GEFS Development for Subseasonal Forecast

- From SubX to FV3

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Introduction

- Recently, the need for numerical guidance covering the **weeks 3&4** period has been increasing, driven primarily by economic requirements to support decision-makers and for preparedness to changes in climate. The NOAA is accelerating its efforts to improve numerical guidance and prediction capability for the extended range–S2S: the weeks 3&4 period that bridges the gap between weather and climate. Covering the extended-range period will enable NOAA to provide **seamless numerical guidance** to the public, protecting life and property. Thus, a better understanding of predictability and numerical model capabilities are necessary to enhance our capabilities of prediction beyond week-2.

- The **NCEP GEFS** has been very successful, providing reliable weather and week-2 probabilistic forecast guidance that has translated into valuable information for the general public. But the S2S **prediction capabilities** of the GEFS have only recently been evaluated. Specifically, these capabilities were evaluated as part of the **NOAA SubX** with a 18-year reforecast is used as a reference system. This study involves a comparison of SubX results with those from the newly developed **FV3-based GEFS**, which includes a different dynamical core, different horizontal resolution, different micro physics, etc. The upper limits of prediction skill will be investigated through these experiments with various evaluation metrics, which include extratropical circulations, MJO and other phenomena.

What do we present?

GEFS

Global ensemble forecast system

- Current
- Next
- Potential

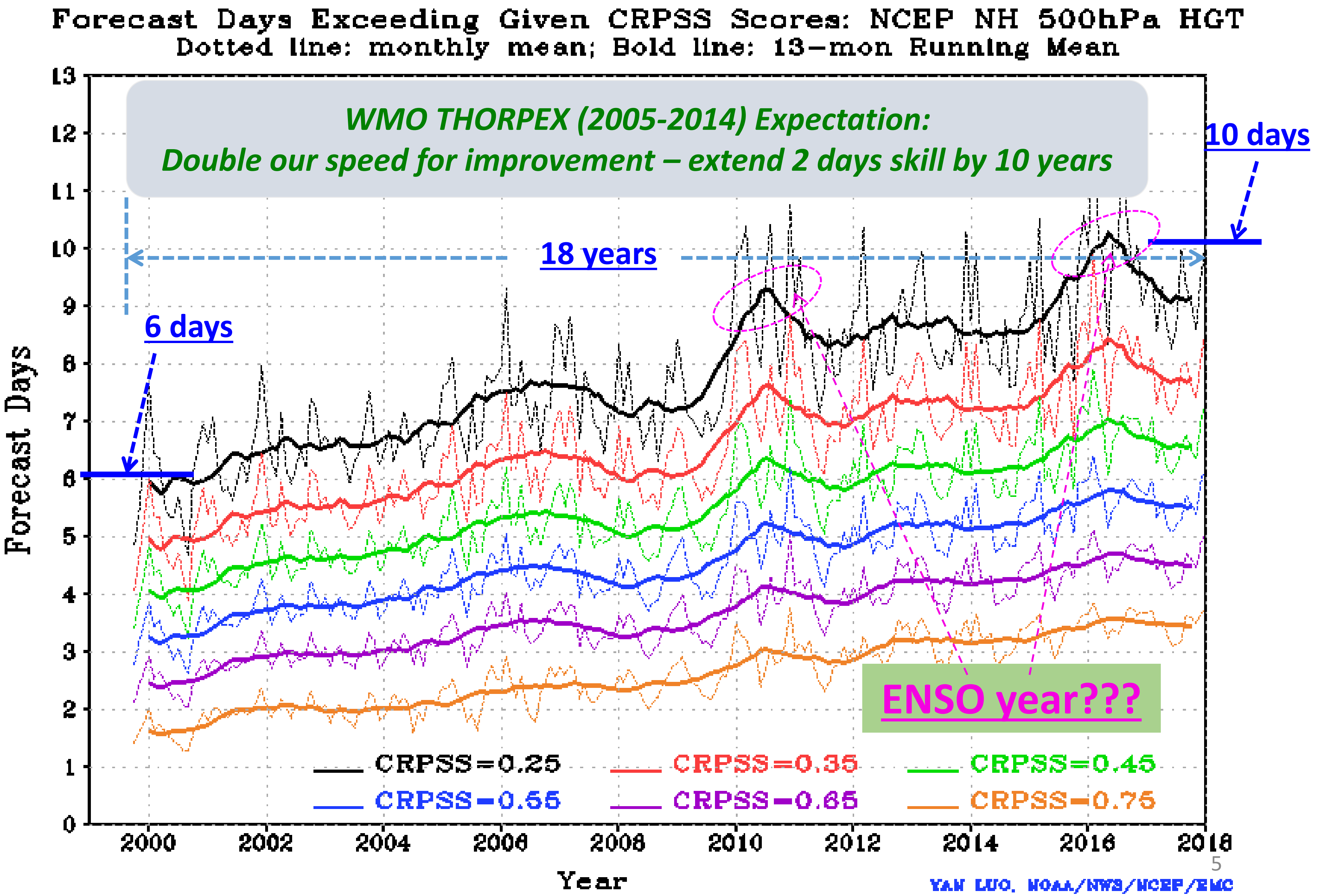
Current: Prediction skills of GEFS (35d forecast to support SubX)

Configuration of GEFS v11 and v11+

- Model: GSMv14 (spectrum model with semi-Lagrange time integration)
- Initial perturbation: F06 of EnKF analysis
- Model perturbation: STTP (stochastic total tendency perturbation)
- Resolutions: TL574L64 (0-8 days); TL384L64 (8-16 days)
- Forecast leads: out to 16 days (and 35 days)
- Members: 20 perturbed + control forecast
- Frequency: 4 times per day (00; 06; 12; 18UTC)
- Output data: 0.5d resolution globally

- ***GEFS v11 + to support SubX in real-time***:
  - ✓ SPPT+SHUM+SKEB (**SPs**) with control version of SST;
  - ✓ SPs with bias corrected CFSv2 forecast SST (**SPs+CFSBC**);
  - ✓ SPs with bias corrected CFSv2 forecast SST and scale aware convection scheme (**SPs+CFSBC+CNV**) ;

CRPSS for NH 500hPa geopotential height



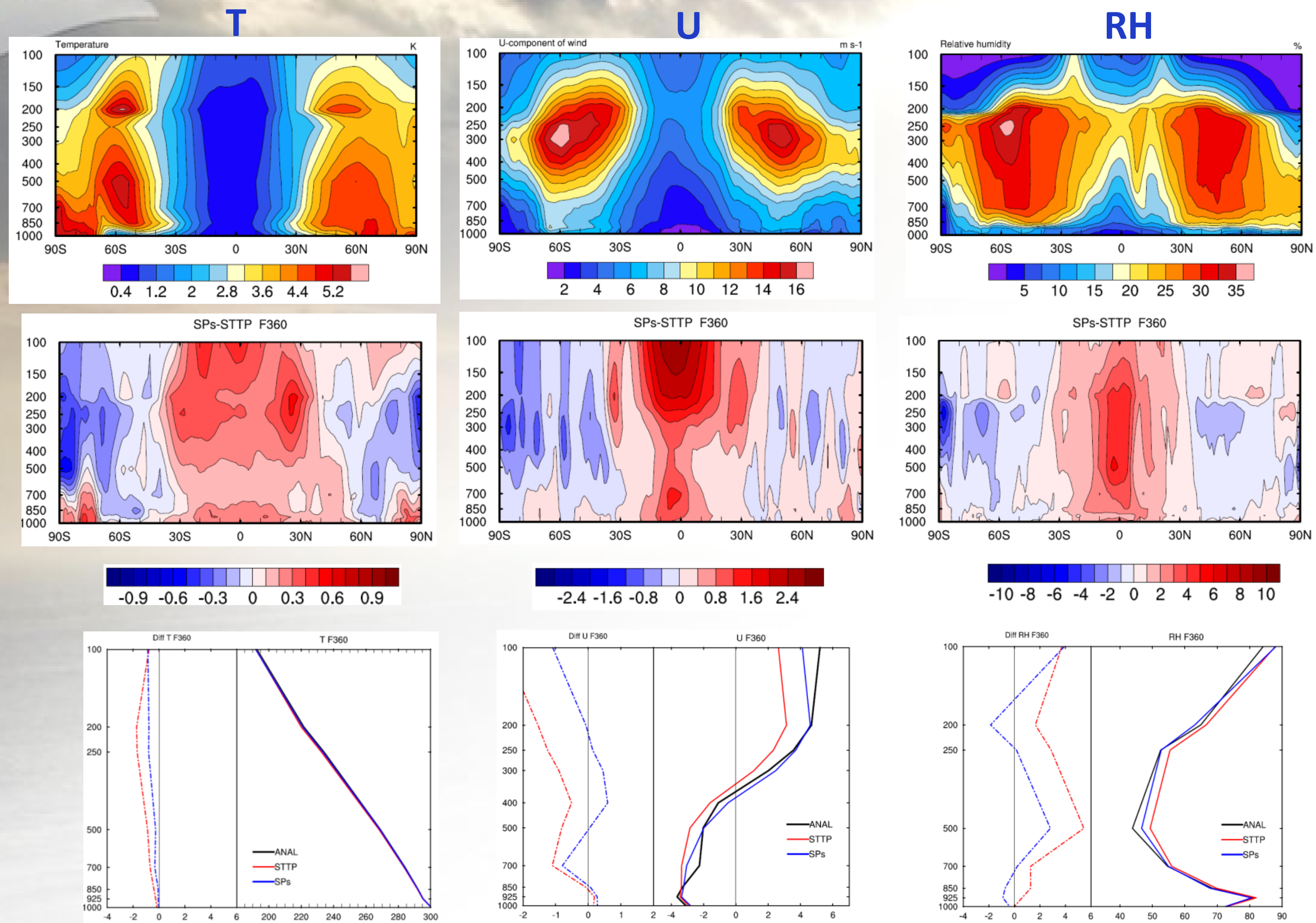
The key areas to focus on …

Atmosphere-ocean interaction

Ensemble Stochast perturbatio tropical are

Tropical convections include cloud, radiation, precipitation and et al.

Effect of the SPs



20160301-20160326 (6 cases average)

SPs – assume a big improvement of MJO skills; good spread, smaller bias in tropical

