GEFSv12: Operational Implementation of UFS Sub-seasonal Application & The Reanalysis for GEFSV12

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Shobha Kondragunta and Xiayang Zhang **(NOAA/NESDIS/STAR)**

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

Acknowledgements

- **EMC Ensemble Project Team:** Global ensemble development
- **EMC Wave Project Team:** Wave development, unification, and support
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- **EMC GFS Project Team:** Support for ensemble development
- **EMC/PSL Reanalysis and Reforecast Project Team:** Production of 20 years reanalysis and support for ensemble development including stochastic physics
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- **EMC Model Evaluation Group:** Evaluation of ensemble performance, coordination with the field
- **EMC 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

Topics

- Proposed GEFSv12 Configuration
- Evaluation of GEFSv12 Retrospectives
- Benefits and Concerns
- Future Plans

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° x 0.5°	**0.25° x 0.25°** and 0.5° x 0.5°
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**

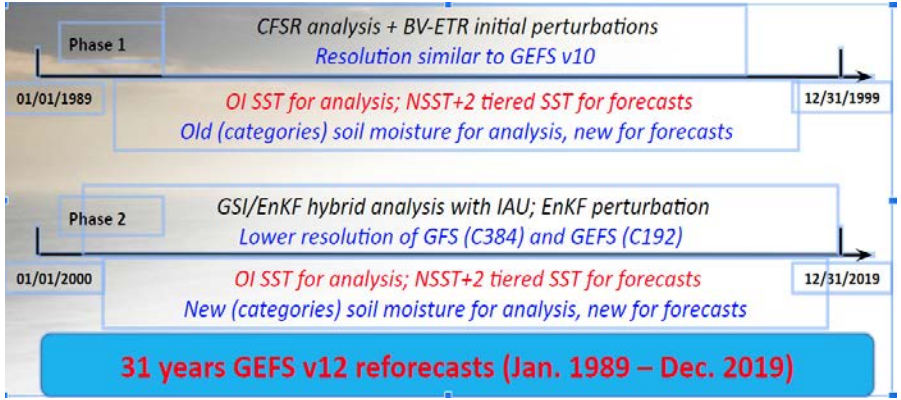
GEFSv12 Reanalysis and Reforecast

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

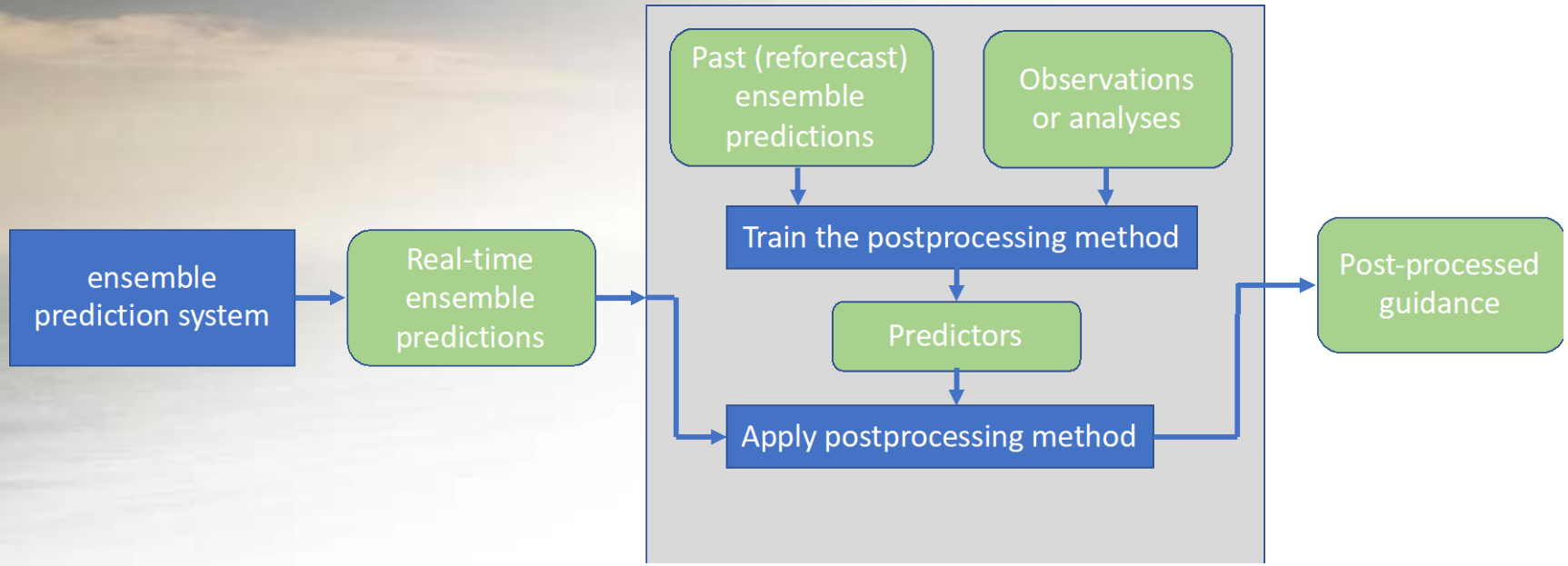
20-year Reanalysis (2000-2019), Led by ESRL/PSL
31-year Reforecast (1989-2019), Led by NCEP/EMC

- **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

See talk by Tom Hamill at 12.45 PM, 7/28/20



Reanalysis and reforecasting as part of an integrated UFS prediction system.



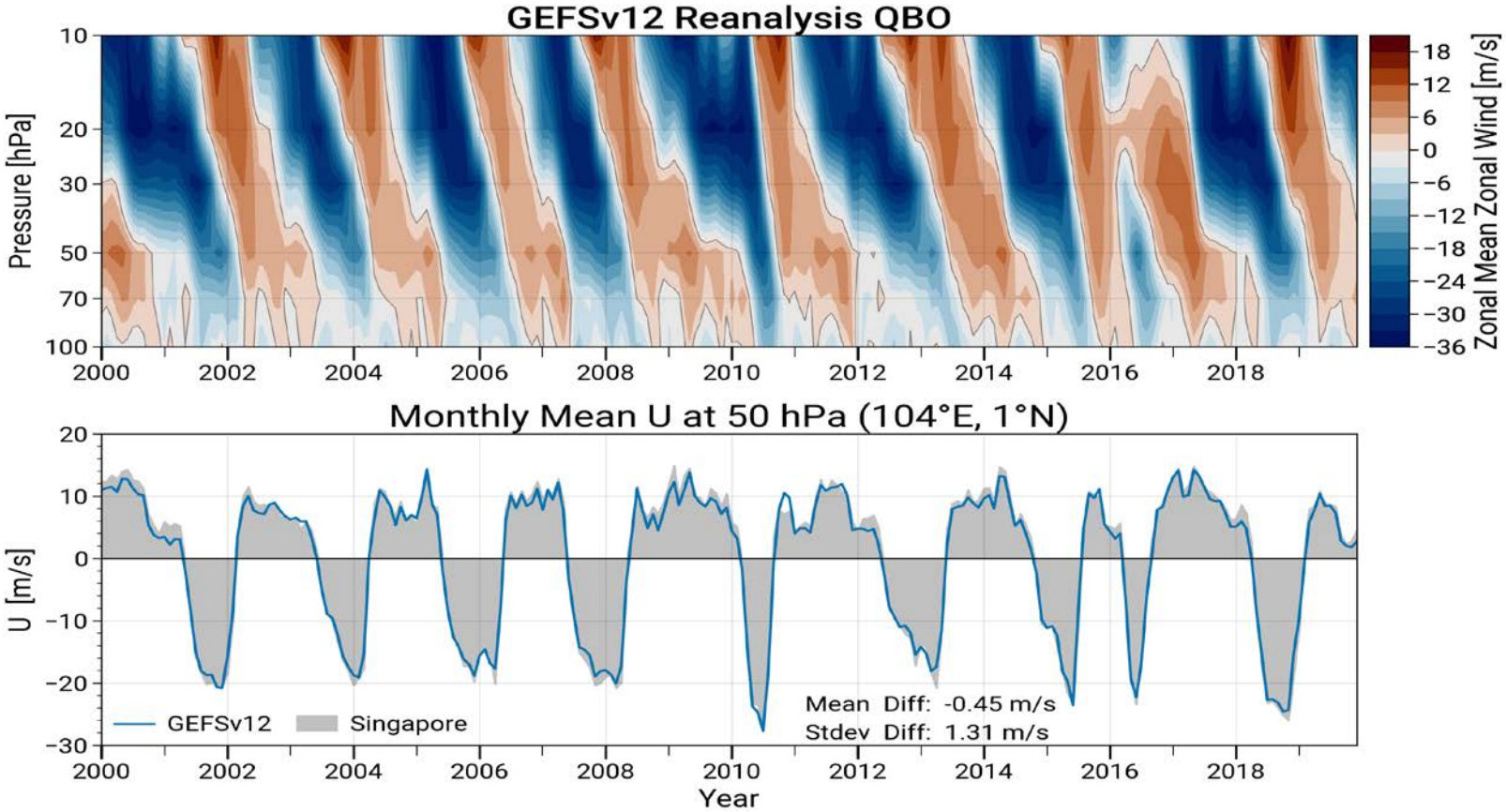
GEFSv12 reanalysis was optimized for reforecast initialization.

