation for all components: **4/27/20**
- MEG final briefing: **4/30/2020**
- EMC CCB: **05/1/2020**
- Science briefing to NCEP OD: **5/5/2020 → Completed today**
- Deliver final package to NCO: **05/15/20**
- Transition to Operations: **09/09/20 (TBD)**

Summary

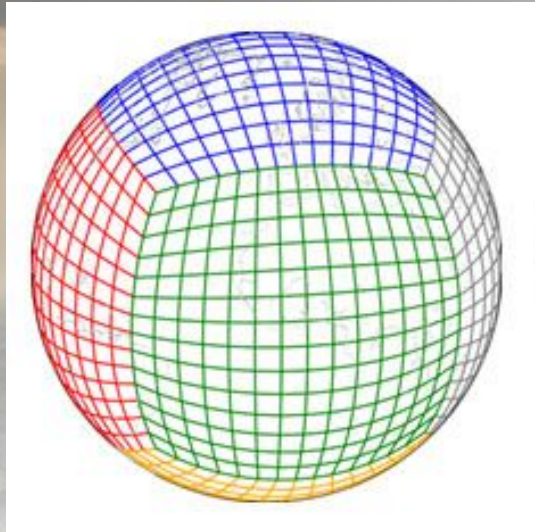
- **The primary objectives of Q4FY20 GEFSv12 upgrades are met:**
  - Implementation of FV3 Dynamic Core and GFSv15 physics including GFDL Microphysics
  - Advanced stochastic physics (SPPT+SKEB)
  - Increased resolution (C384, ~25km), increased ensemble members (31); and extended forecast length (35 days)
  - Unification of Global Wave Ensembles (GWES) and NCEP Global Aerosol Component (NGAC)
  - Extensive evaluation based on 2.5 year retrospective experiments for medium range weather, 31-year reforecasts for extended range and sub-seasonal weather, one year retrospectives for wave component, and 9-month retrospectives for aerosol component
- **Favorable evaluation & unanimous endorsement from stakeholders.**

EMC requests NCEP Director to approve implementation of Q4FY20 GEFSv12 package into operations

Backup Slides

GEFSv12: Transition from Spectral to FV3 Dycore

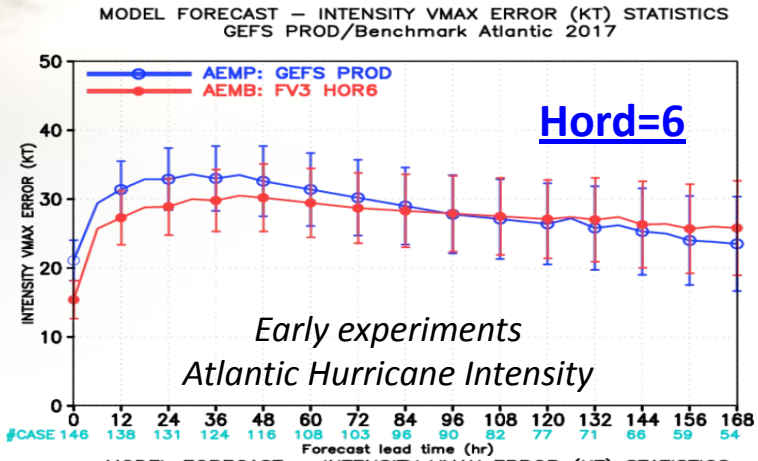
The Finite Volume Cubed Sphere (FV3) dynamic core

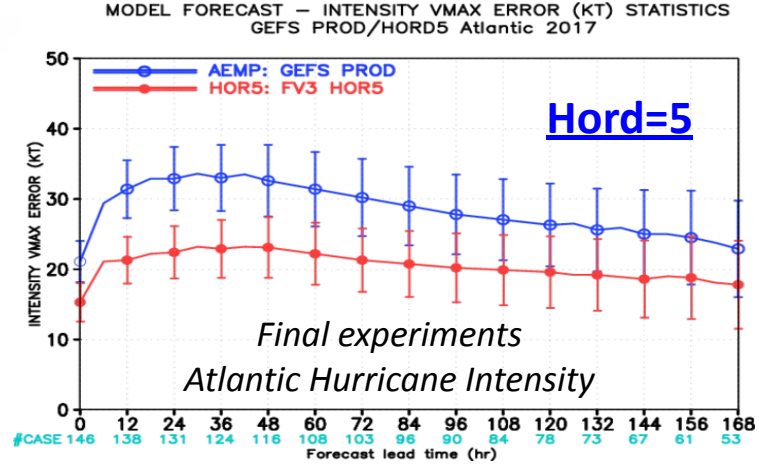


C384L64 ~ 25km resolution
Non-hydrostatic

Key parameters

- ***Time step=450s**; but use 300s for aerosol integration*
- ***ksplit=2**; for vertical mapping*
- *nsplit=**6**; for acoustic wave*
- ***hord=5;** 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*

