NATIONAL WEATHER SERVICE

The UFS coupled ensemble prototype experiments

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Outline

- Introduction of coupled GEFS (Global Ensemble Forecast System)
- Results from 3 coupled GEFS prototypes (EP1,EP2,EP3)
    - Verification scores
    - MJO prediction
    - 2m temperature bias, tropical precipitation
- Summary

UFS coupled model prototypes

UFS prototypes	Model components	Initial conditions				Highlights of updates
		ATM	OCN	ICE	WAV	
P1	C384L64-MOM6-CICE5 NEMS mediator	CFSR	CFSR	CPC ice analysis	N/A	First prototype
P2	C384L64-MOM6-CICE5 NEMS mediator	CFSR	**CPC-3Dvar**	CPC ice analysis	N/A	New ocn ICs
P3	C384L64-MOM6-CICE5 NEMS mediator	CFSR	CPC-3Dvar	CPC ice analysis	N/A	
P4	C384L64-MOM6-CICE5-WW3 NEMS mediator	CFSR	CPC-3Dvar	CPC ice analysis	**CFS forcings**	CCPP, wave feedback to ocn
P5 **EP1 base**	C384L64-MOM6-**CICE6**-WW3 CMEPS mediator	CFSR	CPC-3Dvar	CPC ice analysis	CFS forcings	GFSv15 physics, wav-atm coupling fix, CICE6
P6	C384**L127**-MOM6-CICE6-WW3 CMEPS mediator	CFSR	CPC-3Dvar	CPC ice analysis	CFS forcings	Fractional Grid, L127, sa-tke-EDMF
P7 **EP2 base**	C384L127-MOM6-CICE6-WW3 CMEPS mediator	**GEFS-RR**	CPC-3Dvar	CPC ice analysis	**CEFS forcings**	NOAH-MP, NSST, updated physics
P8 **EP3 base**	C384L127-MOM6-CICE6-WW3- **GOCART** CMEPS mediator	GEFS-RR	CPC-3Dvar	CPC ice analysis	GEFS forcings	Thompson MP, updated physics …

Coupled GEFS and experiments

- **Coupled GEFS is UFS-based fully-coupled global ensemble forecast system**
- Experiment design:
  - Period: Oct. 2017 - Sept. 2019
  - 11 members, out to 35 days
  - Every Wednesday at 00UTC of initial forecast
- GEFSv12 Reforecast - benchmark or reference
  - C384L64 **uncoupled** - GFSv15/GEFSv12 configurations
  - Initial analysis and perturbations
    - GEFSv12 reanalysis (and 3D-IAU replay)
  - Stochastics
    - SKEB (0.6); SPPT-5 scales (0.8,0.4,0.2,0.08,0.04)
- Ensemble Prototypes (EP) experiments (configurations will be showed next)
  - EP1 (p5) - completed by September 2021
  - EP2 (p7) - completed by March 2022
  - EP3 (p8) - completed by September 2022
  - EP4 (p8 +aerosol) - in plan - Q2FY23
- Challenges -
  - Initial conditions of ocean - no cycling, at rest, no ocean currents; No initial perturbations for ocean and land

Initial Conditions (Analysis and Perturbations)

	EP1 (p5) (C384L64, OCN_L75) (model top at 0.2 hPa)	EP2 (p7) (C384L97,OCN_41) (model top at 0.01hPa)	EP3 (p8) (C384L97,OCN_41) (model top at 0.01hPa)
ATM	GFSv15 Retrospective Anl and EnKF (f06)	GFSv15 Retrospective Anl and EnKF (f06) sfc spinup (NOAH-MP)	GFSv15 Retrospective Anl and EnKF (f06) (new oro) sfc spinup (NOAH-MP) updated
OCN	CFSR Salinity and T	CFSR Salinity and T	ORAS5 anl + pert
ICE	CPC ice analysis	CPC ice analysis	CPC ice analysis
WAV	CFSv2 wind/ice forcing	GFSv15 wind/ice forcing	GFSv15 wind/ice forcing

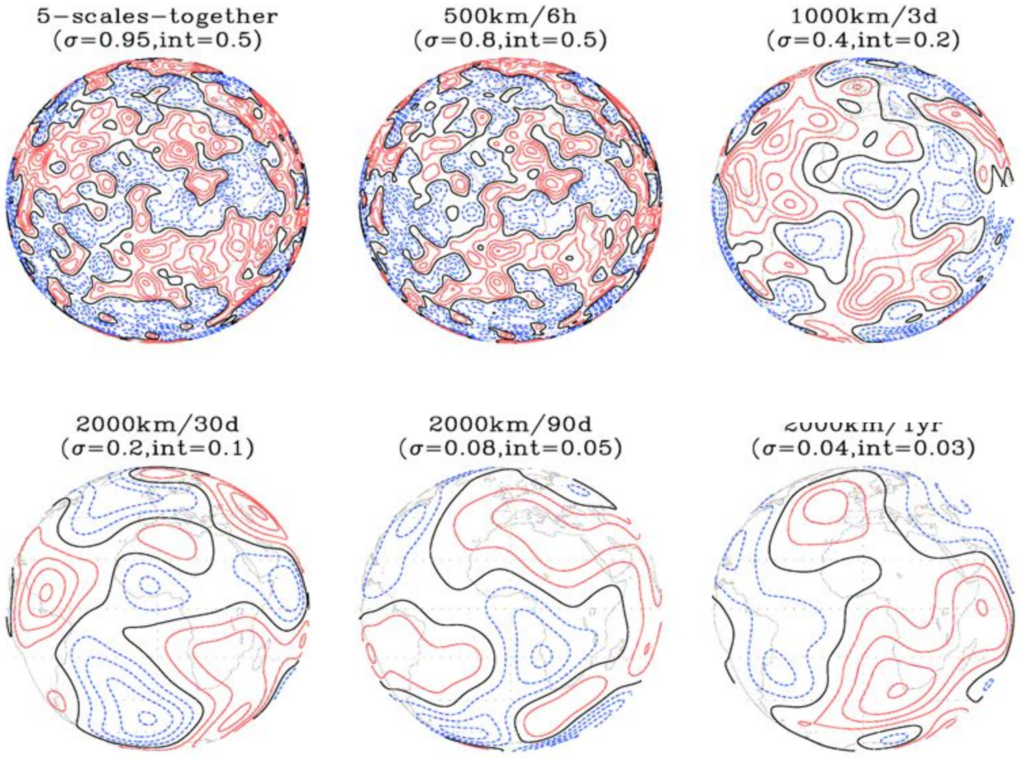
Model Physics and Stochastics

	EP1 (p5) (C384L64, OCN_L75) (model top at 0.2hPa)	EP2 (p7) (C384L97,OCN_41) (model top at 0.01hPa)	EP3 (p8) (C384L97,OCN_41) (model top at 0.01hPa)
phy	Hybrid-EDMF Sa-SAS GFDL-MP GWD (stationary oro) NOAH-LSM …	Sa-TKE-EDMF Sa-SAS (updated) GFDL-MP GWD (stationary oro) NOAH-MP NSST …	Sa-TKE-EDMF (updated) Sa-SAS (updated) Thompson-MP uGWDv0+GSL NOAH-MP (updated) NSST …
stoch	SPPT (0.56,0.28,0.14,0.056,0.028) SKEB (0.7)	SPPT (0.56,0.28,0.14,0.056,0.028) SKEB (0.7) CA pert_mp, radtend ocnSPPT(0.8,0.4,0.2,0.08,0.04) ePBL (0.8,0.4,0.2,0.08,0.04)	SPPT (0.6,0.3,0.15,0.06,0.03) SKEB (0.8) CA pert_mp, radtend ocnSPPT(0.8,0.4,0.2,0.08,0.04) ePBL (0.8,0.4,0.2,0.08,0.04)

