The Development of Subseasonal Forecast through the NCEP GEFS

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Acknowledgements

- SubX –
  - Thank EMC ensemble team members.
  - Thank ESRL scientists
  - "SubX" study is partially supported through NWS OSTI and NOAA's Climate Program Office (CPO)'s Modeling, Analysis, Predictions, and Projections (MMAP) program.
- FV3 GEFS –
  - Thanks EMC ensemble development members
  - Thanks EMC model development members
  - Thanks ESRL/PSD scientists

Highlights

- Acknowledgements and highlights
- Introduction
- Background - NCEP GEFS
- Early study to support “SubX”
  - Evaluations
  - Summary
- FV3GEFS development
  - Evaluations
  - Summary
- GEFSv12 milestone

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).

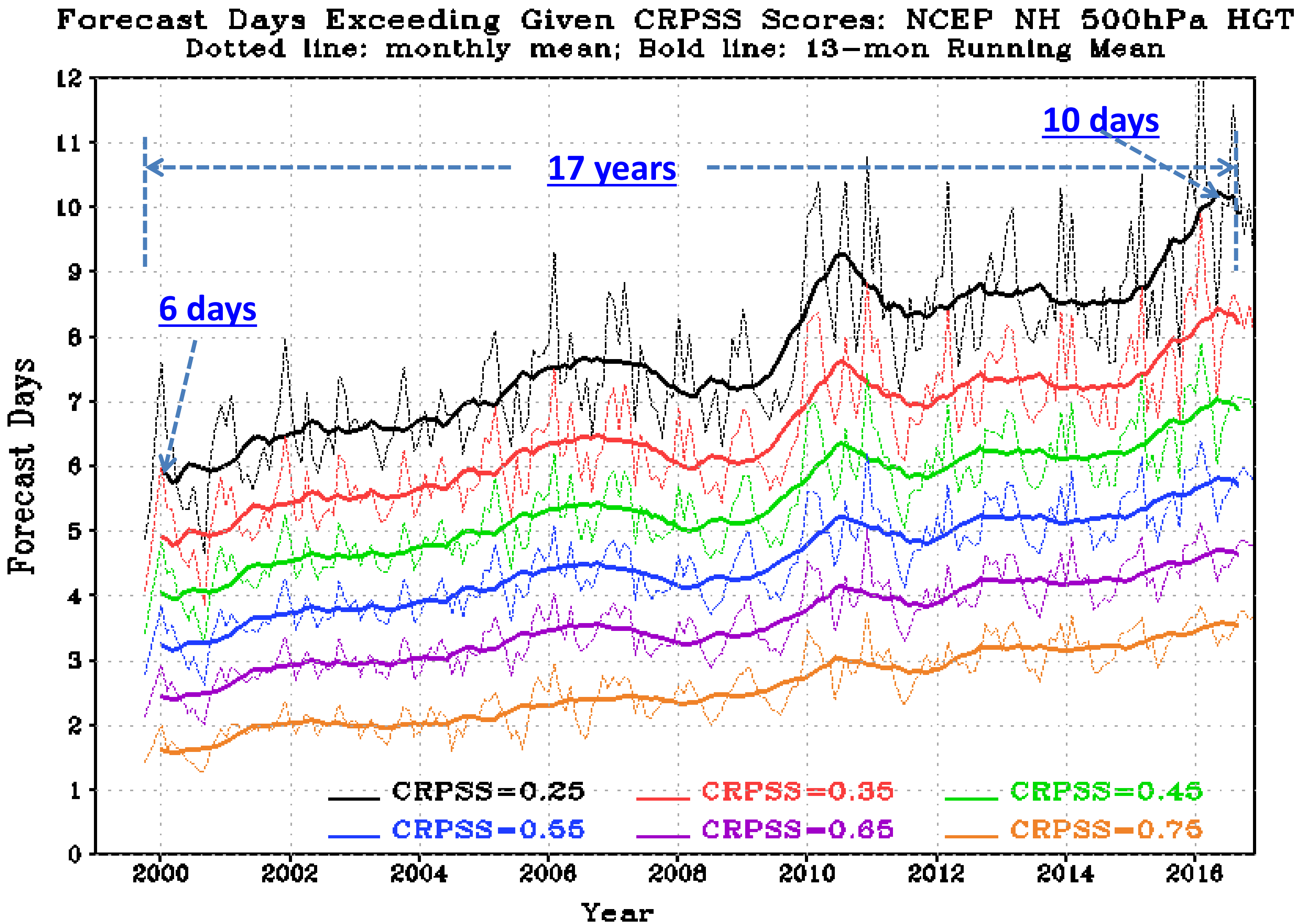
Operation: ECMWF-1992; NCEP-1992; MSC-1998

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



“SubX” 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

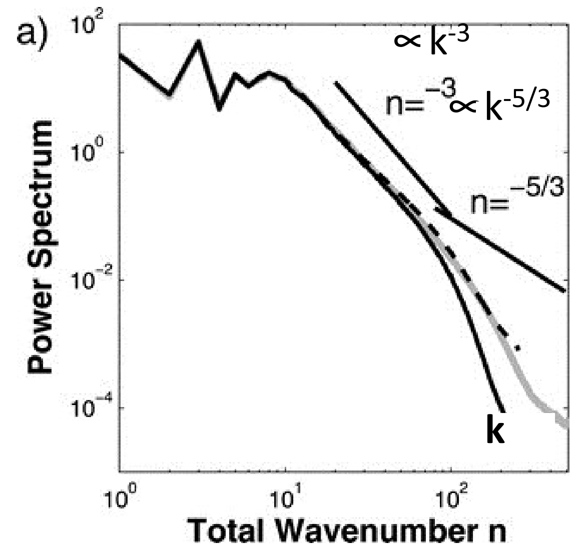
Table*: Configuration differences for four experiments*

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)
- **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)*

Kinetic Energy Spectrum



Berner et al. (2009)

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**

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

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

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

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

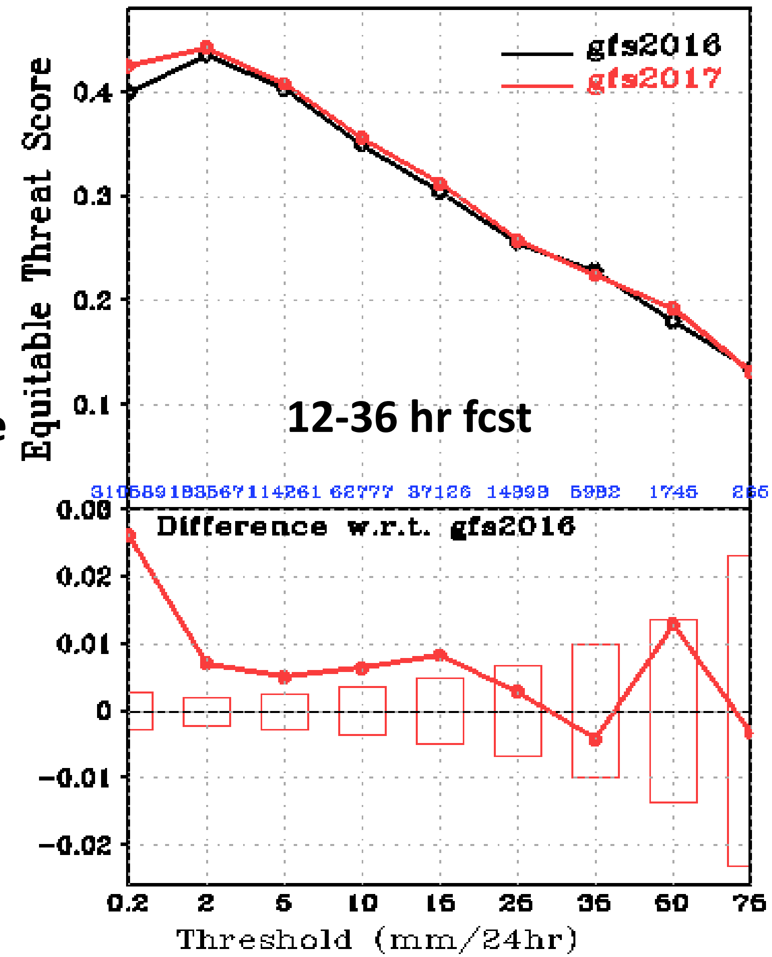
SST_{cfs}^t -- CFS predictive SST (24hr mean) for forecast lead-time t

$SST_{cfs\_c}^t$ -- 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 suppress unrealistically spotty rainfall 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]()

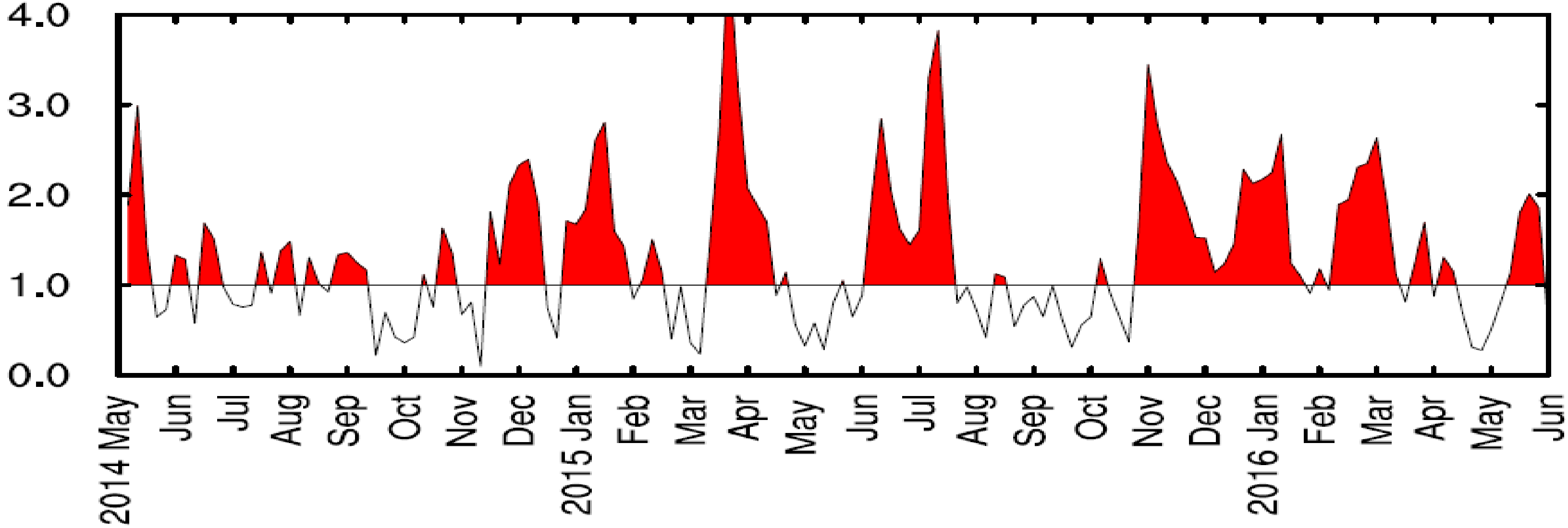
Reference: Han, J. and et al., 2017 Wea. and Fcst.

Evaluation of MJO skills

Based on Wheeler-Hendon Index

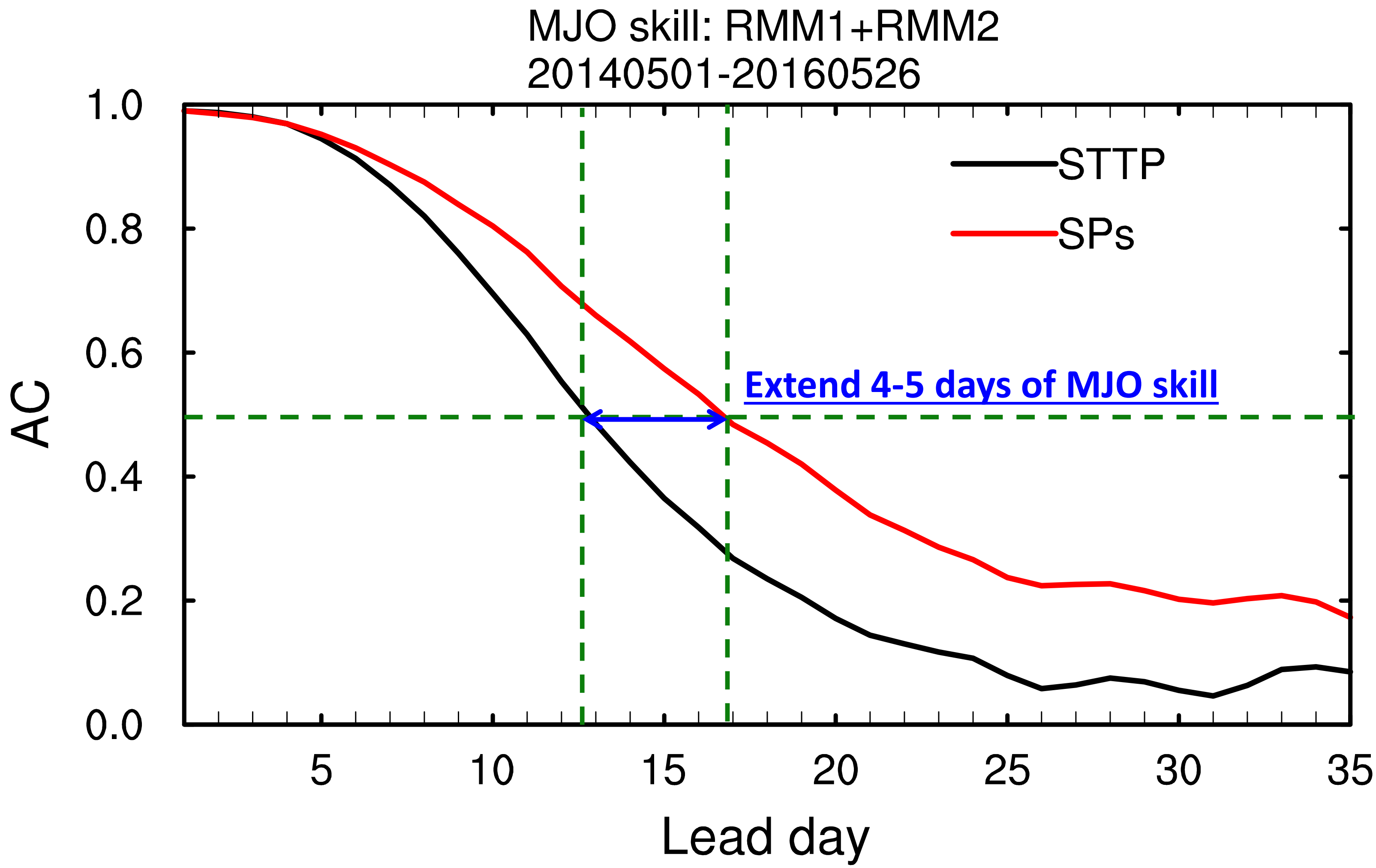
An improvement comes from three areas:

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



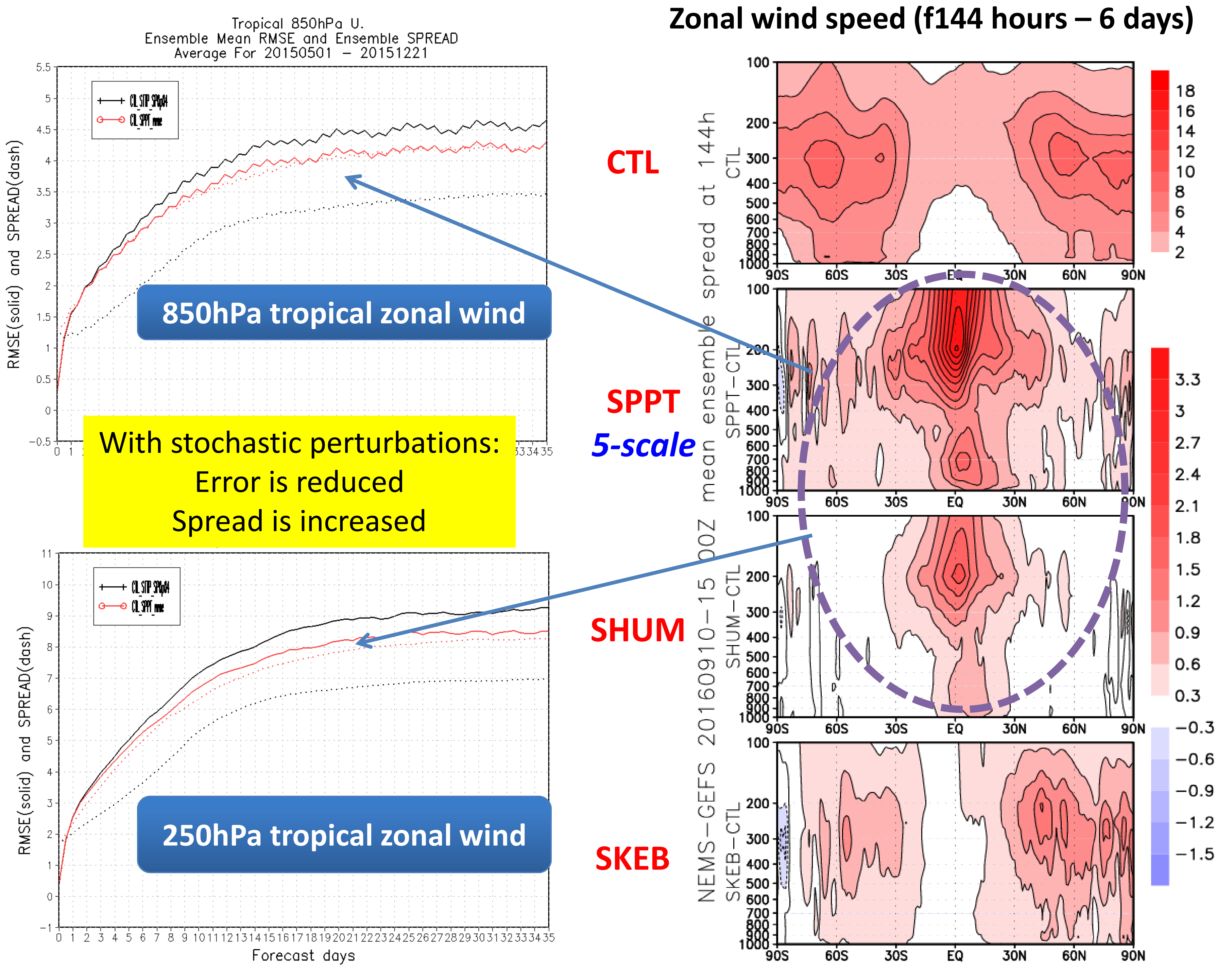
Amplitude of MJO during May 2014- May 2016 from GDAS analysis data. The resolution of the time-series is 5 days

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



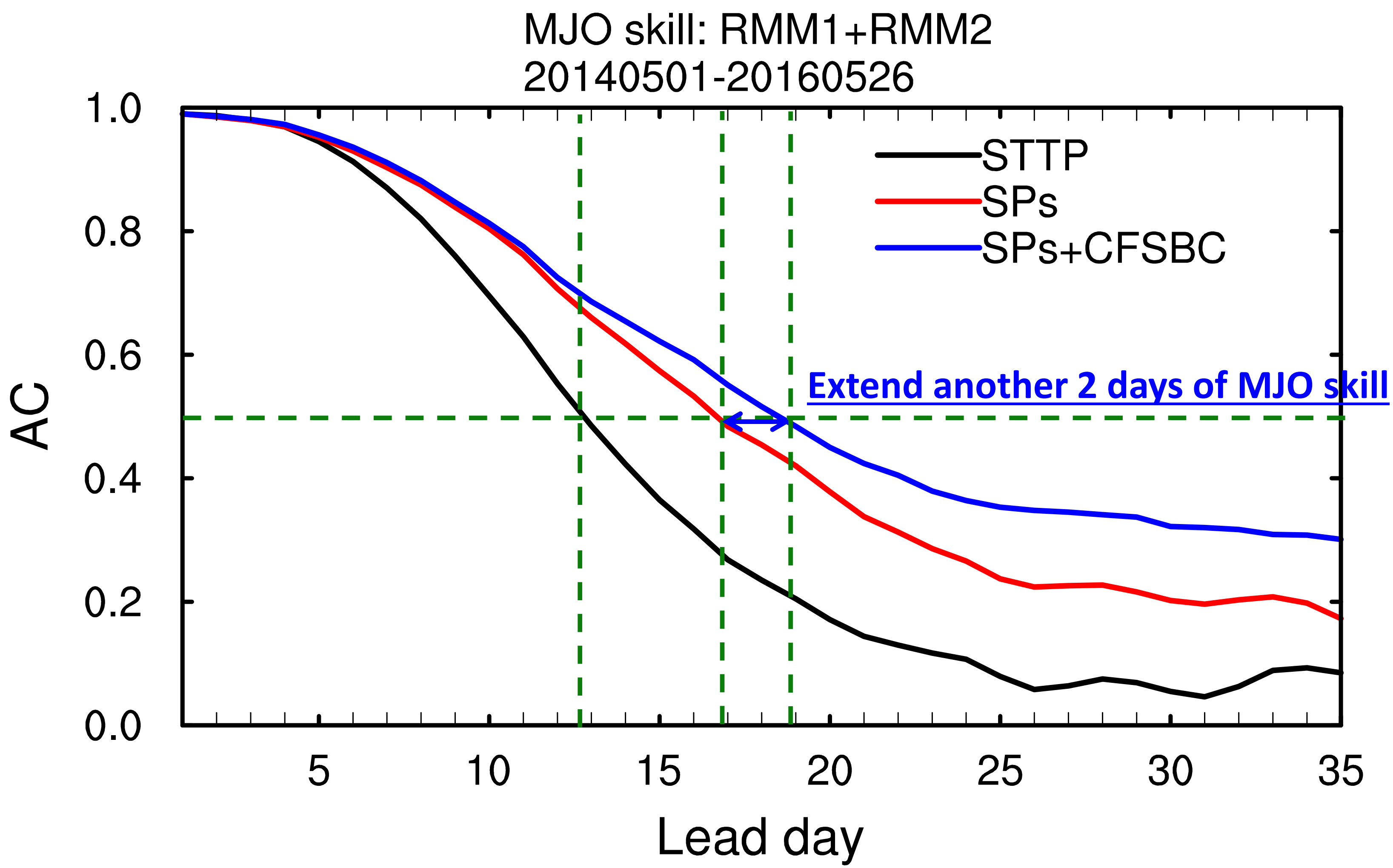
Apply new stochastic schemes:

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



Zonal wind speed (f144 hours – 6 days)
Tropical 850hPa U.
Ensemble Mean RMSE and Ensemble SPREAD
Average For 20150501 – 20151221
RMSE(solid) and SPREAD(dash)
850hPa tropical zonal wind
With stochastic perturbations:
Error is reduced
Spread is increased
250hPa tropical zonal wind
Forecast days
CTL
SPPT
5-scale
SHUM
SKEB
NEMS–GEFS 20160910–15 00Z mean ensemble spread at 144h
CTL
SPPT–CTL
SHUM–CTL
SKEB–CTL
90S
60S
30S
EQ
30N
60N
90N

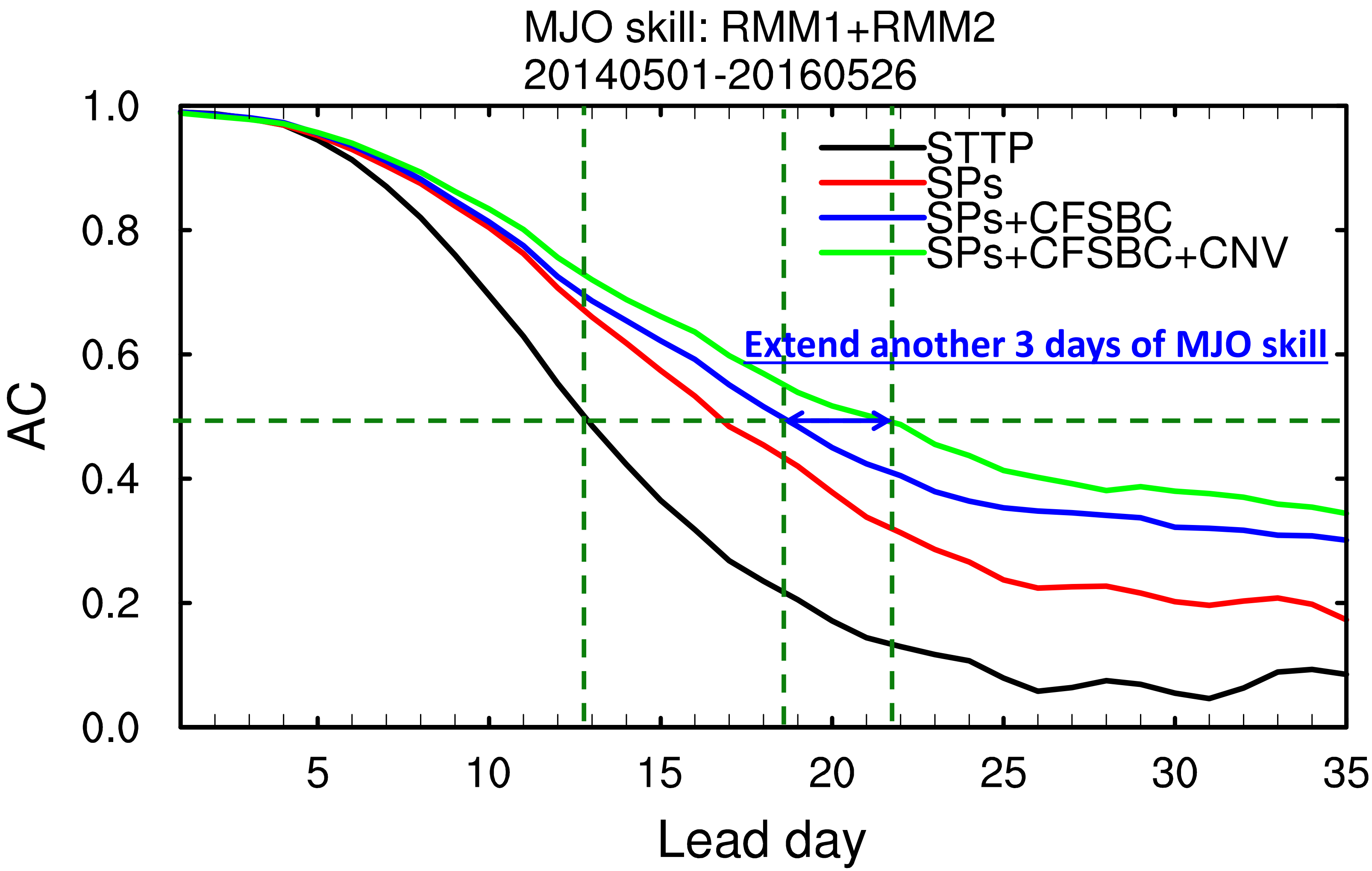
GEFS week 3&4 forecasts (May 2014-May 2016)



2-Tier SST approach (assimilate coupling)

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

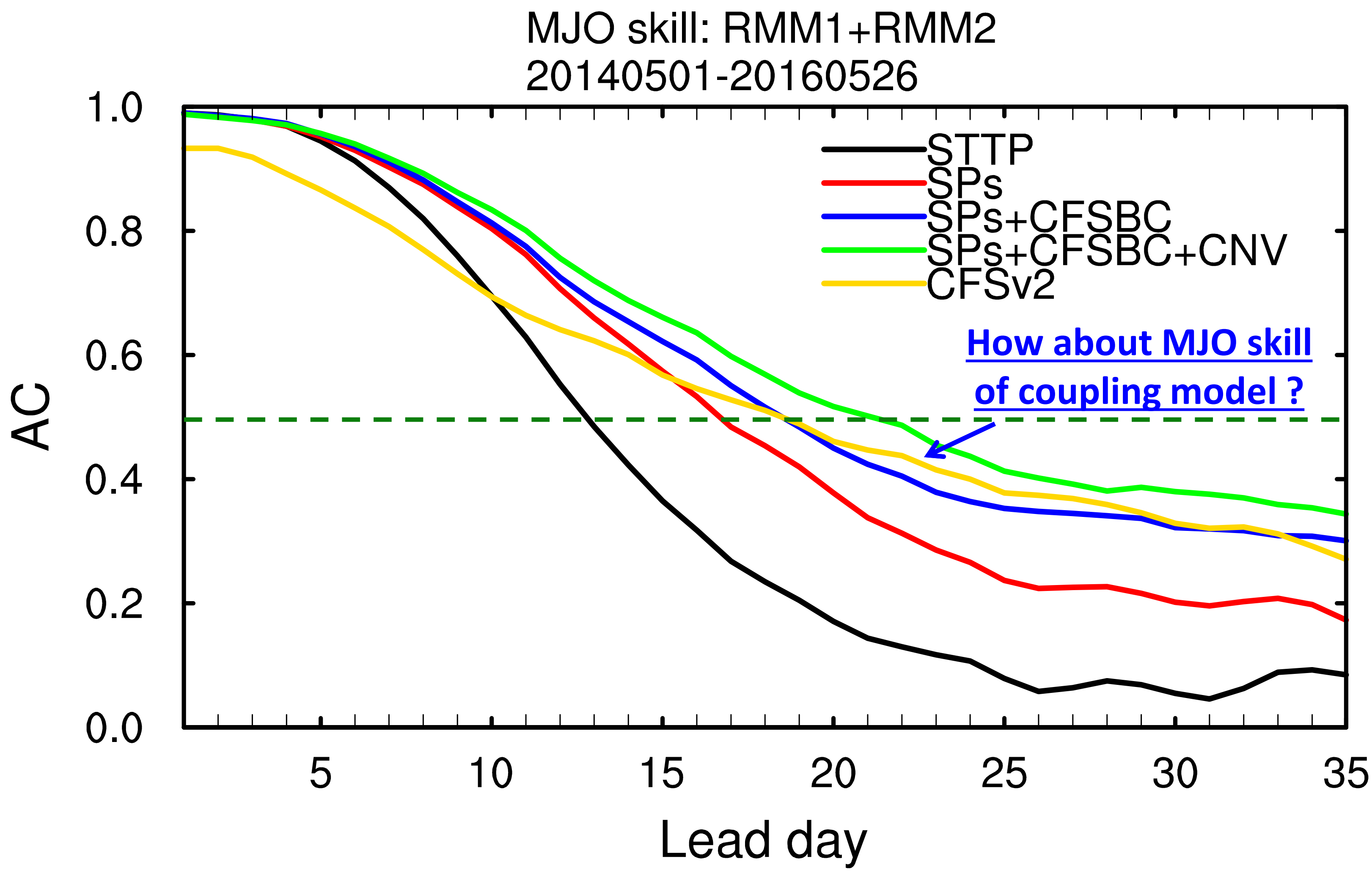
GEFS week 3&4 forecasts (May 2014-May 2016)



