GEFS 35-day forecast experiments
- Support SubX project

Ensemble Team
Environmental Modeling Center
NCEP/NWS/NOAA

Present for:
Monthly sub-seasonal teleconference

February 7th 2017

Outlines

- **Status of the GEFS extended investigation**
- **MJO Evaluation and day-to-day routine verification**
- **Evaluation of 2-m temperature and accumulated precipitation over Week 2, Weeks 3 & 4**
- **Conclusions for the GEFS extended investigation**
- **Open Discussion**

  Capability of GEFS modeling for MJO

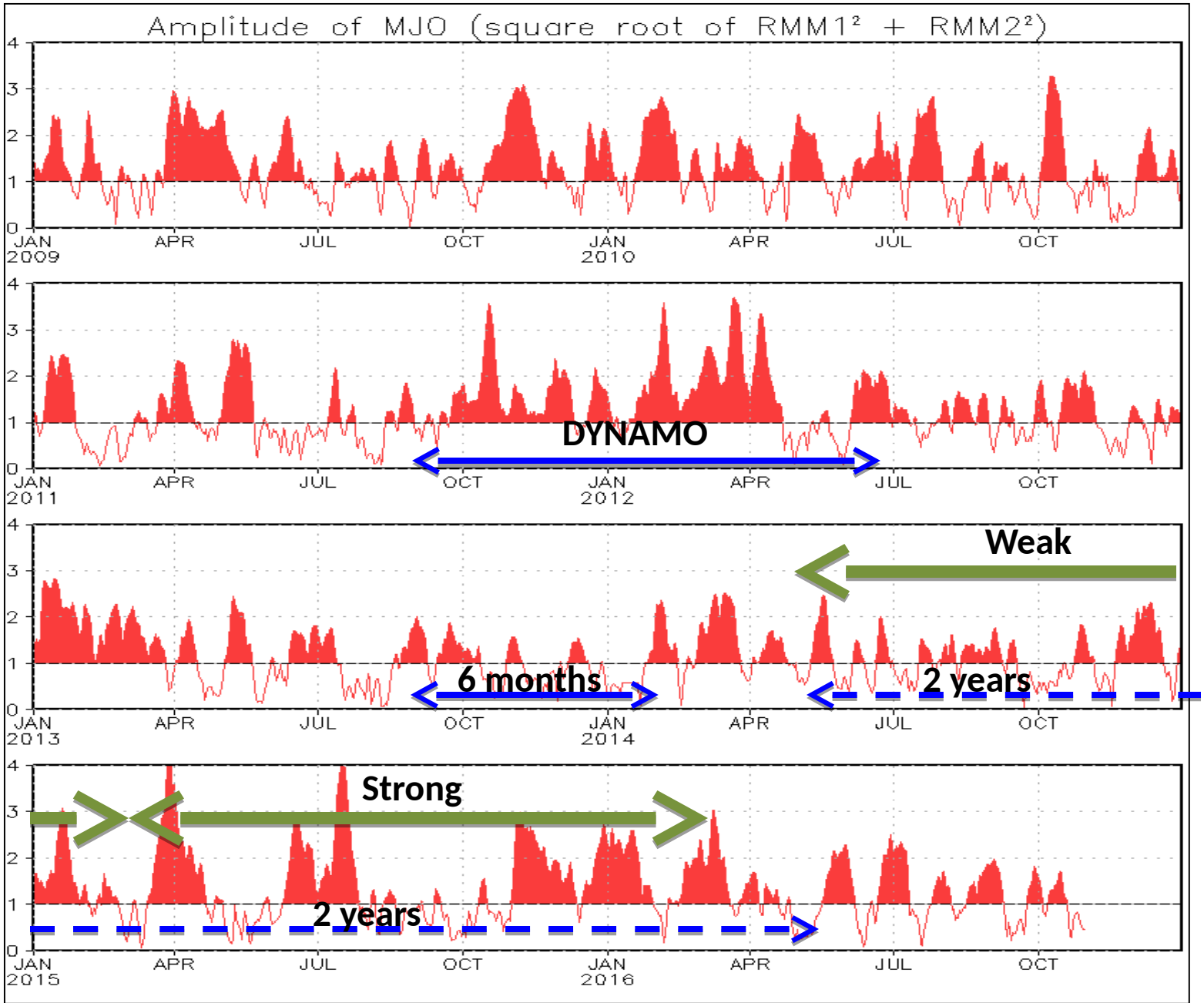
  Tropical source of predictability for North American weather

  Possible improvements

  Configuration for SubX project

Amplitude of MJO

Source: CPC web-site



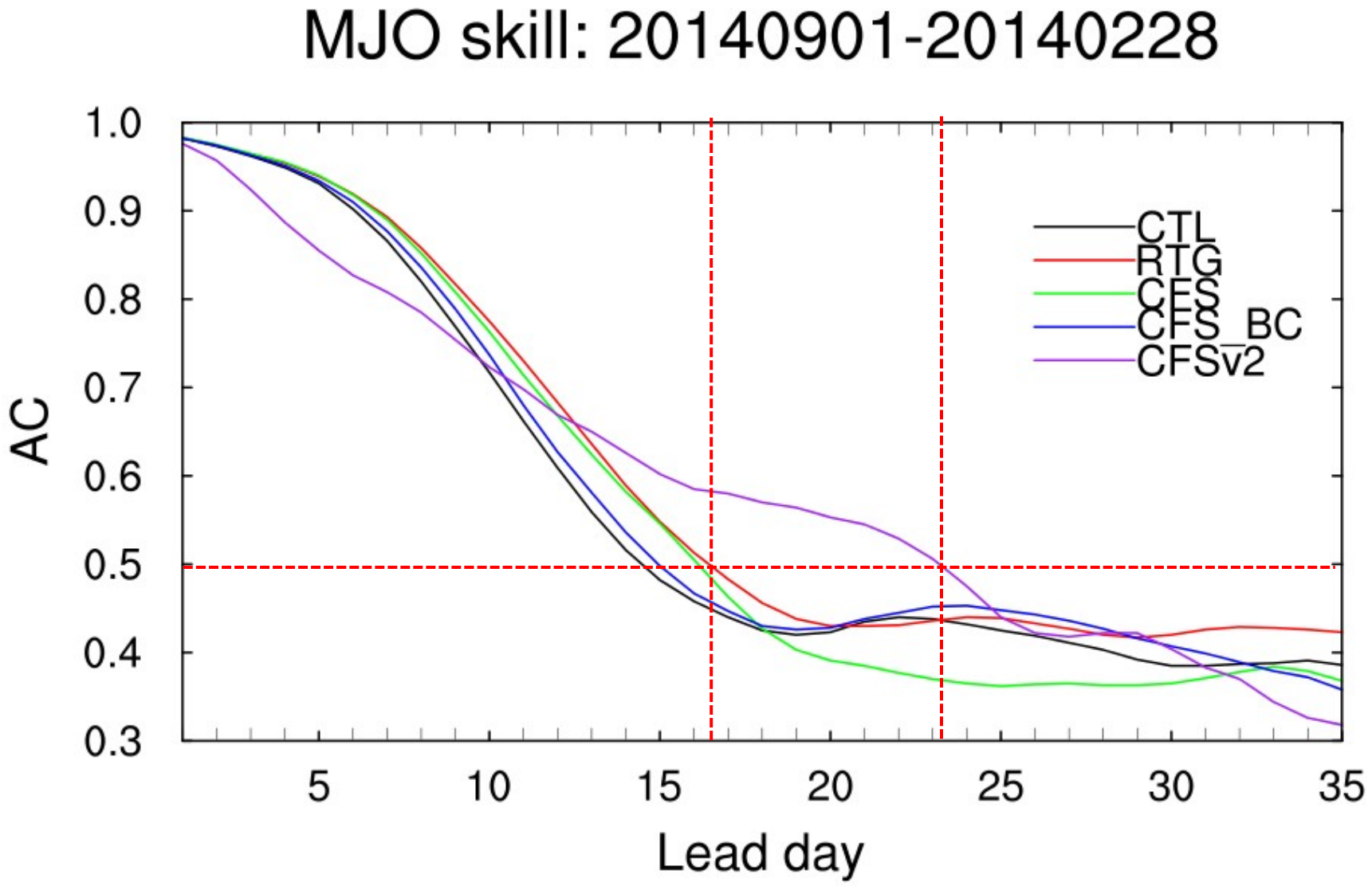
Un-coupled Investigation (1) (GEFS v11)

- New NCEP state-of-art GEFS (version 11.0.0) , based on GFS (version 12.0.0 - 2014), is used for this study. It is semi-Lagrangian model with upgrades to the physical and land-surface models, higher resolution (33km for days 0-8, 55km for days 8-16, **73km for days 16-35**), initial perturbations from EnKF, and Stochastic Total Tendency Perturbation (**STTP**) in forecast integration.

- Extended 2013-2014 winter season (September 1 2013 – February 28 2014). *One initial forecast for each day*.

- Four experiments have be studied:
  - Control (CTL): analysis SST relaxes to climatology
  - Optimum (RTG): realistic SST forcing every 24 hours (AMIP like)
  - Forcing (CFS): CFSv2 predicted SST forcing every 24 hours
  - Forcing (CFSBC): CFSv2 predicted SST anomaly with bias correction

- We have presented experiment results in 2015



Lower resolution (70km) for weeks 3 & 4 with STTP

Conclusion from Investigation (1)

- **WH MJO skill:**
  - During this period:
    - CFSv2 has the largest WH skill at ~23 days;
    - All GEFS experiments provide more skillful forecasts during Week 1 and a portion of Week 2 than CFSv2;
    - Forcing the GEFS with CFS SST provides additional skill over current operational configuration.
- **Weeks 3 & 4 land 2-m Temperature over NA:**
  - During this period, forcing the GEFS with more realistic SST may provide additional land-only 2-m forecast skill (results are not statistically significant; more study is required).

Un-coupled Investigation (2) (GEFS v11)

- New NCEP state-of-art GEFS (version 11.0.0) , based on GFS (version 12.0.0 - 2014), is used for this study. It is semi-Lagrangian model with upgrades to the physical and land-surface models, higher resolution (33km for days 0-8, 55km for days 8-16, **55km for days 16-35**), initial perturbations from EnKF, different stochastic perturbations (either **STTP or SKEB+SPPT+SHUM**), and varying SST (CFS with bias correction with and without **NSST**) in forecast integration.

- Period: May 2014 – May 2016. *One initial forecast for every 5 days*.

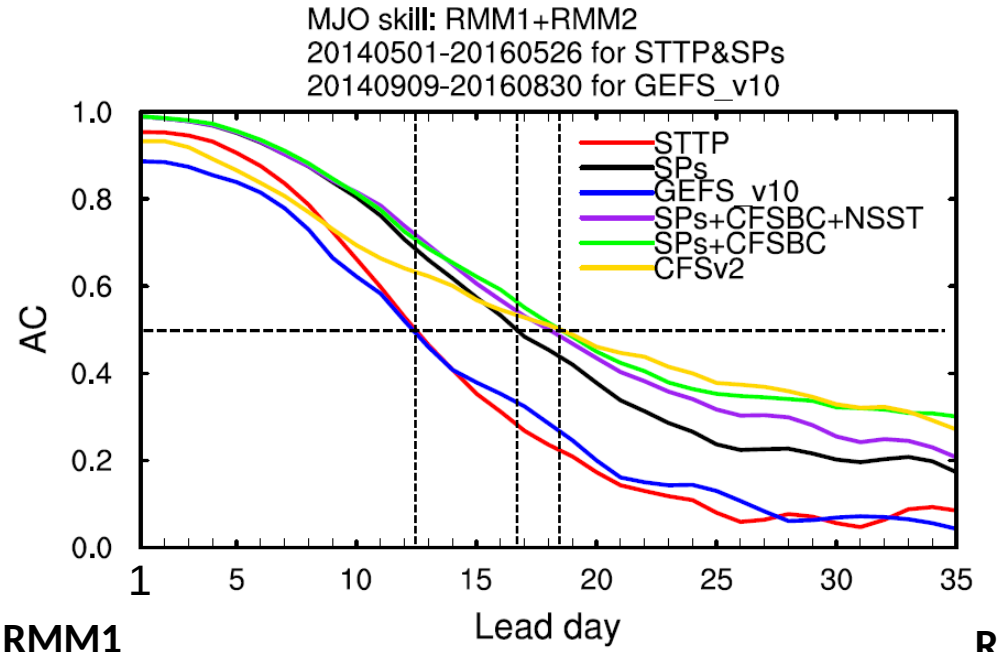
- Four experiments have be studied:
  - CTL (STTP): analysis SST relaxes to climatology (STTP)
  - SPs: CTL with updated stochastic physics (SKEB+SPPT+SHUM)
  - SPs+CFSBC: SPs with CFSv2 predicted SST anomaly with bias correction
  - SPs+CFSBC+NSST: SPs+CFSBC with NSST
  - *SPs+LIM-SST: SST from Linear Inverse Model (not start yet)*

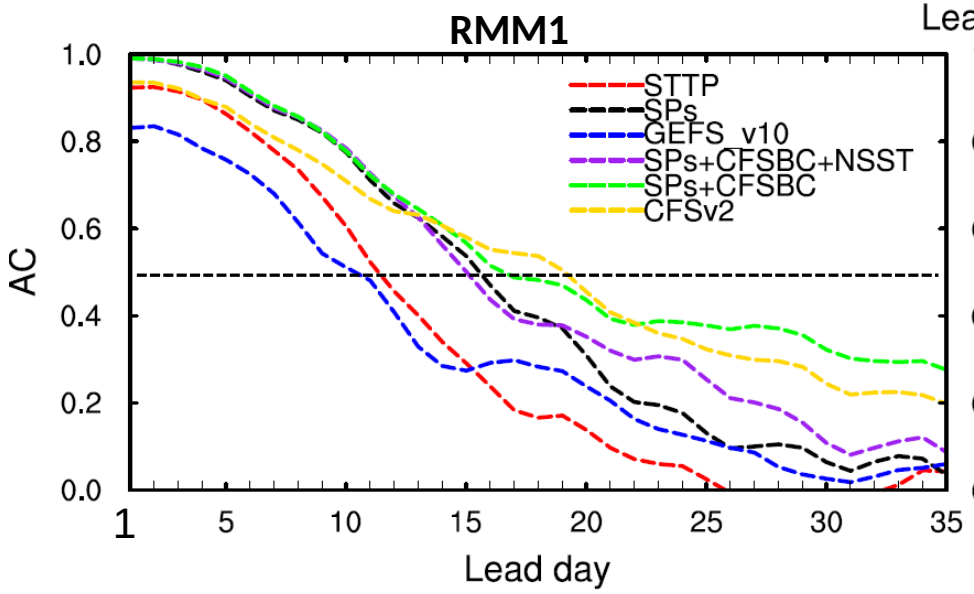
- Support SubX project – real-time forecast for CPC NMME

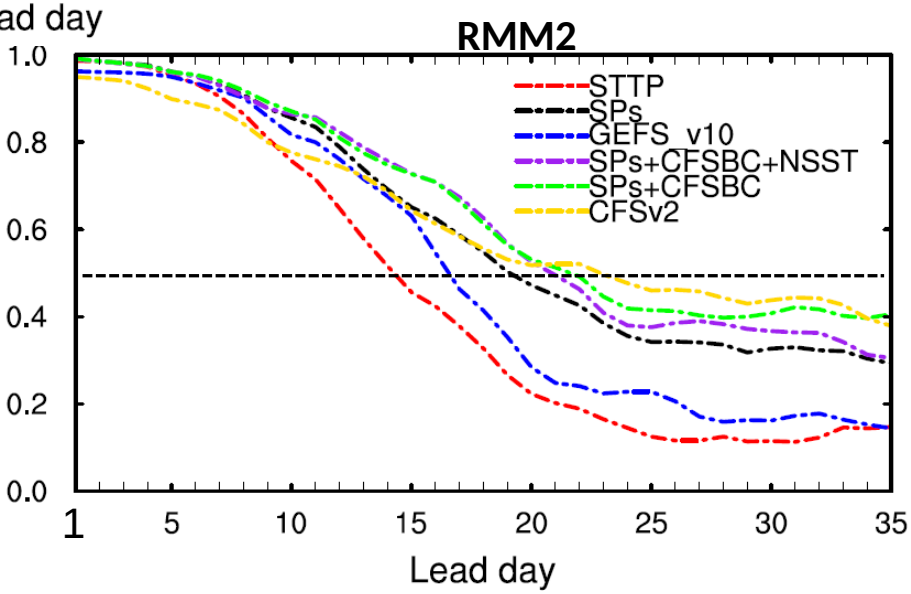
MJO Evaluation and Day-to-Day Verification for Routine Variables

(20140501-20160526)