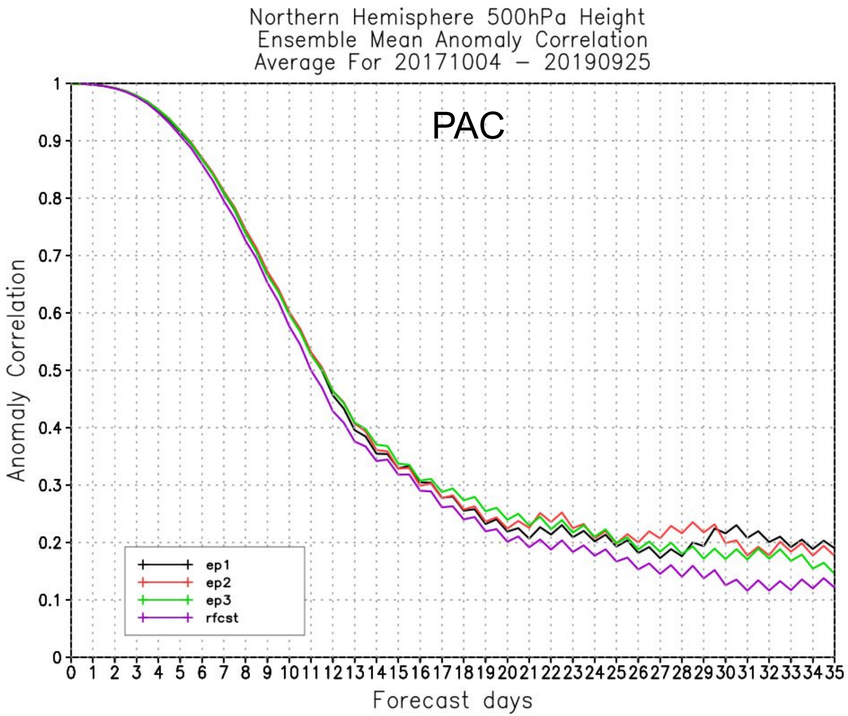
Stochastic schemes used in EP1, EP2, EP3

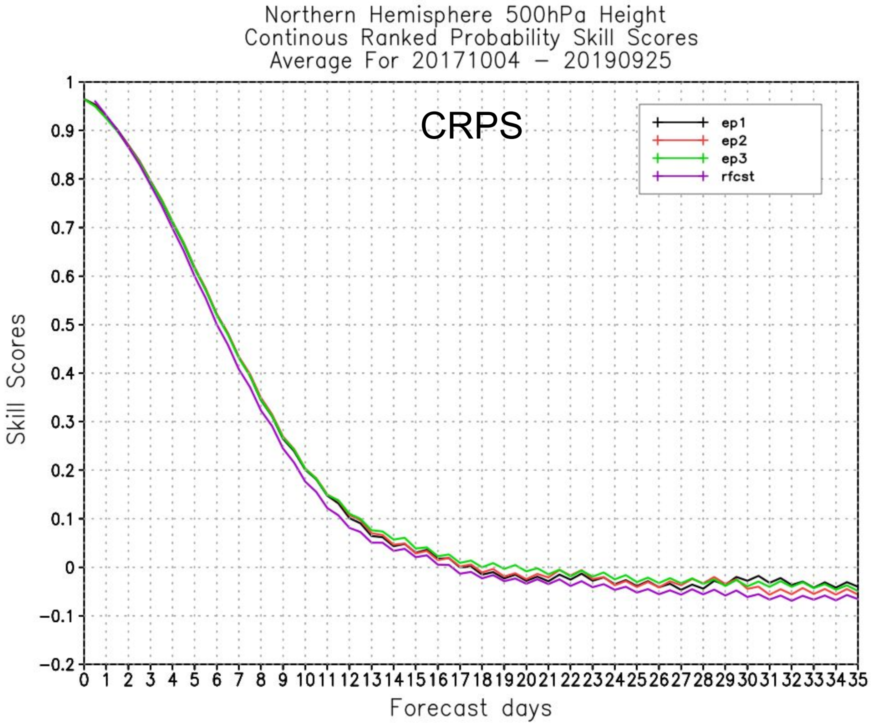
- **SKEB**: Estimate energy lost each time step and inject this energy in the resolved scales. a.k.a stochastic energy backscatter (SKEB; Berner et al. 2009)
- **SPPT**: perturb the results from the physical parameterizations (or tendency) (Palmer et al. 2009)
- CA: Cellular Automata - A Stochastic Parameterization of Organized Tropical Convection (Bengtsson et al. 2021).
- Perturb MP species
- Perturb Radiation tendency
- oSPPT: Perturb the ocean temperature, Salinity and thickness of ocean layer
- ePBL: Perturb the KE generation and dissipation of ocean PBL

Examples of stochastic patterns for SPPT



Performance of 500hPa geopotential height (NH: PAC/CRPS)

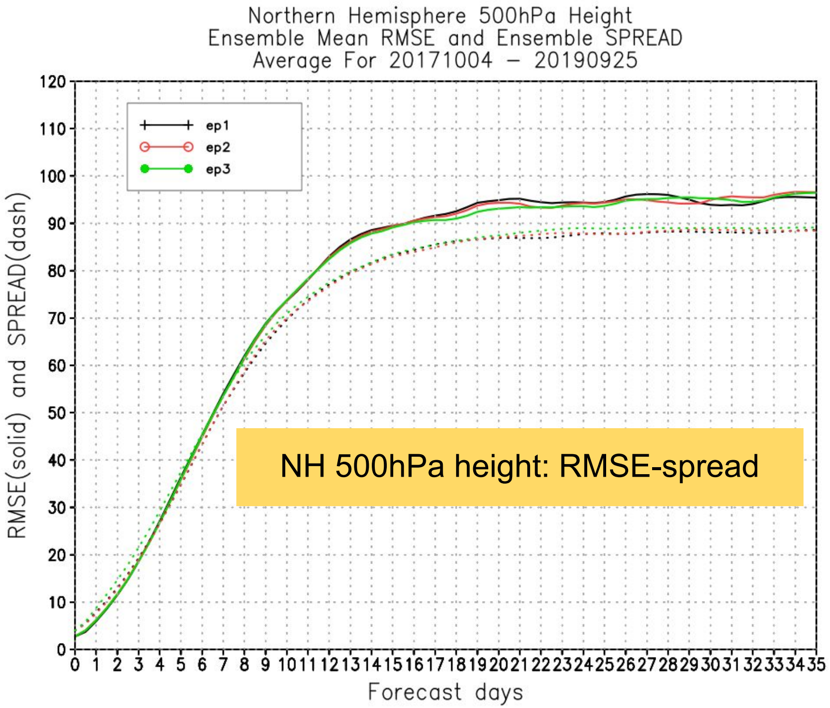


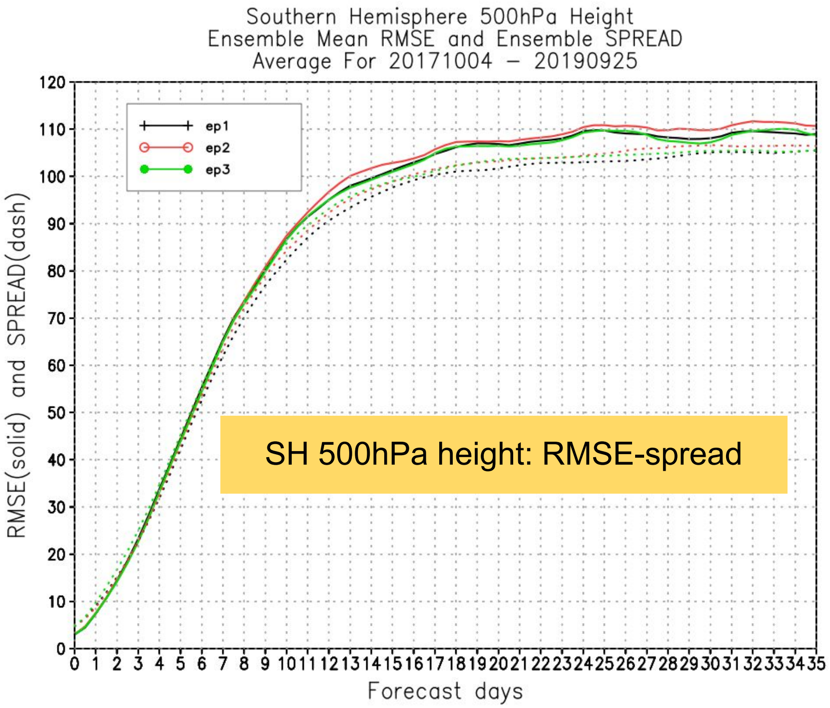


Discussion:

