Evaluating the MJO forecast skill in the NCEP GEFS 35-day Experiments

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NOAA/NCEP/EMC and IMSG

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Outline

- **Background**
- **Experiments and Data**
- **MJO forecast skill**
- **Forecast skill of the key components of MJO**
- **Dependence of MJO skill on ensemble size**
- **Summary**

Background

Description of the ensemble forecast system

Each ensemble member evolution is given by integrating the following equation

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

Initial uncertainty

Model uncertainty

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

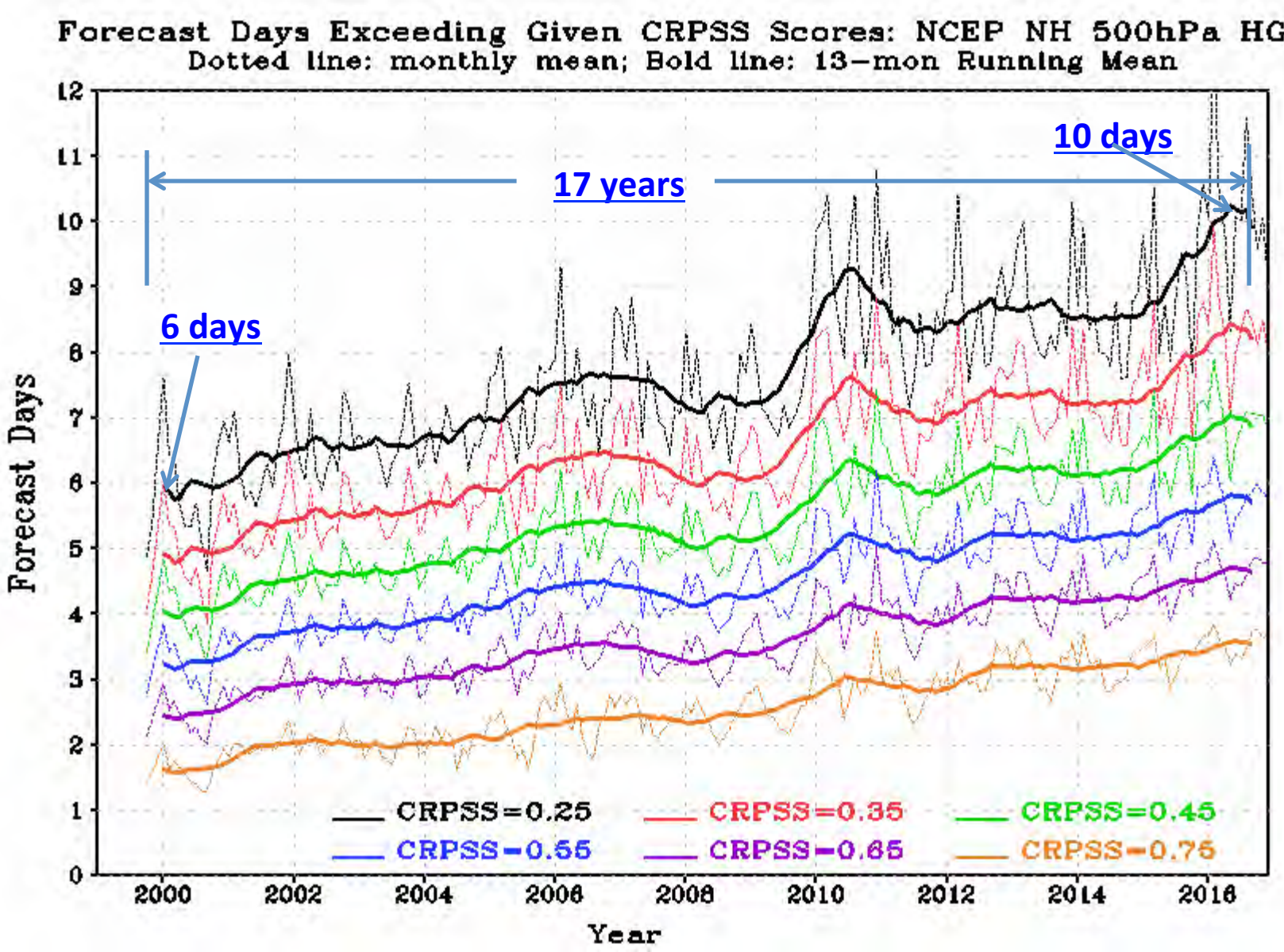
Operation: ECMWF-1992; NCEP-1992; MSC-1998

Reference: - first global ensemble review paper

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

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

CRPSS for NH 500hPa geopotential height



Experiments and Data

- Operational Version:
  - GEFSv11 extended to 35 day forecast (**STTP**);
  - T574 (33 km) for 0-8 days, T382 (55km) after 8days.

- Experiments:
  - 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**) ;

  All experiment cover the period of 20140501-20160526, 5-day interval.

- Analysis data:
  - GDAS during 20140101-20161031; NCEP reanalysis for U and NOAA OLR.

- Both forecast and analysis data using daily mean

1) Stochastic Schemes for Atmosphere

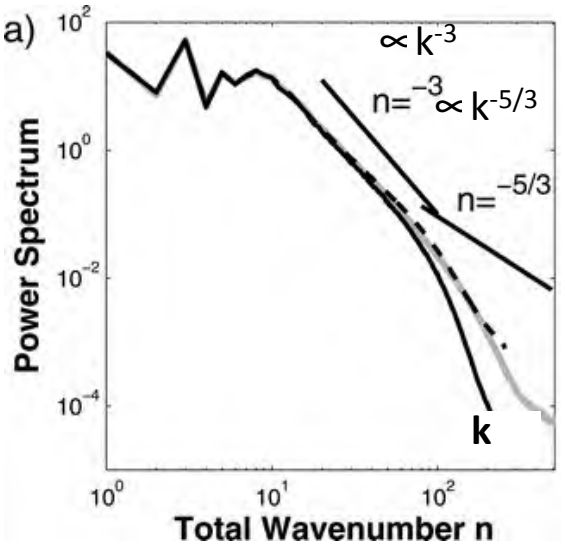
- Applied to GEFS experiments

- **Dynamics**: Due to the model's finite resolution, energy at non-resolved scales cannot cascade to larger scales.
  - Approach: Estimate energy lost each time step, and inject this energy in the resolved scales. a.k.a stochastic energy backscatter (SKEB; Berner et al. 2009)

- **Physics**: Subgrid variability in physical processes, along with errors in the parameterizations result in an under spread and biased model.
  - Approach: perturb the results from the physical parameterizations, and boundary layer humidity (Palmer et al. 2009), and inspired by Tompkins and Berner 2008, we call it SPPT and SHUM

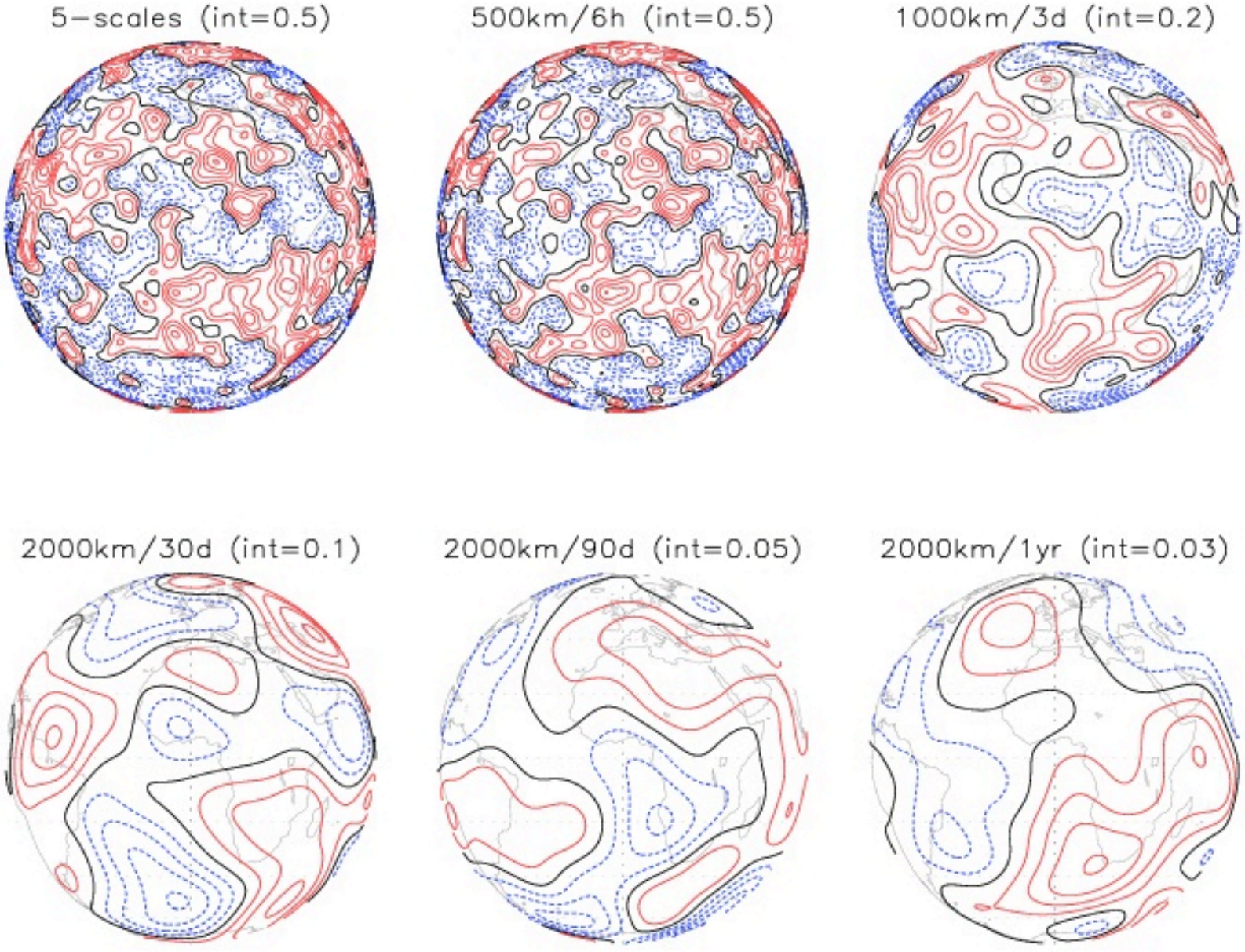
- *Above schemes has been tested for current operational GEFS (spectrum model) with positive response – plan to replace STTP for next implementation (FV3GEFS)*

Kinetic Energy Spectrum



Berner et al. (2009)

Examples of stochastic patterns for SPPT



Courtesy of Dr. Bing Fu

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

- **Operational**

$$SST_f^t = \left[SST_a^{t0} - SST_c^{t0}\right] e^{-(t-t_0)/90} + SST_c^t$$

- **CFSBC**

$$SST_f^t = (1-w) * \left[SST_a^{t0} - SST_{cfsrc}^{t0} + SST_{cfsrc}^t\right] + w * \left[SST_{cfs}^t - (SST_{cfs\_c}^t - SST_{cfsrc}^t)\right]$$

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

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

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

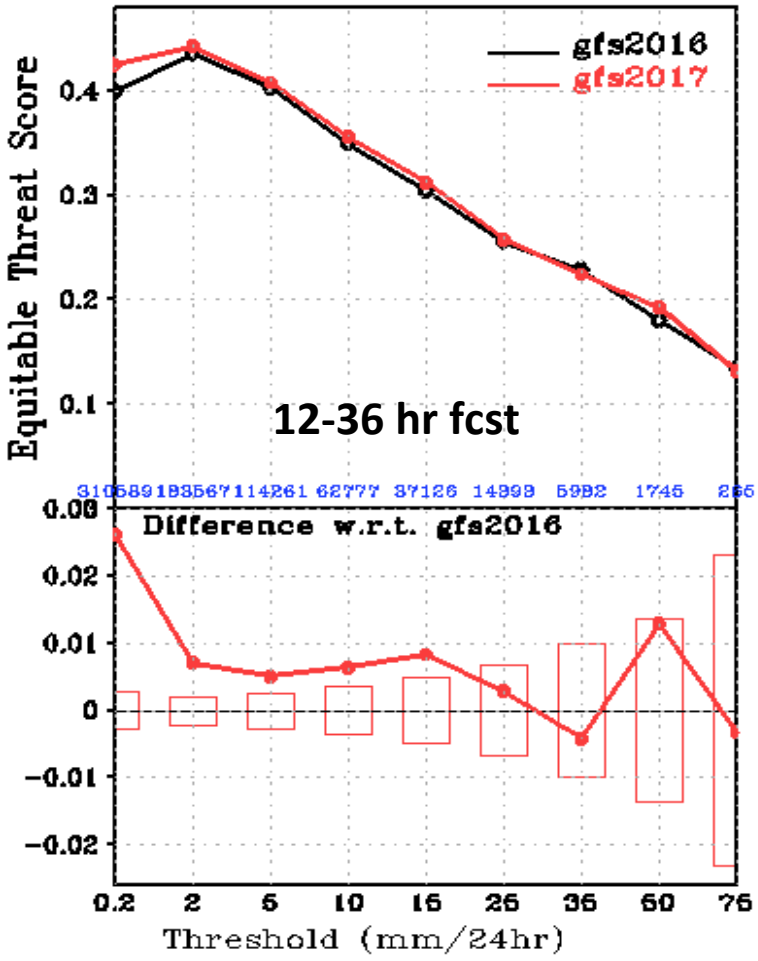
SST_{cfs}^t -- CFS predictive SST (24hr mean) for forecast lead-time t

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

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

3). Update GFS convection scheme

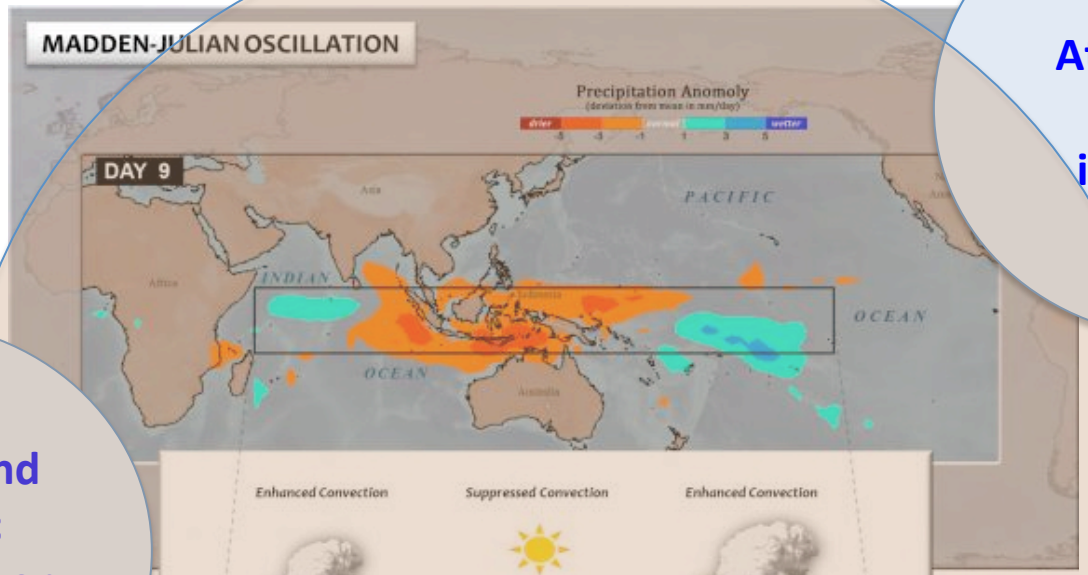
- Scale-aware, aerosol-aware parameterization
- Rain conversion rate decreases with decreasing air temperature above freezing level.
- Convective adjustment time in deep convection proportional to convective turn-over time with CAPE approaching zero after adjustment time.
- Cloud base mass flux in shallow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