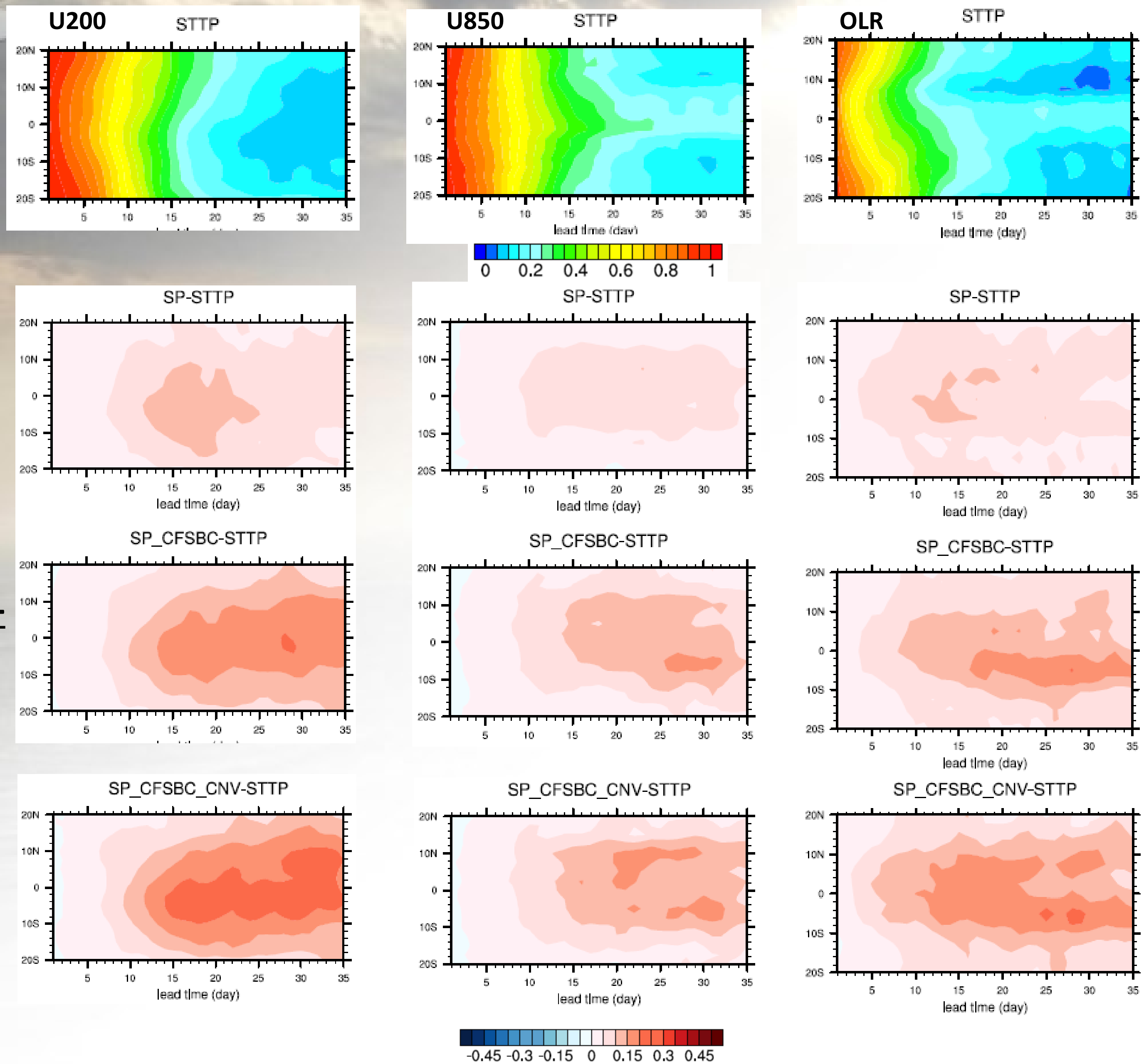
Correlation as a function of lead time

CTL

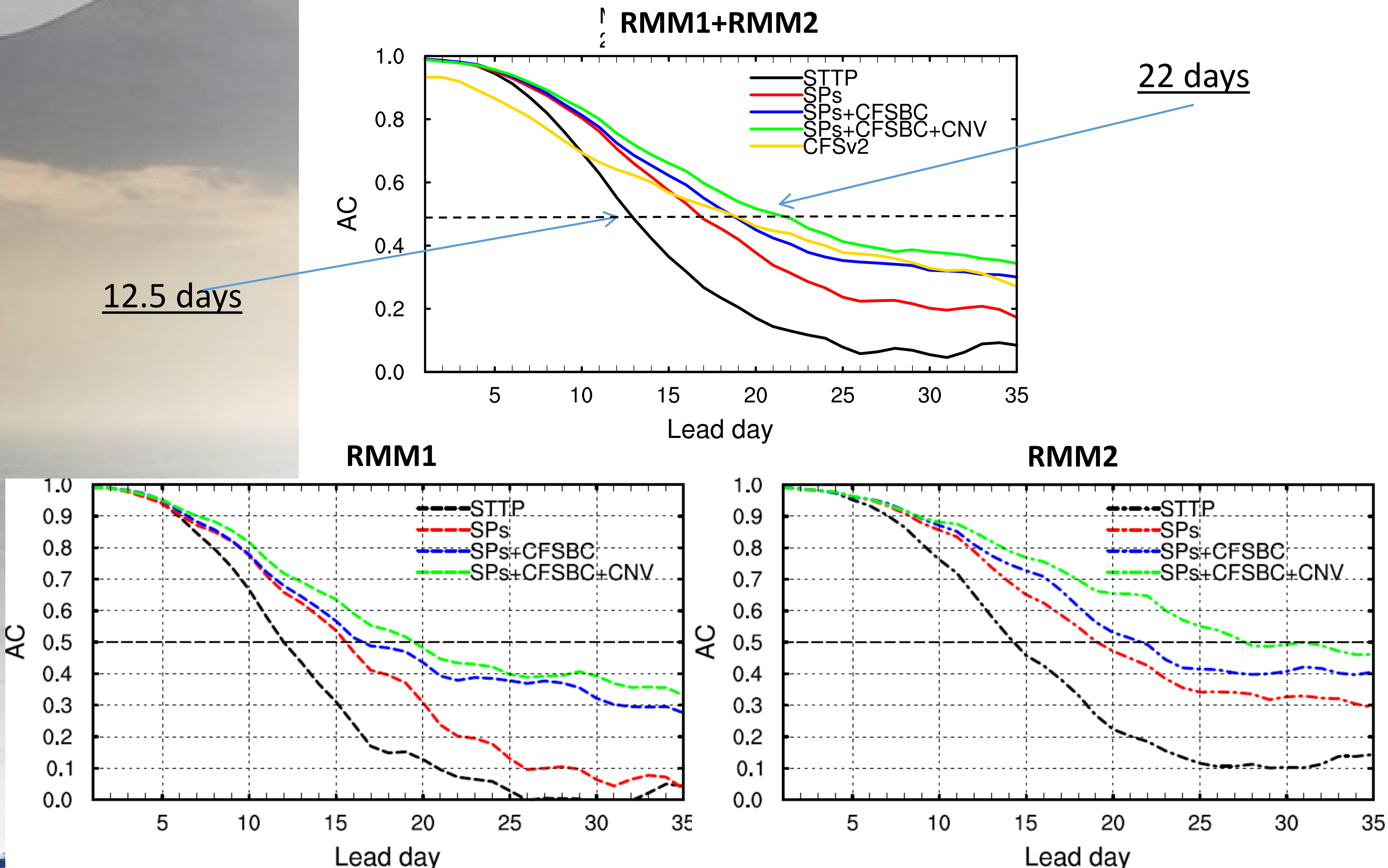
SPs - CTL

SPs+CFSBC - CTL

SPs+CFSBC +CNV - CTL



WH-MJO Forecast Skills for 2-yr Experiments

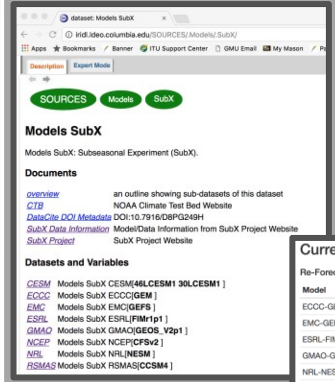


The Subseasonal Experiment (SubX)

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



Forecast & Hindcast data publicly available

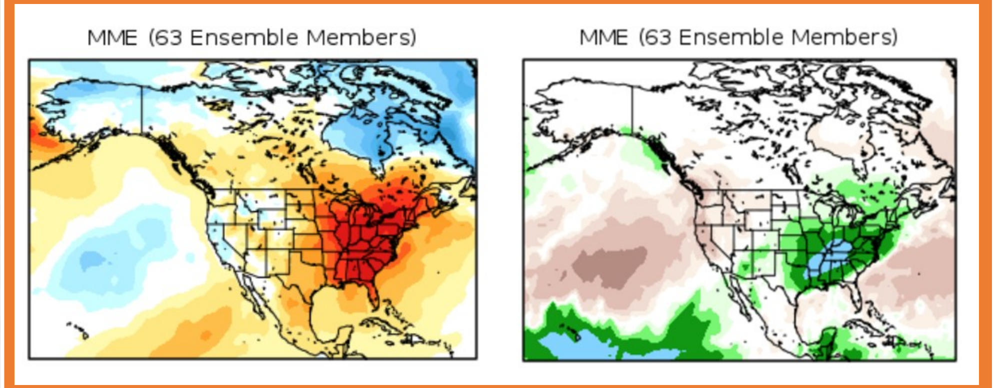
Current Data Holdings (Last updated: Feb 14, 2018)

Re-Forecasts

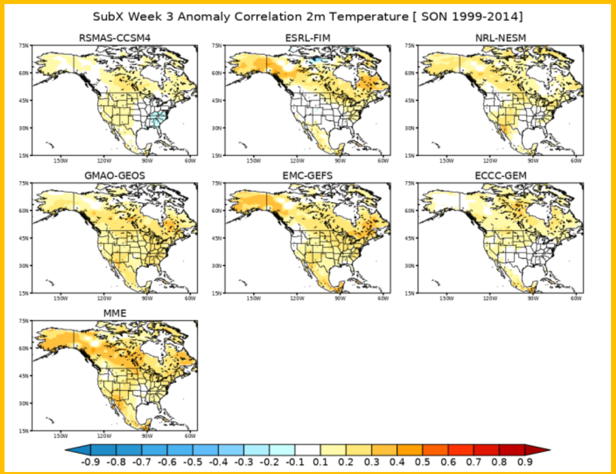
Model	Ens Members	Init Interval	P1	P2	Climo	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ECCC-GEM	4	7-days	✓	✓		1995-2014	✓							✓	✓	✓	✓	✓
EMC-GEFS	11	7-days	✓	✓		1999-2016	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ESRL-FIM	4	7-days	✓	✓		1999-2016	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
GMAO-GEOS	4	5-days	✓			1999-2015	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
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

NCEP GEFS related publication on S2S (since 2016)

- Zhu, Y., X. Zhou, M. Pena, W. Li, C. Melhauser and D. Hou, 2017: *“Impact of Sea Surface Temperature Forcing on Weeks 3 & 4 Forecast Skill in the NCEP Global Ensemble Forecasting System"* Weather and Forecasting, Vol. 32, 2159-2173
- Zhu, Y., W. Li, E. Sinsky, H. Guan, X. Zhou and D. Hou, 2018: *"An Assessment of Subseasonal Forecast Using Extended Global Ensemble Forecast System (GEFS)"* STI Climate Bulletin, P150-153, doi:10.7289/V5/CDPW-NWS-42nd-2 018
- Zhu, Y., X. Zhou, W. Li, and et al., 2018:*"Towards the Improvement of Sub-Seasonal Prediction in the NCEP Global Ensemble Forecast System (GEFS)"* Journal of Geophysical Research, 6732-6745
- Li, W., Y. Zhu, X. Zhou, D. Hou, E. Sinsky, C. Melhauser, M. Pena, H. Guan and R. Wobus, 2018: *"Evaluating the MJO Forecast Skill from Different Configurations of NCEP GEFS Extended Forecast"* Climate dynamics
- Guan, H., Y. Zhu, E. Sinsky, W. Li, X. Zhou, D. Hou, C. Melhauser and R. Wobus, 2018: *"Systematic Error Analysis and Calibration of 2-m Temperature for the NCEP GEFS Reforecast of SubX Project"* Weather and Forecasting (in final process)
- Liu, P., Y. Zhu, and et al., 2017 *"Climatology of Tracked Persistent Maxima of 500-hPa Geopotential Height"*, Climate Dynamics, 701-717
- Liu, P., Q. Zhang, C. Zhang, Y. Zhu, and et al., 2016: *"A Revised Real-Time Multivariate MJO Index"* Monthly Weather Review, Vol. 144, 627-642
- He, B., P. Liu, Y. Zhu, W. Hu 2017: *"Prediction and Predictability of Northern Hemisphere Persistent 2 Maxima of 500-hPa Geopotential Height Eddies in GEFS"* Climate Dynamics (final online version)
- Fu, J-X., W. Wang, Y. Zhu, and et al. 2018: *”Impacts of Different Cumulus Schemes on the Pathways Through Which SST Feedbacks to the Madden-Julian Oscillation"* Journal of Climate
- Pegion and co-authors, 2018: *“The Subseasonal Experiment (SubX): A multi-model subseasonal prediction experiment”,* Submit to BAMS (in review process)

Next: FV3 based GEFS (v12)

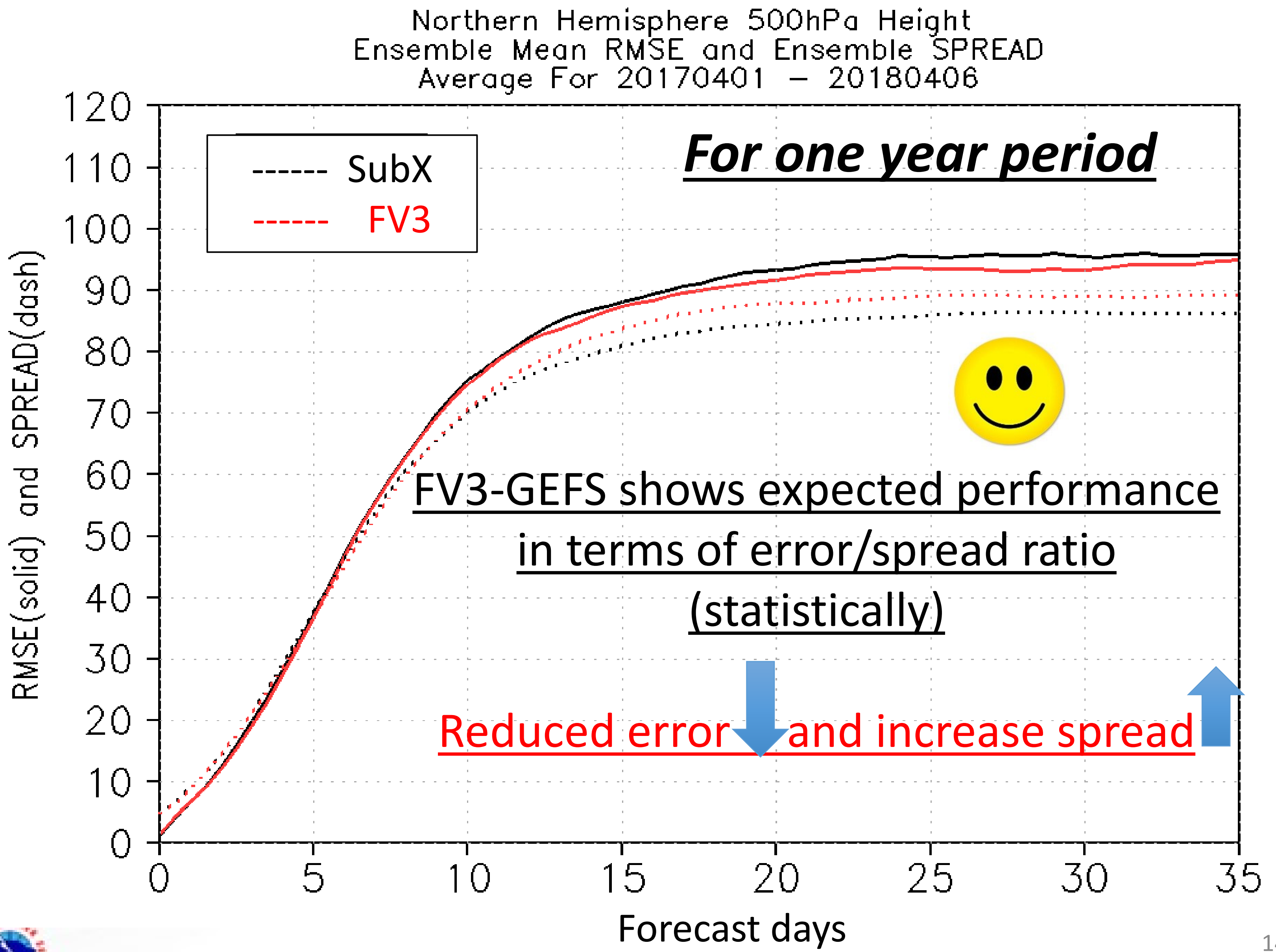
Configuration of GEFS v12 (plan)