Apply scale aware convective scheme

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

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

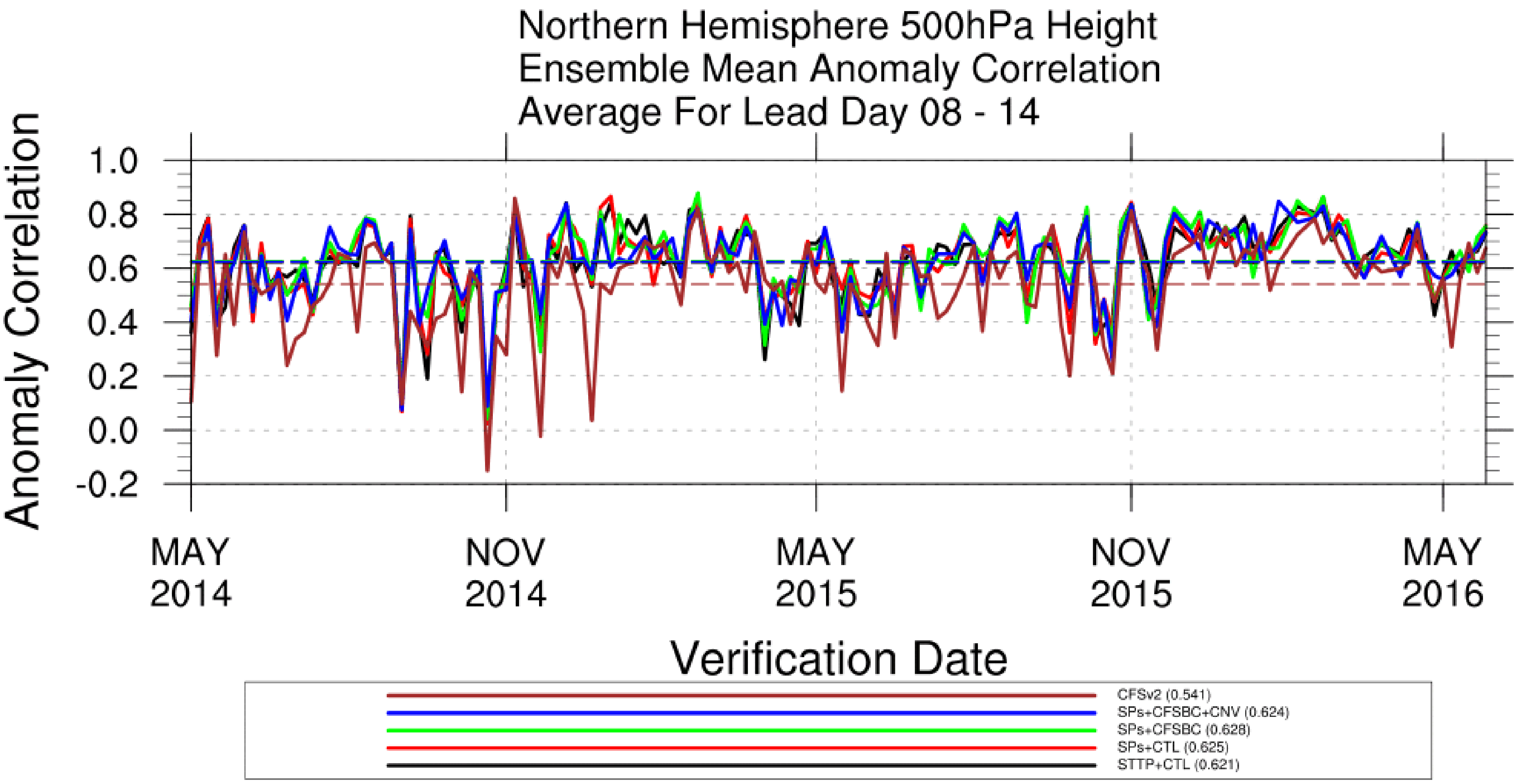
Evaluation of 500hPa height

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**

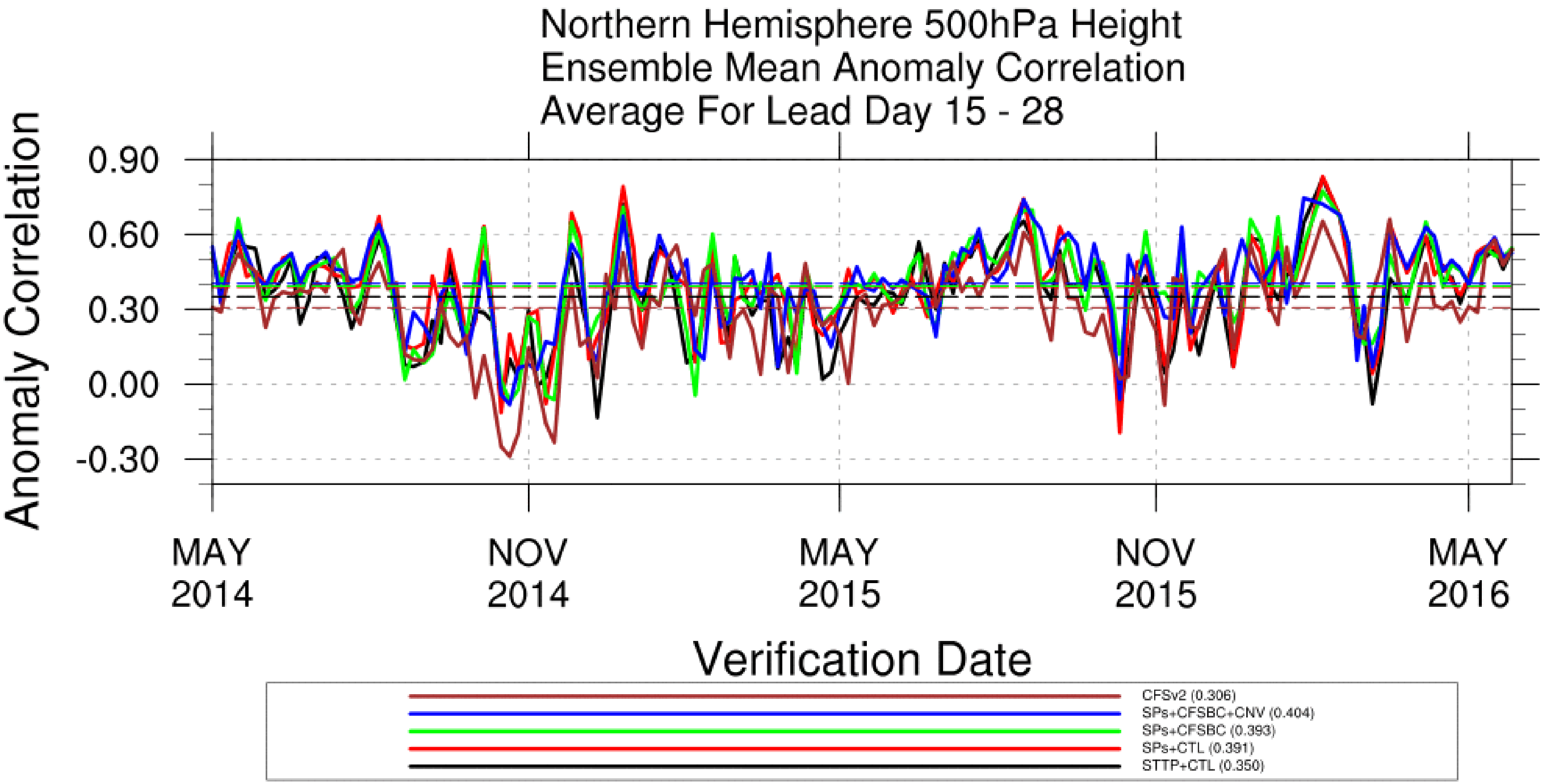
Table - Pattern Anomaly Correlation averaged over 25 months for lead day 8-14 (week 2) and lead day 15-28 (weeks 3 & 4). The bolded blue values represent results that significantly improved from the CTL at the 95% confidence level

Week-2 forecast



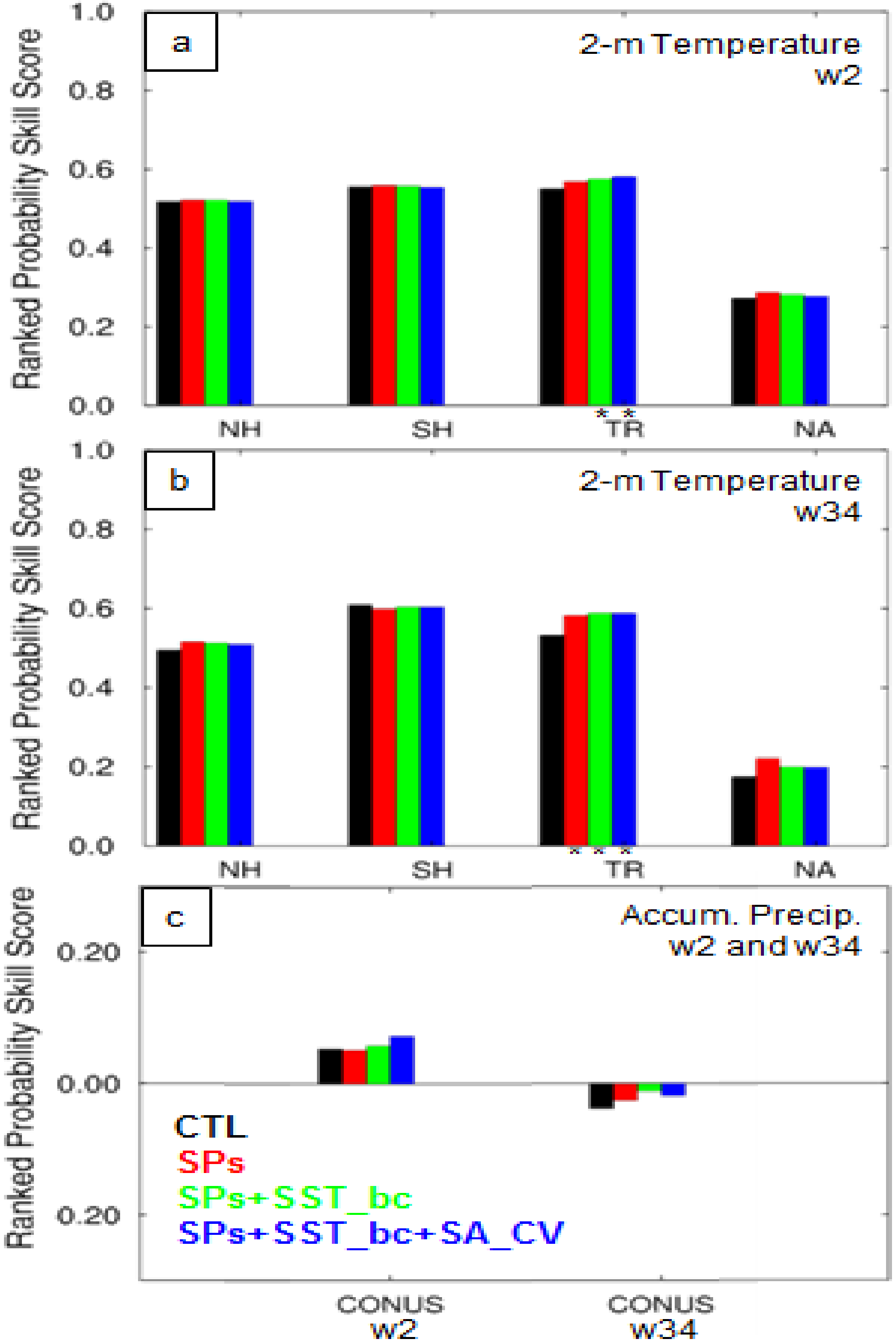
SPs+SST_bc+SA-CV (0.624) **CFSv2 (0.541)**

Weeks 3&4 forecast



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

Evaluation of Surface Elements



** Indicates statistically significant difference from STTP at 95% C.L.*

RPS forecast skills

Surface temperature

Raw forecast

Land only

Week 2 averages

Weeks 3&4 average

Significant test

Precipitation

Raw forecast

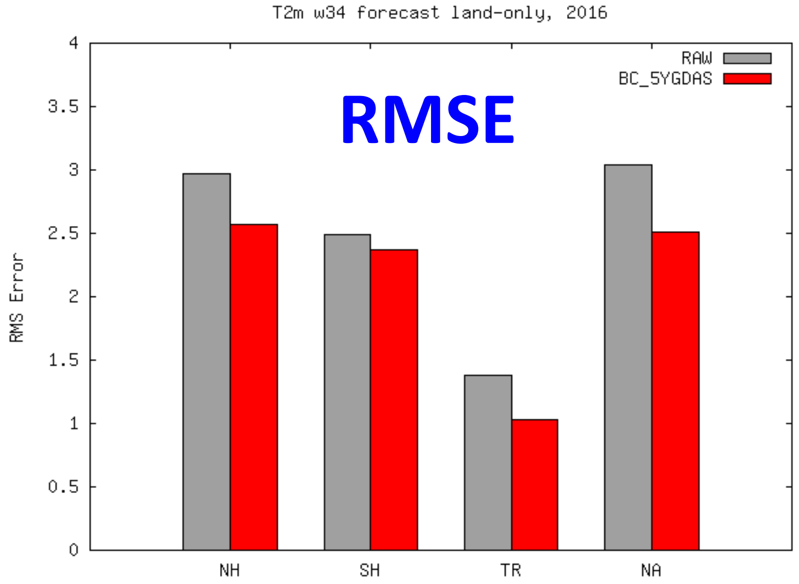
CONUS only

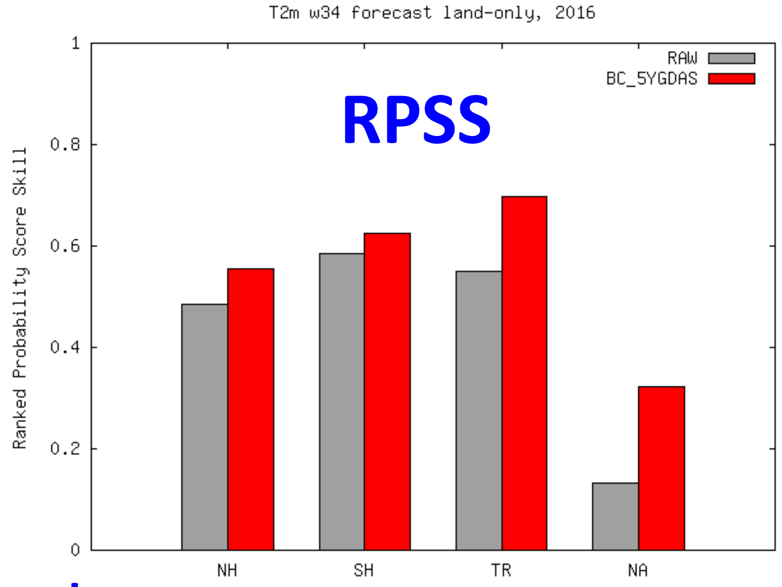
Week 2 accumulation

Weeks 3&4 accum.

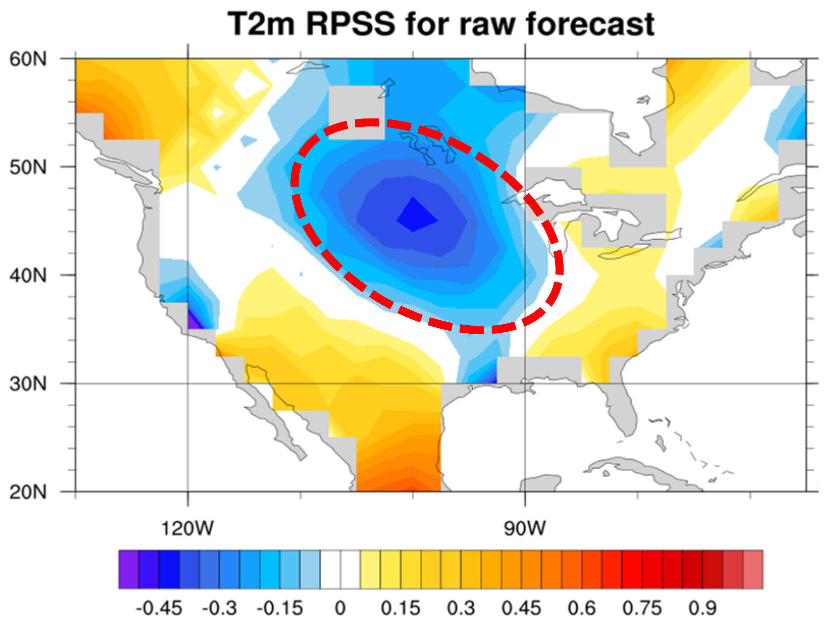
Significant test

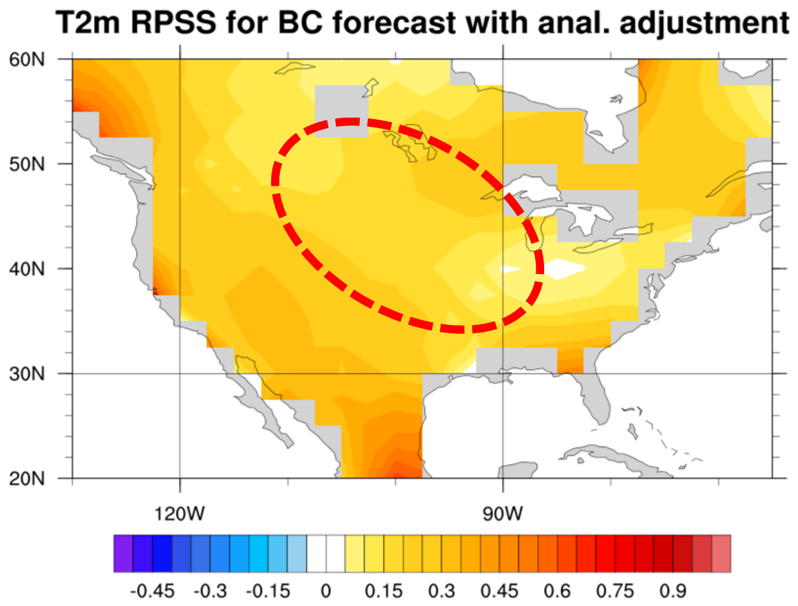
Bias correction for T2m (weeks 3&4)





Land only





The Subseasonal Experiment (SubX)

By the Numbers...