- EP1, EP2, EP3 overall is better than GEFSv12

Performance of 500hPa geopotential height (NH: RMS error/spread)

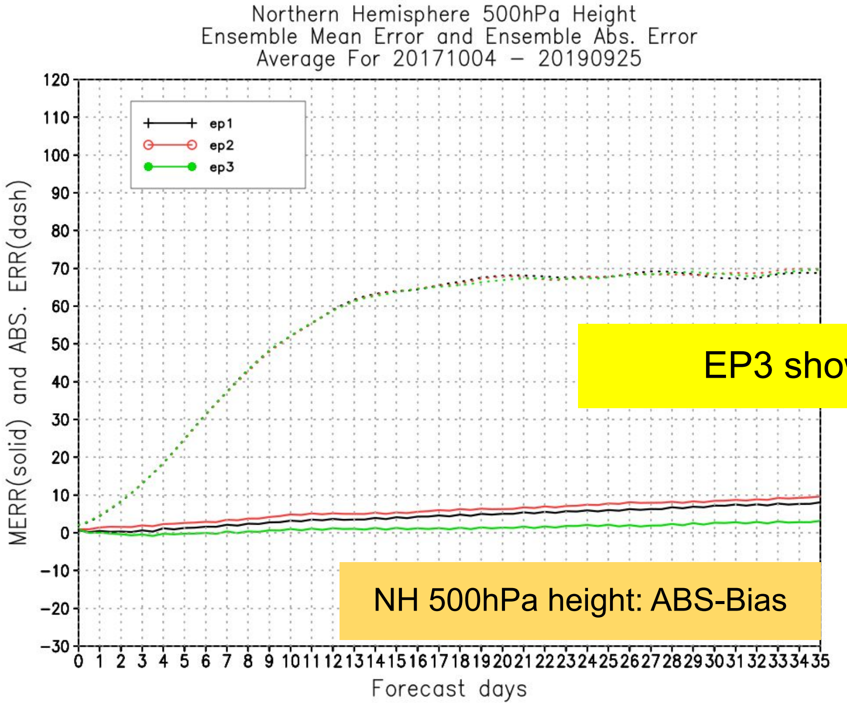


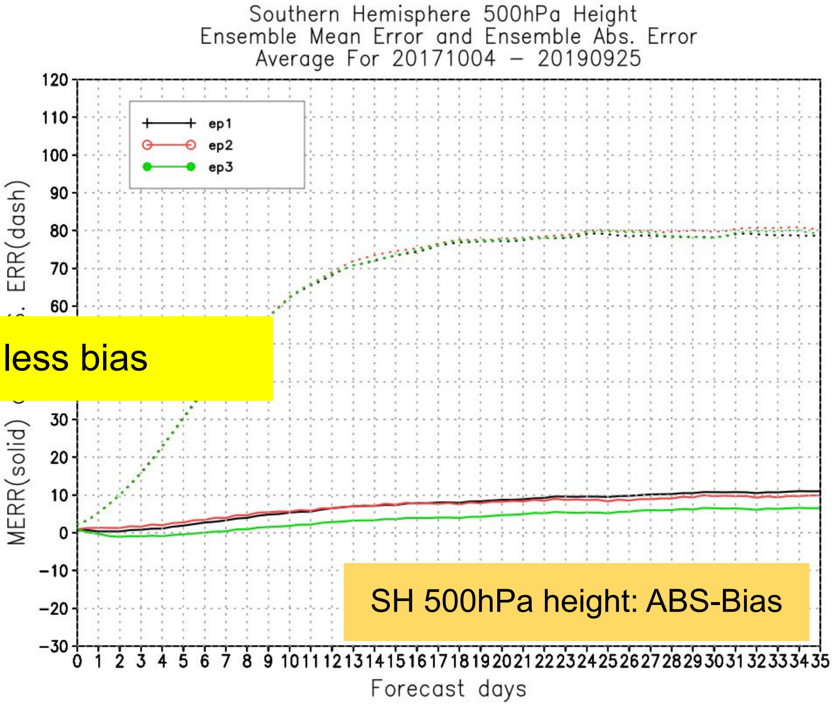


Discussion:

- There is less difference of RMS error and spread.
- In SH, EP2 shows larger RMSE after day-10. EP2 and EP3 show slightly larger spread.
- Overall, all the spreads (EP1, EP2 and EP3) are comparable.

Skills of 500hPa geopotential height (bias)



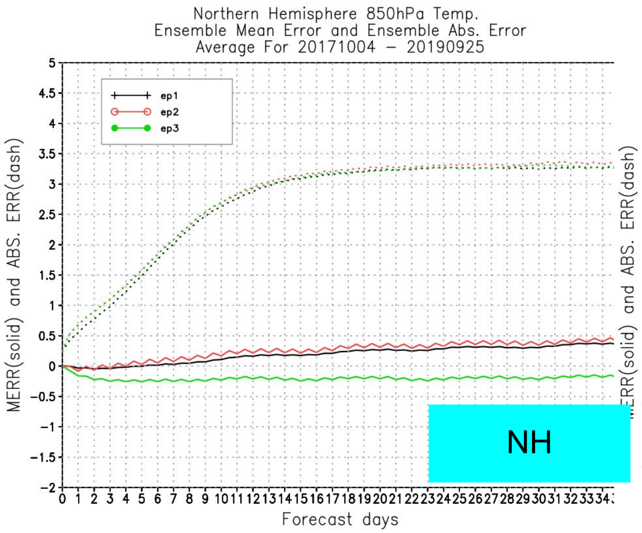


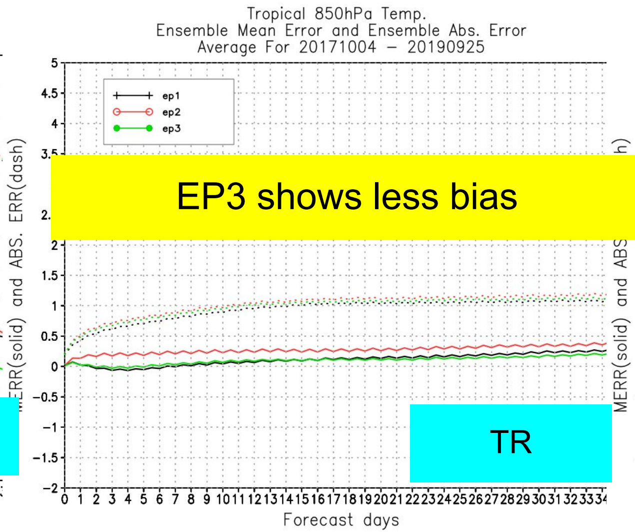
EP3 shows less bias

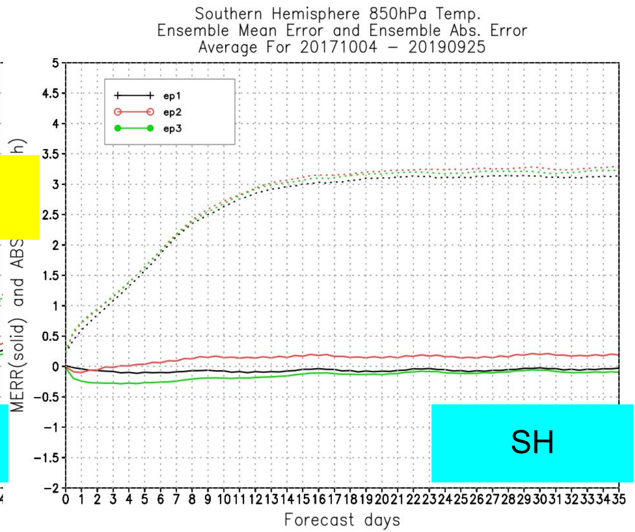
Discussion:

- EP3 has **less bias** for both hemisphere; nearly perfect for NH, much better for SH
- NH (left) 500hPa height - EP2 tends to increase warm bias (possible explanation as following) for NH
  - NSST introduced a small negative bias, but NOAH-MP introduced larger warm bias.
  - Combine these two bias, it could have a net warm bias, see slides

Skills of 850hPa temperature (bias)





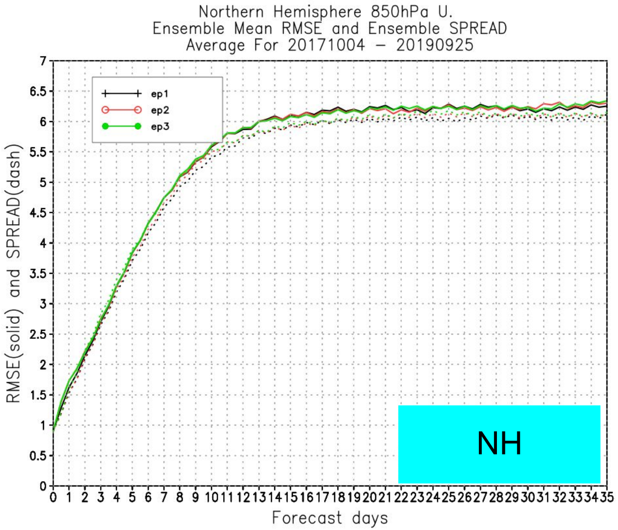


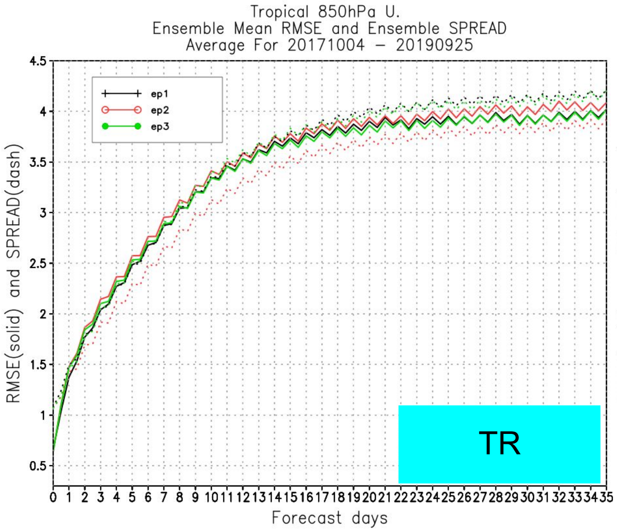
EP3 shows less bias

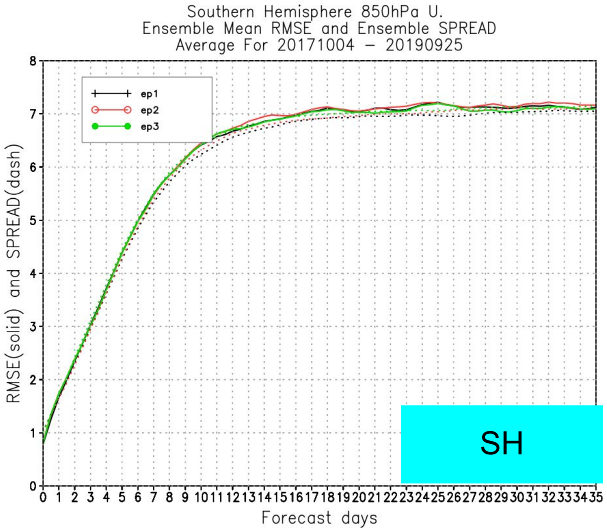
Discussion:

- Overall - EP3 shows **less bias** for all the domains (except for initial adjustment)
- EP2 introduces warm bias for all three domains.

Performance of 850hPa zonal wind (RMS error and spread)



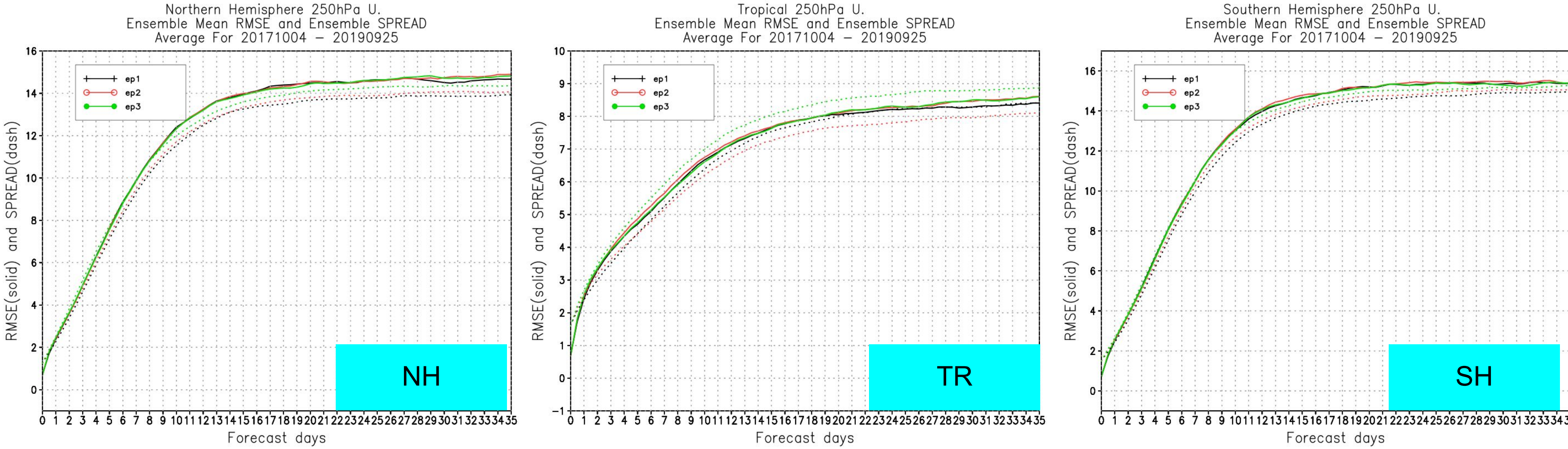




Discussion:

- Spread in the tropics reduced from early lead-time for EP2 (RMS error is slightly larger, but increased for EP3)
  - EP2 includes ocean stochastics (assume an impact is minor);
  - SPPT depends on forecast physical tendency, particular for tropical, without or less convection which is one of the suspects for this significant reduction.
  - P6 and P7 shows significant reduction of tropical precipitation from P5?
  - It shows less convection in GFSv16 due to model upgrade (PBL)
  - Small spread may be good, our RMS error may be overestimated (???)
  - MP scheme is changed for EP3 which may be a big impactor for tropical area