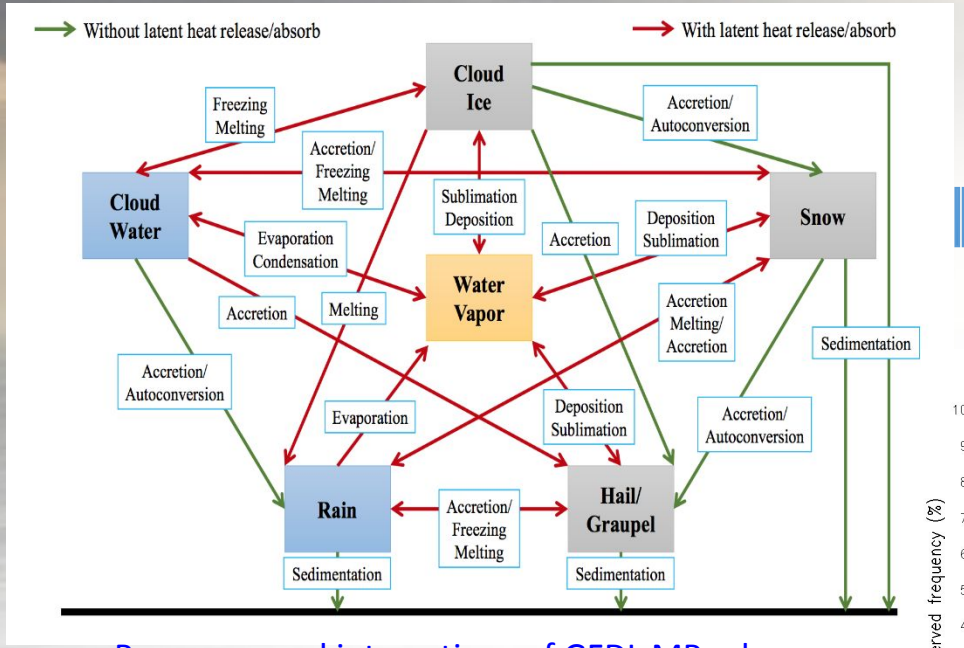




GEFSv12 Physics Changes

Replace Zhao-Carr MP with GFDL MP

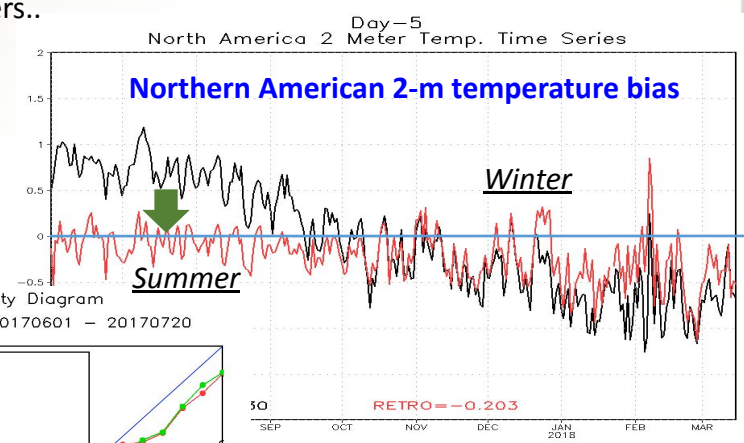
Five prognostics cloud species: Liquid, ice, snow, graupel, rain
more sophisticated cloud processes

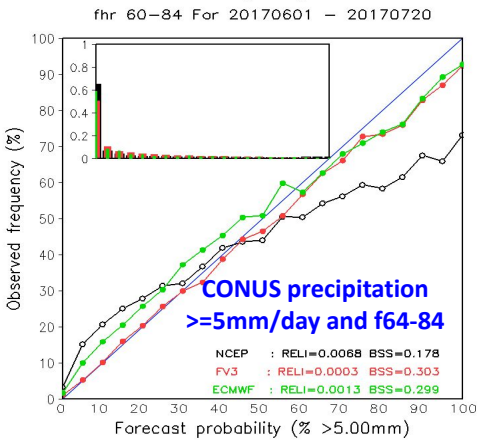


Processes and interactions of GFDL MP scheme

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..



