An new development of week 3&4 prediction through extended NCEP GEFS

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Introduction

- Subseasonal forecasts span the time period between **weather and seasonal** (climate) forecasts. Currently, there are no optimal configurations of numerical weather or climate models that can provide skillful forecast covering the subseasonal time scale. With the ultimate goal to improve forecast skill and deliver useful numerical guidance for subseasonal time scales, we explore the potential forecast skill of an extended Global Ensemble Forecasting System (GEFS) covering the subseasonal time scale.

- In contrast to current seasonal forecasting systems, there are several advantages in extending GEFS to cover the subseasonal time scale, including
  1) Improved initial perturbations using an ensemble Kalman filter (EnKF) data assimilation system (Zhou et al, 2017) which represent observation and analysis uncertainties;
  2) Increased horizontal resolution from weather into the subseasonal time scales allowing small scale process to be resolved and more realistic interactions between scales;
  3) Advanced model physics with various stochastic physics perturbation schemes to represent model uncertainties;
  4) Increased ensemble size (i, e, GEFS currently runs 80+4 members for one synoptic day) to provide more reliable probabilistic guidance;
  5) Suitable configuration (ensemble size and frequency) for real time reforecasts/hindcasts for calibration; and
  6) Seamless forecasts across weather and seasonal time scale.

Background

Description of the ensemble forecast system

Each ensemble member evolution is given by integrating the following equation

$$e_j(T) = e_0(0) + de_j(0) + \int_{t=0}^{T} [P_j(e_j,t) + dP_j(e_j,t) + A_j(e_j,t)]dt$$

Initial uncertainty **Model uncertainty**

where $e_j(0)$ is the initial condition, $P_j(e_j,t)$ represents the model tendency component due to parameterized physical processes (model uncertainty), $dP_j(e_j,t)$ represents random model errors (e.g. due to parameterized physical processes or sub-grid scale processes – stochastic perturbation) and $A_j(e_j,t)$ is the remaining tendency component (different physical parameterization or multi-model).

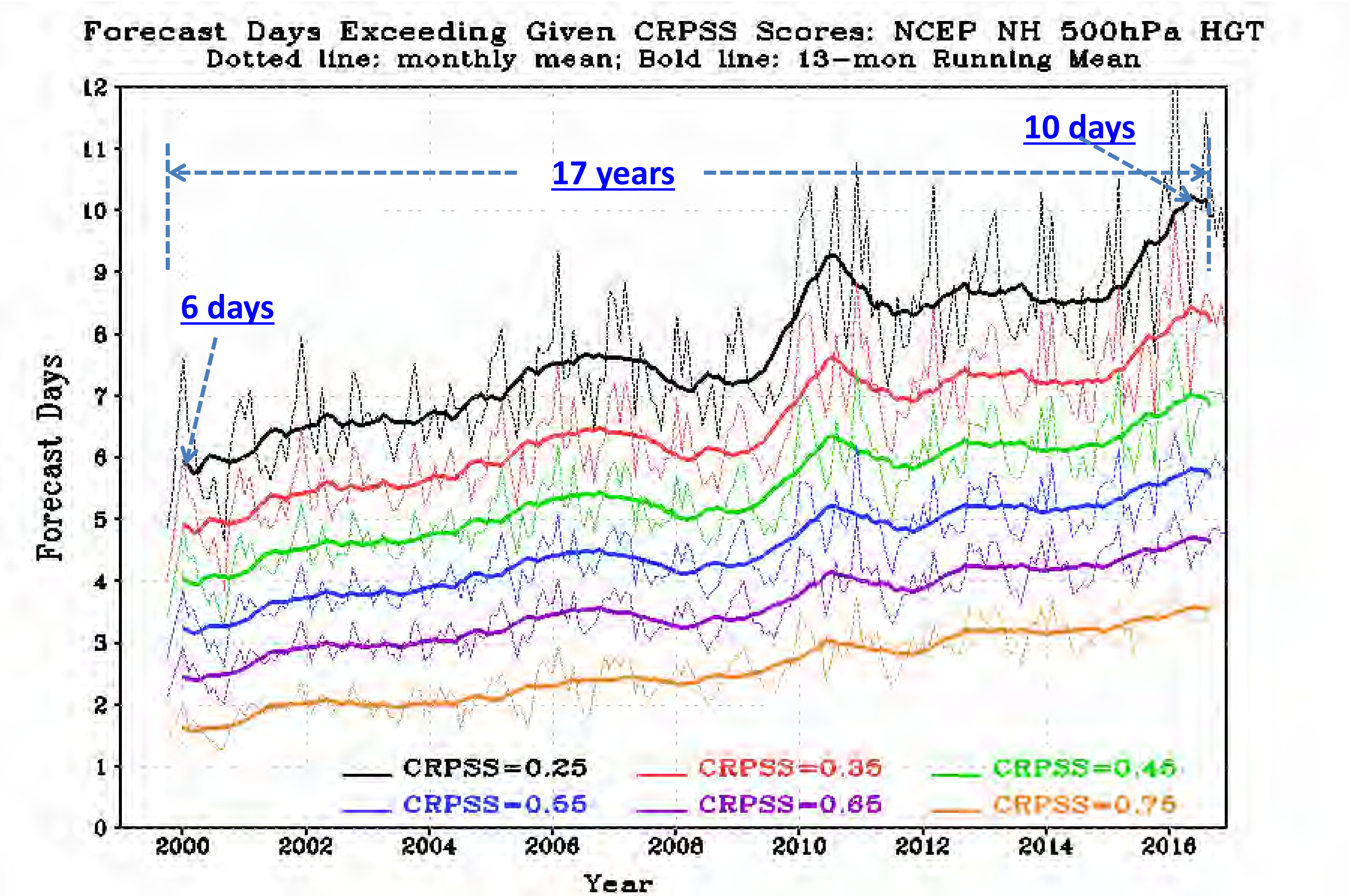
Operation: ECMWF-1992; NCEP-1992; MSC-1998

Reference: - first global ensemble review paper

Buizza, R., P. L. Houtekamer, Z. Toth, G. Pellerin, M. Wei, Y. Zhu, 2005:

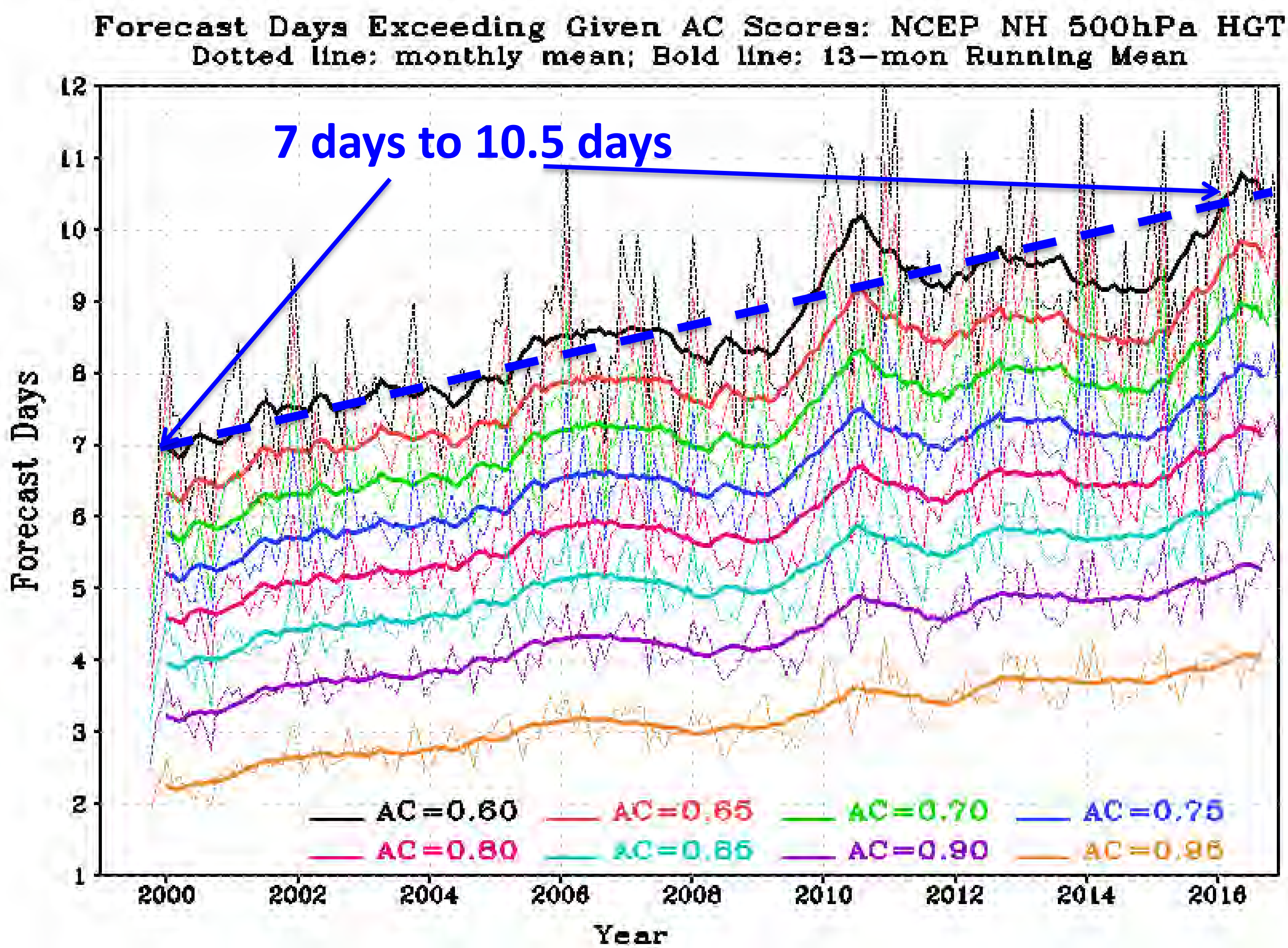
"A Comparison of the ECMWF, MSC, and NCEP Global Ensemble Prediction Systems" Monthly Weather Review, Vol. 133, 1076-1097