- The goal was not to produce a reanalysis that was tuned to be optimally accurate in its own right, but to *produce a reanalysis that was as consistent as practical with the eventual operational analysis system used with GEFSv12*. Consistency > absolute accuracy, bias.
- If you seek reanalysis data for model verification, climate variability analysis, and other applications, ECMWF/Copernicus ERA5 is probably a better choice.
- In the future, with decreases in UFS systematic and better coupling of analyses between state components, one NOAA reanalysis may serve multiple purposes.

Major differences, GEFS v12 vs. previous-generation CFSR reanalysis

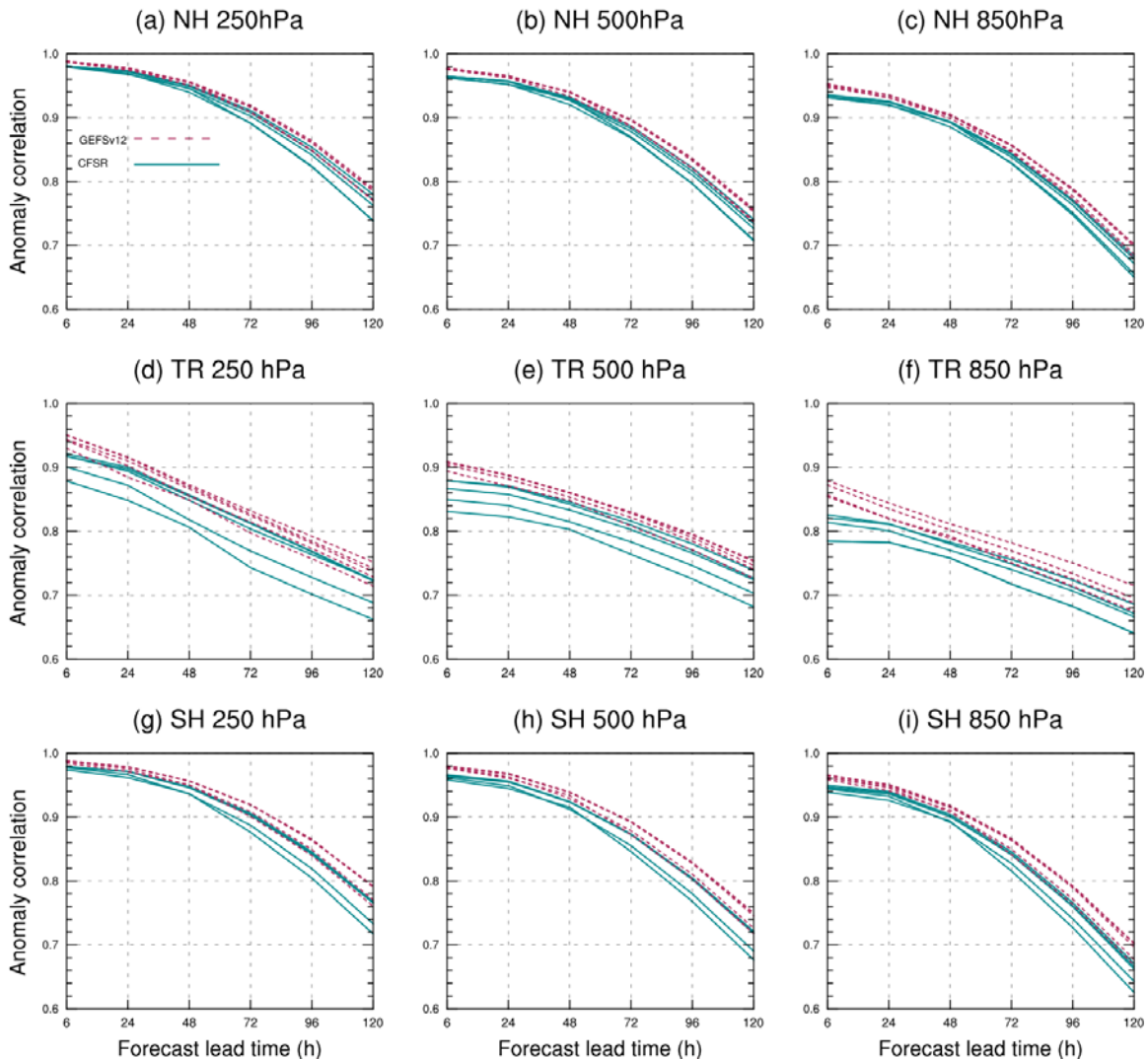
Aspect changed	CFSR configuration	GEFS v12 configuration
Period of record	1978-current	2000 - 2020
Atmospheric dynamical core and control forecast grid spacing	Spectral, T382L64 (~ 38 km grid)	FV3 (Lin 2004, Putman and Lin 2007), C384L64 (~ 25 km grid)
Microphysical parameterization	Zhao-Carr (Zhao and Carr 1997)	GFDL (Phillips and Donner 2006, Zhou et al. 2019)
Other parameterizations	Saha et al. (2010)	GFSv15 (2020)
Atmospheric data assimilation methodology	3D-Var through 2011 (Parrish and Derber 1992, Kleist et al. 2009)	Hybrid En-Var
Ensemble usage in data assimilation	None through 2011, then following operations	80-member EnKF at C128L64 (~ 75 km) to provide background- error covariances
Ensemble stochastic physics	None (single control member for data assimilation)	Stochastically perturbed physical tendencies (SPPT), stochastic boundary-layer relative humidity (SHUM), and stochastic kinetic-energy backsctatter (SKEB) [this paper]
Snow updates	SNODEP (Kiess and Kopp, 1997) before 1997, NESDIS IMS (Helfrich et al. 2007) thereafter. Updated 4x daily.	NESDIS IMS (Helfrich et al. 2007). Updated only at 00 UTC, otherwise climatology for other 3 cycles (a bug).
Land-surface analysis	Separate land-surface analysis with analyzed forcings (Saha et al. 2010)	Land-surface forcings directly from short-term forecasts.
Ocean analysis	SST via OI (Reynolds et al. 2007); rest of ocean state with 3D-Var using MOM4 ocean and weak coupling	SST via OI (Reynolds et al. 2007). No weak coupling in cycled DA, no full ocean analysis.
Tropical cyclone processing	Vortex relocation to observed position (Liu et al. 1999)	Direct assimilation of central pressure, no relocation

QBO in this reanalysis



No smoking-gun problems.

figure c/o
Zac Lawrence,
CIRES and PSL



AC “dieoff” curves of u-wind component.

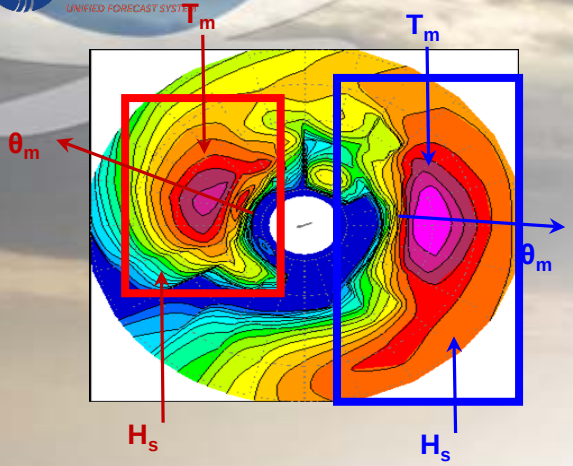
Different curves for each of the different streams to illustrate temporal variability.

The improvement to forecast skill from use of the new reanalysis is evident everywhere, especially in the tropics.

R/R storage update, AWS and NOAA.