- What are the major difference from GEFSv11 (or V11+ SubX version)
  - ✓ Model dynamics – **FV3 (Finite-Volume Cubed-Sphere Dynamical Core)**
  - ✓ Horizontal resolution – C384 ~ 25km
  - ✓ Microphysics – GFDL MP
  - ✓ Correction of physical parameterizations (SWR-MP; Canopy heating)
  - ✓ Tuned Stochastic Physics (use SPPT-5 scales and SKEB(0.6) only)
  - ✓ 31 ensemble members (skills we have demonstrated are from 21 members)
  - ✓ Computation cost – factor of 4

OPS-GEFS (v11) .vs FV3-GEFS (v12)

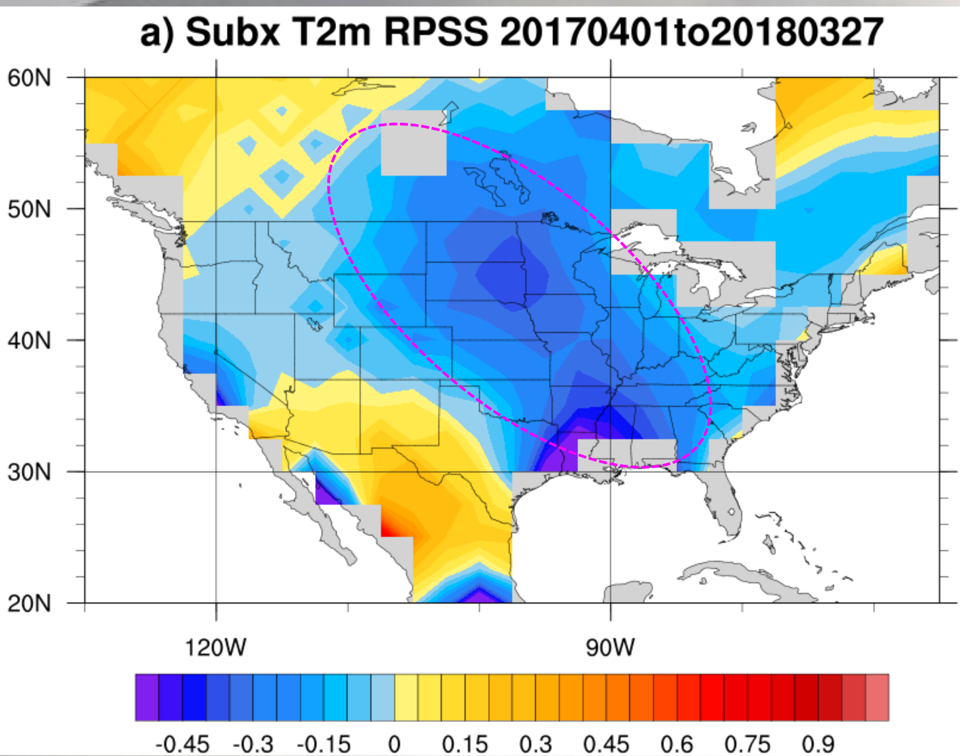
OPS-GEFS (21 members)	FV3-GEFS (31 members)
GSM	FV3
ZHAO-CARR MP	GFDL MP
TL574L64 (~33km) (d1-8)+TL382 (~50km) (d9-16)	C384L64 (~25km) (d1-16) (~25km) (d16-35)
Climatology relaxation	NSST +2-tiered SST
Stochastic STTP	Stochastic physics (SPPT + SKEB)
GSM-GFS EnKF 06 fcst	FV3-GFS EnKF 06h fcst

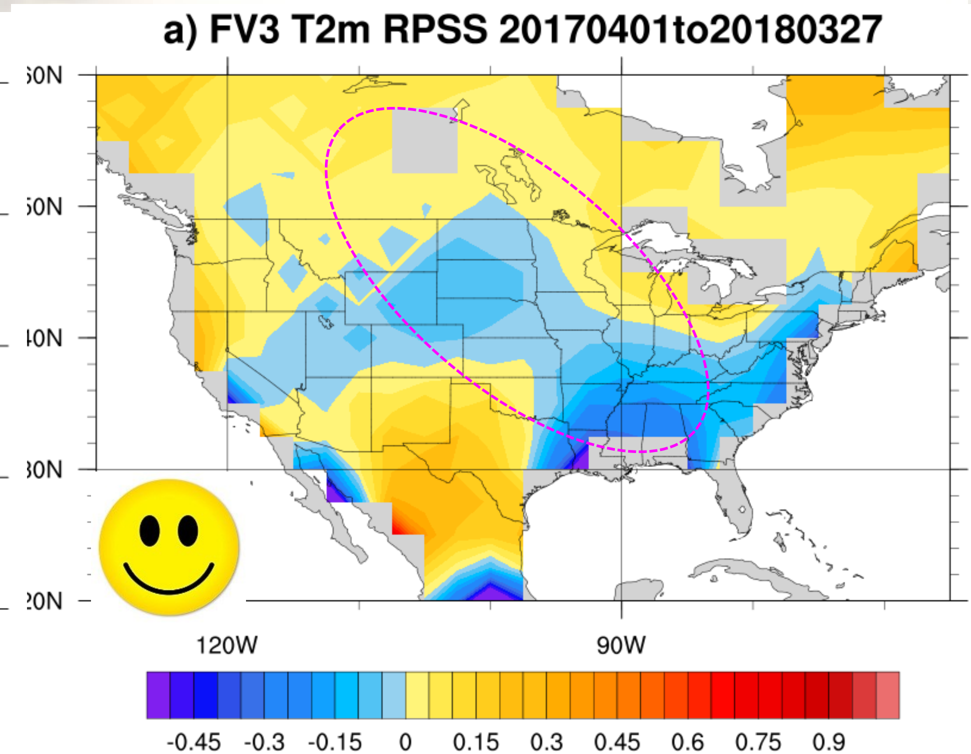
RMSE and Ensemble Spread of NH 500hPa height



RPSS scores for one years 35 days forecasts

Weeks 3&4 average

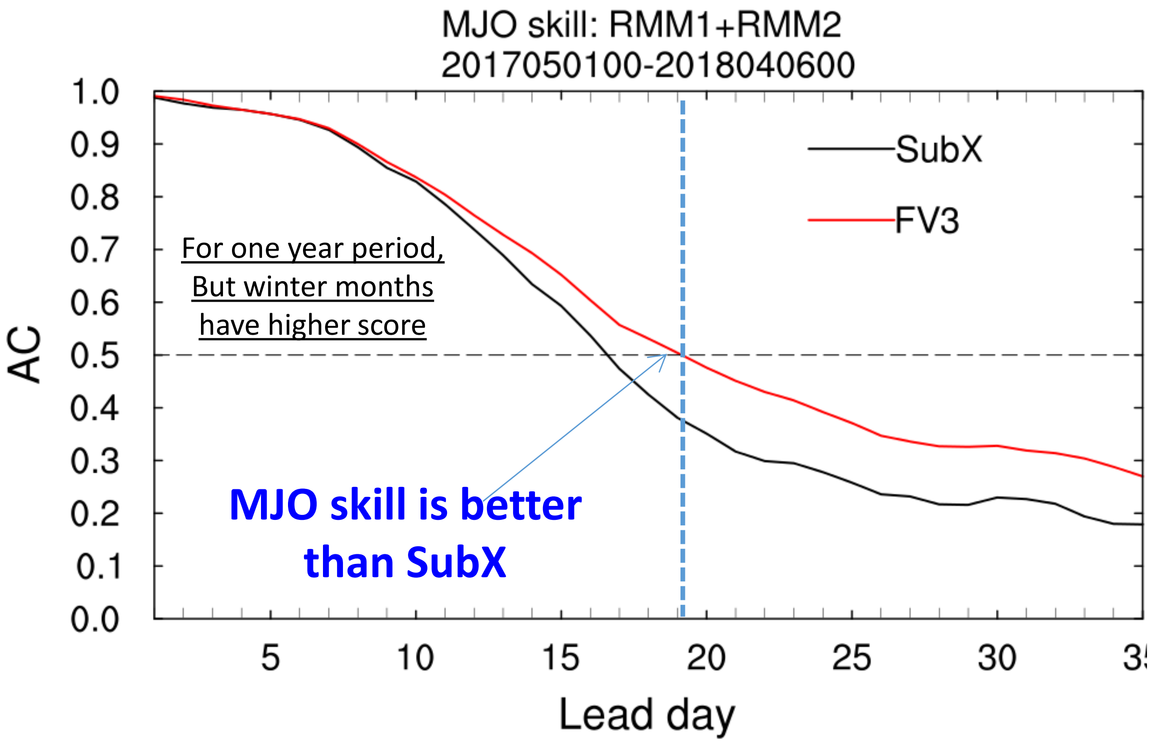


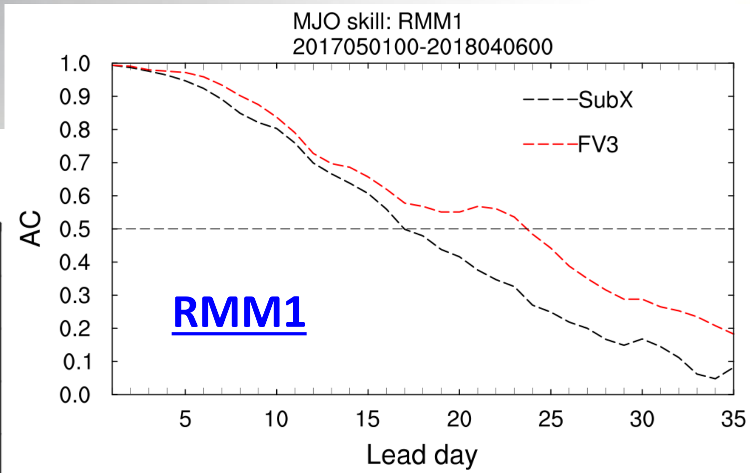


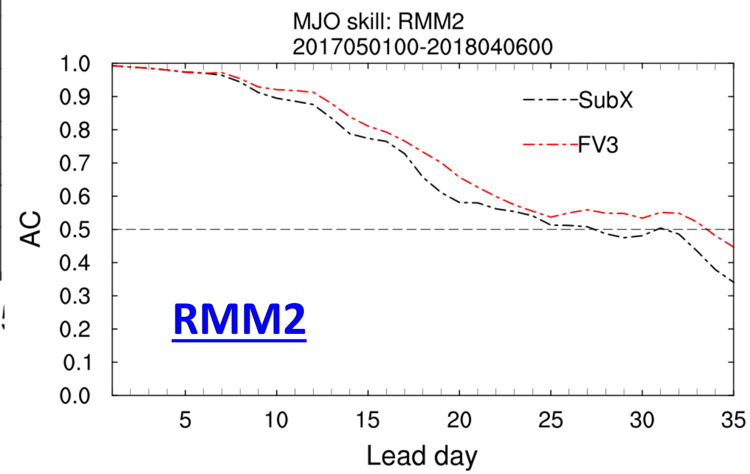
FV3-GEFS indicates an big improvement of T2m for CONUS

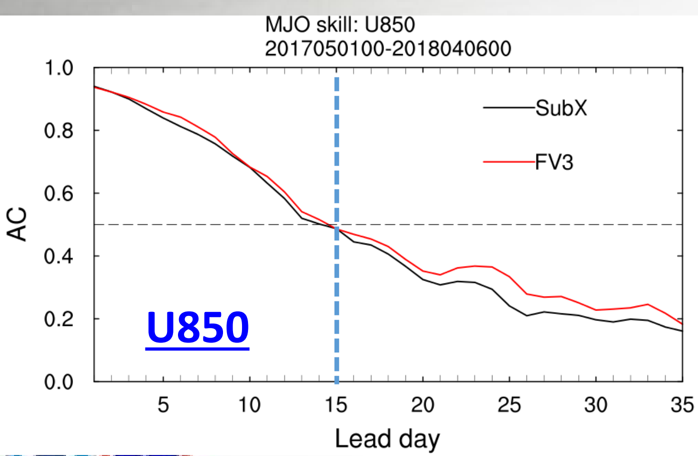
For raw ensemble forecast (no calibration)
Truth: own analysis or f00 at 2.5d resolution