CRPSS for NH 500hPa geopotential height

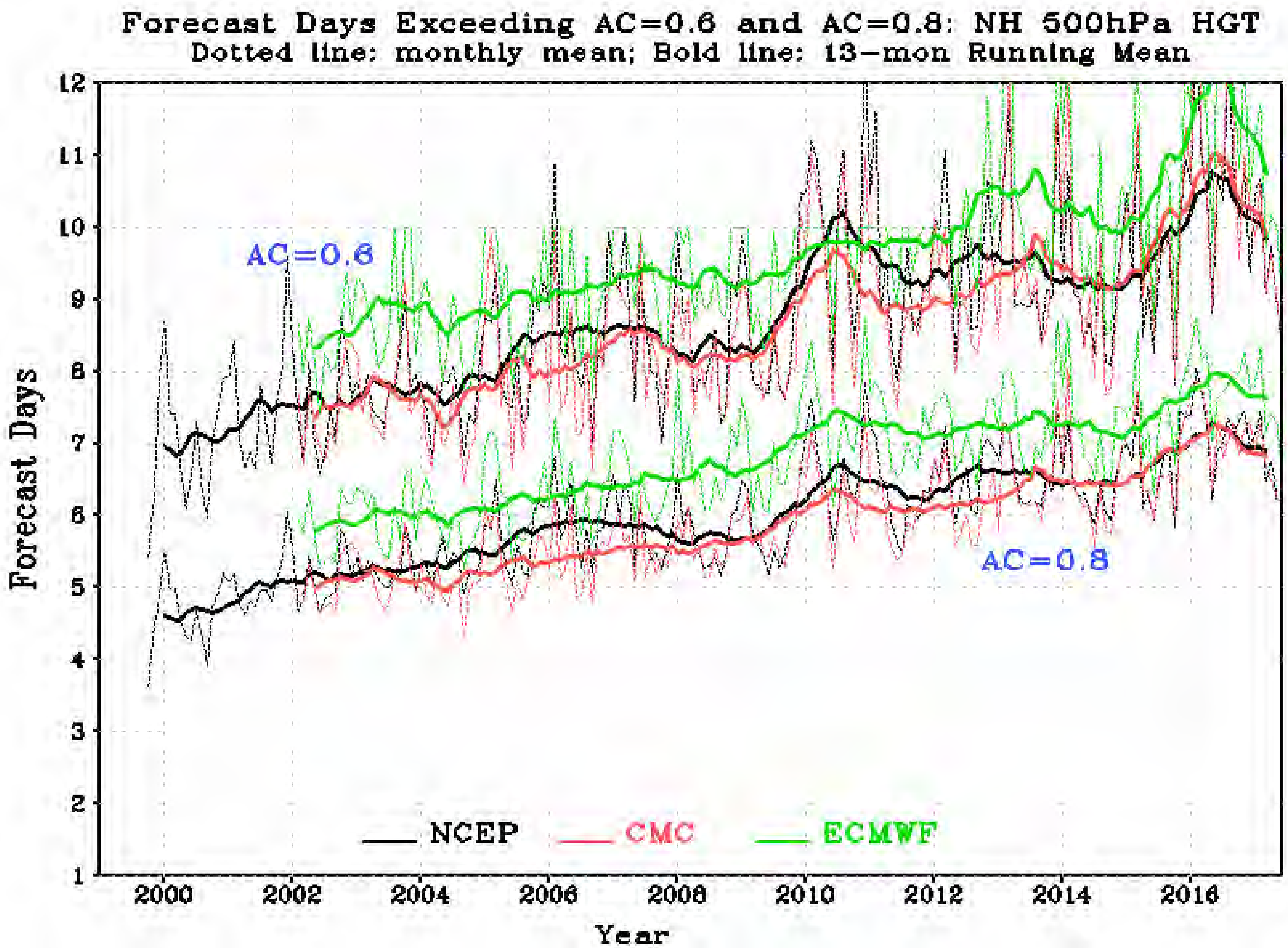


AC for NH 500hPa geopotential height

Ensemble mean

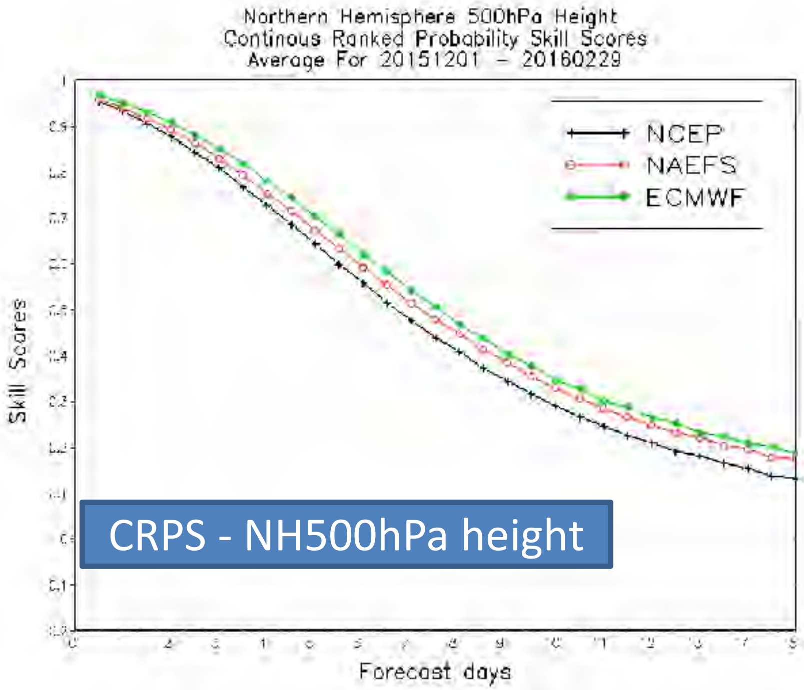


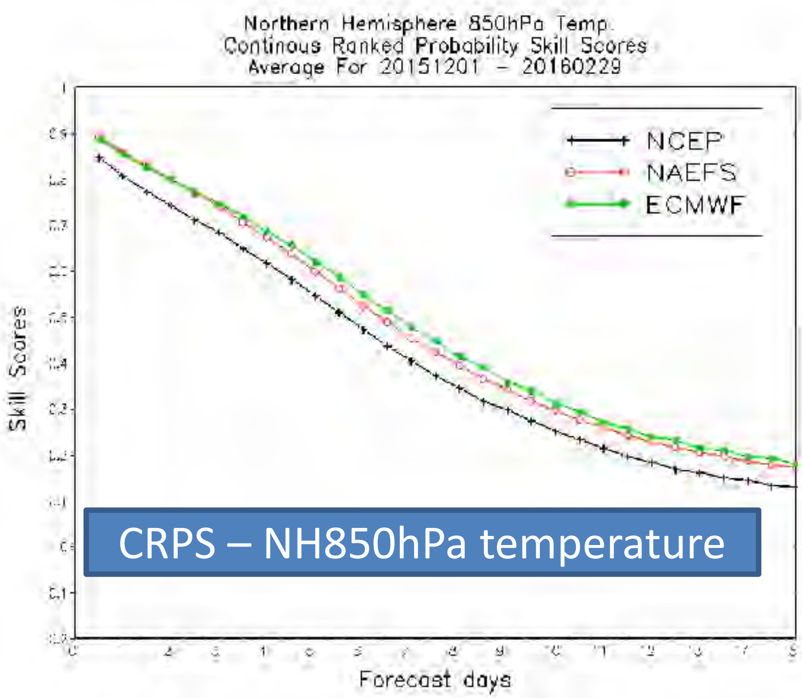
AC for NH 500hPa geopotential height

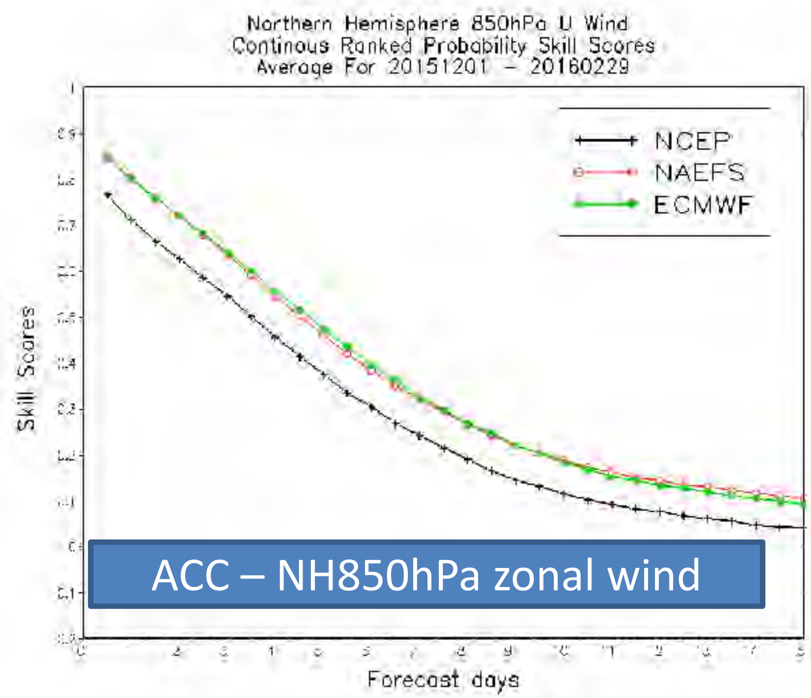


2015-2016 winter

Based on other measure and variable:
NAEFS has much closed skill to ECMWF
But, it is still behind about 6-12 hours,
except for 850hPa zonal wind







Experiments Set Up

- Four different configurations (include control) have been explored to exam the forecast skill of GEFS on subseasonal prediction. In the design of each **experiment configuration**, we compound configuration changes based on early investigations on the effect of some of the configuration changes (Melhauser et al, 2016; Zhu et al, 2017, Han et al. 2017). Although it is useful to independently examine the impact of each configuration change for a full experiment period, running these permutations would be too computationally expensive with a high resolution GEFS and 21 ensemble members for the full experiment period.
- Control experiment is extending from operational GEFS v11 which was implemented on 2 December 2015. It uses a reduced horizontal resolution version of the NCEP GFS Global Spectral Model v12.0 (GSM). The horizontal resolution is approximately 34 km for days 0-8 and 52 km for days 8-35 with 64 hybrid vertical levels. More details of GEFS v11 can be found in Zhou et al. (2017) and Zhu et al. (2017). In addition, the GEFS uses the same SST forcing as the GFS, which is initialized with the Real Time Global (RTG) SST analysis (Gemmill et al, 2008) and damped to analysis climatology (90-d e-folding, Melhauser et al, 2016; Zhu et al, 2017) during model integration. The sea ice concentration is initialized from the daily 0000 UTC sea ice analysis from the Interactive Multisensor Snow and Ice Mapping System (Ramsay 1998).

Experiments Set Up

The period of experiments are from **May 1st 2014 to May 26 2016**, and forecasts are initiated for every 7 days at 00UTC. The main difference of four experiments can be found in table 1.