Courtesy of Dr. Vijay Tallapragada

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

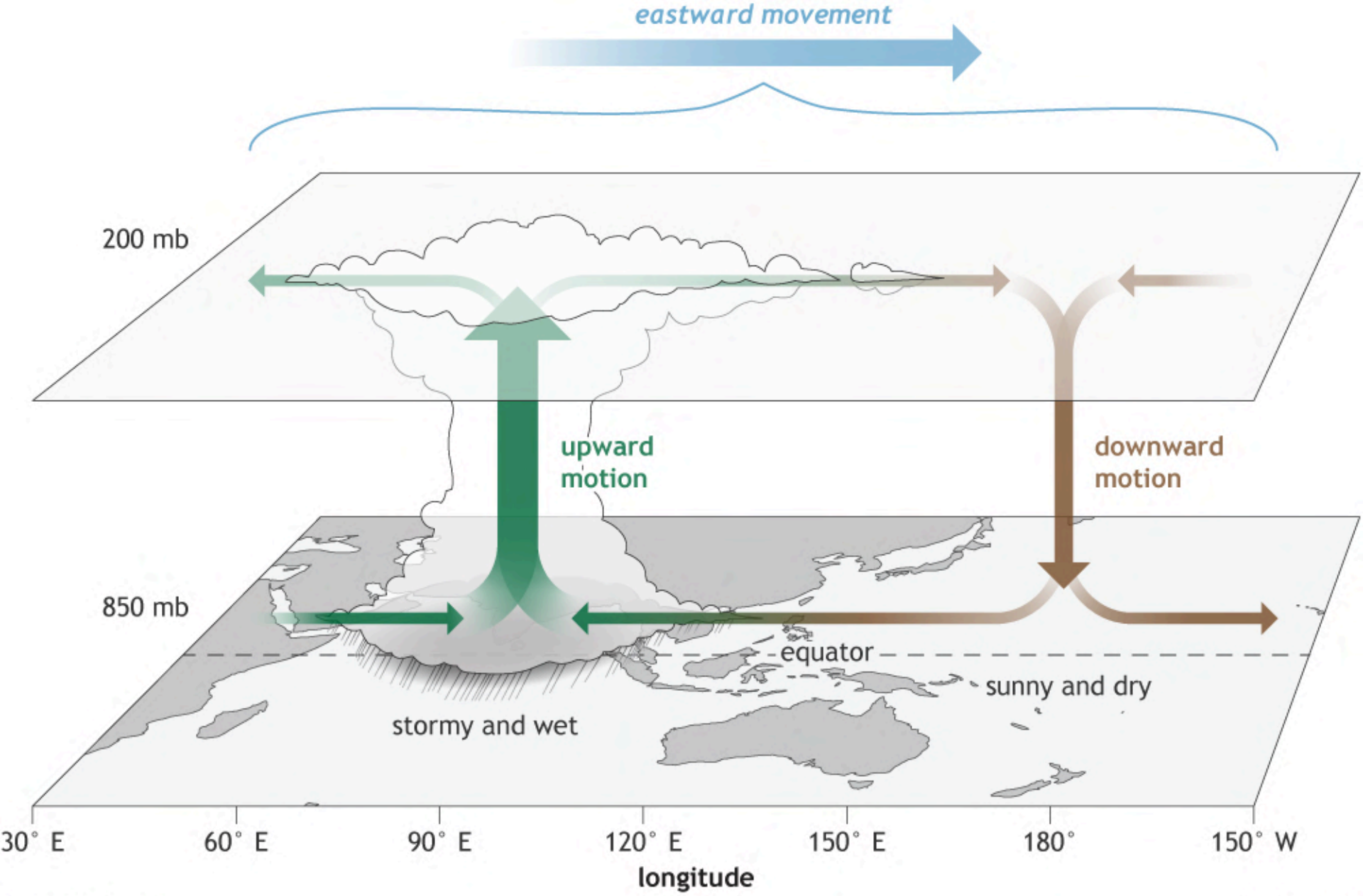
A key area (time scale) to focus on …



Atmosphere-ocean interaction

Ensemble and Stochastic perturbation on tropical area

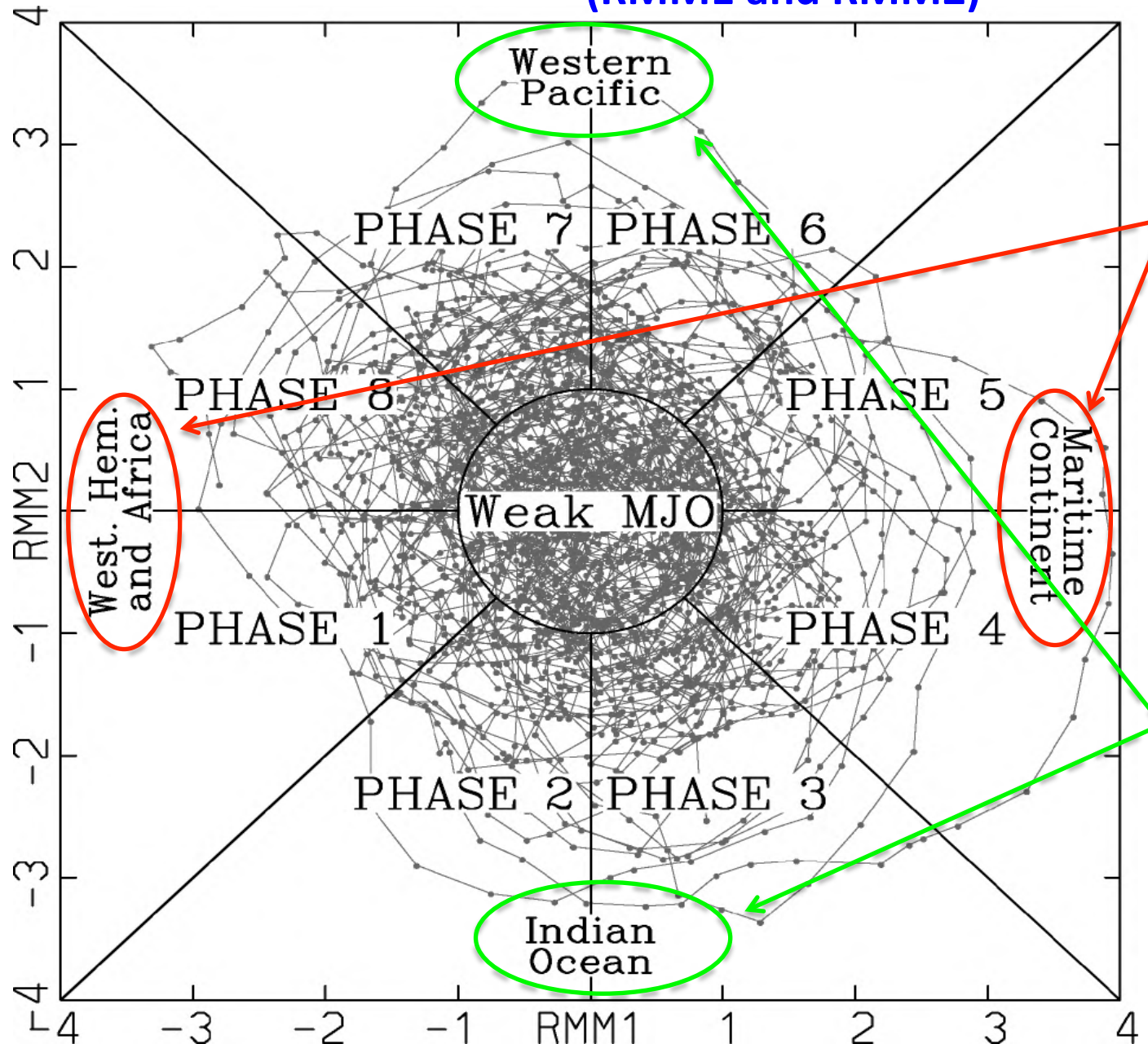
Tropical convections include cloud, radiation, precipitation and et al.



Madden-Julian Oscillation

NOAA Climate.gov

Example of 8 MJO phases with composite of two modes (RMM1 and RMM2)



RMM1 – Enhanced convection over maritime continent

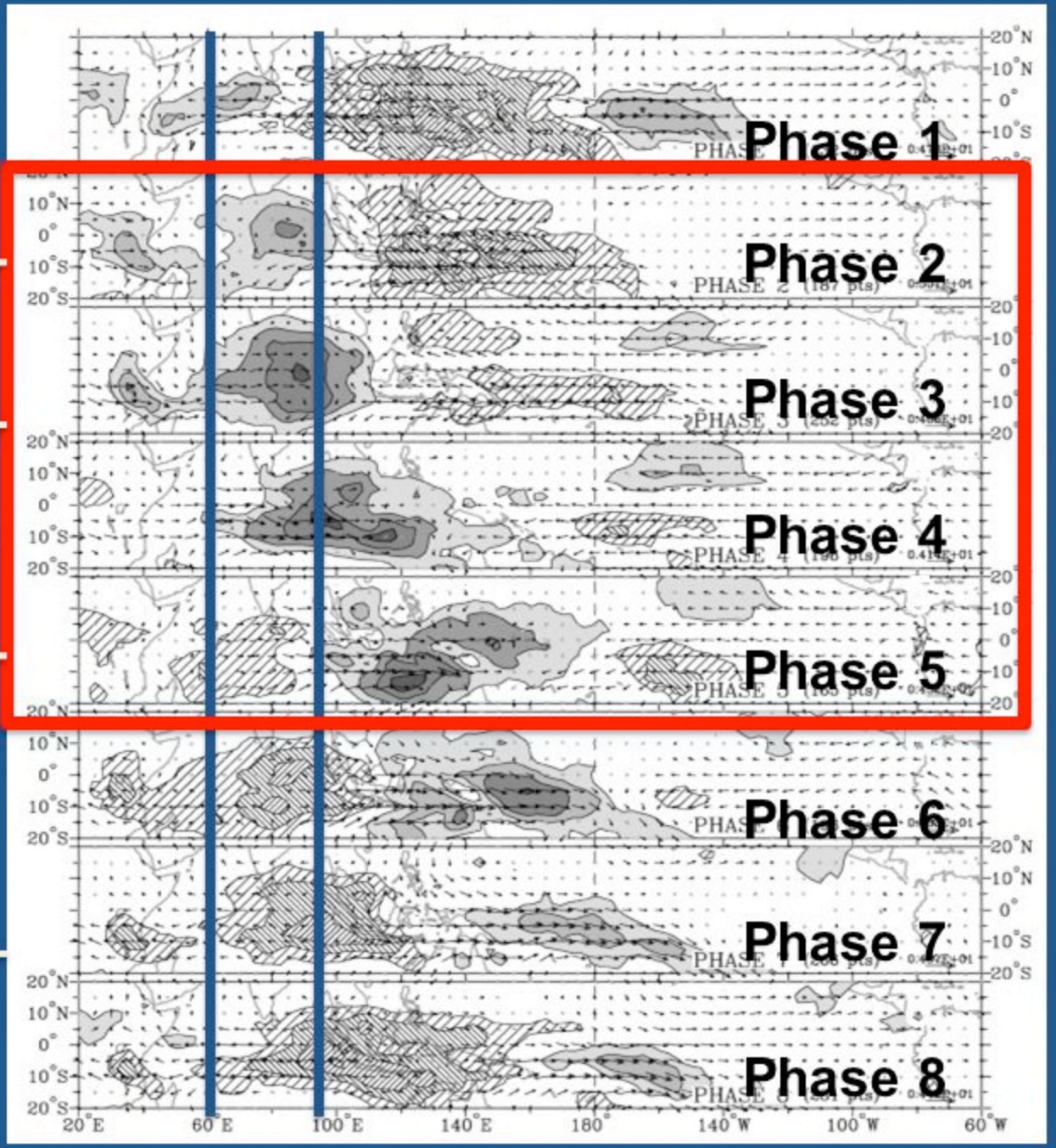
RMM2 – Enhanced convection over Pacific ocean

