An Assessment of Predictability and Prediction of FV3 GEFS for Extreme Event and Uncertainty

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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.

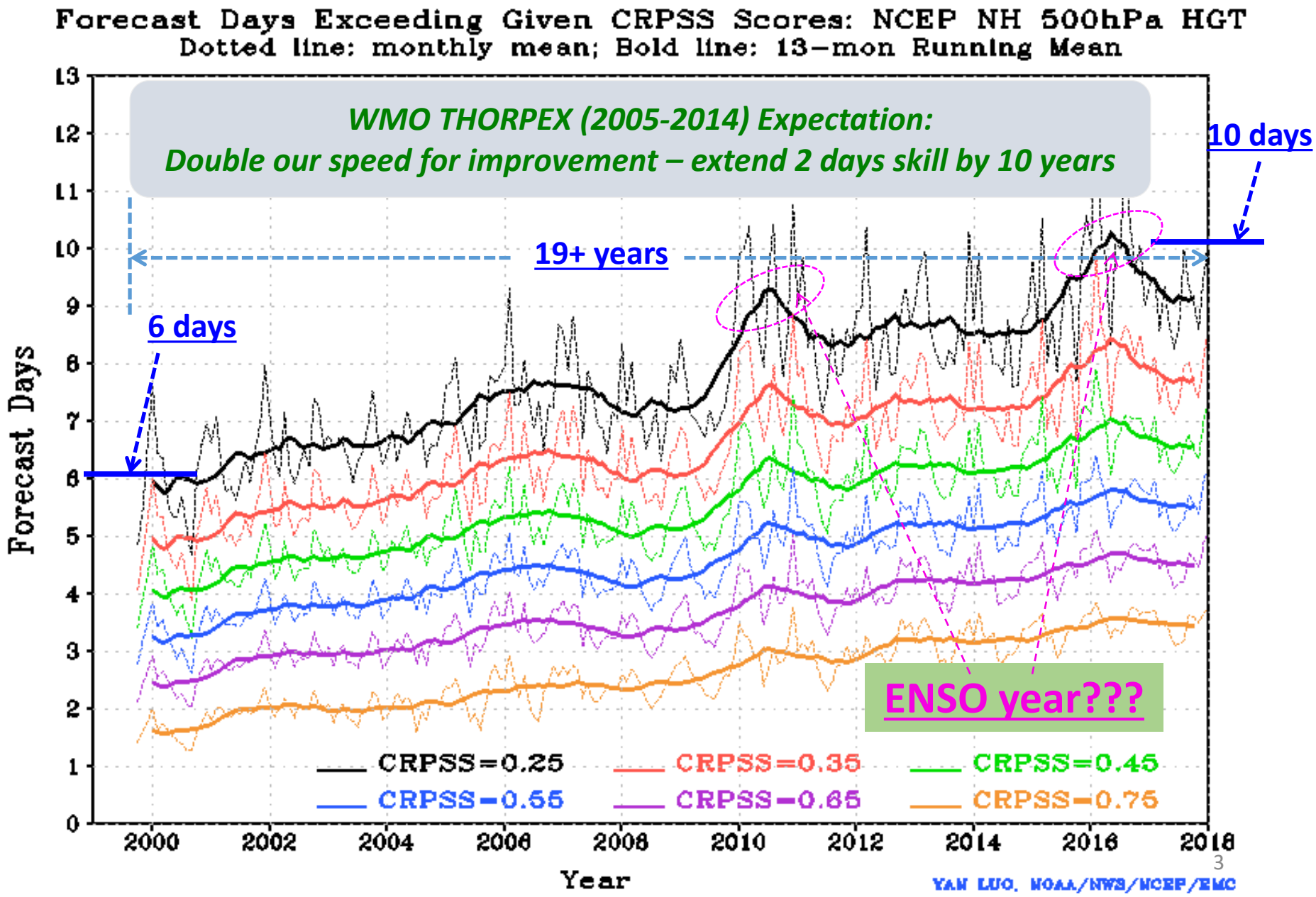
- The NOAA is accelerating its efforts to improve the prediction capability, and provide **seamless numerical guidance** to the public, protecting life and property.

- The **NCEP GEFS** has been very successful to provide reliable weather and week-2 probabilistic forecast guidance for the general public.

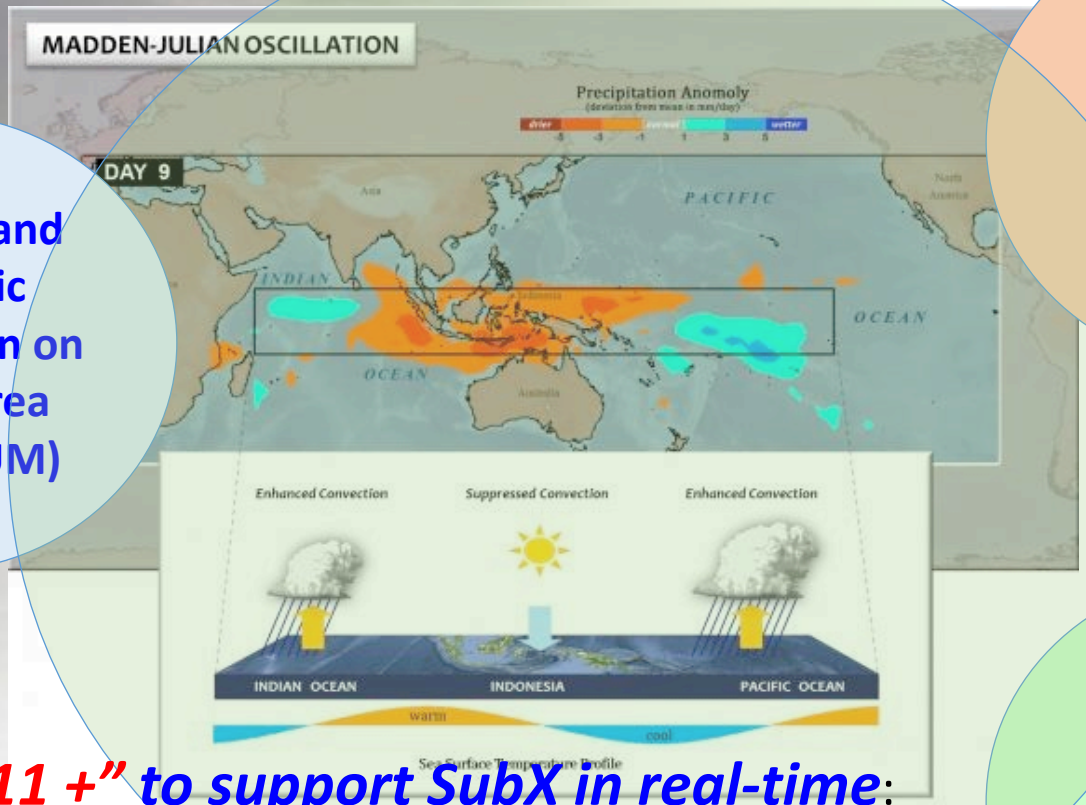
- The NCEP GEFS has been extended to 35 days in real-time with a 18-year reforecast to support **NOAA SubX** project.

- The **FV3-based GEFS** (35 days) has been frozen for implementation with 30-year reforecast toward NOAA **Unified Forecast System** (UFS)

CRPSS for NH 500hPa geopotential height



The key areas to focus on …



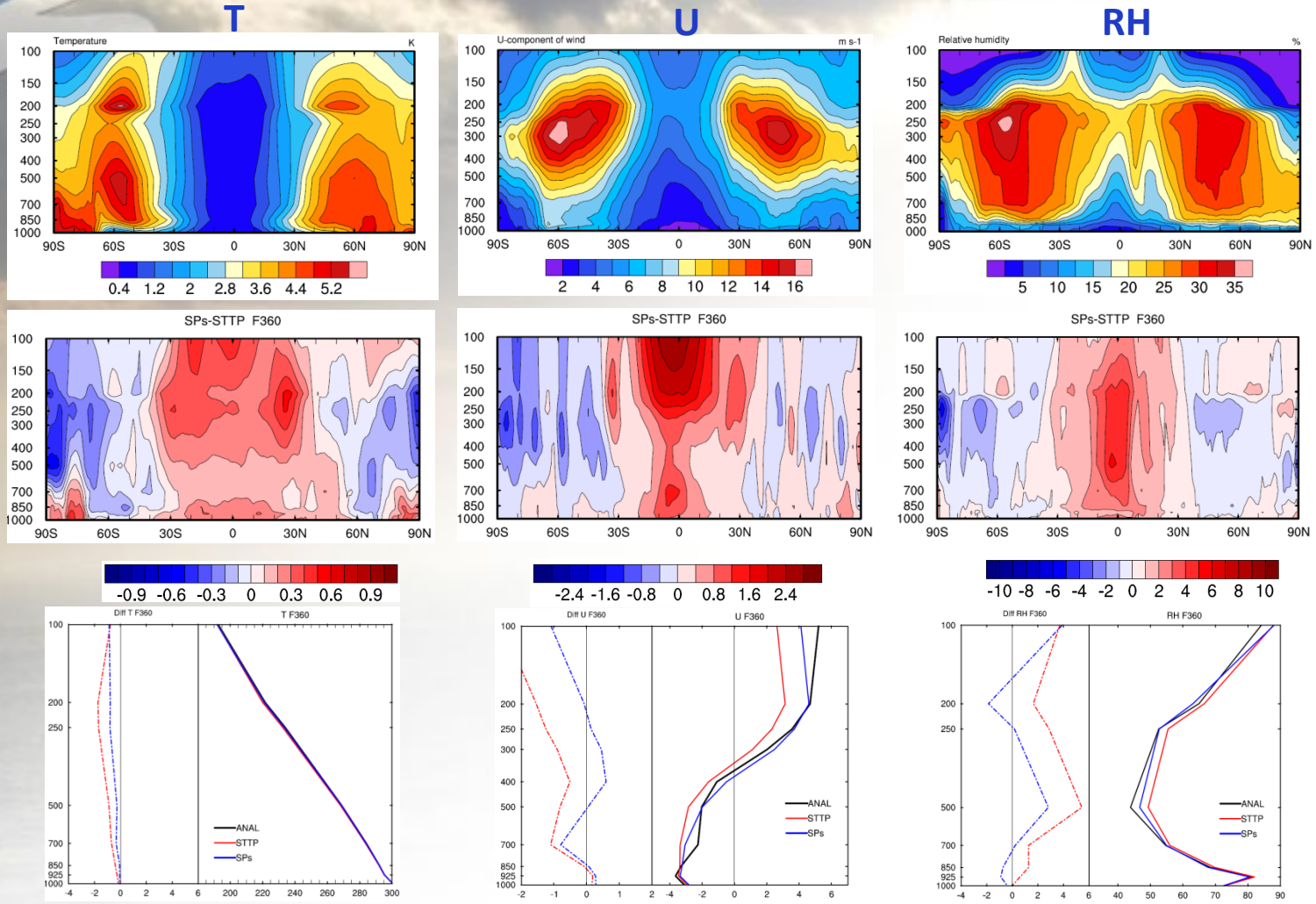
Ensemble and Stochastic perturbation on tropical area (SPPT, SHUM)

Atmosphere-ocean interaction (2-Tier SST)

Tropical convections include cloud, radiation, precipitation and et al. (SA Conv)

- ***"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**) ;

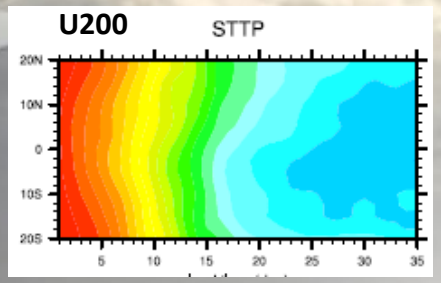
Impact of the Stochastic Physics (SPs)

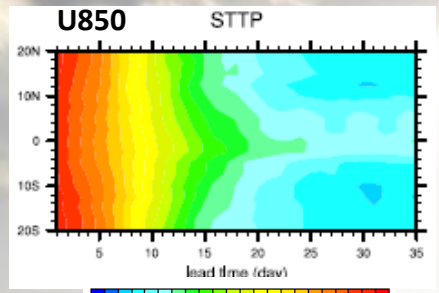


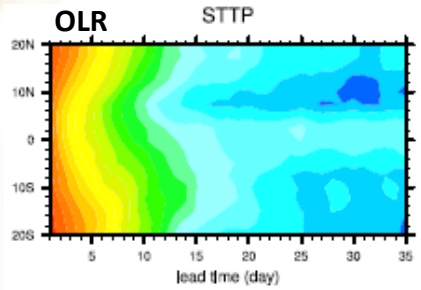
Averaged ensemble spread of the perturbed members in GEFS for temperature, zonal wind and relative humidity at 360 forecast hour (top row, left to right); the difference between SPs and STTP for the corresponding variables (middle row); vertical profiles (solid) and mean errors (dash) for the corresponding variables (bottom row). For each plot, 6 samples during March 2016 (March 1, 6, 11, 16, 21 and 26) was used to calculate the averaged ensemble spread and error.

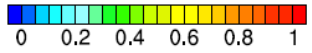
Correlation as a function of lead time

CTL

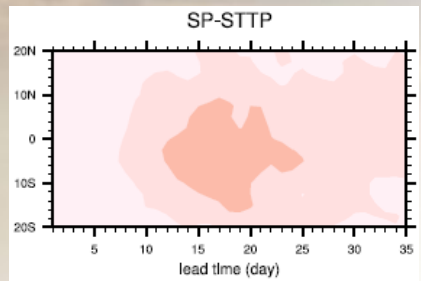


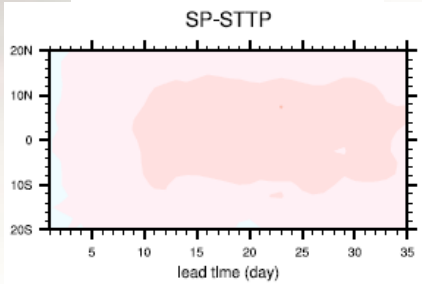


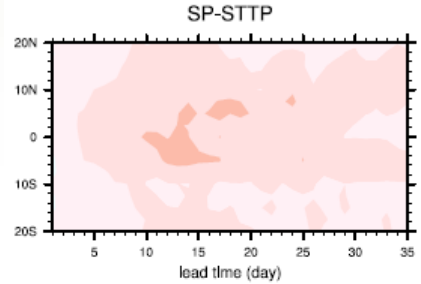




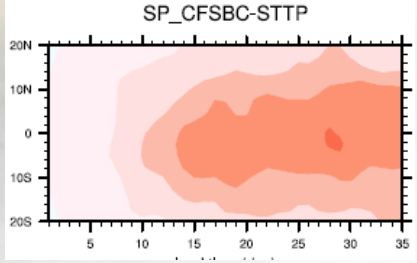
SPs - CTL

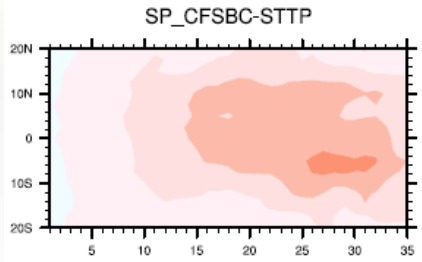


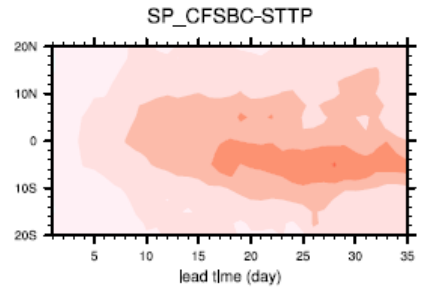




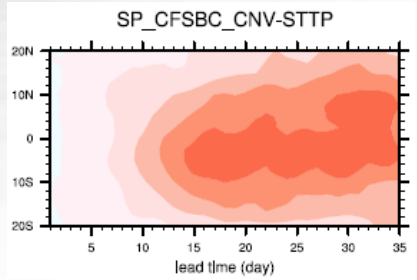
SPs+CFSBC - CTL

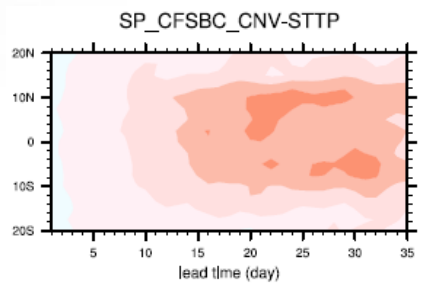


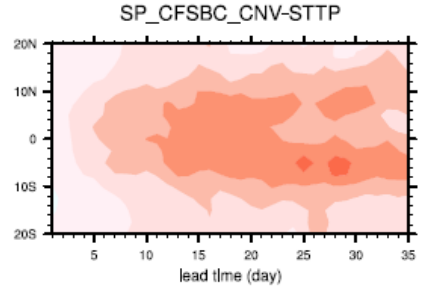


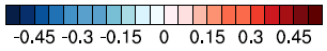


SPs+CFSBC +CNV - CTL









Current: Operational 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**);
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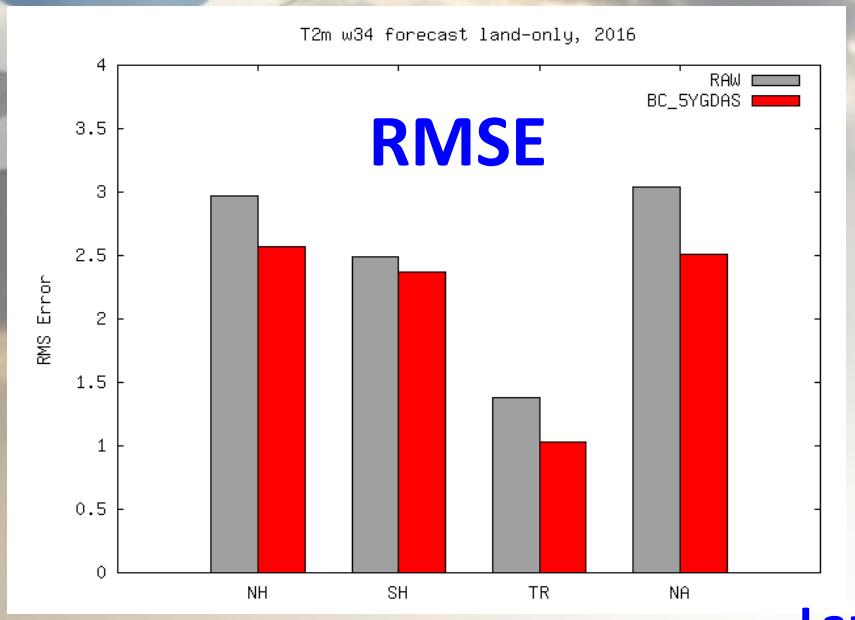
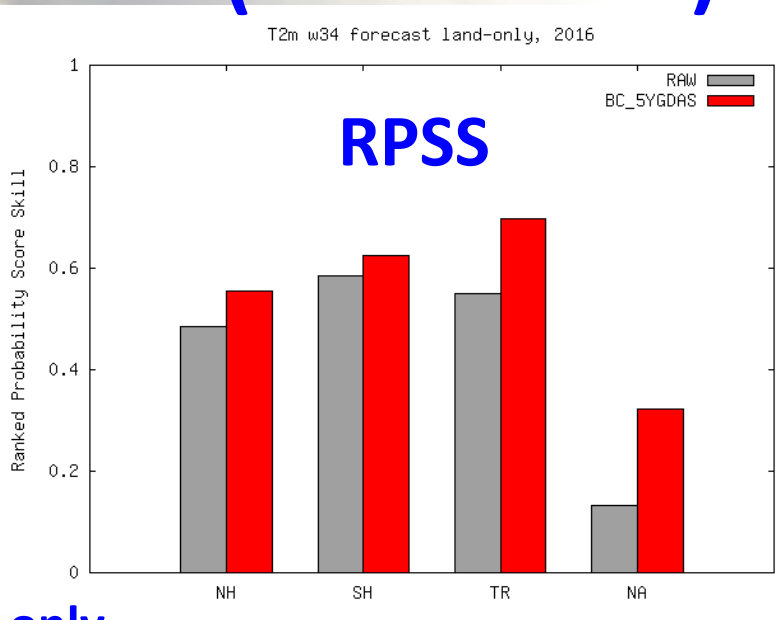
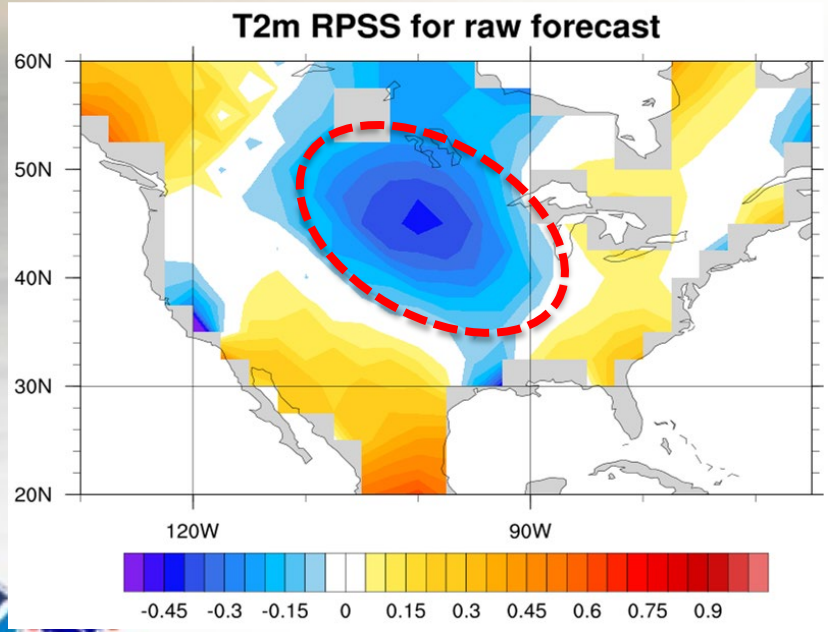
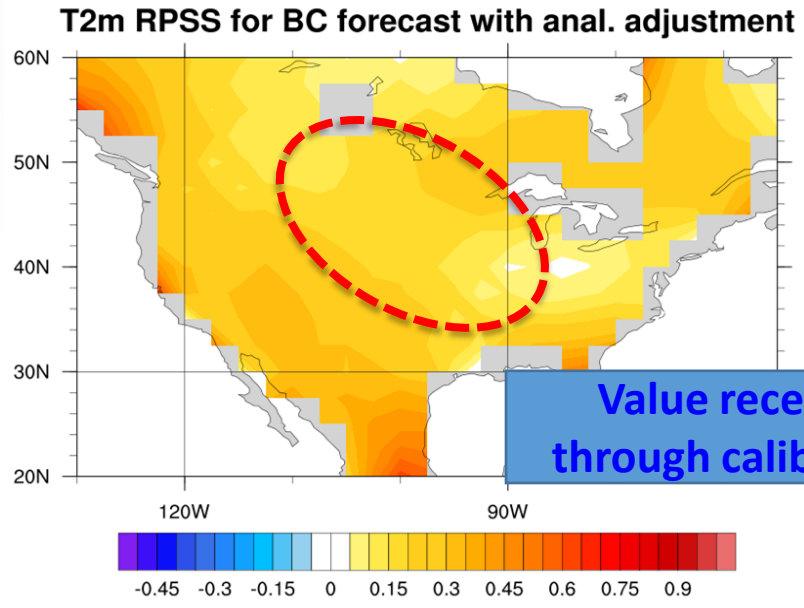
Bias correction for T2m (weeks 3&4)