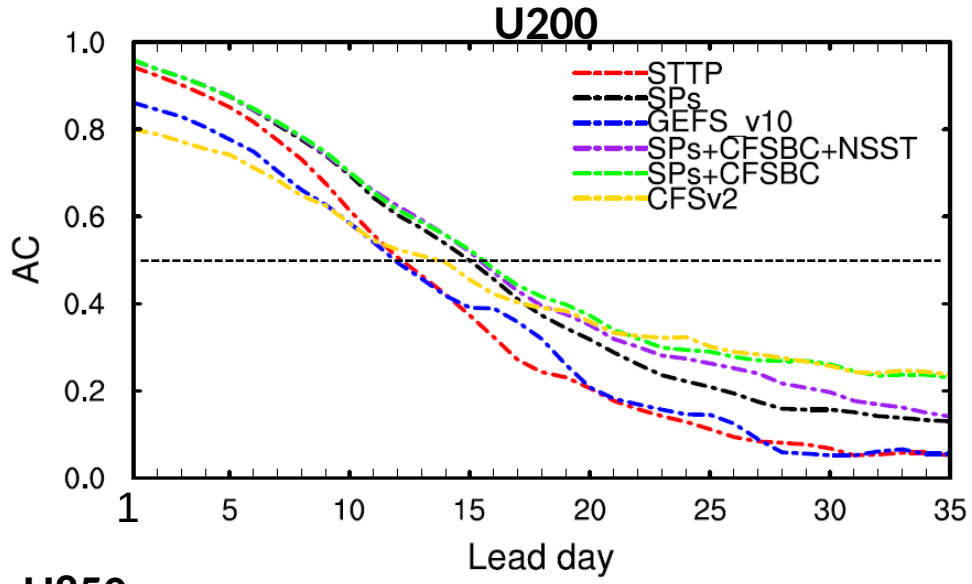
WH-MJO Forecast Skill

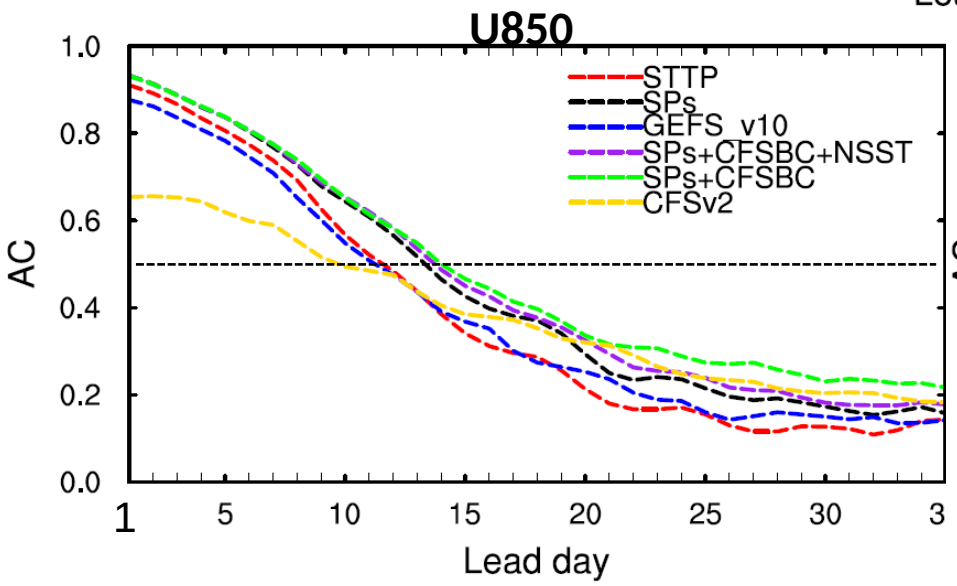


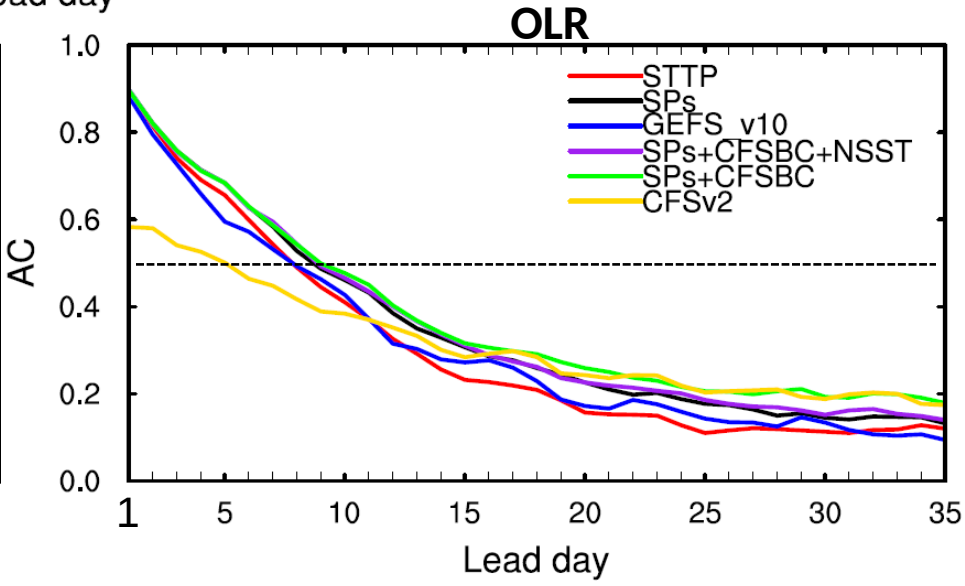




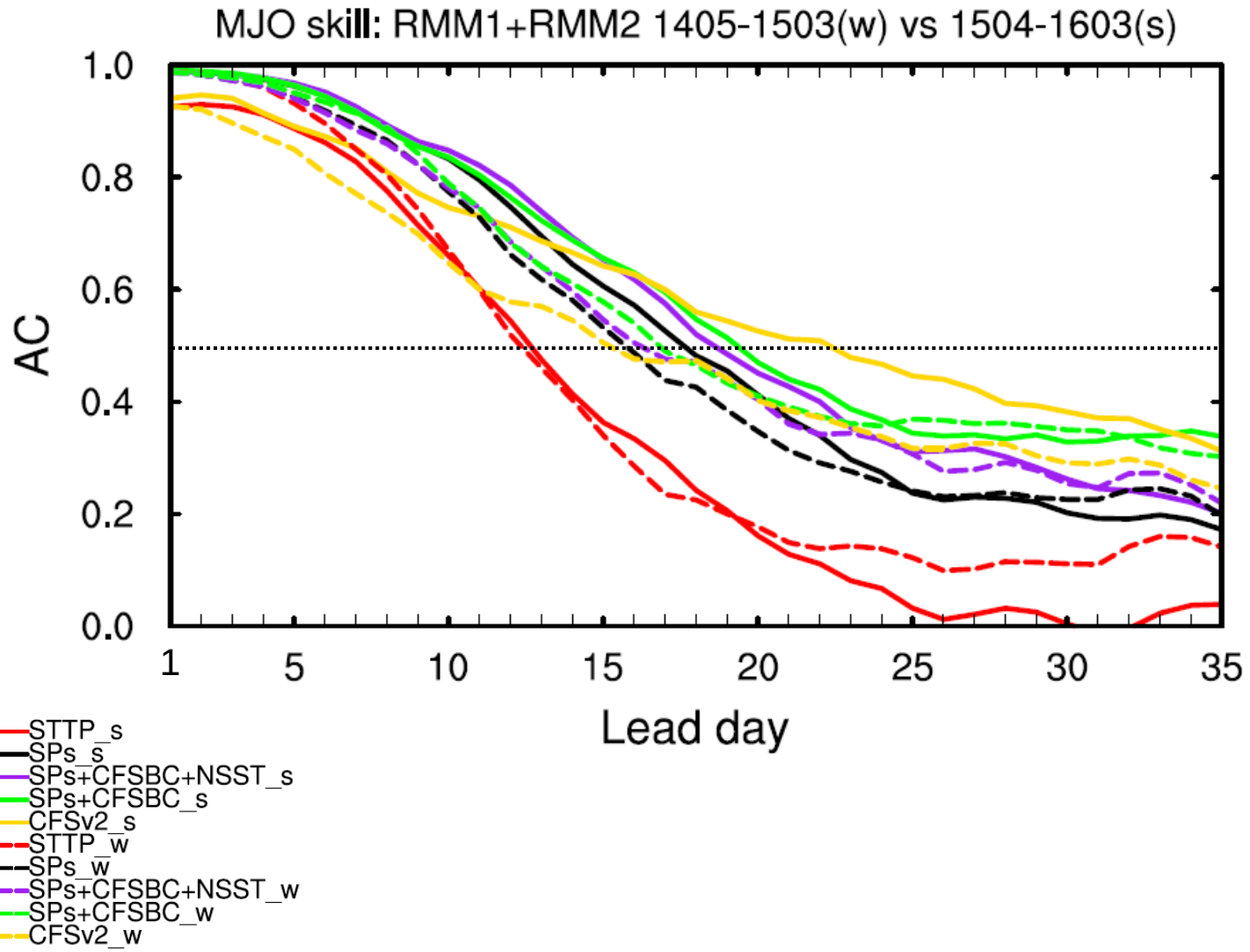
Contribution of Variables







Strong vs Weak Period



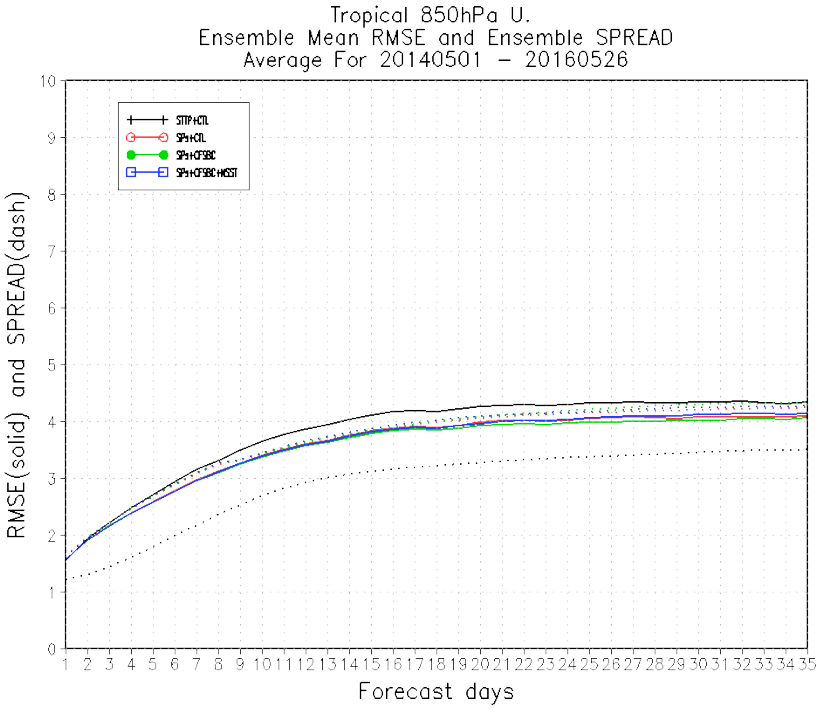
WH MJO skill (ACC=0.5)

20140501-20160526

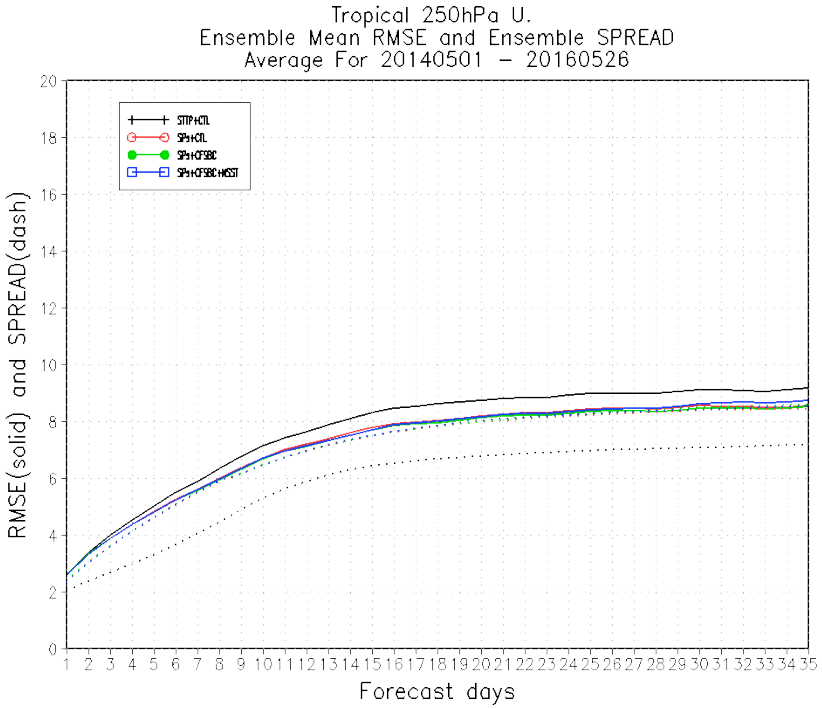
Configurations	Weak	Strong	2-yr
STTP (CTL)	12.2	12.8	**12.5**
SPs (CTL)	15.8	18	**16.8**
SPs+CFSBC	17	19.5	**18.5**
SPs+CFSBC+NSST	16.5	18.5	**18.1**
CFSv2	15.5	22.5	**18.5**
GEFS_v10			**12.5**