- Under the “Big Data” project, ~200 reforecast fields are being stored from the 2000-current reforecast in the AWS cloud.
- s3://noaa-gefs-retrospective
- URL: https://noaa-gefs-retrospective.s3.amazonaws.com/
- Browser: https://noaa-gefs-retrospective.s3.amazonaws.com/index.html
- https://noaa-gefs-retrospective.s3.amazonaws.com/Description_of_reforecast_data.pdf
- Reforecast (and control from reanalysis, + spread) are also being stored on NOAA-owned disk, attached to the “rzdm” computer in College Park, MD.

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
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

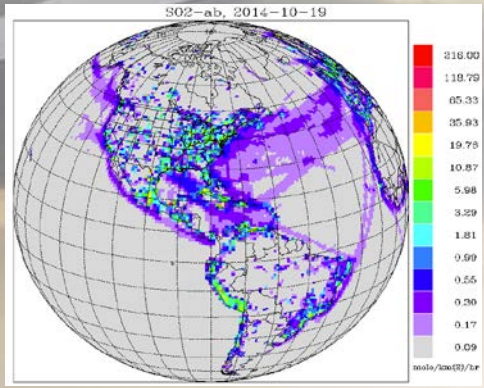
GWES→GEFSv12-Wave

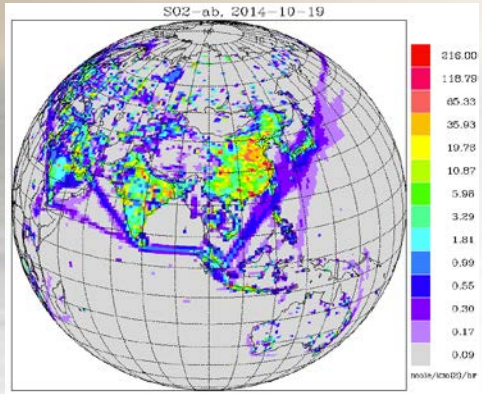
- **"The first global-scale UFS coupled system at NCEP"**
- Integration of wave model to GFS global-workflow,
- Improved source-terms;
- Objective optimization with hourly GFS surface-wind forcing

- 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

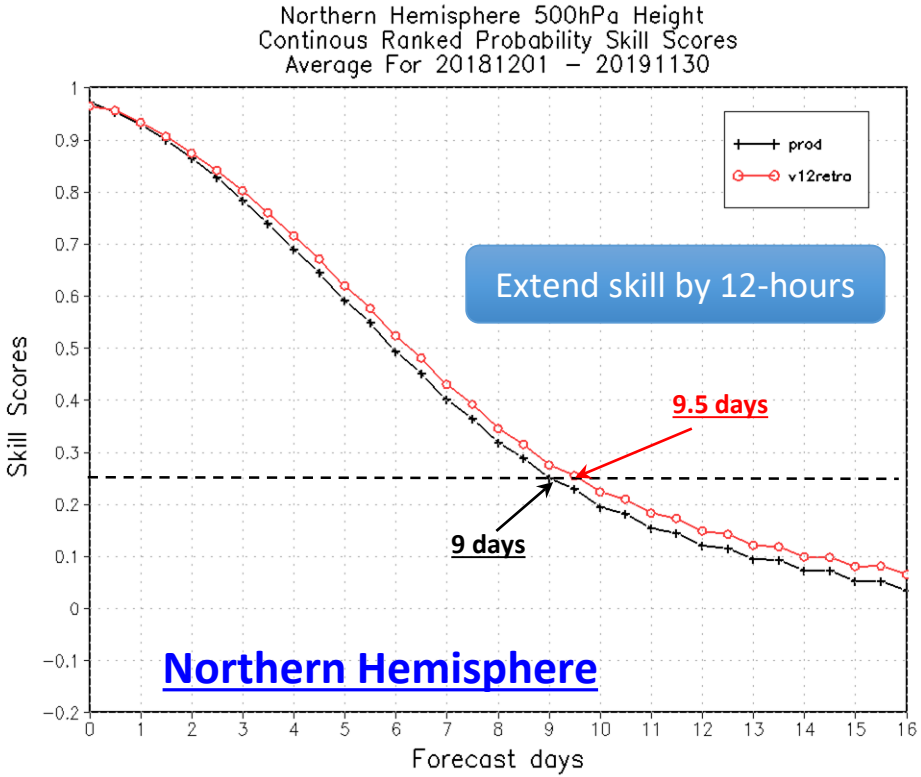
- **One additional member of GEFSv12 for aerosols**
- Replace operational NGACv2
- GFS meteorology (based on GFSv15) at C384 (~25 km), 64 levels, to 120 hrs, 4x/day
- Inline aerosol representation based on GOCART (GSD-Chem)
- Sulfate, Organic Carbon, Black Carbon, Dust, Sea Salt
- **Emissions**: CEDS-2014 (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

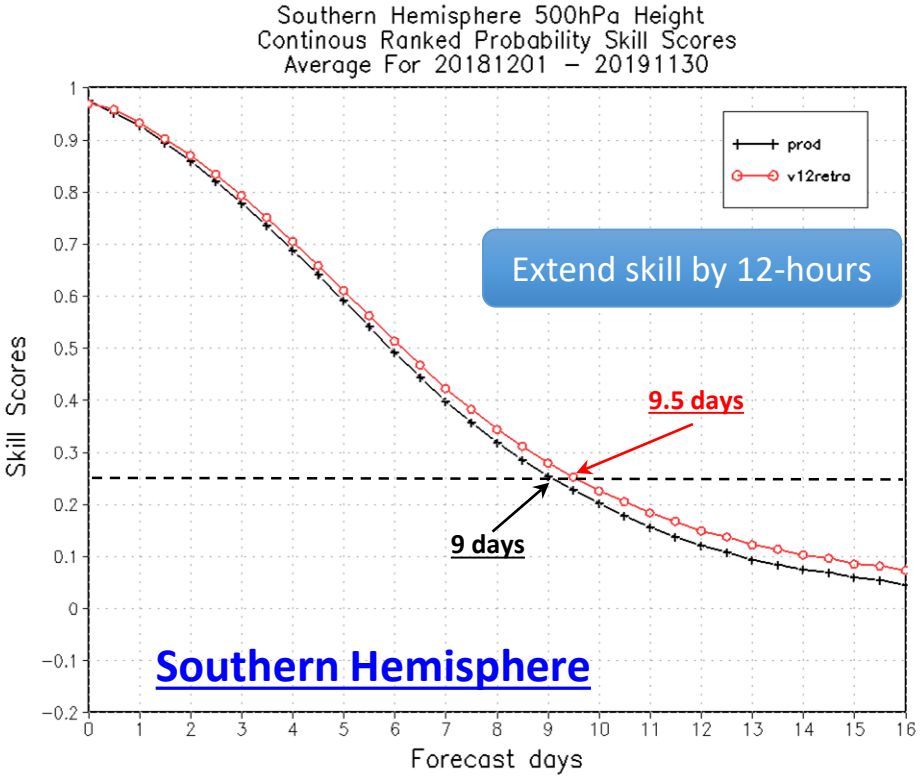
Tracer transport and wet scavenging are included in Simplified Arakawa-Schubert (SAS) scheme. Fluxes are calculated positive definite. Scavenging coefficient is α=0.2 for all aerosol species.

Talks by Li Zhang, Barry Baker, Jeff McQueen, Ivanka Stajner

Statistical Evaluation of GEFSv12-Atmosphere

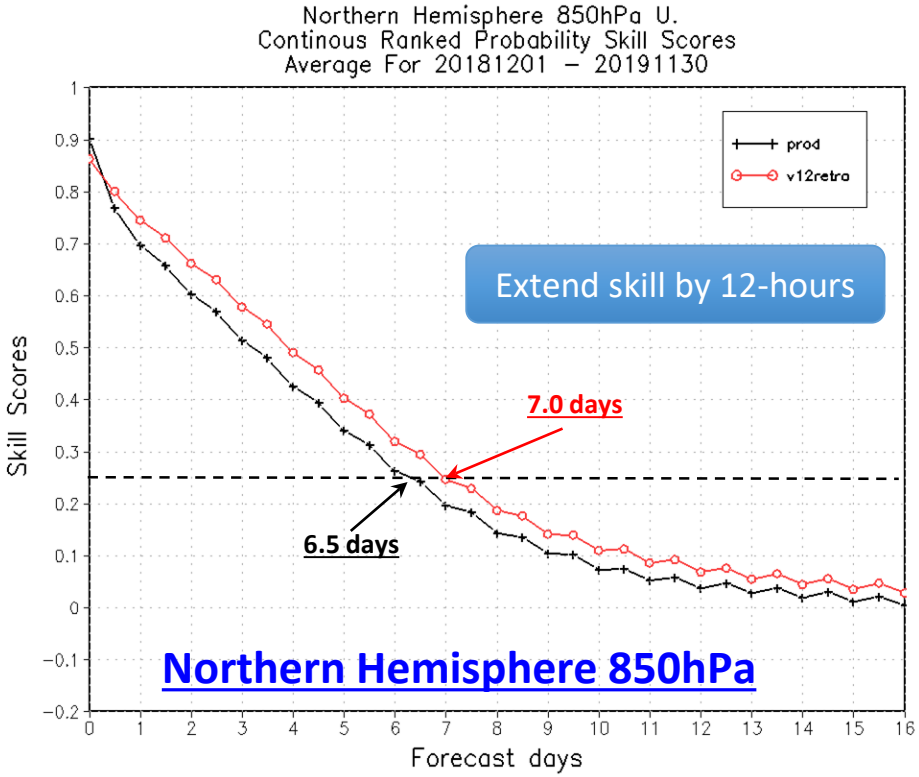
CRPS Skill of 500hPa geopotential height