Land only

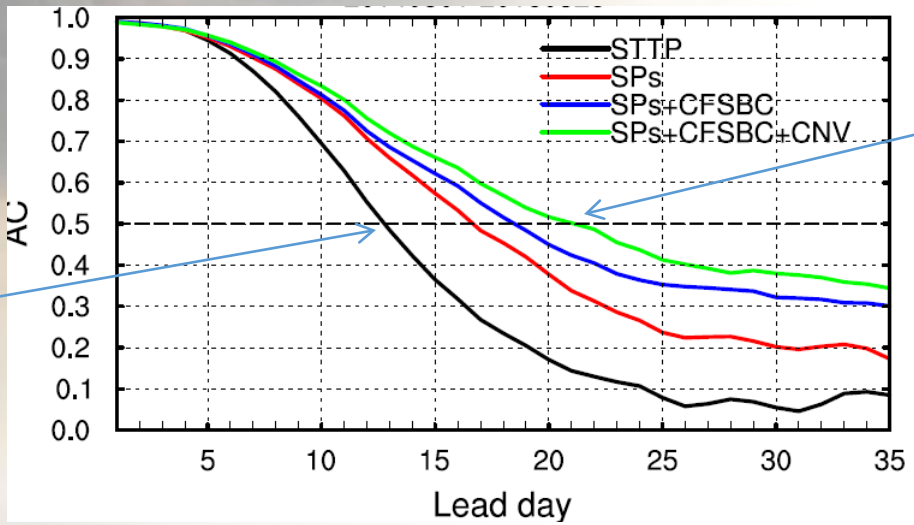




Value received through calibration

WH-MJO Forecast Skills for 2-yr Experiments

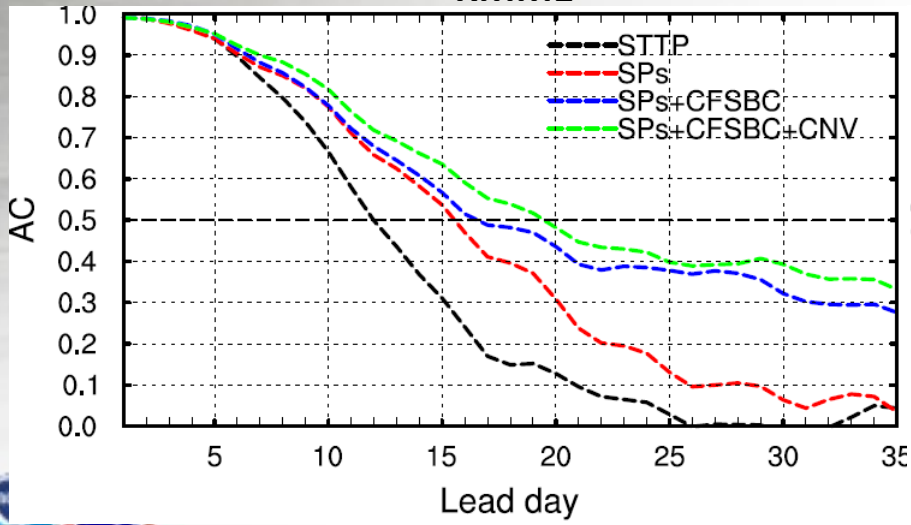
RMM1+RMM2



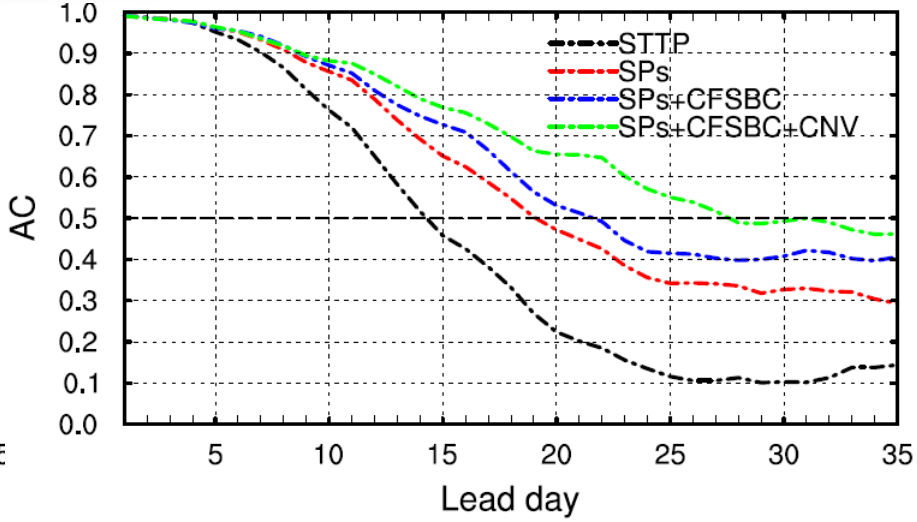
22 days

12.5 days

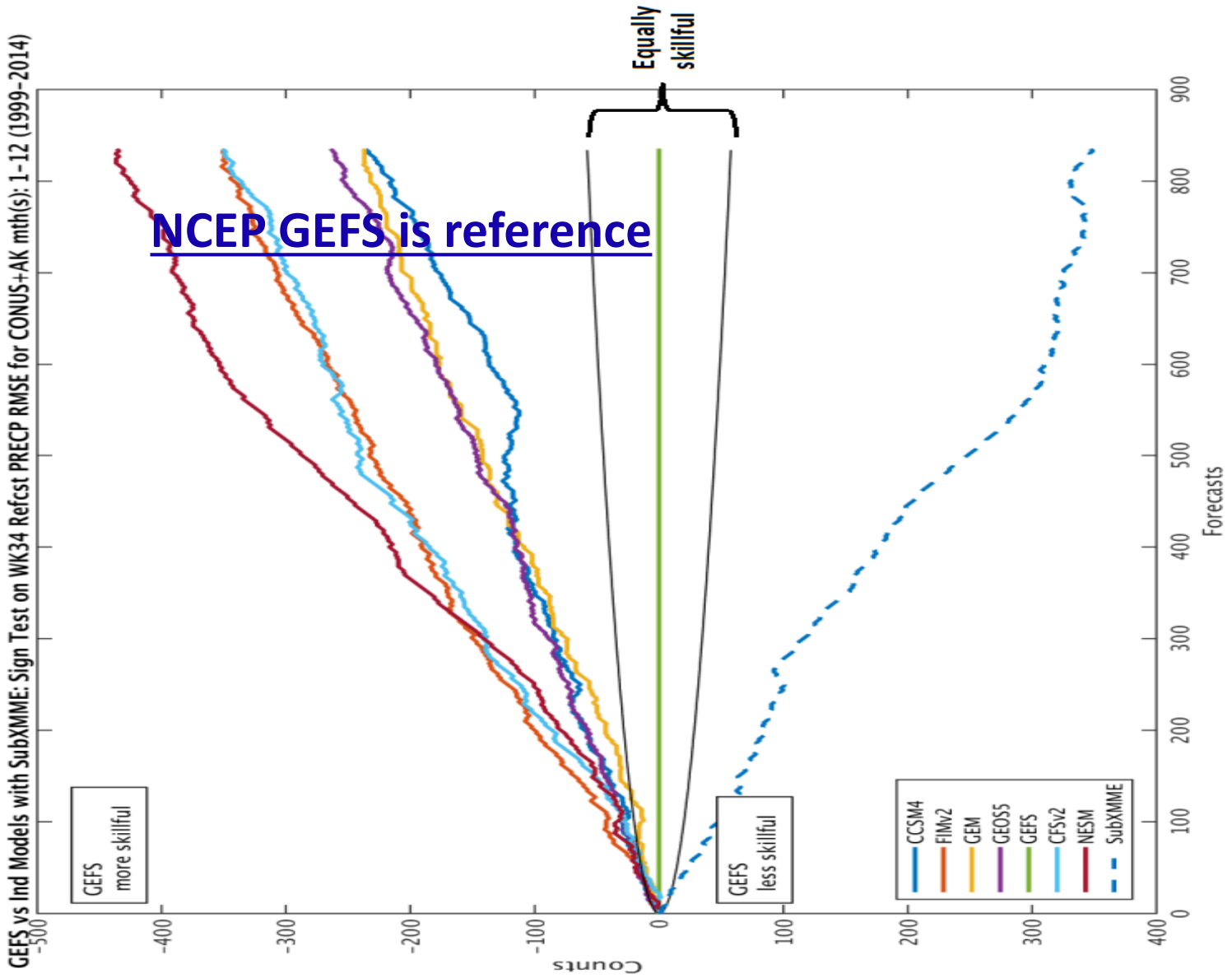
RMM1



RMM2

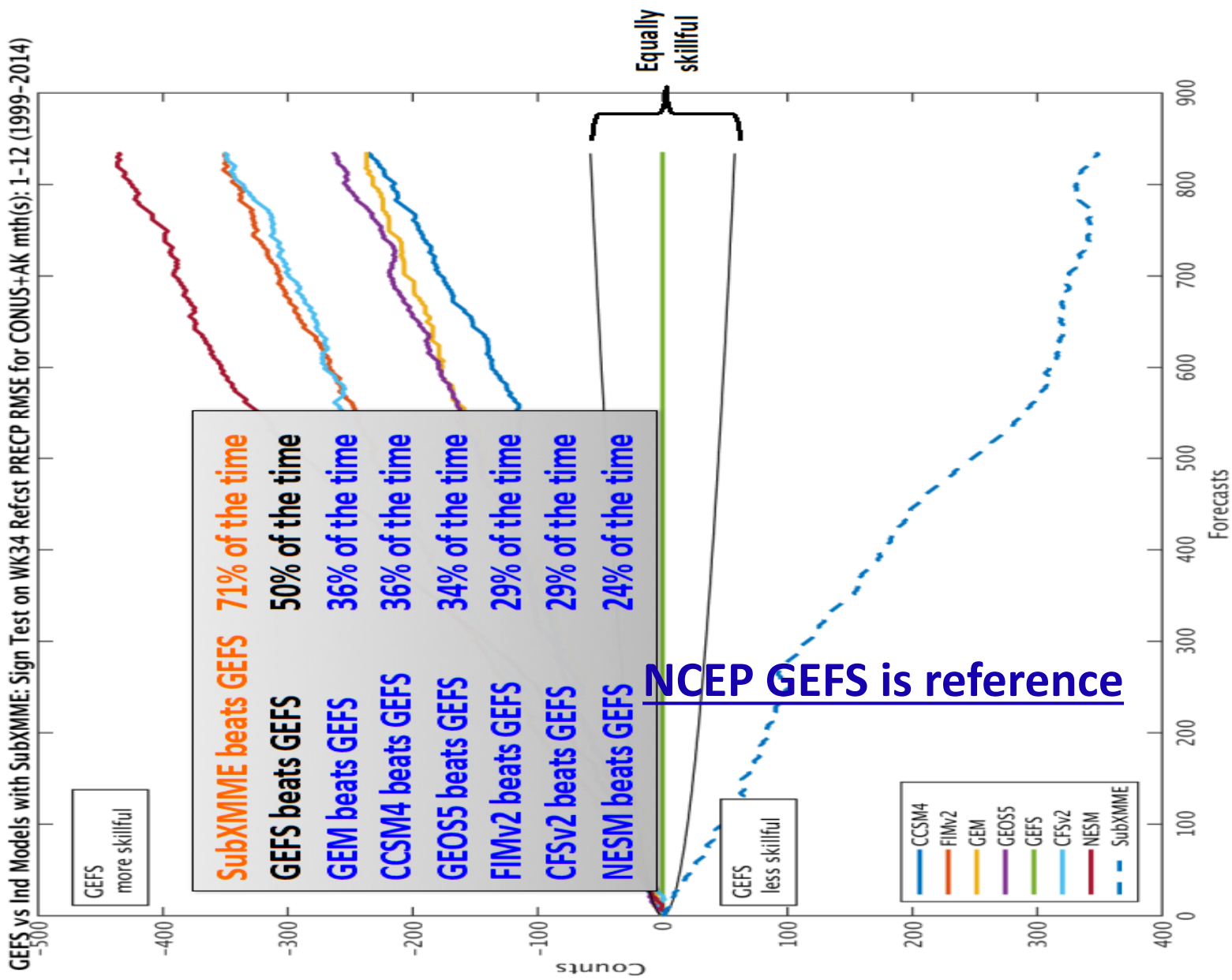


SubX Comparison based on 16-y reforecasts (CPC)



Courtesy of Emerson LaJoie and Dan Collins

SubX Comparison based on 16-y reforecasts (CPC)



NCEP GEFS is reference

Courtesy of Emerson LaJoie and Dan Collins

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)

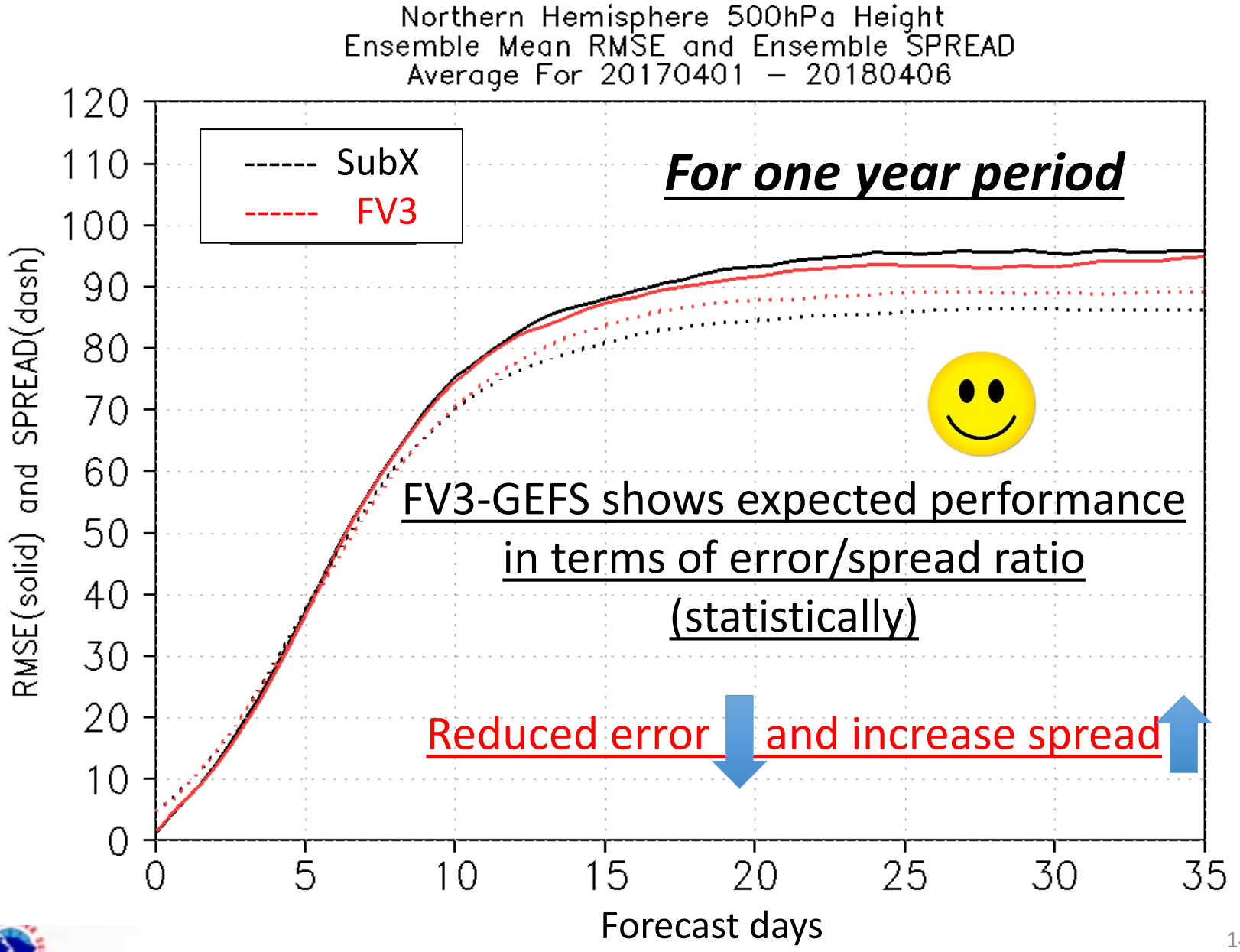
Configuration of GEFS v12 (plan)

- 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
  - ✓ Tuned Stochastic Physics (turn out SHUM)
  - ✓ 31 ensemble members (skills we have demonstrated are from 21 members)
  - ✓ More ……

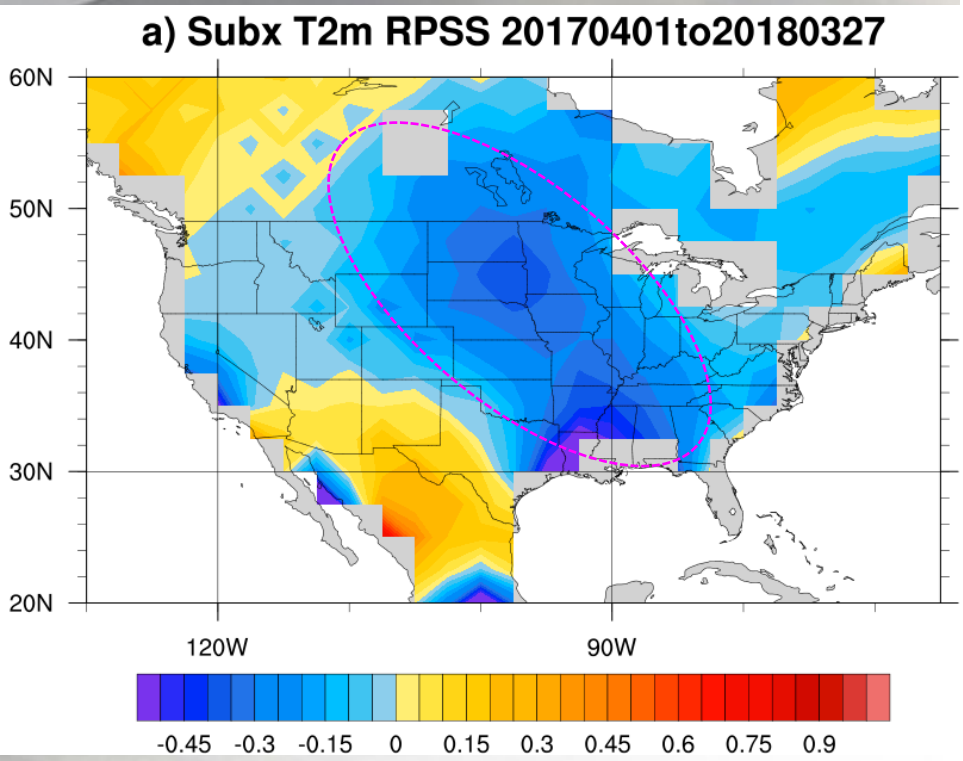
  - ✓ Computation cost – factor of 4

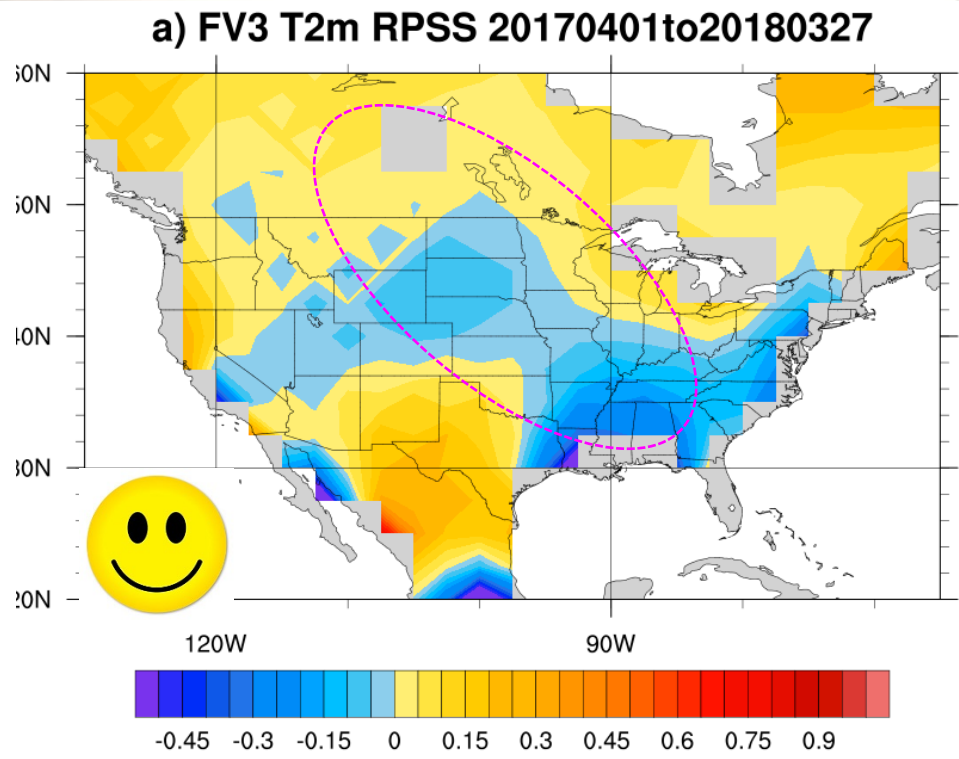
RMSE and Ensemble Spread of NH 500hPa height