Day-to-day Verification
- RMSE and Spread

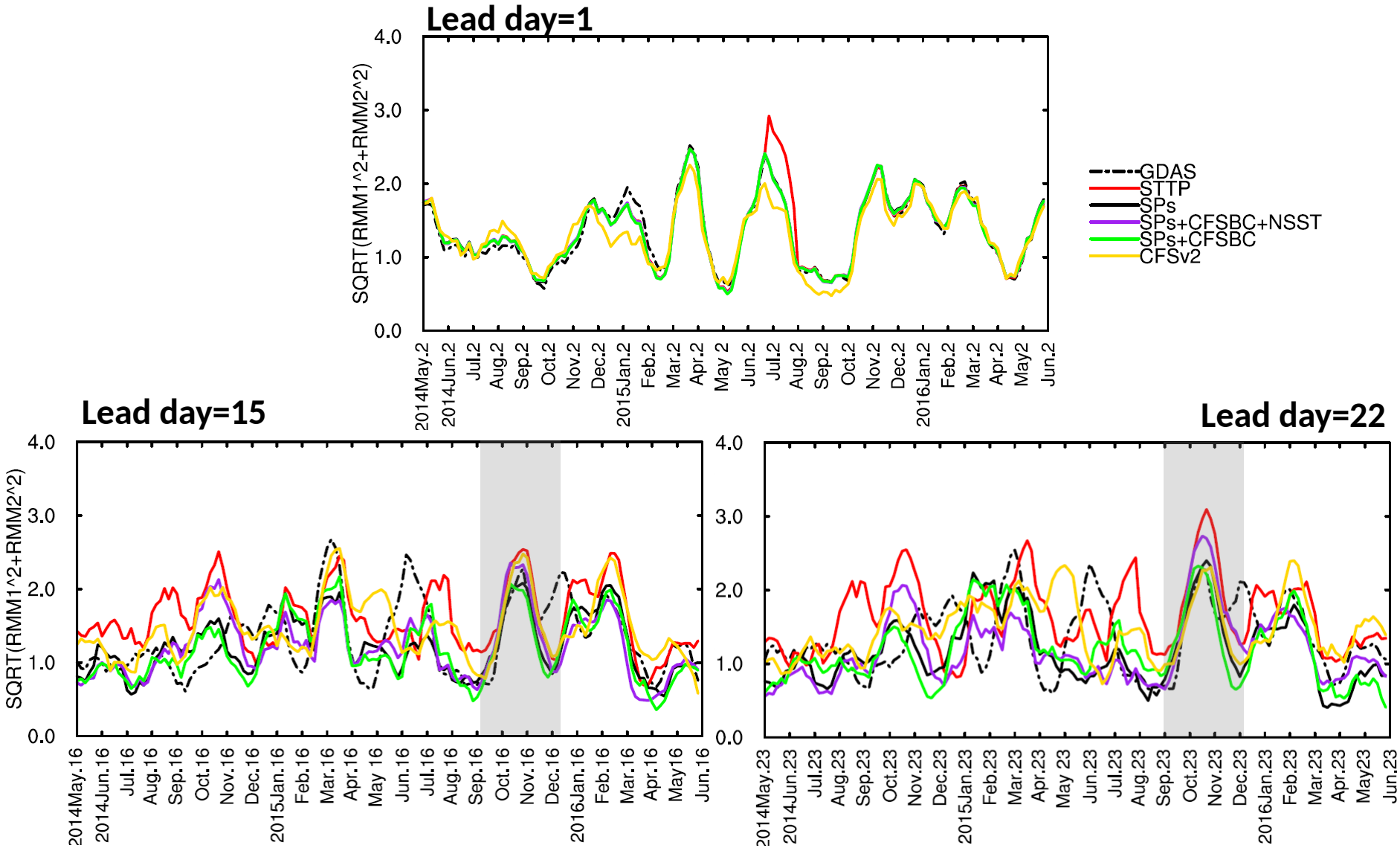
U850



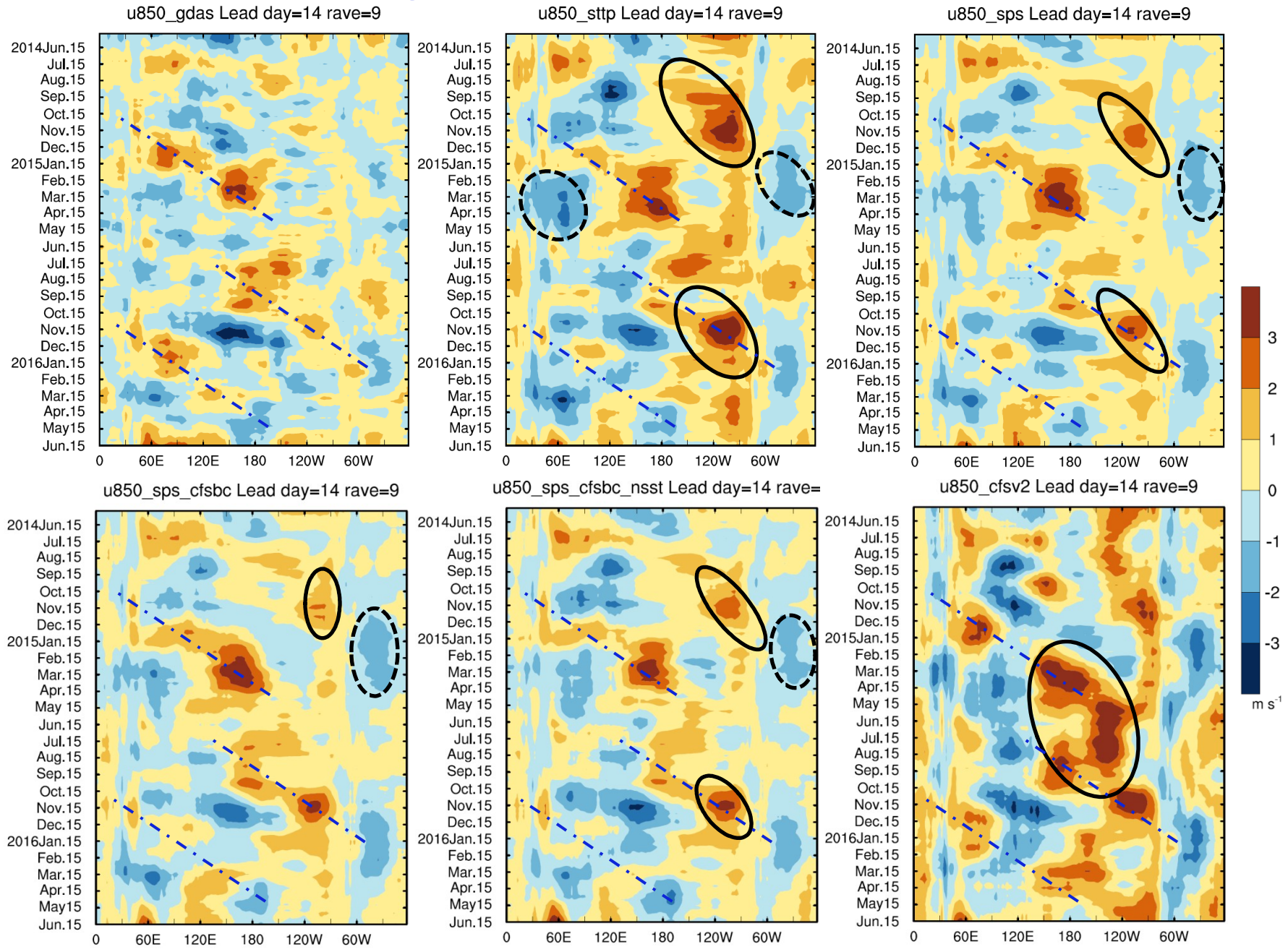
U250



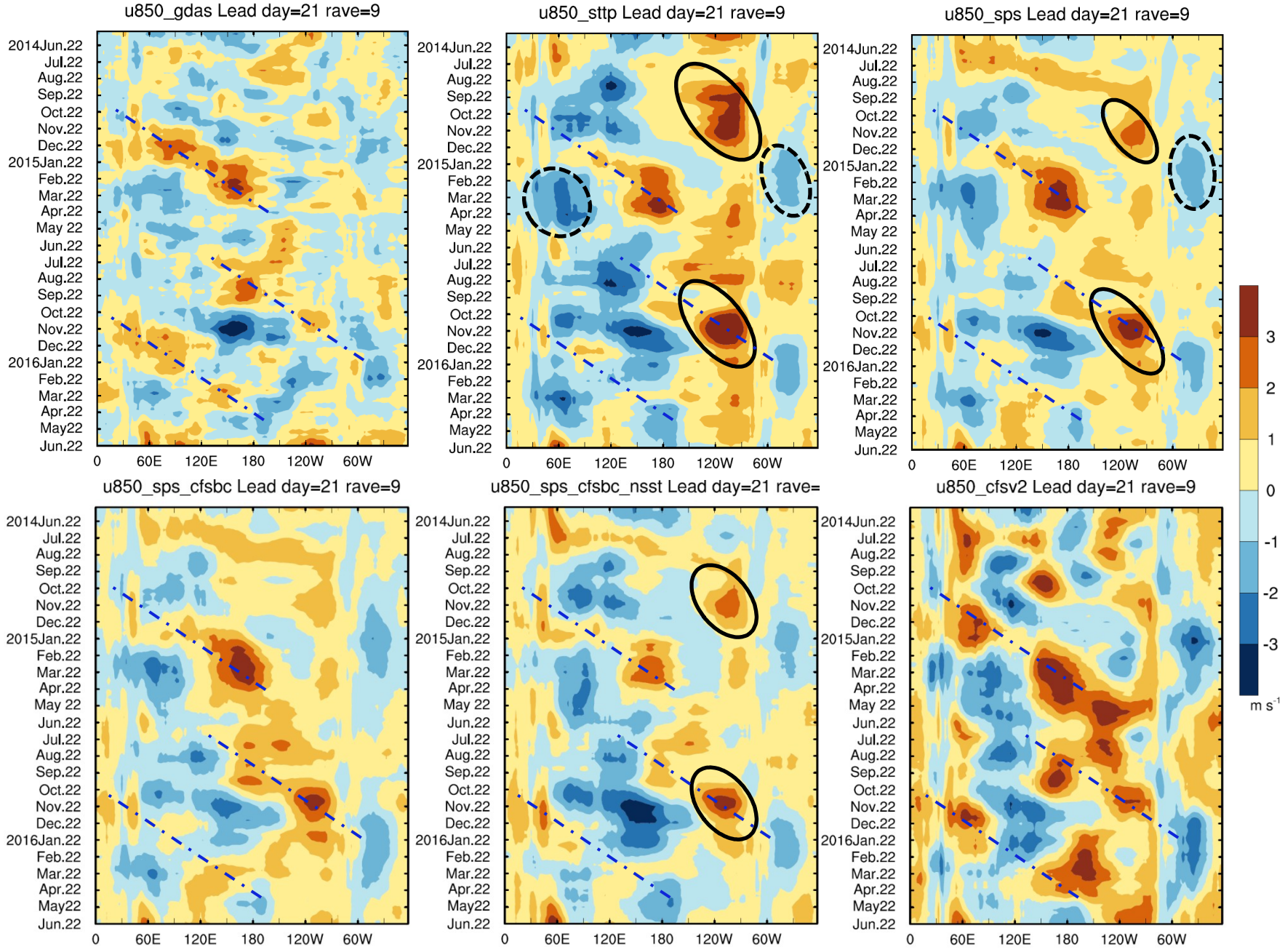
MJO index


Lead day=1
SQRT(RMM1^2+RMM2^2)
4.0
3.0
2.0
1.0
0.0
2014May.2
2014Jun.2
Jul.2
Aug.2
Sep.2
Oct.2
Nov.2
Dec.2
2015Jan.2
Feb.2
Mar.2
Apr.2
May 2
Jun.2
Jul.2
Aug.2
Sep.2
Oct.2
Nov.2
Dec.2
2016Jan.2
Feb.2
Mar.2
Apr.2
May2
Jun.2
GDAS
STTP
SPs
SPs+CFSBC+NSST
SPs+CFSBC
CFSv2
Lead day=15
SQRT(RMM1^2+RMM2^2)
2014May.16
2014Jun.16
Jul.16
Aug.16
Sep.16
Oct.16
Nov.16
Dec.16
2015Jan.16
Feb.16
Mar.16
Apr.16
May 16
Jun.16
Jul.16
Aug.16
Sep.16
Oct.16
Nov.16
Dec.16
2016Jan.16
Feb.16
Mar.16
Apr.16
May16
Jun.16
Lead day=22
2014May.23
2014Jun.23
Jul.23
Aug.23
Sep.23
Oct.23
Nov.23
Dec.23
2015Jan.23
Feb.23
Mar.23
Apr.23
May 23
Jun.23
Jul.23
Aug.23
Sep.23
Oct.23
Nov.23
Dec.23
2016Jan.23
Feb.23
Mar.23
Apr.23
May23
Jun.23

MJO signal : U850 Anomaly (Lead day=14)



MJO signal : U850 Anomaly (Lead day=21)



Tercile Ranked Probability Skill Score for 2-m Temperature and Accumulated Precipitation Verification

Ranked Probability Skill Score (RPSS) measures the improvement of a multi-category (3 categories in this case) forecast to a reference.

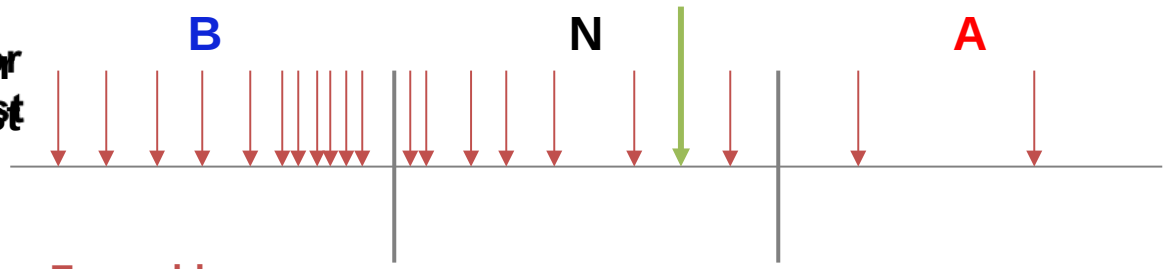
$$RPSS = 1 - \frac{RPS_f}{RPS_c}$$ where RPS_f is the forecast ranked probability score
RPS_c is the climatological ranked probability score

For each forecast-observation pair (n),

$$RPS_f = \frac{1}{N}\left(\sum_{n=0}^{N}(probB_n - obsB_n)^2 + (probN_n - obsN_n)^2 + (probN_n - obsN_n)^2\right)$$

where $probX_n$ and $obsX_n$ are the ranked cumulative forecast probability and observation probability for each bin (B, N, and A). The ranked forecast probability for each bin is the cumulative number of ensemble members divided by the total number of ensemble members. The cumulative observation probability is either 1 or 0. RPS_c is calculated the same way, but the forecast probability is assumed 1/3 for each bin.

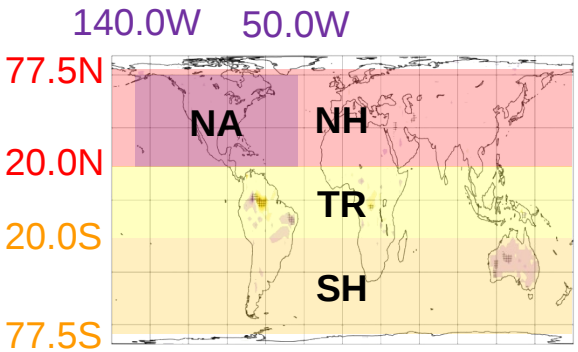
For example, for a single forecast observation pair:

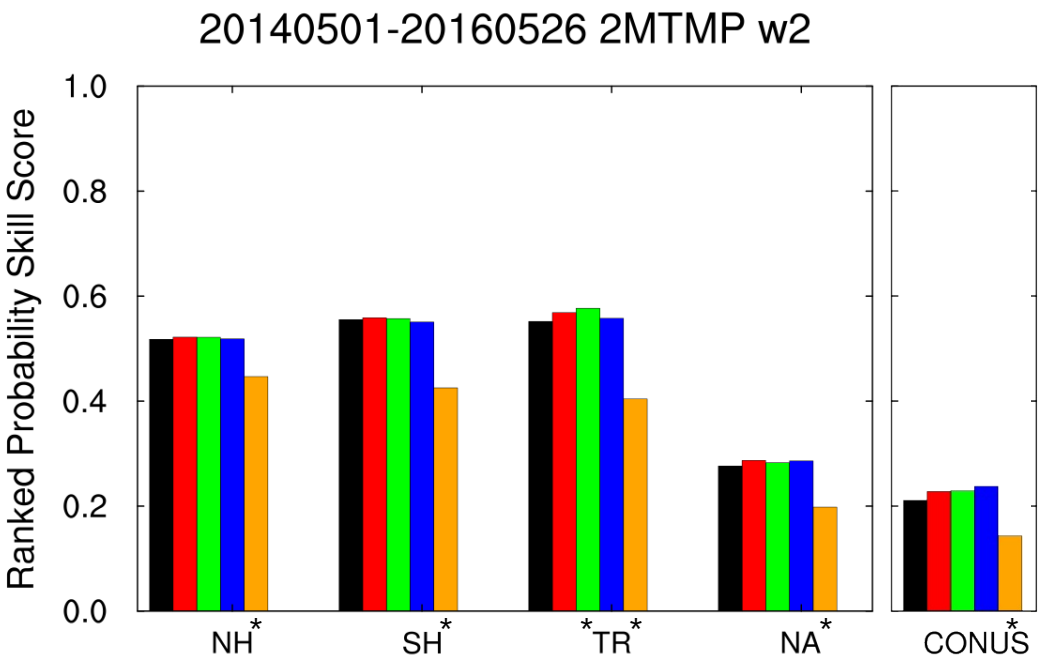


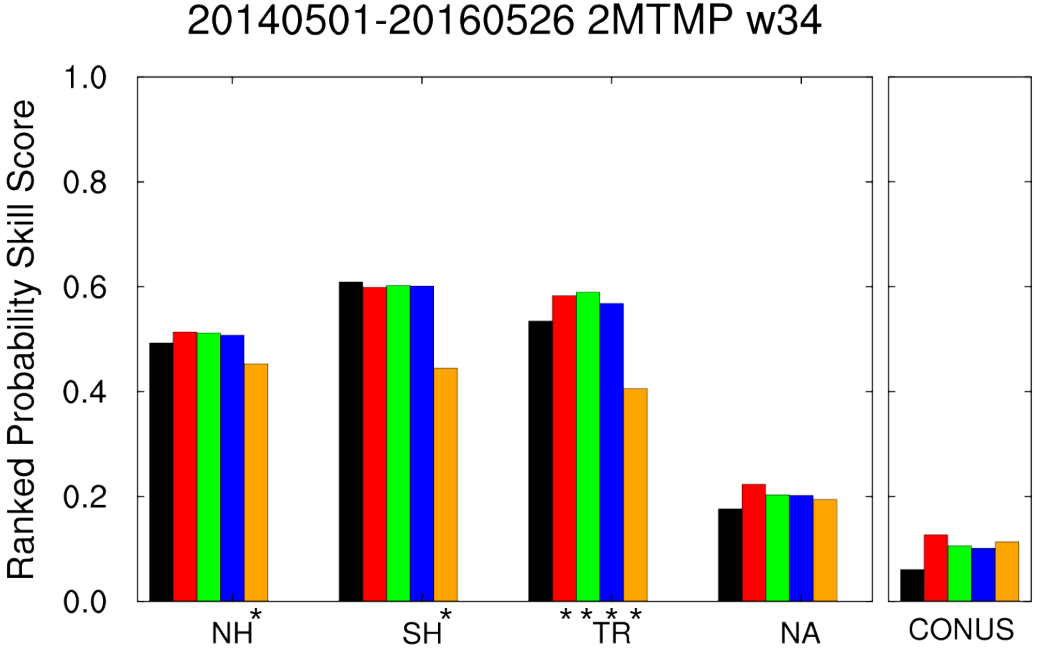
Source: NOAA NCEP CPC

Combined 2-m Temperature RPSS

Period:
20140501 to 20160526
every 5 days for land only



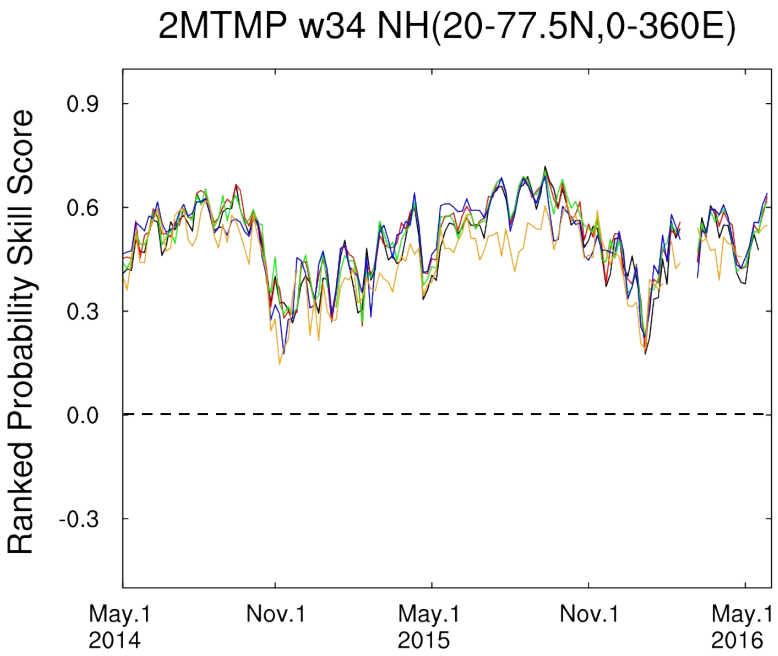


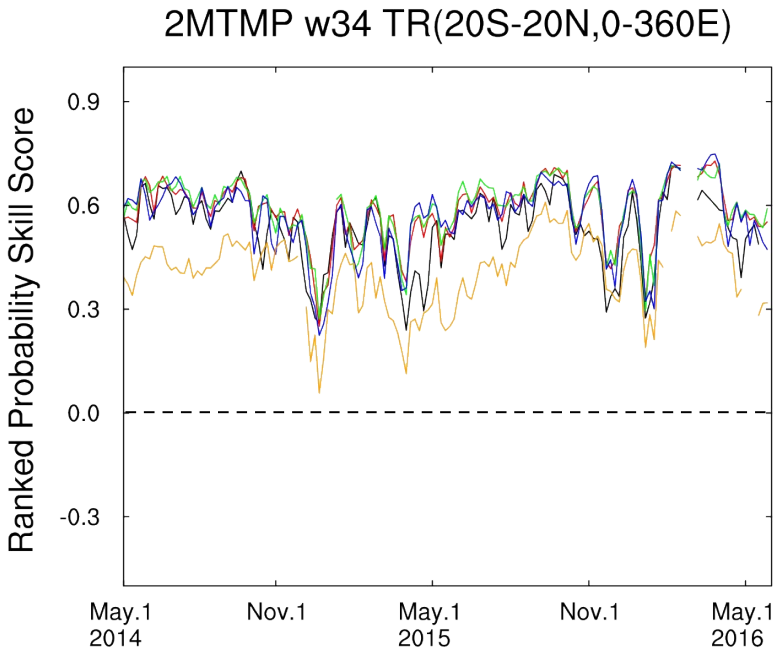


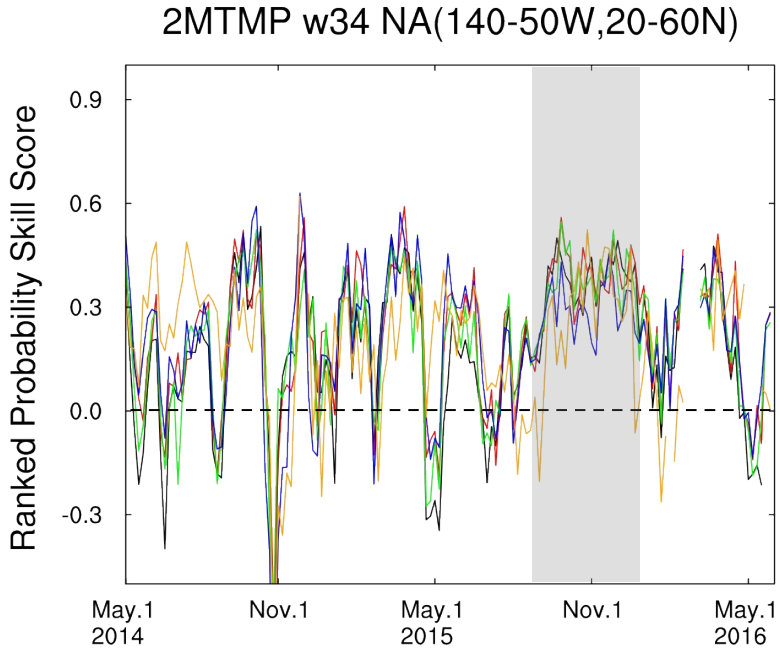
Experiment Key (ALL LAND ONLY):
CTL: STTP w/ operational SST
SPs: CTL w/ SPs
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST
CFSv2: CFSv2 operational forecast
** statistically significant difference from CTL at 95% C.L.*

W34 2-m Temperature Time Series

Period:
20140501 to 20160526 every 5 days







Experiment Key (ALL LAND ONLY):
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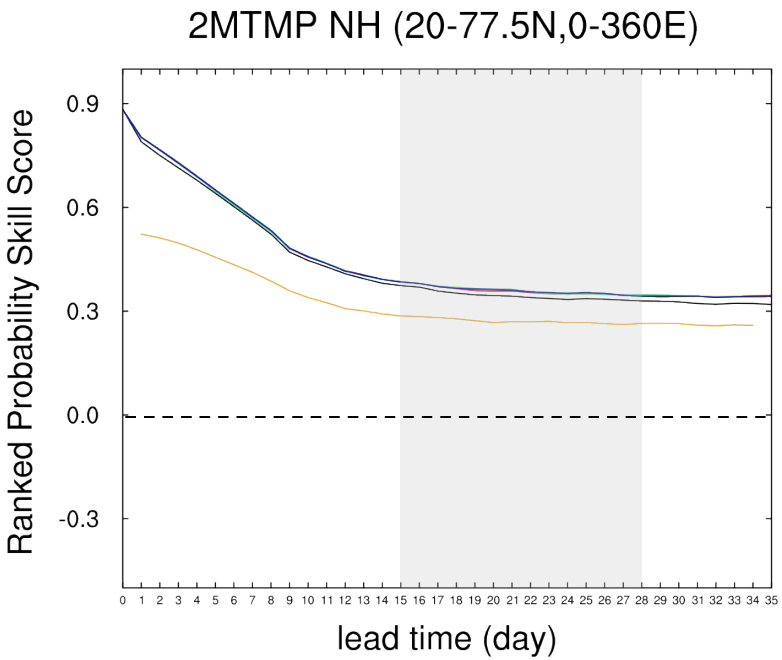
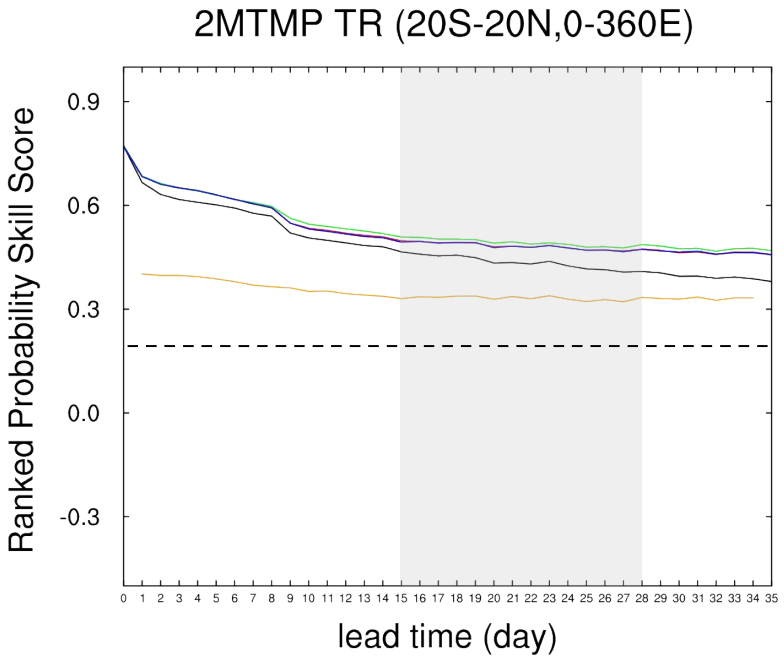
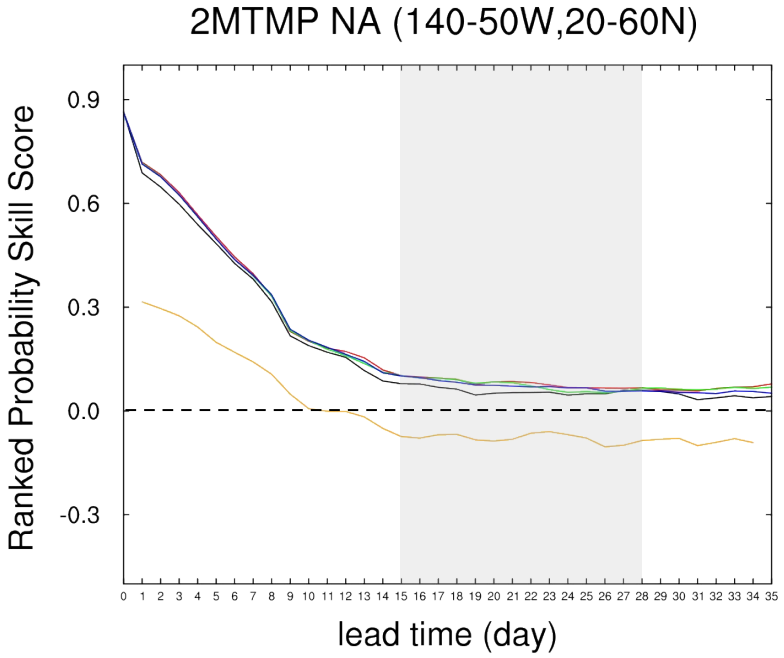
SPs: CTL w/ SPs
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST
CFSv2: CFSv2 operational forecast

W34 2-m Temperature Day-to-Day

Period:
20140501 to 20160526 every 5 days







Experiment Key (ALL LAND ONLY):
CTL: STTP w/ operational SST
SPs: CTL w/ SPs
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST
CFSv2: CFSv2 operational forecast

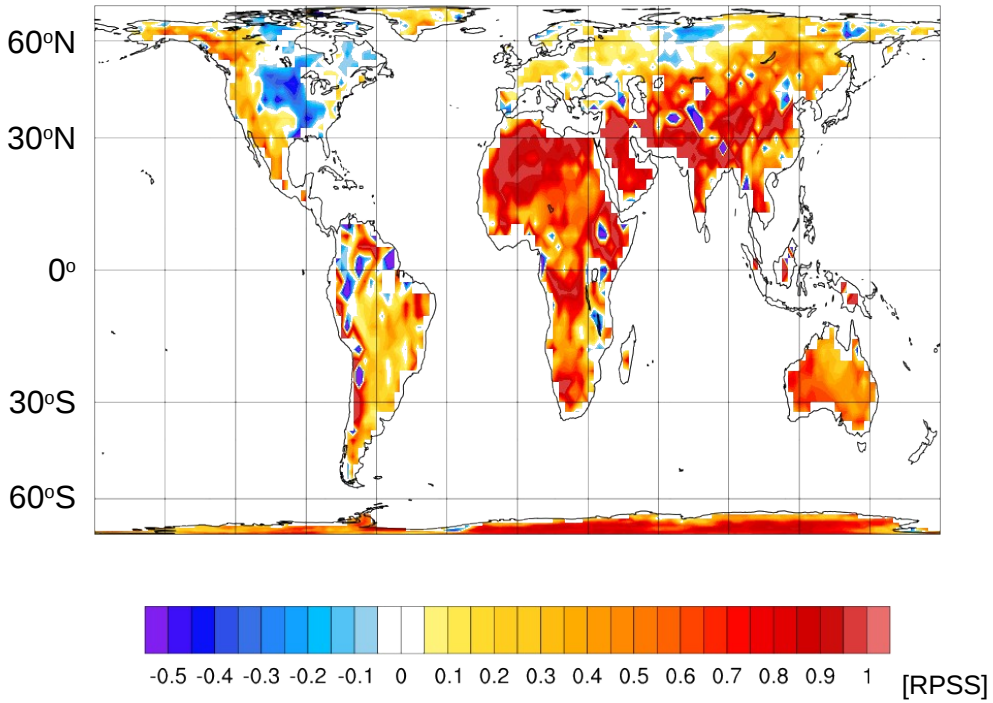
W34 Spatial

2-m Temperature RPSS

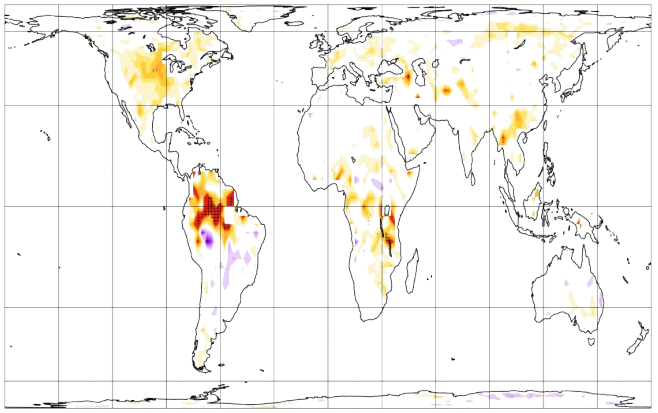
Period:

20140501 to 20160526 every 5 days

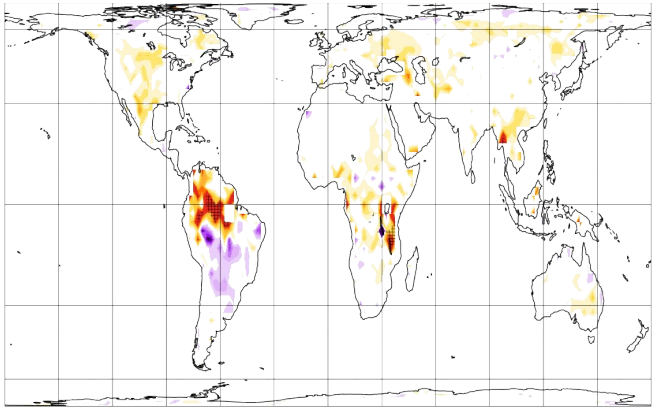
W34 **CTL** RPSS



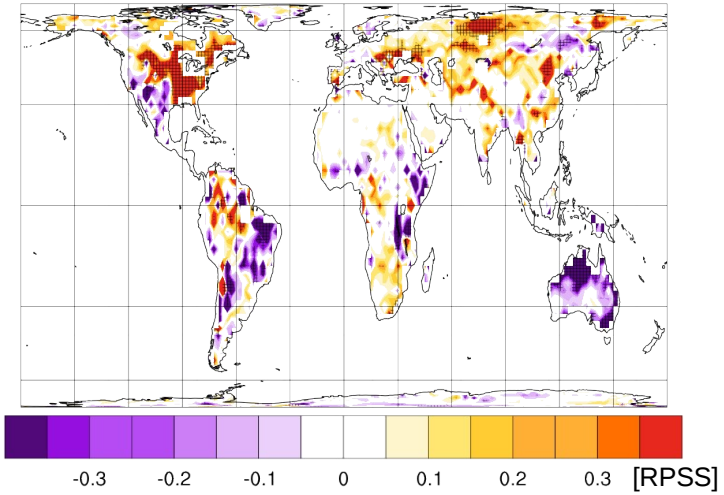
SP RPSS difference from **CTL**



SP+CFSBC RPSS difference from **CTL**



CFSv2 RPSS difference from **CTL**



Experiment Key (ALL LAND ONLY):

CTL: STTP w/ operational SST

SPs: CTL w/ SPs

SPs+CFSBC: SPs w/ bias corrected CFSv2 SST

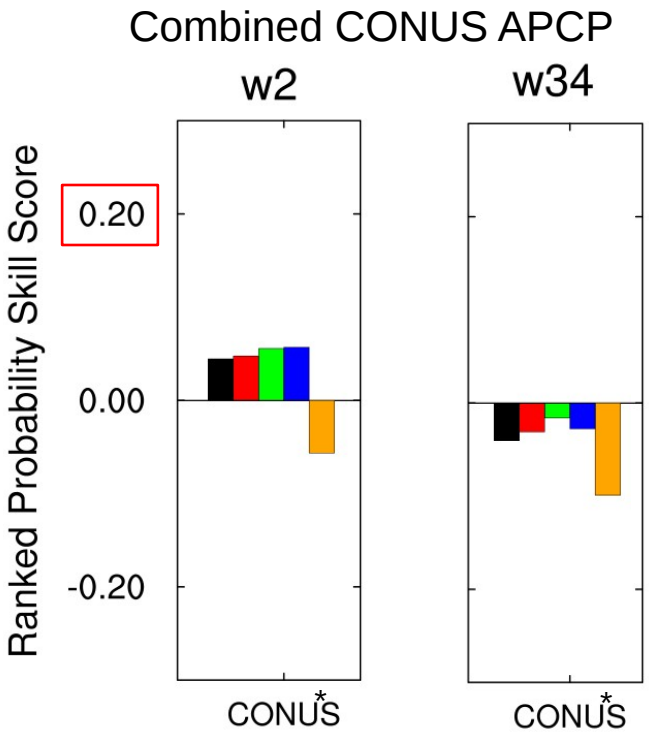
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST

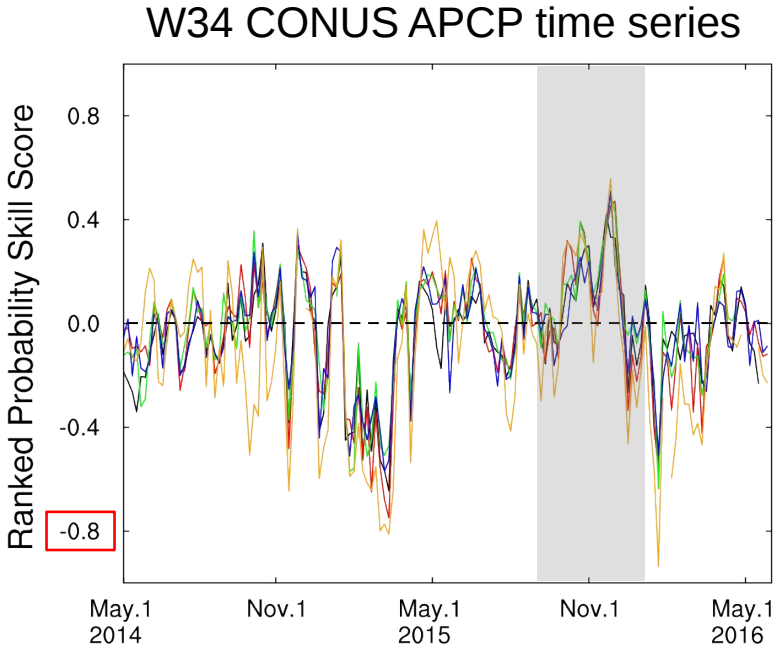
CFSv2: CFSv2 operational forecast

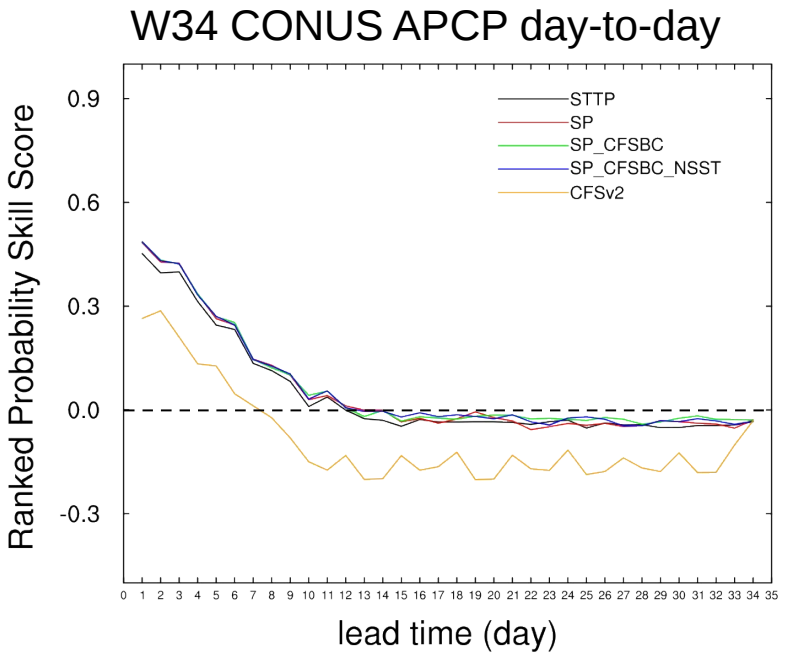
Hatching statistically significant difference from CTL at 95% C.L.