Experiments	Stochastic Schemes	Boundary (SST)	Convection
CTL	STTP	Default	Default
SPs	SKEB+SPPT+SHUM	Default	Default
SPs+SST_bc	SKEB+SPPT+SHUM	2-Tiered SST	Default
SPs+SST_bc+SA_CV	SKEB+SPPT+SHUM	2-Tiered SST	Scale Aware Convection

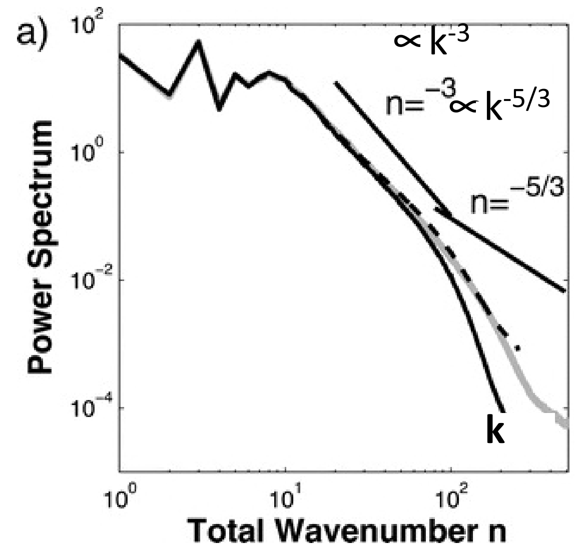
Table: *Configuration differences for four experiments*

1) Stochastic Schemes for Atmosphere

- Applied to GEFS experiments

- **Dynamics**: Due to the model's finite resolution, energy at non-resolved scales cannot cascade to larger scales.
  - Approach: 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)

Kinetic Energy Spectrum



Berner et al. (2009)

- **Physics**: Subgrid variability in physical processes, along with errors in the parameterizations result in an under spread and biased model.
  - Approach: 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

- *Above schemes has been tested for current operational GEFS (spectrum model) with positive response – plan to replace STTP for next implementation (FV3GEFS)*

2). SST Schemes (operation) and 2-tier SST approach
- Assimilate coupling

- **Operational**

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

- **CFSBC**

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

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

$SST_a^{t_0}$ -- SST analysis at initial time (RTG)

SST_c^t -- Climatological daily SST from RTG analysis for forecast lead-time t

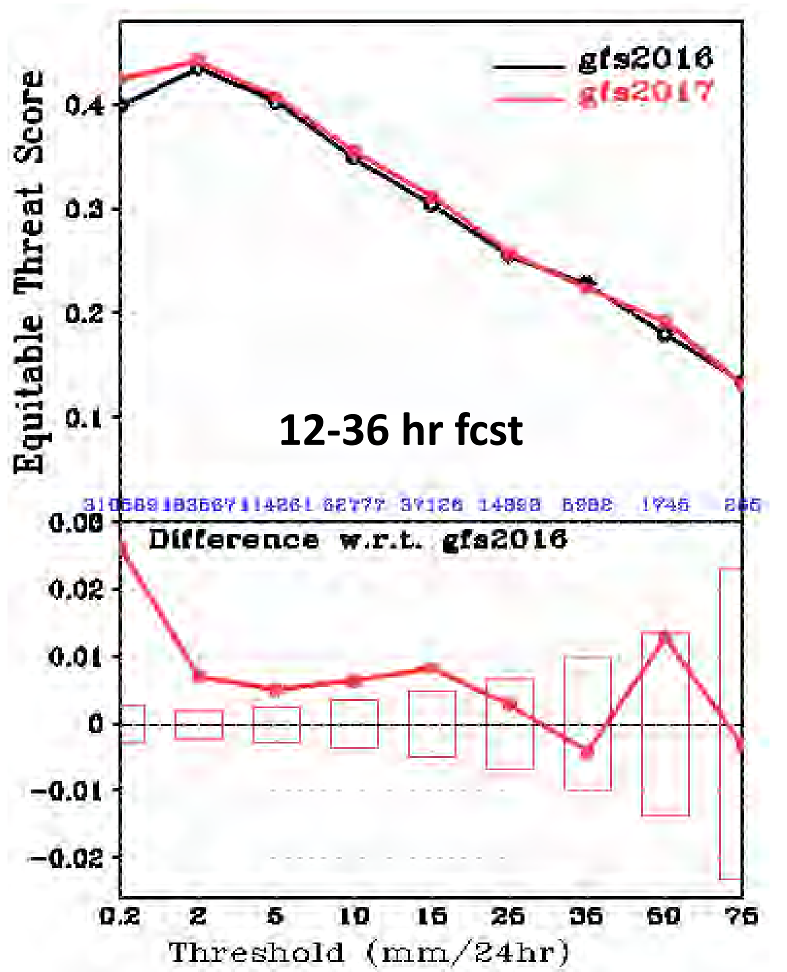
SST_{cfs}^t -- CFS predictive SST (24hr mean) for forecast lead-time t

$SST_{cfs\_c}^t$ -- CFS model climatology (predictive SST) for forecast lead-time t

SST_{cfsrc}^t -- CFS reanalysis daily climatology for forecast lead-time t

3). Update GFS convection scheme

- Scale-aware, aerosol-aware parameterization
- Rain conversion rate decreases with decreasing air temperature above freezing level.
- Convective adjustment time in deep convection proportional to convective turn-over time with CAPE approaching zero after adjustment time.
- Cloud base mass flux in shallow convection scheme function of mean updraft velocity.
- Convective inhibition (CIN) in the sub-cloud layer additional trigger condition to <u>suppress unrealistically spotty rainfall</u> especially over high terrains during summer
- Convective cloudiness enhanced by suspended cloud condensate in updraft.
- Significant improvement especially CONUS precip in summer.



Courtesy of Dr. Vijay Tallapragada

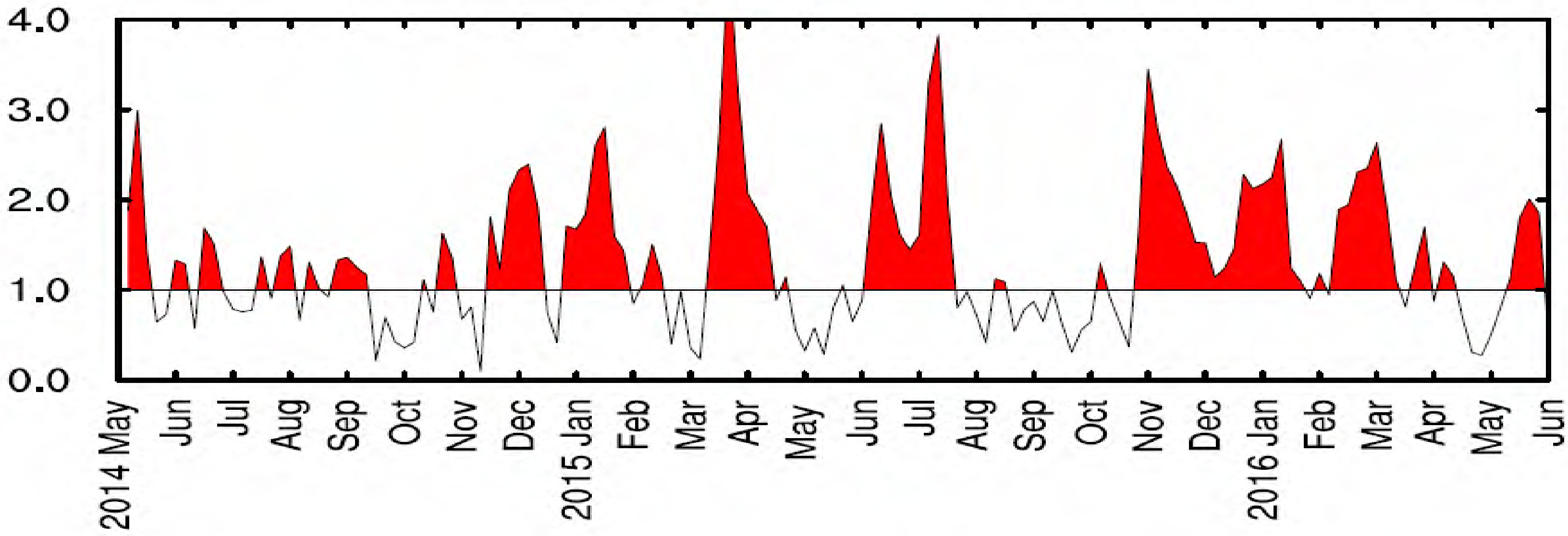
Reference: Han, J. and et al., 2017 Wea. and Fcst.