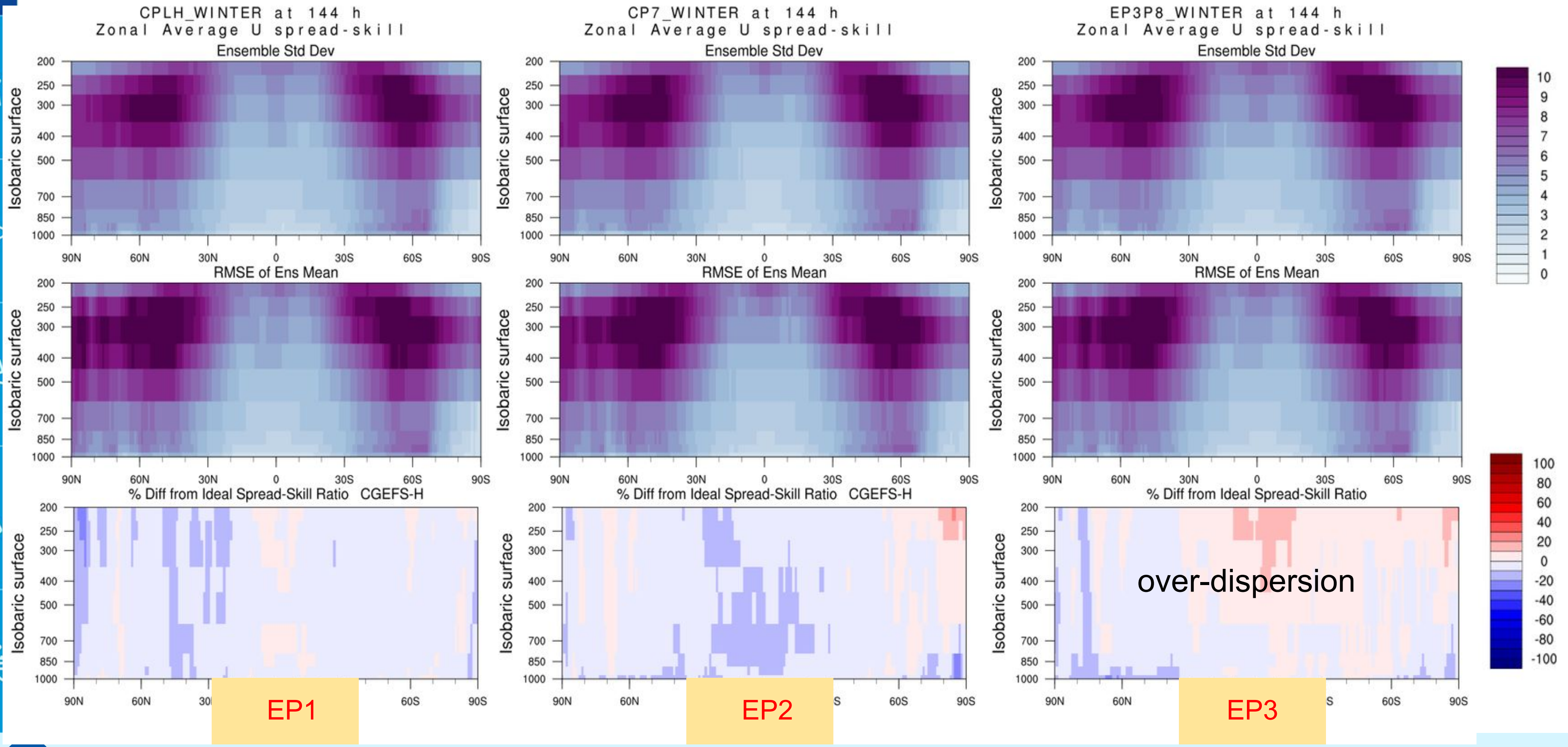
Performance of 250hPa zonal wind (RMS error and spread)



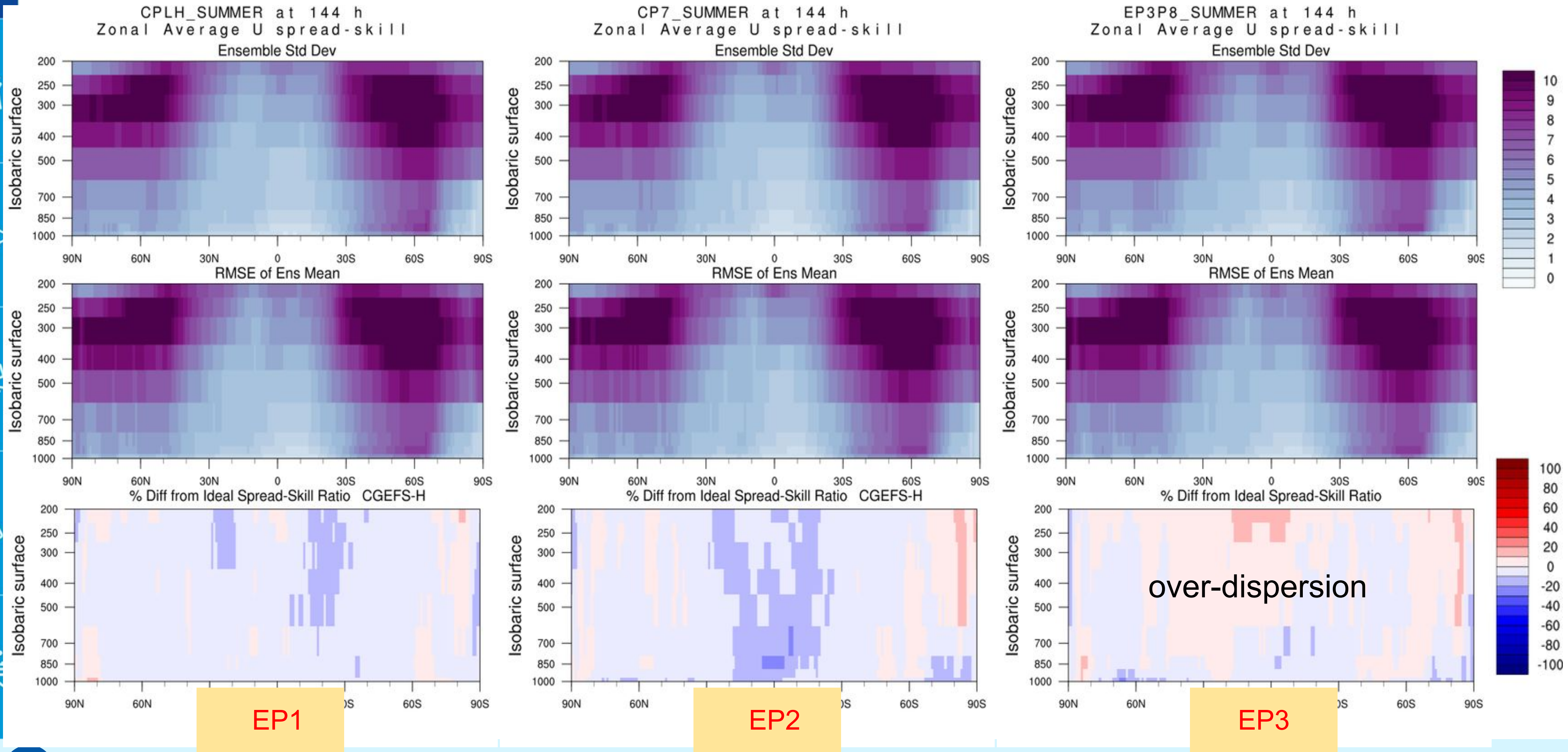
Discussion:

- Spread in the tropics is reduced for EP2, increased for EP3. Can we explain this?
  - EP2 includes ocean stochastics; atmospheric stochastics should be very similar.
  - EP3 increased SKEB (from 0.7 to 0.8) and SPPT (30% reduced to 25% reduced) slightly
- Ex Tropical domain has very comparable spread (Mainly SKEB’s contribution)
- Does this indicate the convection may be the difference for tropical domain?
  - Both EP2 and EP3 adjust PBL scheme, EP3 use Thompson MS replacing GFDL MP (big change?)