Phases of the MJO

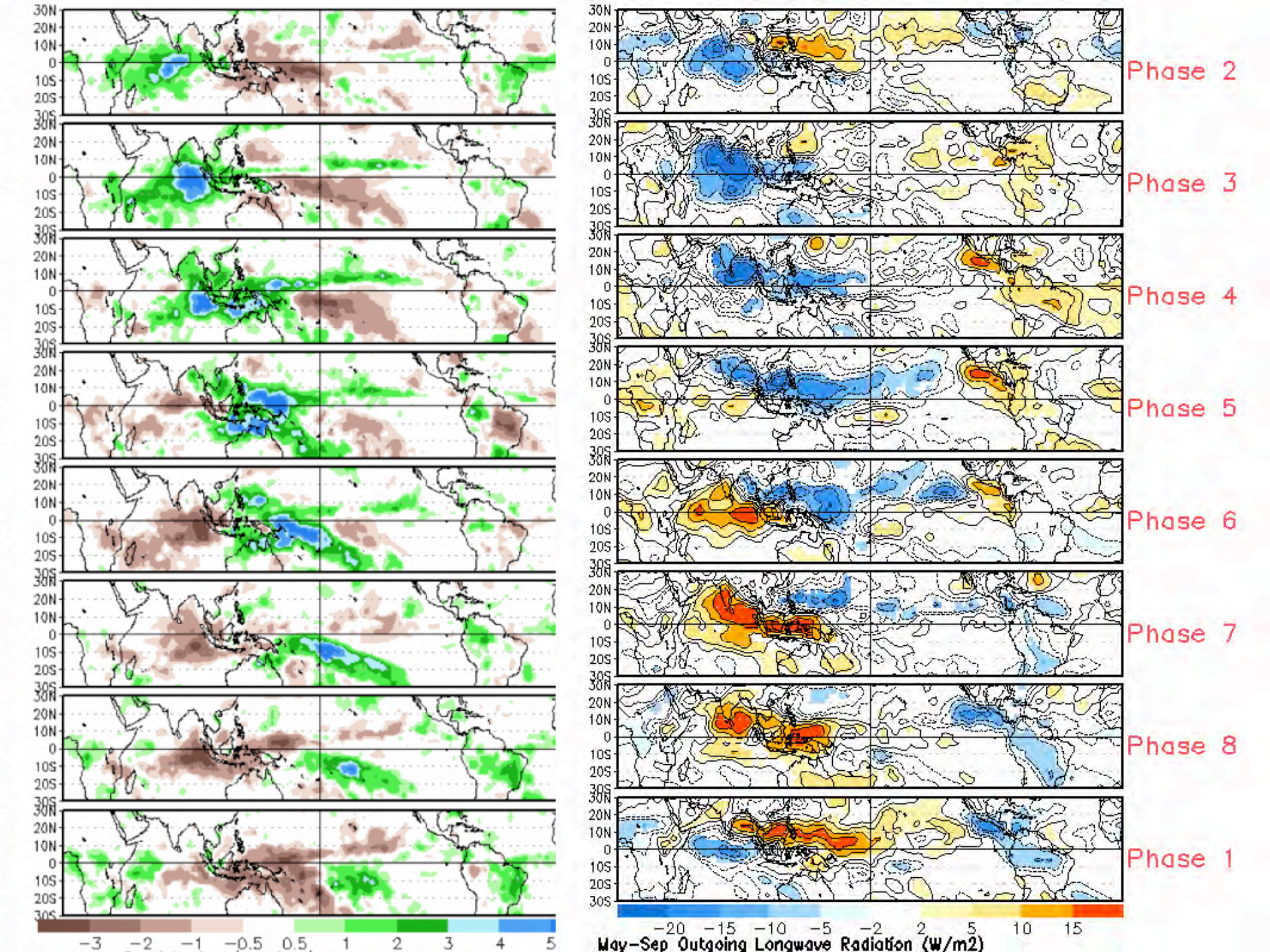
ACTIVE STAGE

END OF ACTIVE STAGE

SUPPRESSED STAGE



Wheeler and Hendon 2004

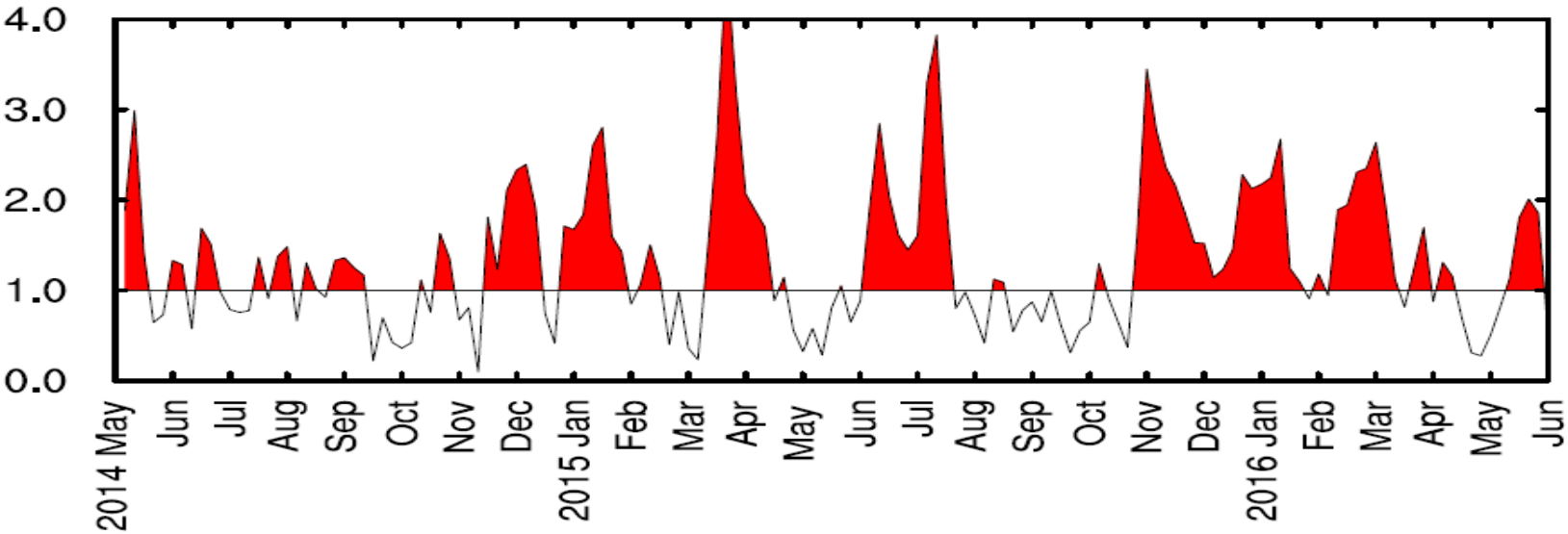

Phase 2
Phase 3
Phase 4
Phase 5
Phase 6
Phase 7
Phase 8
Phase 1
−3 −2 −1 −0.5 0.5 1 2 3 4 5
−20 −15 −10 −5 −2 2 5 10 15
May-Sep Outgoing Longwave Radiation (W/m2)

Evaluation of MJO skills

Based on Wheeler-Hendon Index

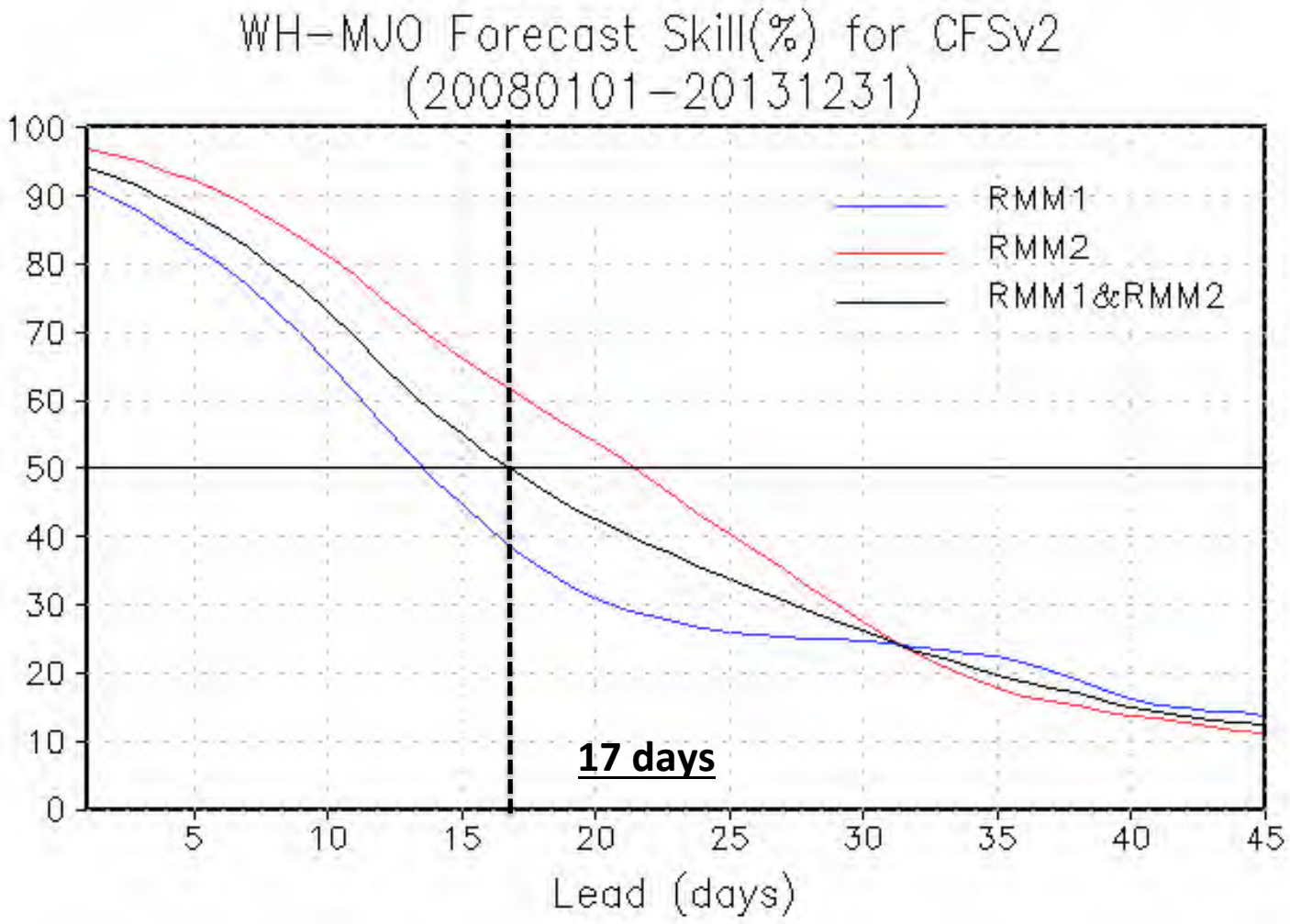
An improvement comes from three areas:

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



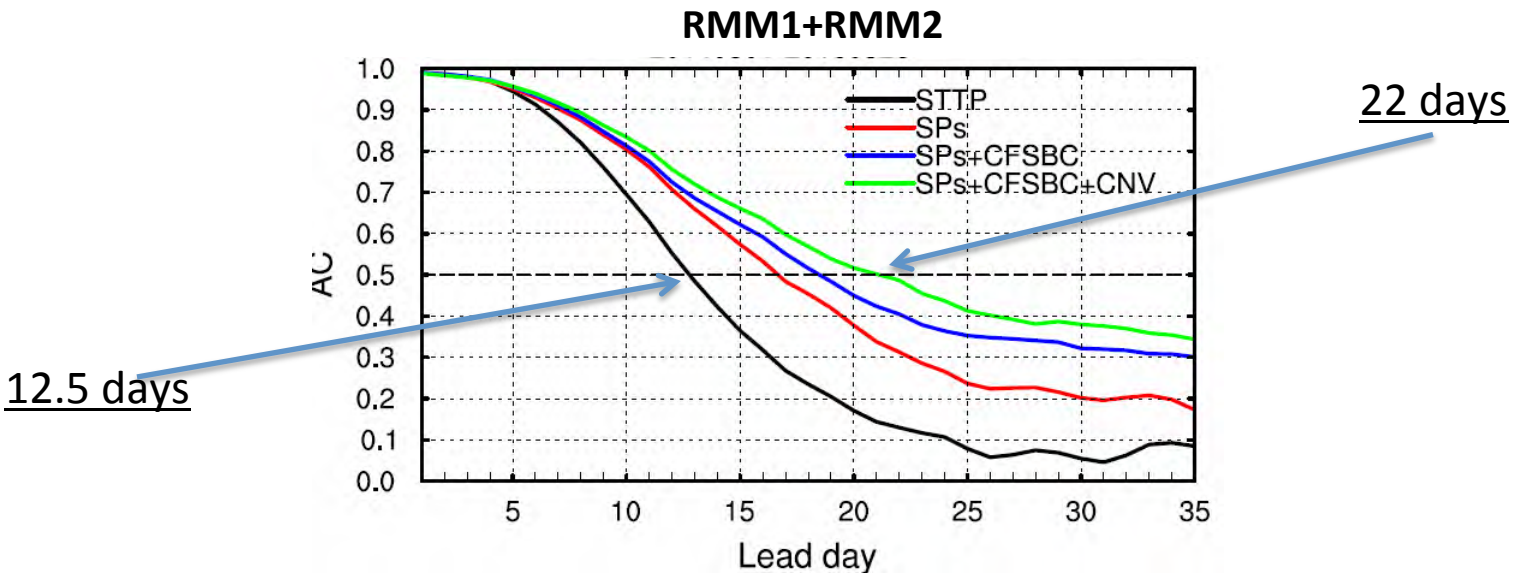
Amplitude of MJO during May 2014- May 2016 from GDAS analysis data. The resolution of the time-series is 5 days

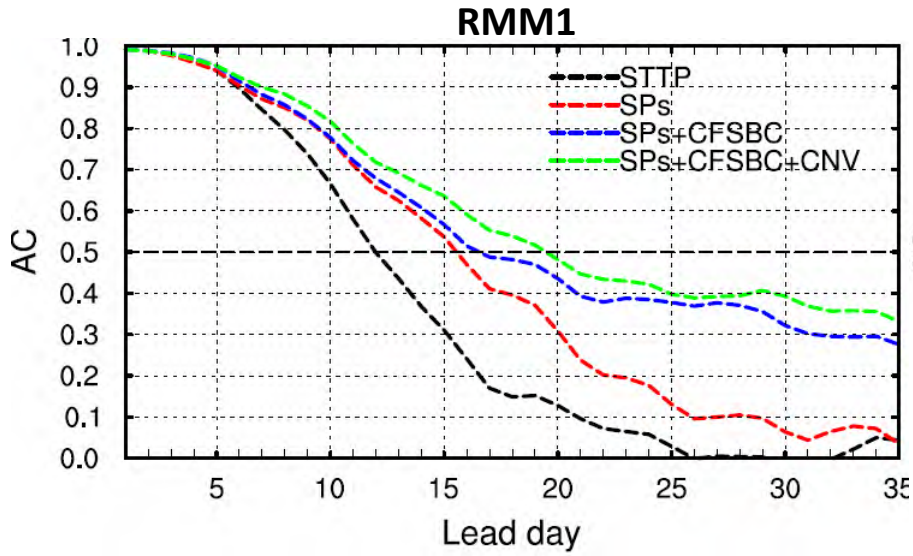
6-year average WH-MJO forecast skills for CFSv2