7 Global Models
17 Years of Retrospective Forecasts
1 Year of Real-time Forecasts
3-4 Week guidance for CPC Outlooks

IRI Data Library

dataset: Models SubX
iridl.ldeo.columbia.edu/SOURCES/.Models/.SubX/
Apps Bookmarks Banner ITU Support Center GMU Email My Mason
Description Expert Mode
SOURCES Models SubX

Models SubX

Models SubX: Subseasonal Experiment (SubX).

Documents

overview	an outline showing sub-datasets of this dataset
CTB	NOAA Climate Test Bed Website
DataCite DOI Metadata	DOI:10.7916/D8PG249H
SubX Data Information	Model/Data Information from SubX Project Website
SubX Project	SubX Project Website

Datasets and Variables

CESM	Models SubX CESM[**46LCESM1 30LCESM1**]
ECCC	Models SubX ECCC[**GEM**]
EMC	Models SubX EMC[**GEFS**]
ESRL	Models SubX ESRL[**FIMr1p1**]
GMAO	Models SubX GMAO[**GEOS_V2p1**]
NCEP	Models SubX NCEP[**CFSv2**]
NRL	Models SubX NRL[**NESM**]
RSMAS	Models SubX RSMAS[**CCSM4**]

Forecast & Hindcast data publicly available

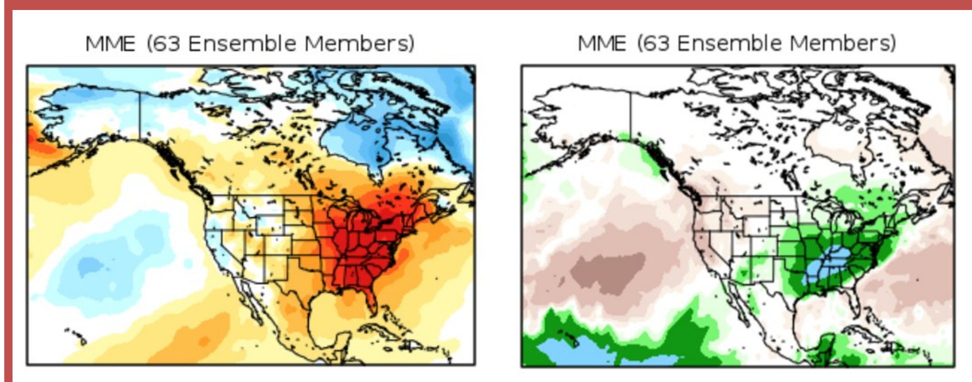
Current Data Holdings (Last updated: Feb 14, 2018)

Re-Forecasts

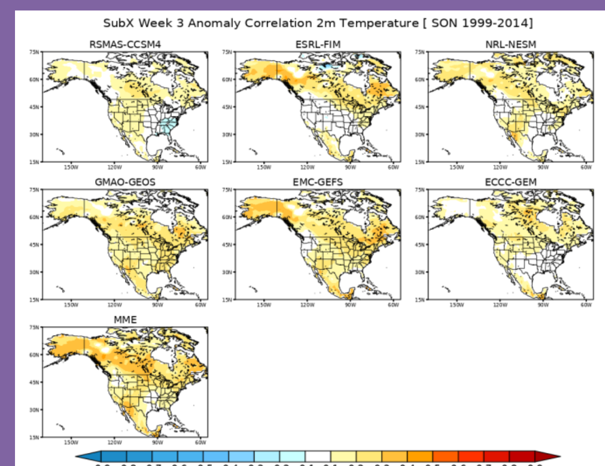
Model	Ens Members	Init Interval	P1	P2	Climo	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ECCC-GEM	4	7-days	☑	☑		1995-2014	☑							☑	☑	☑	☑	☑
EMC-GEFS	11	7-days	☑	☑		1999-2016	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
ESRL-FIM	4	7-days	☑	☑		1999-2016	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
GMAO-GEOS	4	5-days	☑			1999-2015	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
NRL-NESM	1	4 inits every 7-days	☑	☑		1999-2016	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
RSMAS-CCSM4	3	7-days	☑			1999-2016	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
NCEP-CFSv2	4	1-days	tas,pr			1999-2016	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

http://iridl.ldeo.columbia.edu/SOURCES/.Models/.SubX/

Real-time Multi-model Forecasts

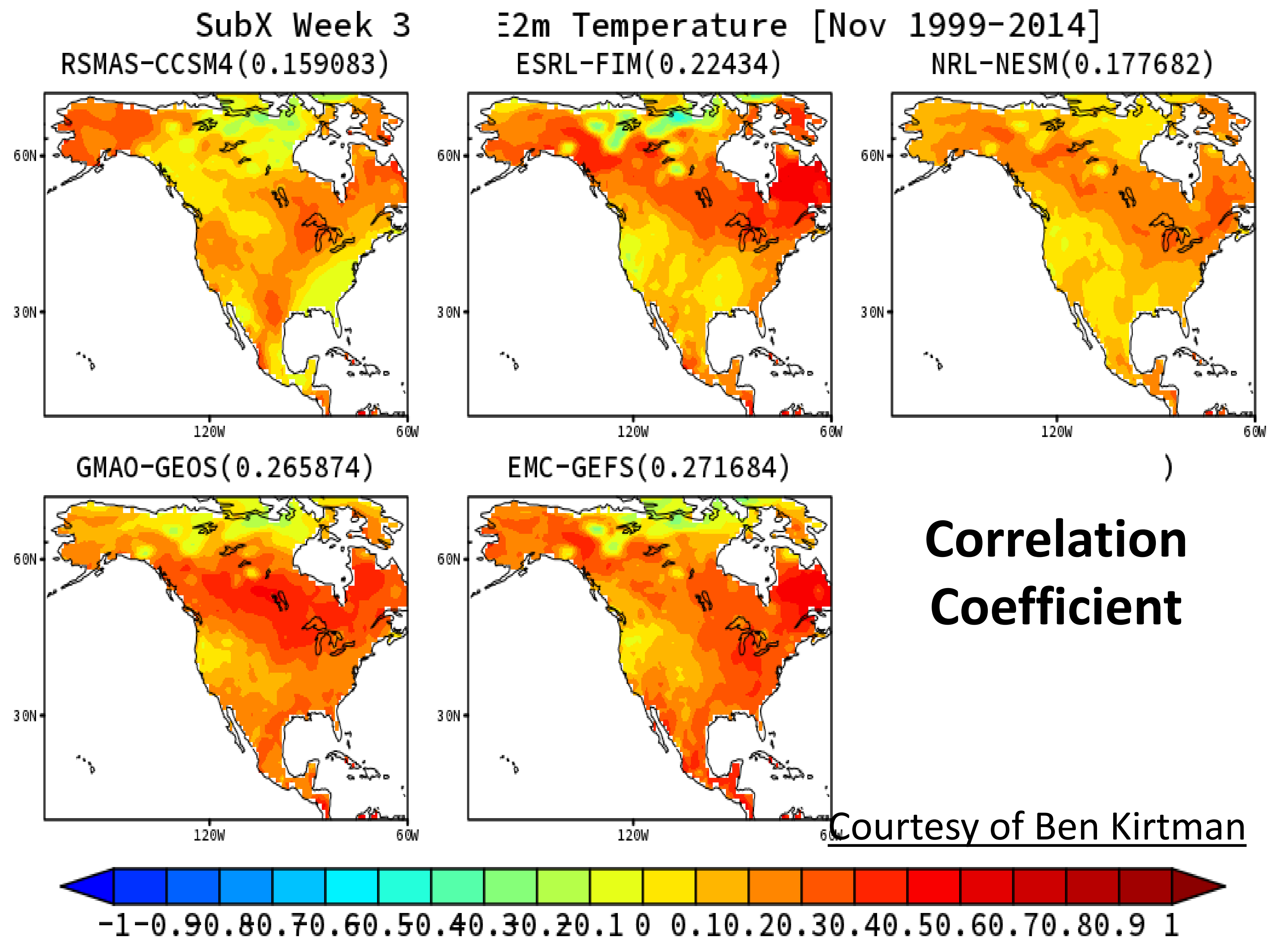


Skill Evaluation



SubX Team

http://cola.gmu.edu/kpegion/subx



SubX Week 3 E2m Temperature [Nov 1999-2014]
RSMAS-CCSM4(0.159083)
ESRL-FIM(0.22434)
NRL-NESM(0.177682)
GMAO-GEOS(0.265874)
EMC-GEFS(0.271684)
60N
30N
120W
60W
Correlation Coefficient
Courtesy of Ben Kirtman
-1 -0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

Ensemble Mean PNA and NAO Correlation

NCEP GEFS has best score of PNA and NAO (green) based on 16 years hindcast

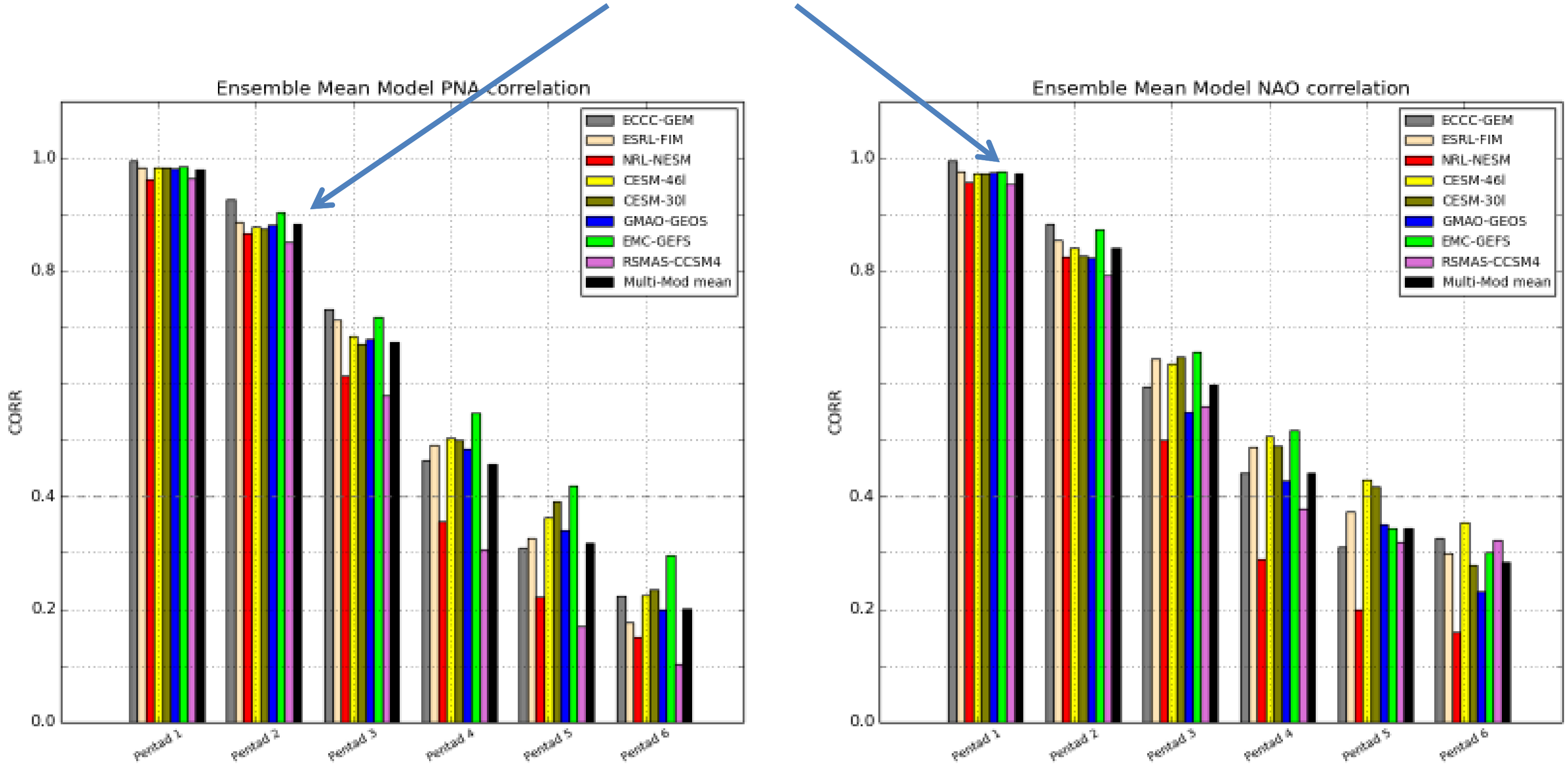


Figure 4 : Ensemble mean PNA and NAO Correlation SKILL over 6 pentads forecast range SubX datasets. The hindcast period spans from 1999 to 2014 and over the extended winter time (November to March). Roughly 350 forecast sample was used for each model

Courtesy of E. Poan and H. Lin

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.
- 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 since October 2017.

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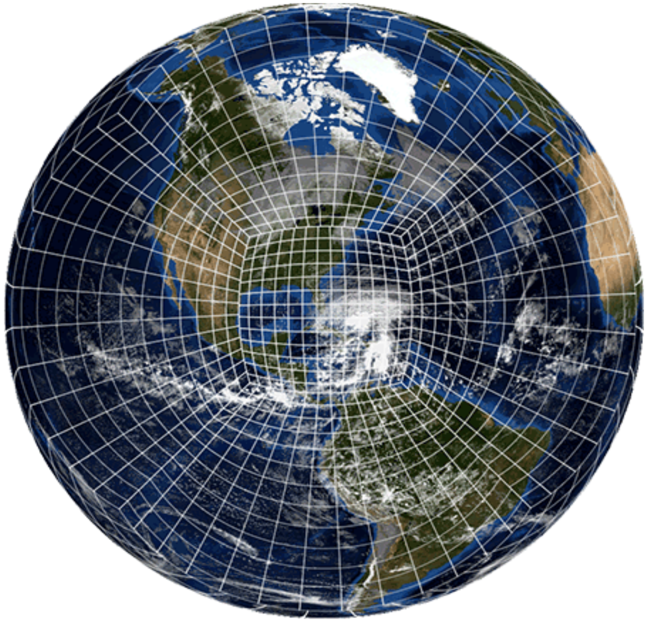
FV3 Dycore and Global Models

GFS (Deterministic)

- March 2018: Real Time FV3GFS Beta Version
  - C768L64 (~13km)
  - GFDL MP
- Q1-Q2 2019: Implement FV3GFS Beta Version



GEFS (Ensemble) v12

- Configuration
  - C384L64 (~25km)
  - 31 members, 4 cycles/day
  - 35 days forecast
- Q3FY18: Start to produce 20 years (1999-2018) reanalysis
- Q4FY18: Start to produce 30 years (1989-2018) reforecast
- Q2FY19: Start to produce retrospective runs (2-3 years)
- Q3FY19: Start users evaluation
- Q1FY20: Implement FV3GEFS operational version (v12)

What's "Finite-Volume" about FV3?