Accumulated Precipitation RPSS

Period:
20140501 to 20160526 every 5 days







Experiment Key (ALL LAND ONLY):
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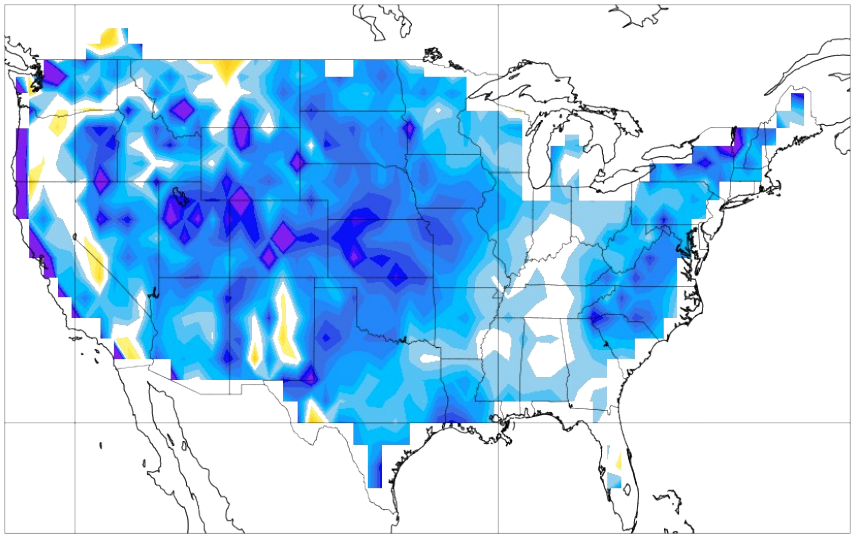
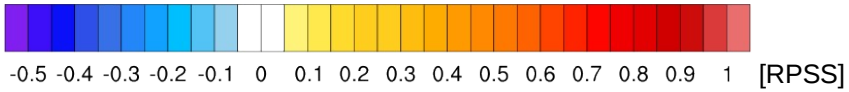
SPs: CTL w/ SPs
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST
CFSv2: CFSv2 operational forecast
** statistically significant difference from CTL at 95% C.L.*

W34 Spatial Accumulated Precipitation RPSS

Period:
20140501 to 20160526 every 5 days

W34 **CTL** RPSS





Experiment Key (ALL LAND ONLY):
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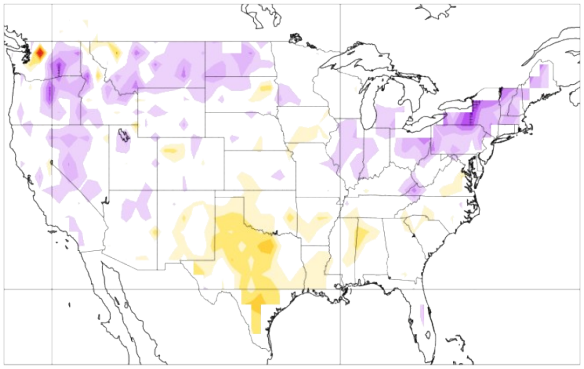
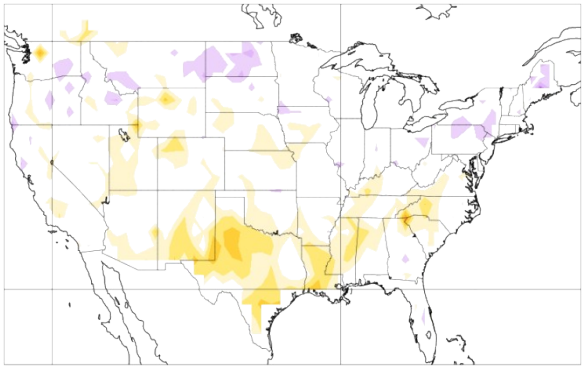
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST
CFSv2: CFSv2 operational forecast
Hatching statistically significant difference from CTL at 95% C.L.

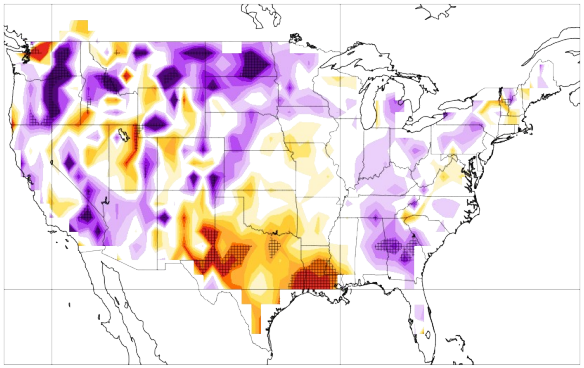
SP RPSS difference from **CTL**

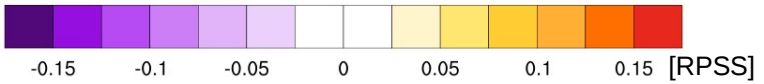


SP+CFSBC RPSS difference from **CTL**



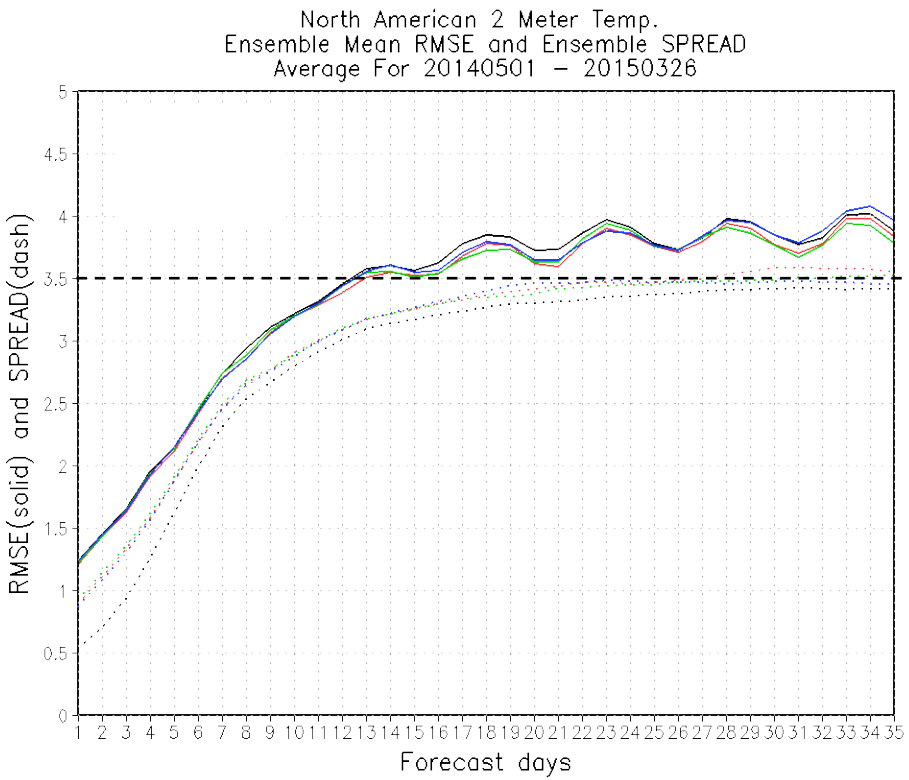
CFSv2 RPSS difference from **CTL**



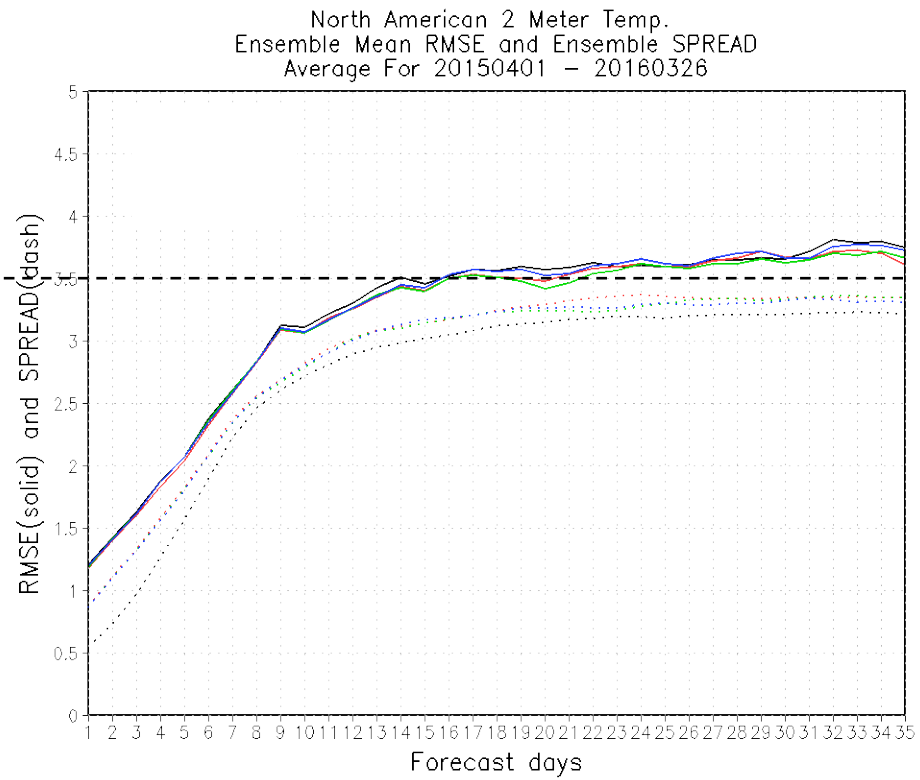


Strong vs Weak Period (Land + Ocean)

Weak MJO
20140501-20150326



Strong MJO
20150401-20160326



Experiment Key:
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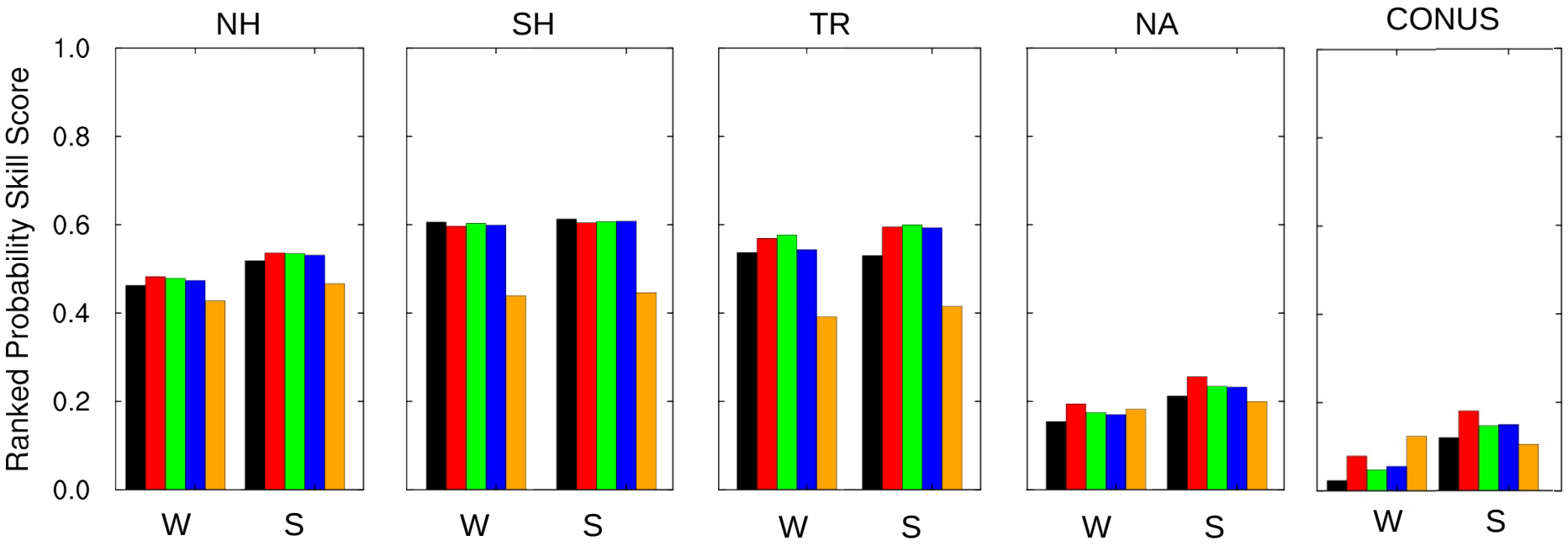
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST

W34 Strong vs Weak MJO Period
Combined 2-m Temperature RPSS

Period:

W: 20140501 to 20150326 every 5 days

S: 20150401 to 20160326 every 5 days



Experiment Key (ALL LAND ONLY):

CTL: STTP w/ operational SST

SPs: CTL w/ SPs

SPs+CFSBC: SPs w/ bias corrected CFSv2 SST

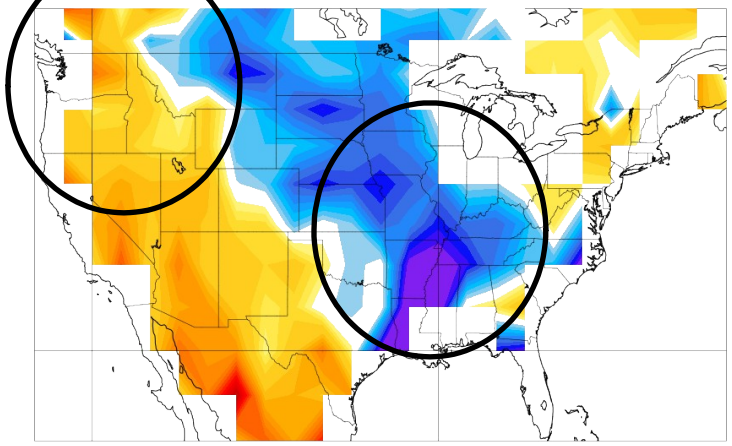
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST

CFSv2: CFSv2 operational forecast

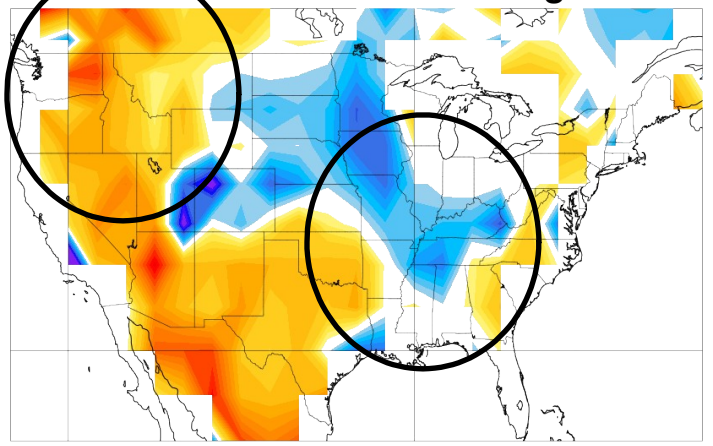
W34 Strong vs Weak MJO Period
2-m Temperature RPSS

Period: W: 20140501 to 20150326 every 5 days
S: 20150401 to 20160326 every 5 days