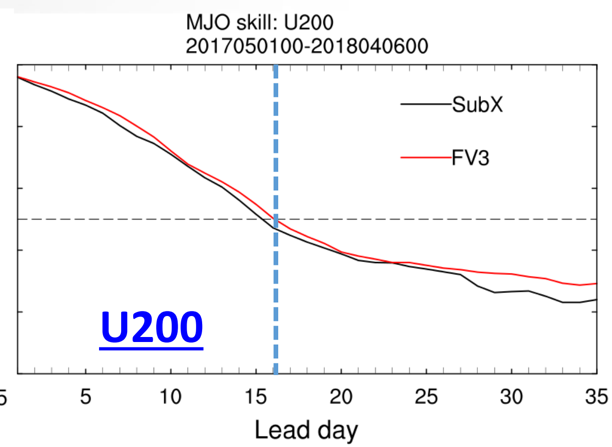
Tropical Prediction Skills

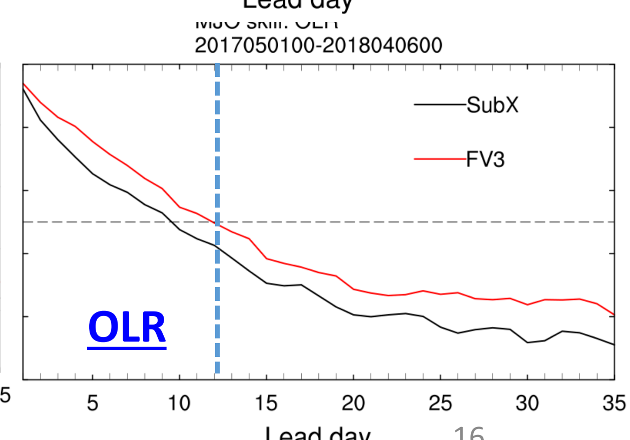












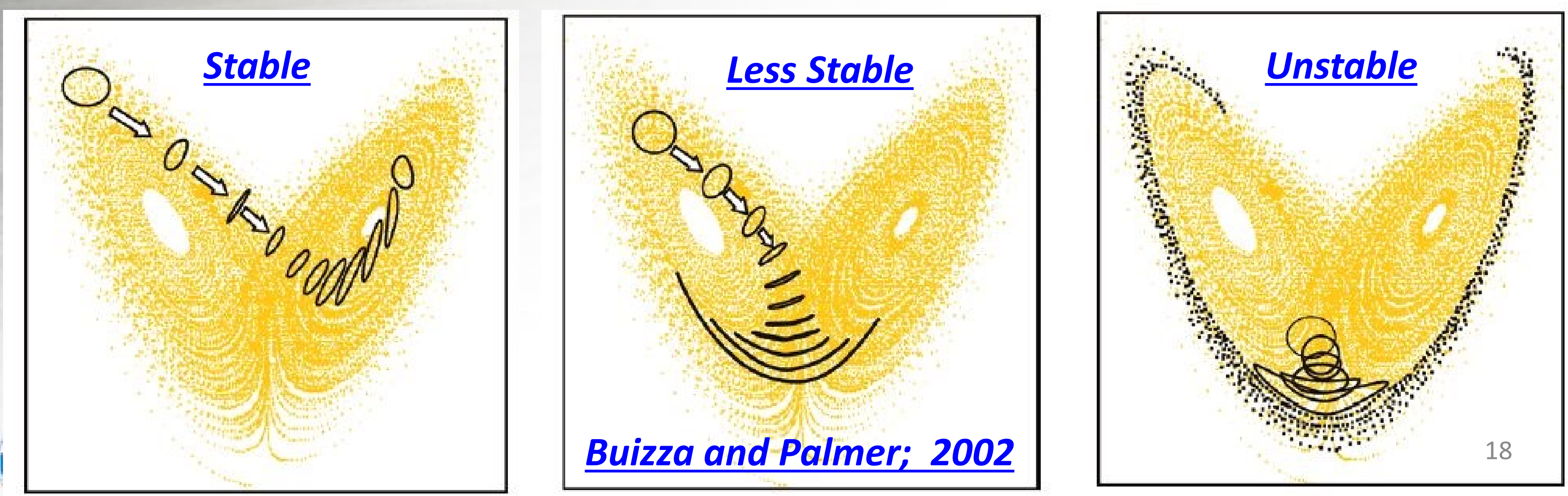
Potential forecast capability - Predictability

Our assumptions:

1. Model is perfect
2. Ensemble system is perfect
3. Ensemble mean represents best forecast
4. Errors come from observation uncertainties and chaotic system

Background

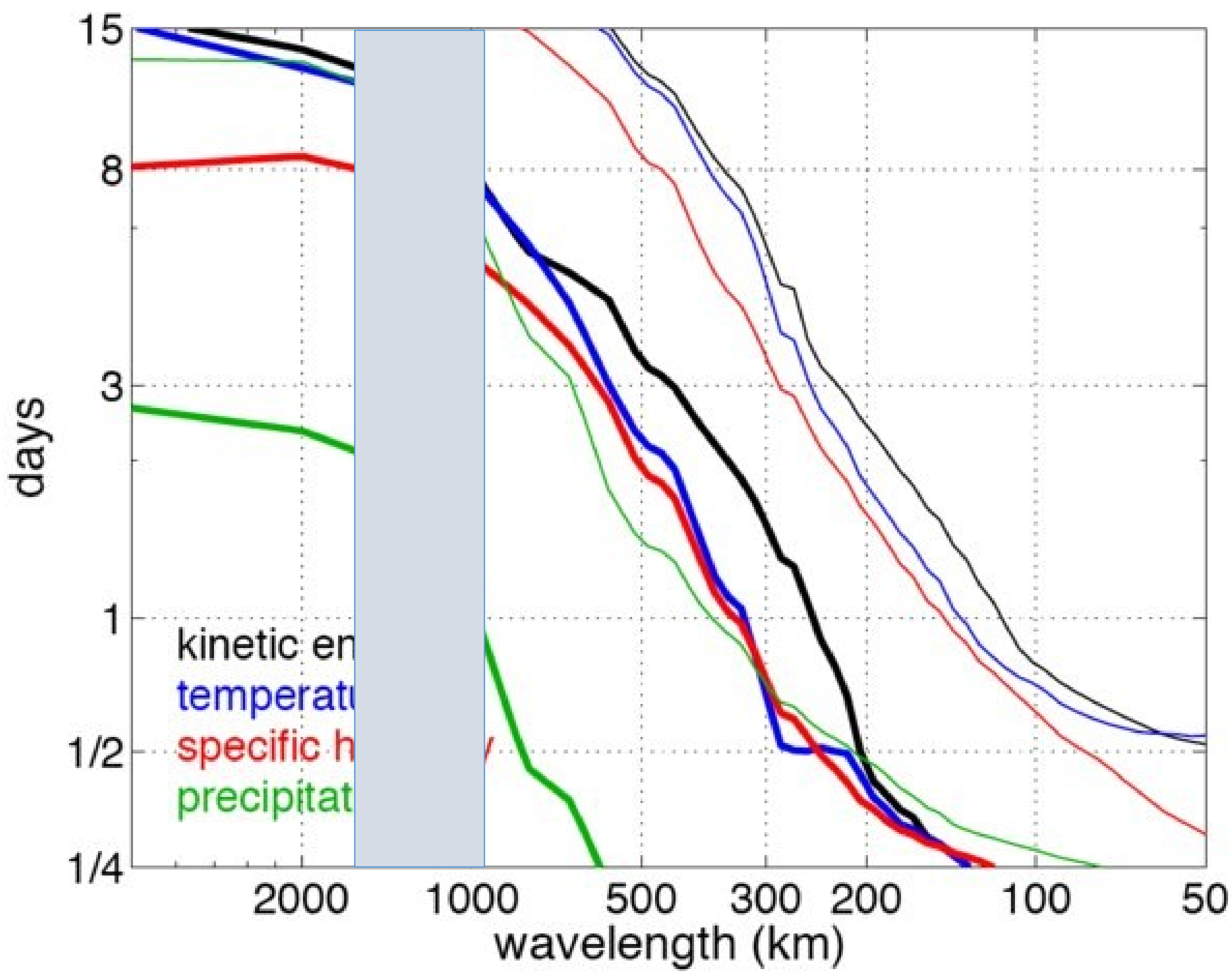
- **Predictability** is the degree to which a correct prediction or forecast of a system's state can be made either qualitatively or quantitatively
- Charney (1951) indicated that forecast skill would break down, but he attributed it to **model errors** and errors in the **initial conditions**
- Lorenz (1963) discovered that even with a perfect model and almost perfect initial conditions the forecast loses all skill in a finite time interval **because chaotic system**
- Now, we are getting closer to the **2 week limit of predictability**, and we have to extract the maximum information



Buizza and Palmer; 2002

One example of many interesting studies

Ying and Zhang, 2017; JAS - Practical and Intrinsic Predictability of Multiscale Weather and Convectively Coupled Equatorial Waves during the Active Phase of an MJO



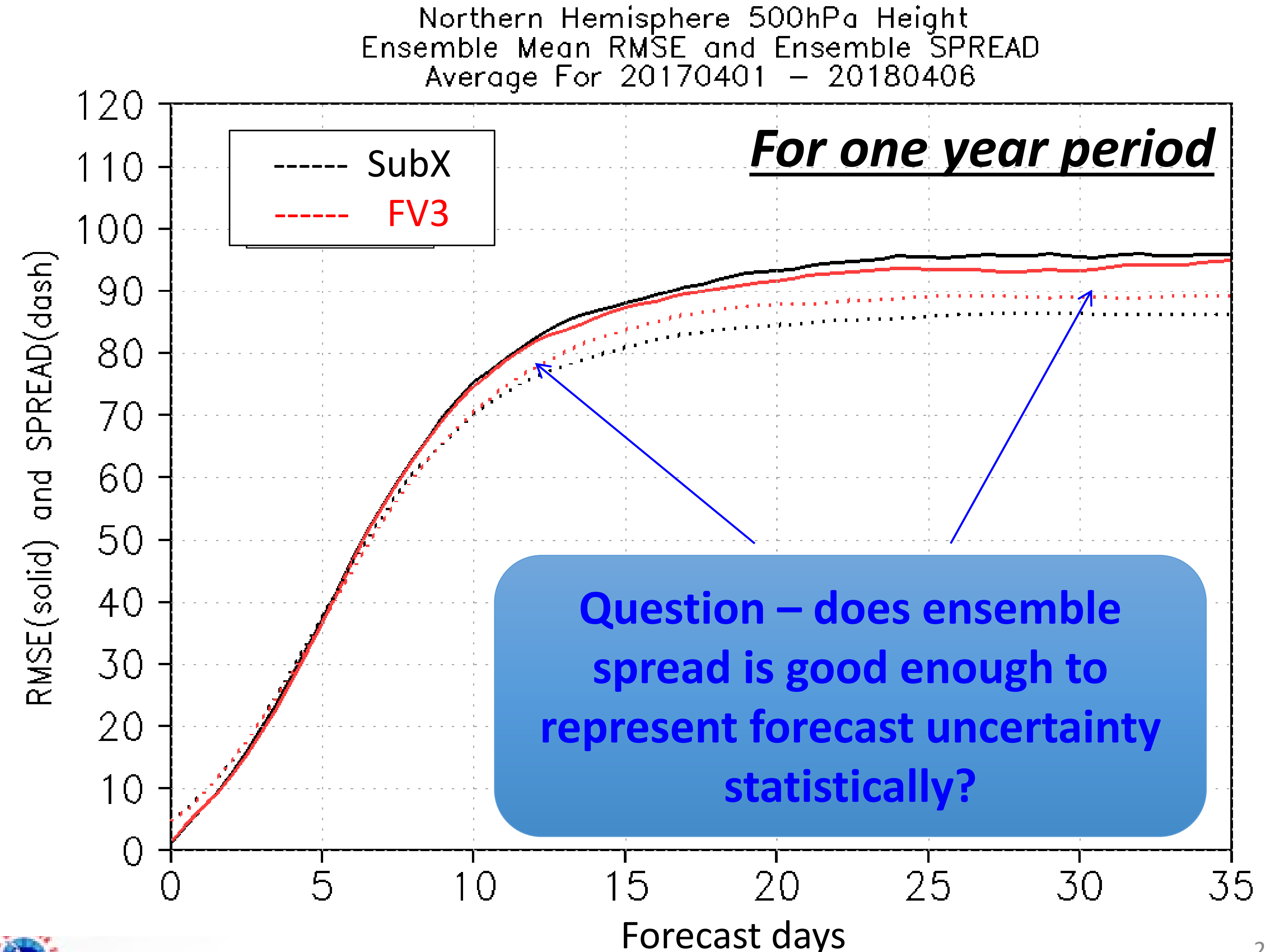
Predictable timescale (days) for kinetic energy, temperature, humidity, and precipitation as a function of horizontal wavenumber (labeled as corresponding wavelength in km). Intrinsic predictability limits are shown in thin lines, and practical predictability limits in thick lines.

Based on all these referred studies – we could explore "predictability" to useful prediction kills