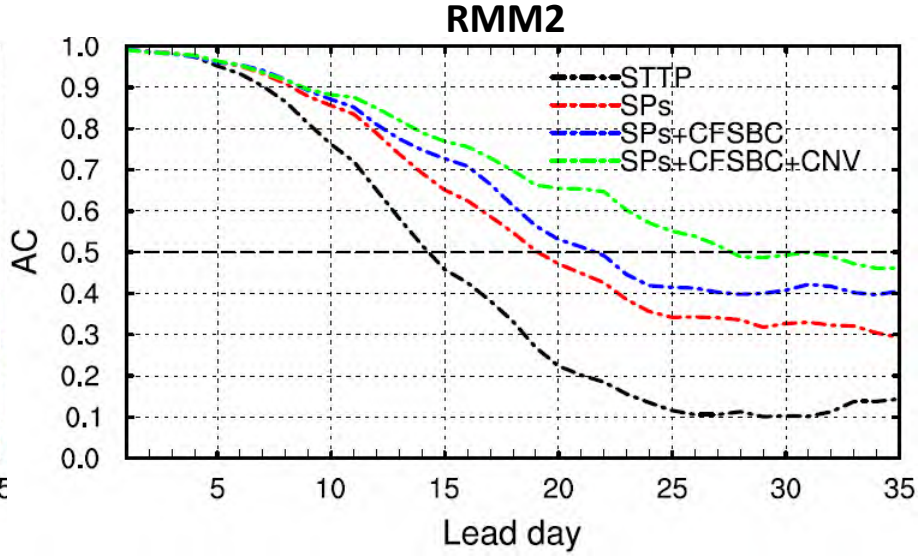


Courtesy of Dr. Qin Zhang

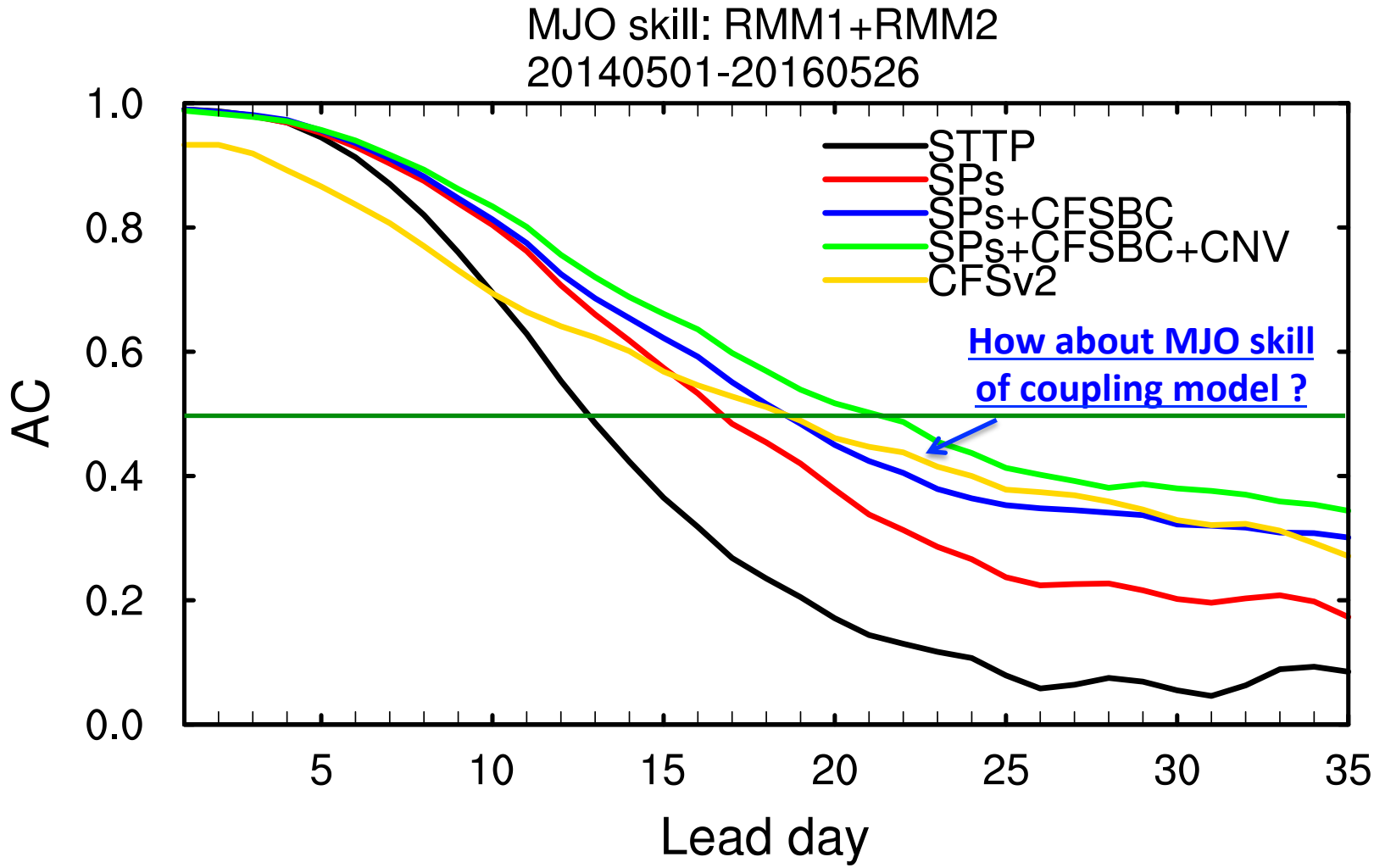
WH-MJO Forecast Skills for 2-yr Experiments





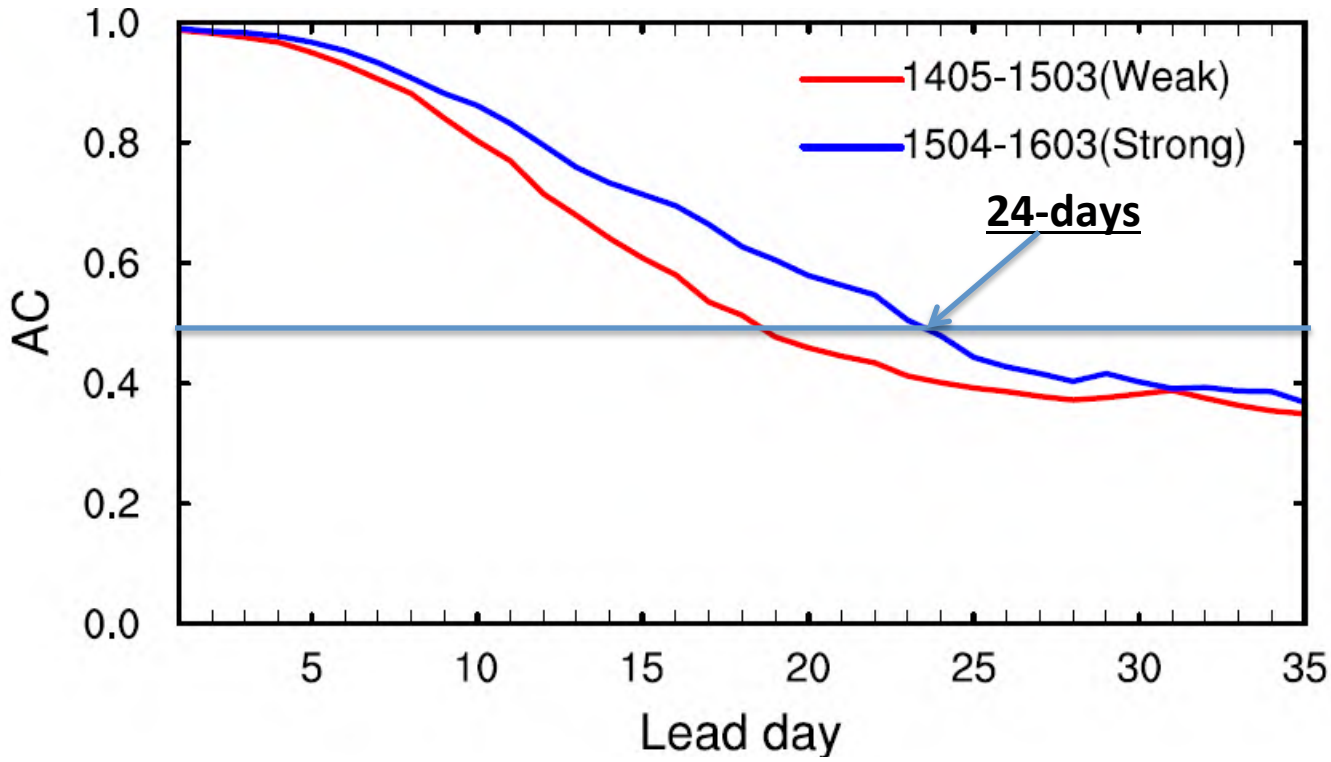


GEFS week 3&4 forecasts (May 2014-May 2016)



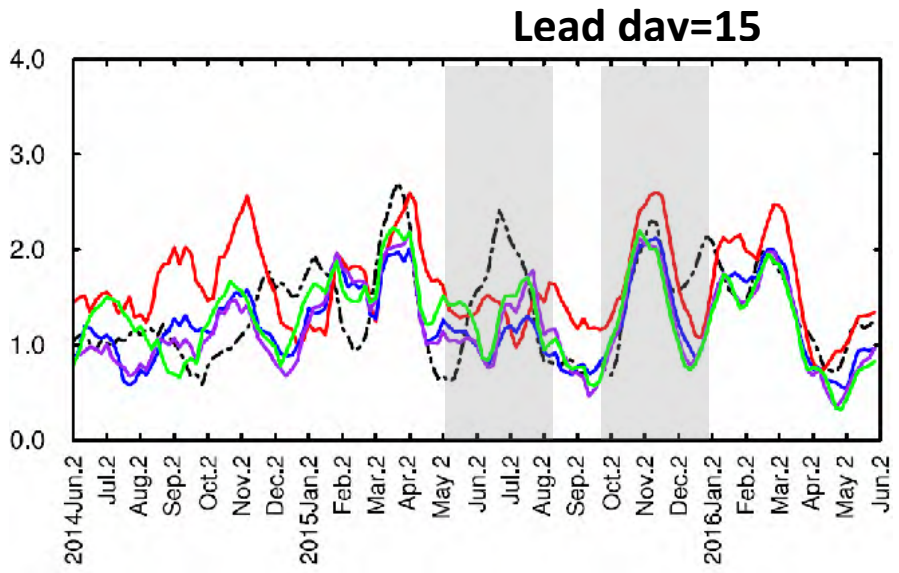
CFSv2 is NCEP operational climate forecast system (coupling) implemented on 2011 – 16 members leg (24 hours) ensemble

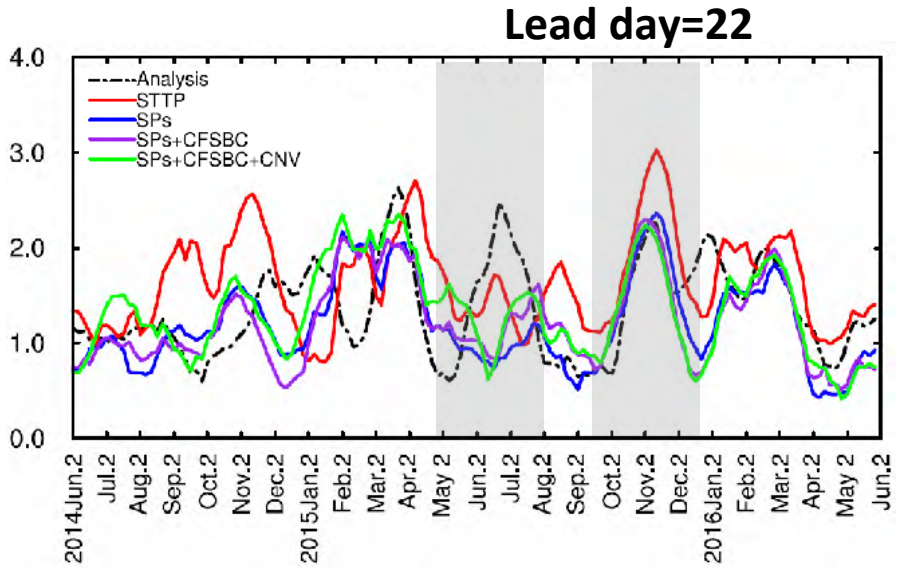
Strong vs Weak Period



For “strong” and “weak” periods (relatively), our best configuration (SPs+CFSBC+CNV)

Variability of the MJO index

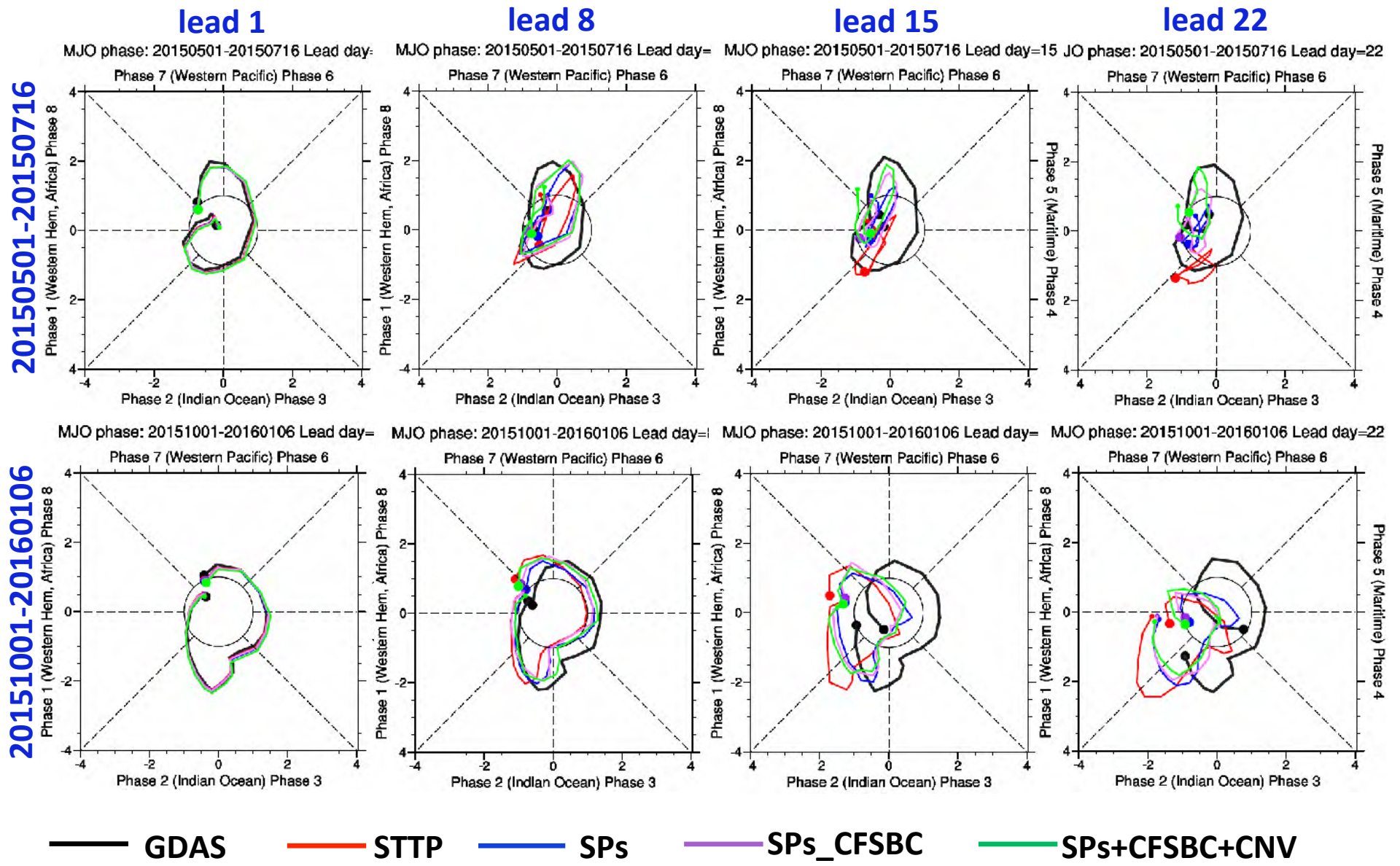




----- Analysis
----- STTP (CTL)
----- SPs
----- SPs+CFSBC
----- SPs+CFSBC+CNC

1. CTL forecasts are much stronger
2. Biases are similar from different leads
3. Biases are varied for different experiments