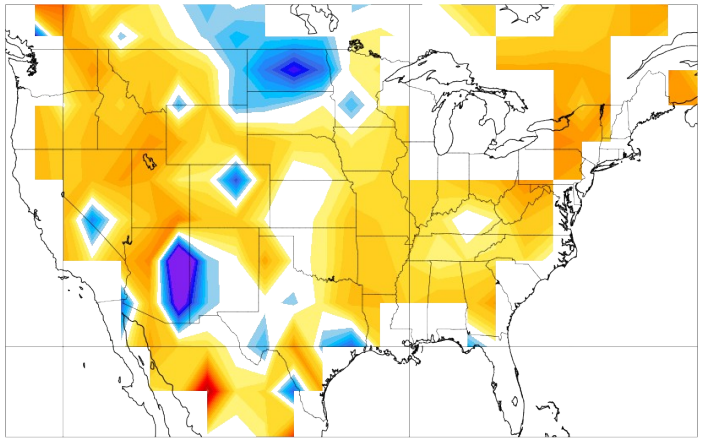
W34 SP+CFSBC **Weak**



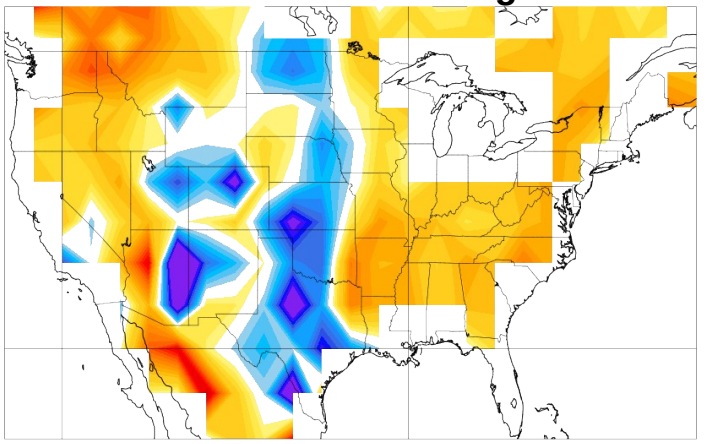
W34 SP+CFSBC **Strong**

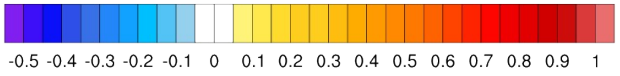


W34 CFSv2 **Weak**



W34 CFSv2 **Strong**



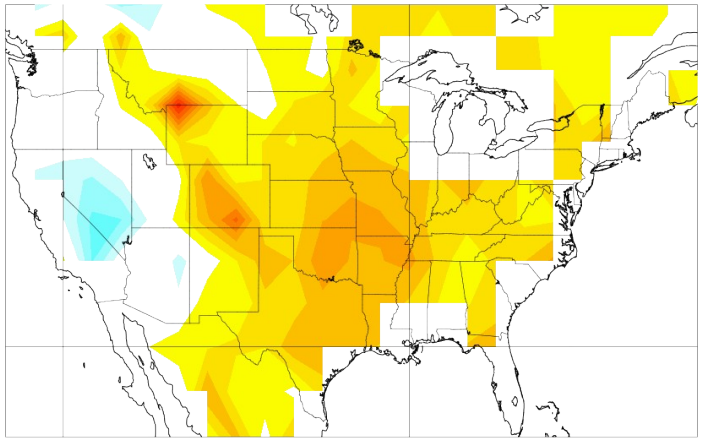


Experiment Key (ALL LAND ONLY):
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
CFSv2: CFSv2 operational forecast

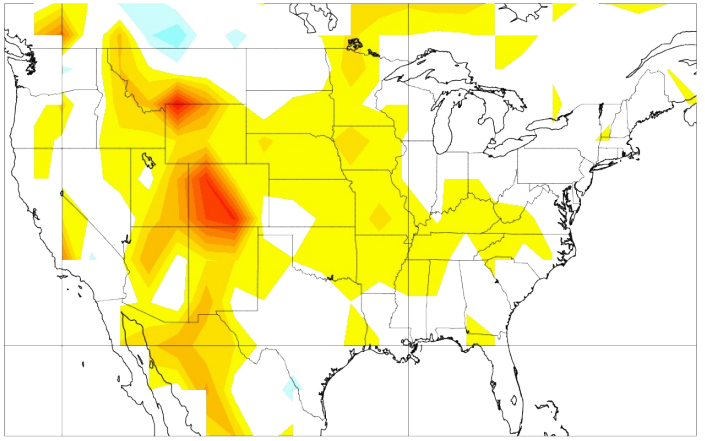
W34 Strong vs Weak MJO Period
2-m Temperature Bias

Period: W: 20140501 to 20150326 every 5 days
S: 20150401 to 20160326 every 5 days

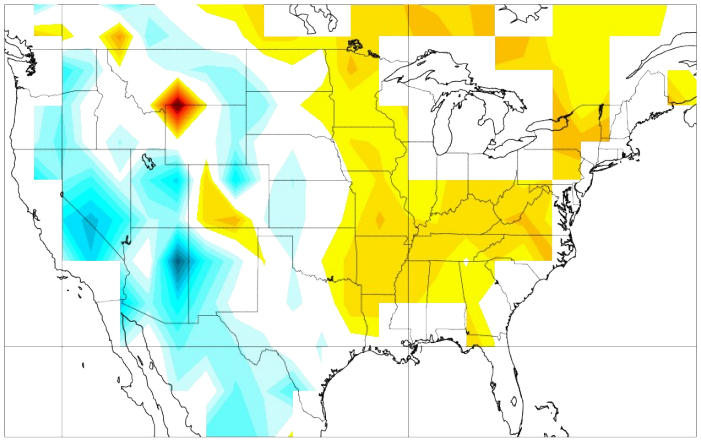
W34 SP+CFSBC **Weak**



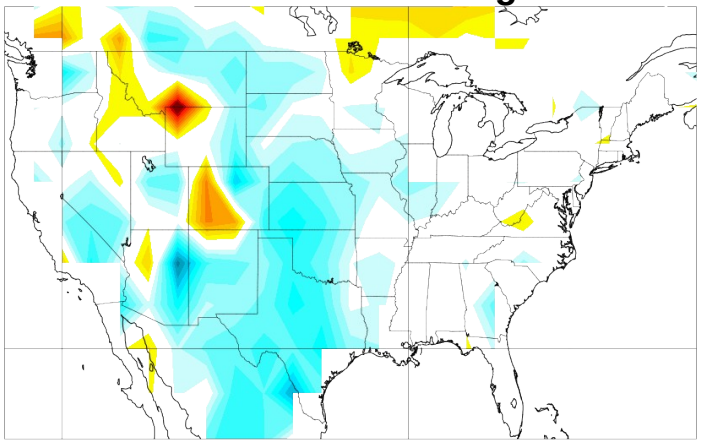
W34 SP+CFSBC **Strong**



W34 CFSv2 **Weak**



W34 CFSv2 **Strong**



[K]

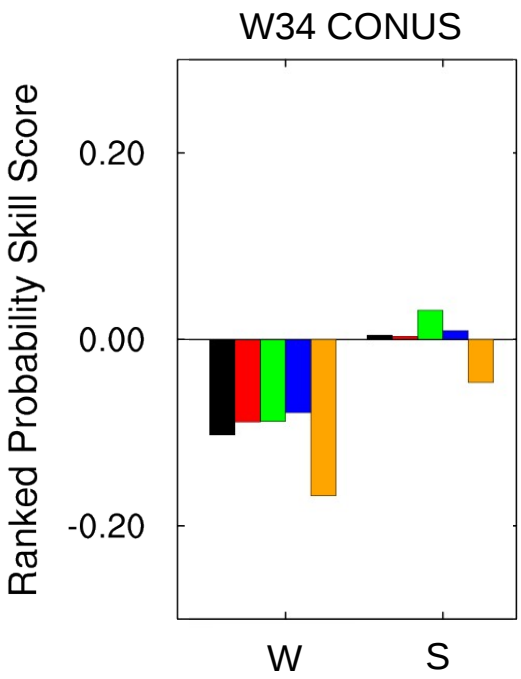
Experiment Key (ALL LAND ONLY):
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
CFSv2: CFSv2 operational forecast

W34 Strong vs Weak MJO Period
Combined Accumulated Precipitation RPSS

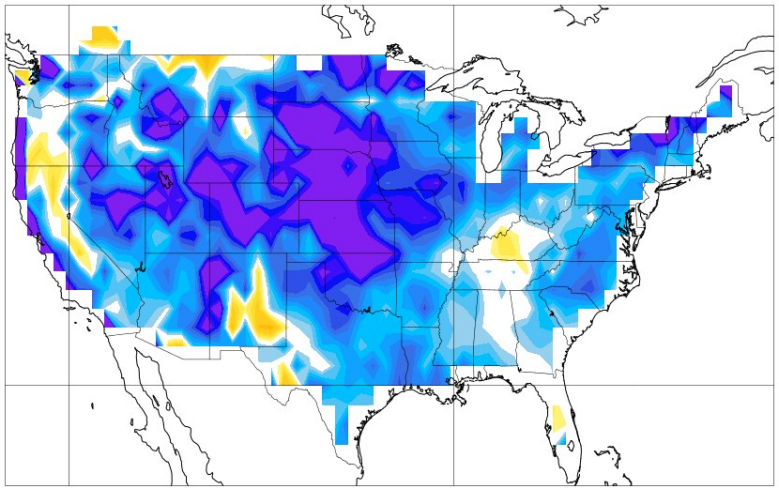
Period:

W: 20140501 to 20150326 every 5 days

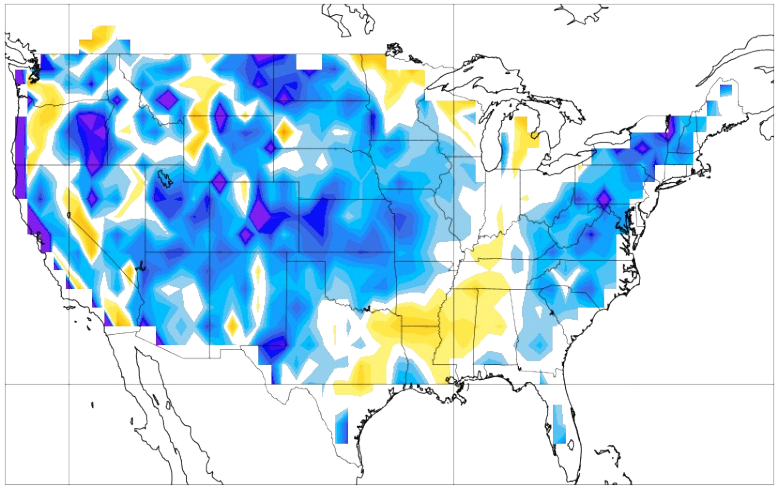
S: 20150401 to 20160326 every 5 days

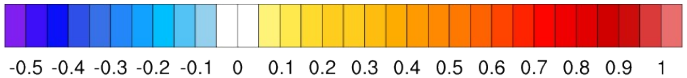


W34 **SP+CFSBC Weak**



W34 **SP+CFSBC Strong**





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SP: SP w/ operational SST

SP+CFSBC: SP w/ bias corrected CFSv2 SST

SP+CFSBC+NSST: SP+CFSBC w/ NSST

CFSv2: CFSv2 operational forecast

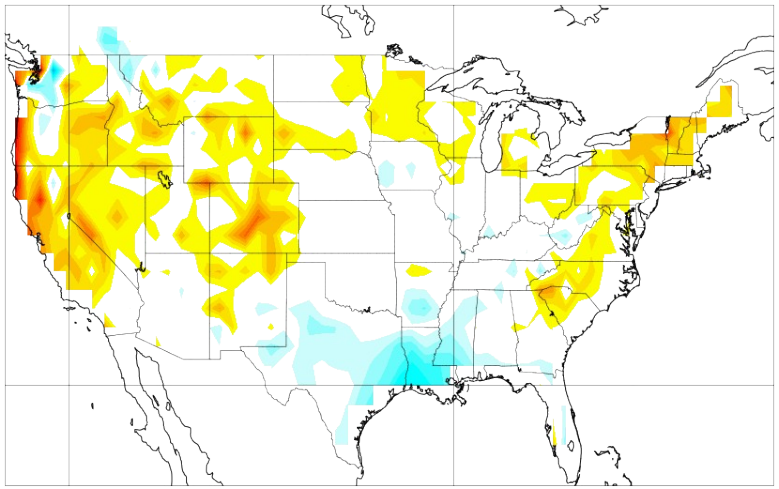
Strong vs Weak MJO Period
Combined Accumulated Precipitation Bias

Period:

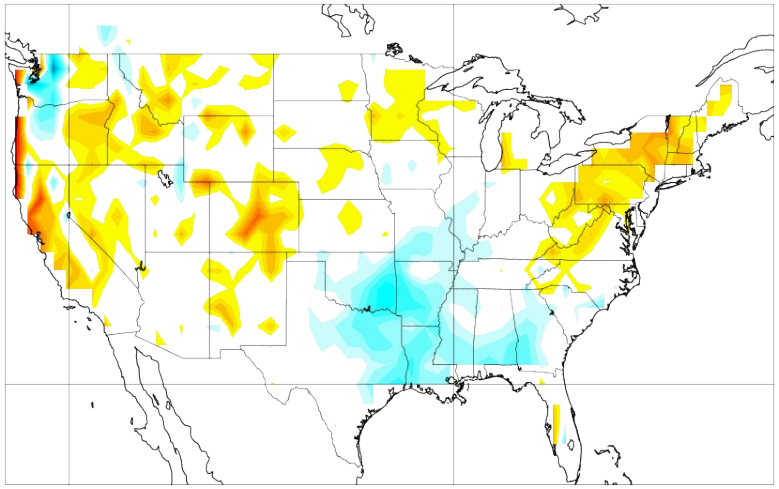
W: 20140501 to 20150326 every 5 days

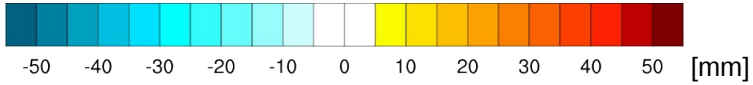
S: 20150401 to 20160326 every 5 days

W34 **SP+CFSBC** **Weak**



W34 **SP+CFSBC** **Strong**





Experiment Key (ALL LAND ONLY):

SP+CFSBC: SPs w/ bias corrected CFSv2 SST

Conclusion from Investigation (2)

- **WH MJO skill:**
  - The **SPs+CFSBC**, **SPs+CFSBC+NSST**, and **CFSv2** have the best skill (~18 days) with **SPs** close (~16 days) and **STTP** (~13 days). Stochastic physics appears to have the largest benefit with SST a secondary impact;
  - MJO skill of strong period is greater than weak period;
  - The skill of RMM2 is greater than RMM1 and is variable dependent (U200>U850>OLR);
  - MJO signal is significant in forecast data at 14 and 21 lead day.
  - Bias in U850 over tropical East Pacific for some initial time especially in **STTP**, **SPs** and **SPs+CFSBC+NSST** experiments.
  - **Day-to-Day verification:**
    - SPs (**CTL**, **CFSBC** and **CFSBC+NSST**) have higher skill than STTP with **SPs+CFSBC** being slightly better than other SPs configurations.

- **Week3&4 land 2m Temperature and Precipitation over NA:**
  - SPs (**CTL**, **CFSBC** and **CFSBC+NSST**) may provide additional land-only 2-m forecast skill (improvements are not statistically significant). Larger impact comparing SPs to **CTL** than between SPs with various SST configurations.
  - Forecast skill for 2-m temperature and accumulated precipitation has larger skill (especially over CONUS) during strong MJO period compared to weak.

Open Discussion

- Capability of GEFS modeling for MJO (un-coupled)

  Dependency of the MJO predictability

  - Forecast system related: stochastic perturbations, underlying boundary condition
  - Non-forecast system related: initial strength, MJO phase

- Tropical source of predictability for North American weather/climate.

  Possible linkage between MJO and NA sub-seasonal scale forecast?

- Possible improvement for:

  MJO skill – tune NSST to reduce warm bias

  CONUS forecast skill – remove systematic error from reforecasts

- **Configuration for SubX project**

  SPs+CFSBC or SPs+CFSBC+NSST?

Backup slides!!!