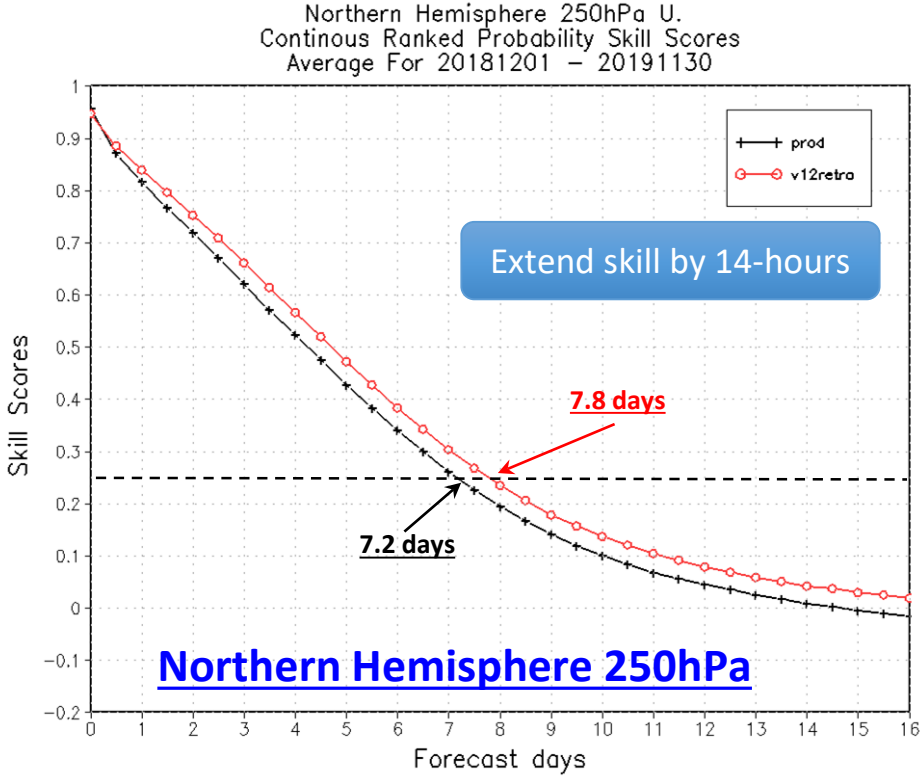




CRPSS – *Continuous Ranked Probabilistic Skill Score is one of evaluation tools to measure ensemble based probabilistic forecasts. CRPSS=1 is for perfect forecast, CRPSS=0 is for no skill from reference (climatology), CRPSS=0.25 is similar to PAC=0.6 (pattern anomaly correlation of ensemble mean).* ***GEFS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

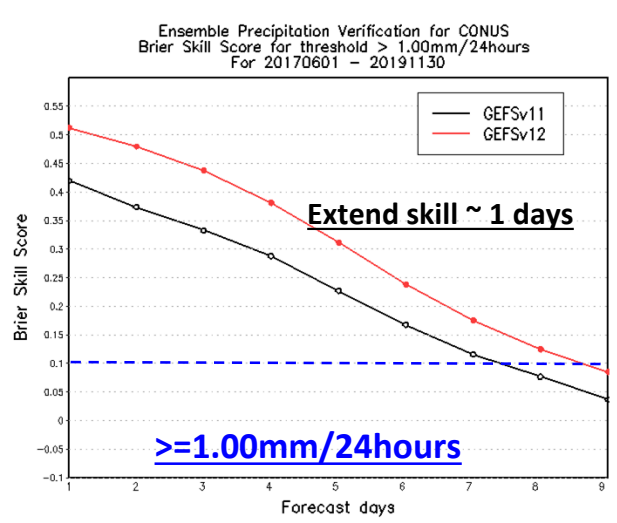
CRPS Skill of 850hPa and 250hPa zonal winds

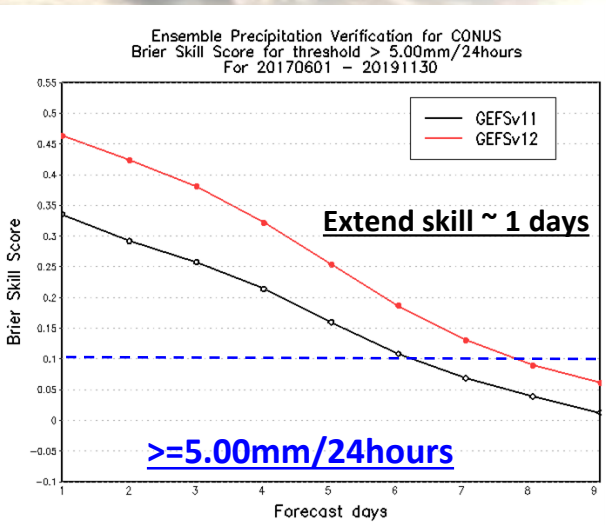


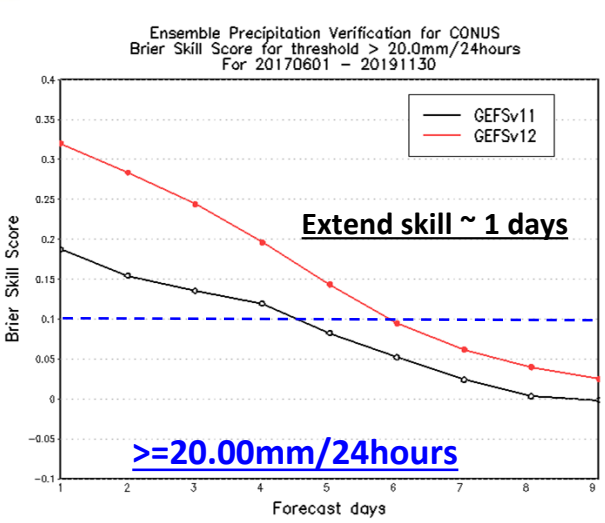


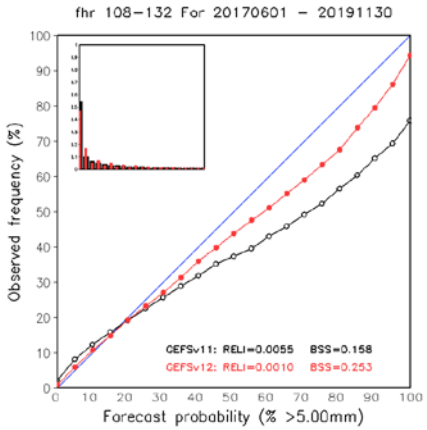
GEFS v12 has better CRPS for both Northern Hemisphere 850hPa and 250hPa zonal winds.