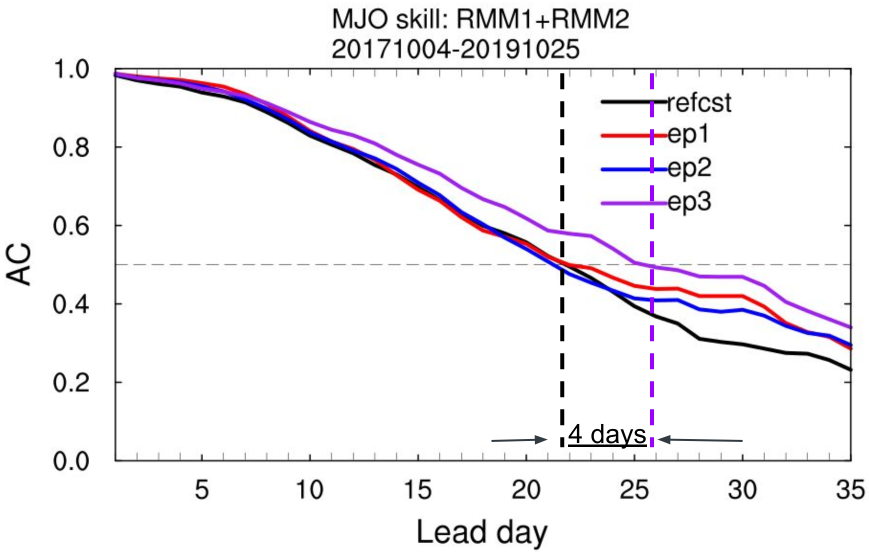
Vertical cross section of the RMS error - spread ratio for zonal winds Winter 6 months (144 hours)

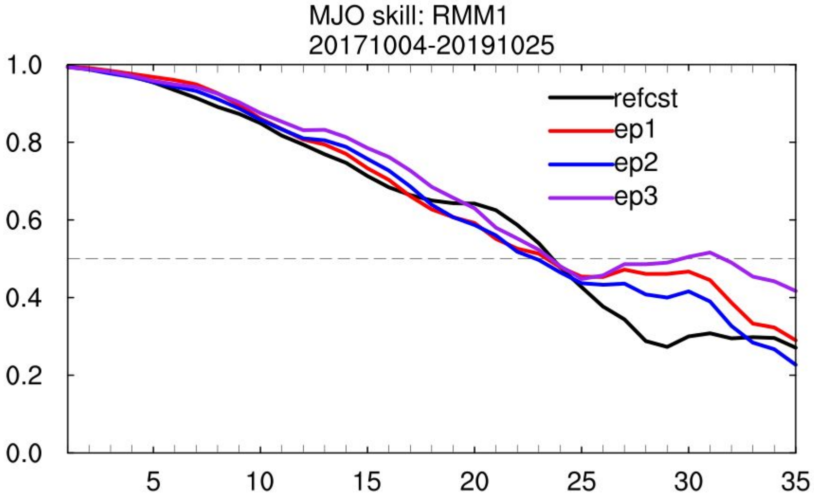


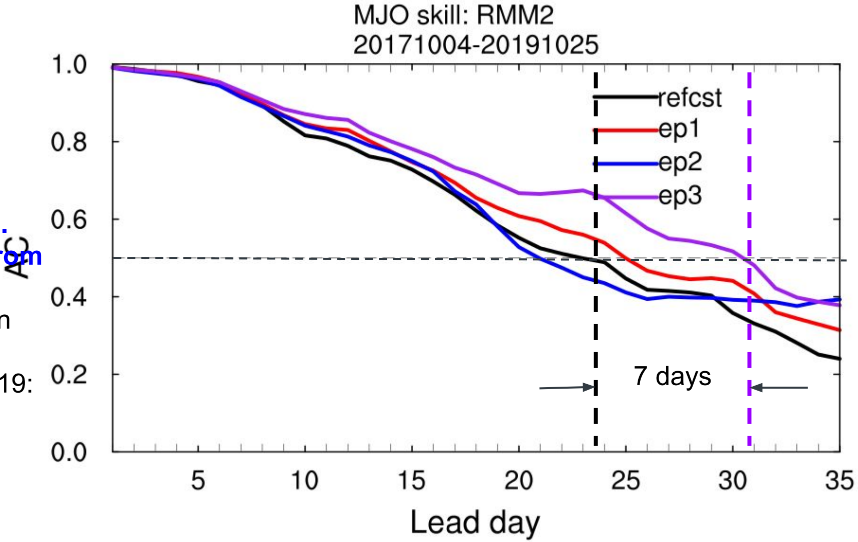
Vertical cross section of the RMS error - spread ratio for zonal winds
Summer 6 months (144 hours)



MJO skills of the RMMs (comparison)



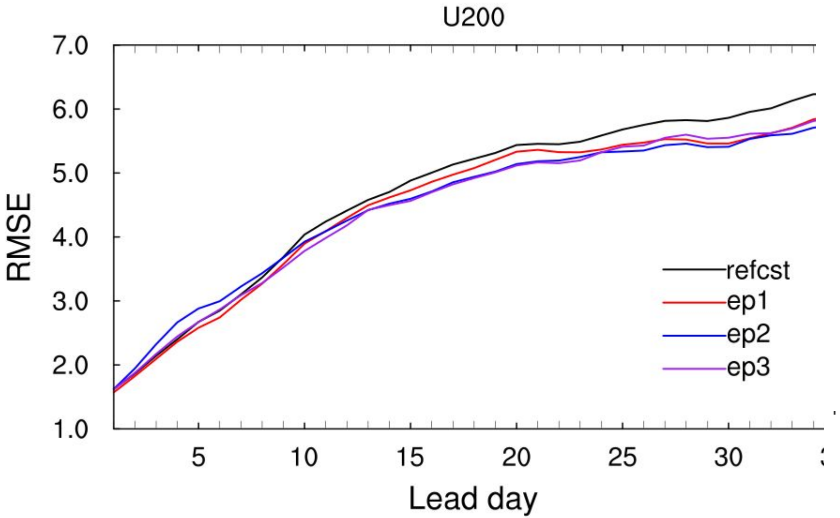


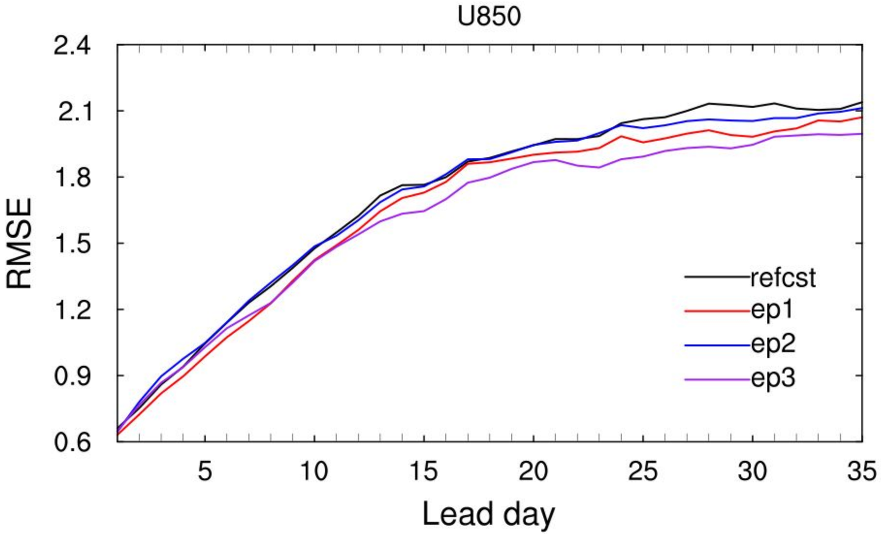


Discussion:

- Both model and analysis climatology - NCEP/NCAR reanalysis
- **Overall - EP3 MJO skills are better than reforecast, EP1 and EP2. The total skill (RMM1+RMM2) reaches 26 days which is mainly from RMM2 (30+ days).**
- Please note that the MJO skill for "reforecast" (or GEFS SubX version was excellent when compared to other national/international models which participated SubX project (Ref: Pegion, K., and co-authors, 2019: The Subseasonal Experiment (SubX): A multi-model subseasonal prediction experiment, Bull. Amer. Meteor. Soc. 100 2043-2060)