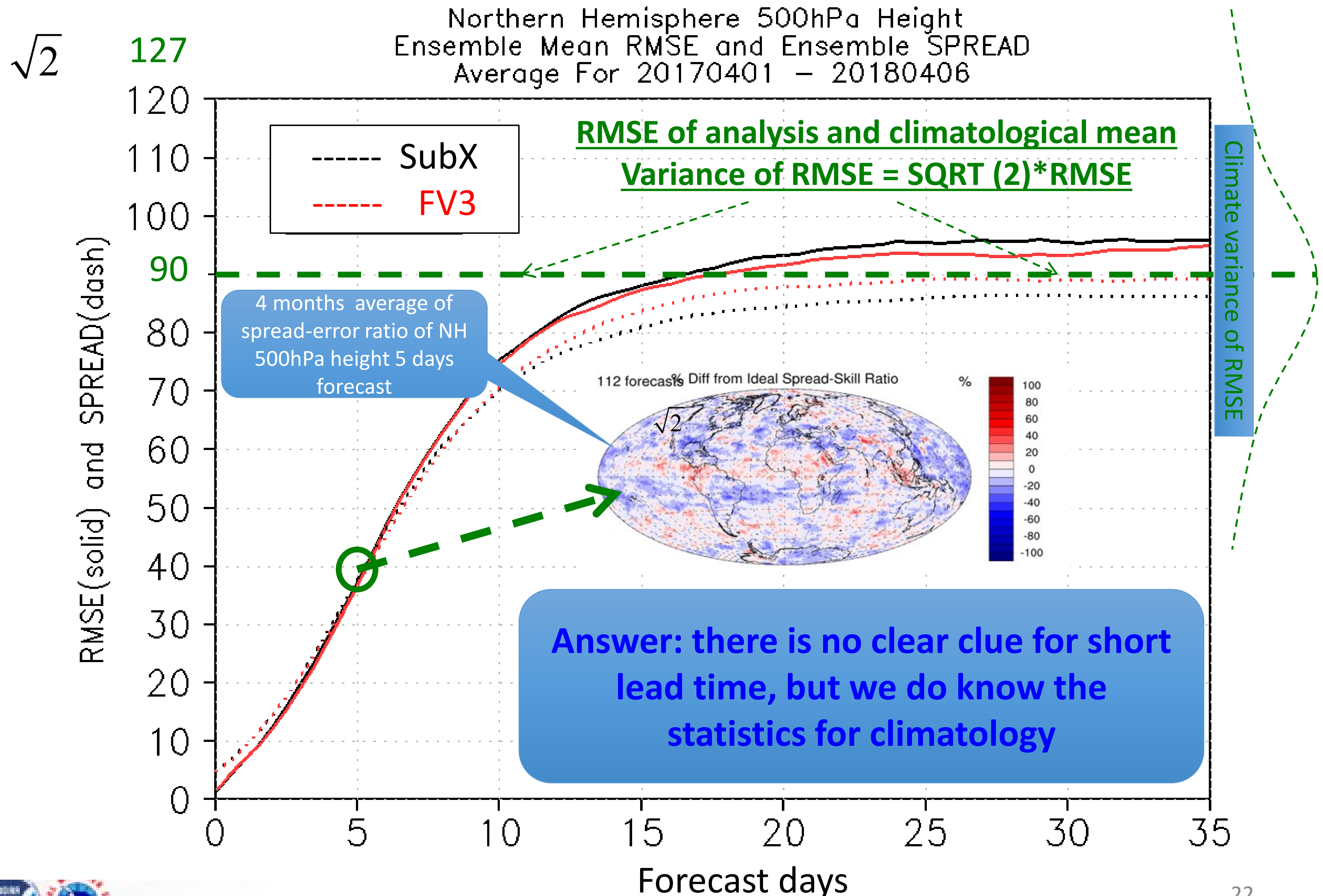
This investigation will focus on

- State-of-art global ensemble forecast system (GEFS)
  - Present initial uncertainty (EnKF) and model uncertainty (SPs)
- Principal assumptions (hypotheses) are
  - Ensemble system is perfect
  - Ensemble spread really represents true forecast uncertainty
  - All individual perturbed forecast could be proxy truth (and equal)
  - Ensemble mean will be best forecast solution for large scale forecast
- Large scale systems (or events) in terms of
  - Spatial resolution
  - Temporal resolution
- Calculation of anomaly correlation in terms of
  - Pattern
  - Time series of domain average
- Prediction skills are based on
  - NH 500hPa geopotential height - PAC
  - Tropical MJO RMM1+RMM2 (850hPa and 200hPa zonal wind and MJO)
- Prediction skills are presented for
  - Useful and true skills for current system
  - Potential useful skills – kind of predictability

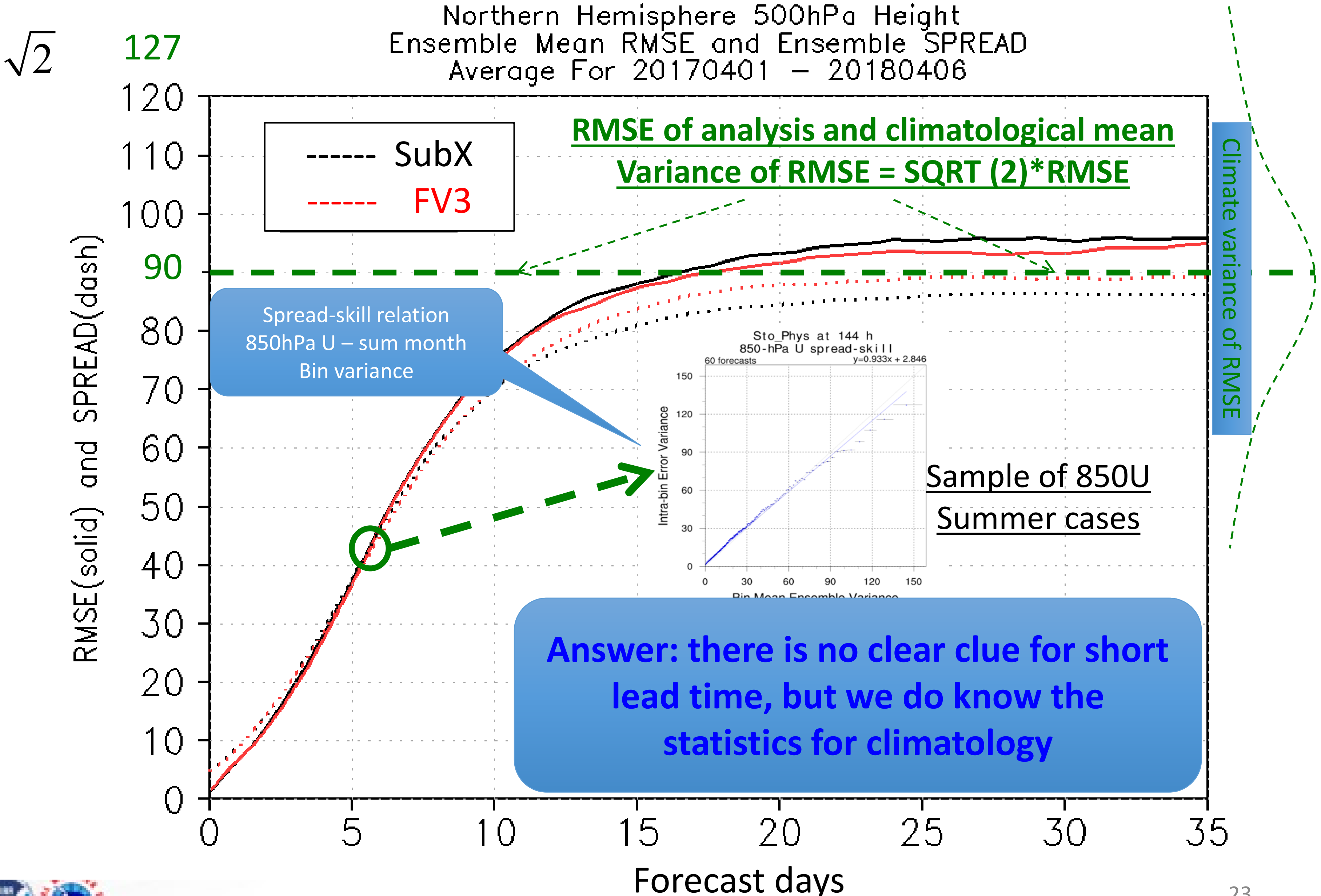
RMSE and Ensemble Spread of NH 500hPa height



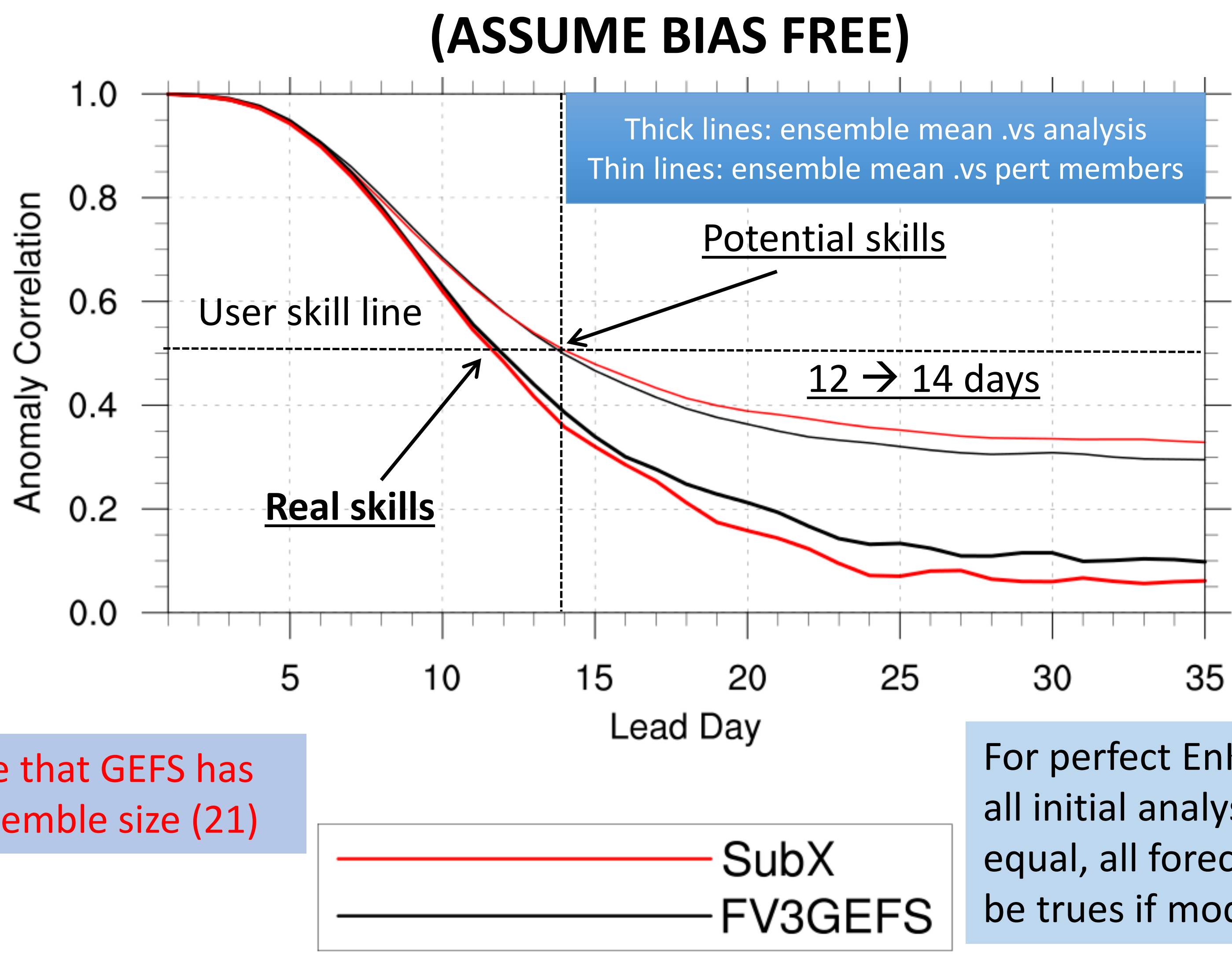
RMSE and Ensemble Spread of NH 500hPa height



RMSE and Ensemble Spread of NH 500hPa height



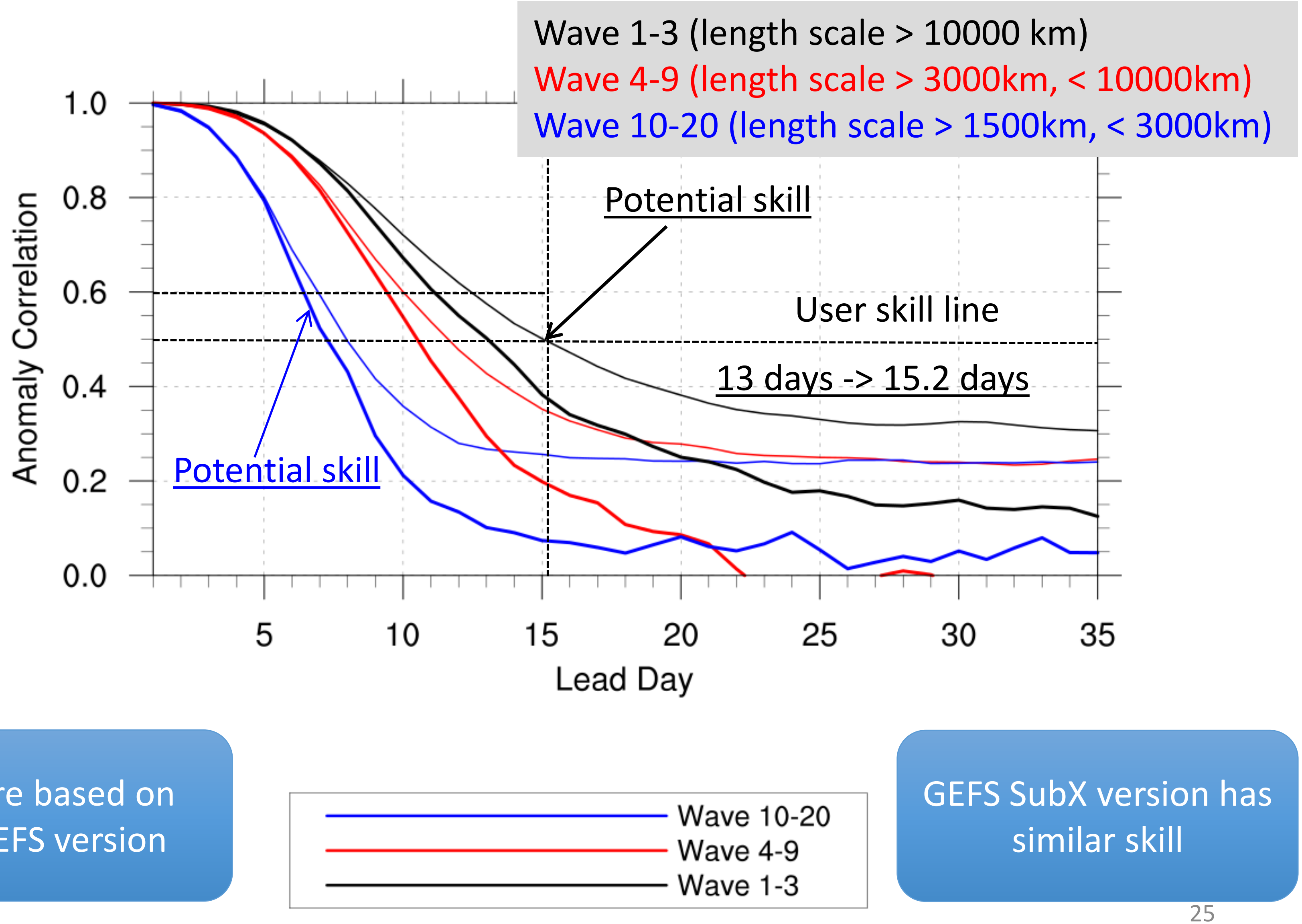
Over-all prediction and potential prediction skills for NH 500hPa height extra-tropics (day-to-day)