Brier Skill Scores of the CONUS PQPF





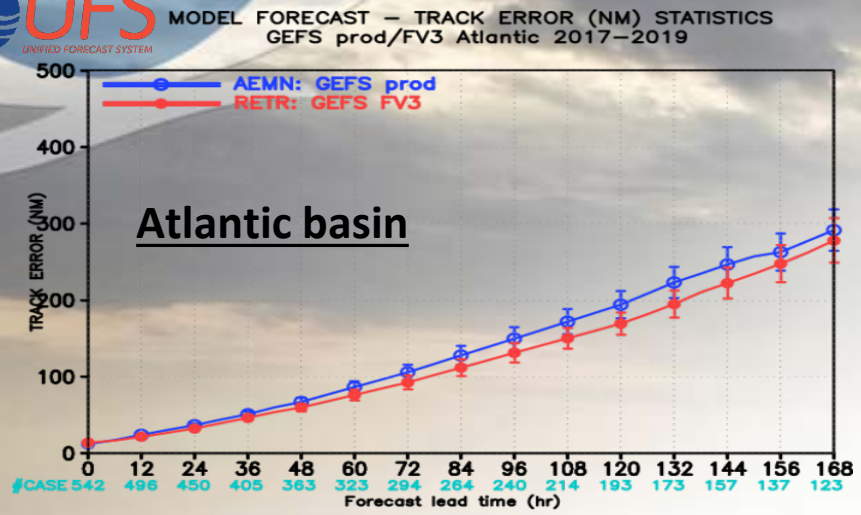




Brier Skill Score: *BSS=1 is for perfect forecast, BSS=0 is for no skill from reference climatology.*

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

GEFSv12 forecasts are more reliable than GEFSv11.

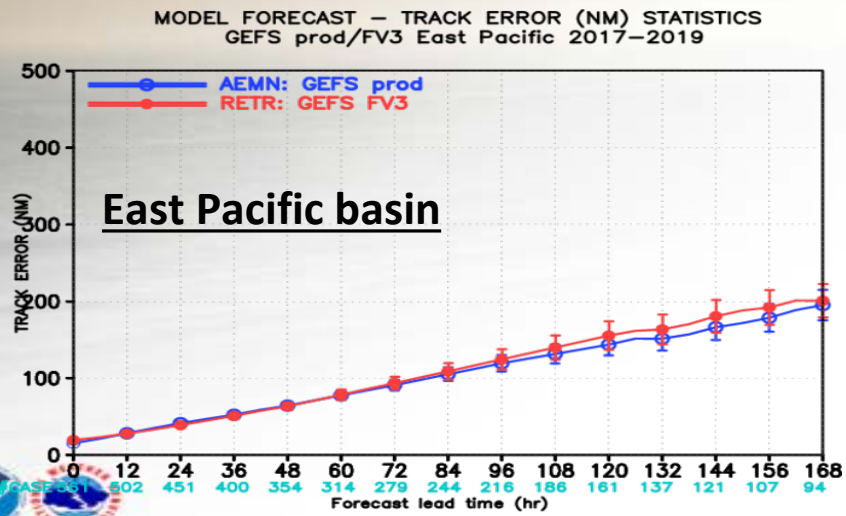


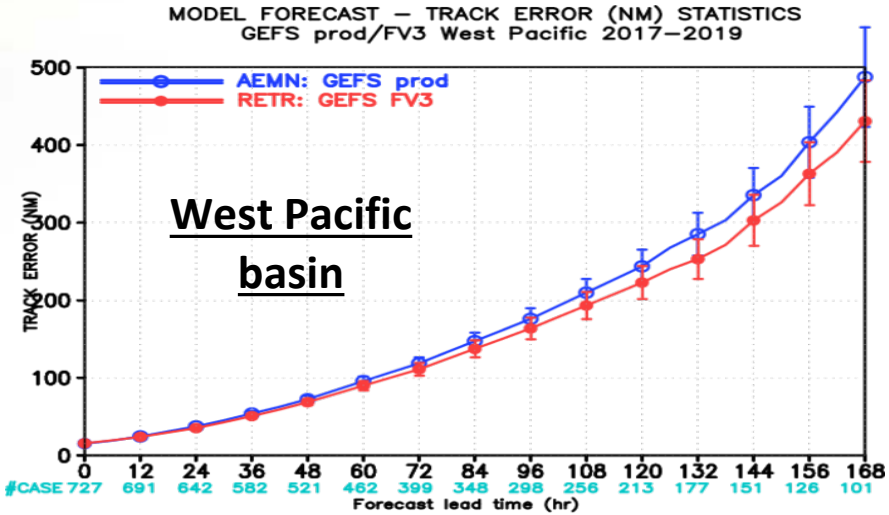
TC track verification

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



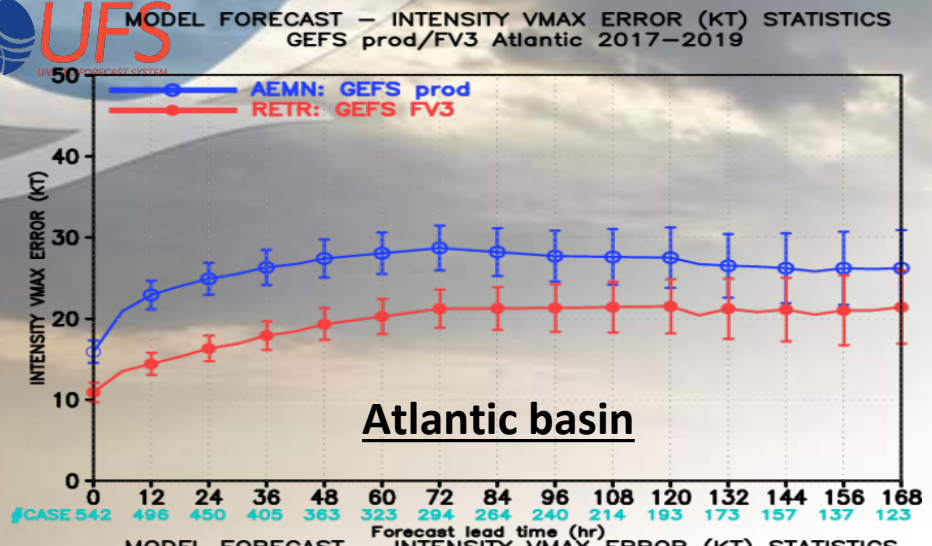


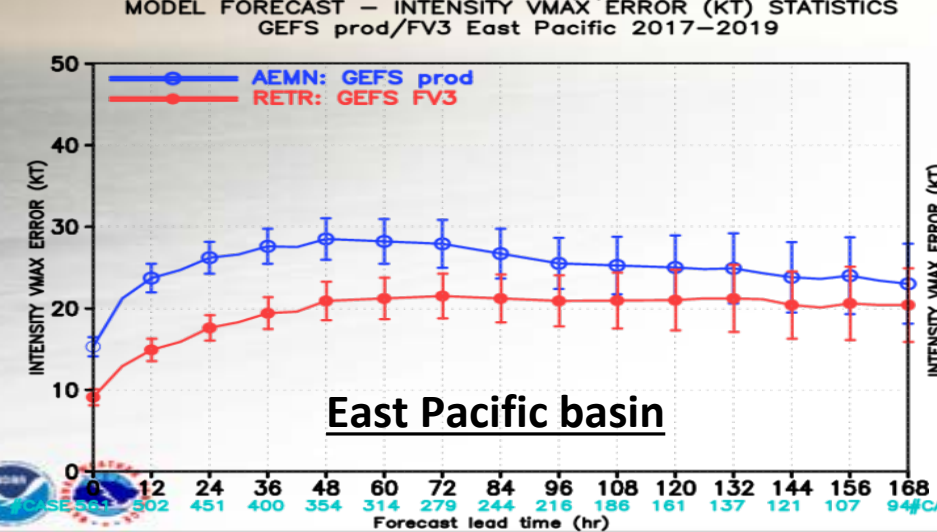
TC intensity verification

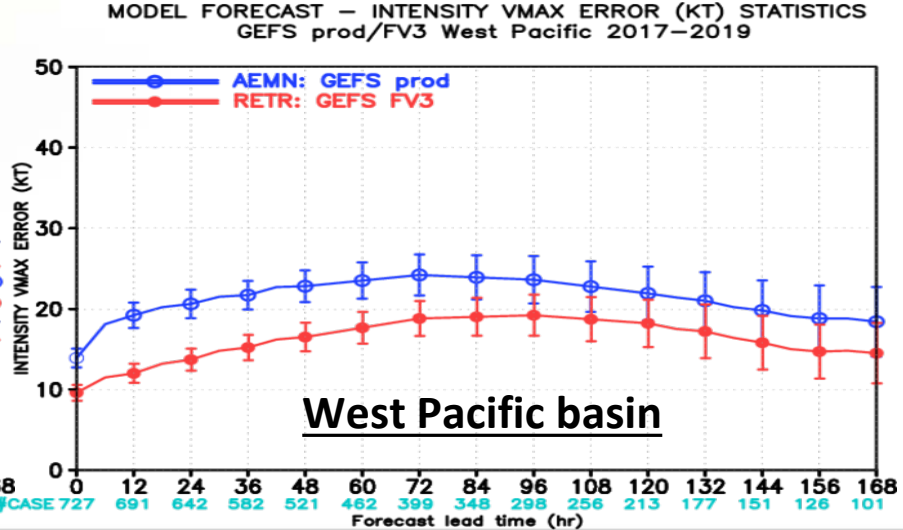
2017: 00Z 06/01----11/30; 12Z 07/01----10/31