Evaluation of MJO skills

Based on Wheeler-Hendon Index

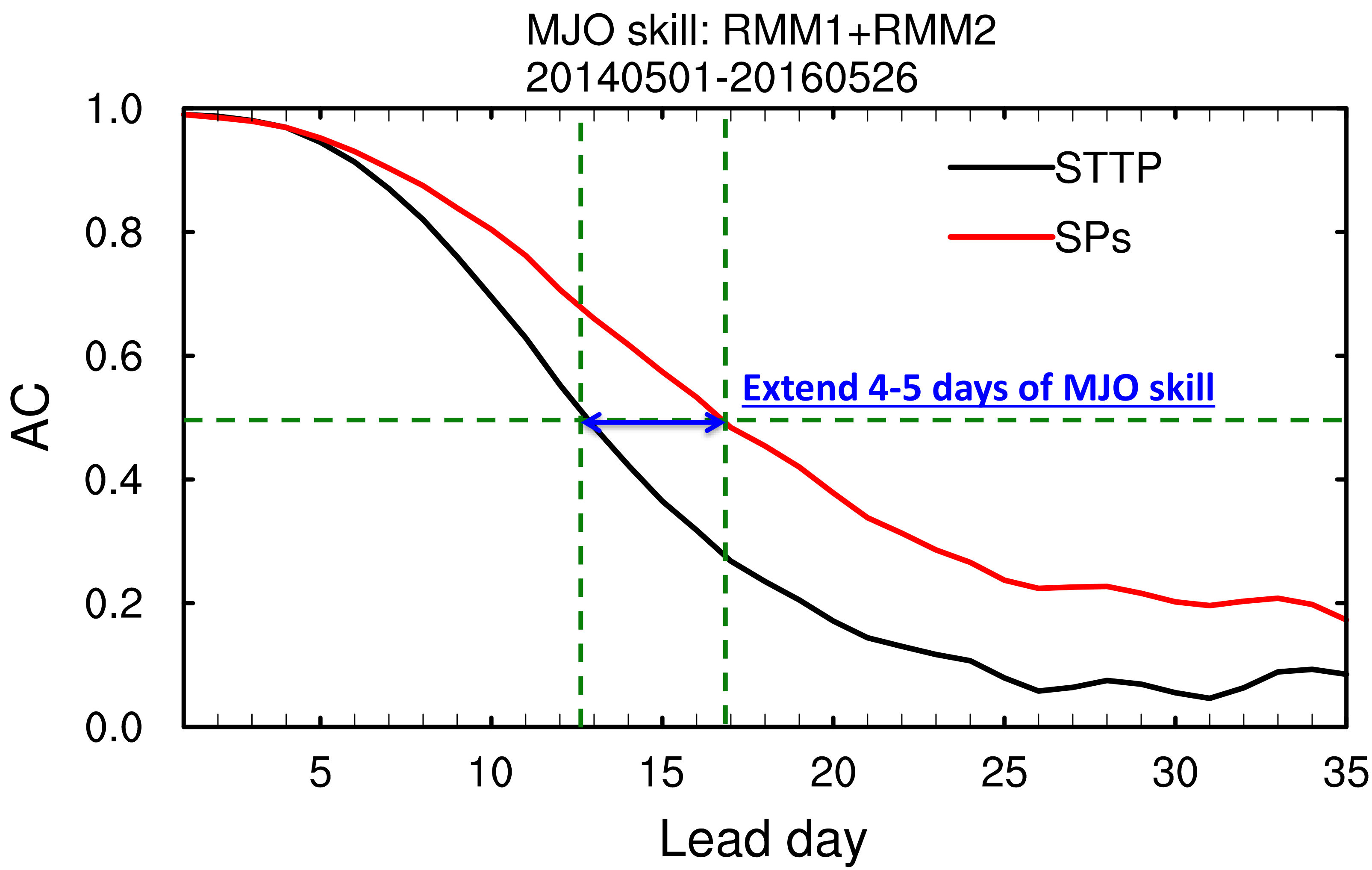
An improvement comes from three areas:

1. Ensemble and stochastic physic perturbations
2. 2-tier SST to assimilate impact of coupling
3. New scale-aware convective scheme



Amplitude of MJO during May 2014- May 2016 from GDAS analysis data. The resolution of the time-series is 5 days

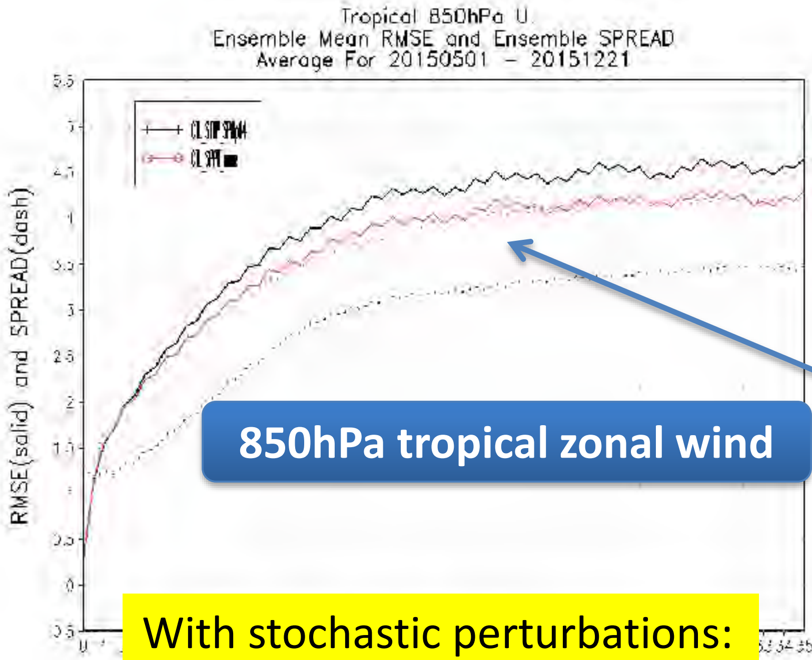
GEFS week 3&4 forecasts (May 2014-May 2016)



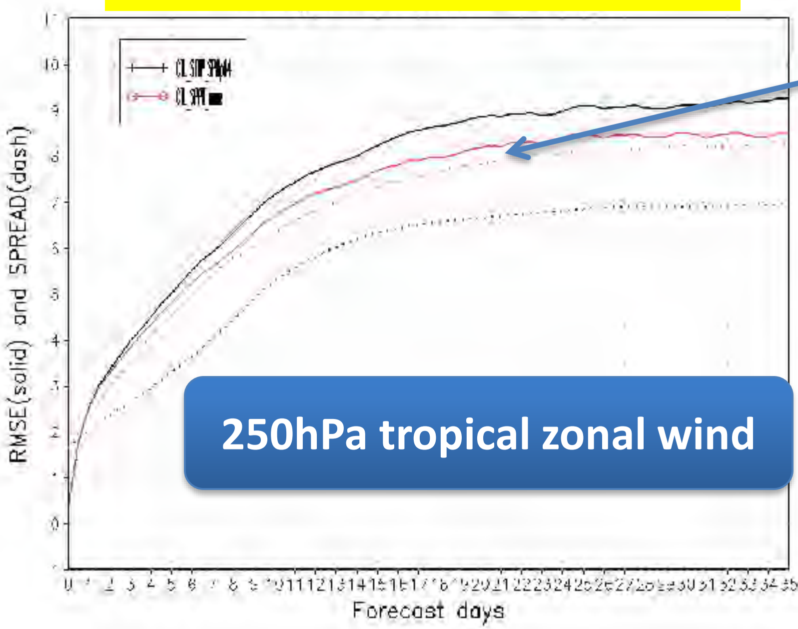
Apply new stochastic schemes:

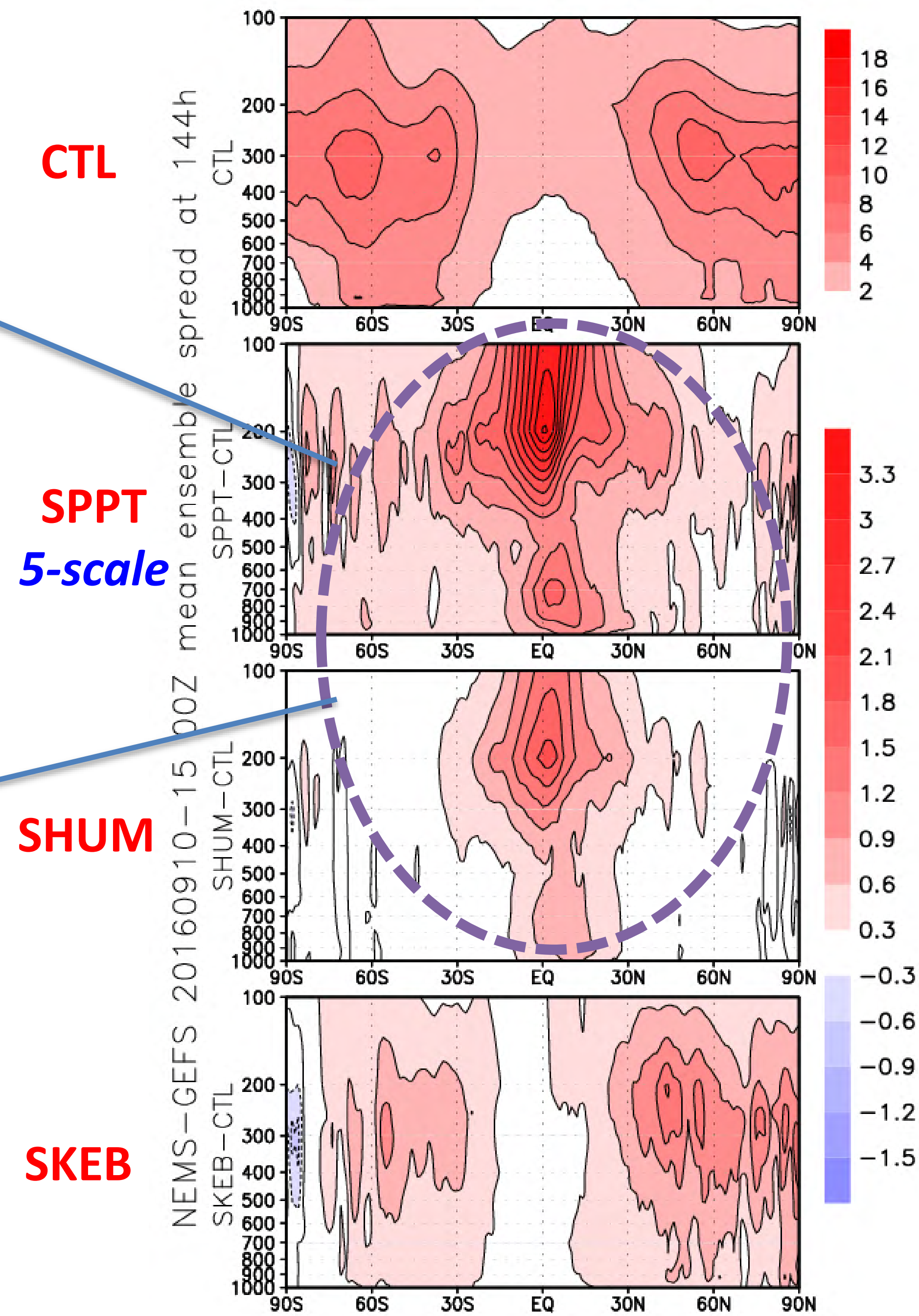
Higher resolution (~50km) for week 3&4 with different SPs

Zonal wind speed (f144 hours – 6 days)