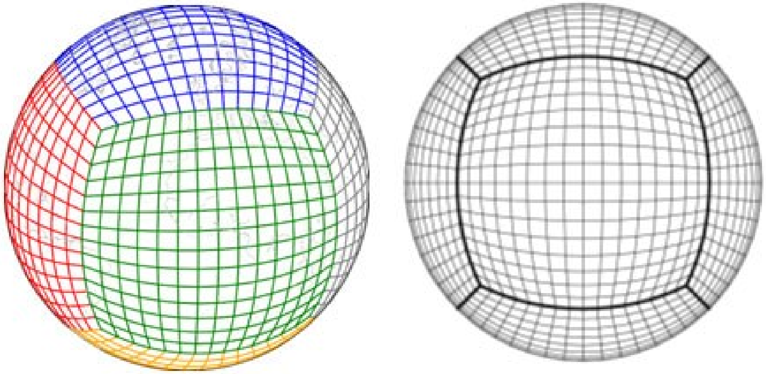
1. Vertically Lagrangian control-volume discretization based on 1st principles (Lin 2004)
   - Conservation laws solved for the control-volume bounded by two Lagrangian surfaces

2. Physically based forward-in-time "horizontal" transport (between two Lagrangian surfaces)
   - Conservative analog to the highly efficient trajectory based two-time-level semi-Lagrangian schemes in IFS; locally conservative and (optionally) monotonic via constraints on sub-grid distributions (Lin & Rood 1996; Putman & Lin 2007) – good for aerosols and cloud MP
   - Space-time discretization is non-separable -- hallmark of a physically based FV algorithm

3. Combined use of C & D staggering with optimal FV representation of <u>Potential Vorticity</u> and <u>Helicity</u>
   → important from synoptic-scale down to storm-scale

4. Finite-volume integration of pressure forces (Lin 1997)
   - Analogous to the forces acting upon an aircraft wing (lift & drag forces)
   - Horizontal and vertical influences are non-separable (Arakawa-type linear analyses are not applicable to FV's Lagrangian discretization)

5. For non-hydrostatic extension, the vertically Lagrangian discretization reduces the sound-wave solver into a 1-D problem (solved by either a Riemann solver or a semi-implicit solver with conservative cubic-spline)



FV3 on Cubed-Sphere Grid

<u>Courtesy of Dr. S. J. Lin</u>

FV3GEFS experiments

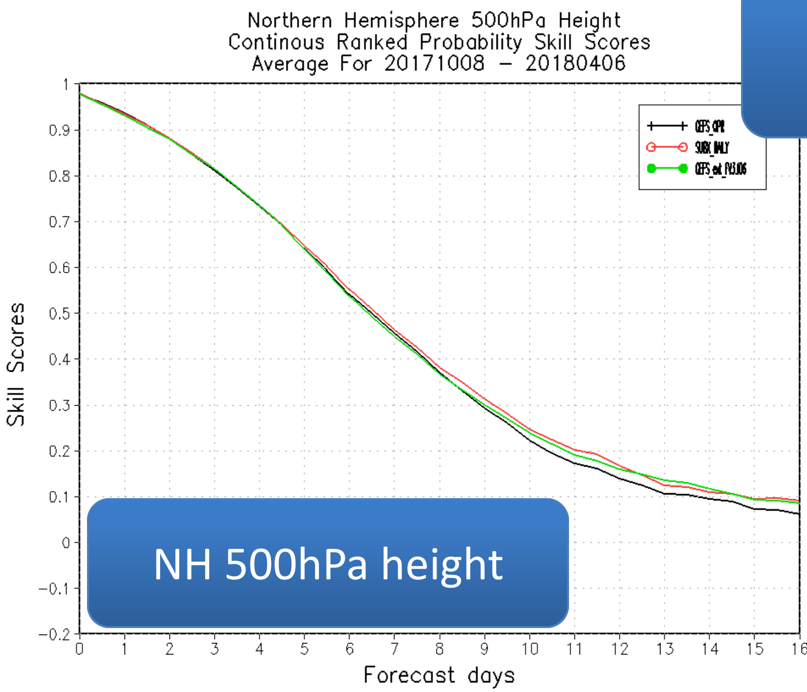
- Resolution – C384 (~25km)
- Lead time – 35 days
- Ensemble members – 20 perturbed + 1 control
- Period: Oct. 8 2017 – Apr. 6 2018 (37 cases)
- Model and initial perturbations
  - GFS physics with GFDL MP
  - NSST – assimilate diurnal variation
  - EnKF f06 for ensemble initial perturbation (operation)
- Sciences
  - Three stochastic schemes (SKEB, SPPT and SHUM)
  - 2-tier SST
  - New SA convective parameterization scheme

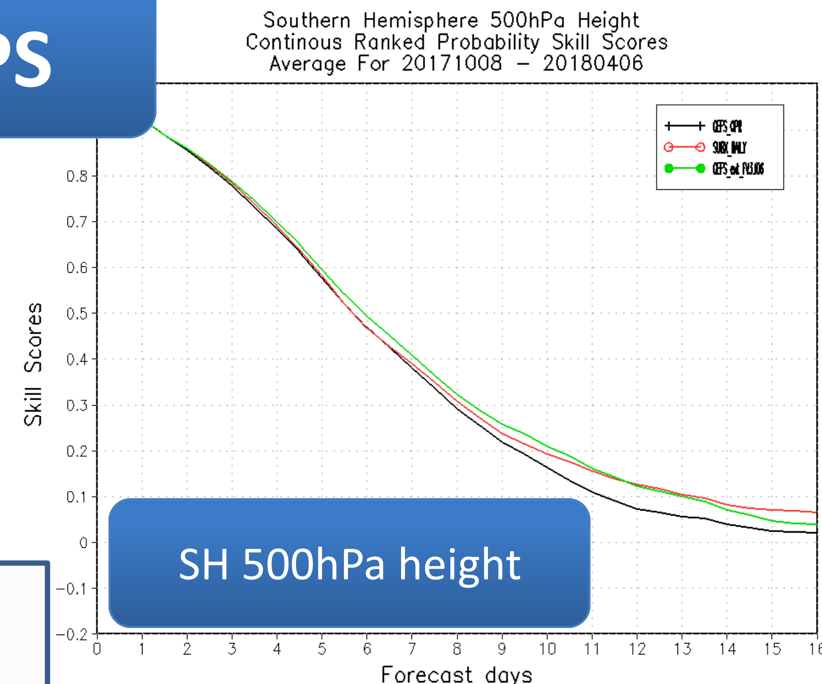
Possible experiences to share

- Initial uncertainties
- Model uncertainties
- Model dynamic
- Model physics
- Boundary forcing
- Calibration

Weather Forecast (plus Week-2)