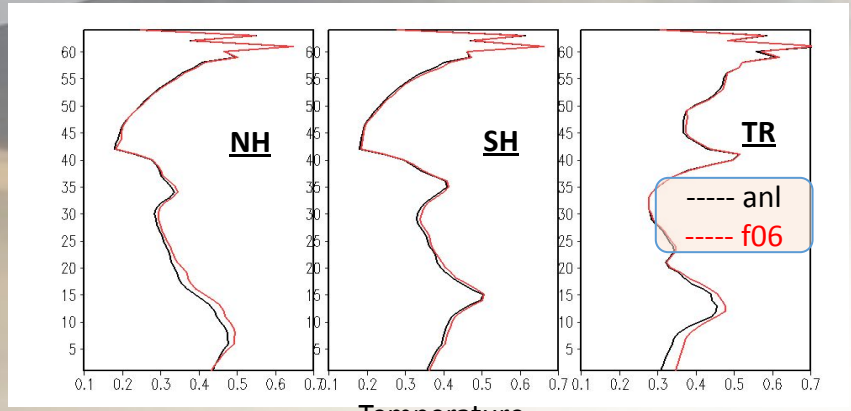


- *Top: NA 2-m temperature bias is much reduced in summer (warm) and winter (cold).*
- *Left: increase CONUS precipitation spread, and improve forecast reliability*