Please note that GEFS has limited ensemble size (21)

For perfect EnKF system, all initial analyses are equal, all forecast should be trues if model is perfect

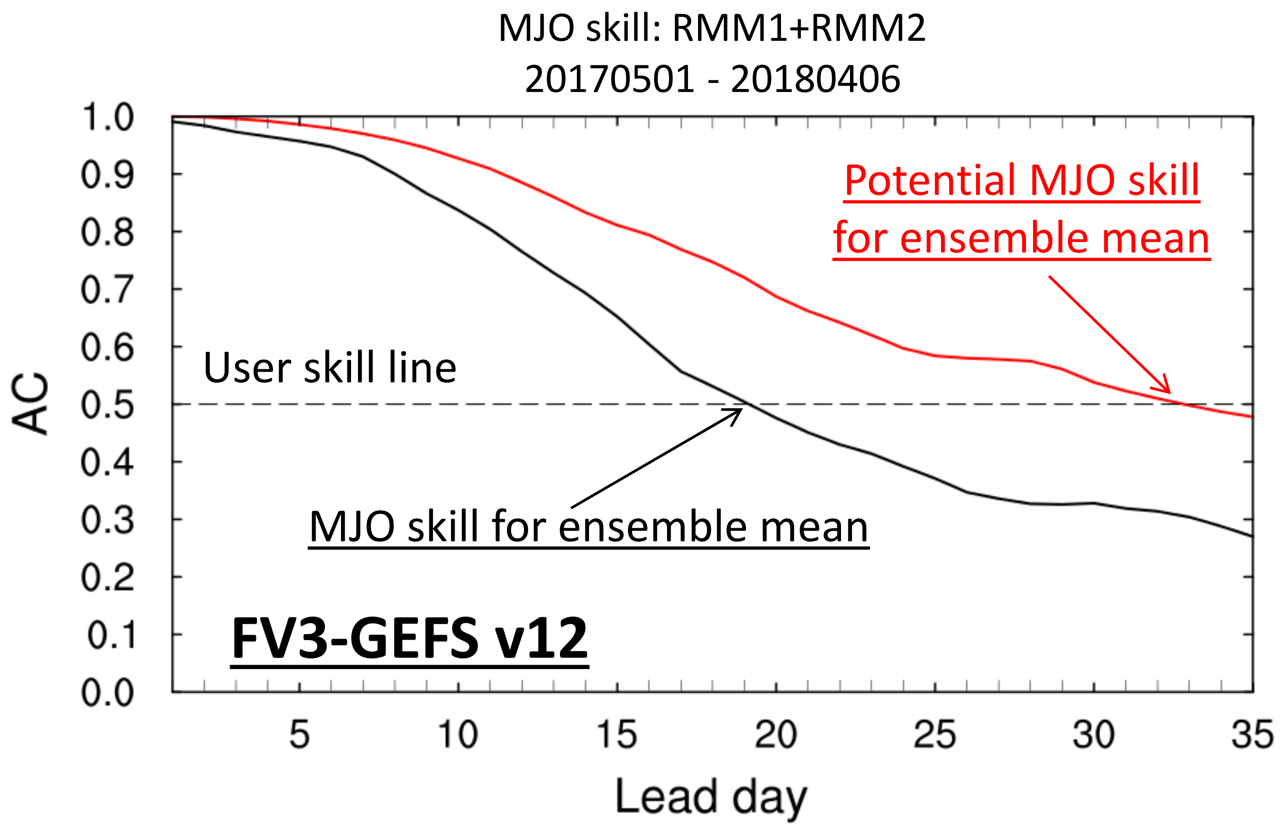
Prediction and predictability for NH 500hPa height extra-tropics (diff. scales)



Skills are based on FV3-GEFS version

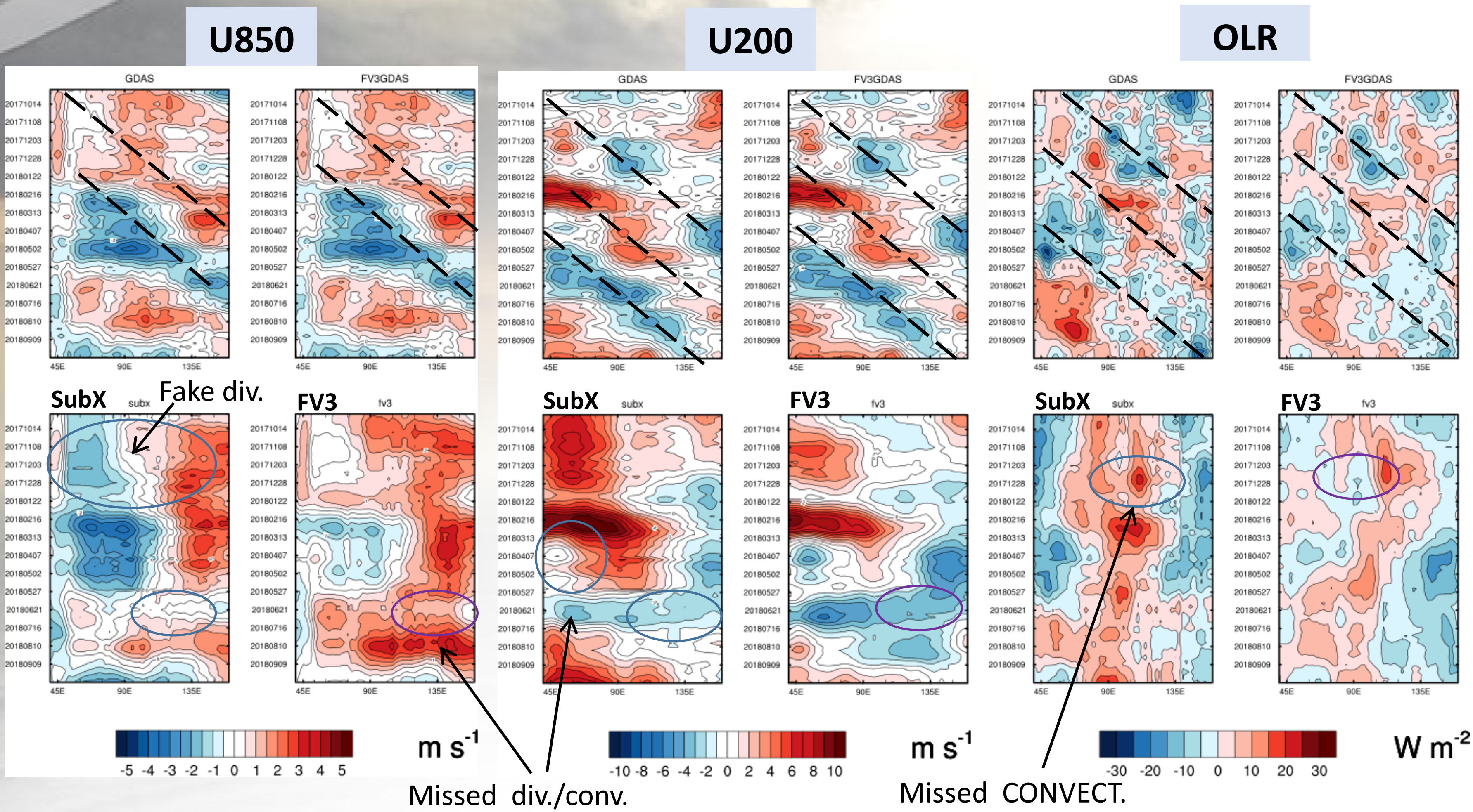
GEFS SubX version has similar skill

Prediction and predictability of MJO



Discussion: Black line shows the MJO skills from current 1-year FV3-GEFS (v12) experiment (ensemble mean .vs analysis); Red line shows the potential MJO skills from the same 1-year experiment, but uses ensemble mean against ensemble control. We have assumed 1). Ensemble system is perfect; 2). Ensemble mean has best performance of large scale solution (TRUE); 3). Ensemble control forecast is perfect if model is perfect; 4). Ensemble control is independent of ensemble mean (and/or each perturbed forecast). **Q: does this indicate that there is large room for us to improve MJO prediction?**

Challenge ----MJO propagation : lead day=16



- Bias in magnitude over both Indian Ocean and West Pacific
- Inaccurate zonal convergence/divergence position
- Both SubX and FV3 didn’t show good propagatoin
- FV3 has better OLR forecast than SubX

When FV3-GFS will deliver to public?

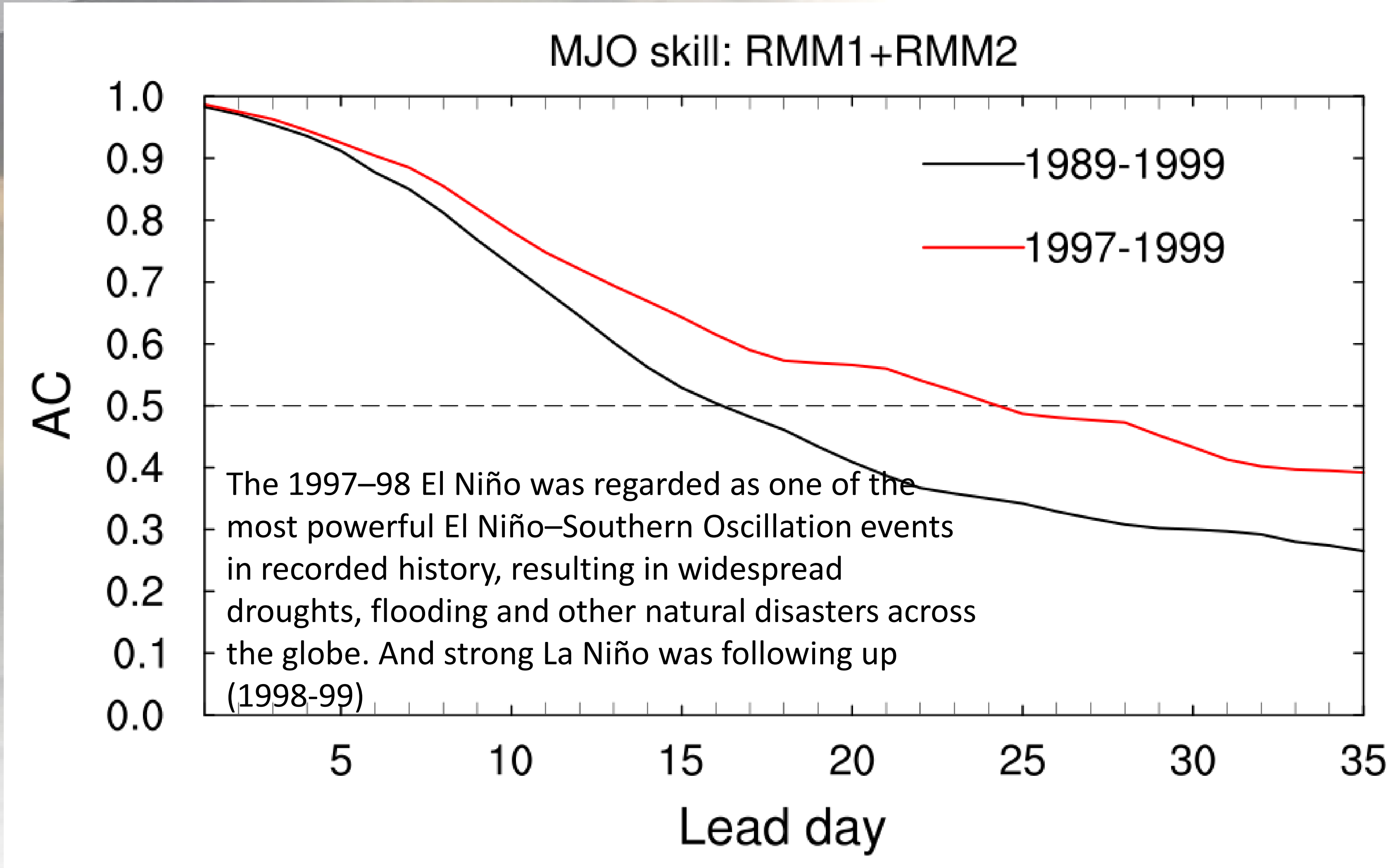
Spring 2020

25km resolution
31 members
4 times per day
Out to 35 days (once per day)