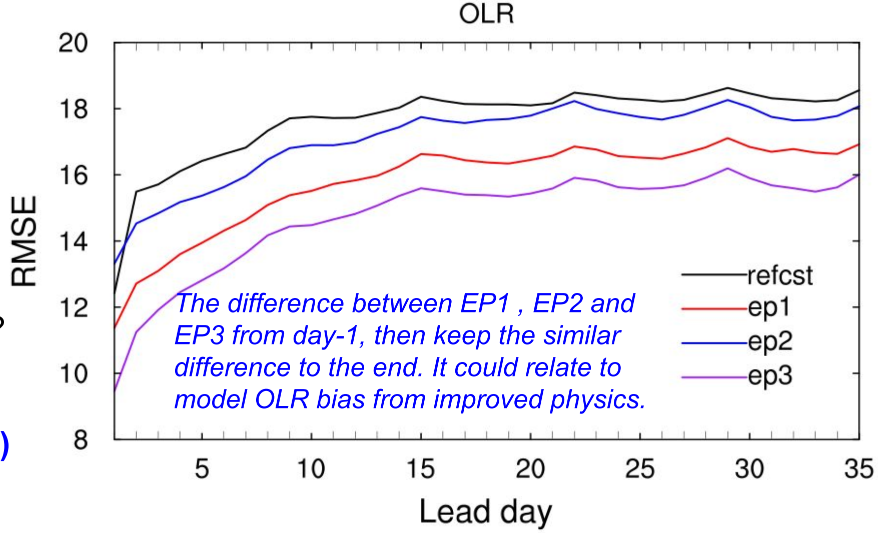
RMSE of MJO related components



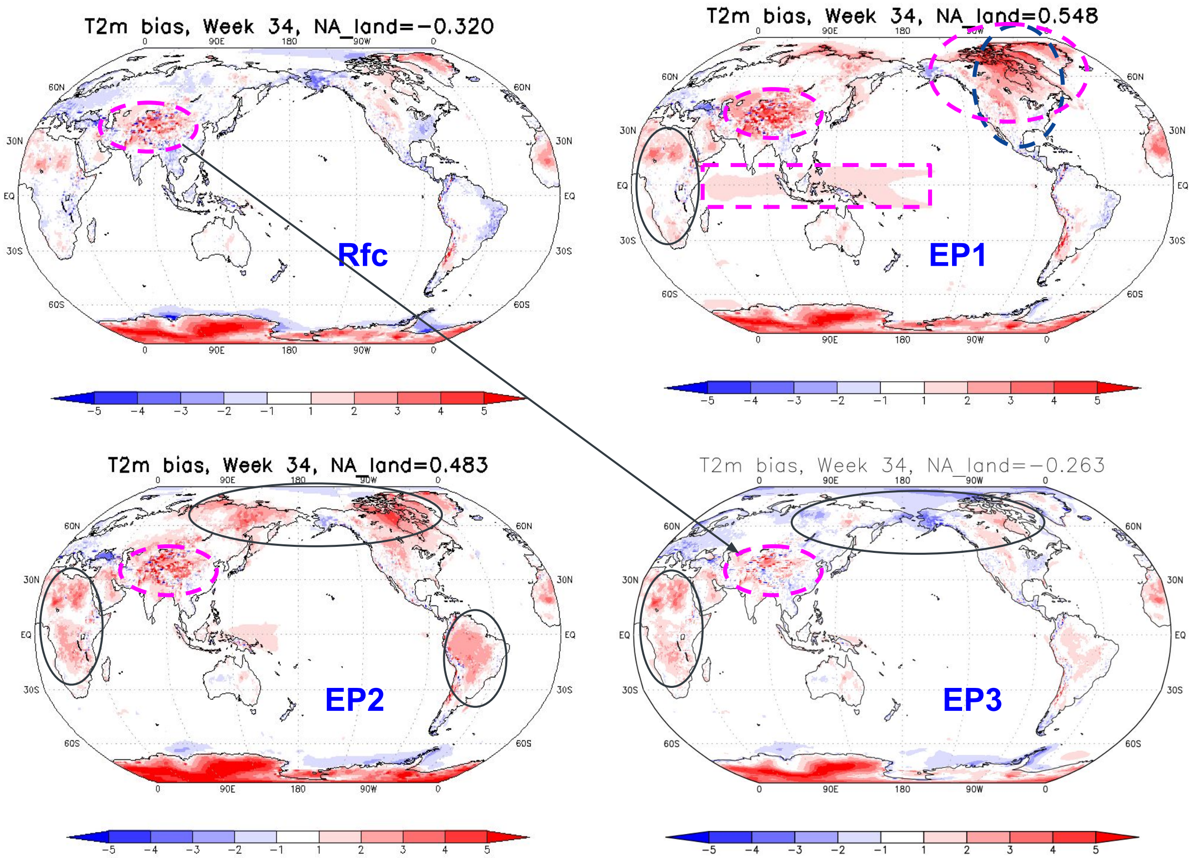


Discussion:

- EP2 is degraded from EP1 for all three components.
  - The degradation of zonal wind -
    - Possible from reduced ensemble spread?
  - The degradation of OLR -
    - Possible due to reduced tropical convection? (Lydia's early evaluation of P5/P6/P7)
- **EP3 has smaller RMS errors for all 3 components; especially OLR (Wei and Lydia show the similar for P8)**