RPSS scores for one years 35 days forecasts

Weeks 3&4 average



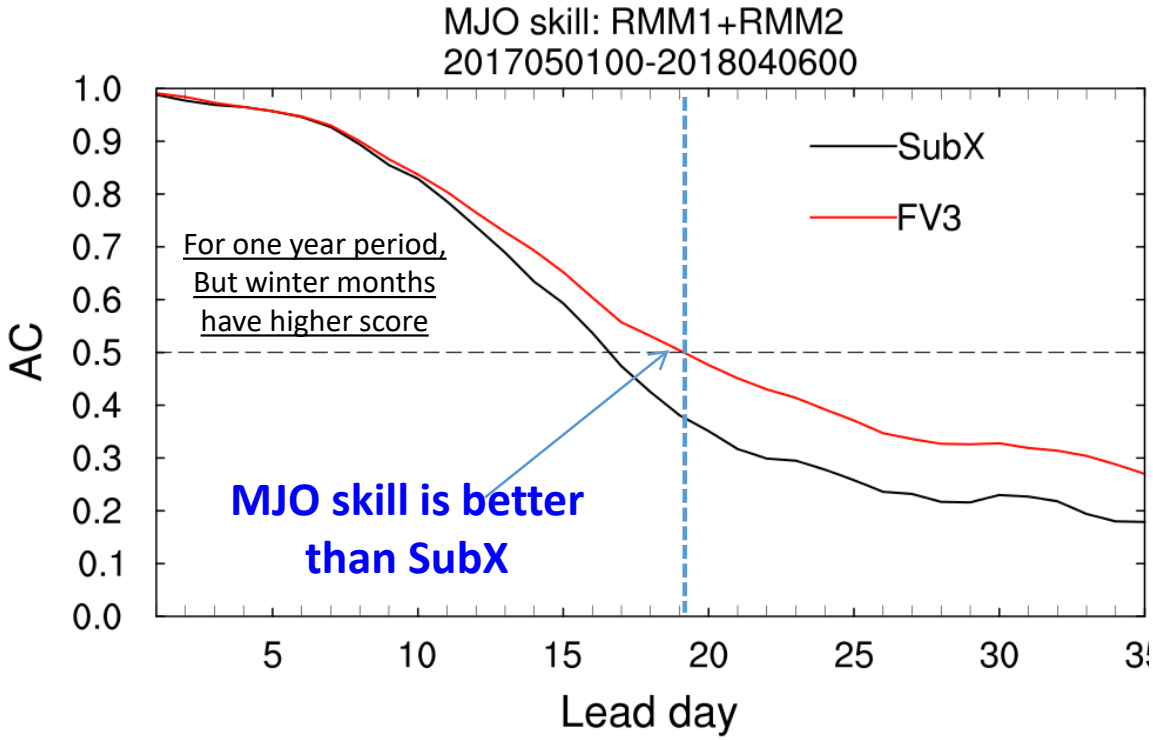


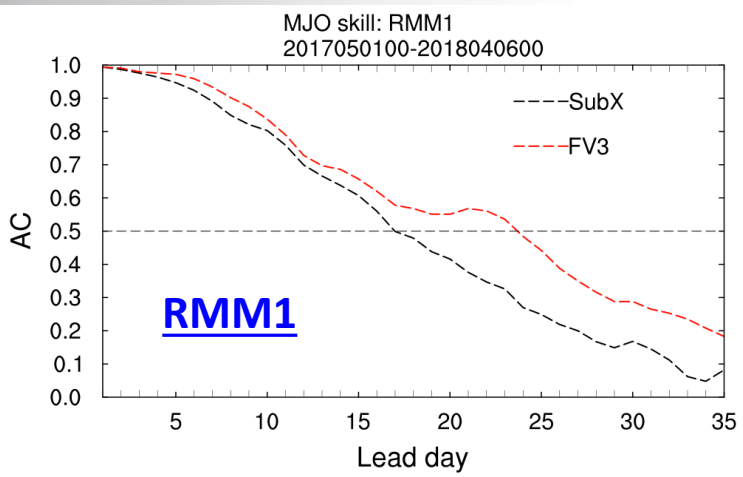
FV3-GEFS indicates an big improvement of T2m for CONUS

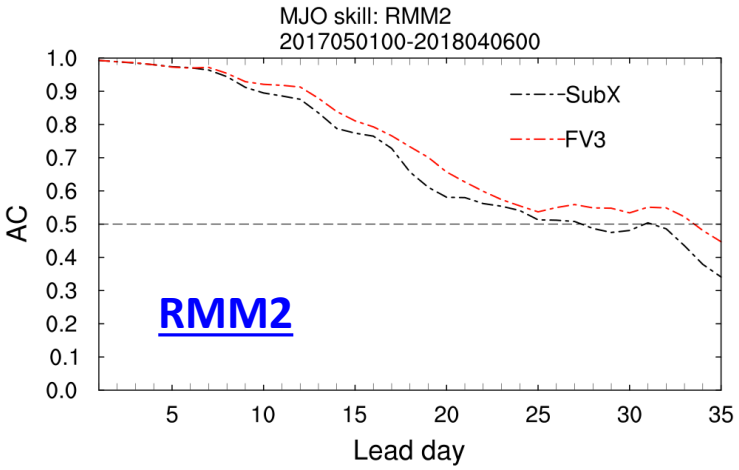
For raw ensemble forecast (no calibration)

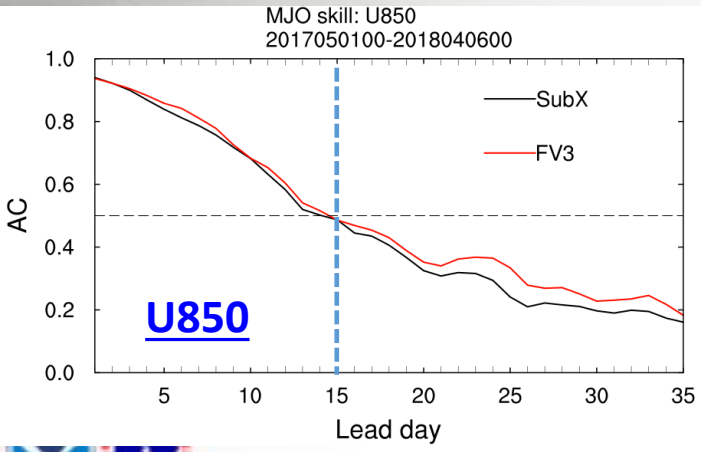
Truth: own analysis or f00 at 2.5d resolution

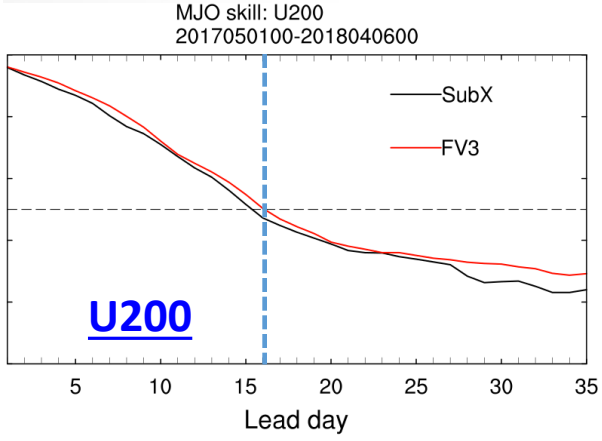
Tropical Prediction Skills

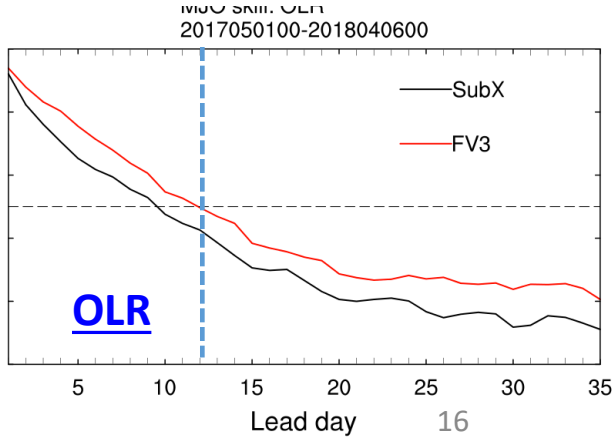












Potential forecast capability - Predictability

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

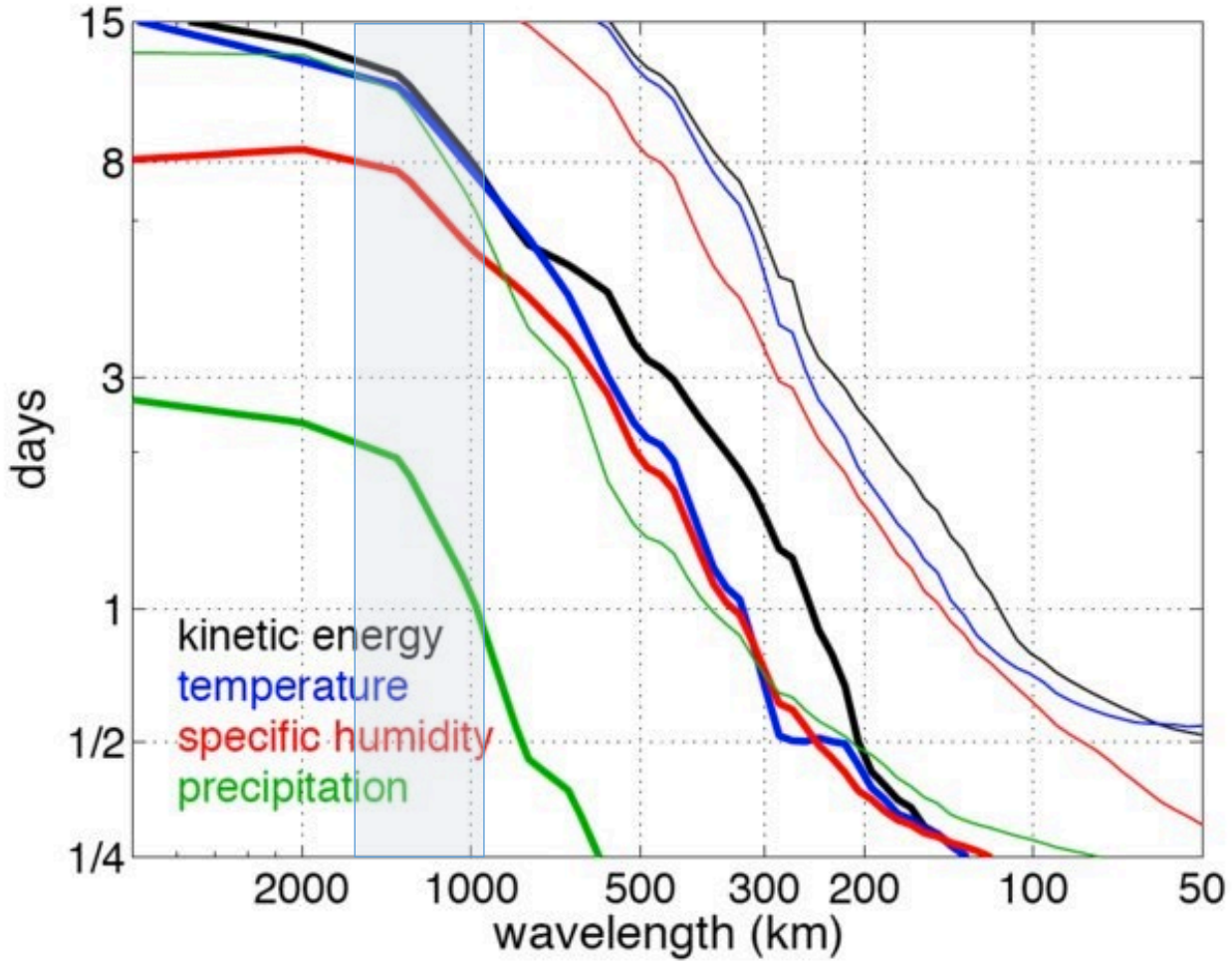
- ✓ Charney (1951) indicated that forecast skill would break down, but he attributed it to **model errors** and errors in the **initial conditions**

- ✓ 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

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



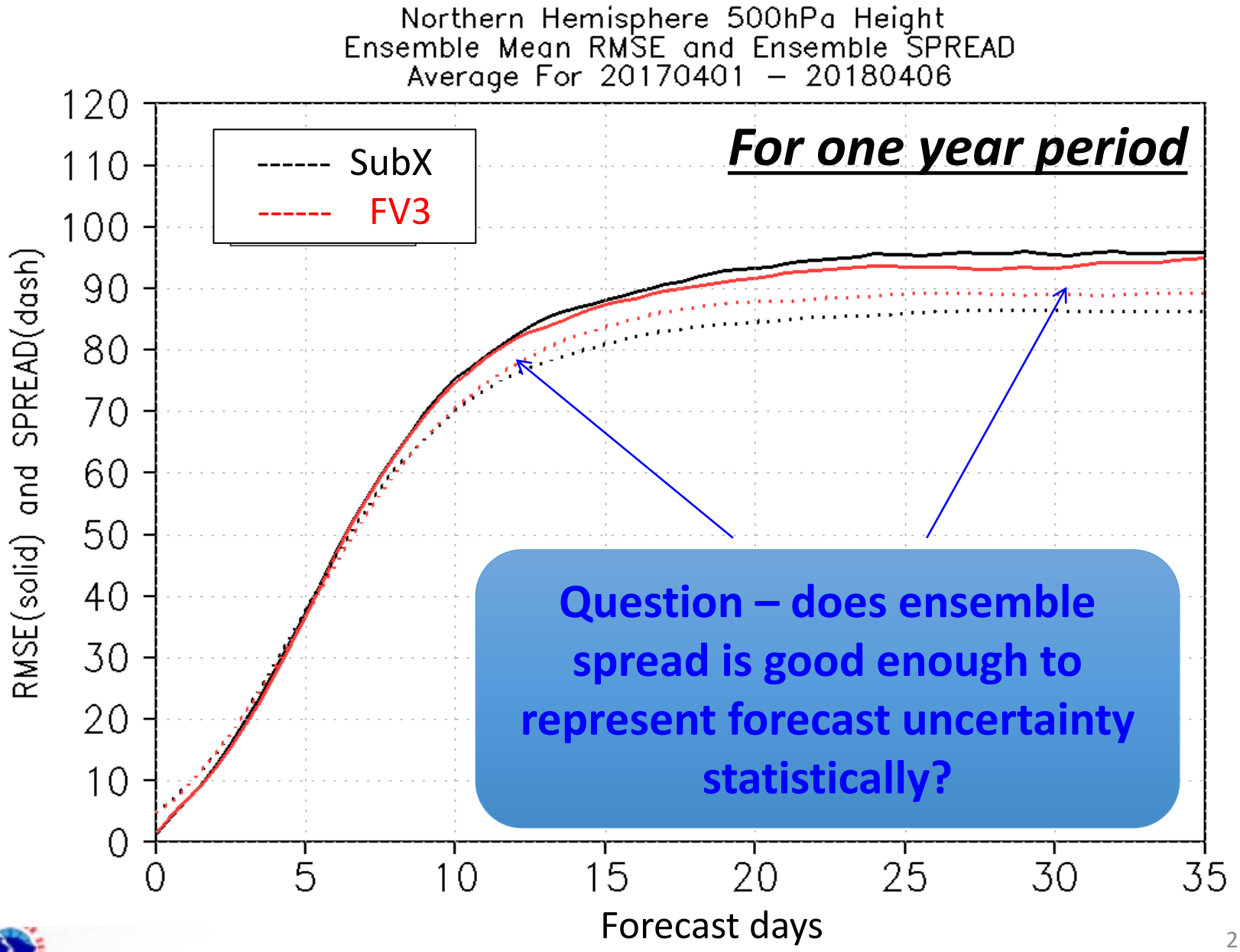
Predictable timescale (days) for kinetic energy, temperature, humidity, and precipitation as a function of horizontal wavenumber (labeled as corresponding wavelength in km). Intrinsic predictability limits are shown in thin lines, and practical predictability limits in thick lines.