CRPS

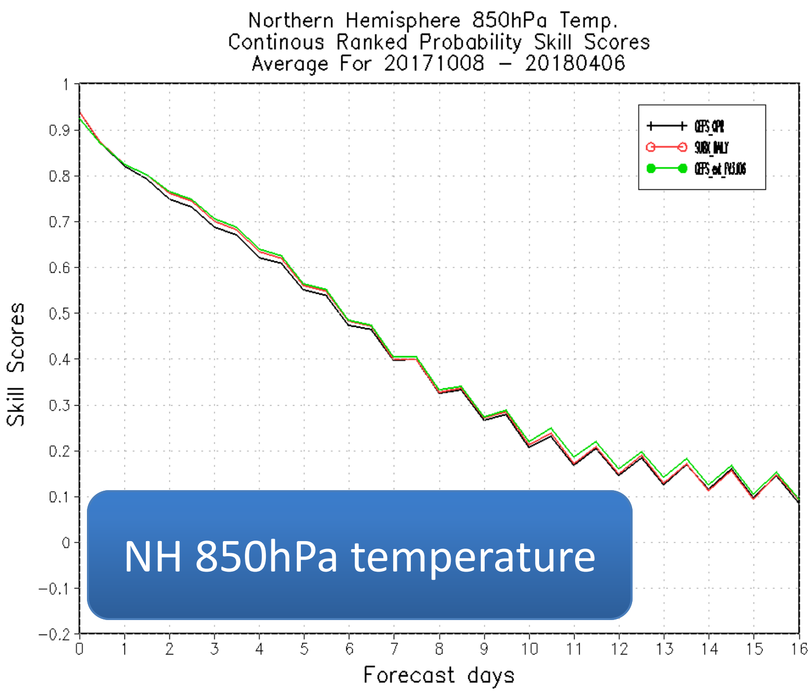


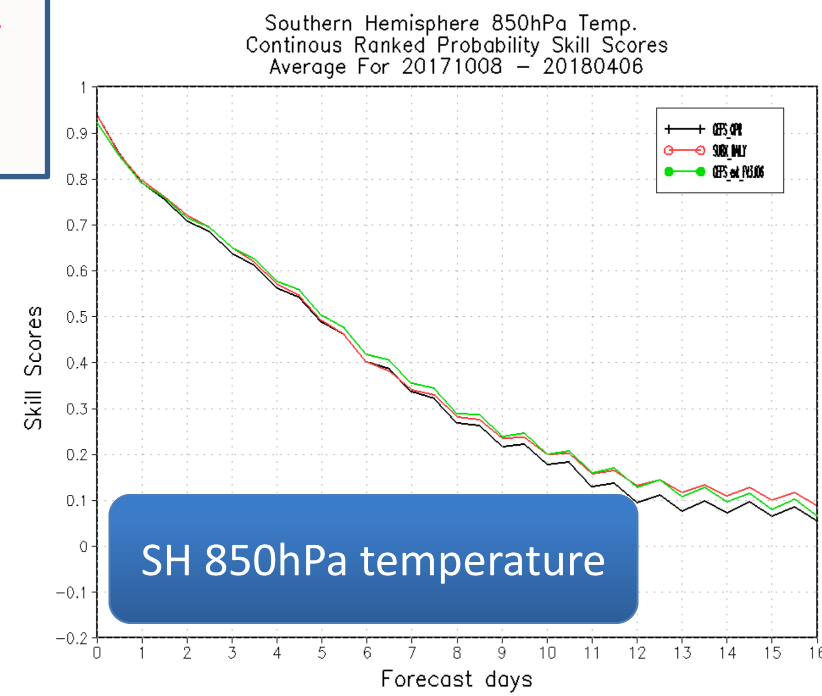


OPR

SubX

FV3



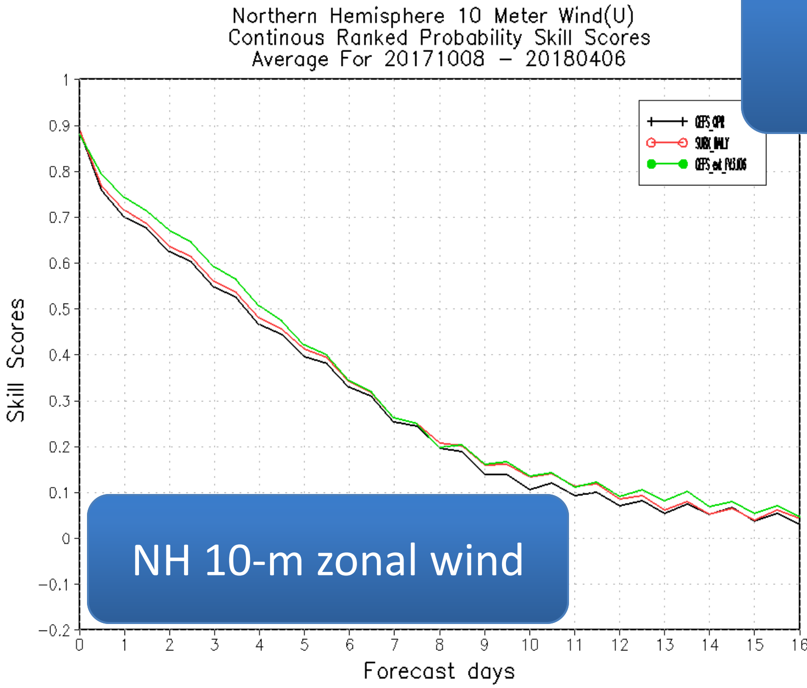


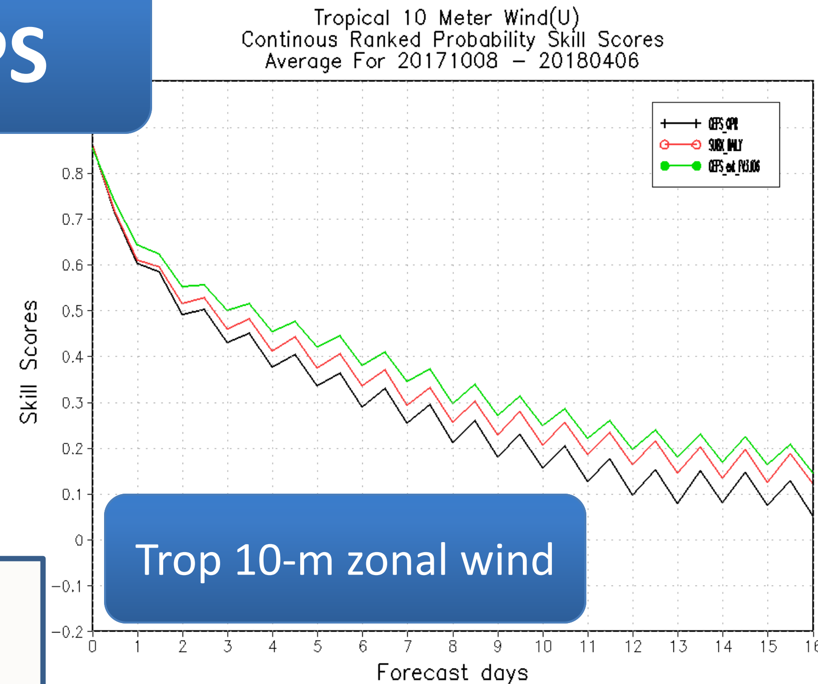
CRPS

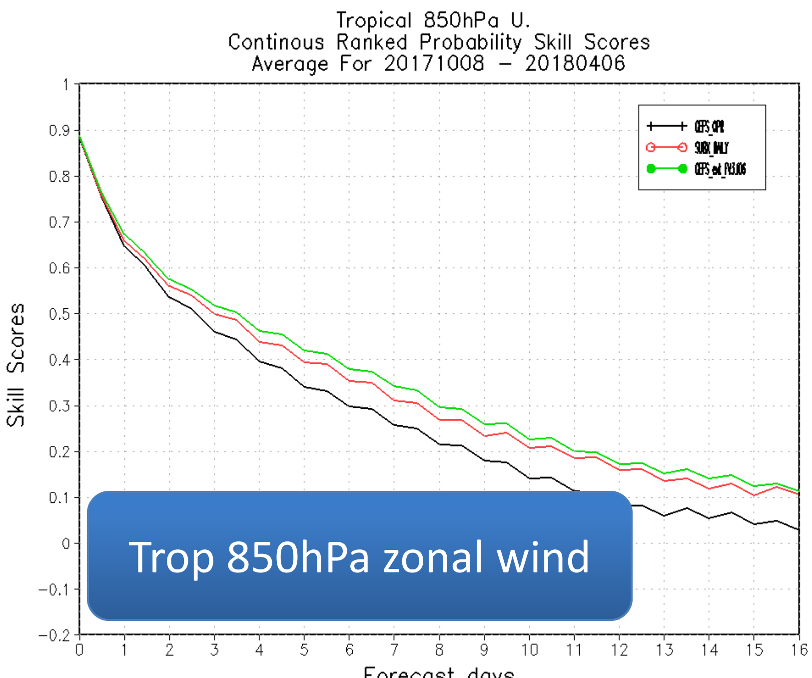
OPR

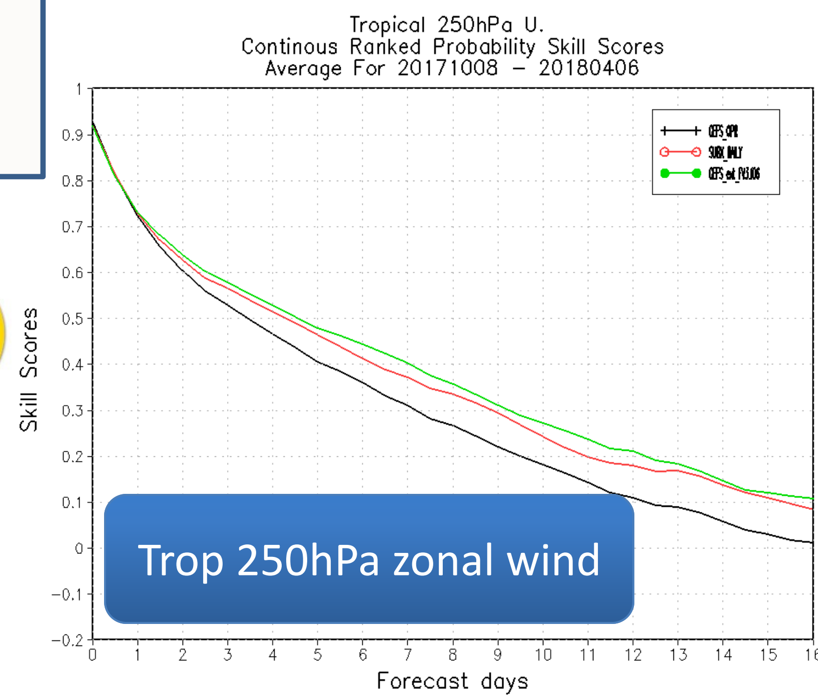
SubX

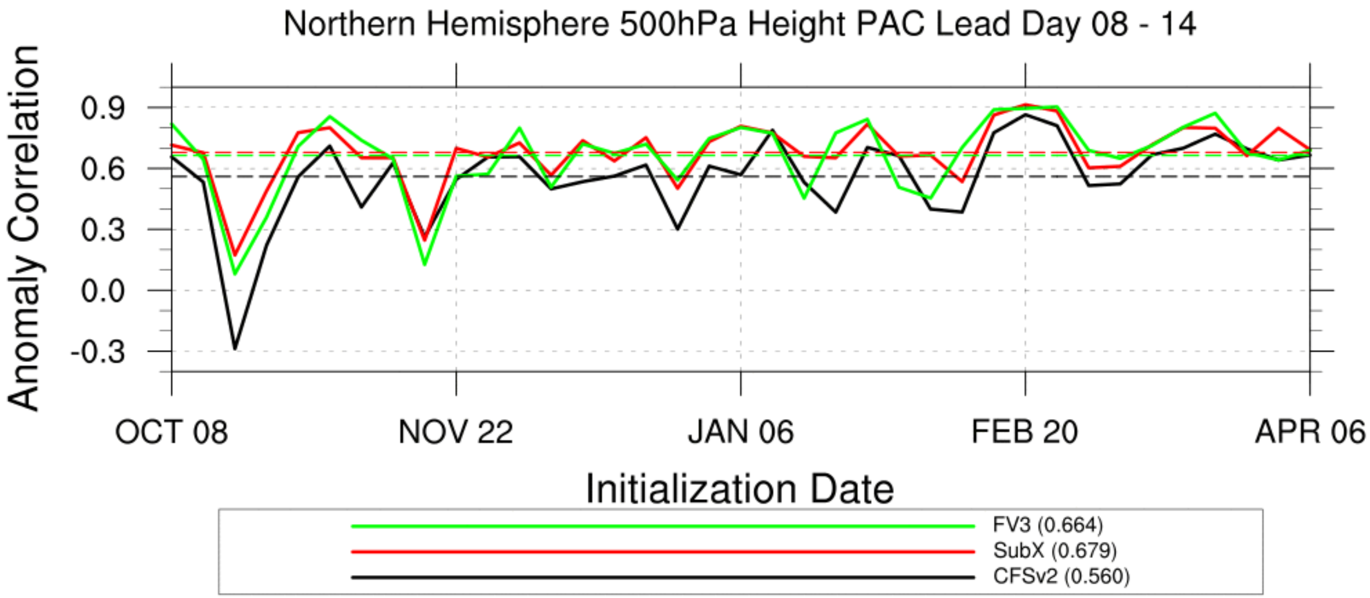
FV3









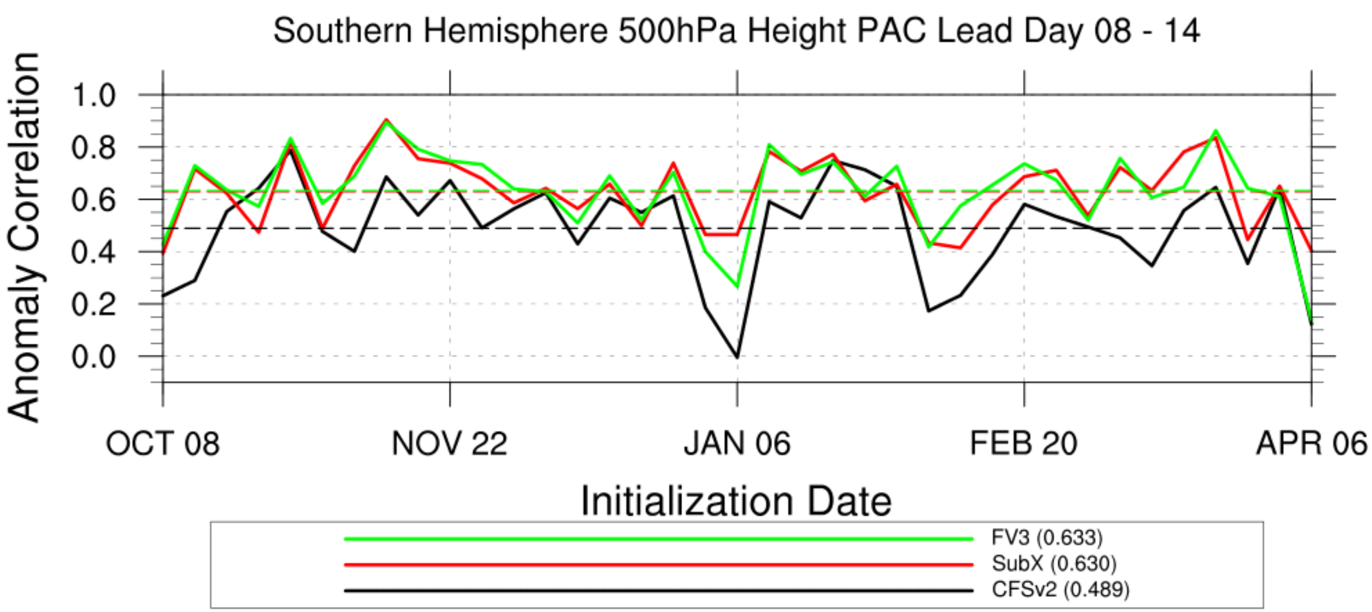


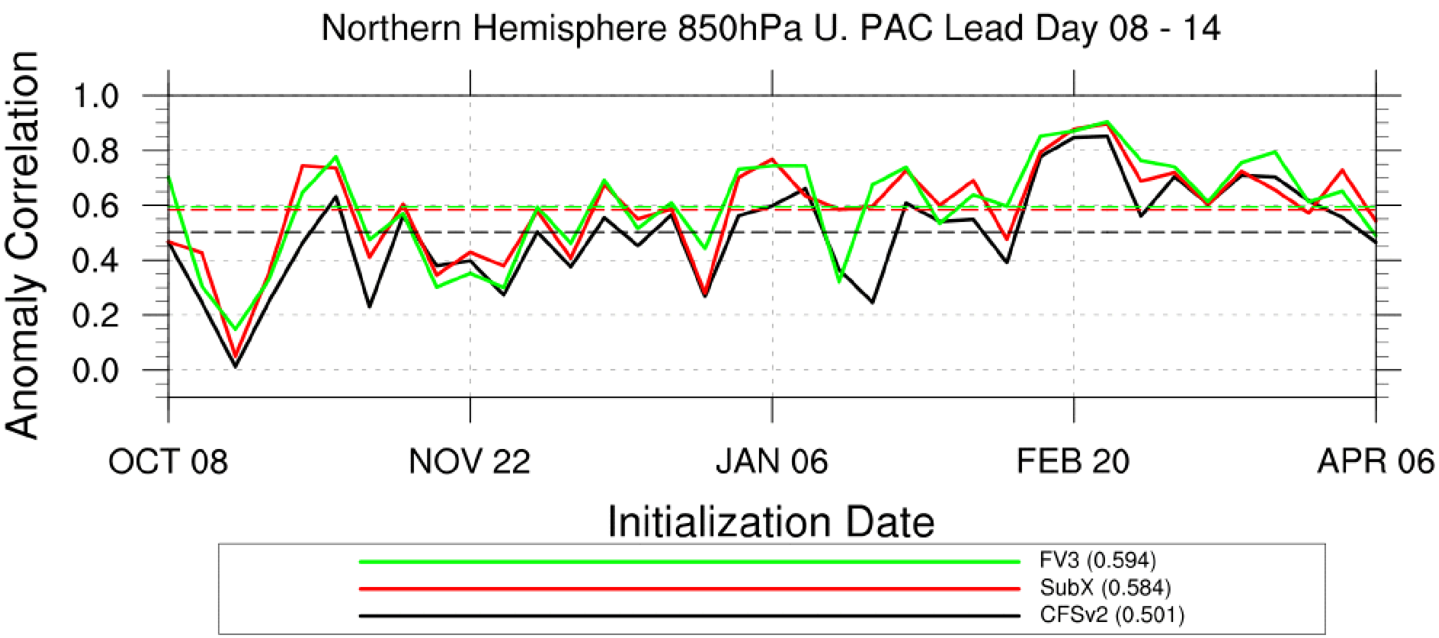
Week 2 average

CFSv2 --- 0.560
SubX --- 0.679
FV3 --- 0.664

Week 2 average

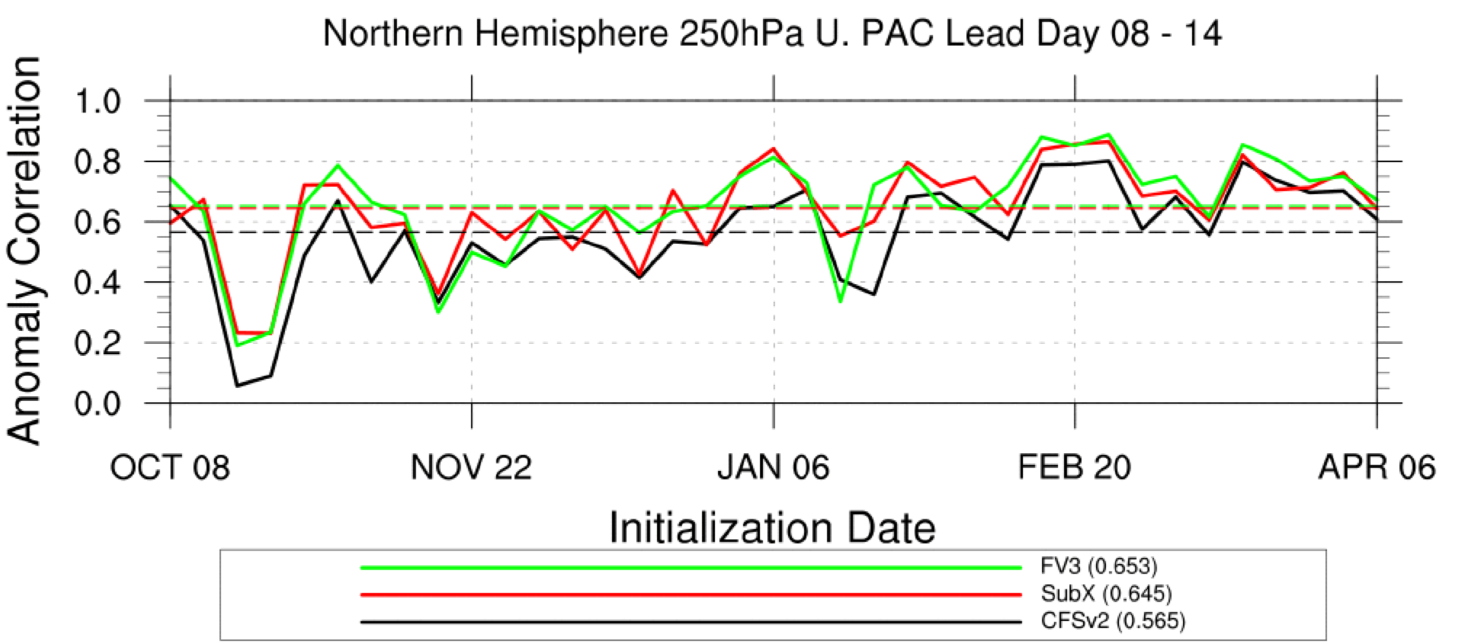
CFSv2 --- 0.489
SubX --- 0.630
FV3 --- 0.633





Week 2 average

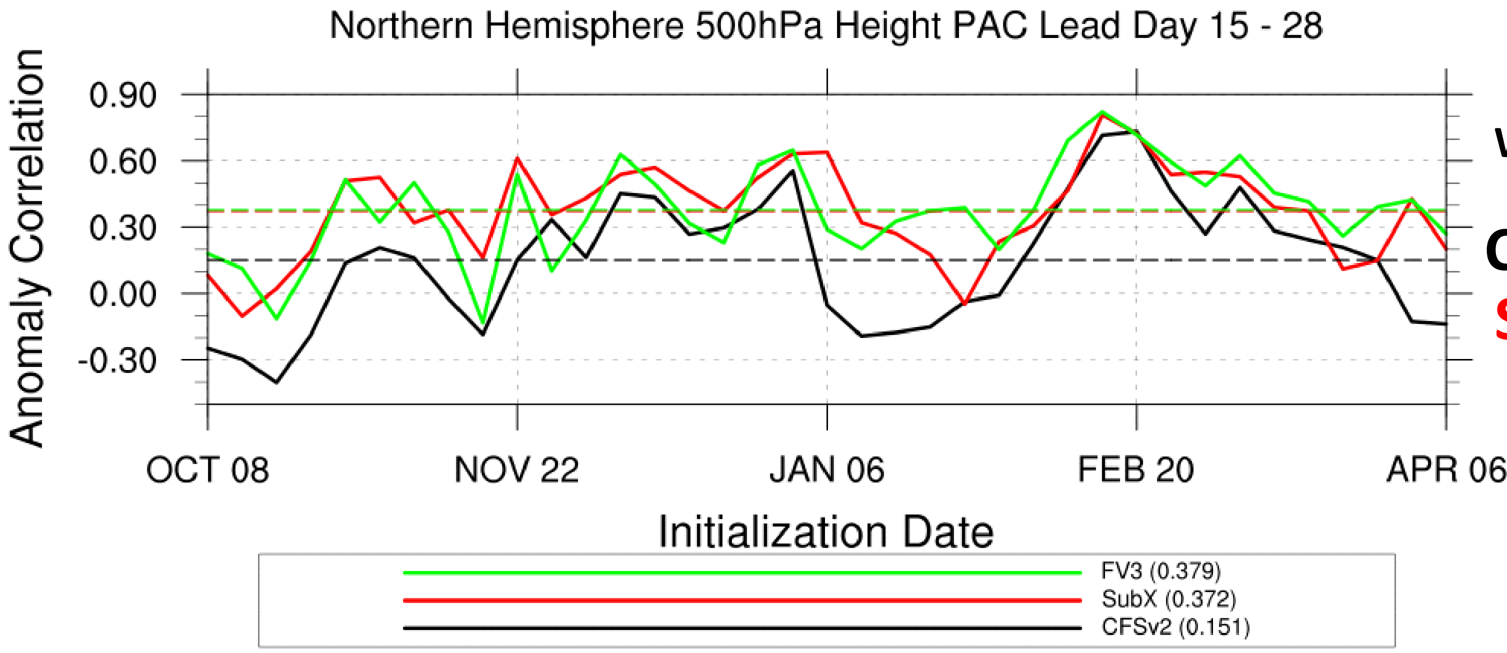
CFSv2 --- 0.501
SubX --- 0.684
FV3 --- 0.694



Week 2 average

CFSv2 --- 0.565
SubX --- 0.645
FV3 --- 0.653

Weeks 3&4 Forecast (plus MJO)