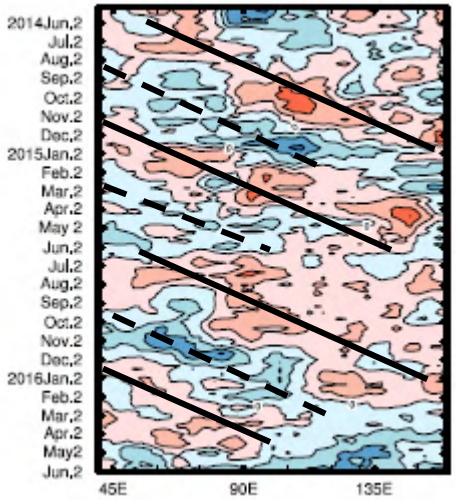
MJO evolution



MJO propagation : lead day=1

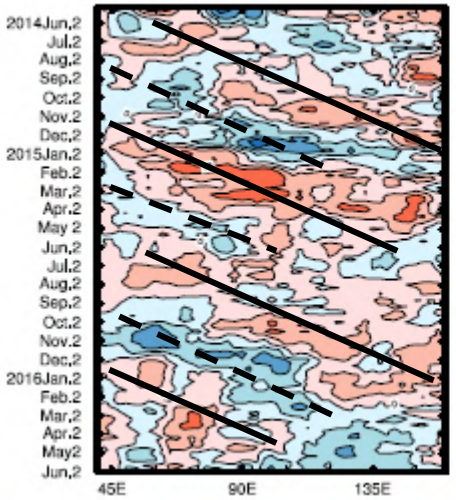
NOAA

olr_anal Lead day=1 rave=9



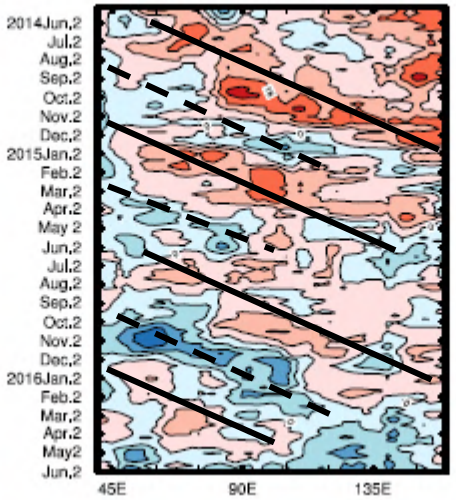
GDAS

olr_anal Lead day=1 rave=9



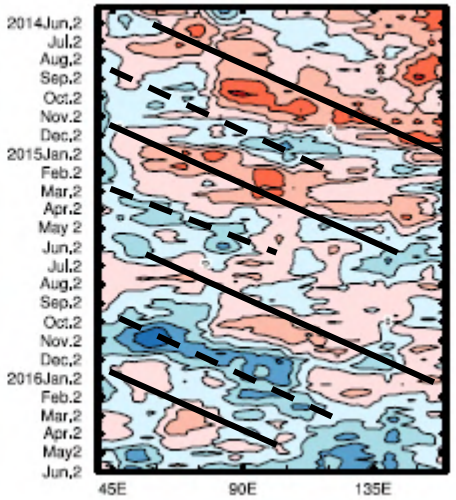
STTP

olr_sttp Lead day=1 rave=9



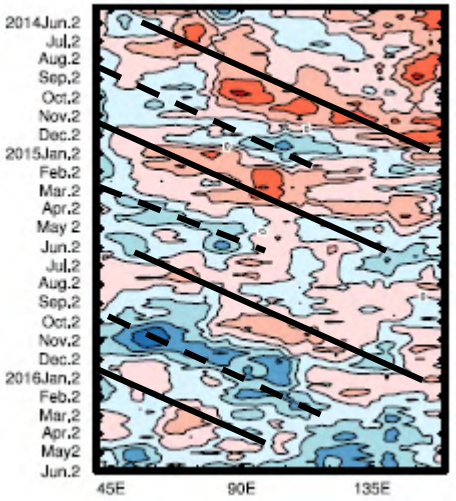
SPs

olr_sps Lead day=1 rave=9



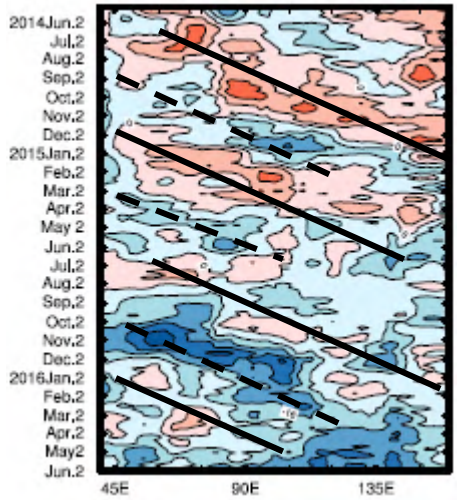
SPs+CFSBC

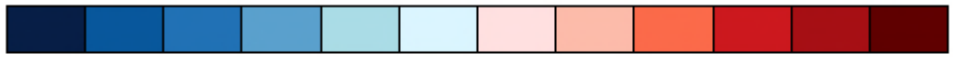
olr_sps_cfsbc Lead day=1 rave=9



SPs+CFSBC+CNV

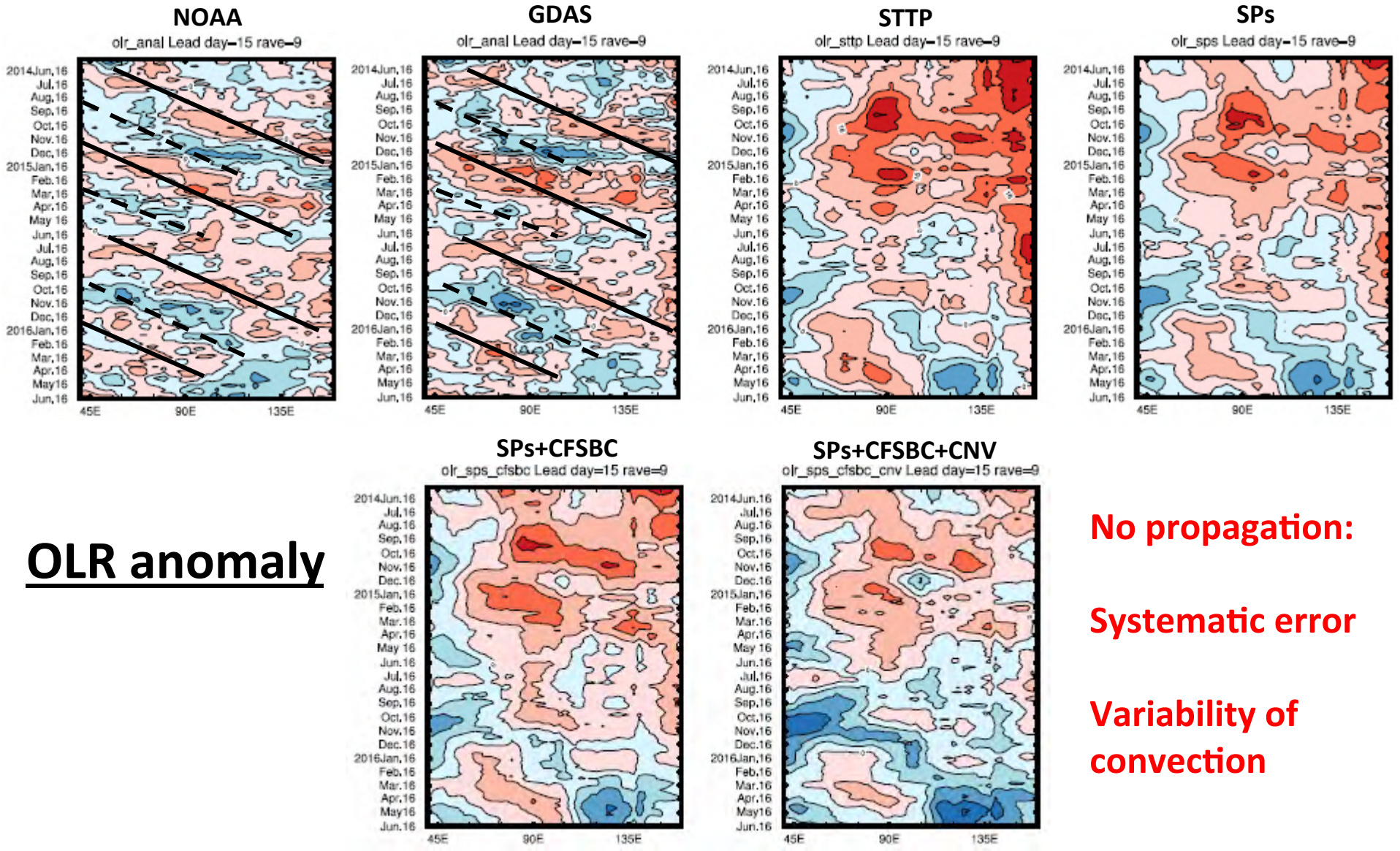
olr_sps_cfsbc_cnv Lead day=1 rave=9





W m^2

MJO propagation : lead day=15



OLR anomaly

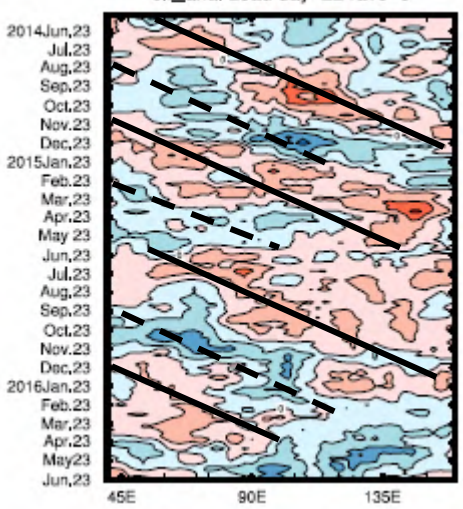
No propagation:

Systematic error

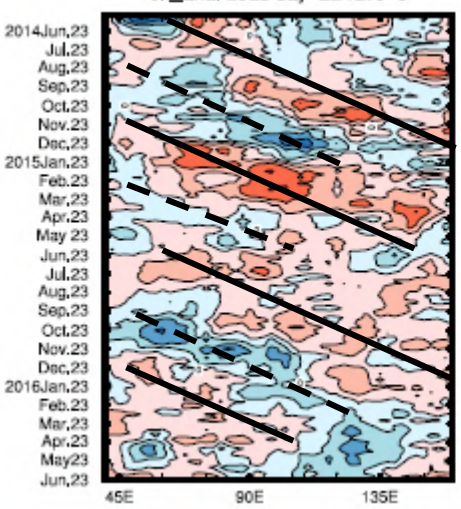
Variability of convection

MJO propagation : lead day=22

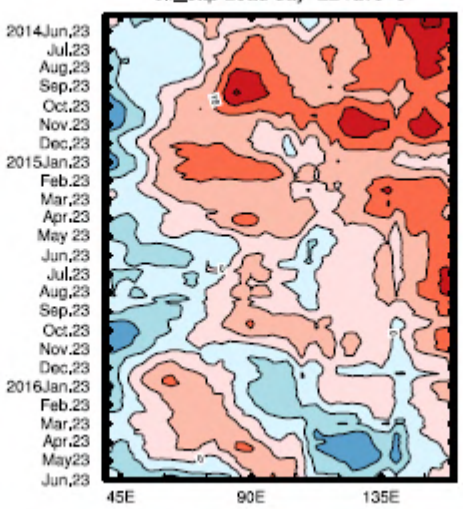
NOAA



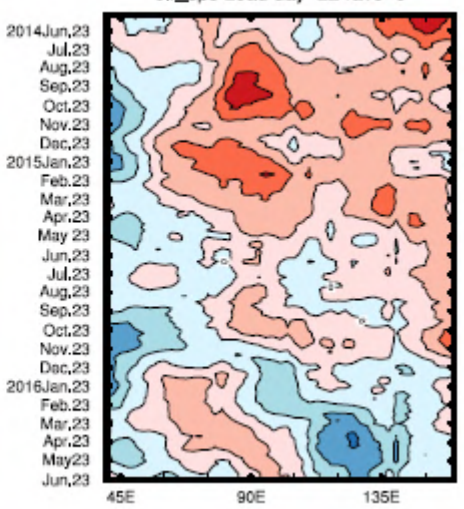
GDAS



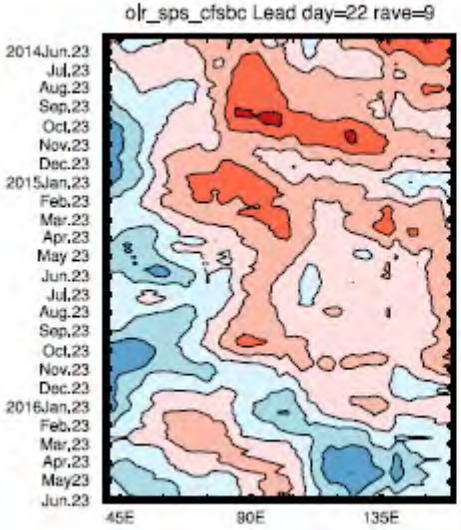
STTP



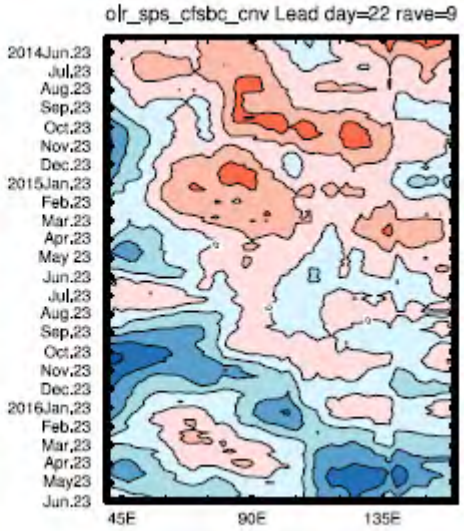
SPs



SPs+CFSBC



SPs+CFSBC+CNV



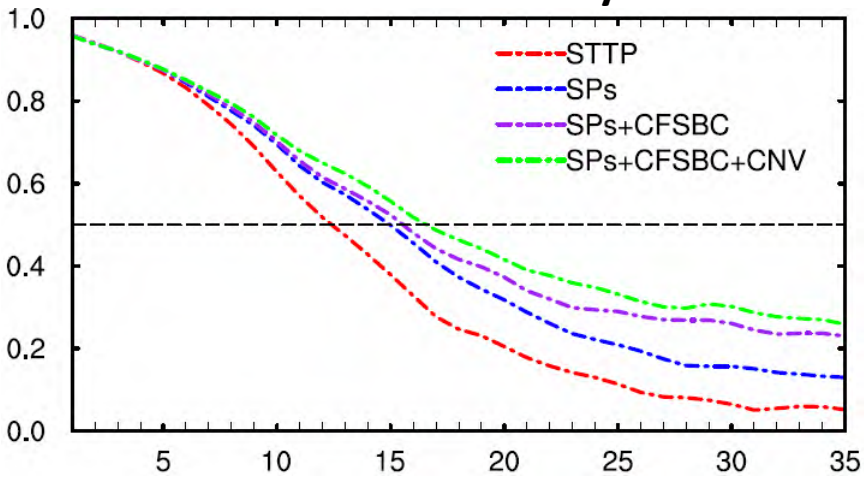
No propagation:

Systematic error

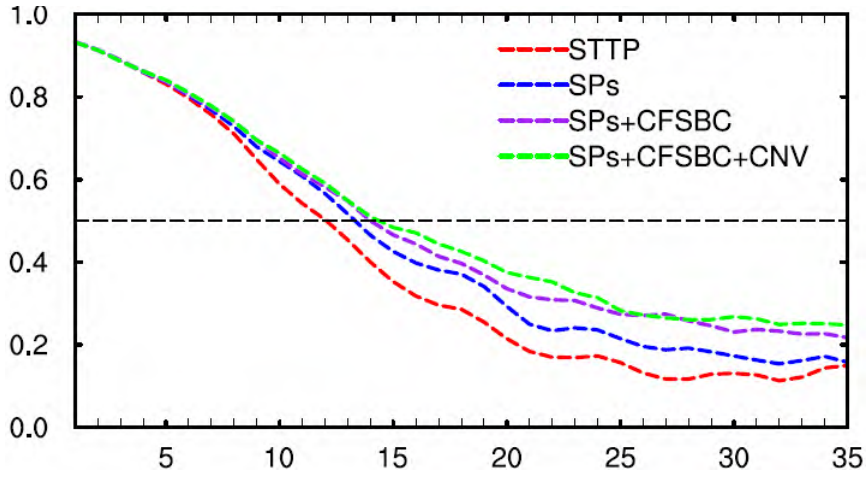
Variability of convection

Forecast skill of the key Variables

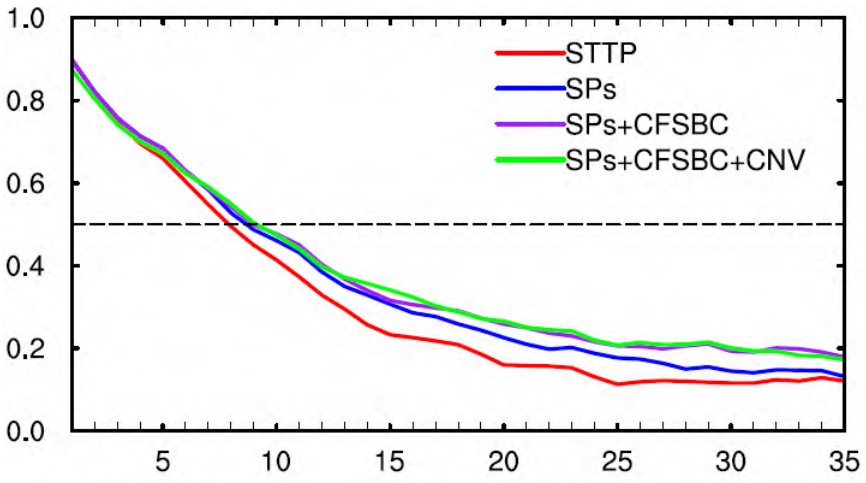
U200 anomaly



U850 anomaly

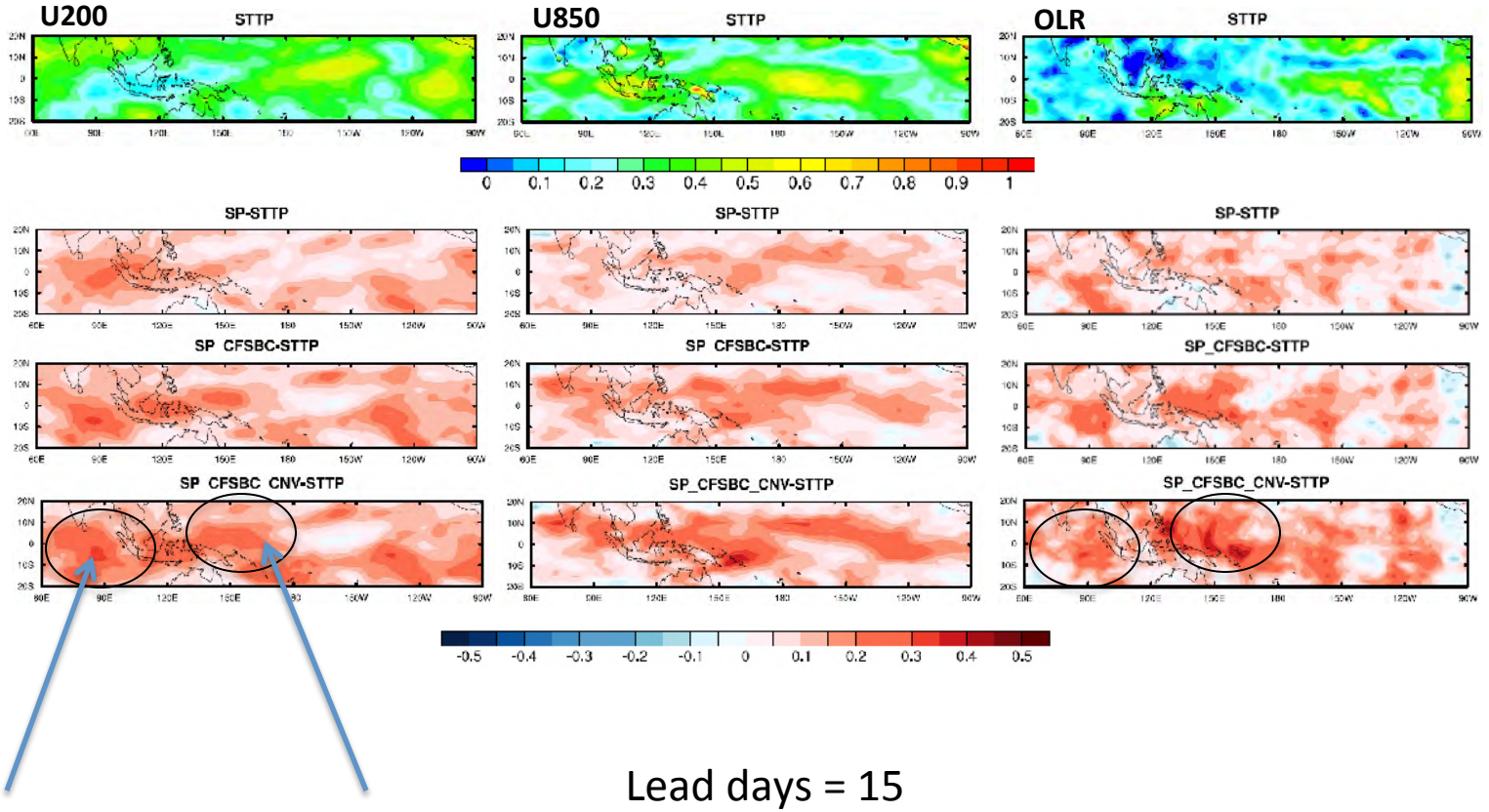


OLR anomaly



Much improvement for zonal winds – circulation; but not much for OLR

Correlation map of the key Variables

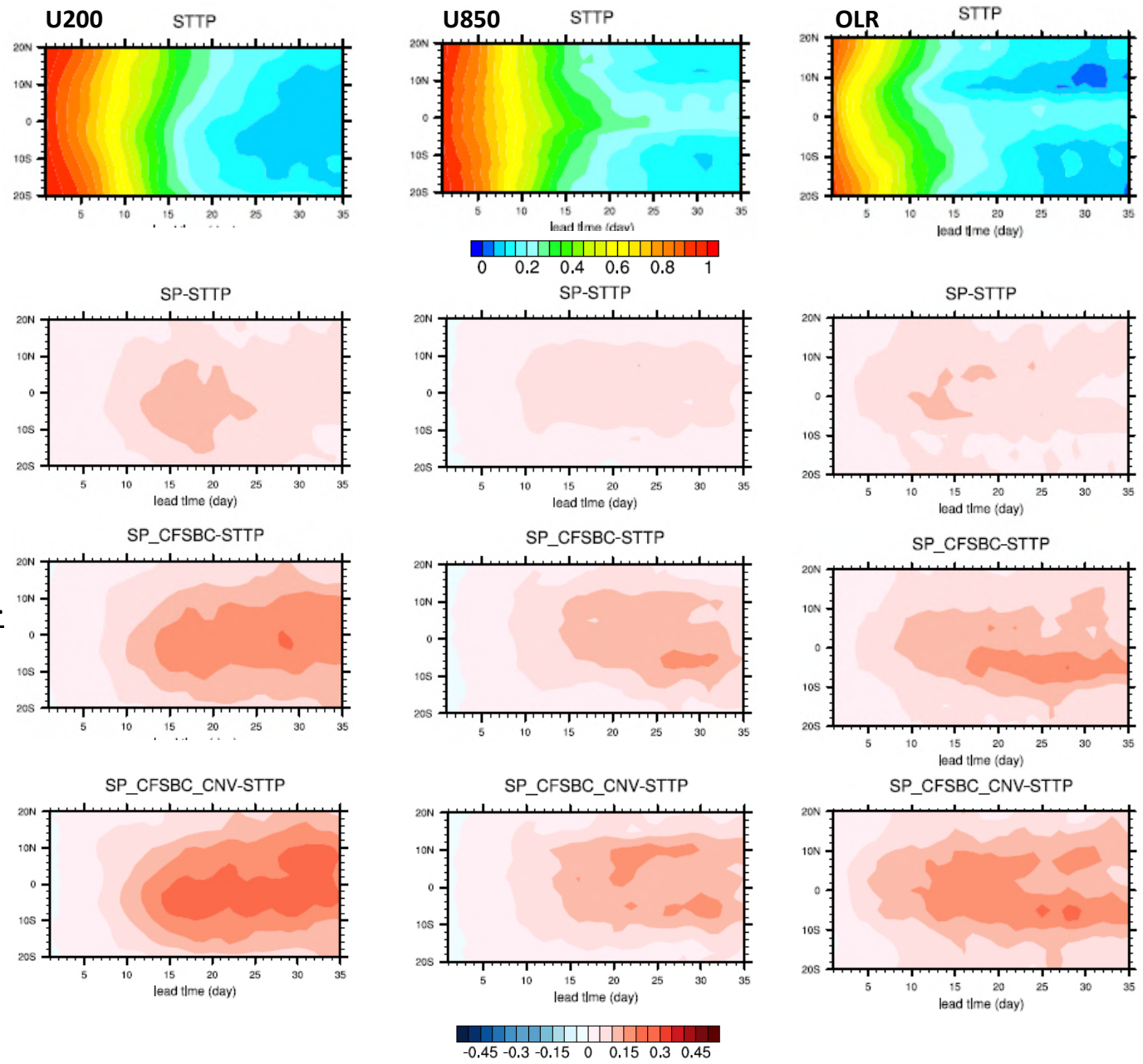


Lead days = 15

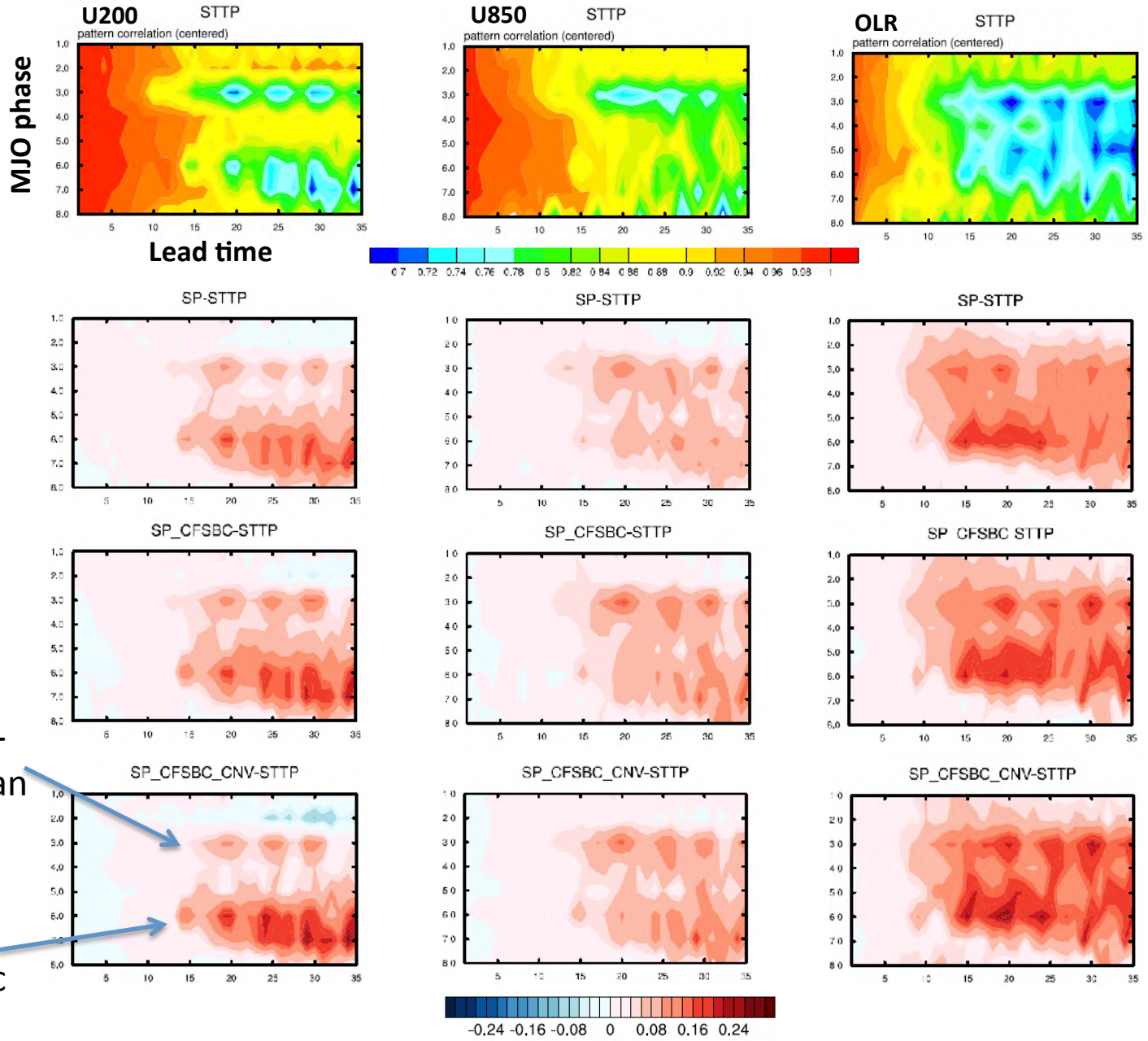
India ocean

W. Pacific

Correlation as a function of lead time



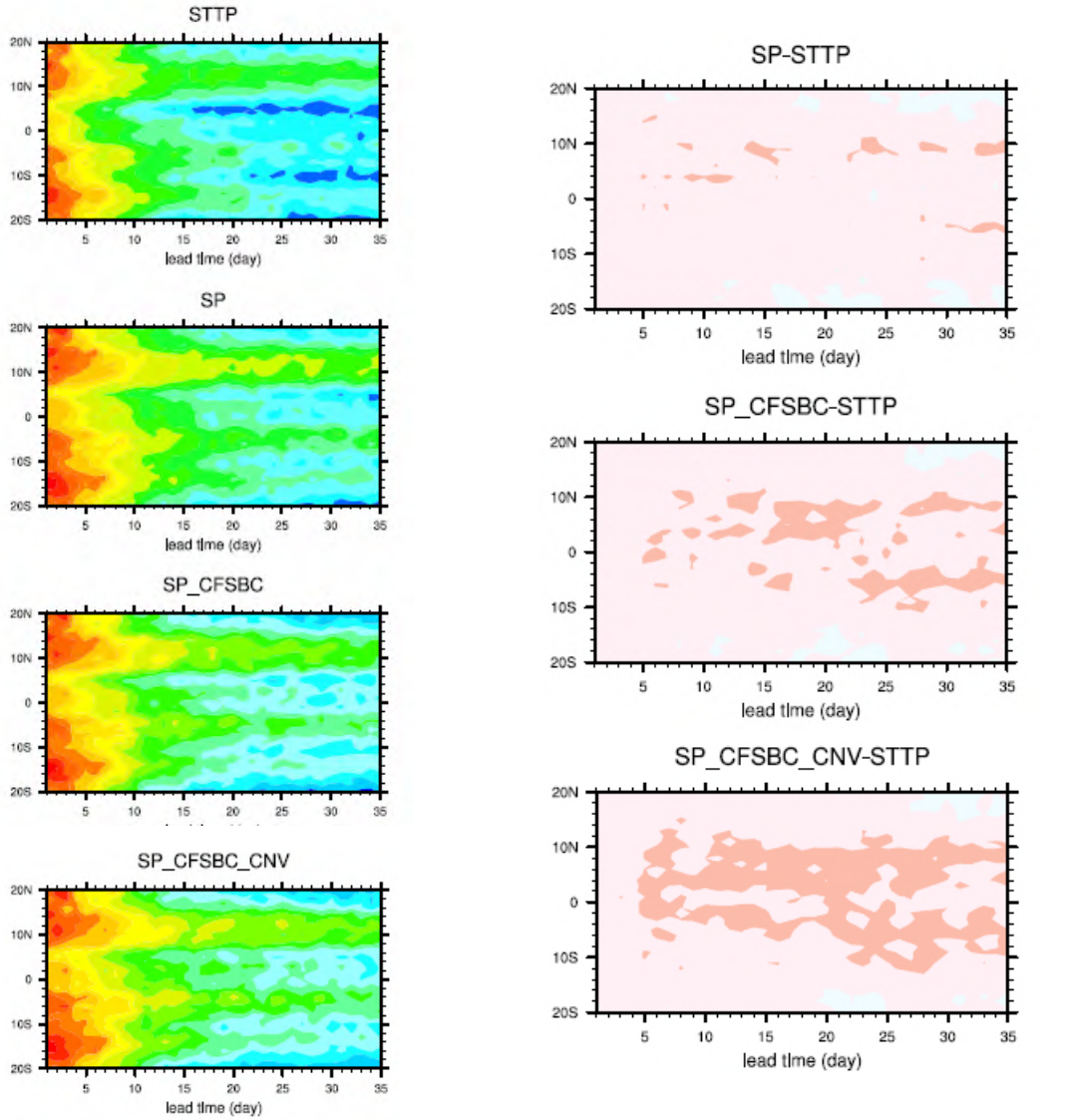
Pattern correlation of the composite variables in MJO phases