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



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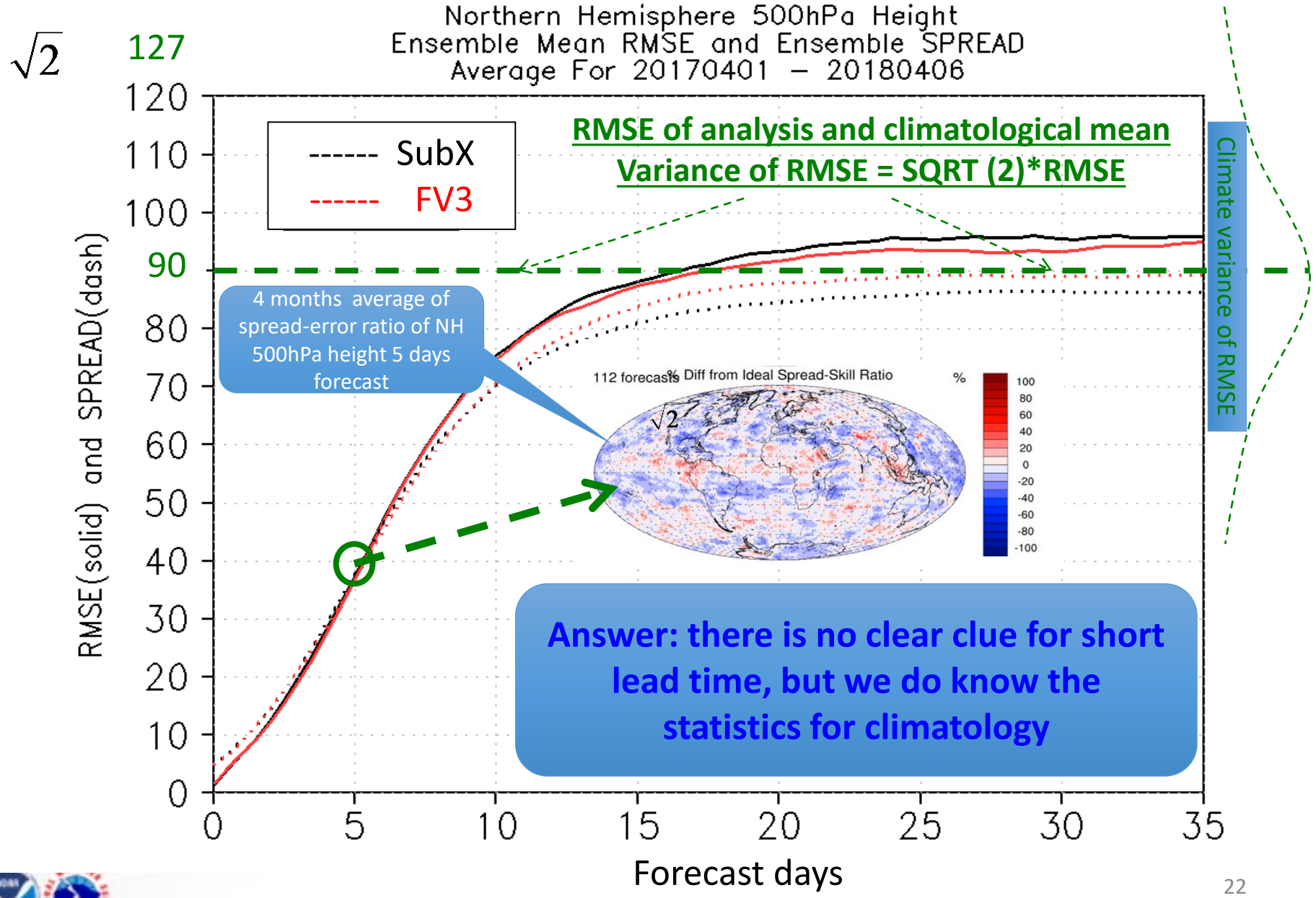
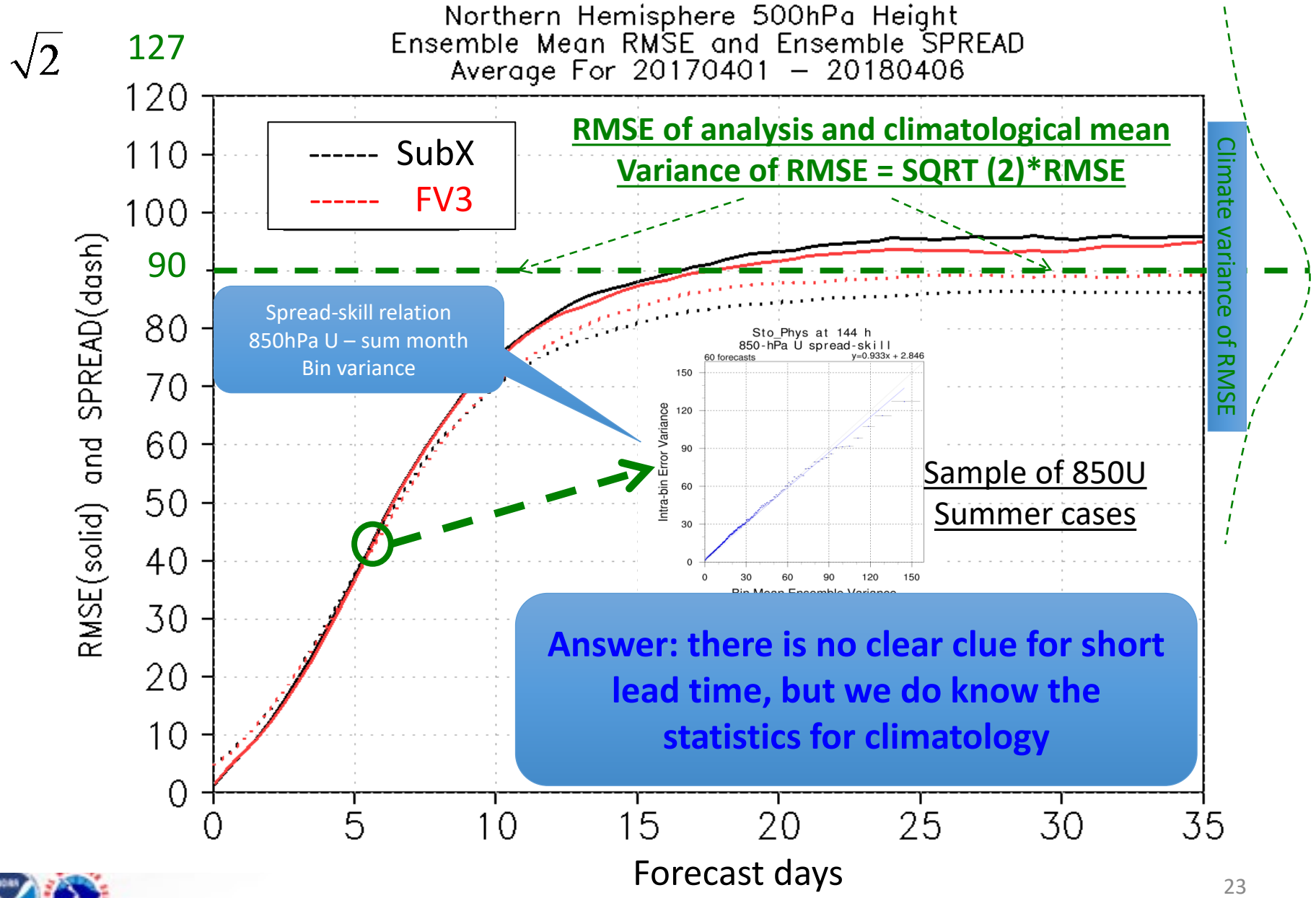
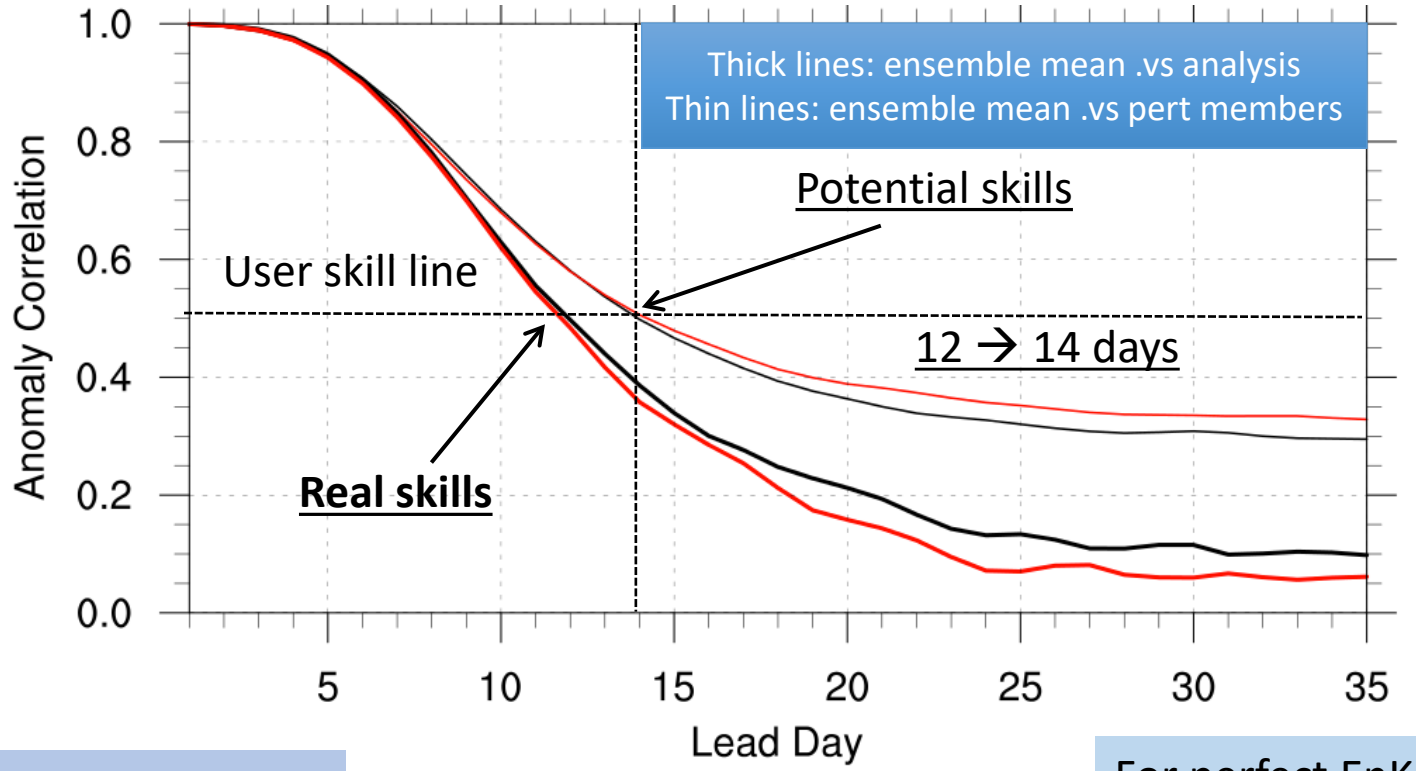


RMSE and Ensemble Spread of NH 500hPa height



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

(ASSUME BIAS FREE)



Please note that GEFS has limited ensemble size (21)

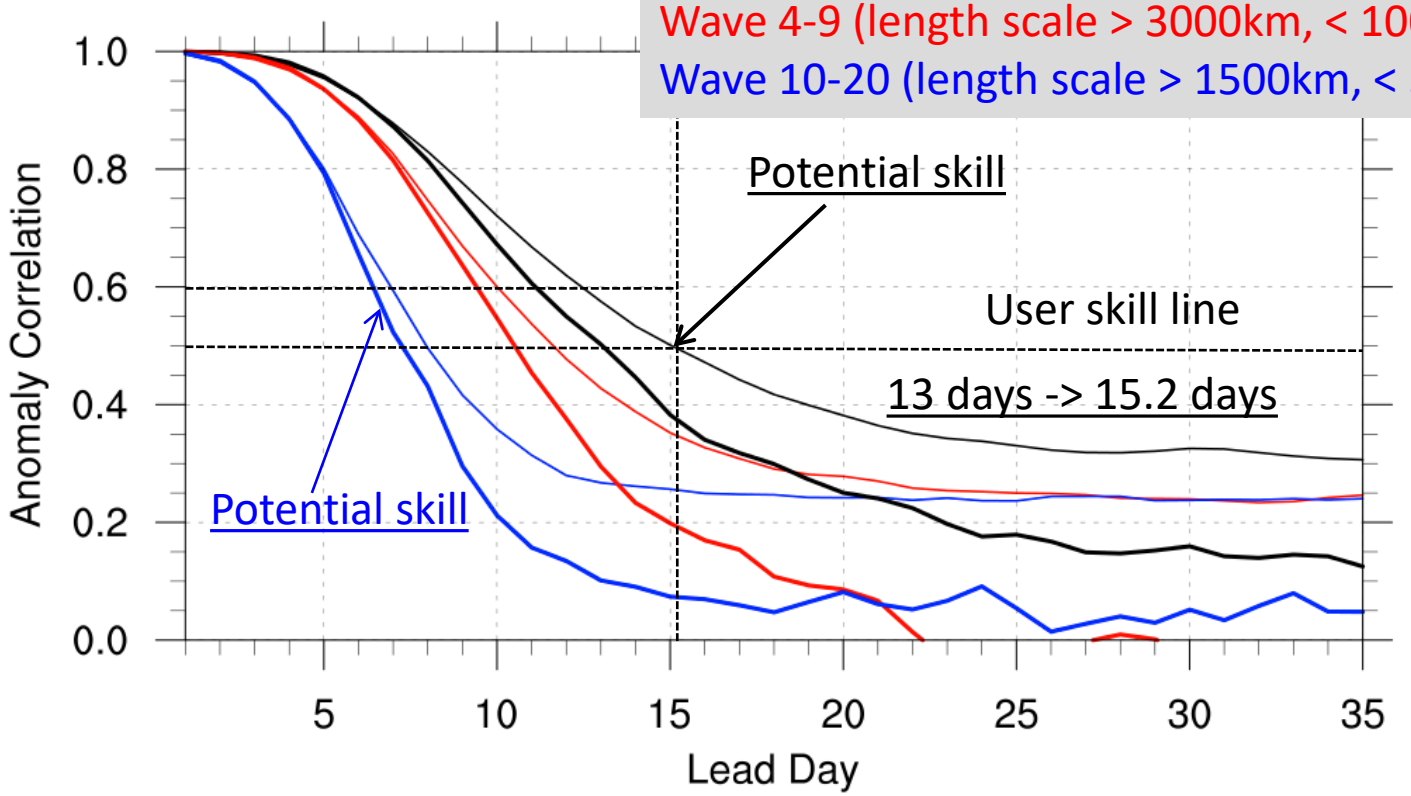
SubX

FV3GEFS

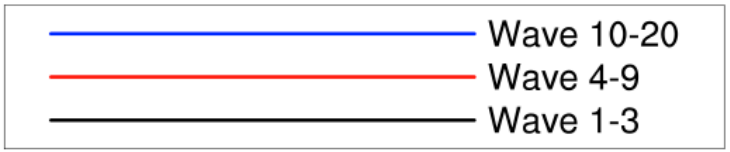
For perfect EnKF system, all initial analyses are equal, all forecast should be trues if model is perfect

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

Wave 1-3 (length scale > 10000 km)
Wave 4-9 (length scale > 3000km, < 10000km)
Wave 10-20 (length scale > 1500km, < 3000km)

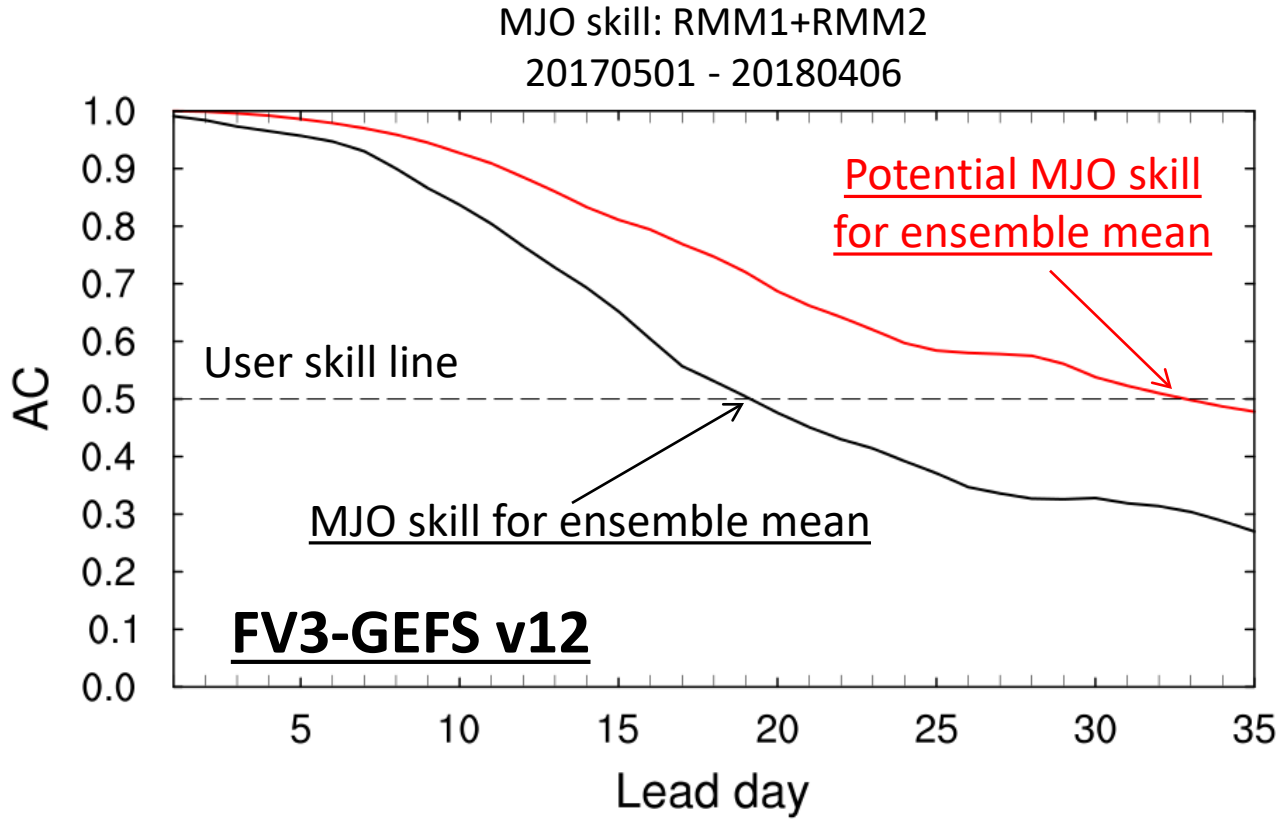


Skills are based on FV3-GEFS version



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?**

Summary

Prediction of Current and next GEFS

- Weeks 3&4 average
  - SubX version is better than CFSv2
  - FV3 version is similar to SubX
- Weeks 3&4 bias
  - FV3 version shows much better bias than SubX (not shown)
  - FV3 version has better RPSS skill than SubX for CONUS T2m
- Tropical area
  - SubX version has better MJO skills than CFSv2
  - FV3 version shows better MJO skills than SubX

Potential prediction skills

- Overall
  - Potential 2+ days skillful forecast could be added from current prediction through improving our model
- Different scales
  - Planetary scales (>1000km) could be 15+ days skill
  - Large scales (wave 4-9) could be 10+ days
  - Synoptic scales (wave 10-20) could be 8+ days
- Tropical area
  - Large potential to enhance tropical prediction, such as MJO

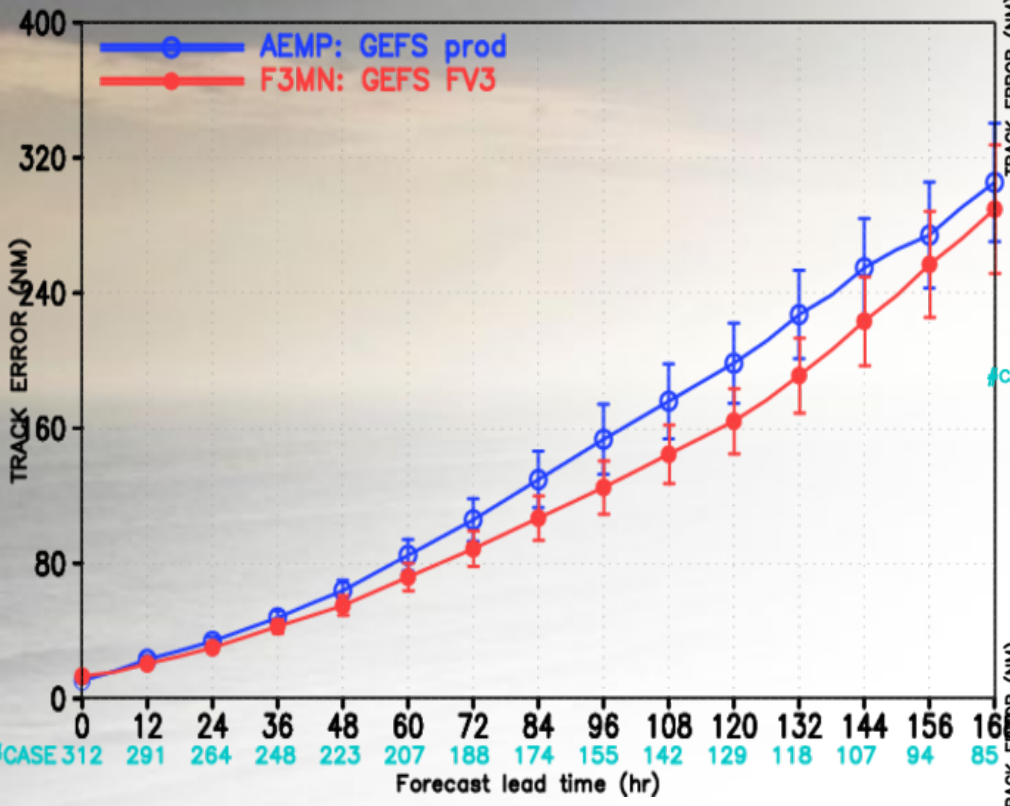
Will continue to investigate probabilistic forecast skills!!!