SST Schemes

- **Operational**

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

- **CFSBC**

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

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

$SST_a^{t_0}$ -- 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

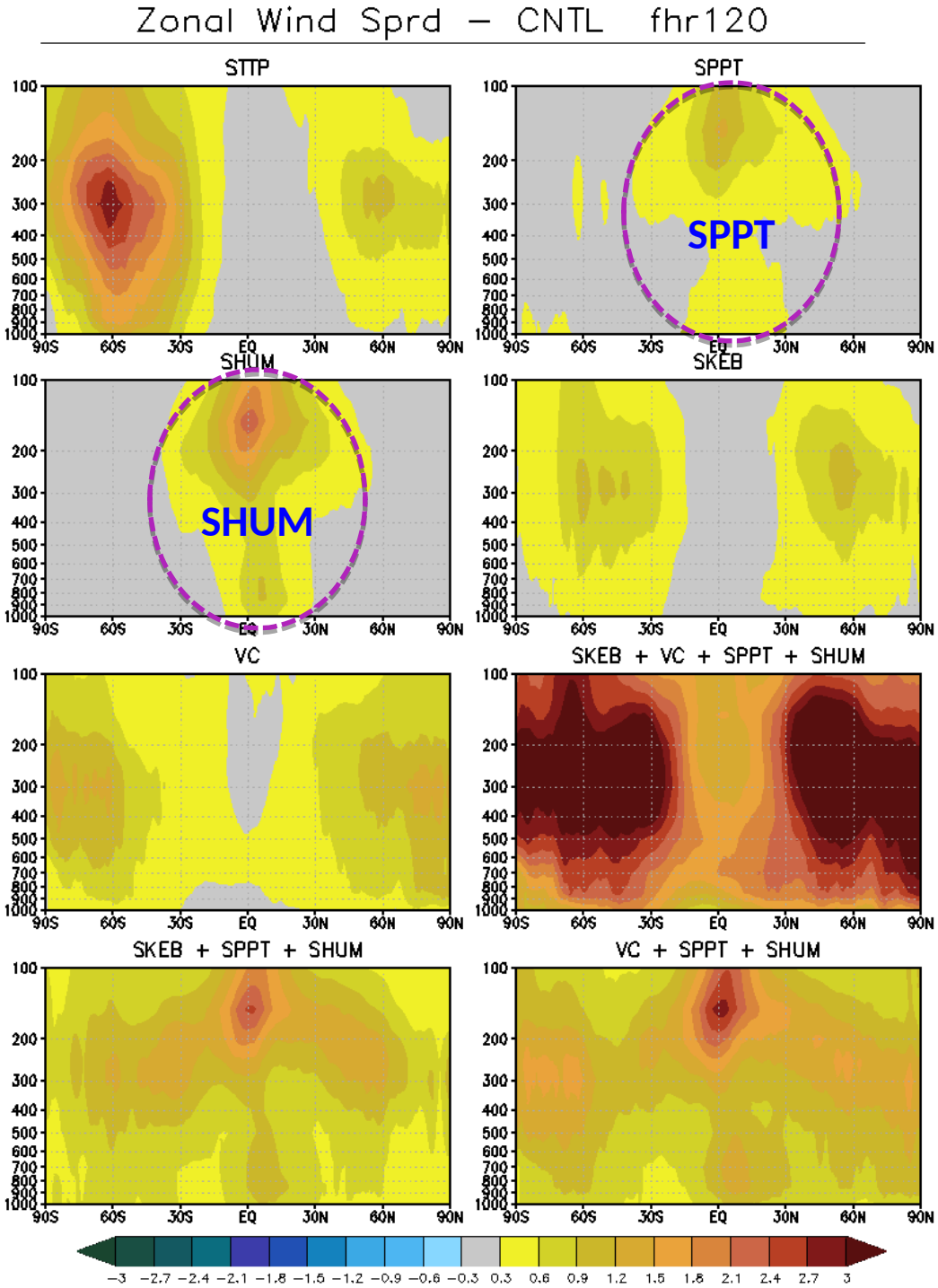
SST_{cfsrc}^t -- CFS reanalysis daily climatology for forecast lead-time t

New Stochastic Schemes for Atmosphere
- Testing for GEFS

- **Stochastic Kinetic Energy Backscatter (SKEB)**
  - Represents process absent from model
  - Stream function is randomly perturbed to represent upscale kinetic energy transfer (Berner et al., 2009)

- **Stochastic Perturbed Physics Tendencies (SPPT)** – (ECWMF tech memo 598)
  - Designed to represent the structural uncertainty (or random errors) of parameterized physics
  - Multiplicative noise used to perturb the total parameterized tendencies (Palmer et al., 2009)
  - Biggest impact on tropic

- **Stochastically-perturbed boundary layer HUMidity (SHUM)**
  - The same formula as SPPT
  - Designed to represent influence of sub-grid scale humidity variability on the the triggering of convection (Tompkins and Berner 2008)
  - Biggest impact on tropic



Characteristics of one summer month test

STTP strong at winter hemisphere

SKEB similar to STTP, but for large scale

SPPT big impact is tropical, not mid-latitude

SHUM – big impact is tropical, duplicate to SPPT

VC – big impact is high latitude

The NSST in the NCEP GFS

Xu Li

IMSG at EMC/NCEP/NOAA

Acknowledgements:

John Derber, Andrew Collard (DA)

Moorthi Shrinivas, Jun Wang (Model, NEMSIO)

Diane Strokes, SST Group (SST)

Ilya Rivin & Carlos Lozano (NSST model initial stage)

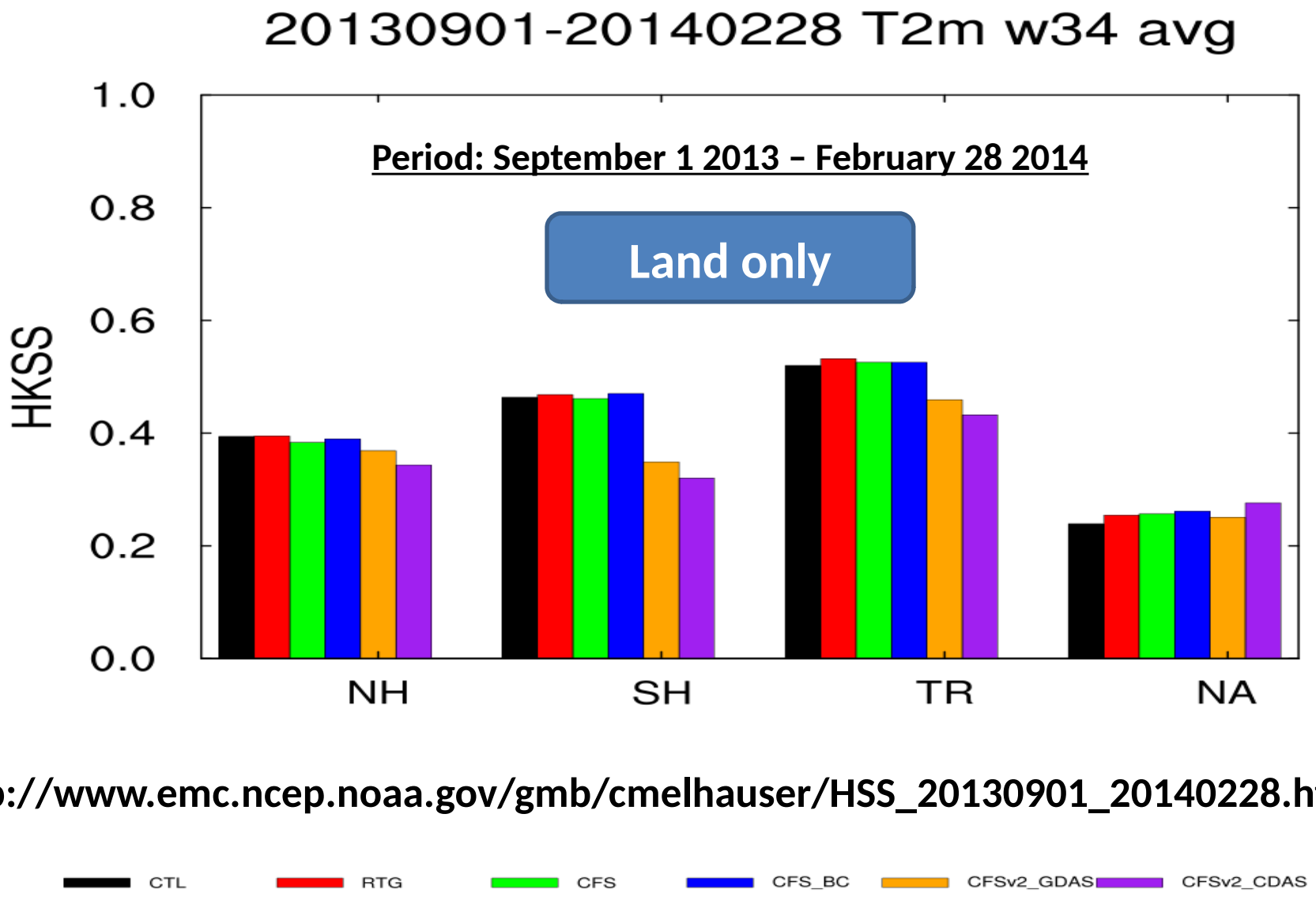
Fanglin Yang, Russ Treadon, George Gayno (Parallel run, validation, chgres)

Xingren Wu, David Buheringer (Sea ice, Coupled)

Dennis Keyser & Jeff Whiting (Data)

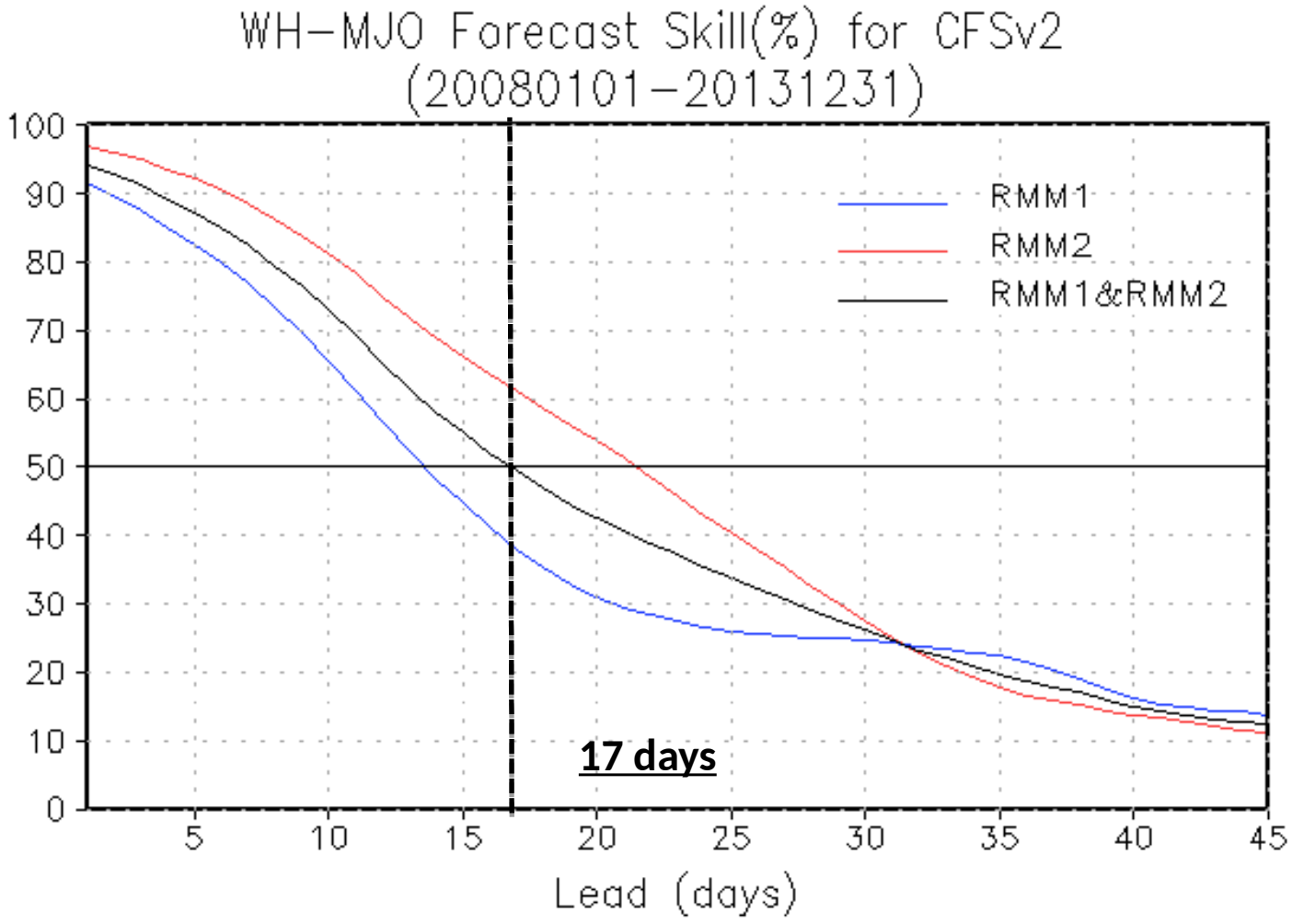
October 27, 2016
GCWMB bi-weekly meeting

Combined Heidke Skill Score for T2m (WK3&4)



http://www.emc.ncep.noaa.gov/gmb/cmelhauser/HSS_20130901_20140228.html

6-year average WH-MJO forecast skills for CFSv2



Courtesy of Dr. Qin Zhang

Experiments and Data

- Forecast system:
  - GEFSv11, 0-35 day forecast;
  - T574 (33 km) for 0-8 days, T382 (55km) for 8-35 days.

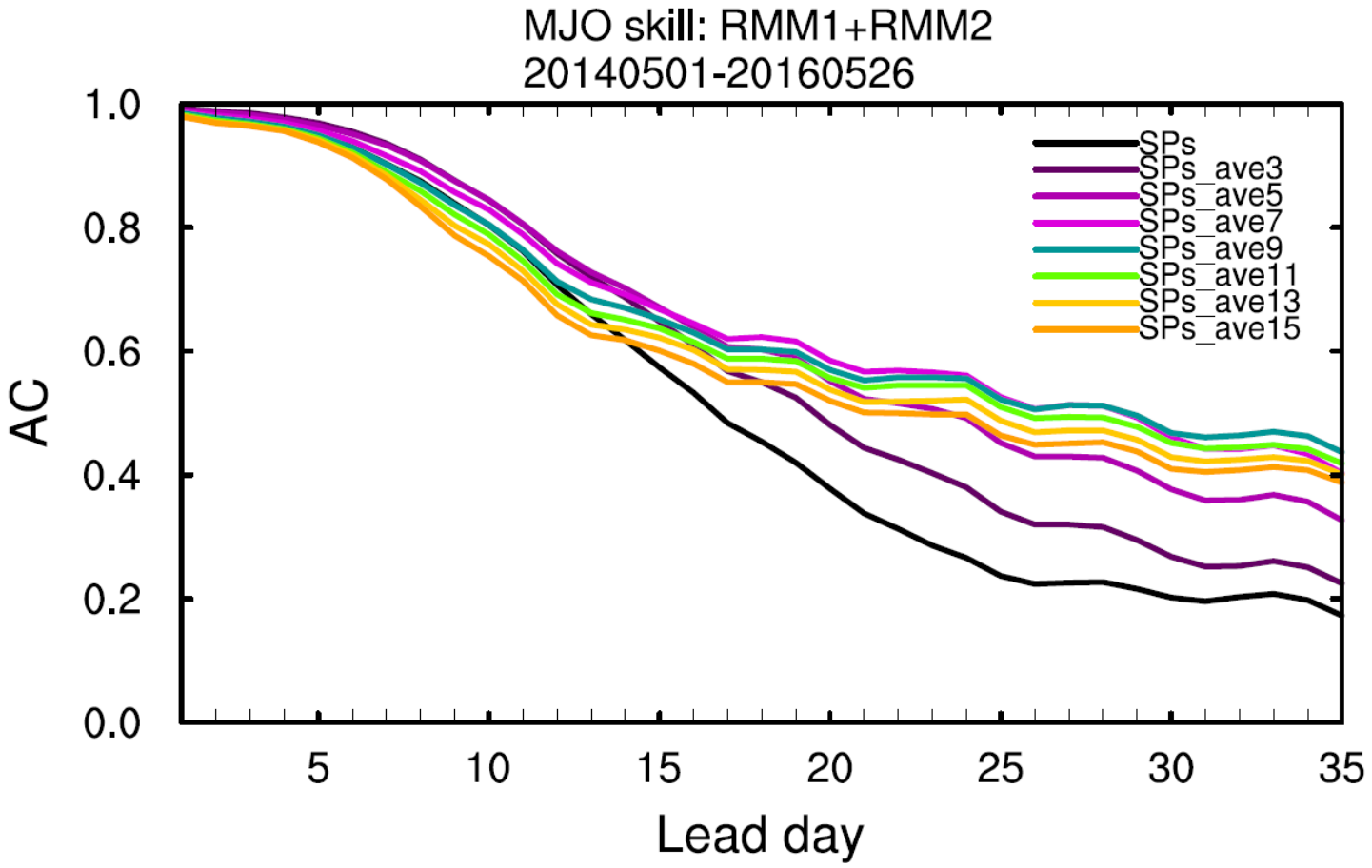
- Experiments:
  - STTP with control version of SST
  - SPPT+SHUM+SKEB (SPs) with control version of SST;
  - SPs with bias corrected CFSv2 forecast SST;
  - SPs with bias corrected CFSv2 forecast SST and NSST;
- All experiment cover the period of 20140501-20160526, 5-day interval.