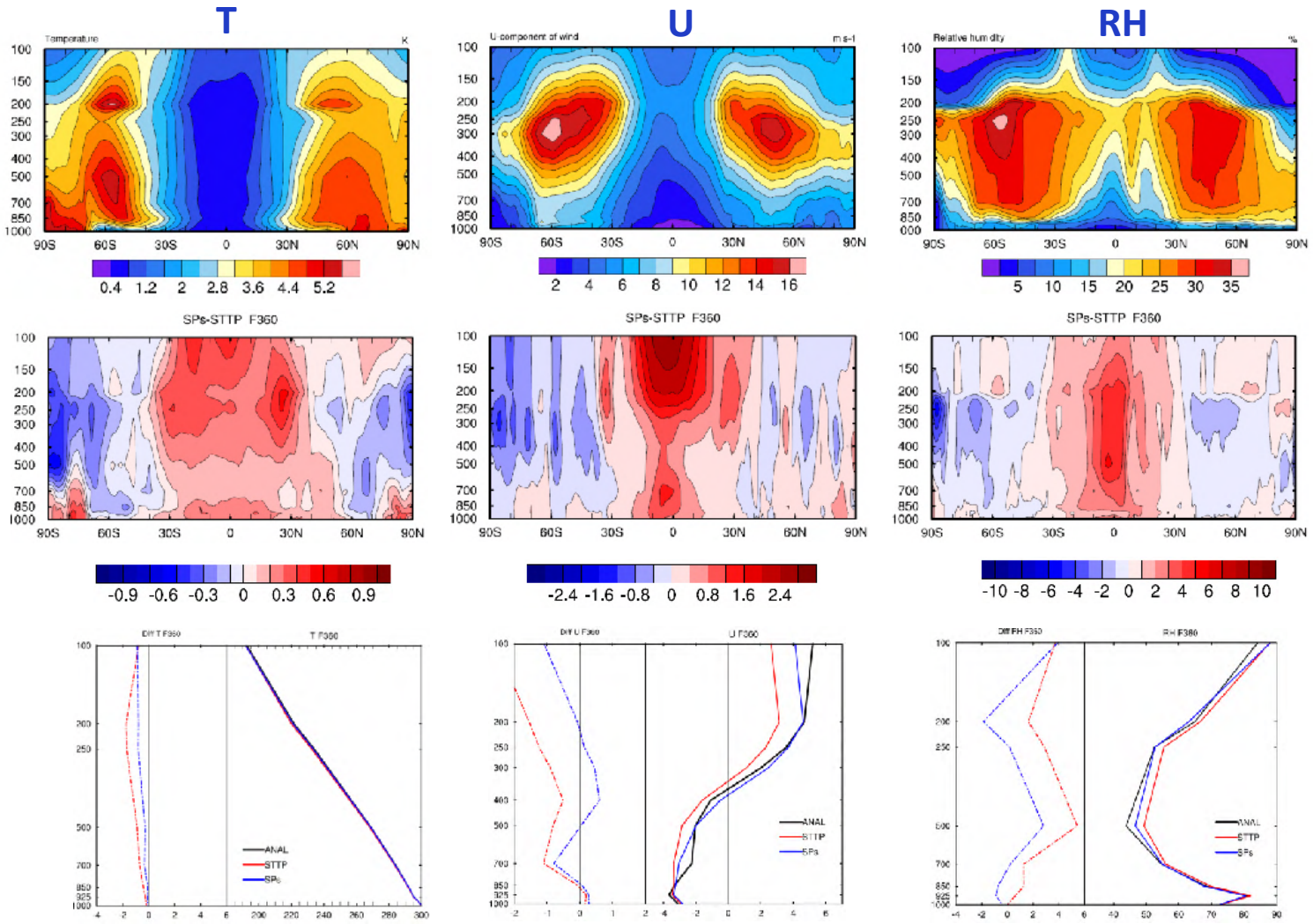
Phase3 – India Ocean

Phase6 – W. Pacific

CORR as a function of lead time: APCP



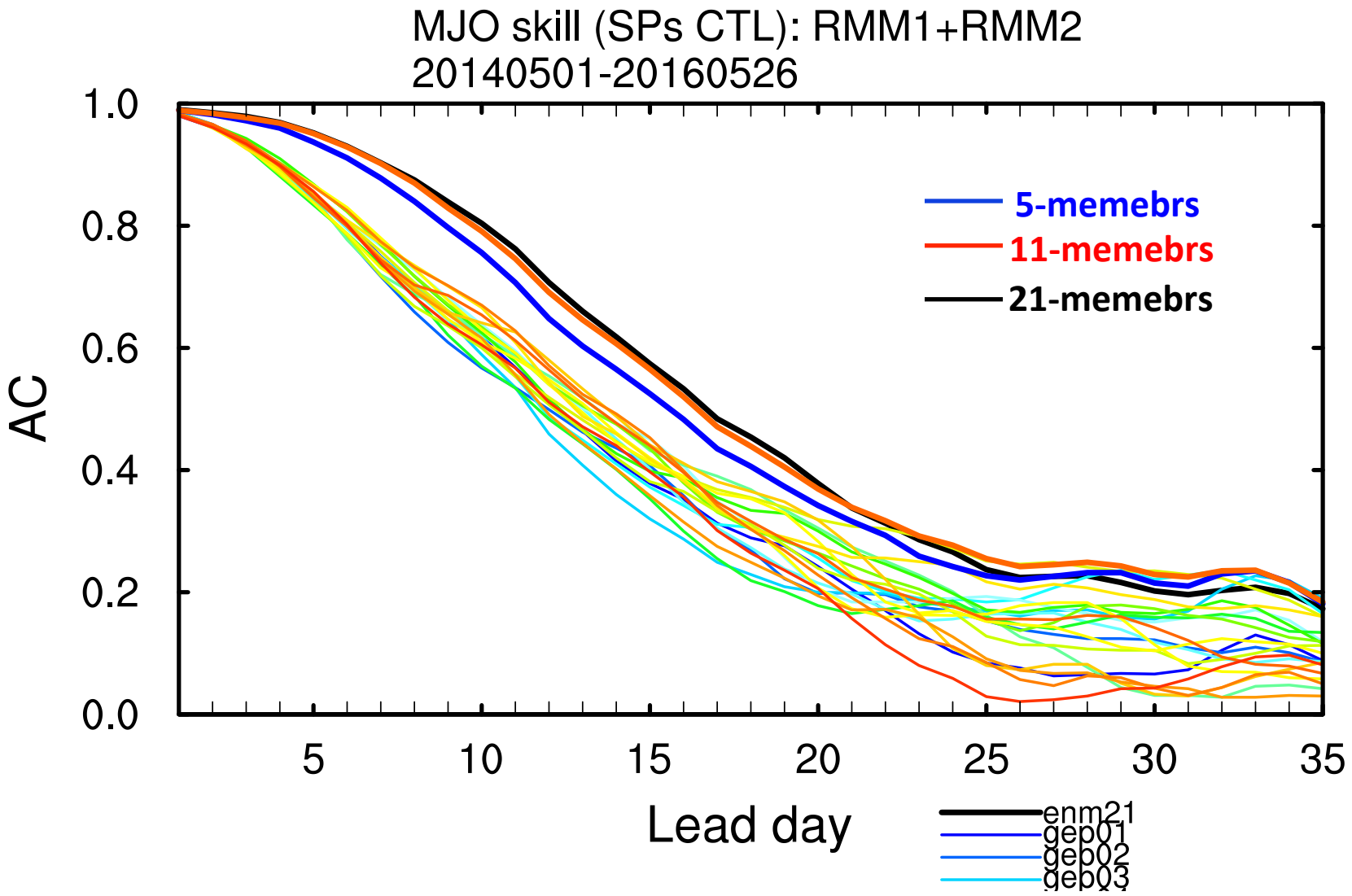
Effect of the SPs



20160301-20160326 (6 cases average)

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

WH-MJO Forecast Skills: Ensemble mean vs each member



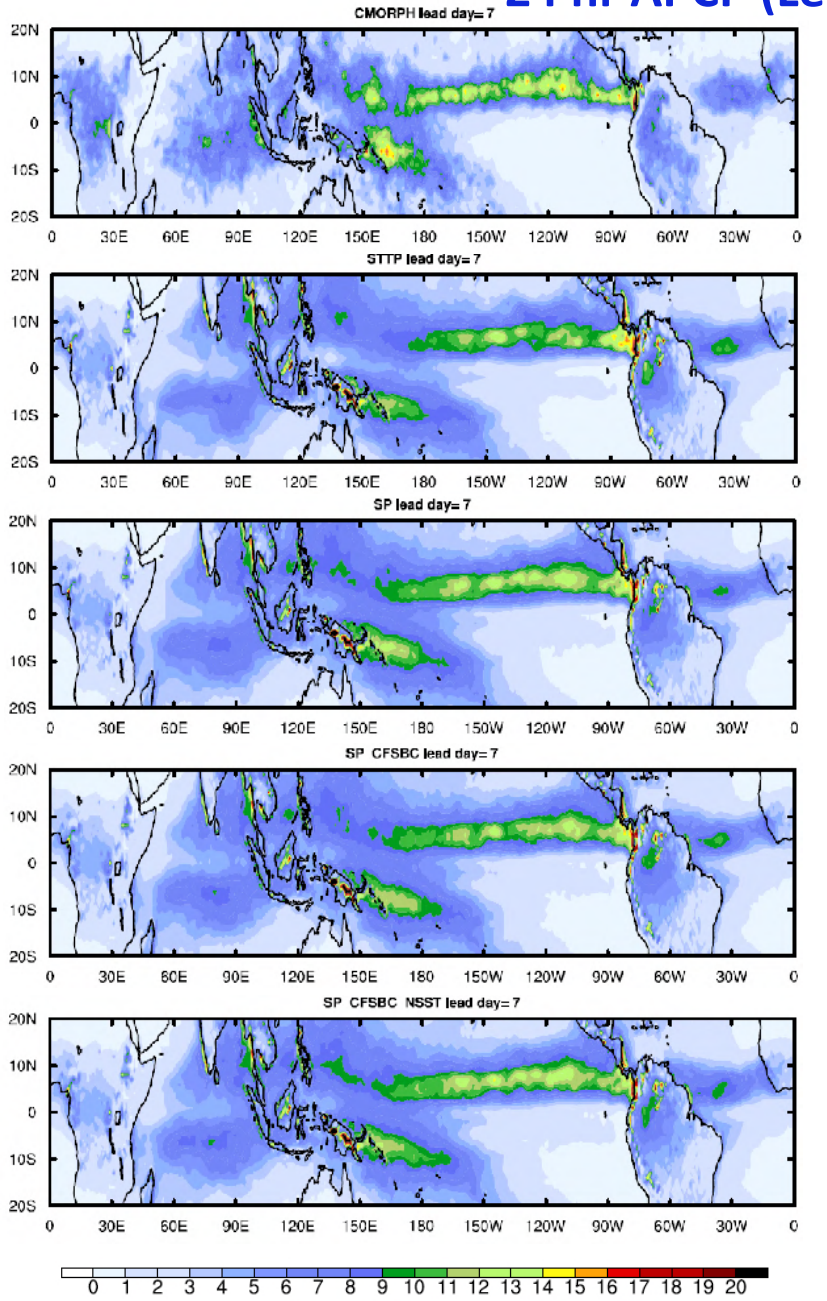
This study based on SPs configuration only!!!

Summary

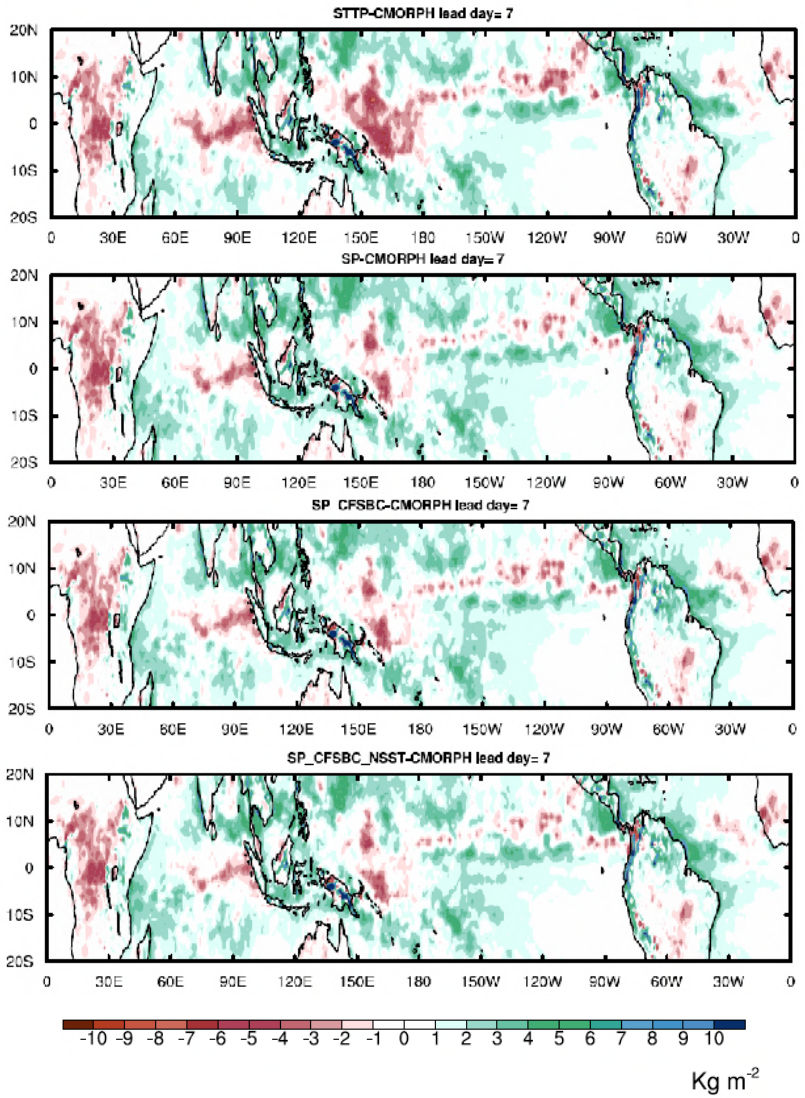
- **MJO forecast skill : SPs +CFSBC+CNV (22 days) > SPs+CFSBC (18.5 days) > SPs (16.8 days) > STTP (12.5 days)**
- **Component Forecast skill: U200 > U850 > OLR**
- **Most evident improvement occurs over the tropical west Pacific and Indian Ocean.**
- **MJO skill of 21 member is similar to 11 member and both 21 and 11 member skill is better than 5 member skill**
- **MJO propagation – could relate several issues, such as model physics – tropical convection?**