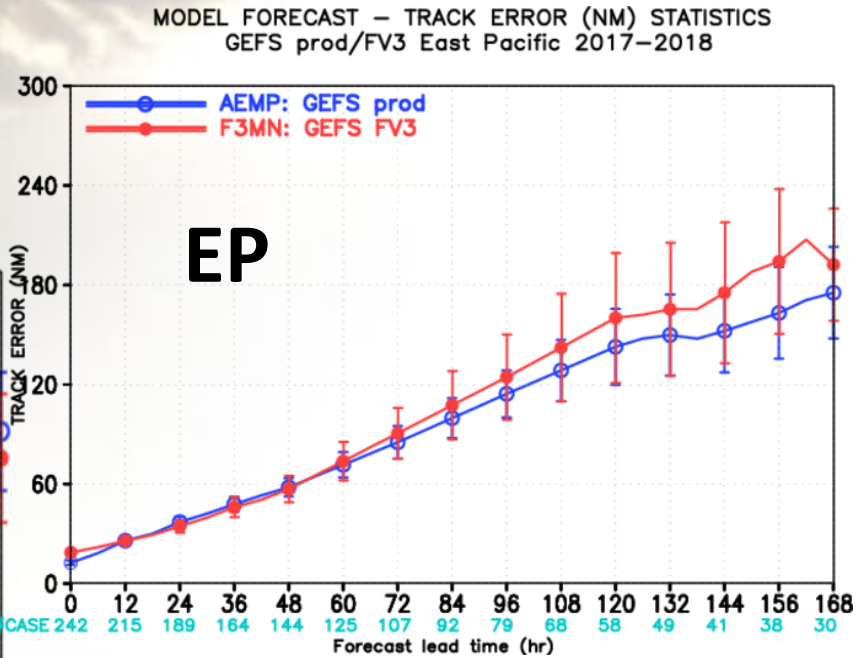
Advantage of FV3 GEFS

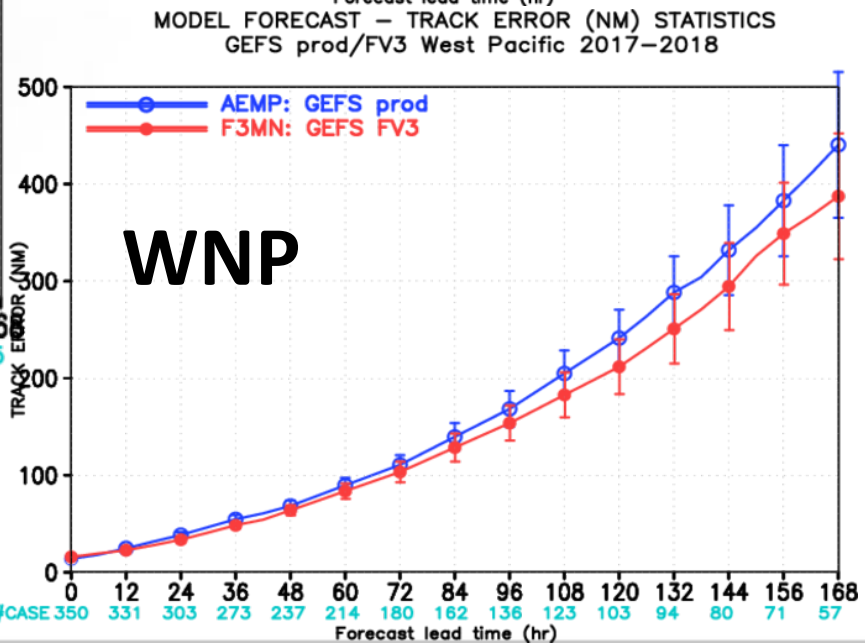
- Tropical storm prediction
- Precipitation

Tropical cyclone track forecast (2017 & 2018)

Atlantic

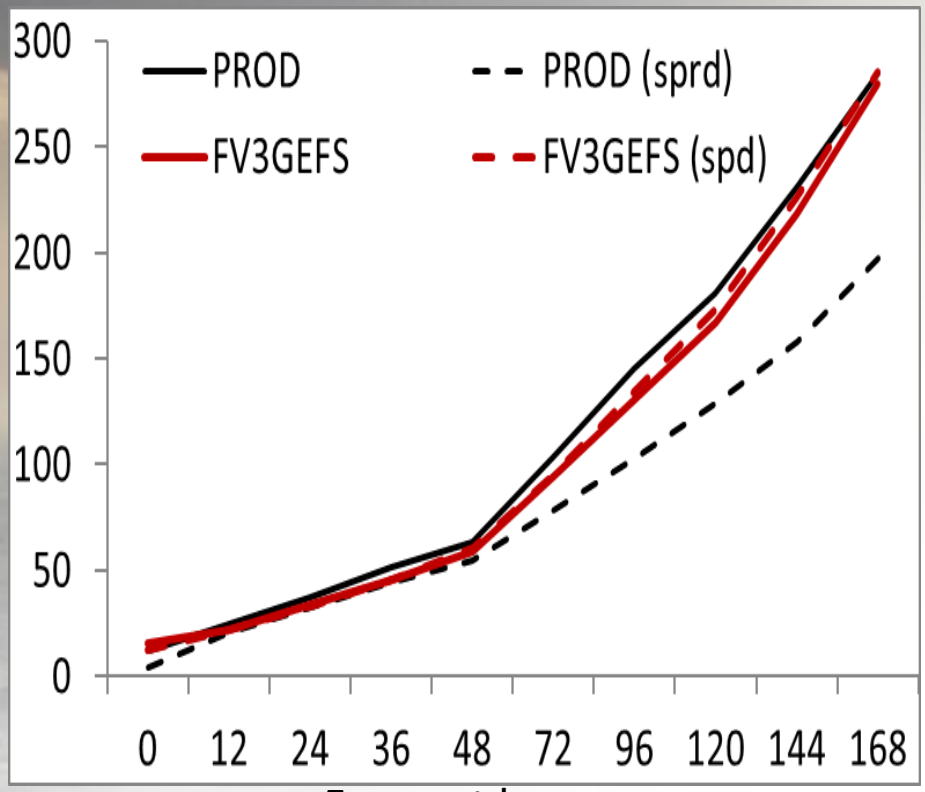






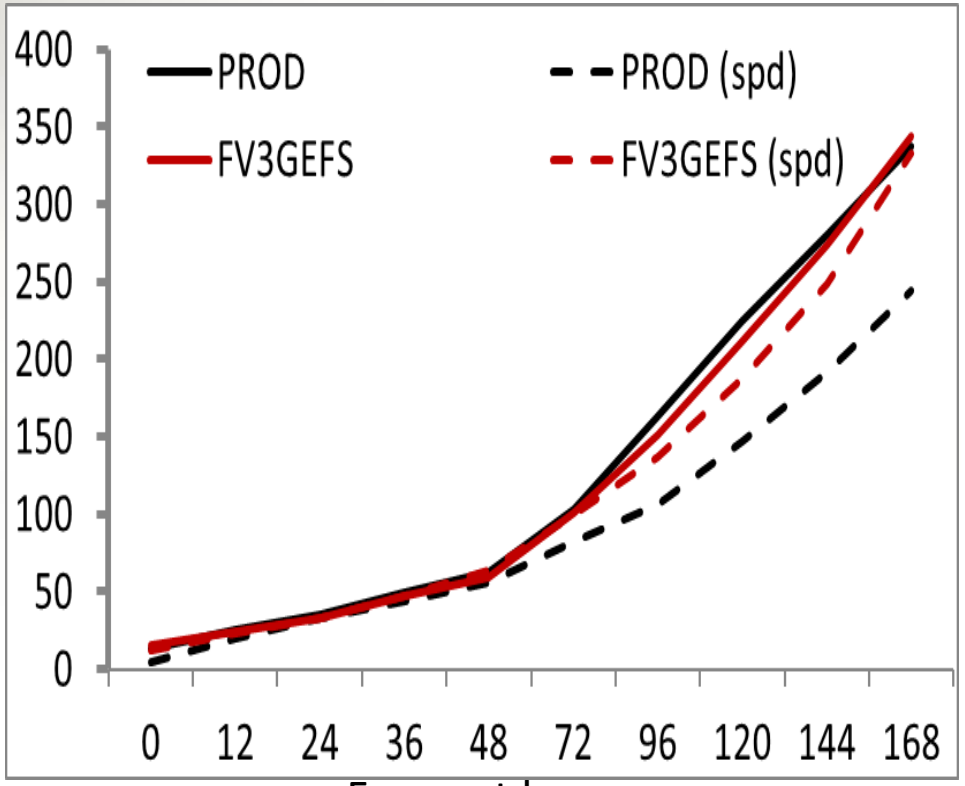
Track forecast error and spread (WNP/EP/ATL)

2017



CASES 297 268 241 210 184 141 106 82 66 53

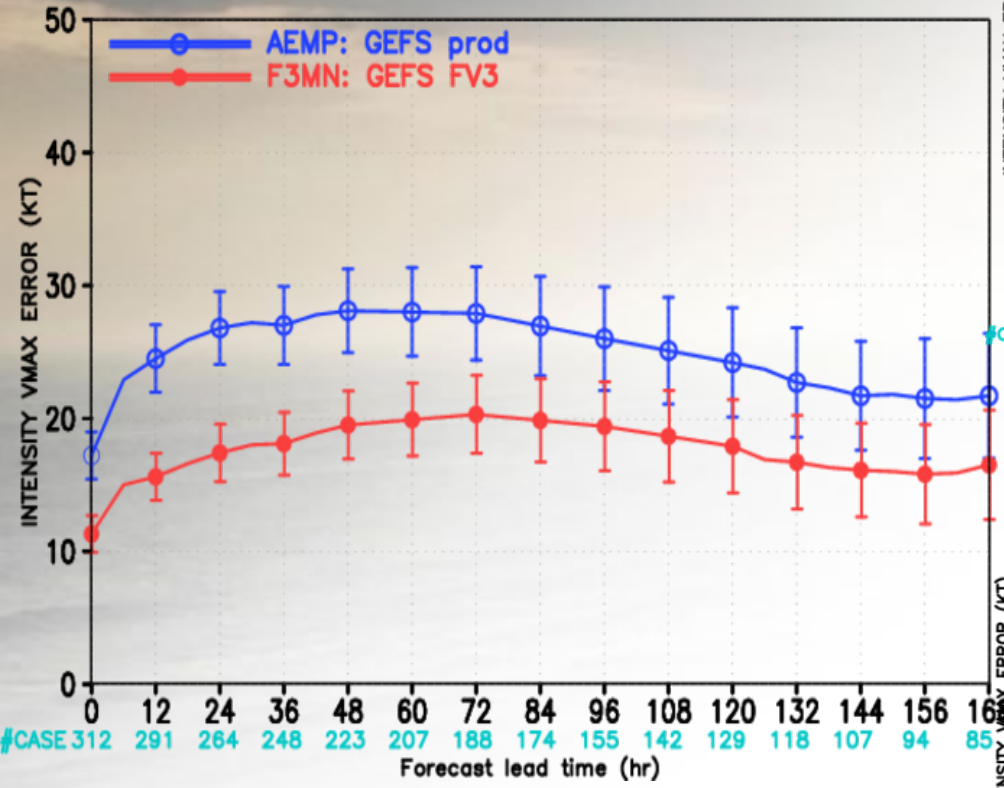
2018

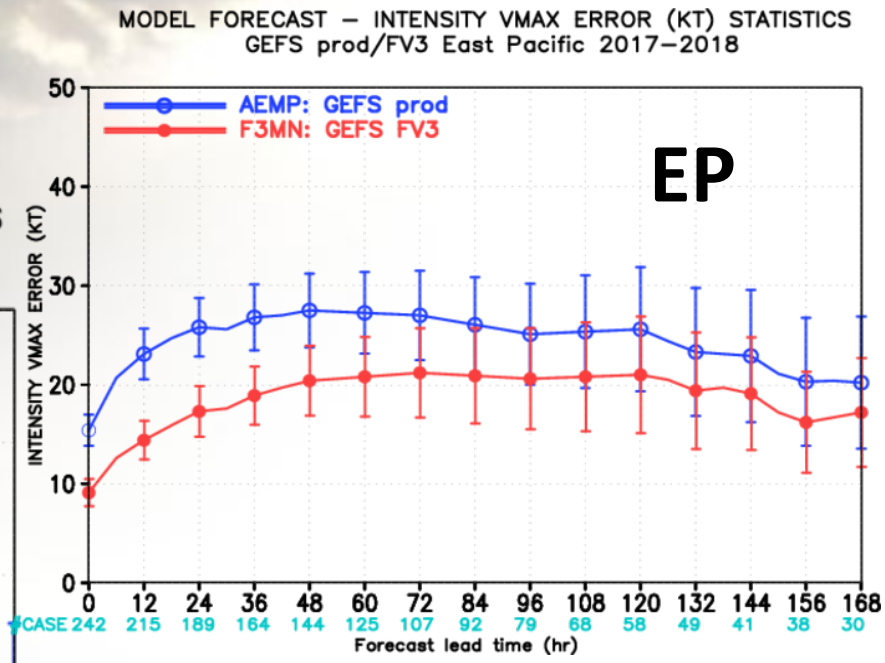


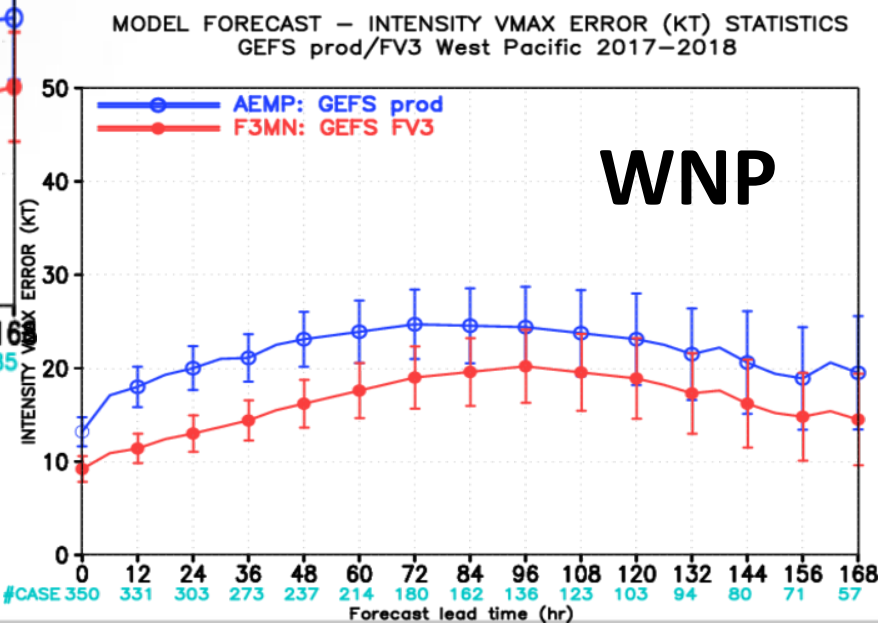
CASES 328 301 268 238 209 157 117 89 66 51

Tropical cyclone intensity (2017 &2018)

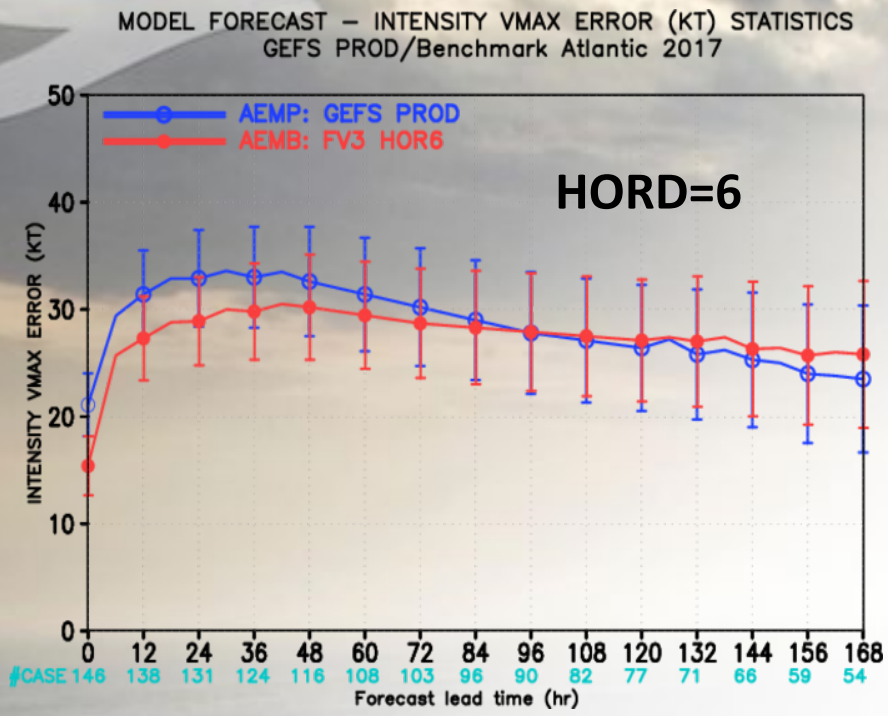
Atlantic

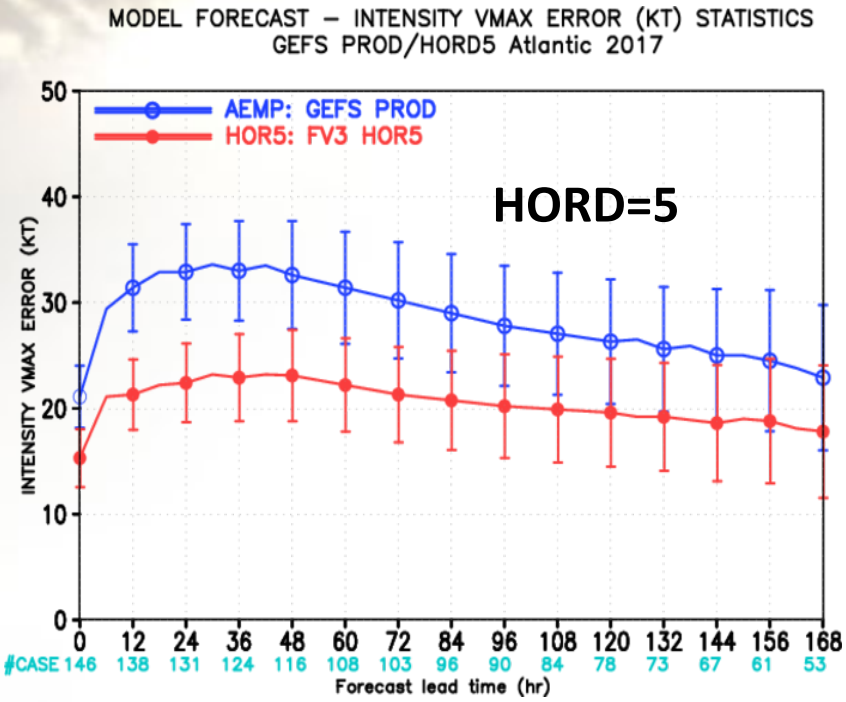






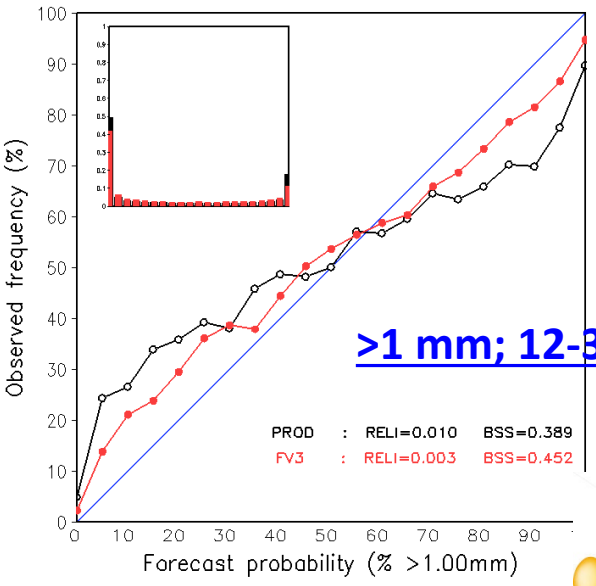
Influence of the advection scheme on TC intensity



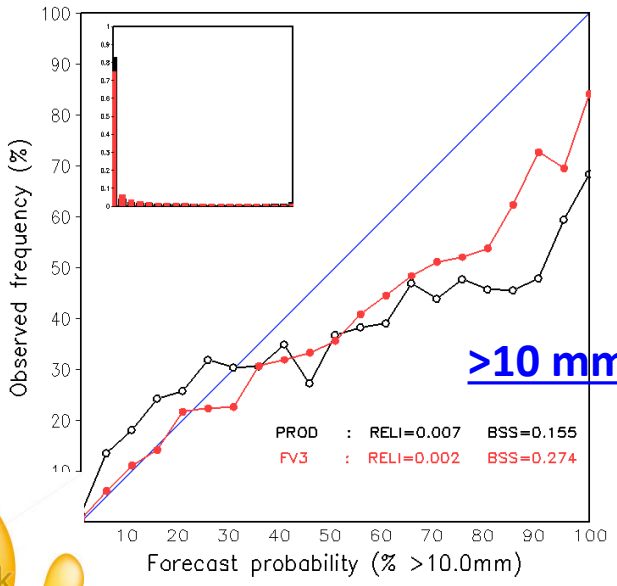


- **Intensity forecast is improved significantly with less diffusive advection scheme (Hord=5)**
  - Hord=5 or 6: the advection schemes, both use PPM with same accuracy order except Hord=5 has a weaker $2\Delta x$ filter and less diffusive
  - Amplitude of SKEB is tuned with Hord=5