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

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

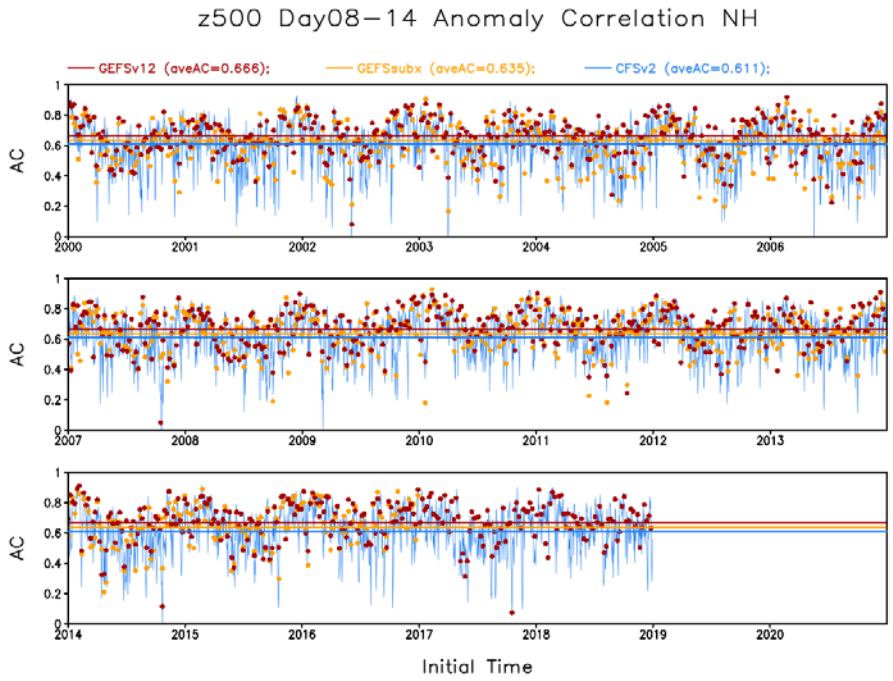




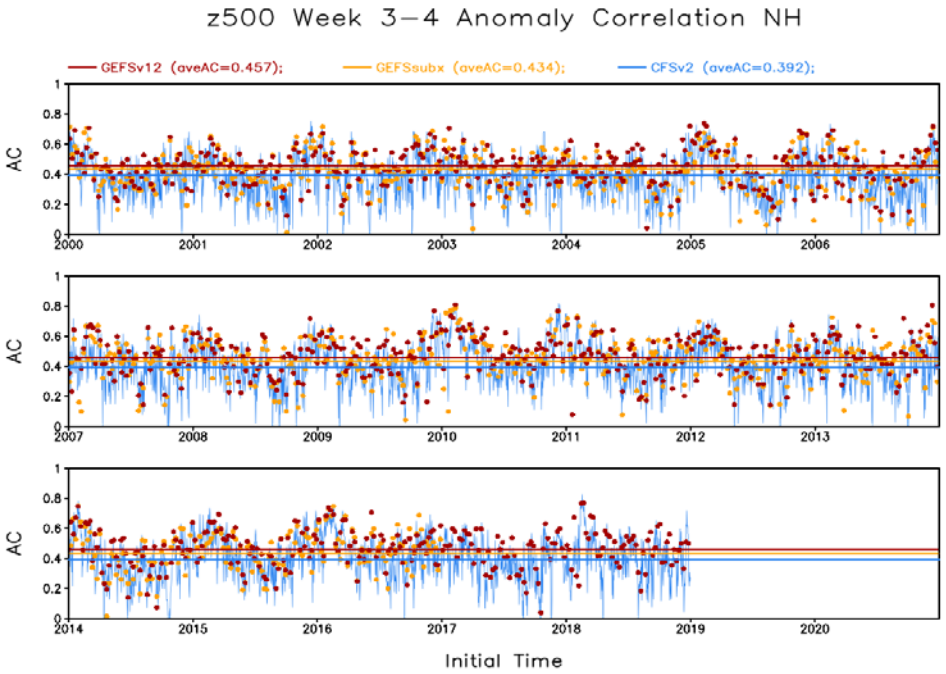


NH z500 ACC

Week 2



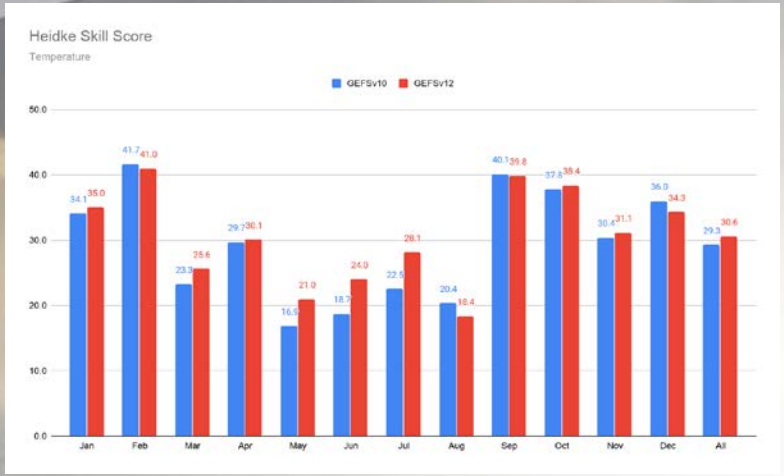
Week 3-4

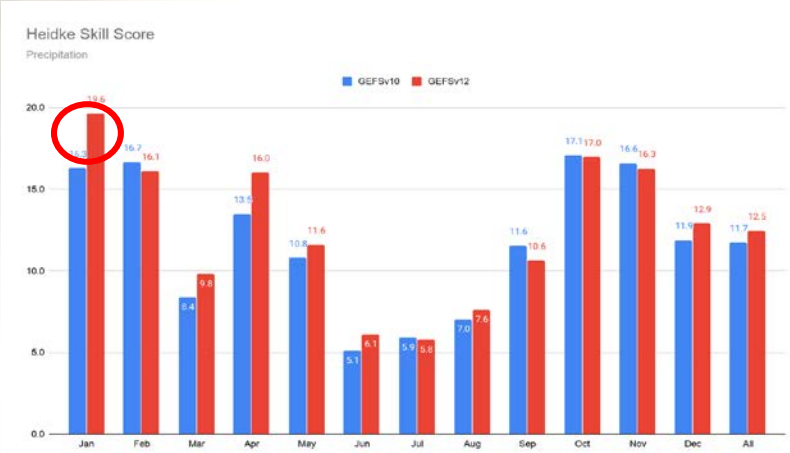


GEFSv12	**0.666**
GEFSSubX	0.635
CFSv2	0.611

GEFSv12	**0.457**
GEFSSubX	0.434
CFSv2	0.392

Week 2 Temperature/Precipitation: Average Heidke Skill Score



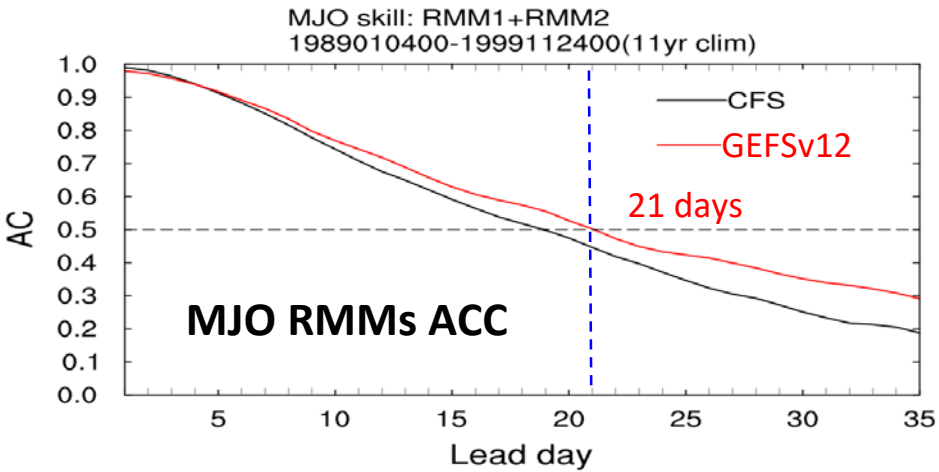


- GEFSv12 HSS is higher in 8 out of 12 months – especially in May, June, and July
- Overall GEFSv12 skill higher than GEFSv10 (95% sig.)