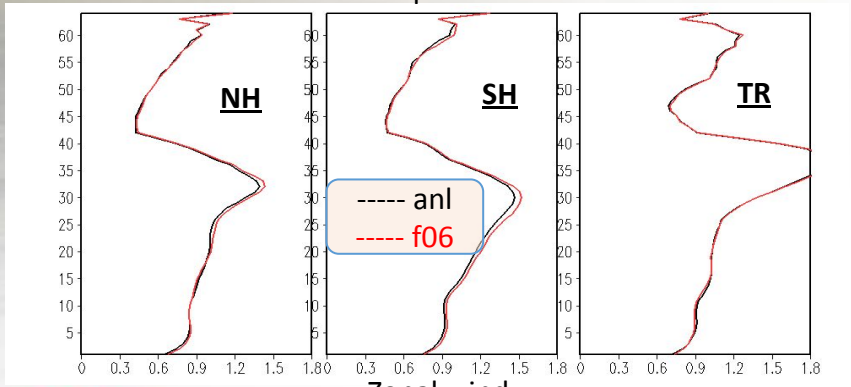
80

GEFSv12 IC and Model Uncertainty, No TC Relocation

Example of FV3-EnKF spread vertical profile



Temperature



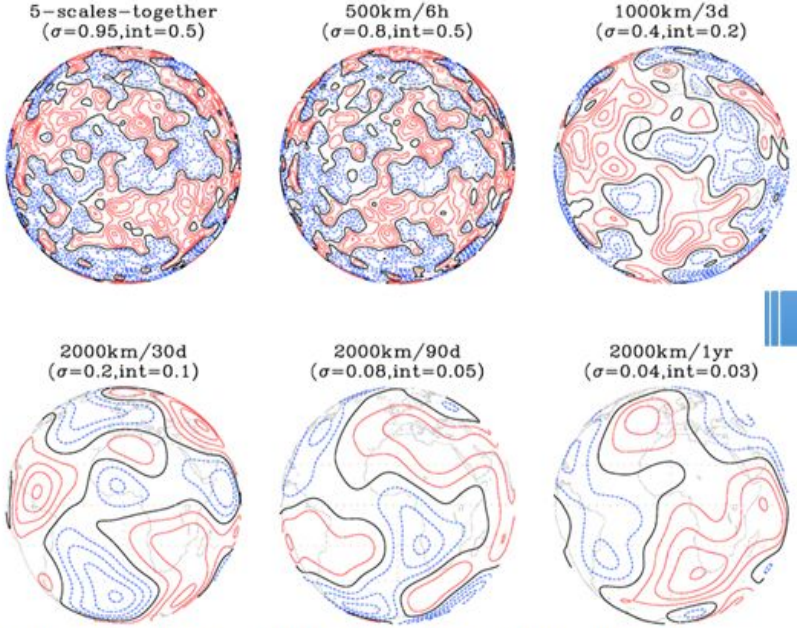
Zonal wind

- **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***

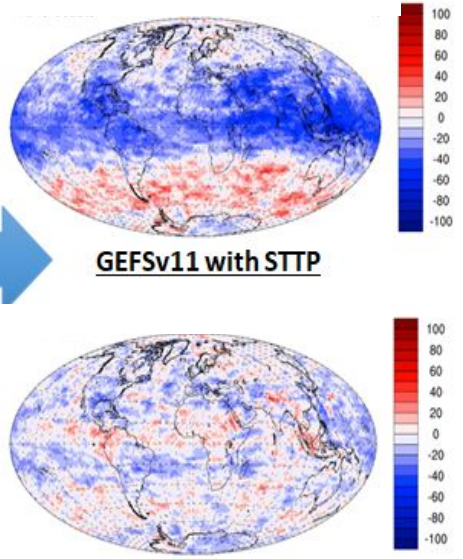
Examples of stochastic patterns for SPPT



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

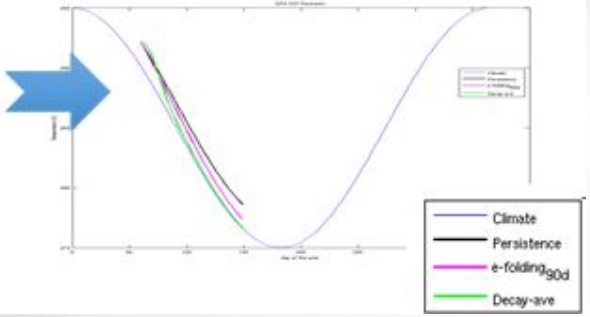
- **V11: Persistent + relaxation**

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

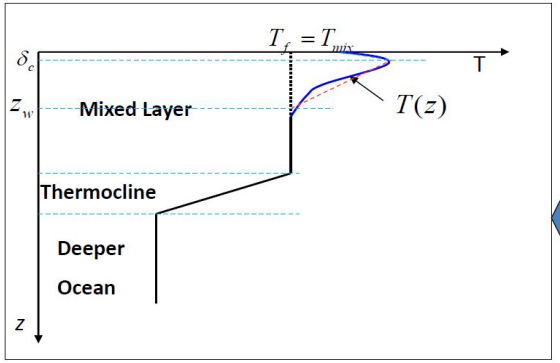
analysis - climatology at *t0*

Climatology at *t*

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

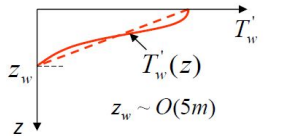


NSST is a **T-Profile** just below the sea surface.
Here, only the vertical thermal structure due to **diurnal thermocline layer warming** and **thermal skin layer cooling** is resolved



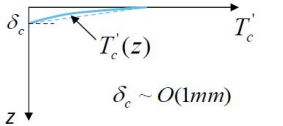
Diurnal Warming Profile

$$T_w'(z) = (1 - z/z_w)T_w'(0)$$



Skin Layer Cooling Profile

$$T_c'(z) = (1 - z/\delta_c)T_c'(0)$$



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

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

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

$$SST_f^t = (1-w) * \left[SST_a^{t0} - SST_{cfsrc}^{t0} + SST_{cfsrc}^t\right] + w * \left[SST_{cfs}^t - (SST_{cfs\_c}^t - SST_{cfsrc}^t)\right]$$

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*

Analysis, Perturbations and SSTs for GEFSv12 Reforecasts

Phase 1

CFSR analysis + BV-ETR initial perturbations

Resolution similar to GEFS v10

01/01/1989 — **12/31/1999**

OI SST for analysis; NSST+2 tiered SST for forecasts

Old (categories) soil moisture for analysis, new for forecasts

Phase 2

GSI/EnKF hybrid analysis with IAU; EnKF perturbation

Lower resolution of GFS (C384) and GEFS (C192)