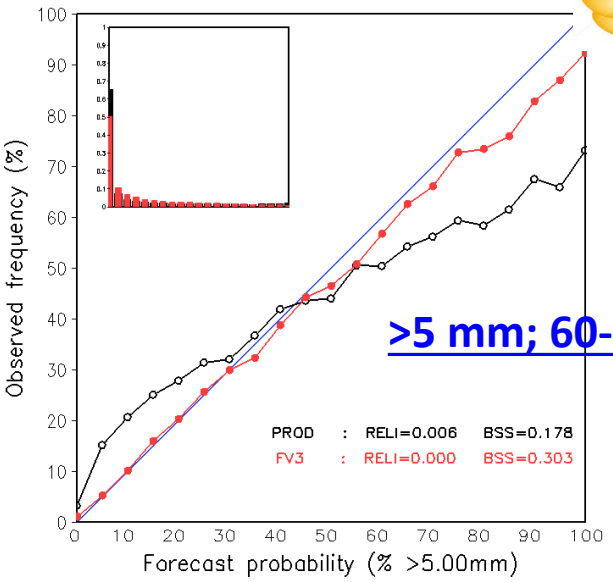
Precipitation



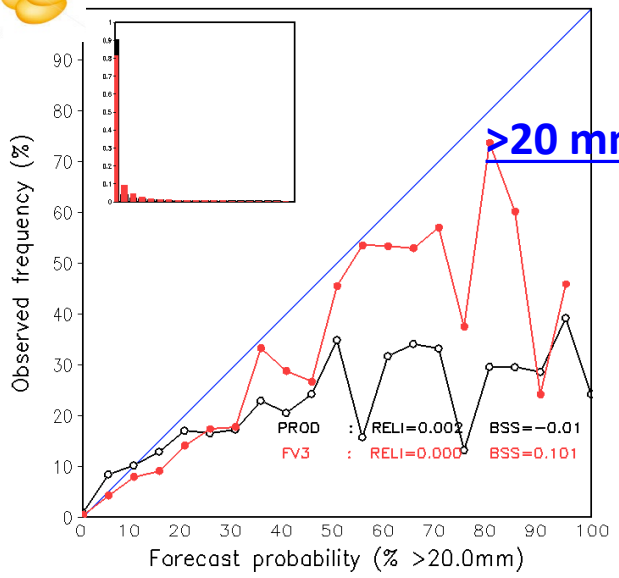
>1 mm; 12-36 hrs



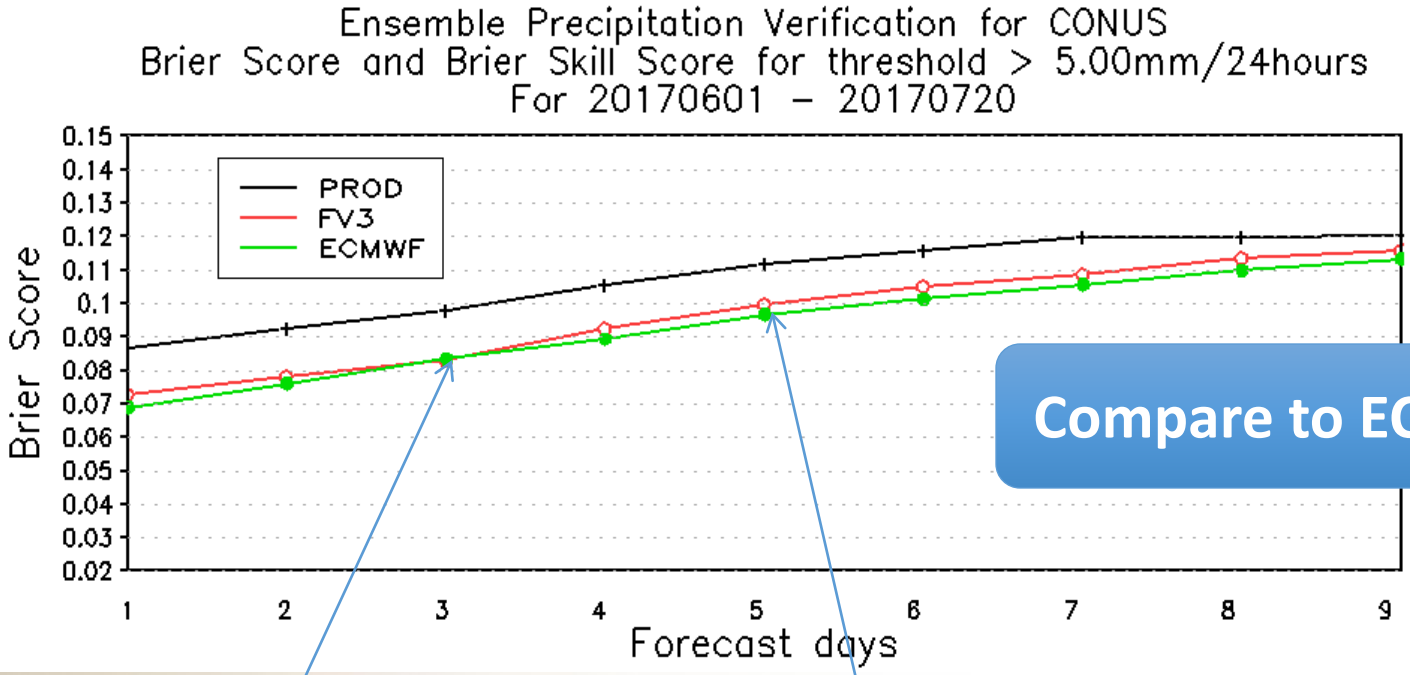
>10 mm; 12-36 hrs



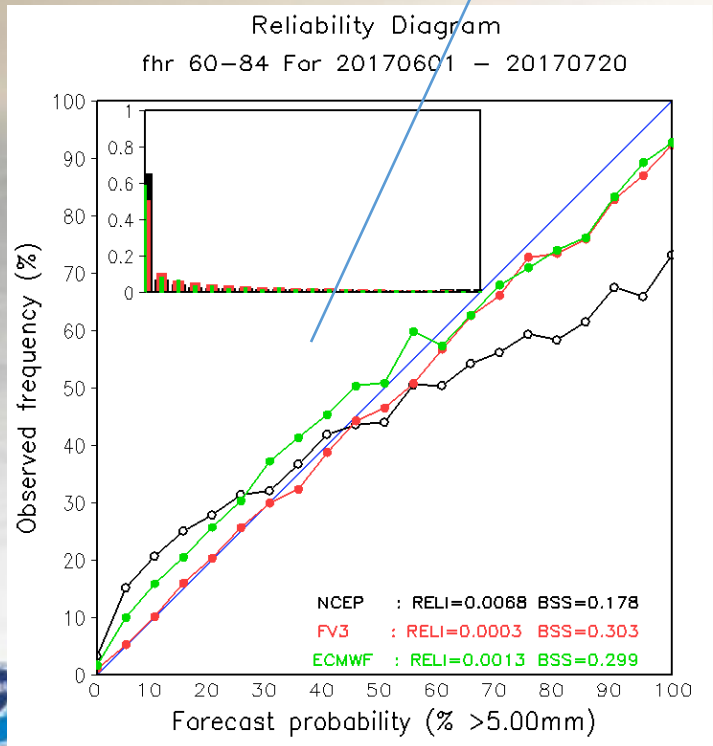
>5 mm; 60-84 hrs

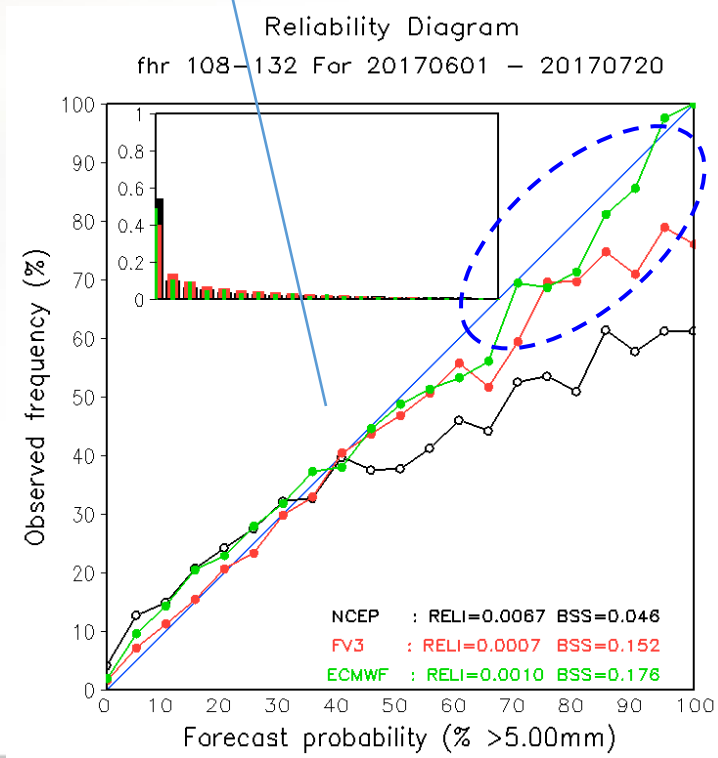


>20 mm; 60-84 hrs



Compare to ECMWF



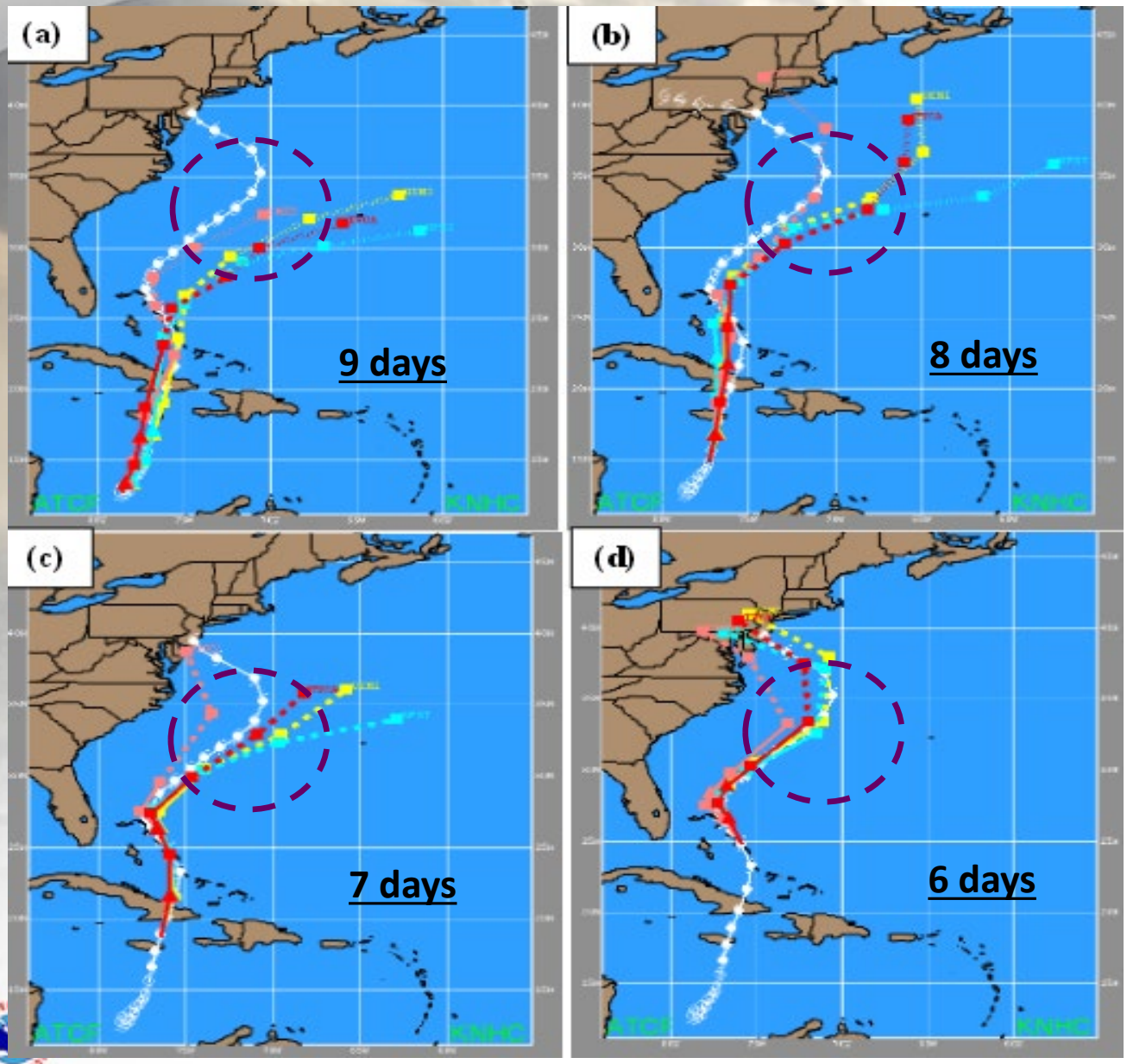


Could be "ensemble size"

Forecast Extreme (cases)

- TS tracks (example)
- Forecast extreme products
  - Anomaly forecast
  - Extreme forecast index (EFI)
  - Evaluations
- Still challenges for extreme events
  - Improved cases

Example of Hurricane Sandy

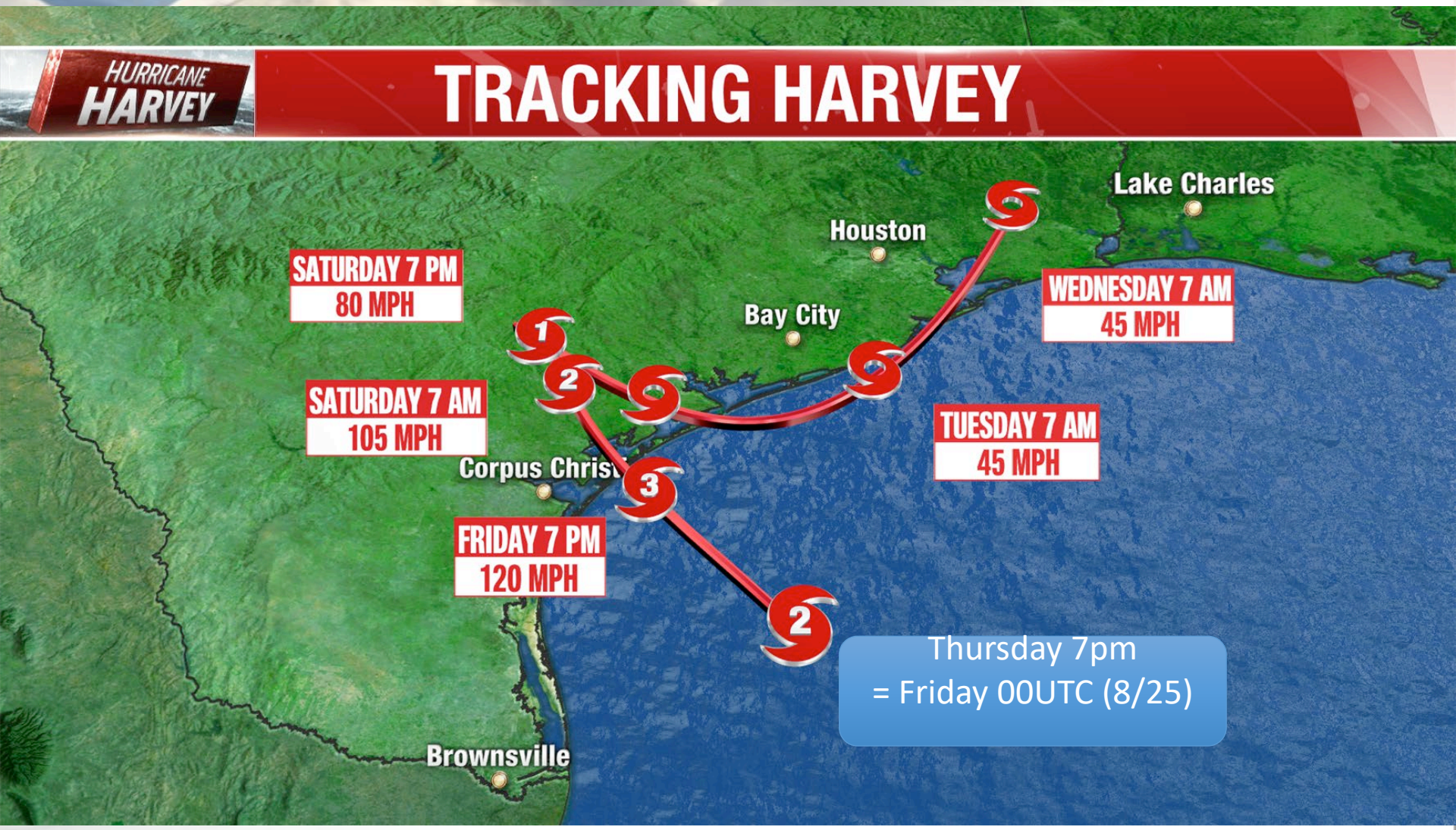


Key: we need to understand the forecast uncertainty.

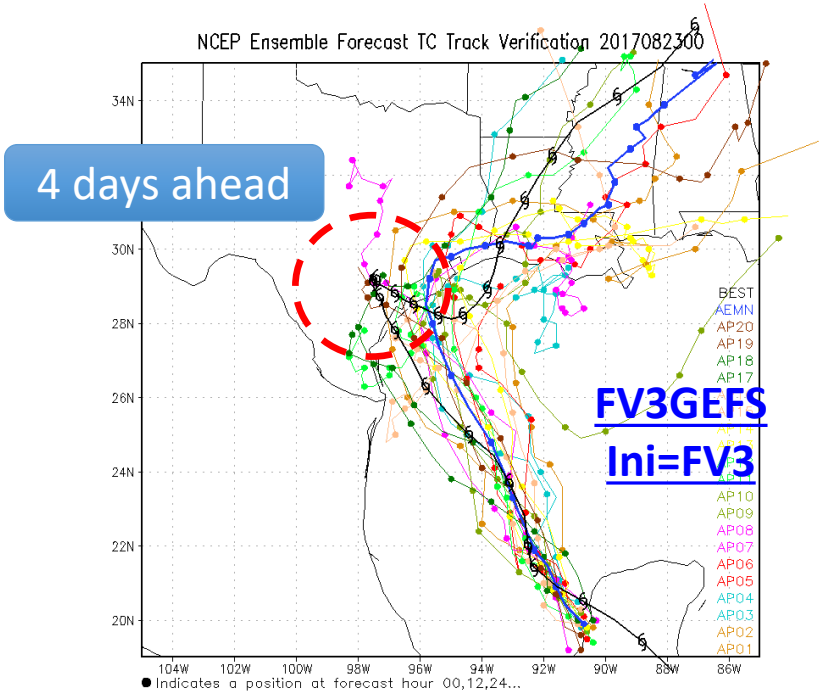
Where is a uncertainty? It is a point to turn north west.

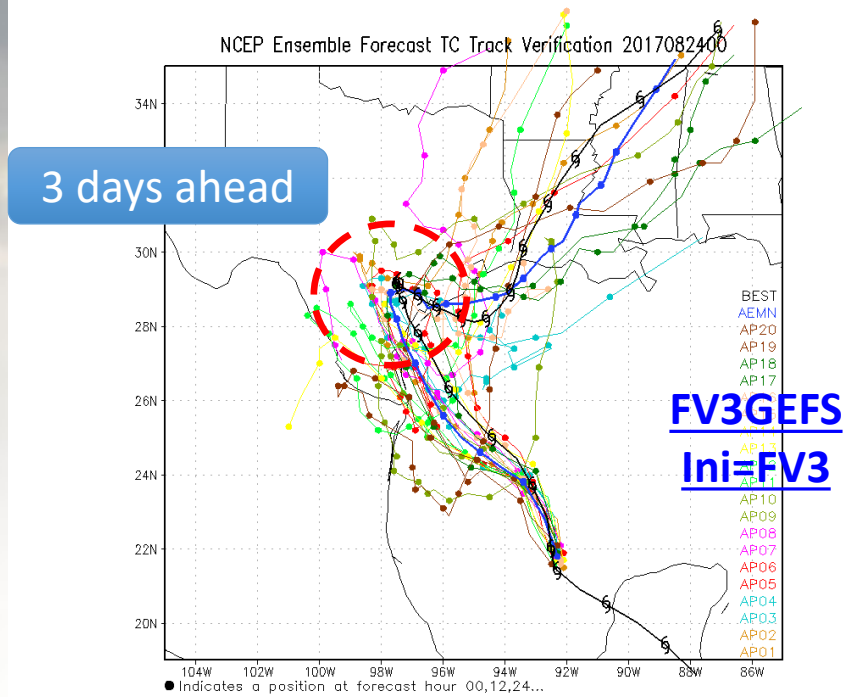
It does not matter you agree or not. It is there!!!