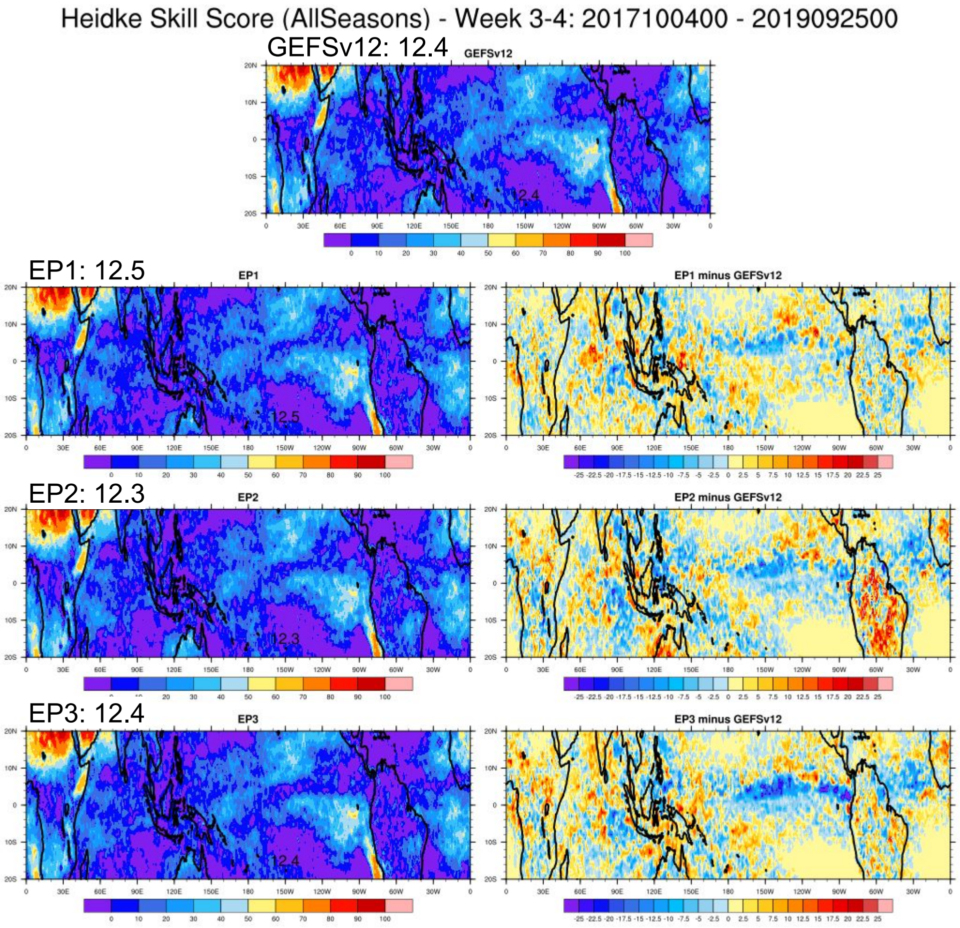


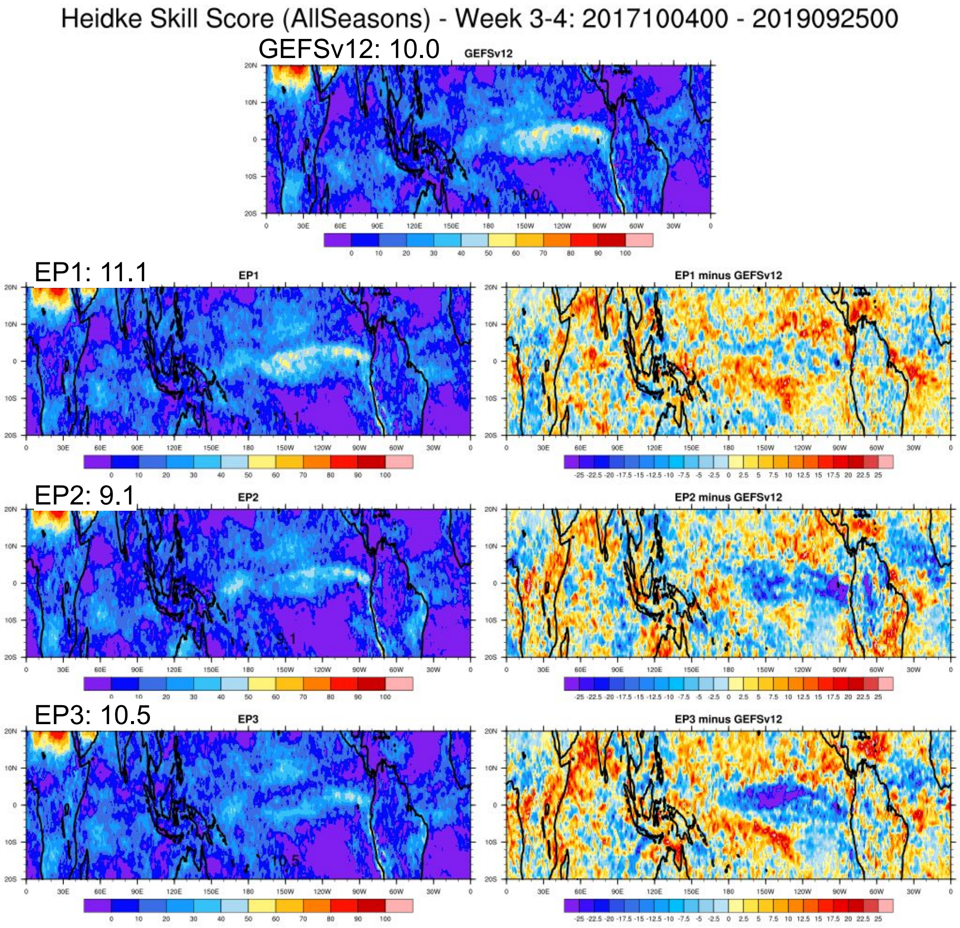
Bias estimation of 2m temperature (Weeks 3&4)



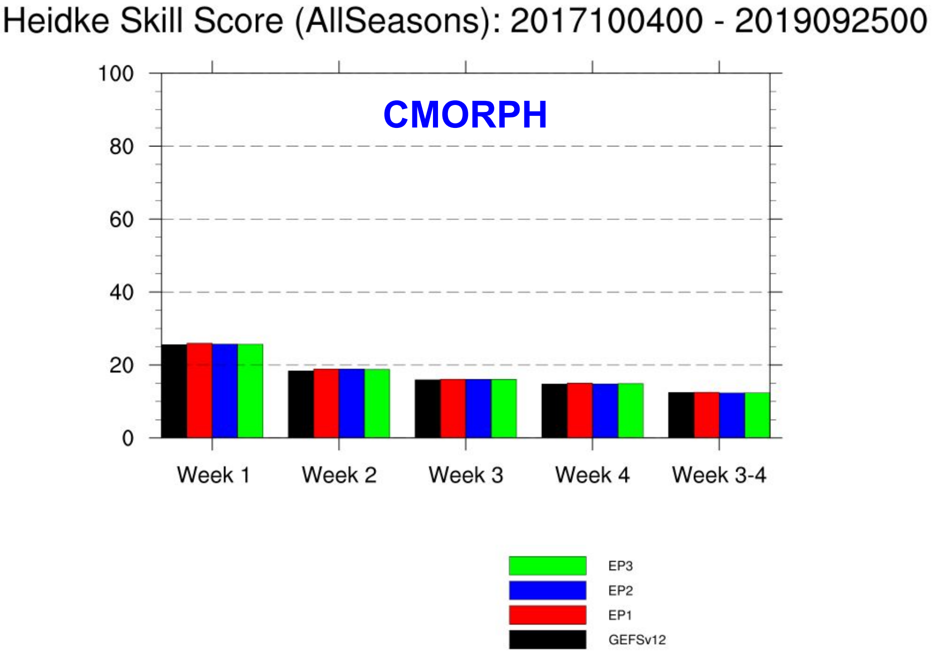
- Reforecast - a warm bias for central Asia.
- Coupling EP1- the warm bias for NA, and around tropical indian ocean and west central Pacific.
- Coupling EP2 - similar to EP1 except the larger warm bias over South America and Southern Africa and less bias over the tropical oceans
- Coupling EP3 - Overall, it is better than EP1 & EP2.
- NA land only, EP3 shows it closed to refcast, less bias than EP1 & EP2.

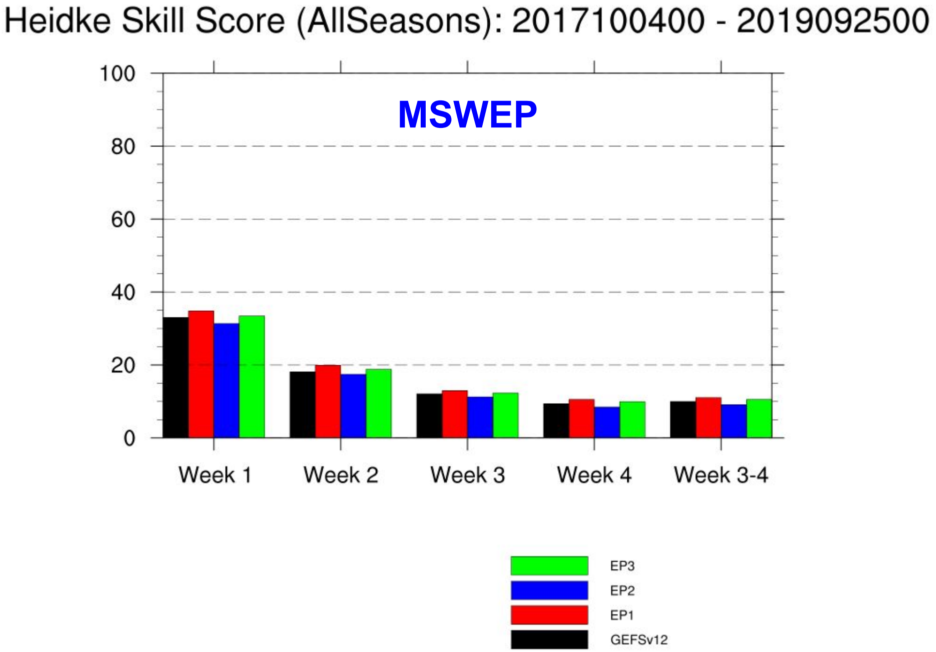
CMORPH Global tropical Precipitation MSWEP





- CMORPH: NOAA CPC Morphing Technique
    - Link: https://www.cpc.ncep.noaa.gov/products/janowiak/cmorph_description.html
- MSWEP: Multi-Source Weighted-Ensemble Precipitation
    - Link: https://gwadi.org/multi-source-weighted-ensemble-precipitation-mswep





- Between two precipitation analyses (CMORPH and MSWEP)
    - All experiments have the closed scores against CMORPH
    - EP1 and EP3 show the higher scores than refcst and EP2 against MSWEP analysis for all lead-time

Summary of Ensemble Prototype Experiments

- In most categories, coupled GEFSs (EP1, EP2 and EP3) are better than uncoupled GEFS (or GEFSv12 reforecast).
- EP1 shows very good results - significantly better than uncoupled GEFS for 500 hPa height for most lead-time, and all domains
- EP2 shows less skills and larger bias compared with EP1 and EP3
- EP3 demonstrates less bias, best MJO skills and improved tropical precipitation