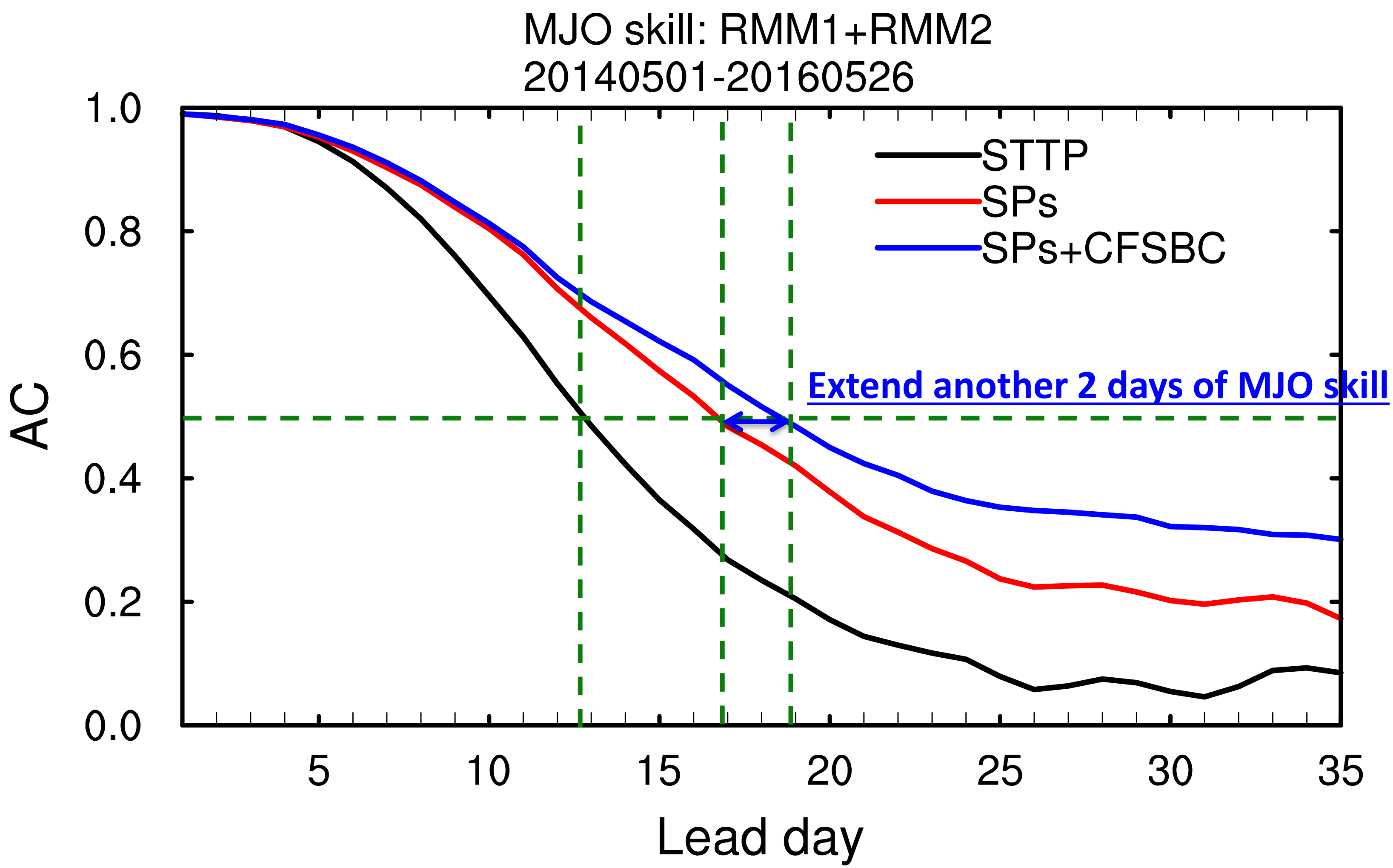


With stochastic perturbations:
Error is reduced
Spread is increased





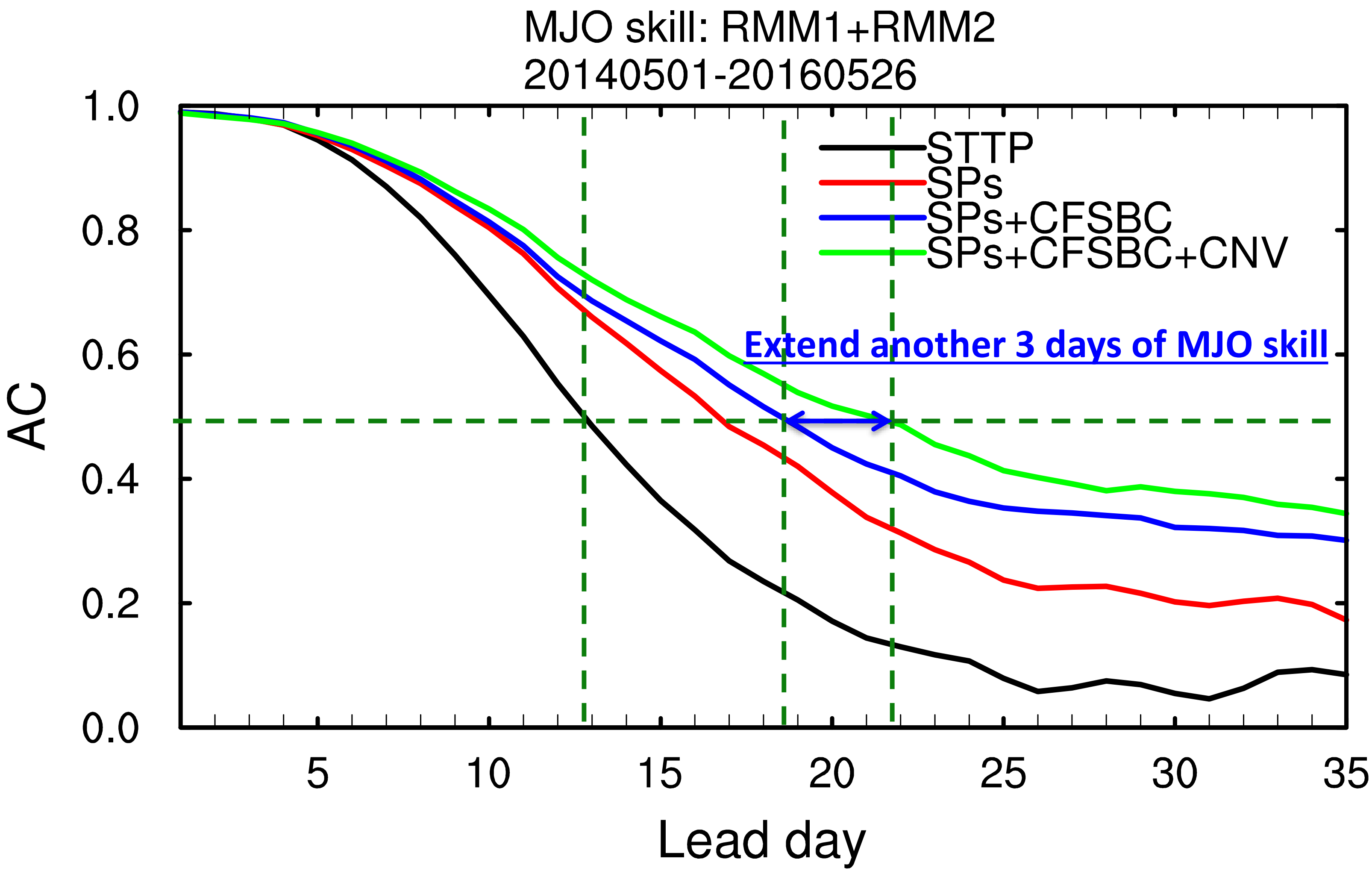
GEFS week 3&4 forecasts (May 2014-May 2016)



2-Tier SST approach (assimilate coupling)

Higher resolution (~50km) for week 3&4 with different SPs

GEFS week 3&4 forecasts (May 2014-May 2016)



Apply scale aware convective scheme

Higher resolution (~50km) for week 3&4 with different SPs

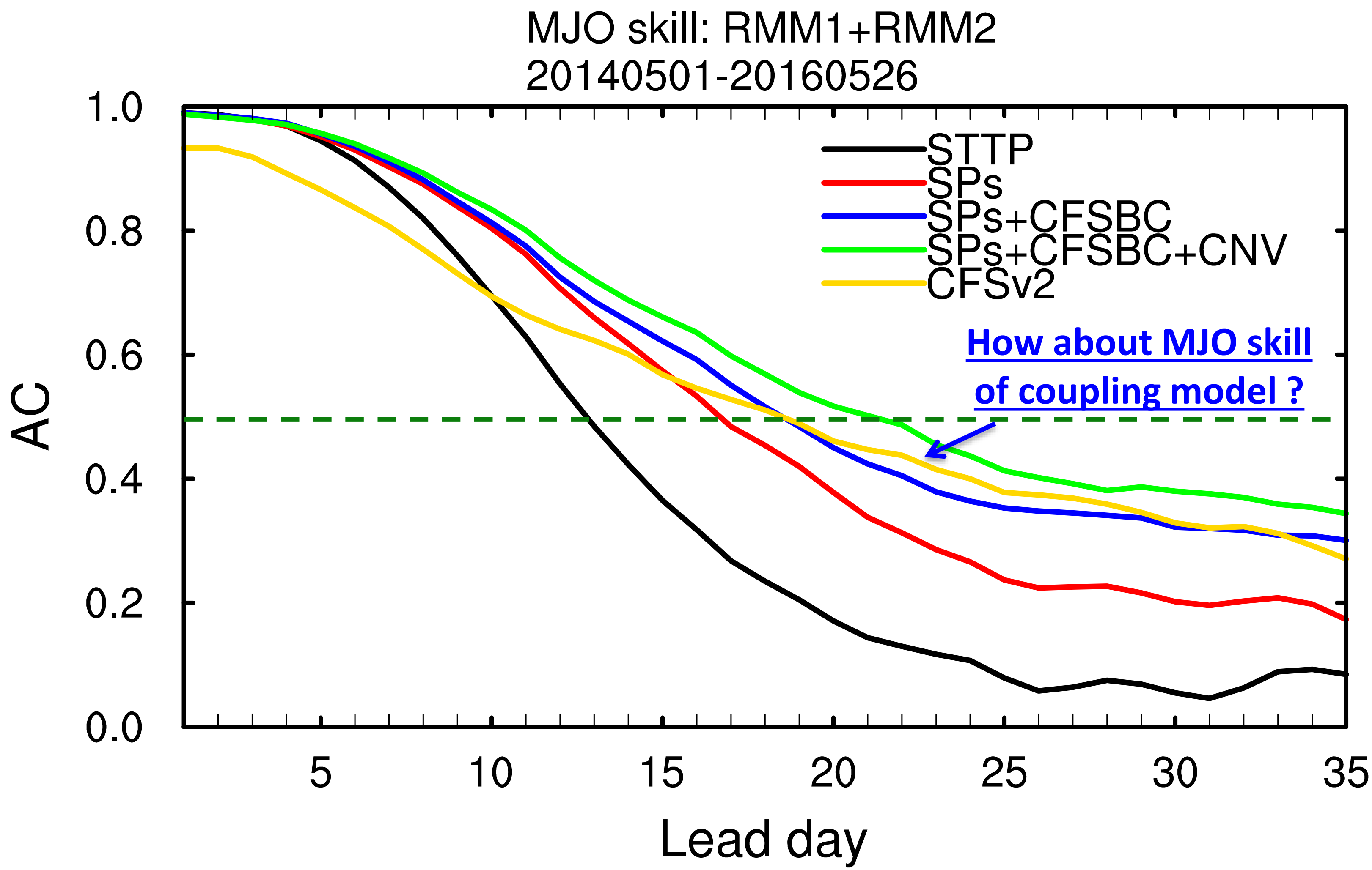
WH MJO skill (ACC=0.5)