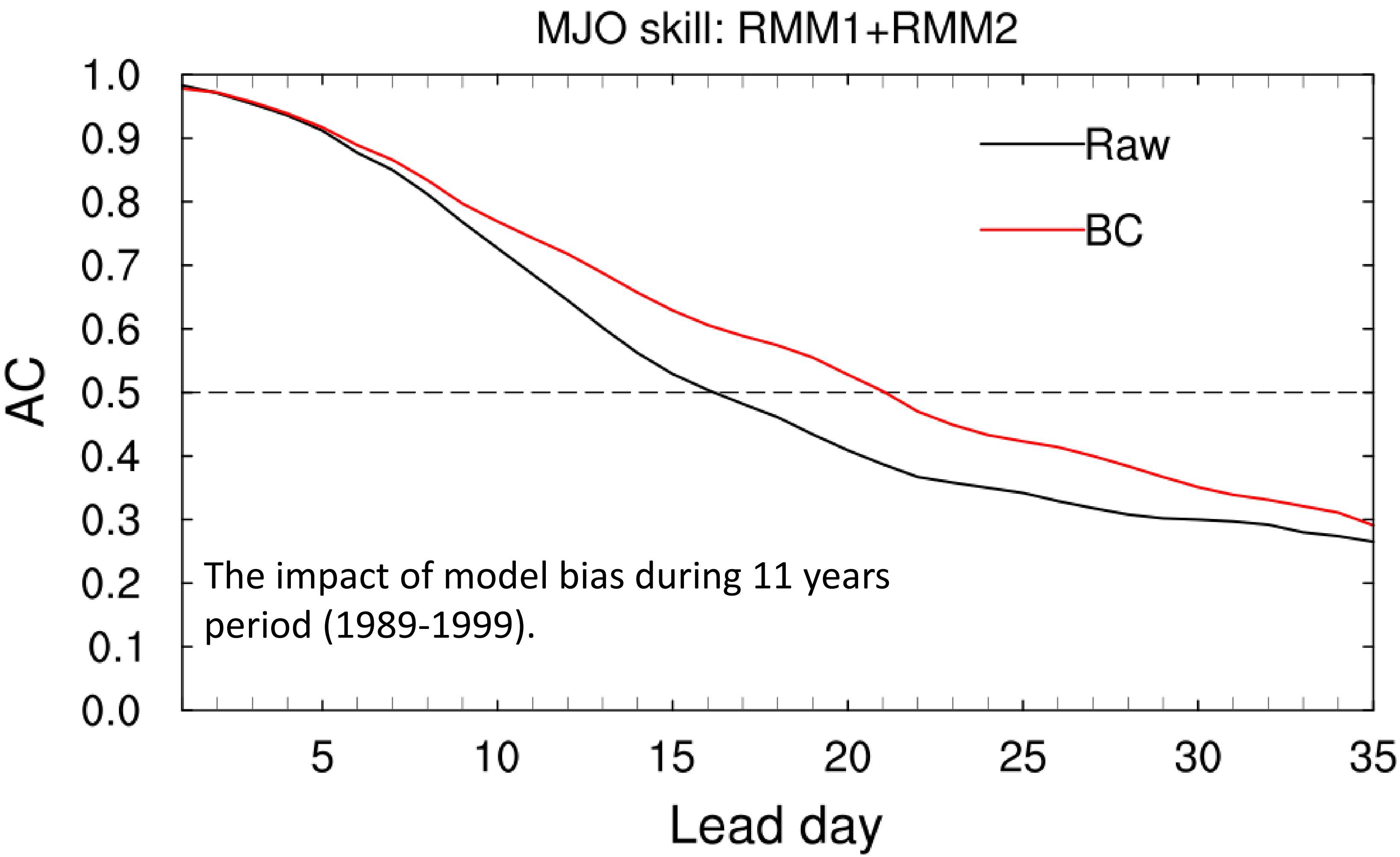
PLUS

30 years GEFS reforecast
Once per day at 00UTC
5 members out to 16 days
Except for every Wednesday
11 members out 35 days

MJO skill from GEFS 11 years reforecast



MJO skill from GEFS 11 years reforecast



The impact of model bias during 11 years period (1989-1999).

GEFS future – v13

Expect to be around 2023

Full coupled system
More vertical levels
Extend to 45 days
Advanced model physics

The key areas to focus on …

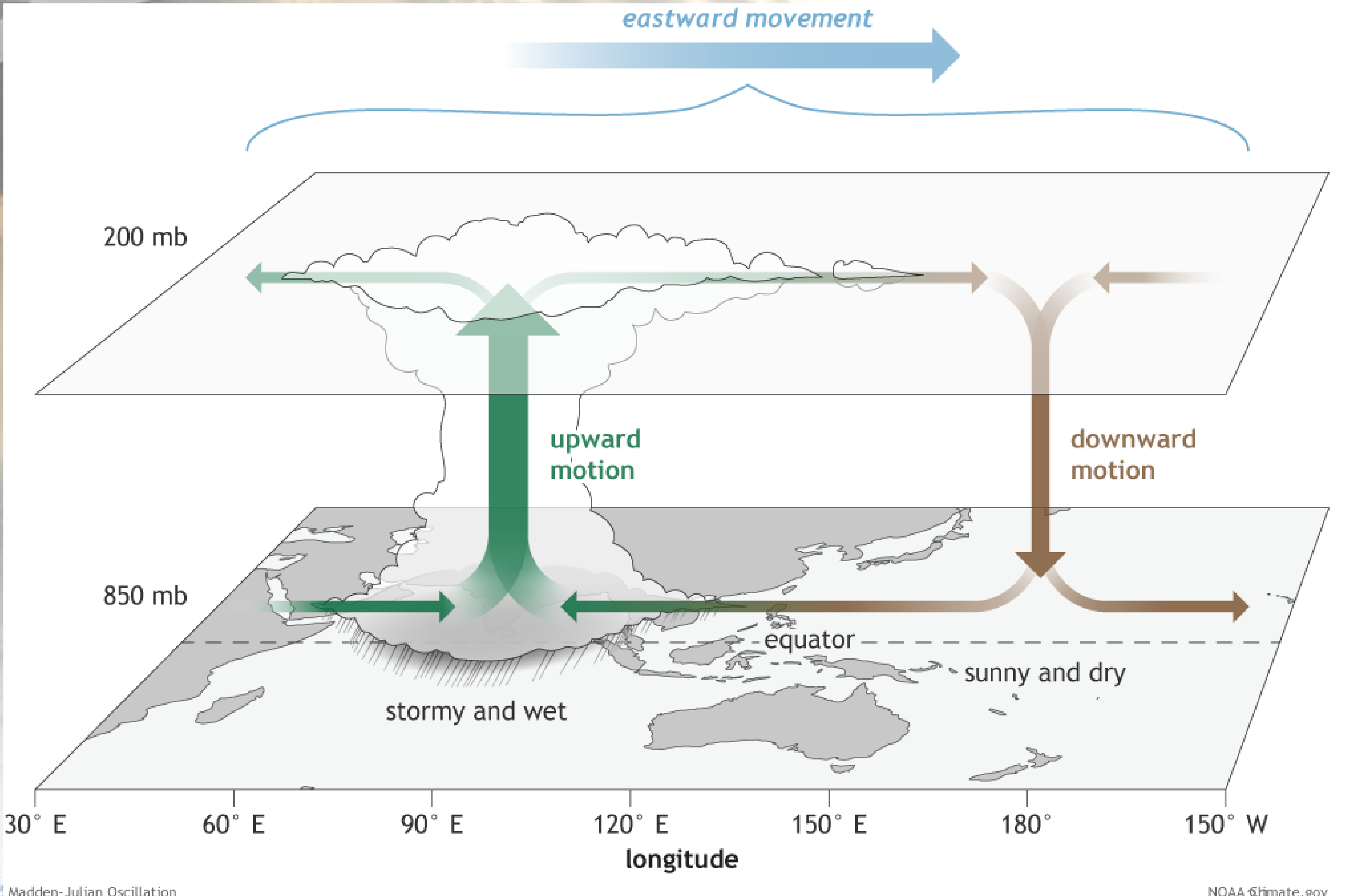
Ensemble and Stochastic perturbation on tropical area
CA proces

Atmosphere-ocean-seaice interaction
ull coupling

Stratosphere Polar Jet Stream; Meridional Circulation
126 vertical levels

Tropical onvections nclude cloud, radiation, precipitation and et al.
Advance Physics

Schematic Diagram of Madden Julian Oscillation



Proposed Physical Suites

	Suite 1 (GFS v15)	Suite 2	Suite 3	Suite 4
Deep convection	sa-SAS	sa-SAS	sa-CSAW	sa/aa-GF
Shallow convection	sa-MF	sa-MF	sa-MF	MYNN-EDMF and sa GF
Microphysics	GFDL	GFDL	aa-MG3	aa-Thompson
PBL/Turbulence	K-EDMF	sa-TKE-EDMF	K-EDMF	MYNN-EDMF
Land Surface Model	Noah	Noah	Noah	RUC

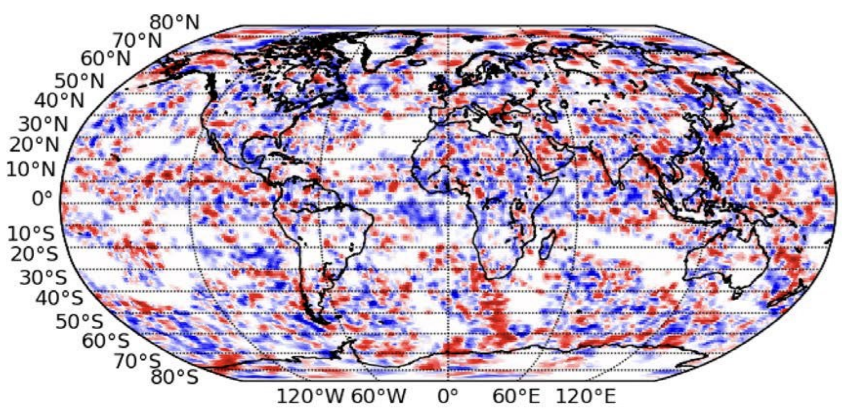
Table 1. Physics suites evaluated for possible implementation in GFSv16.
sa: Scale-aware; aa: aerosol aware; SAS: Simplified Arakawa Schubert; MF: Mass flux; MYNN: Mellor–Yamada–Nakanishi–Niino; EDMF: Eddy-diffusivity/Mass-flux; TKE: turbulent kinetic energy; CSAW: Chikira-Sugiyama-Arakawa-Wu; GF: Grell-Freitas Convection Parameterization; GFDL: Geophysical Fluid Dynamics Laboratory; MG3: Morrison-Gettelman; RUC: Rapid Update Cycle.

PBL/turbulence: K-EDMF => sa-TKE-EDMF
Land surface: Noah => Noah-MP
GWD: separate orographic/non-orographic => unified gravity-wave-drag
Radiation: updates to cloud-overlap assumptions, empirical coefficients, etc. in **RRTMG**

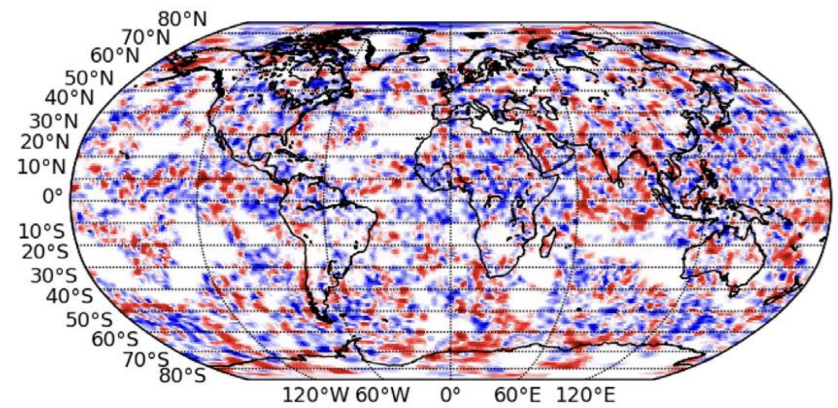
Courtesy of Dr. Jack Kain

New developments of independent patterns for PBL, shallow convection and deep convection.

- Different large-scale criteria masks the region where the CA is active; CAPE, counter gradient term, mass-flux depending on the process we would like to perturb.
- All CA's are evolved based on sub-grid fluctuations about the grid-mean vertical velocity in that region.



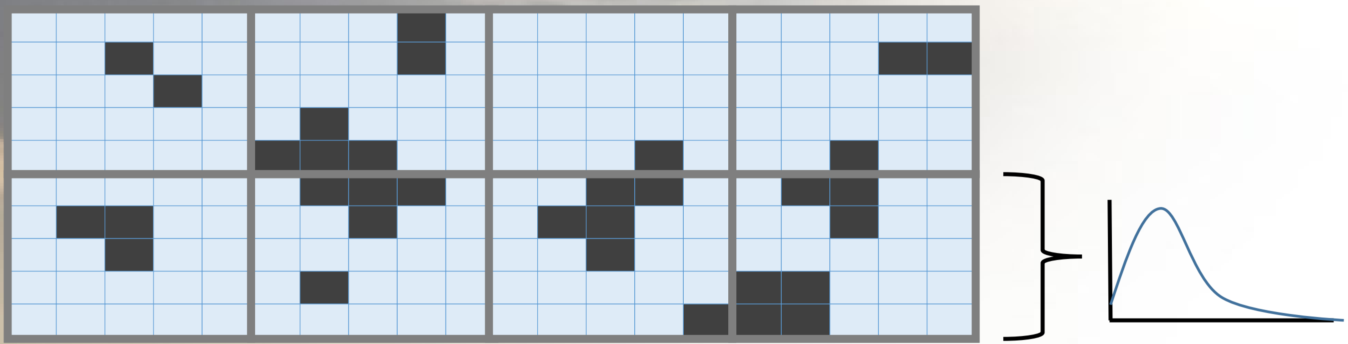
Shallow Convection

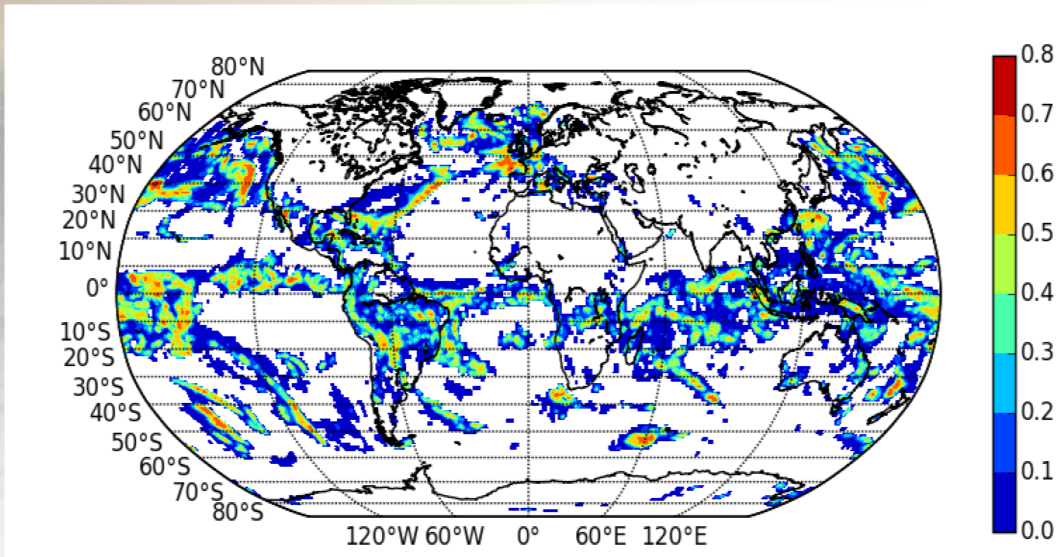


Turbulence

Courtesy of Dr. Jian-Wen Bao et al… 2019

Cellular Automaton (CA) in FV3





- Condition the cellular automaton on a skewed sub-grid distribution of updraft vertical velocity, and CAPE.
- Run at higher resolution than the NWP grid.
- Coarse grain back to NWP grid.