Backup Slides

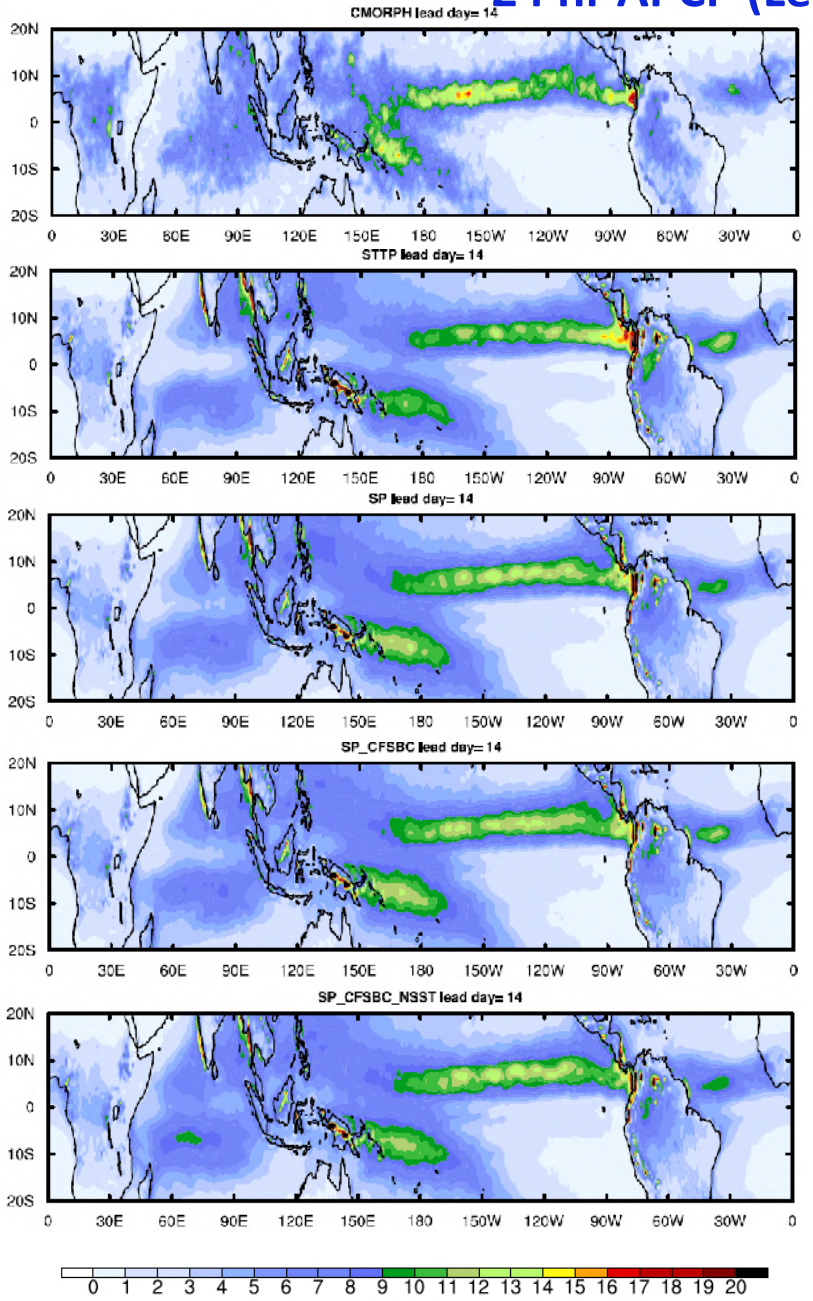
24 hr APCP (Lead day=7), 2yr ave.



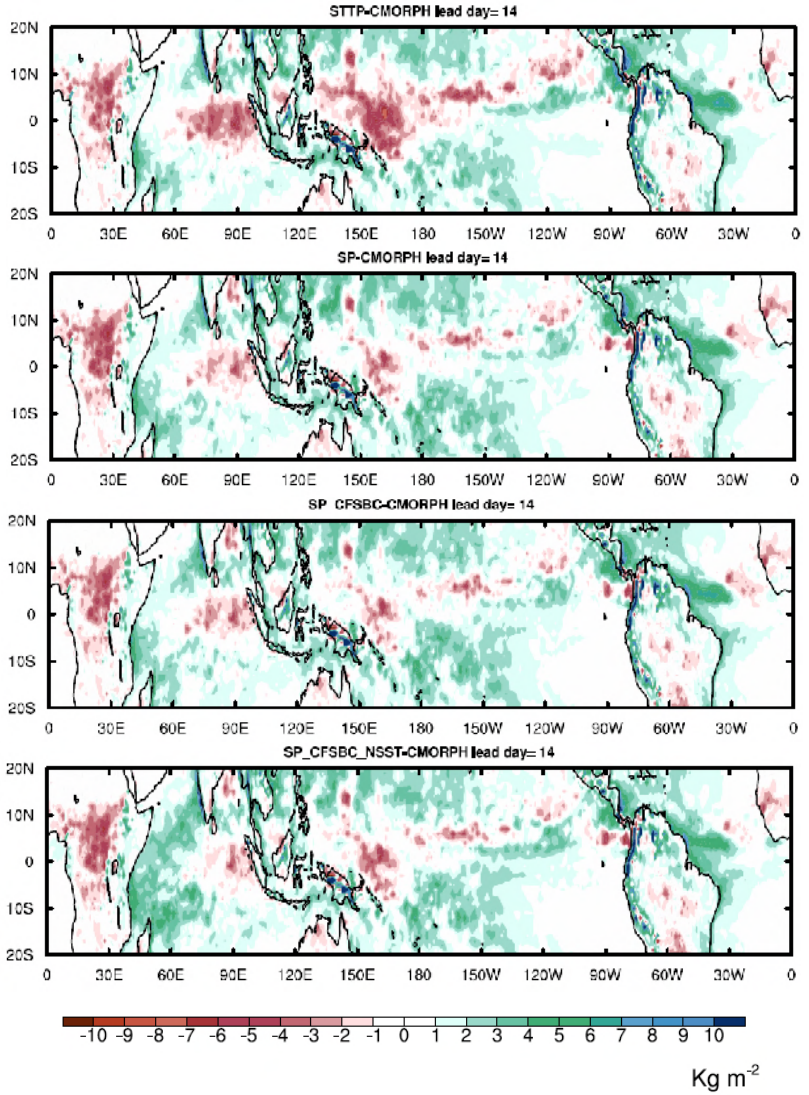
Difference Maps



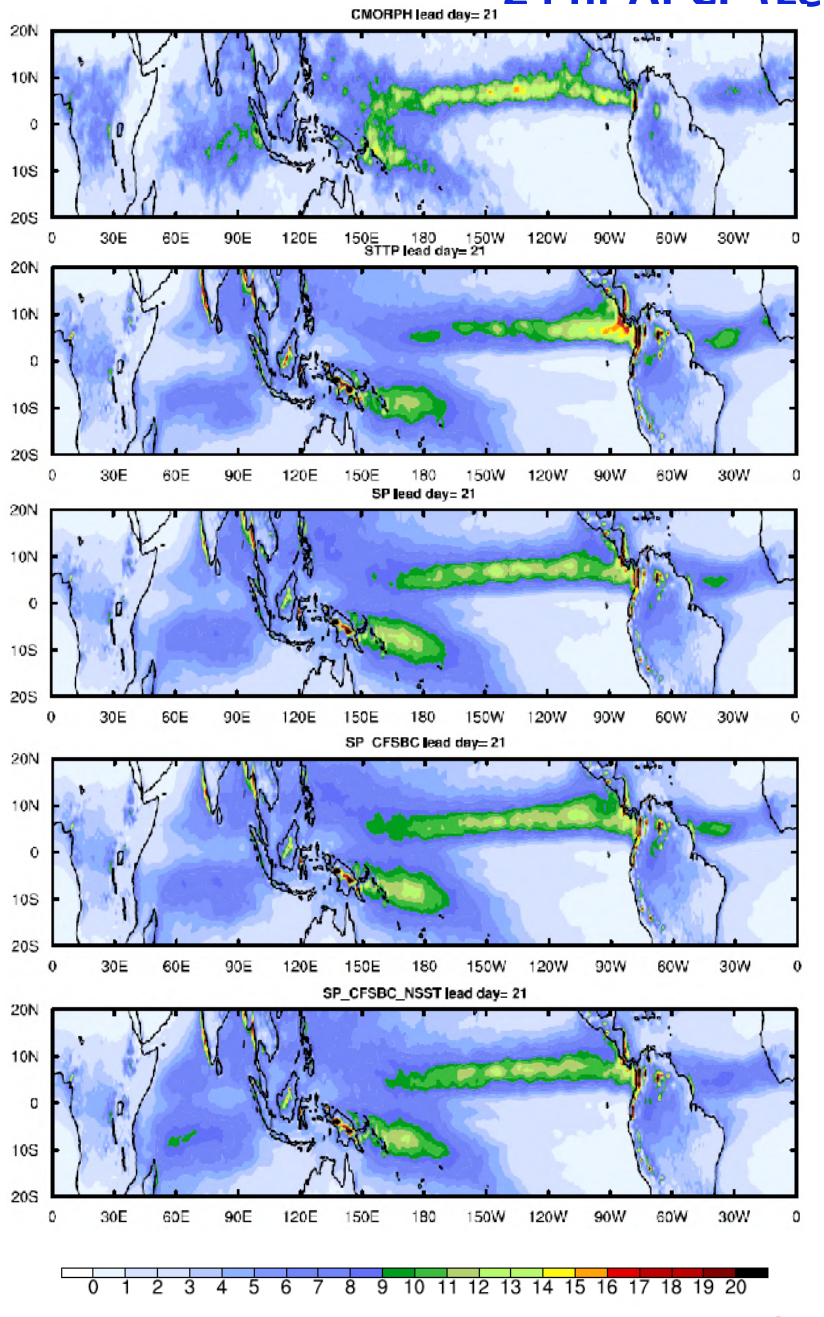
24 hr APCP (Lead day=14), 2yr ave.



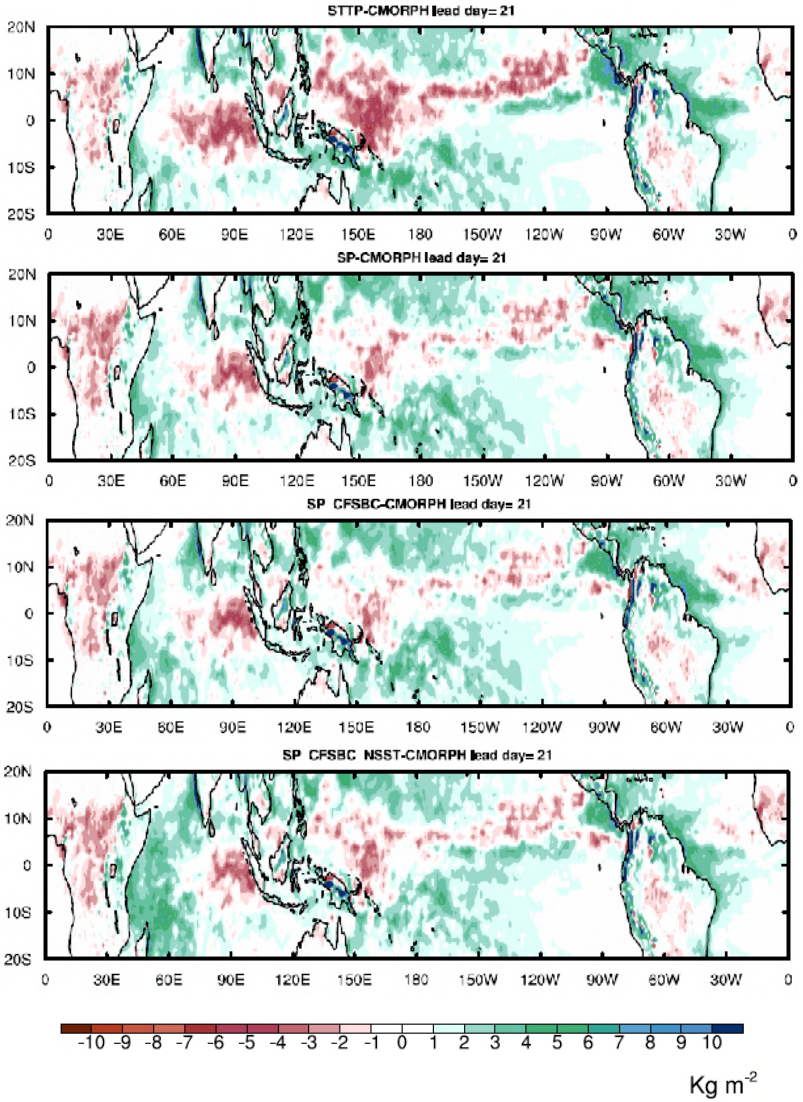
Difference Maps



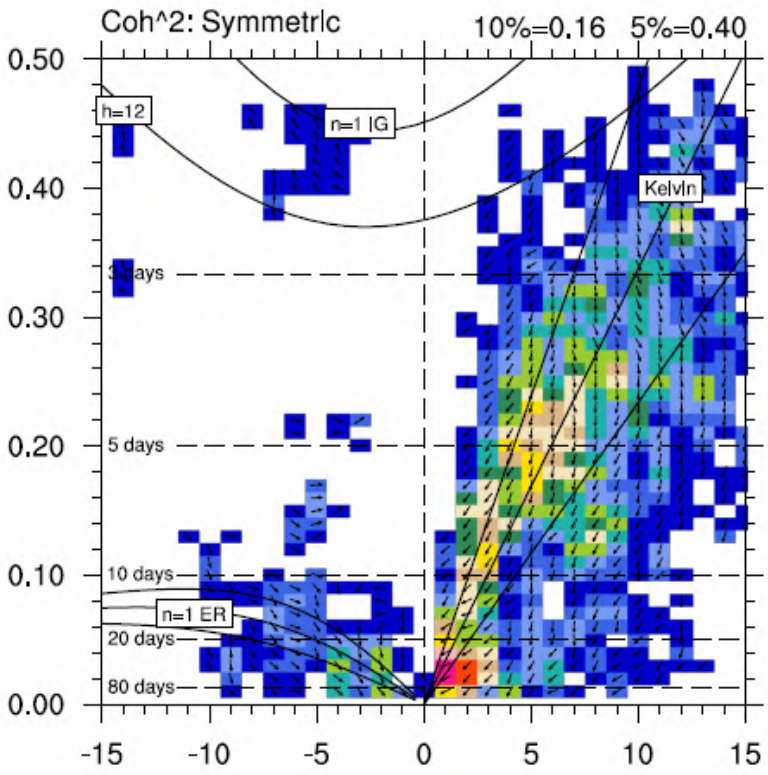
24 hr APCP (Lead day=21), 2yr ave.



Difference Maps



20140501-20160630, Daily



20140501-20160526, 5d