20140501-20160526

Configurations	Weak	Strong	2-yr +
STTP (CTL)	12.2	12.8	**12.5**
SPs (CTL)	15.8	18	**16.8**
SPs+CFSBC	17	19.5	**18.5**
SPs+CFSBC+SA-CNV	18+	23+	**22.0**
GEFS_v10			**12.5**

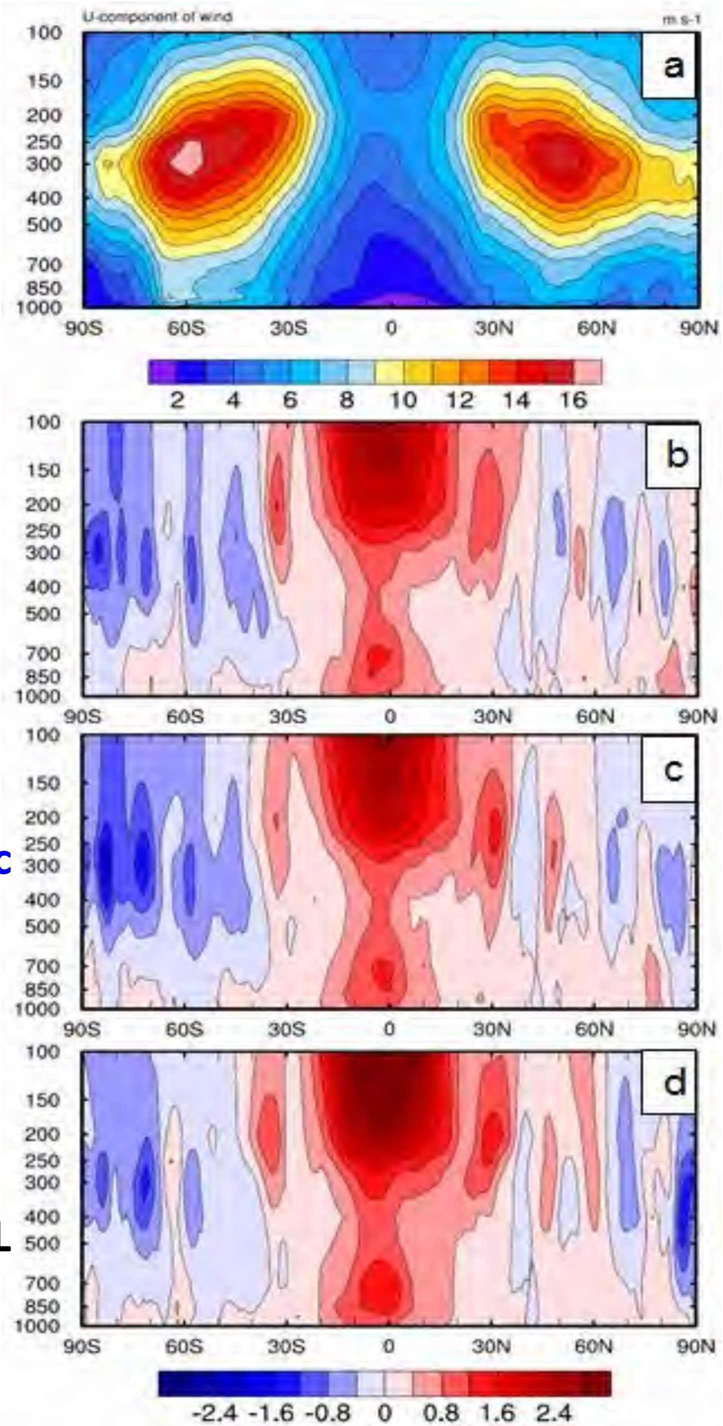
There is no difference for MJO skills between GEFSv10 and GEFSv11

GEFS week 3&4 forecasts (May 2014-May 2016)



CFSv2 is NCEP operational climate forecast system (coupling) implemented on 2011 – 16 members leg (24 hours) ensemble

Improvement of Tropical Winds



CTL

SPs - CTL

SPs+SST_bc - CTL

SPs+SST_bc +SA_CV - CTL

Figure. Global meridional cross section of the zonal wind spread [m s-1] at 360 forecast hours (15 days) for a) CTL, b) SPs minus CTL, c) SPs+SST_bc minus CTL; and d) SPs+SST_bc+SA_CV minus CTL. The result is calculated using 6 cases starting the 1st of March 2016 every 5-days.