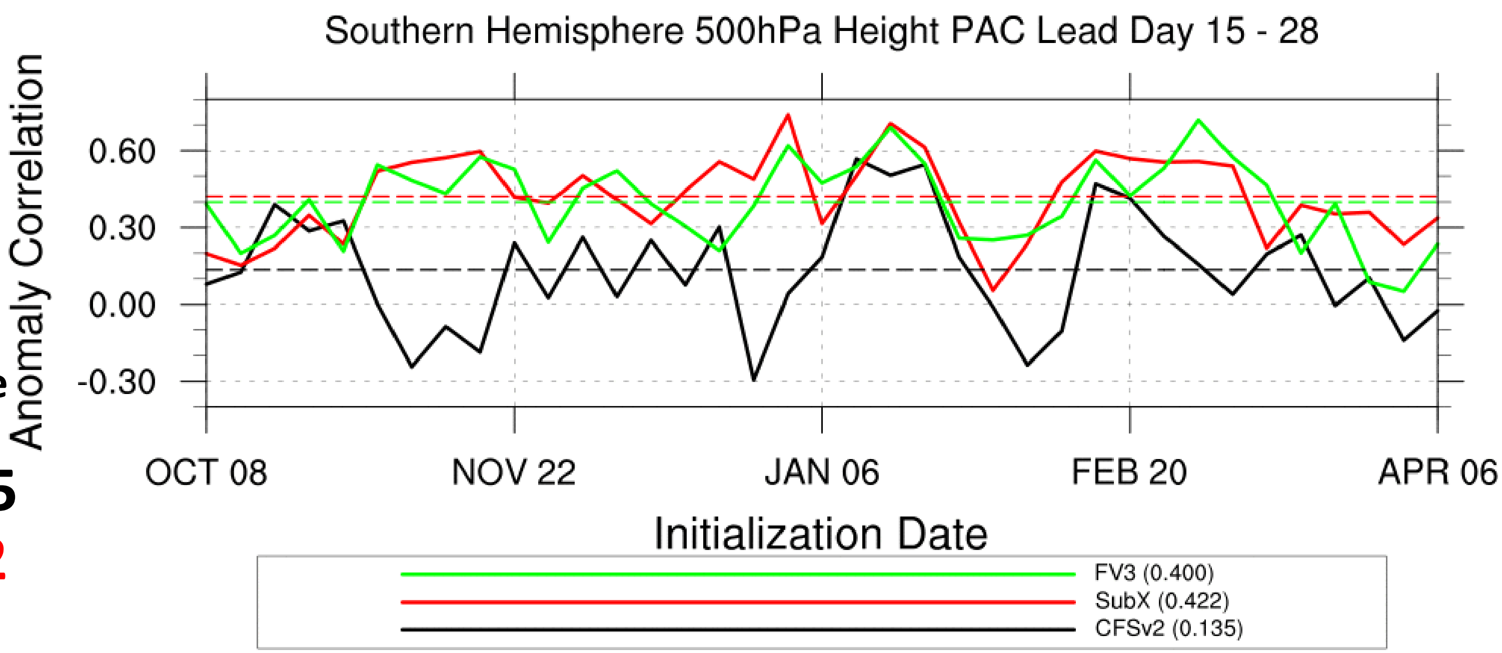


Weeks 3&4 average

CFSv2 --- 0.151

SubX --- 0.372

FV3 --- 0.379

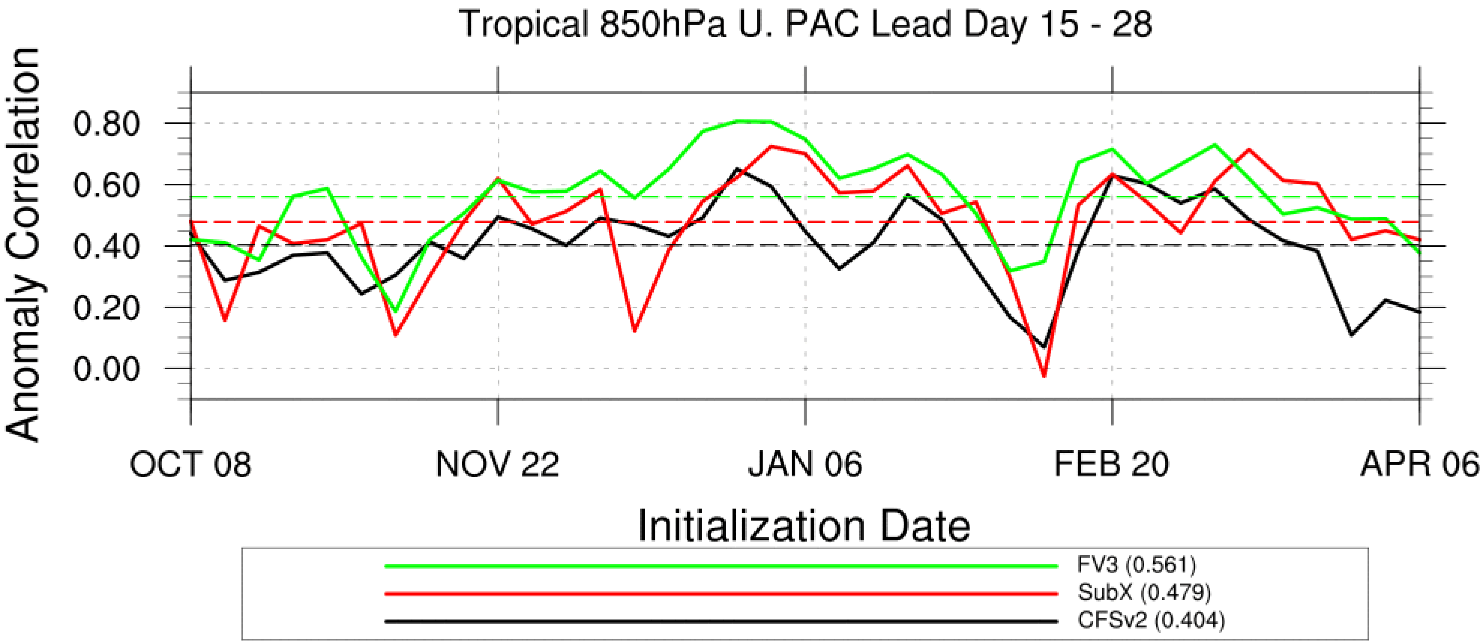


Weeks 3&4 average

CFSv2 --- 0.135

SubX --- 0.422

FV3 --- 0.400

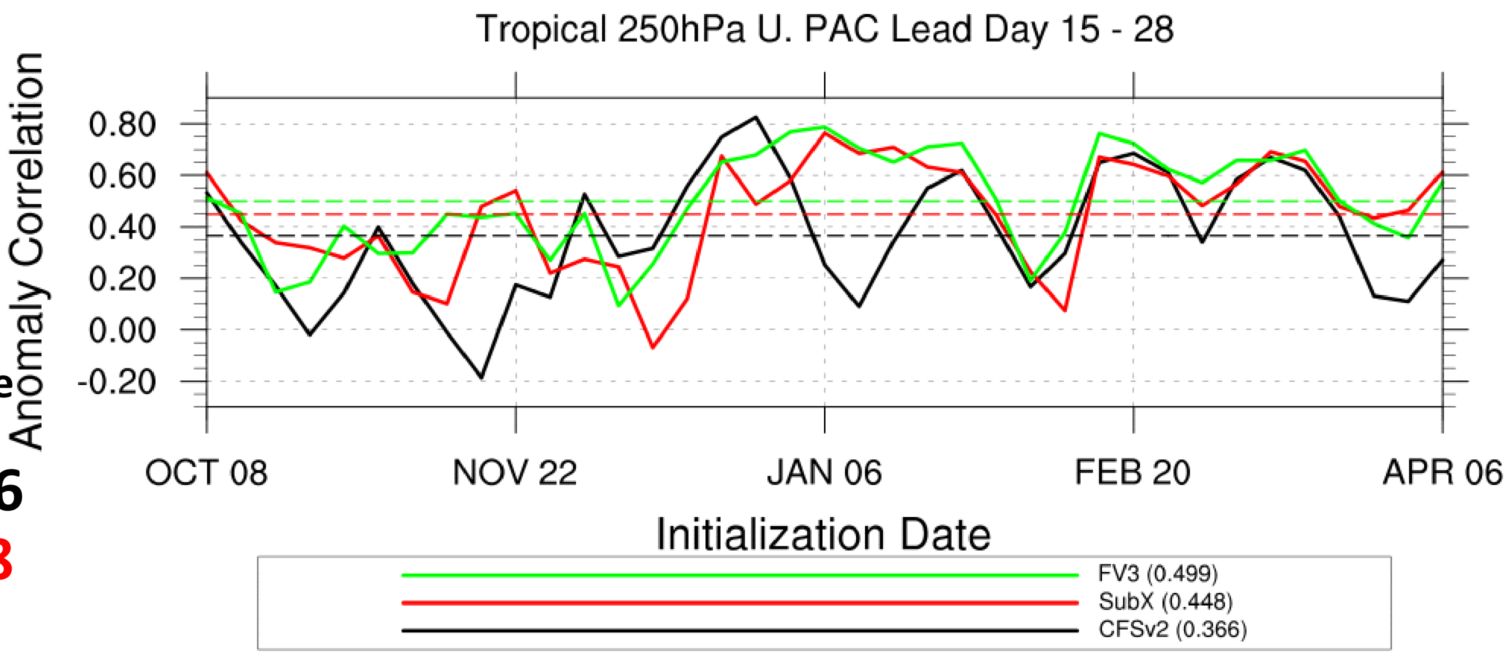


Weeks 3&4 average

CFSv2 --- 0.404

SubX --- 0.479

FV3 --- 0.561

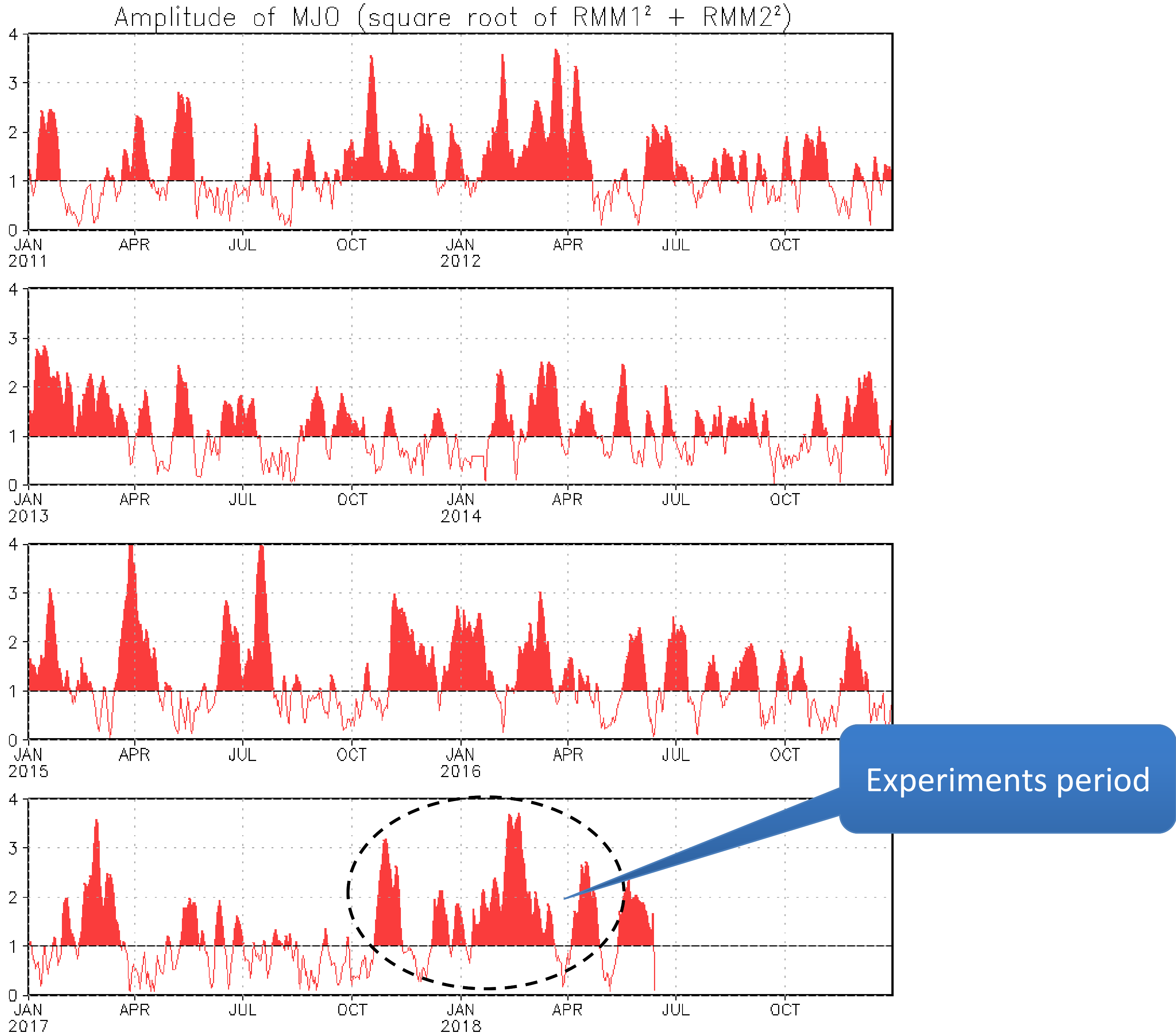


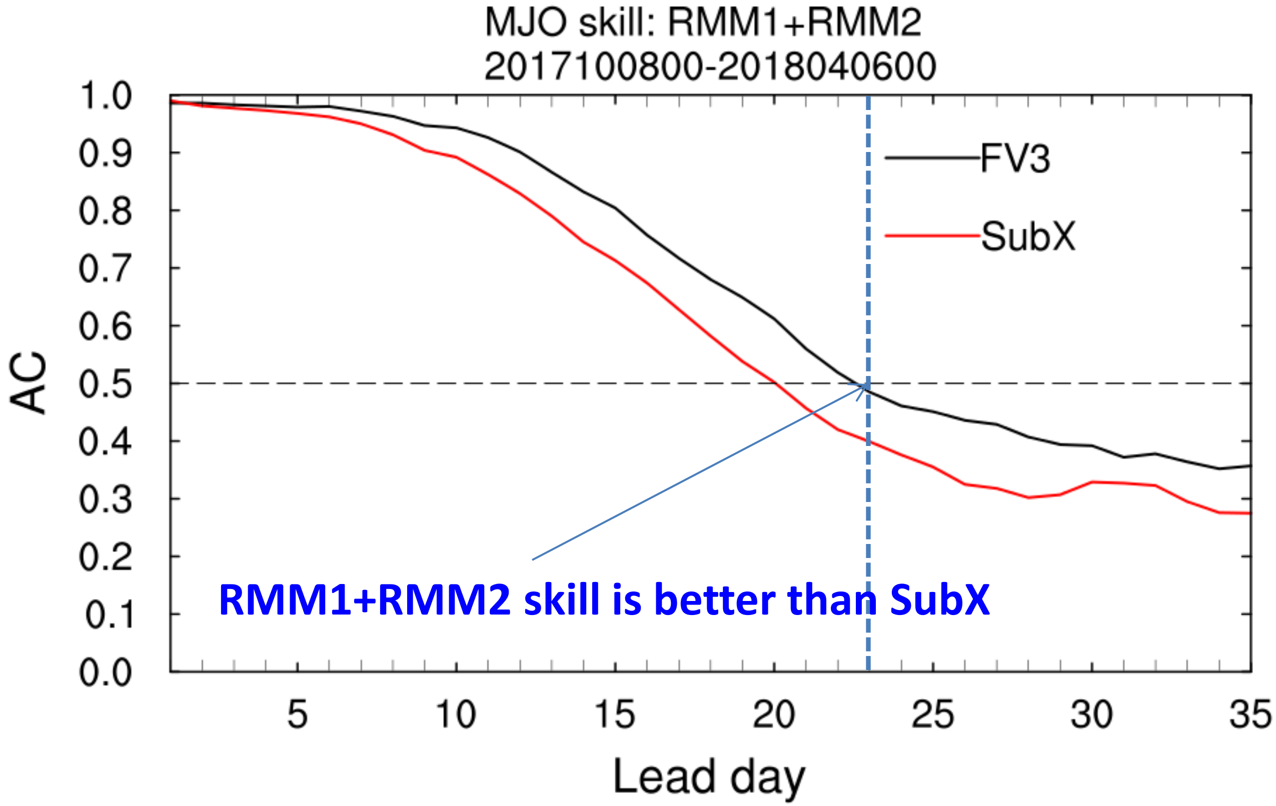
Weeks 3&4 average

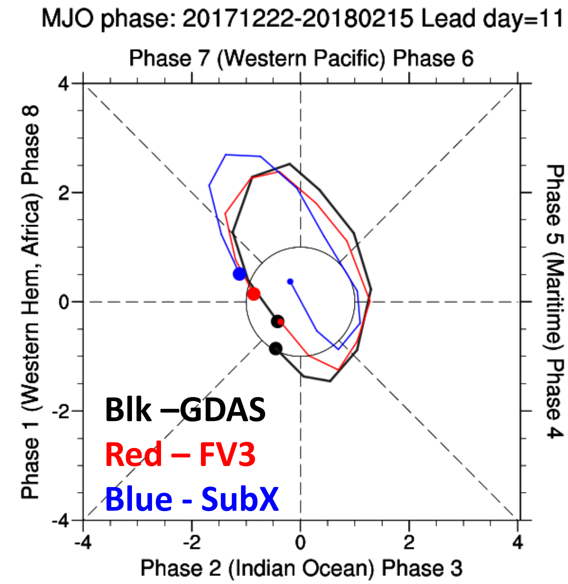
CFSv2 --- 0.366

SubX --- 0.448

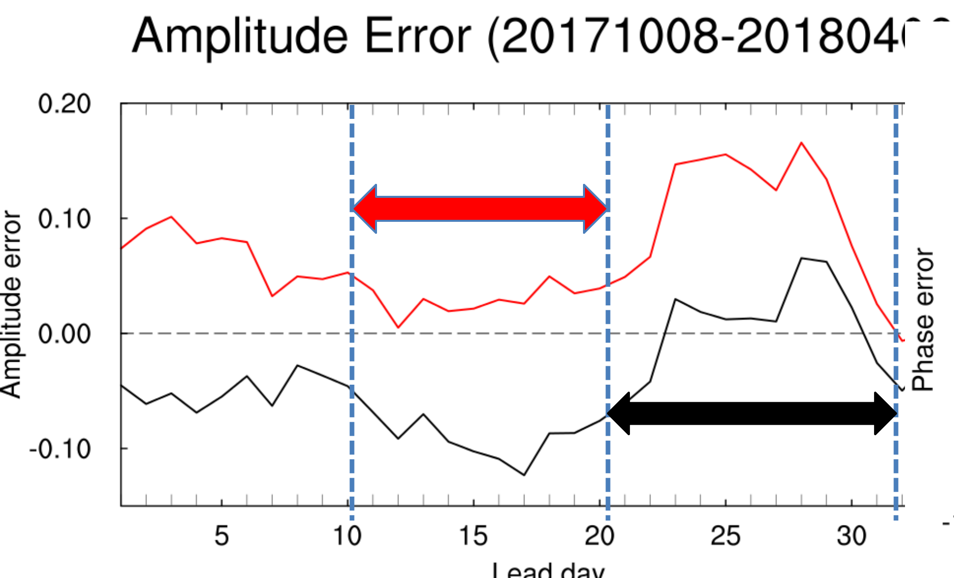
FV3 --- 0.499

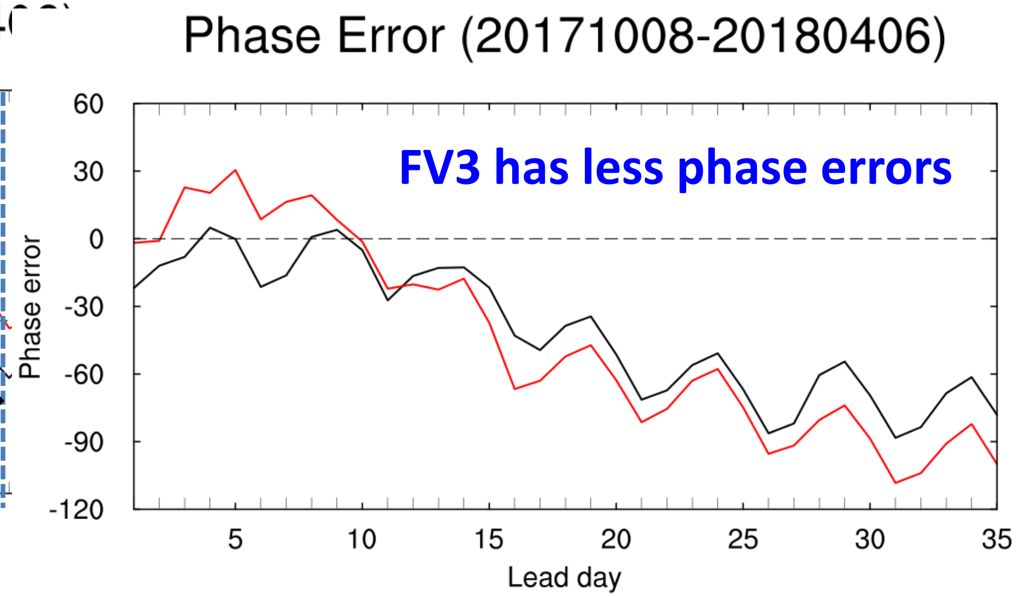

Amplitude of MJO (square root of RMM1² + RMM2²)
0
1
2
3
4
JAN
2011
APR
JUL
OCT
JAN
2012
APR
JUL
OCT
JAN
2013
APR
JUL
OCT
JAN
2014
APR
JUL
OCT
JAN
2015
APR
JUL
OCT
JAN
2016
APR
JUL
OCT
JAN
2017
APR
JUL
OCT
JAN
2018
APR
JUL
OCT
Experiments period



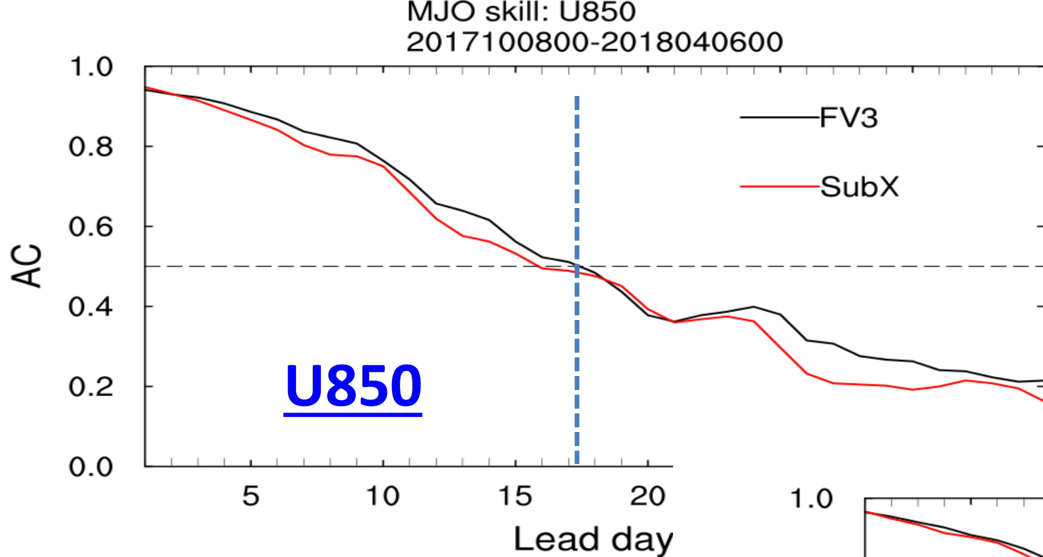


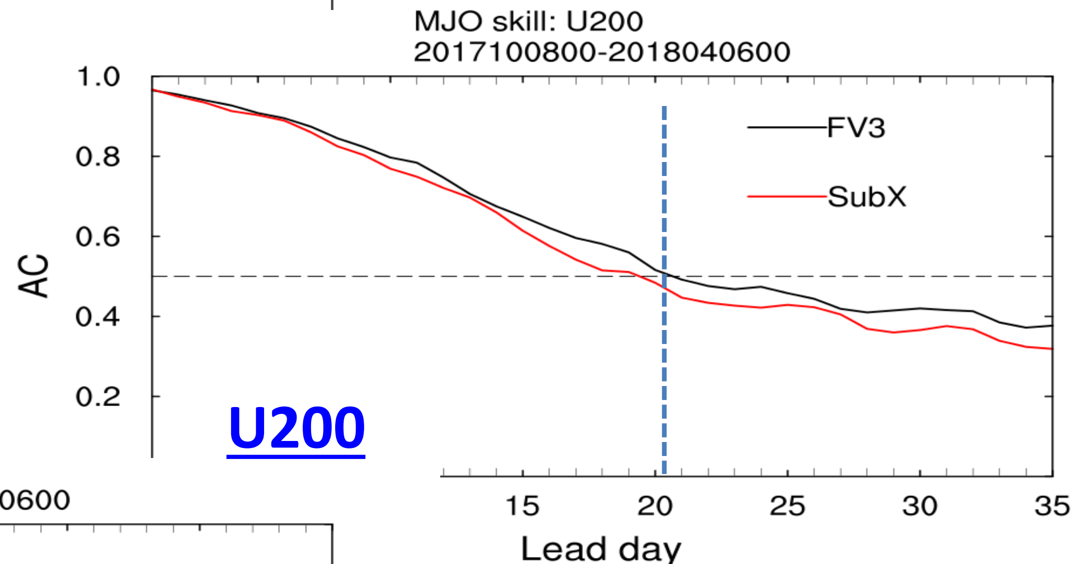
Example of one MJO phase (lead – 11 days)

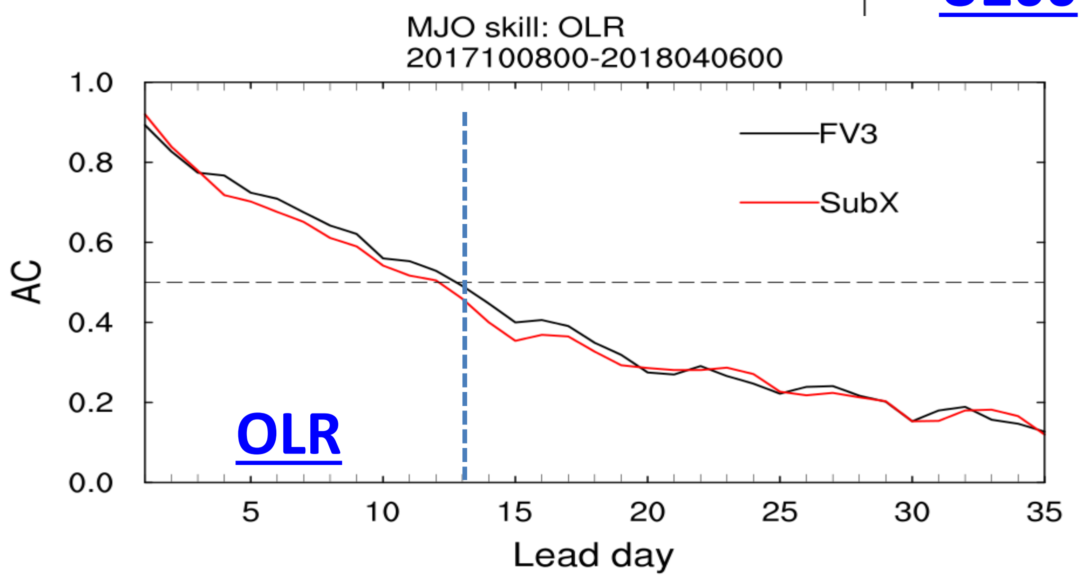




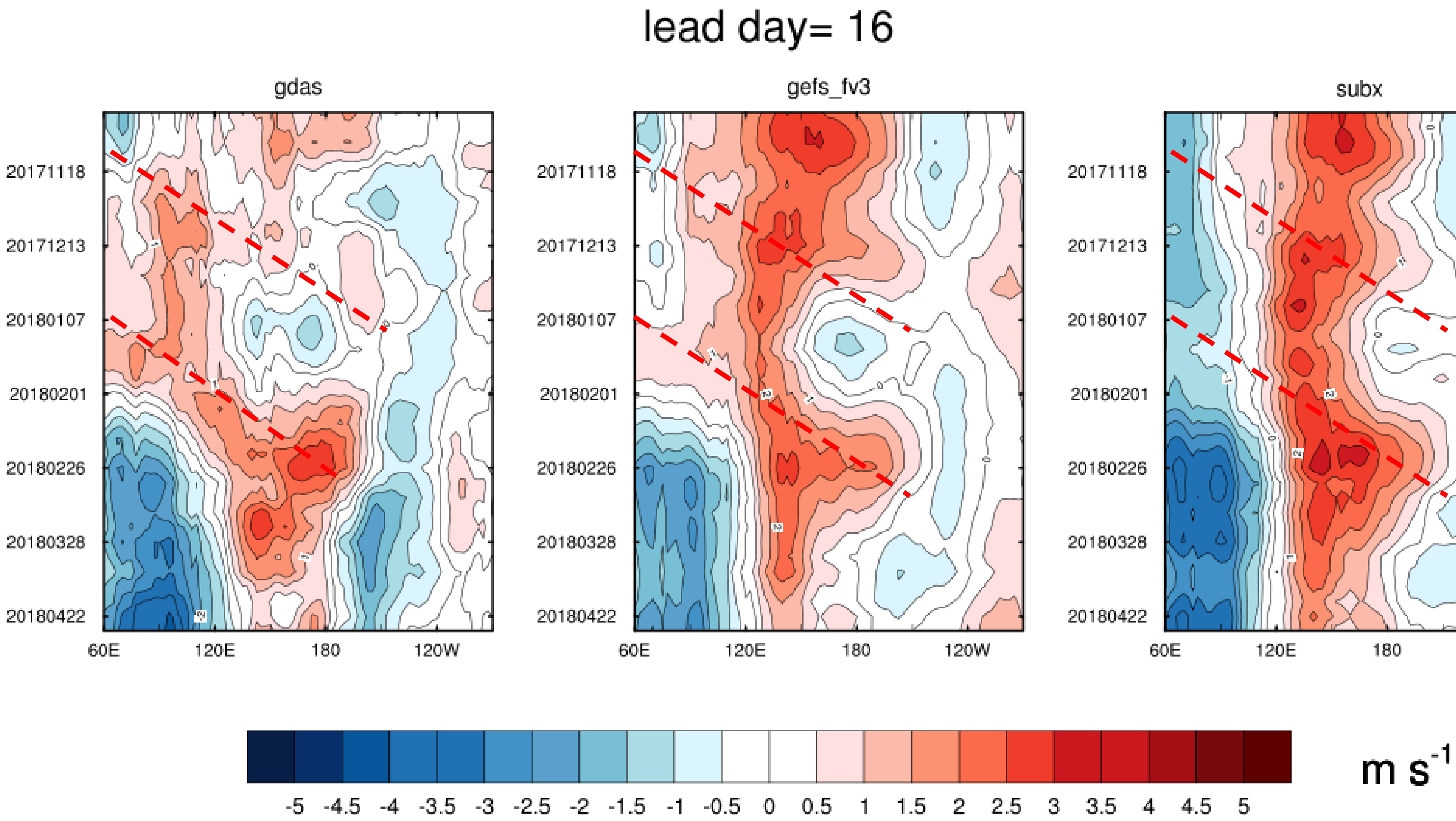
Full “time correlation”







850hPa zonal wind anomaly (10ºN – 10ºS)



Period: 10/8/2017 – 4/6/2018

Summary

- FV3 GEFS has been tested for short period
- Short-range forecast (day-to-day)
  - FV3 GEFS has over-all best performance
- Week-2 forecast
  - NH 500hPa is slightly degraded from SubX
- Weeks 3&4 forecast
  - NH 500hpa height has best score
  - SH 500hPa height has slightly degraded from SubX
  - 850hPa and 200hPa zonal winds are best for extra tropical and tropical domain
- MJO (and related) scores