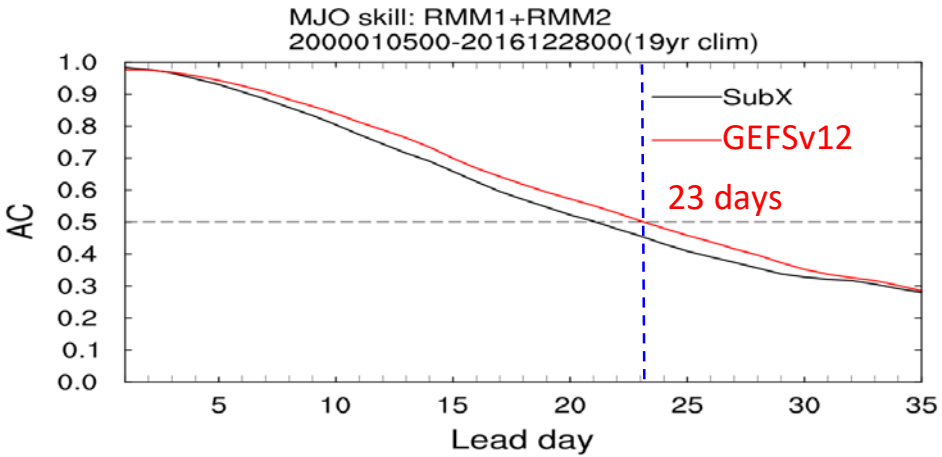
- GEFSv12 HSS is during 8 out of 12 months
- Overall GEFSv12 skill higher than GEFSv10, but only 87% statistically significant

MJO skill comparison

GEFSv12 vs. CFSv2
(1989-1999)



GEFSv12 vs. SubX
(2000-2016)



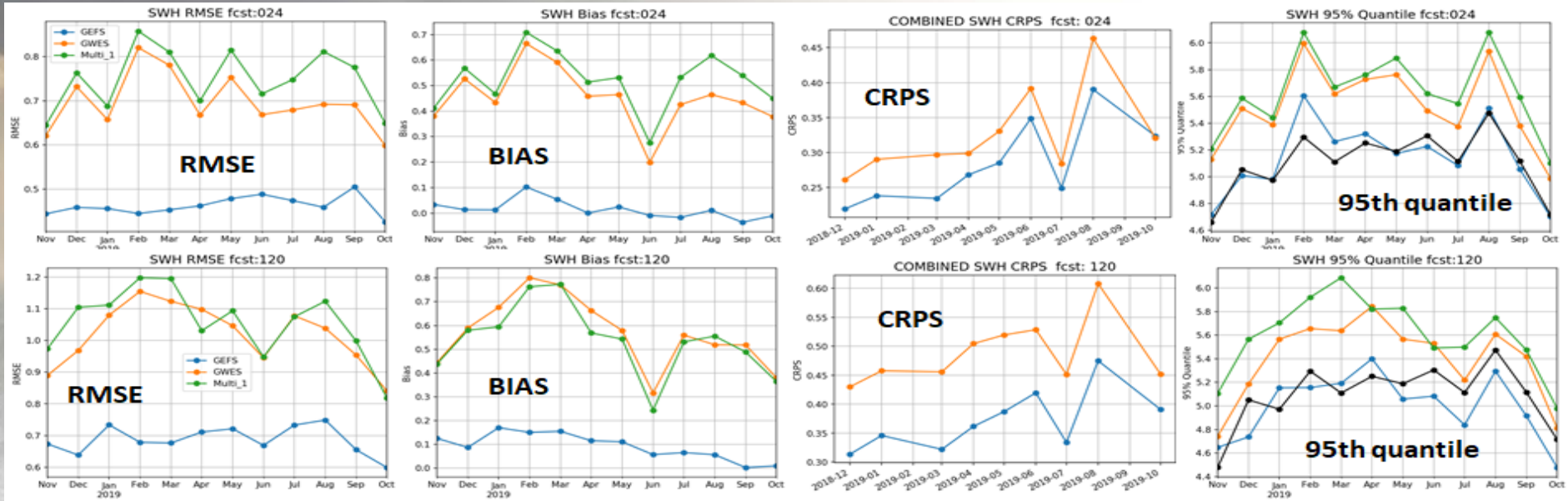
- *Both MJO skills are lower, but GEFSv12 is better than CFSv2 about 2 days*
- *The same for MJO components skill, GEFSv12 is better than CFSv2*

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

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

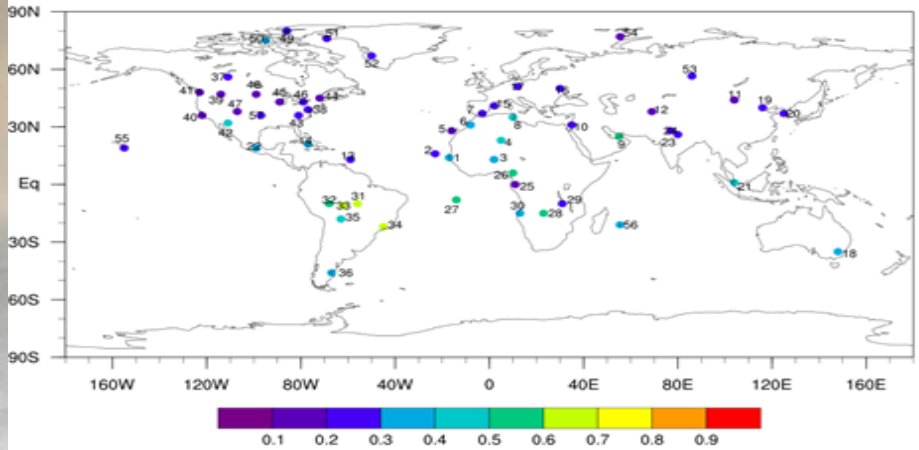
Courtesy: Henrique Alves & Deanna Spindler

Statistical Evaluation of GEFSv12-Aerosols

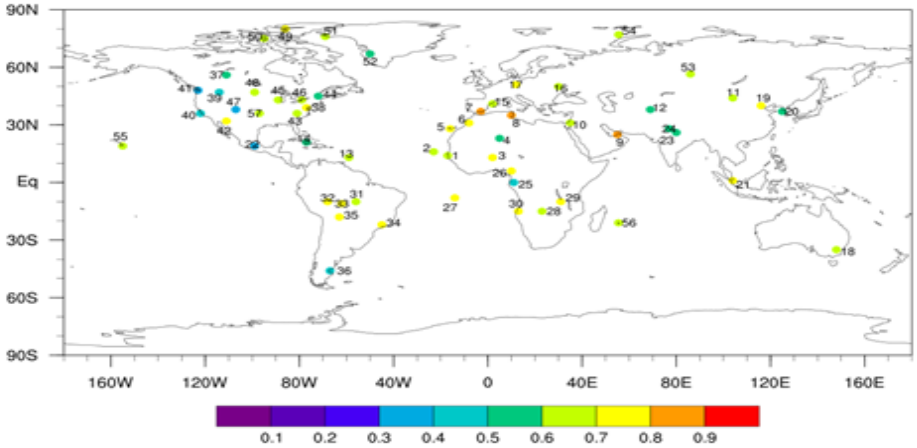
based on 9-month retrospective forecasts (July 2019 – March 2020)