Evaluation of 500hPa height

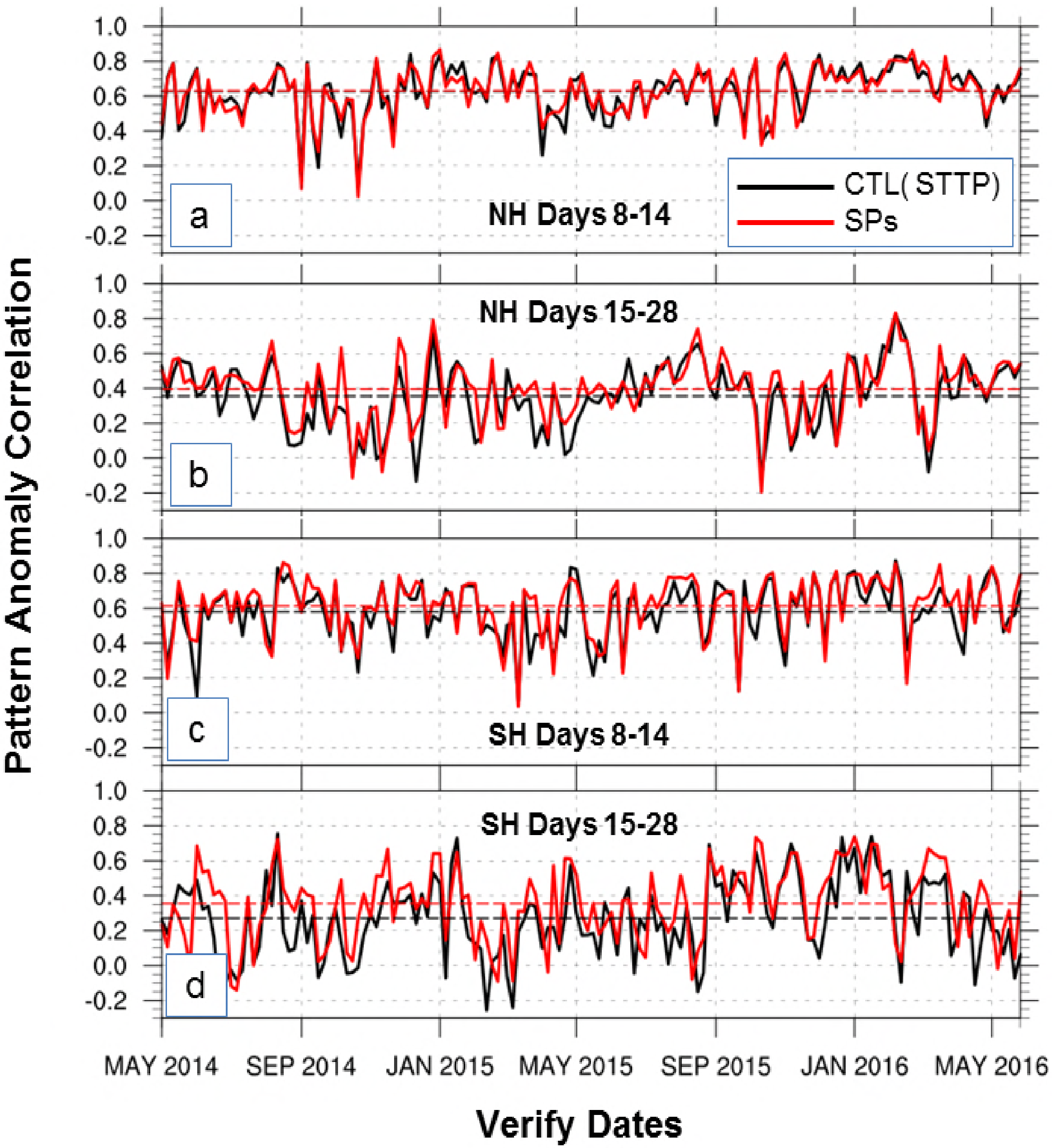


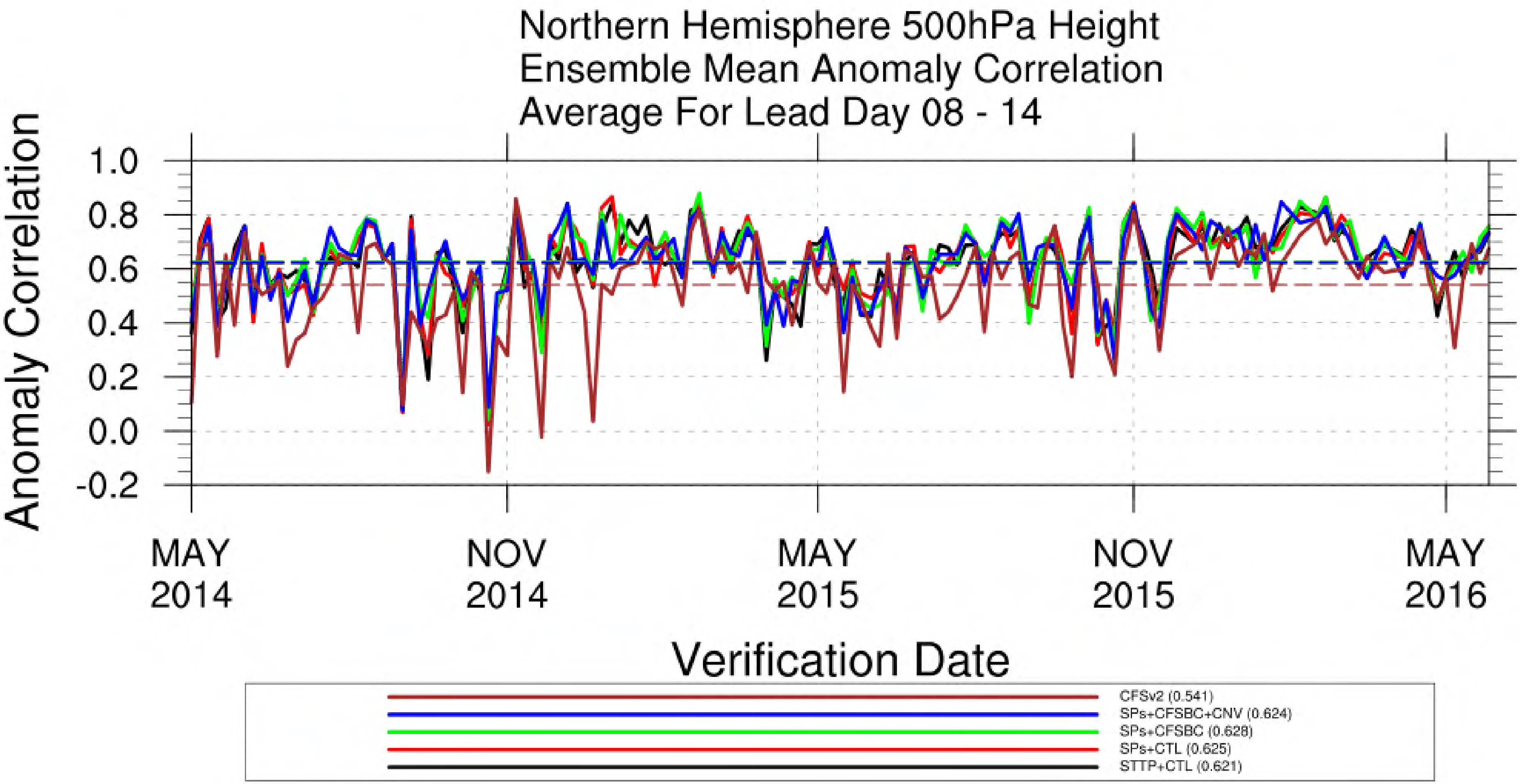
Figure. Ensemble mean Anomaly Correlation time series for Northern Hemisphere 500 hPa geopotential height from May 2014 - May 2016 for CTL (black) and SPs (red) for a) days 8-14 and b) days 15-28 (weeks 3 & 4). Panel c) and d) are the same as a) and b) except for the Southern Hemisphere. Average scores are shown by straight dashed lines matching the color of CTL and SPs

Evaluation of 500hPa height

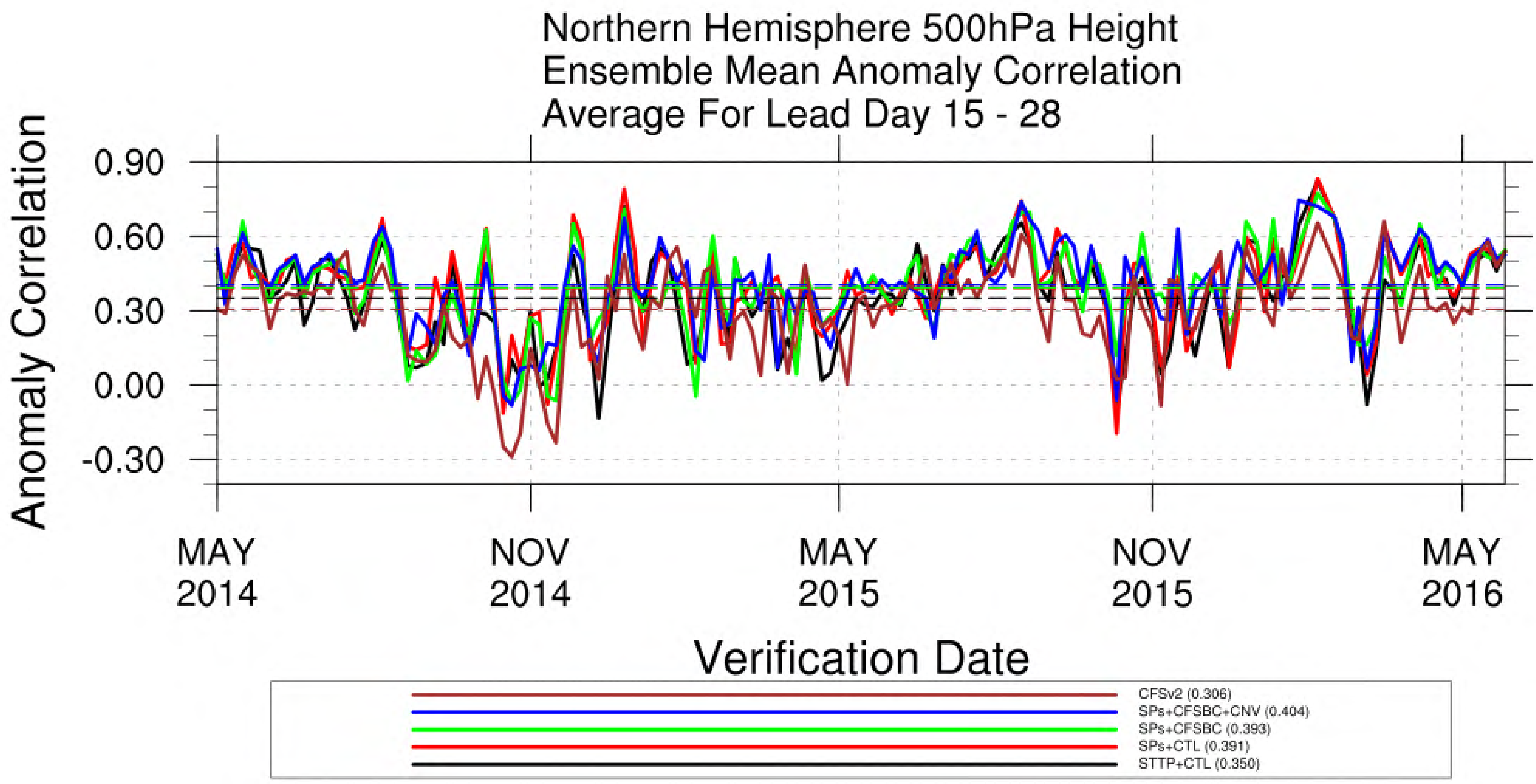
ACC scores for week-1 and week 3&4

PAC scores	CTL	SPs	SPs+SST_bc	SPs+SST_bc+SA_CV
NH day 8-14	0.627	0.630	0.632	0.629
NH day 15-28	0.355	0.396	**0.398**	**0.409**
SH day 8-14	0.580	0.615	**0.620**	**0.618**
SH day 15-28	0.271	**0.366**	**0.367**	**0.379**

Table - Pattern Anomaly Correlation averaged over 25 months for lead day 8-14 (week 2) and lead day 15-28 (weeks 3 & 4). The bolded blue values represent results that significantly improved from the CTL at the 95% confidence level