- Analysis data:
  - GDAS during 20140101-20161031

- Both forecast and analysis data using daily mean

WH-MJO Forecast Skills After Smoothing

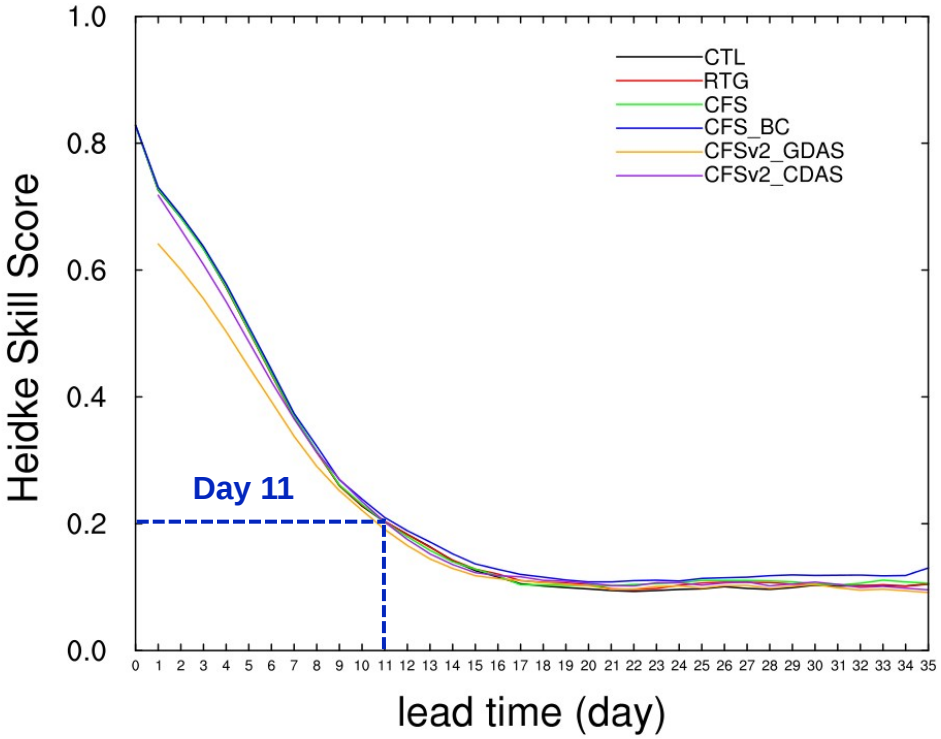
SPs case



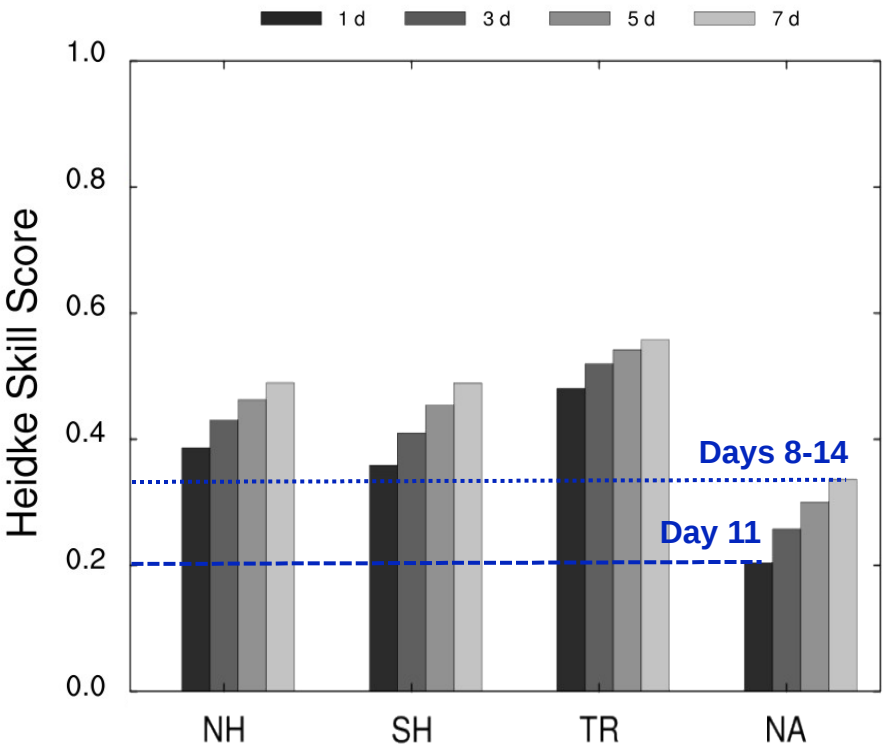
Forecast Skill Score Dependence on Averaging Period

Period: 20130901-20140228 every day

N. America Day-to-Day
2 m Temperature



N. America Averaged
2 m Temperature (CFS_BC)



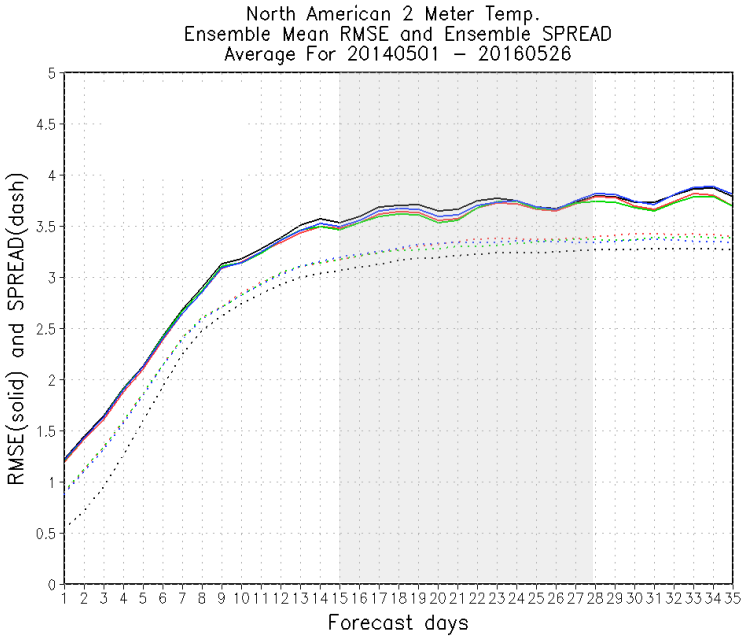
Heidke Skill Score (terciles)

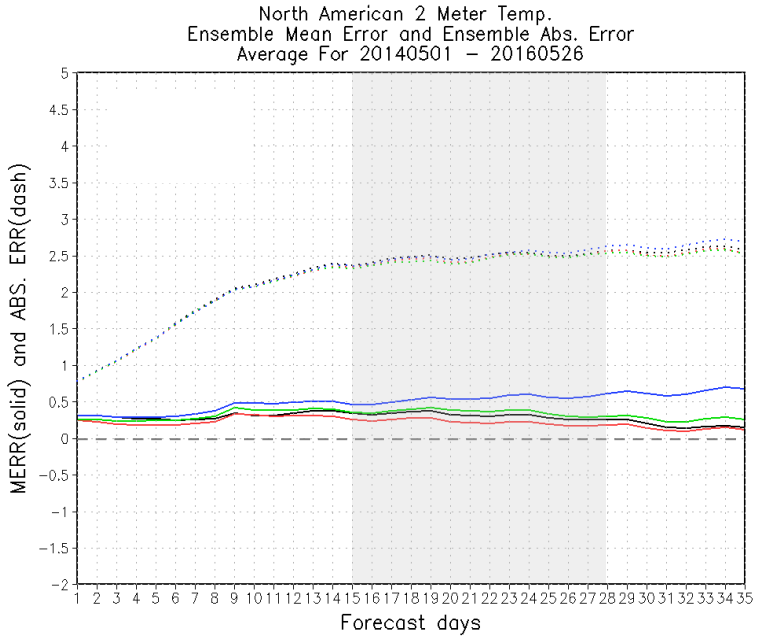
$$\mathrm{HKSS} = \frac{\mathrm{H} - \mathrm{E}}{\mathrm{T} - \mathrm{E}}$$

H = # of correct forecasts (probabilistic)
E = 1/3 expected # of correct forecasts
T = total # of forecast-observation pairs

Weeks 3 & 4 2-m Temperature
NA Ensemble Mean Statistics (Land + Ocean)

Period:
20140501 to 20160526 every 5 days





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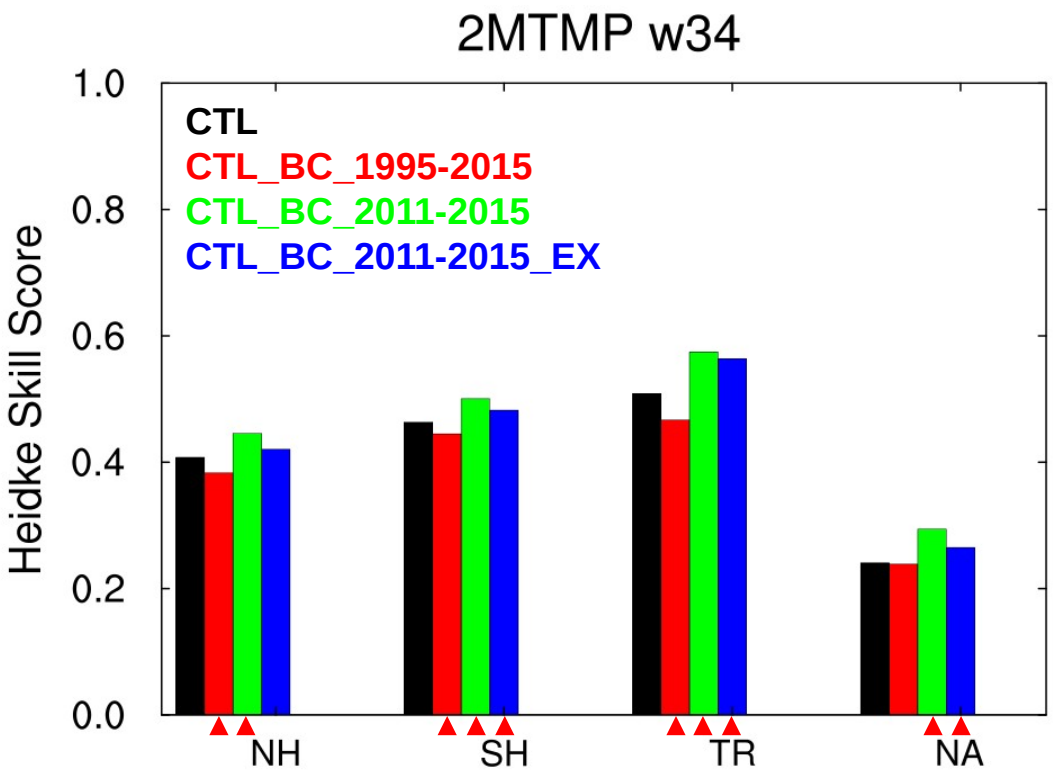
SPs+CFSBC: SPs w/ bias corrected CFSv2 SST
SPs+CFSBC+NSST: SPs+CFSBC w/ NSST
CFSv2: CFSv2 operational forecast

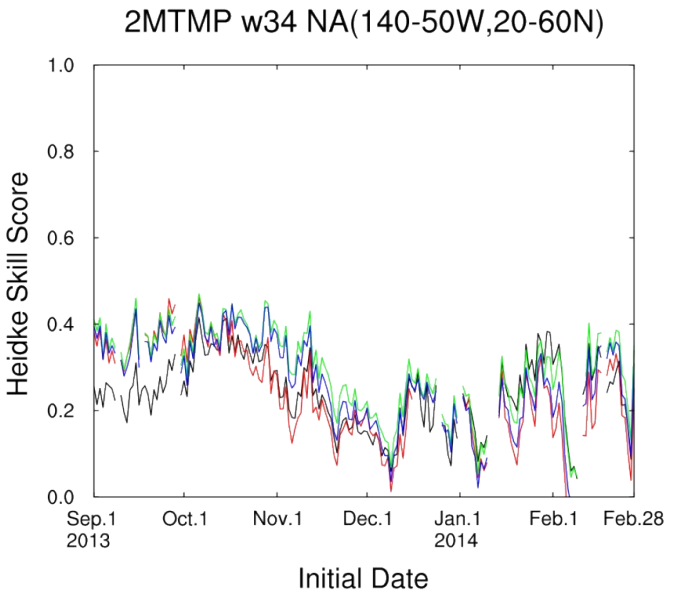
Courtesy: Eric Sinsky

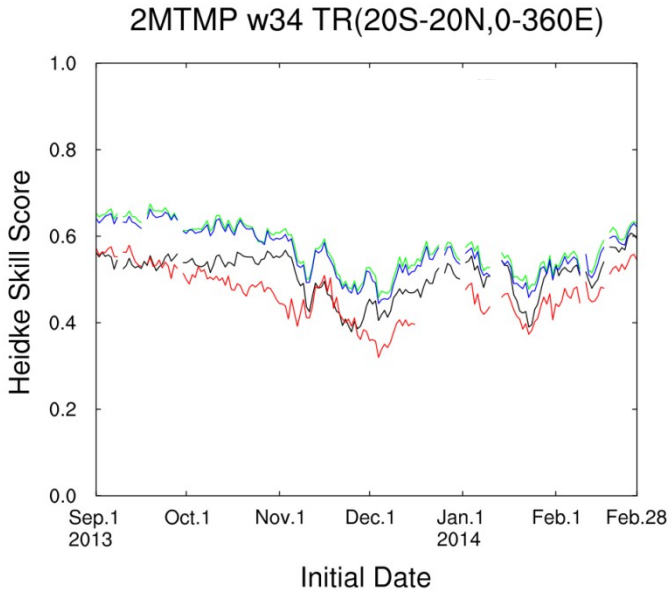
Weeks 3 & 4 2-m Temperature Bias Correction with Week 2 GEFS Reforecast

Period: 20130901-20140228 every day



▲ *Red triangle indicates statistically significant difference at 95% CL from CTL*





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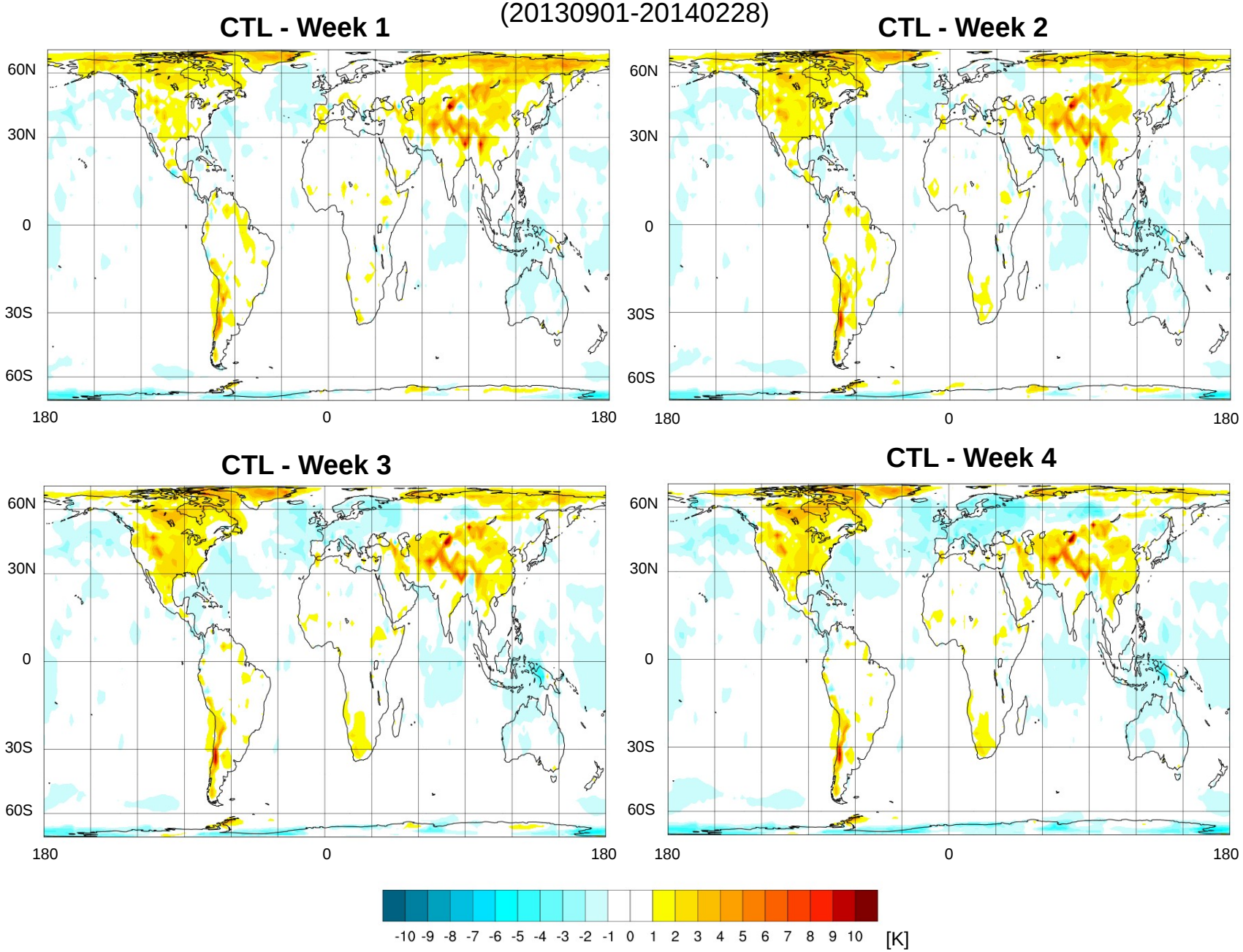
CTL Weekly 2-m Temperature Bias

(20130901-20140228)



Extra Slides !!!

Suggest to follow up

- Evaluation of day-to-day forecast – Wei
  - NH, SH?, Tropical
- Evaluation of tropical – Wei
  - MJO and related variables, decomposition
  - Weak MJO and Strong MJO
- Evaluation of forecast elements - Chris
  - T2m for week 2, week 3&4
  - Precipitation for week 2, week 3&4
  - Separation for weak/strong MJO
- Connection of tropical to extra-tropical – discussion – Wei and Chris
  - Capability of GEFS modeling for MJO?
  - Predictability for weather?
  - West CONUS is impacted by MJO?
- Configuration of SubX project - Wei
  - Our proposal –
  - CPC's comment -

GEFS 35-day forecast experiments
- Support SubX project

Presenters
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Eric Sinsky, Walter Kolczynski, Malaquias Peña
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