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

Courtesy: Jeff McQueen, Partha Bhattacharjee & Ivanka Stajner

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

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

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

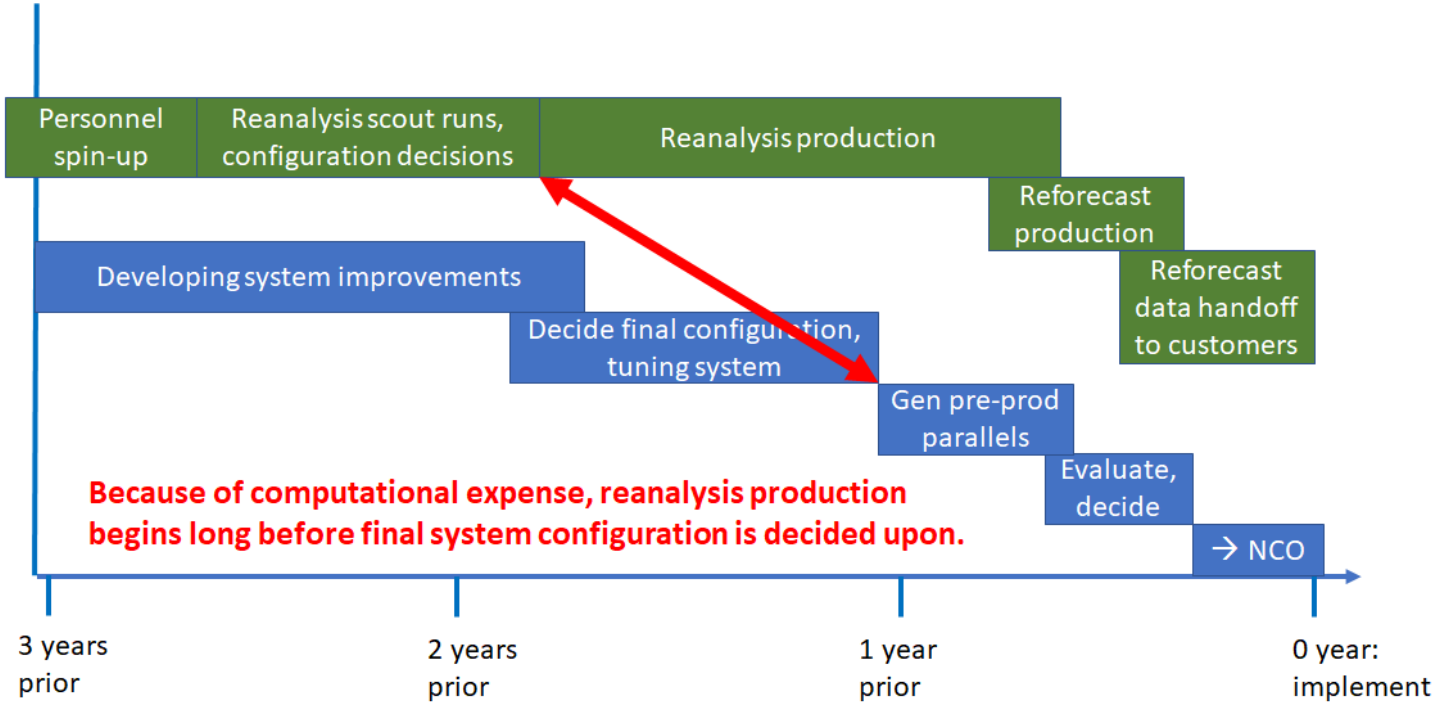
Summary of GEFSv12 Evaluation: Concerns

- **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?)

We expect to do reanalyses again to remain consistent with major system changes.

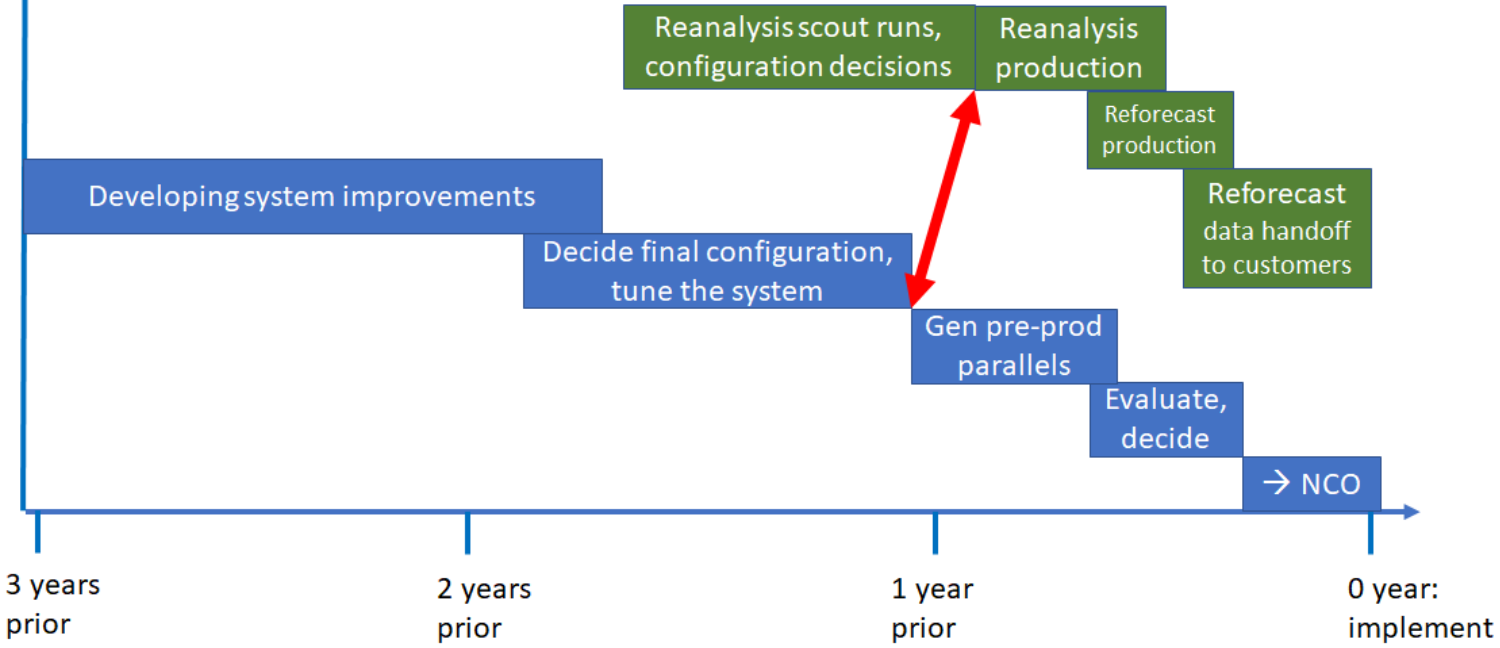
- *Statistical characteristics of the (re-)analyses are likely to change significantly with increased coupling*.
- GEFSv12 is **uncoupled**.
  - Forecast: Ocean-state anomalies from climatology transplanted from CFSR.
  - Atmosphere analyses: Hybrid 4D-En-Var; control SST background via NSST (diurnal variability)
  - Ocean analysis: NSST, GODAS.
- GEFSv13 likely to be **weakly coupled.**
  - Forecast: coupled GFS / MOM6.
  - Atmosphere to use ocean forecast background(s) in its DA.
  - Ocean to use atmospheric forecast background(s) in its DA.
- GEFSv14 likely to be **strongly coupled**.
  - Forecast: coupled GFS / MOM6.
  - Coupled DA utilizing cross covariances between state components; ocean obs make increments to atmosphere, atmospheric observations make increments to ocean.

A challenge with GEFSv12 reanalysis: the sequencing of reanalysis production with the operational upgrade schedule.



Surging reanalysis/reforecast in the cloud.

- Potentially leveraging a cloud surge, we can wait to produce reanalyses till after next-gen configuration is more settled.



Future Plans

- Continue developing fully coupled (Atmosphere-Land-Ocean-Sea Ice-Wave-Aerosol) UFS with coupled DA
- Coupled Reanalysis and Reforecast Project to support sub-seasonal and seasonal forecasts
- UFS R2O Proposal to support the development of GFSv17 and GEFSv13 as a true community effort
- Merge GFSv17 and GEFSv13 as a single UFS Medium Range and Sub-Seasonal Application
- Focus on addressing concerns from GFSv15/16 and GEFSv12 while retaining/enhancing the positive improvements

NPS Modeling System	Current Version	Q1 FY 20	Q2 FY 20	Q3 FY 20	Q4 FY 20	Q1 FY 21	Q2 FY 21	Q3FY 21 - Q2FY22 MORATORIUM	Q3 FY 22	Q4 FY 22	Q1 FY 23	Q2 FY 23	Q3 FY 23	Q4 FY 23	Q1 FY 24	Q2 FY 24	Q3 FY 24	Q4 FY 24	UFS Application
Global Weather & Global Analysis	GFS/ GDASv15						GFSv16									GFSv17/ GEFSv13			UFS Medium Range & Sub-Seasonal
Global Waves	GWMv3																		
Global Weather Ensembles	GEFSv11				GEFSv12														
Global Wave Ensembles	GWESv3																		
Global Aerosols	NGAC v2																		
Short-Range Regional Ensembles	SREFv7																		
Global Ocean & Sea-Ice	RTOFSv1.2					RTOFSv2					RTOFSv3								UFS Marine & Cryosphere
Global Ocean Analysis	GODASv2										GODASv3								
Seasonal Climate	CDAS/ CFSv2																	SFSv1	UFS Seasonal

Thanks for your attention.

Questions?