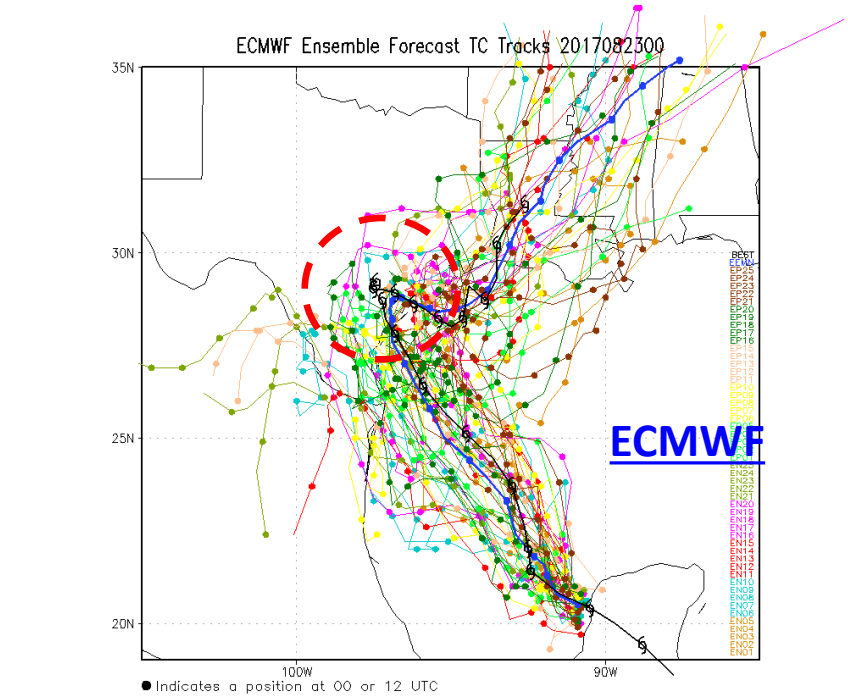
What we can do? --- reduce this uncertainty

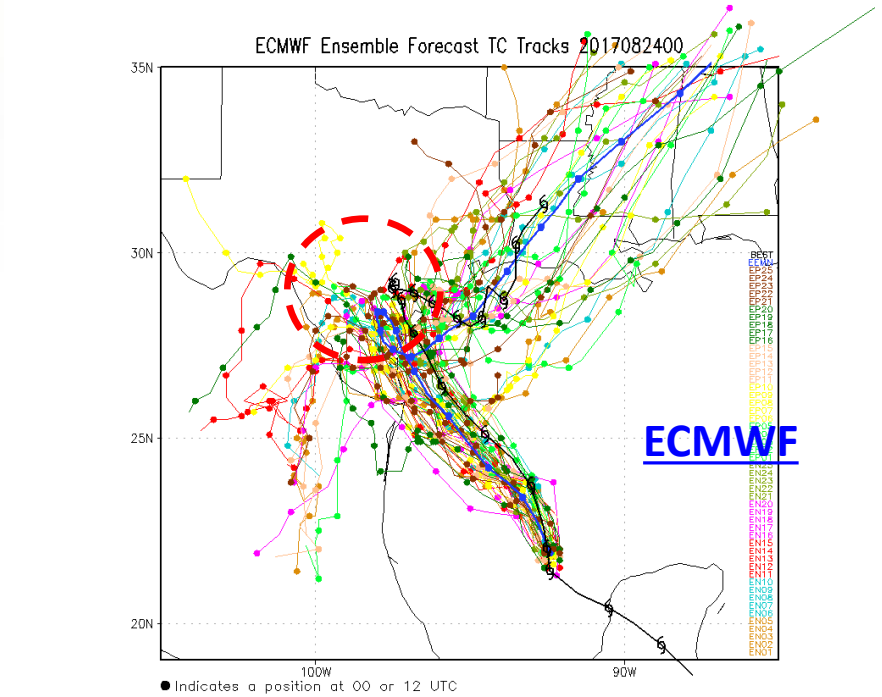


Wednesday – 8/23 00UTC EC made a good forecast;
Thursday – 9/24 00UTC NCEP made a good forecast


NCEP Ensemble Forecast TC Track Verification 2017082300
4 days ahead
FV3GEFS
Ini=FV3
BEST
AEMN
AP20
AP19
AP18
AP17
AP10
AP09
AP08
AP07
AP06
AP05
AP04
AP03
AP02
AP01
34N
30N
28N
26N
24N
22N
20N
104W
102W
100W
98W
96W
94W
92W
90W
88W
86W
Indicates a position at forecast hour 00,12,24...


NCEP Ensemble Forecast TC Track Verification 2017082400
3 days ahead
FV3GEFS
Ini=FV3
BEST
AEMN
AP20
AP19
AP18
AP17
AP10
AP09
AP08
AP07
AP06
AP05
AP04
AP03
AP02
AP01
34N
30N
28N
26N
24N
22N
20N
104W
102W
100W
98W
96W
94W
92W
90W
88W
86W
Indicates a position at forecast hour 00,12,24...

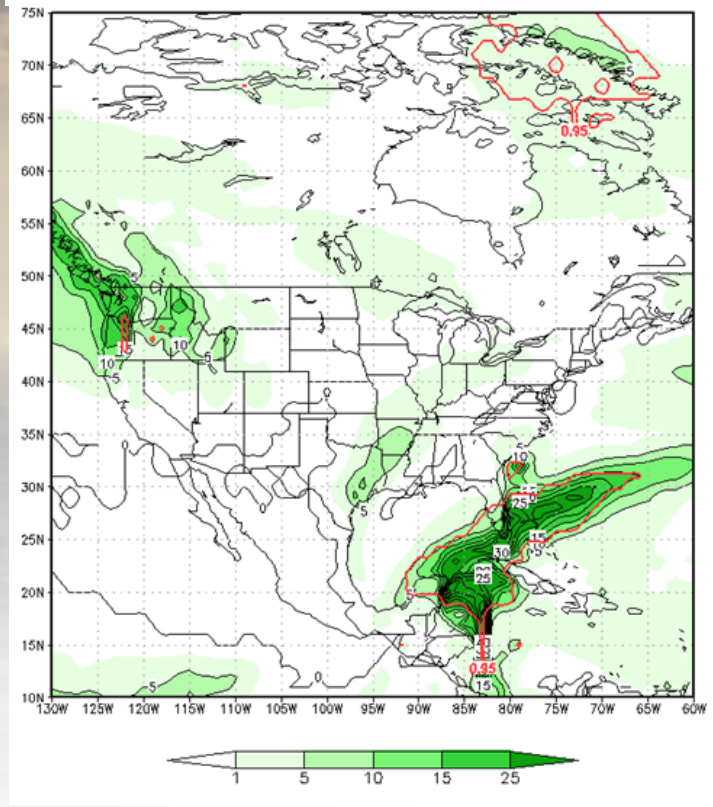

ECMWF Ensemble Forecast TC Tracks 2017082300
ECMWF
35N
30N
25N
20N
100W
90W
Indicates a position at 00 or 12 UTC


ECMWF Ensemble Forecast TC Tracks 2017082400
ECMWF
35N
30N
25N
20N
100W
90W
Indicates a position at 00 or 12 UTC

Example of Extreme Precipitation Forecast

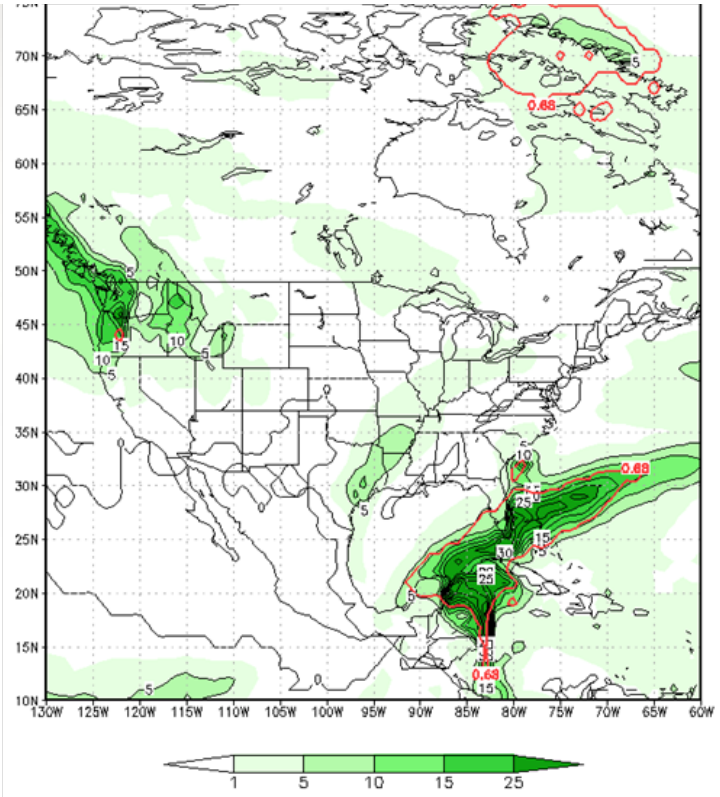
ANF

a. acpr (shaded) and ANOMF=0.95 (contour)
96hr forecast ini. 2014010600



EFI

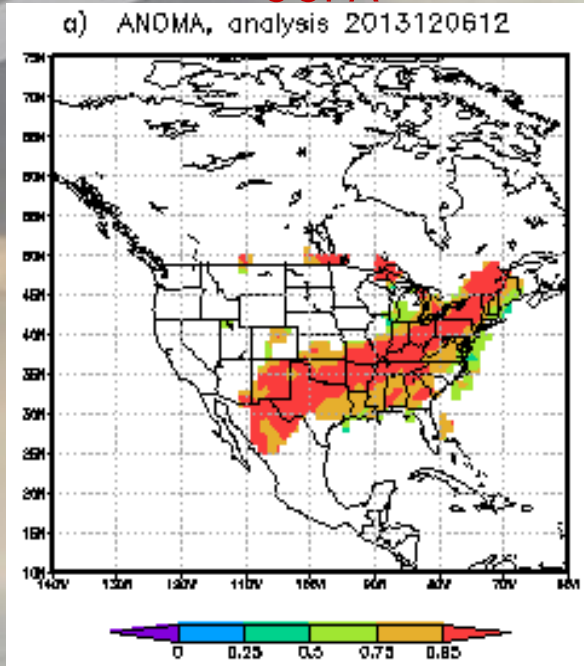
b. acpr (shaded) and EFI=0.687 (contour)
96hr forecast ini. 2014010600



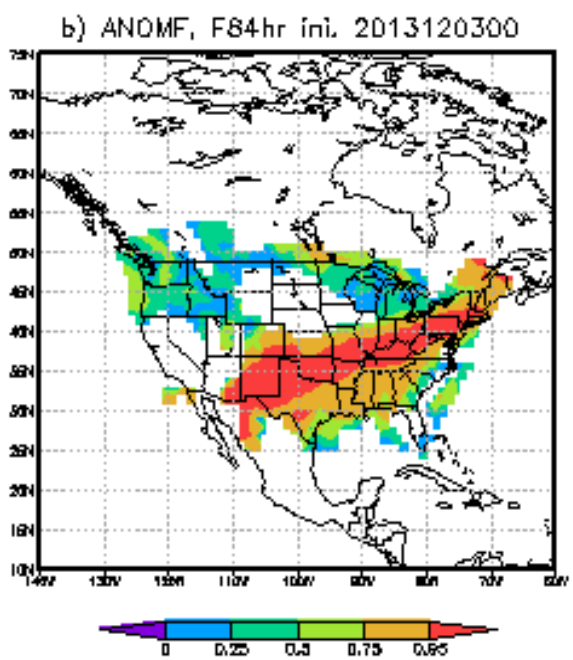
The dependence of the extreme precipitation on the geographic location