SPs+SST_bc+SA-CV (0.624) **CFSv2 (0.541)**



SPs+SST_bc+SA-CV (0.404) **CFSv2 (0.306)**

Comparison of Ensemble Size

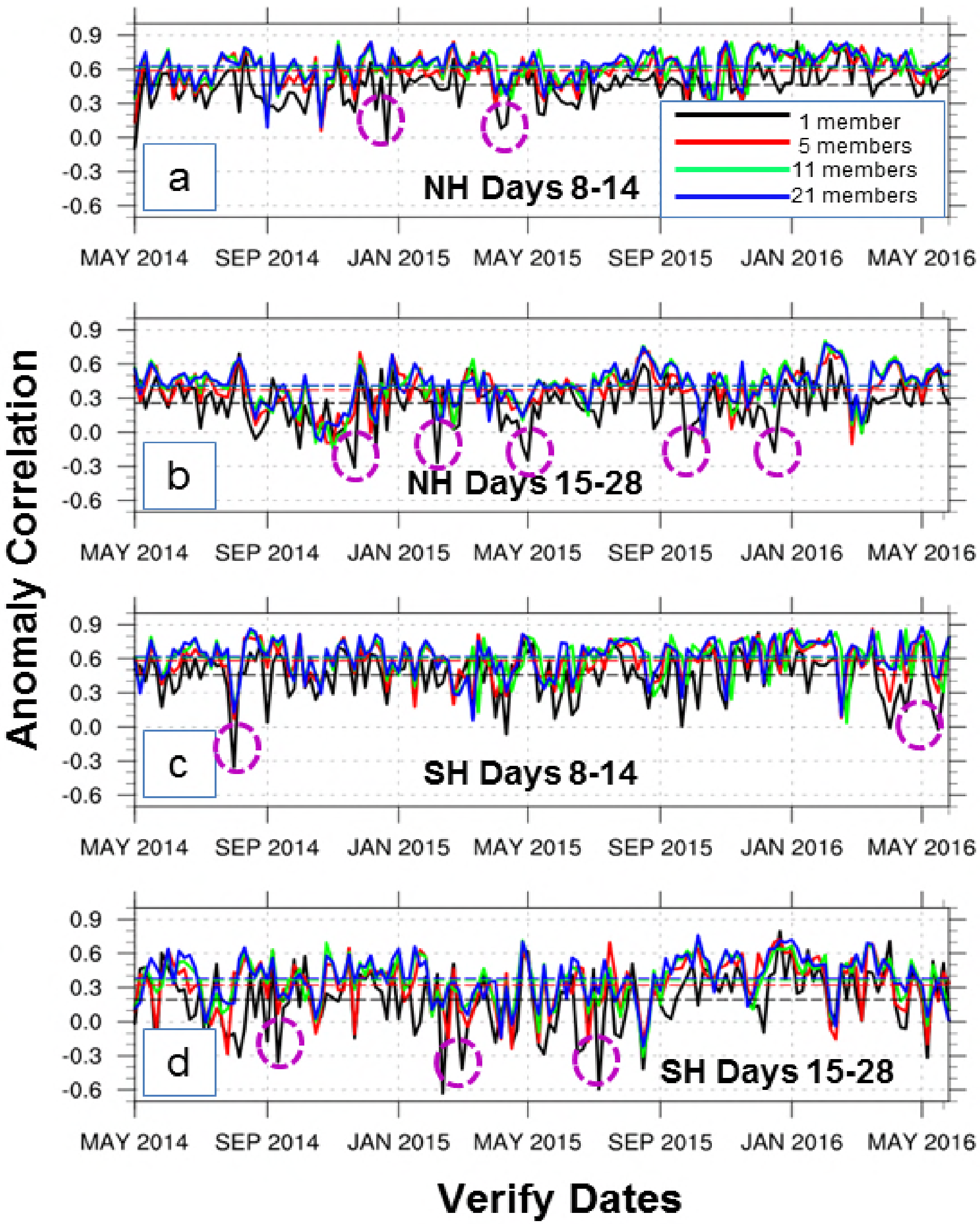
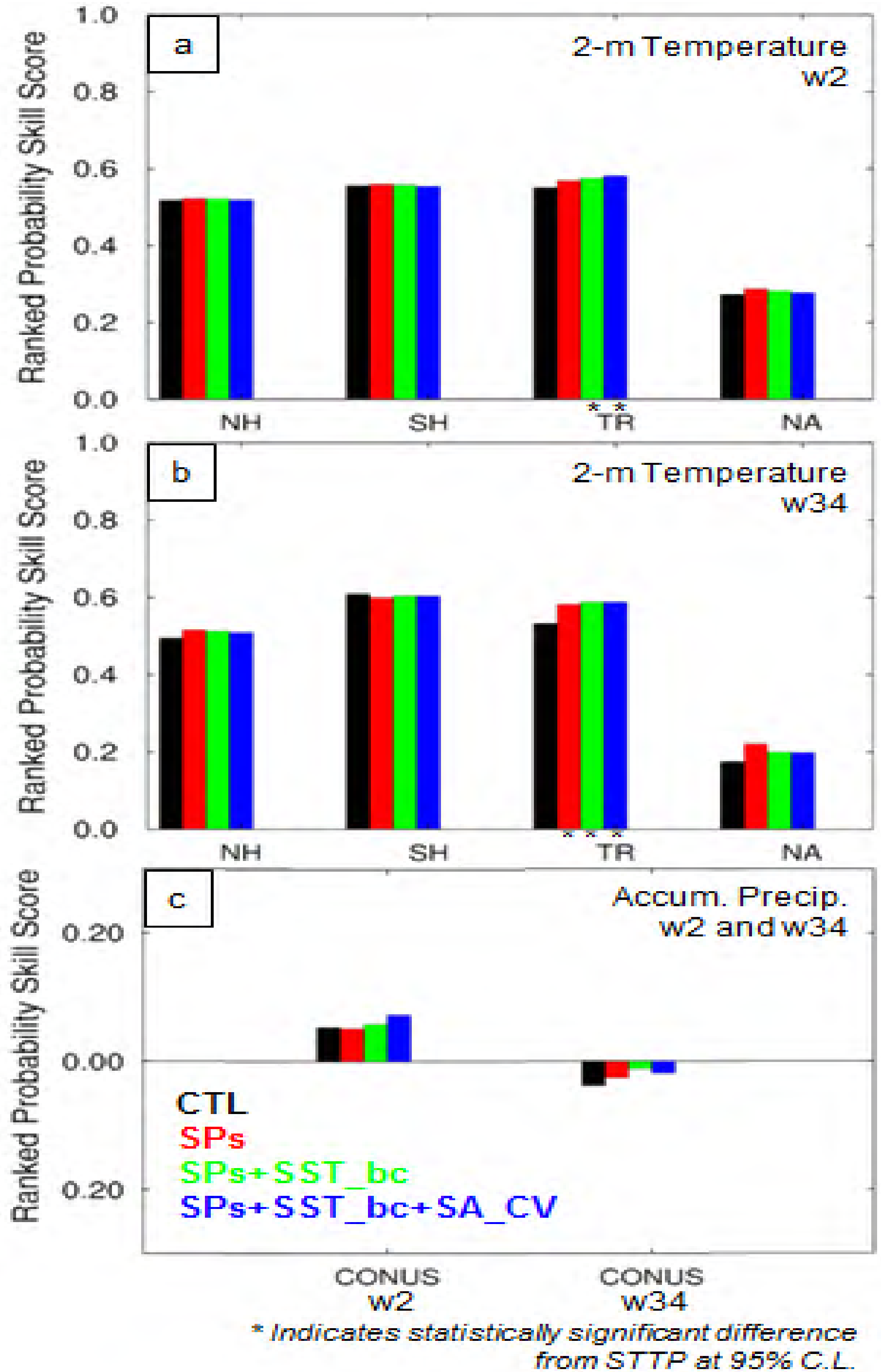


Figure. Ensemble mean Anomaly Correlation time series for Northern Hemisphere 500 hPa geopotential height from May 2014 - May 2016 for 1 member (black), 5 members (red), 11 members (green), and 21 members (blue) for a) days 8-14 and b) days 15-28 (weeks 3 & 4). Panel c) and d) are the same as a) and b) except for the Southern Hemisphere. Average scores are shown by straight dashed lines matching the color of different member sizes.

Comparison of Ensemble Size

PAC Scores	Domains	Variables	21 Members	11 Members	5 Members	1 Member
Day 8-14	NH	z500	0.628	0.619	**0.586**	**0.463**
	SH	z500	0.620	0.609	0.582	**0.458**
	TR	u850	0.686	0.673	**0.646**	**0.501**
		u250	0.641	0.630	**0.605**	**0.490**
Day 15-28	NH	z500	0.410	0.405	**0.372**	**0.257**
	SH	z500	0.380	0.363	0.323	**0.194**
	TR	u850	0.583	0.571	**0.544**	**0.400**
		u250	0.430	0.420	0.409	**0.300**

Table - Anomaly Correlation for different ensemble sizes from SPs+SST_bc+SA_CV averaged over 25 months for lead days 8-14 (week 2) and lead days 15-28 (weeks 3 & 4). The bolded values represent results that are significantly degraded from the 21-member ensemble experiment at the 95% confidence level.



Evaluation of Surface Elements

RPS forecast skills

Surface temperature

Raw forecast

Land only

Week 2 averages

Weeks 3&4 average

Significant test

Precipitation

Raw forecast

CONUS only

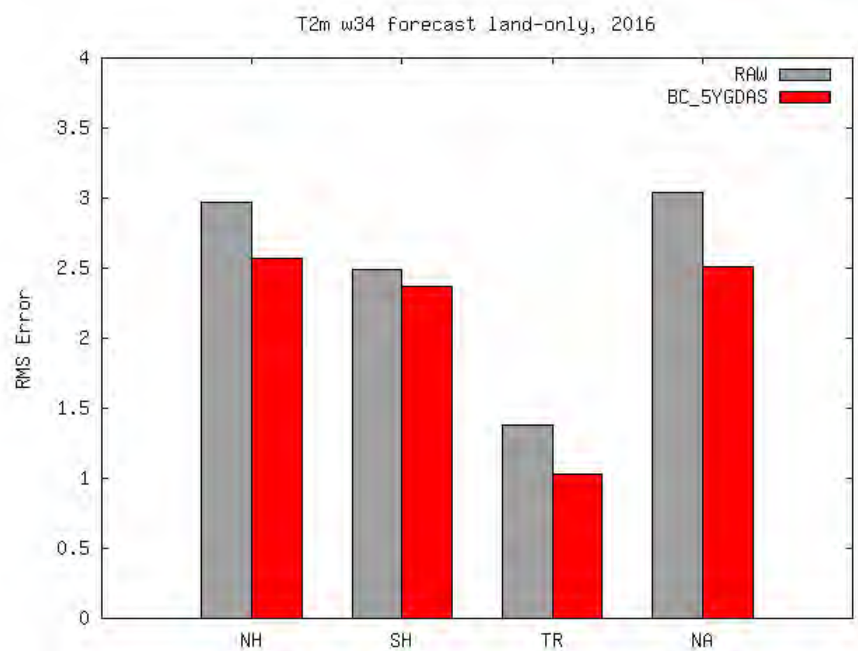
Week 2 accumulation

Weeks 3&4 accum.

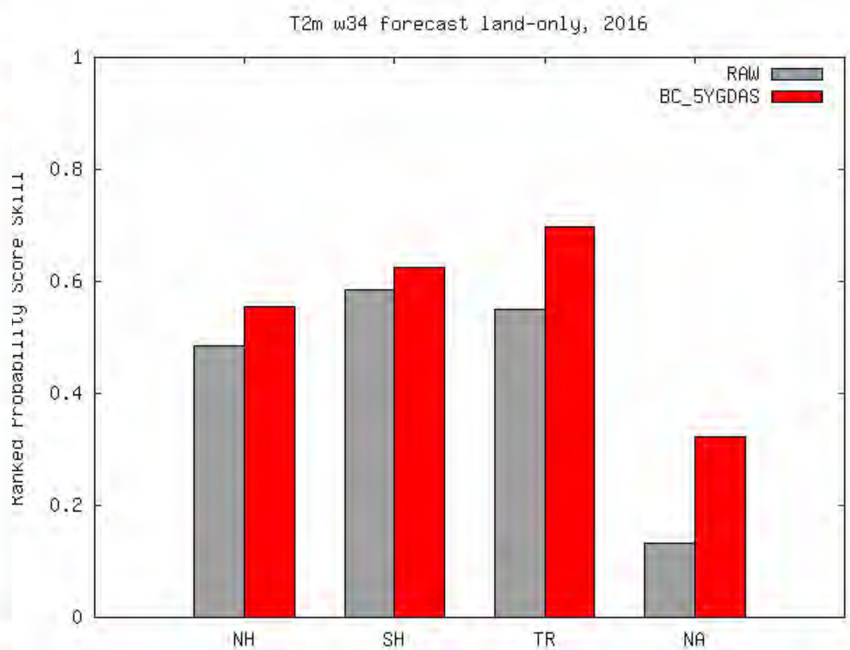
Significant test

Bias correction for T2m (weeks 3&4)

RMSE



RPSS



Land only

Using 5-year reforecast (2011-2015) to calibrate 2016 T2m forecast

Summary

- 25 months experiments has been finished.
- "SPs+SST_bc+SA_CV"'s performance is best overall (mainly MJO)
- Improvement of NA surface elements is very minor, bias correction is required.
- 5-member ensemble will degrade performance significantly
- 18 years reforecast has been done for best configuration.
- 2-meter temperature skill could be improved through bias correction from reforecast
- Real-time 35-d forecast (every Wednesday) has started since July.
- NMME/SubX real-time has started.
- **Coupled atmo-ocean for GEFS subseason forecast is in testing.**

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Thanks!!!