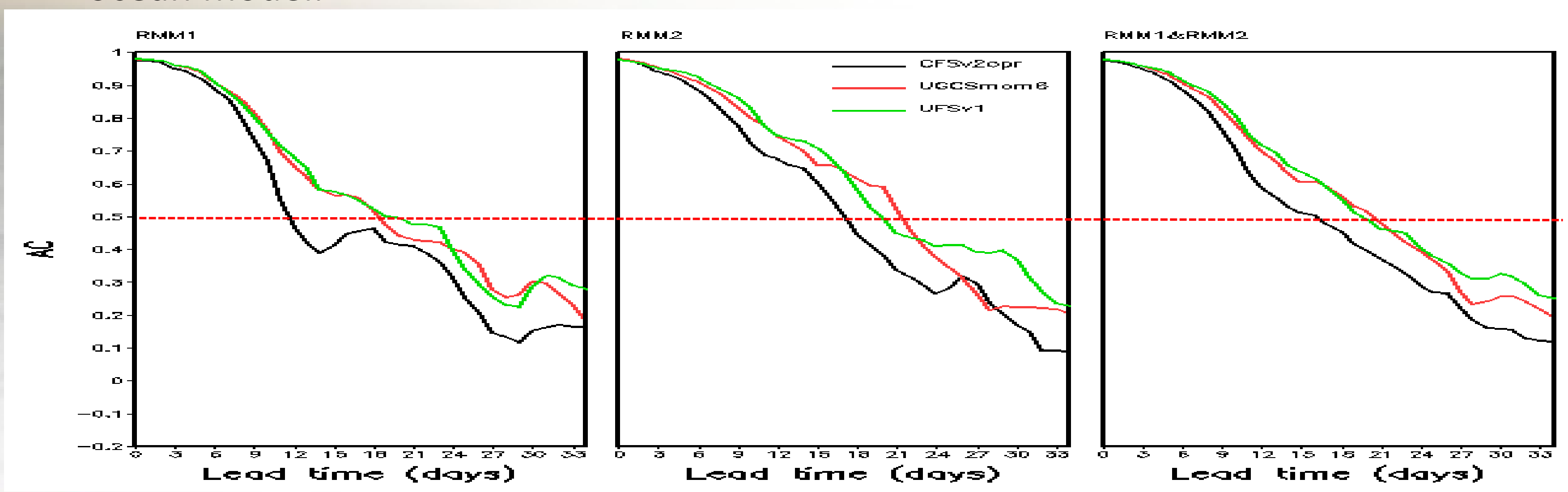
Courtesy of Dr. Jian-Wen Bao et al… 2019

The development of FV3 GFS + MOM6 + CICE5 coupled system

A. FV3: Atmospheric model with FV3 dynamic core at C384 resolution (28 Km)
B. MOM6: GFDL Ocean Model. Hybrid-coordinates, Tripolar grid 0.25° global.
C. CICE5: Los Alamos SeaIce Model. Same grid as MOM6 ocean model.

Correlation Skill for MJO index RMM1 and RMM2 and Bivariate Correlation Skill for MJO index (RMM1 + RMM2)

April 2011 to March 2018 (7 years, 168 forecasts).



Courtesy of EMC coupling group and Suranjana Saha

Sudden Stratospheric Warming (SSW)

Opportunity –
Next FV3-GFS will increase vertical resolution from 64 to 126

SSWs can increase the probability of record-breaking cold temperatures and snowfall in eastern North America.

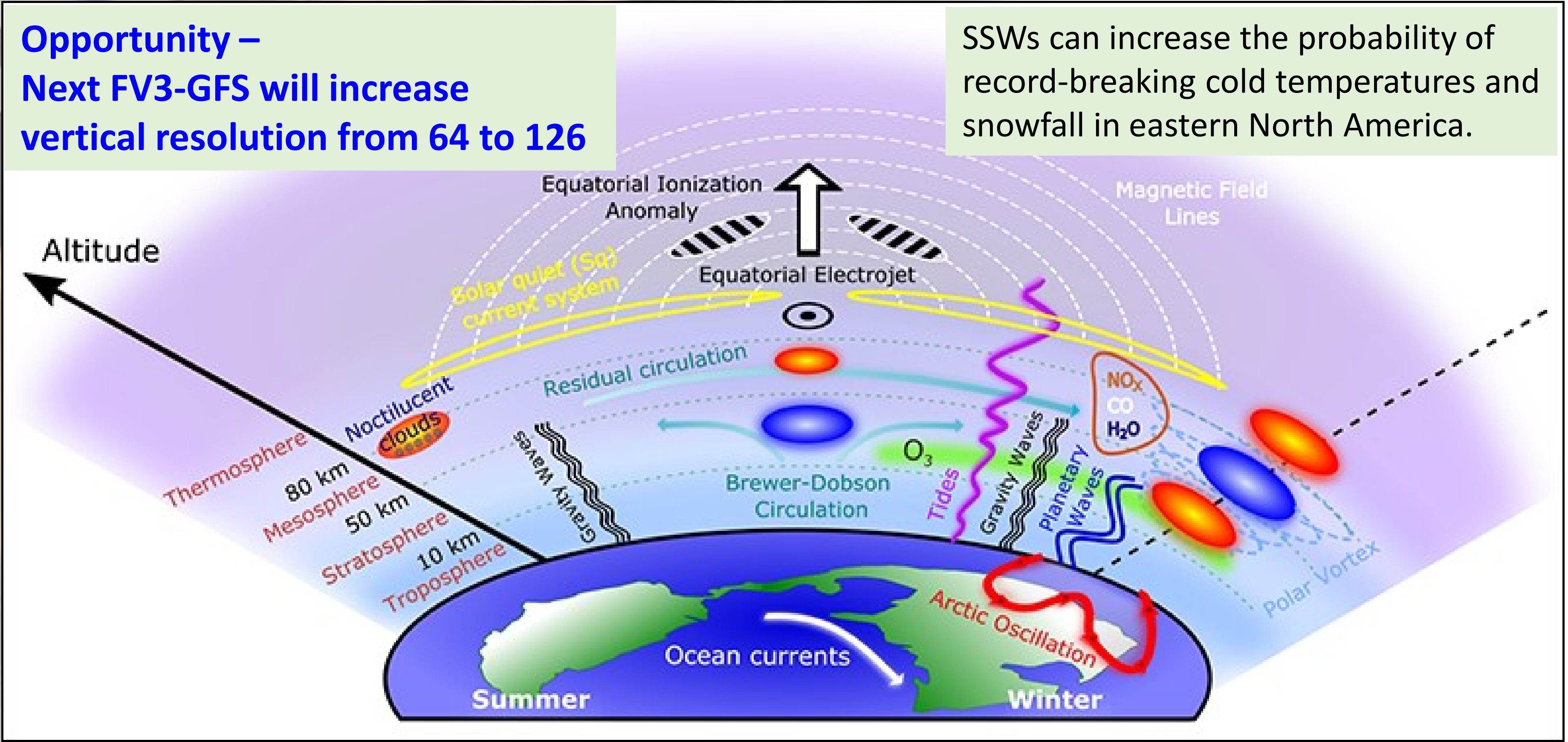


Fig. 1. Schematic of the coupling processes and atmospheric variability that occur during sudden stratospheric warming events. Red and blue circles denote regions of warming and cooling, respectively.

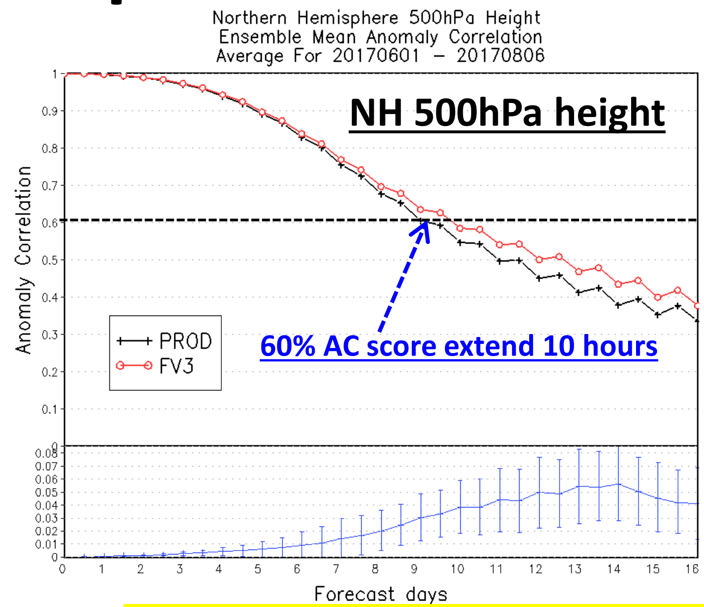
SSW is an event in which the observed stratospheric temperature rises by several tens of kelvins (up to about 50 °C (90 °F)), over the course of a few days. The change is preceded by a situation in which the Polar jet stream of westerly winds in the winter hemisphere is disturbed by natural weather patterns or disturbances in the lower atmosphere

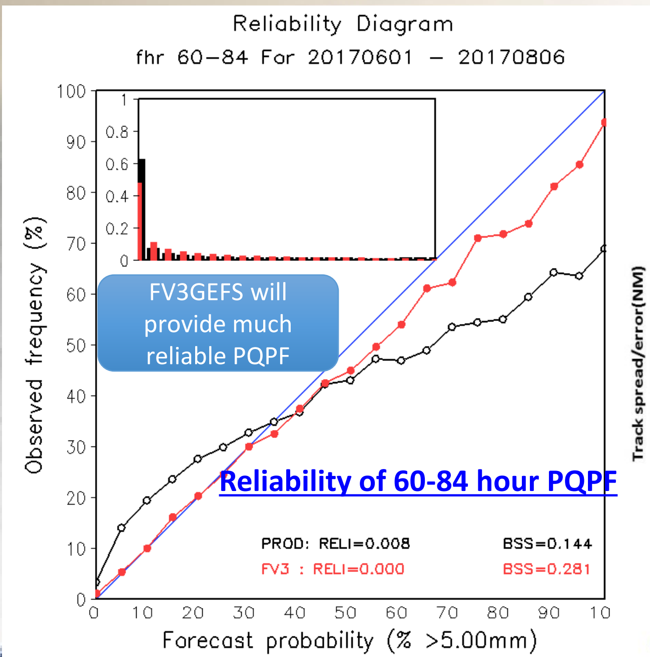
https://eos.org/features/how-sudden-stratospheric-warming-affects-the-whole-atmosphere

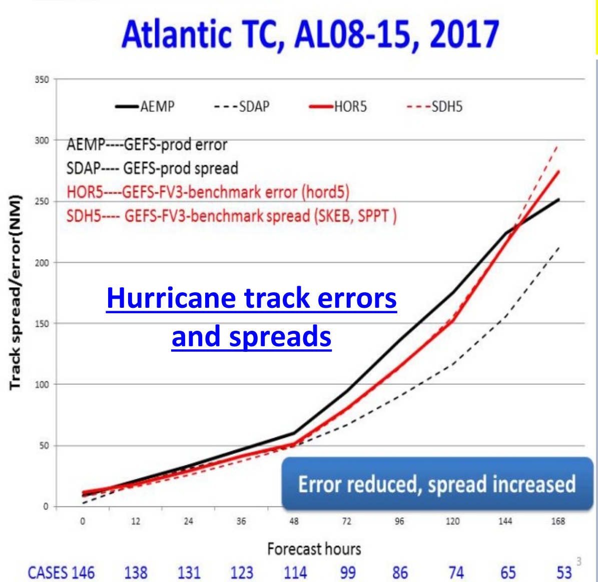
Thanks for your attention!!!

Next GEFS for operational implementation

	OPS-GEFS (v11)	FV3-GEFS (v12)
Dynamics	GSM	FV3
Physics	GFS physics (ZHAO-CARR MP)	GFS physics (GFDL MP)
Resolutions	TL574L64 (d1-8) TL382L64 (d9-16)	C384L64 (d1-16) C384L64 (d16-35)*
Members	20+1; 4 times per day	30+1; 4 times per day
Initial perts	GSM-GFS EnKF 06 fcst	FV3-GFS EnKF 06 fcst
Model uncertainties	STTP	SPPT+SKEB
Boundary SST	Relaxation to Climatology	NSST+2-tiered SST







When/what will FV3-GEFS deliver to public?

Expect: Later summer of 2020

25km horizontal resolution

31 members;

4 times per day; out to 16 days

once per day; out to 35 days

+++

30 years GEFS reforecasts

Once per day at 00UTC

5 members out to 16 days

Except for every Wednesday

11 members out 35 days