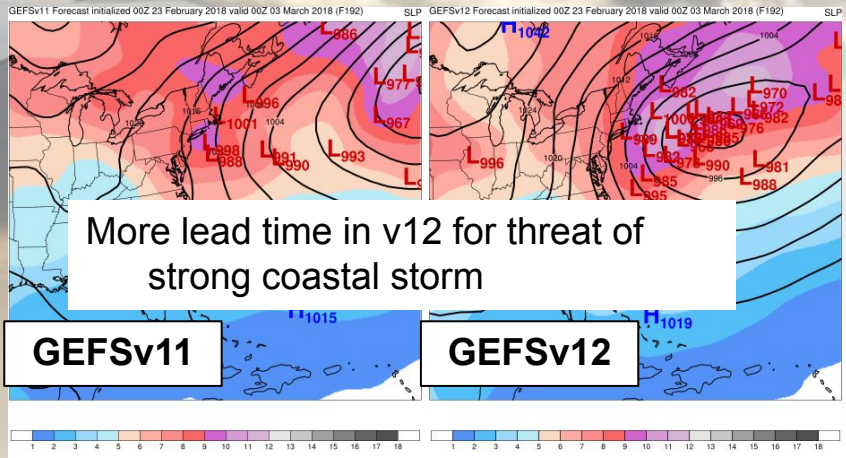
01/01/2000 — **12/31/2019**

OI SST for analysis; NSST+2 tiered SST for forecasts

New (categories) soil moisture for analysis, new for forecasts

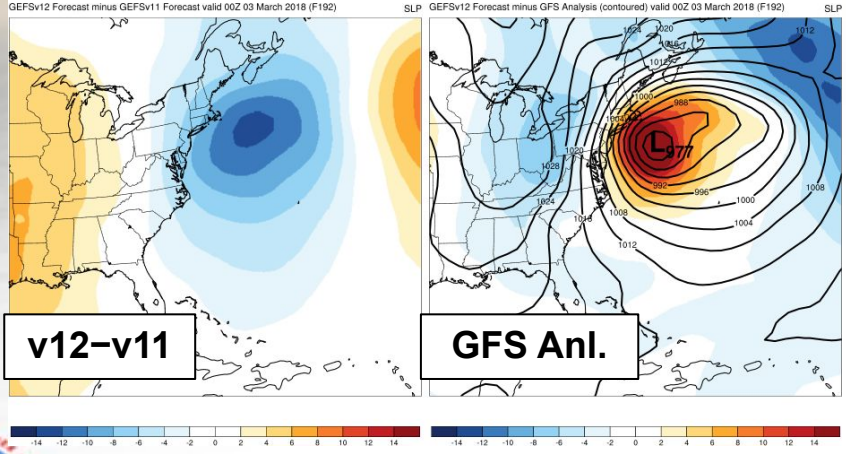
31 years GEFS v12 reforecasts (Jan. 1989 – Dec. 2019)

Improved Synoptic Predictability & Cyclone Deepening

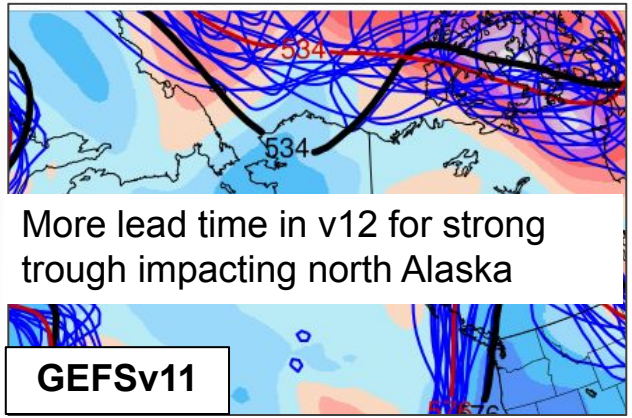


More lead time in v12 for threat of strong coastal storm

GEFSv11 **GEFSv12**

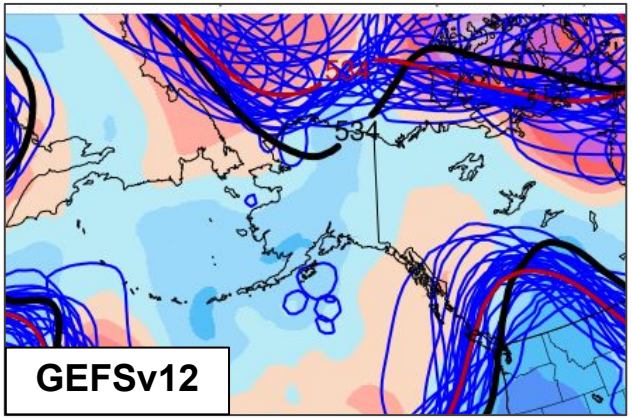


v12−v11 **GFS Anl.**



More lead time in v12 for strong trough impacting north Alaska

GEFSv11



GEFSv12