  - FV3 is better than SubX overall
  - FV3 is better than SubX for individual components (U850, U200 and OLR)
  - FV3 has less amplitude errors for 20-30 days, less phase errors
- Will have more (longer period) tests to come

Major Milestones (GEFSv12)

- **Q2FY18 -** Prepare FV3-GFS for reanalysis project: Develop and test low-resolution version of FV3-GFS and FV3-GDAS, and configure the model for reanalysis project.
- **Q4FY18 -** Determine ensemble configuration for FV3-GEFS: Configure for optimum ensemble size (# members), resolution, physics, and coupling to Ocean, Ice, Land and Wave models using NEMS/NUOPC mediator; conduct testing for quality assurance and computational efficiency.
- **Q3FY19 -** Produce ~20-year reanalysis datasets: Mainly ESRL/PSD activity. Determine configuration of the reanalysis system; develop observational database for reanalysis; prepare observational inputs; and produce reanalysis suitable for reforecasts and calibration.
- **Q4FY19 -** Produce ~30-year reforecast datasets for FV3-GEFS: Finalize ensemble configuration and produce reforecasts consistent with the reanalysis data; extend the reforecast length to 35 days.
- **Q4FY19** – Produce 2-3 year retrospective forecast for FV3-GEFS: Use the same configuration as real-time, and retrospective FV3GFS/EnKF analysis.
- **Q1FY20 -** Transition FV3-GEFS into operations: Conduct pre-implementation T&E; transition the system for operational implementation. Replace GEFSv11 and stop GEFSv10 (legacy run to support NWC) ???

Thank you for your time!!!

Question???