Example of Extreme Precipitation Forecast and Verification

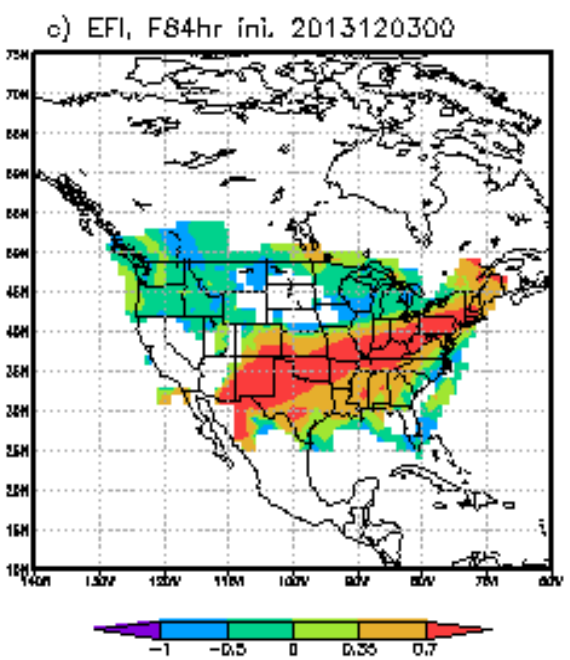
CCPA

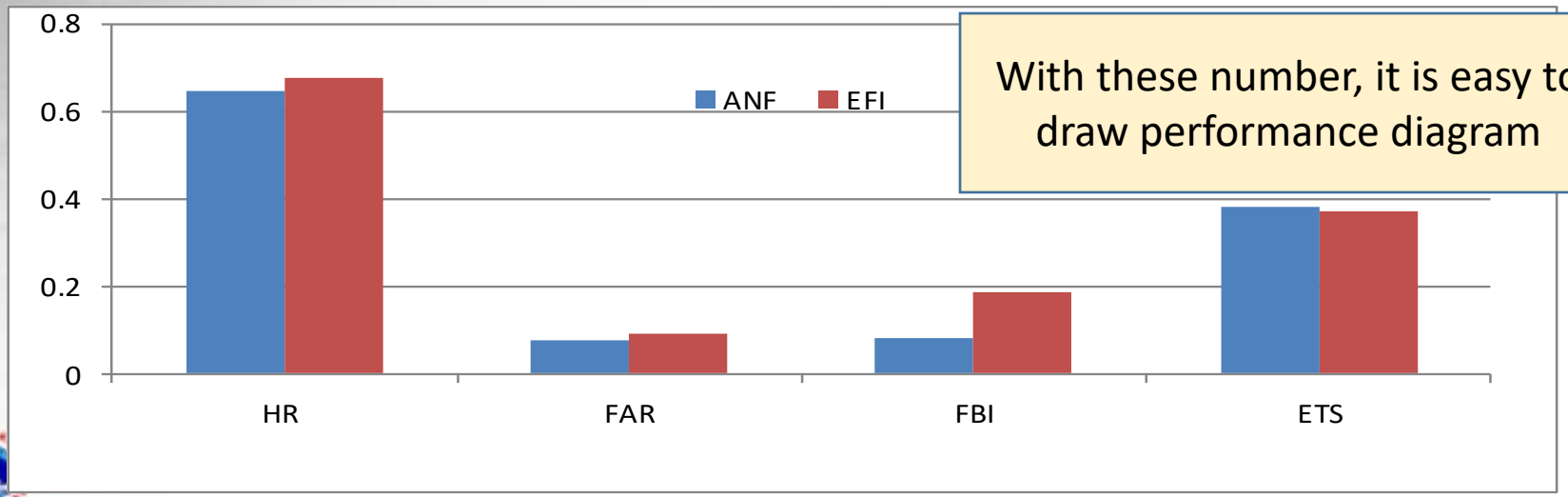


ANF



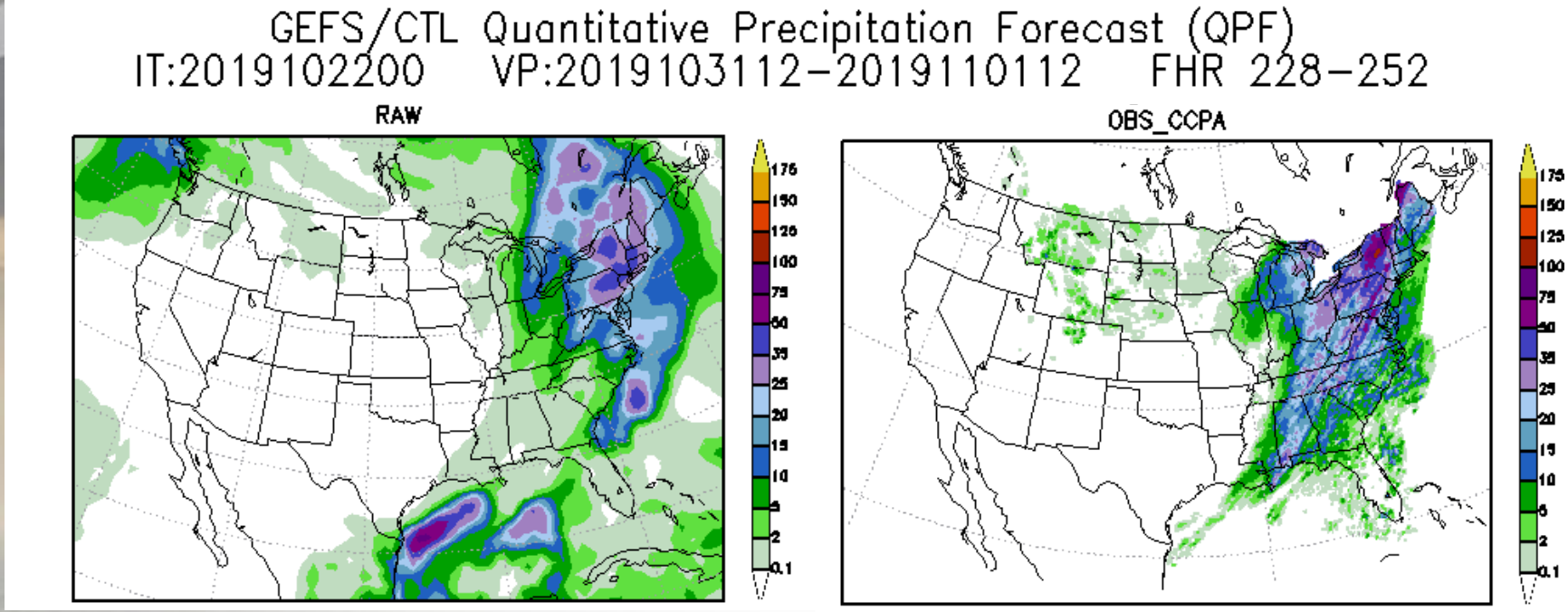
EFI





With these number, it is easy to draw performance diagram

Storm case during Oct. 31 – Nov. 1st 2019

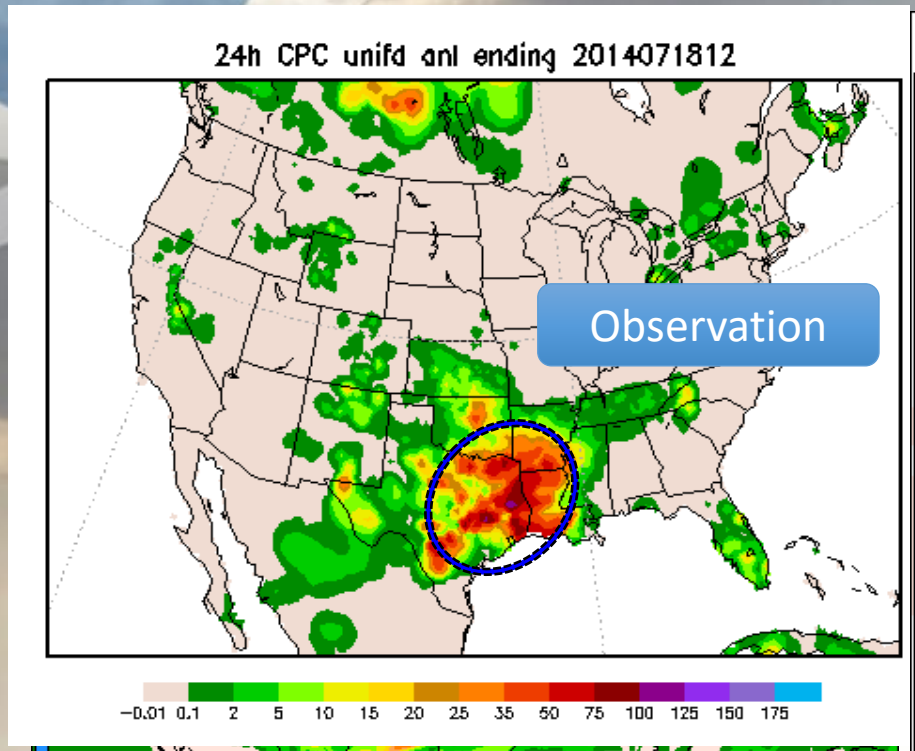


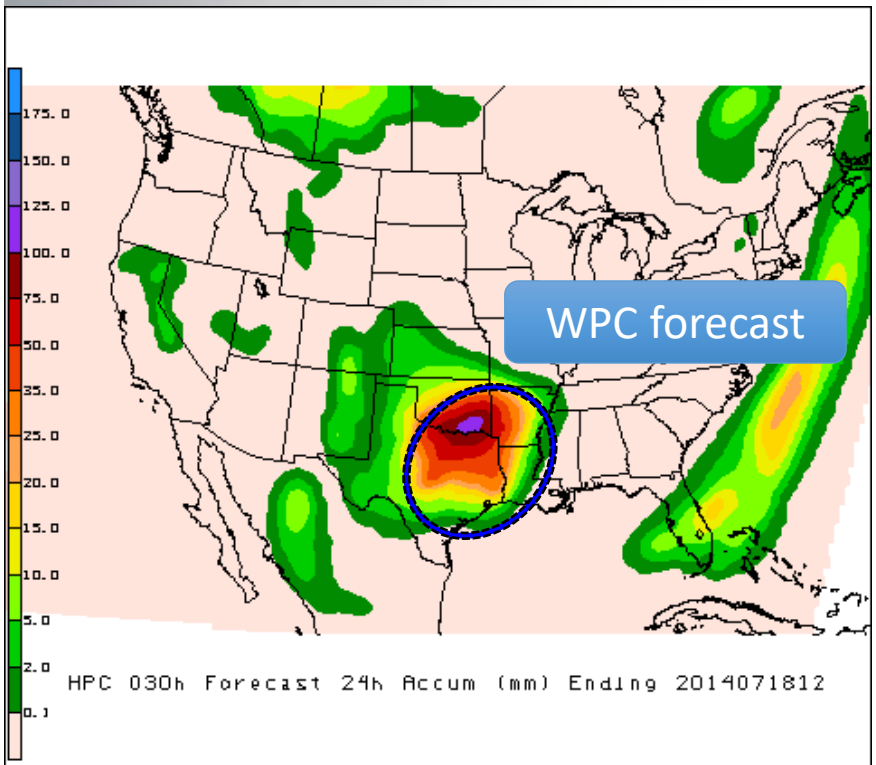
Forecast lead – 10 days

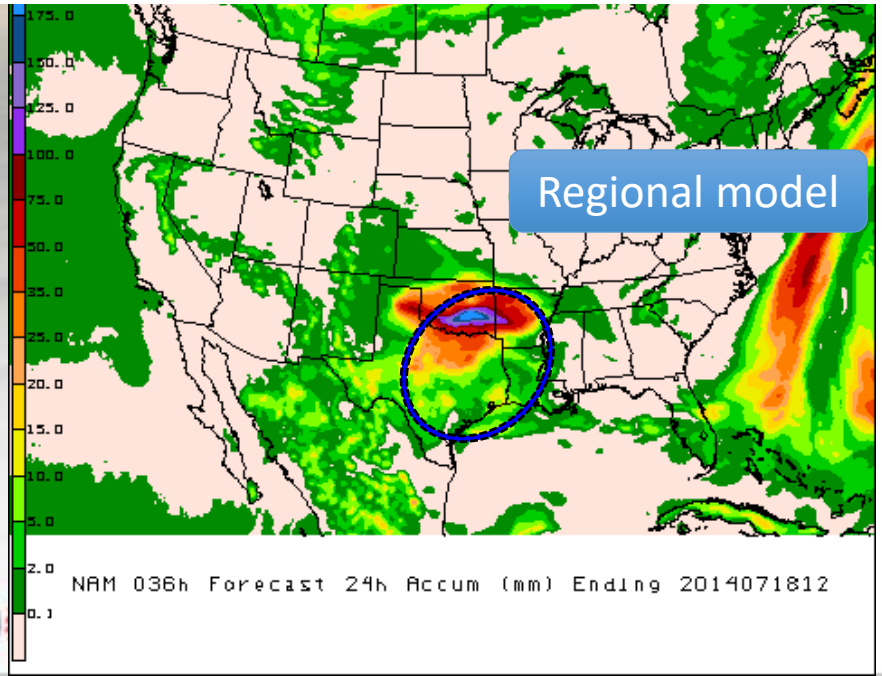
CCPA analysis – 24 hours accumulation

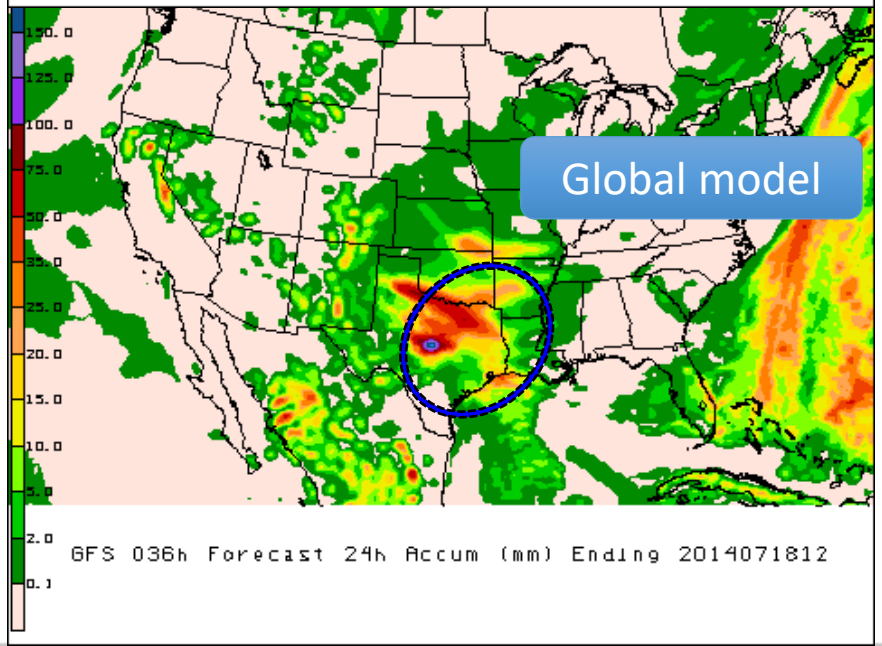
Notes:

- This is current operational GEFS control forecast at horizontal resolution 33km (0-8 days), 55km (8-16 days).
- Raw QPF has predicted a stronger storm 10 days ahead, and verified by observation in terms of position and intensity.
- Conclusion – there is capability to predict forecast extreme.

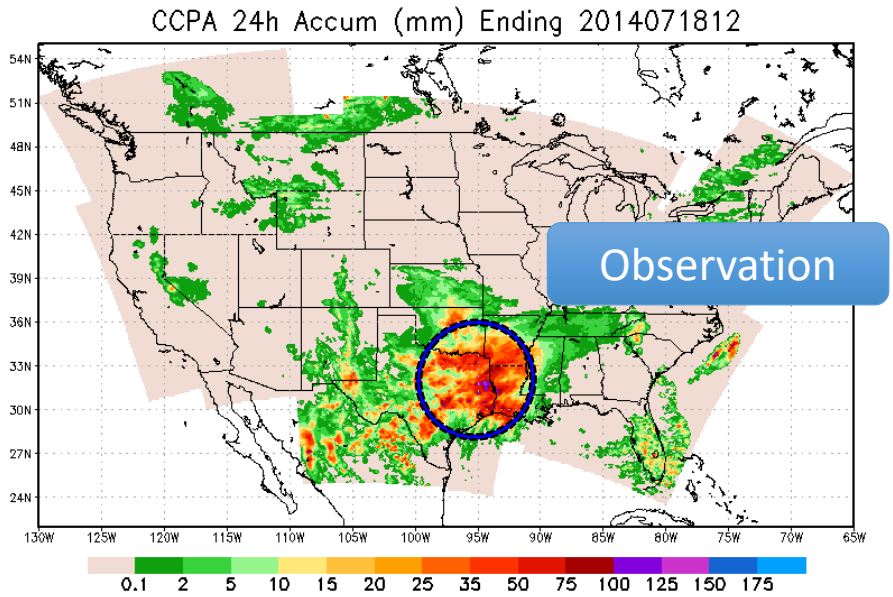

24h CPC unifd anl ending 2014071812
Observation
-0.01 0.1 2 5 10 15 20 25 35 50 75 100 125 150 175

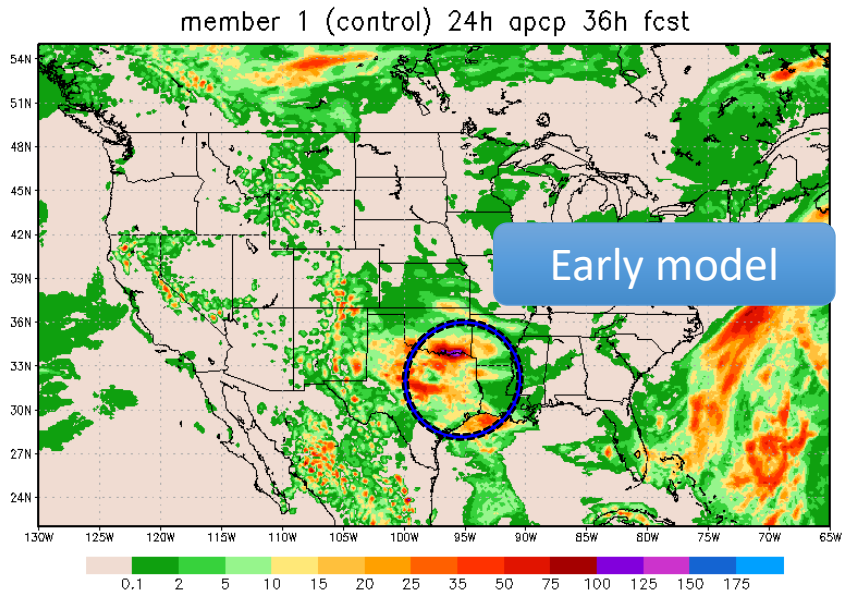

WPC forecast
HPC 030h Forecast 24h Accum (mm) Ending 2014071812

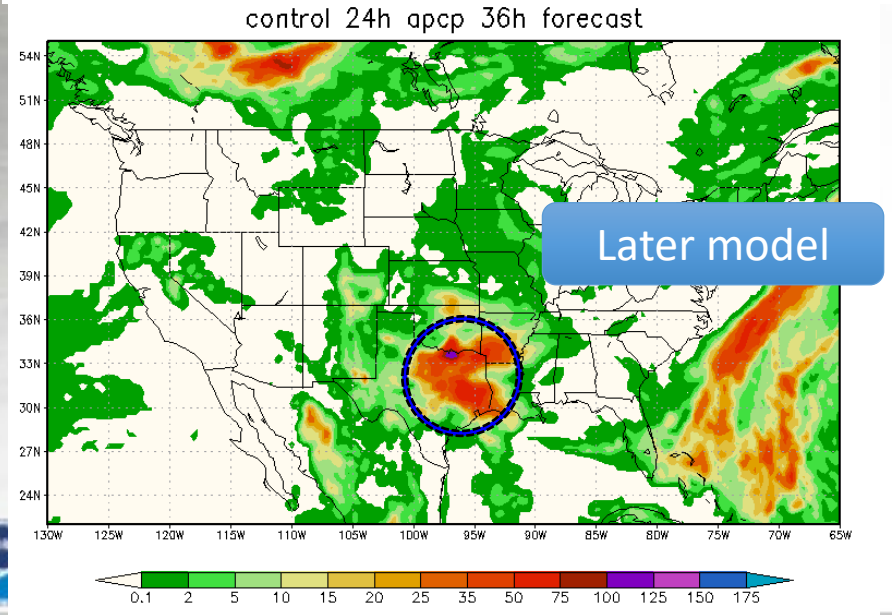

Regional model
NAM 036h Forecast 24h Accum (mm) Ending 2014071812


Global model
GFS 036h Forecast 24h Accum (mm) Ending 2014071812

Analysis (CCPA) vs. Forecast
36 hours forecast by the end of 12UTC July 18 2014



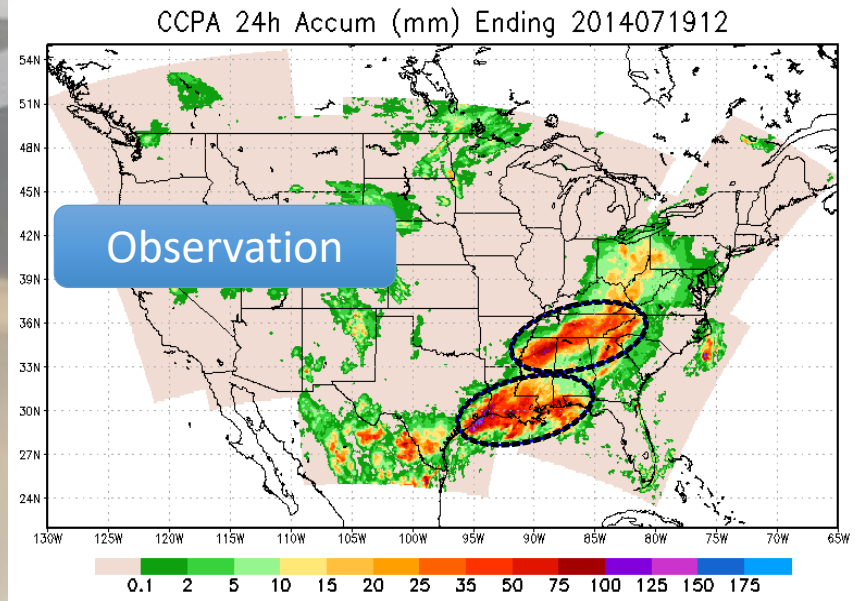


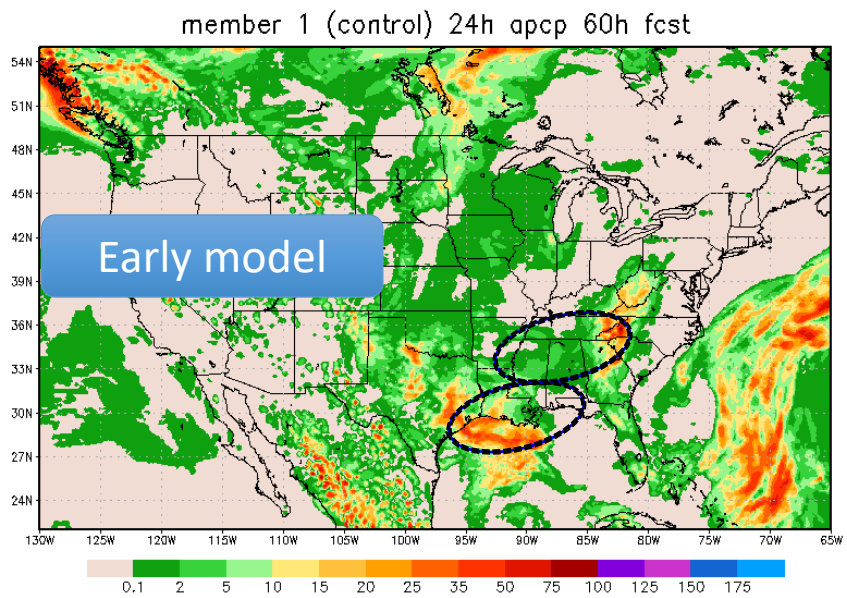


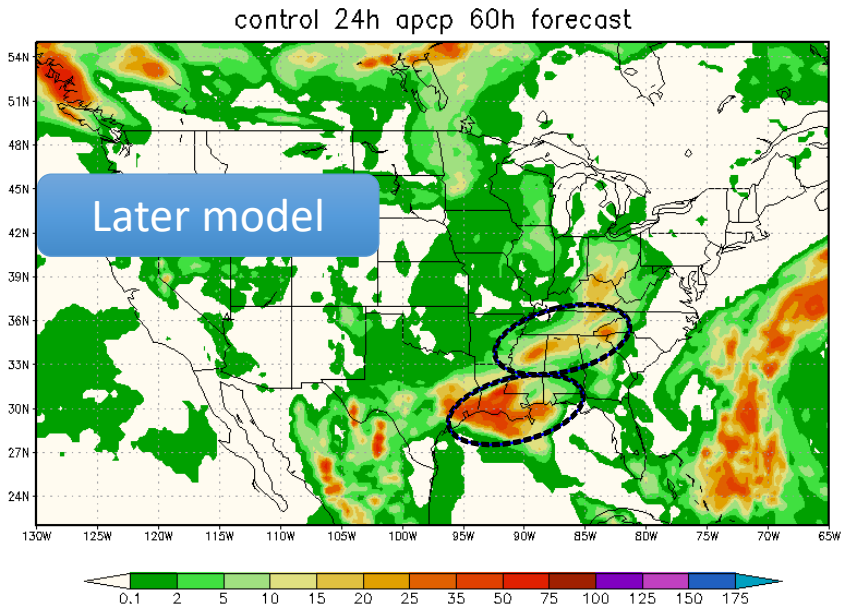
Summary:

- Early model – GEFSv11 (spectrum model) with full new stochastic physical scheme.
- Later model – GEFSv12 (FV3) with new stochastic physics scheme, and GFDL MP
- FV3-GEFS shows a capability to predict this heavy precipitation event in terms of position and intensity

60 hours forecast by the end of 12UTC July 19 2014







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When/What will FV3-GEFS deliver to public?

August 26 2020

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

PLUS

30 years GEFS reforecast (90% finished)
Once per day at 00UTC
5 members out to 16 days
11 members out to 35 days (every Wednesday)

Thanks for your attention!!!

Evaluation of 500hPa height

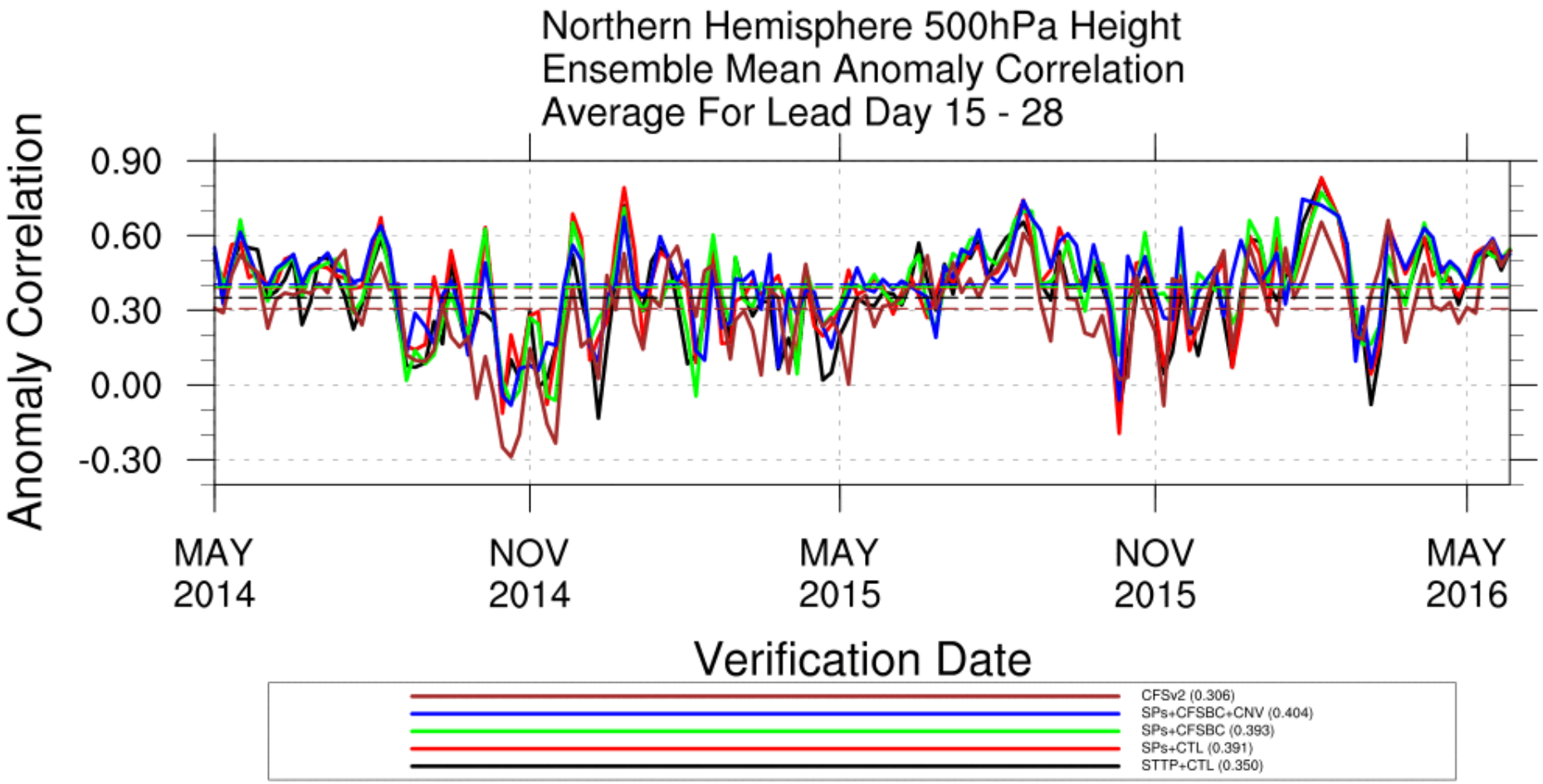
ACC scores for week-2 and week 3&4

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**

Significantly better than control

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

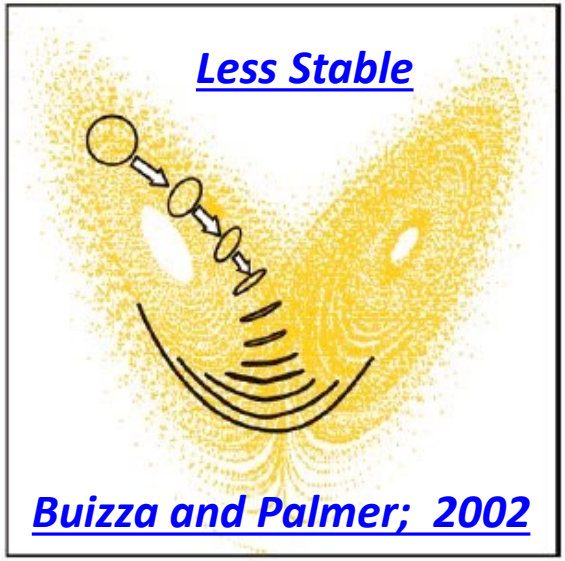
Weeks 3&4 forecast



SPs+SST_bc+SA-CV (0.409) **CFSv2 (0.306)**

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



Week of Hindcast Dates and Target Dates	Jan 1	Jan 2	Jan 3	Jan 4	Jan 5	Jan 6	Jan 7	Jan 8 Forecast Day	Week 3-4 Outlook: Jan 22 – Feb 05
Day of the week and Days to Target Dates	Fri 22:35	Sat 21:34	Sun 20:33	Mon 19:32	Tues 18:31	Wed 17:30	Thurs 16:29	Fri 15:28	2 weeks from Sat + 13 days → WK34
Center-Model	---------- Reforecast Grab Period ----------								
ECCC-GEM **4 members** 32 days								Forecast Day	= Realtime
EMC-GEFS **11 members** 35 days								Forecast Day	
ESRL-FIMv2 **4 members** 32 days								Forecast Day	
NASA-GEOS **4 members** 45 days								Forecast Day	* GEOS5 roves in Realtime
NCEP-CFSv2 **4 members** 44 days								Forecast Day	
NRL-NESM **4 lagged members** 45 days								Forecast Day	
RSMAS-CCSM4 **3 members** 45 days								Forecast Day	
Coming Soon: NCAR-CESM 10 members 45 days								Forecast Day	