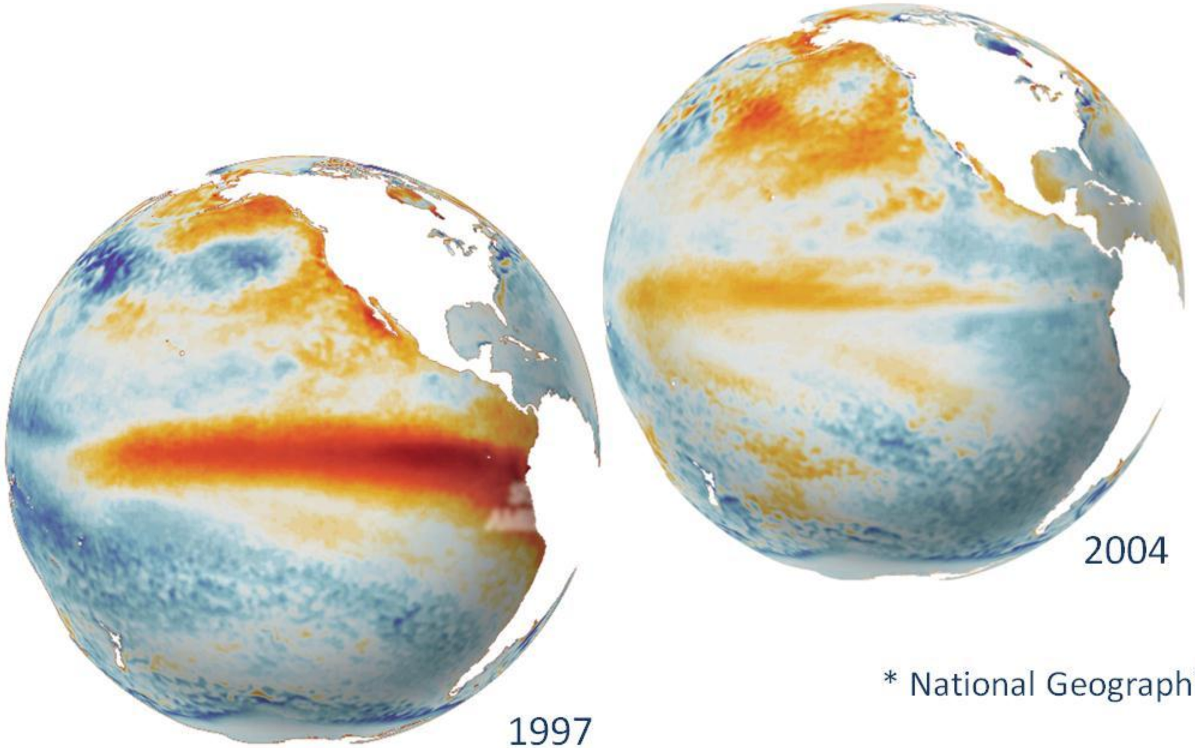
ENSO and ENSO teleconnections



* National Geographic (Feb, 2010)

Hyemi Kim and Peter J. Webster

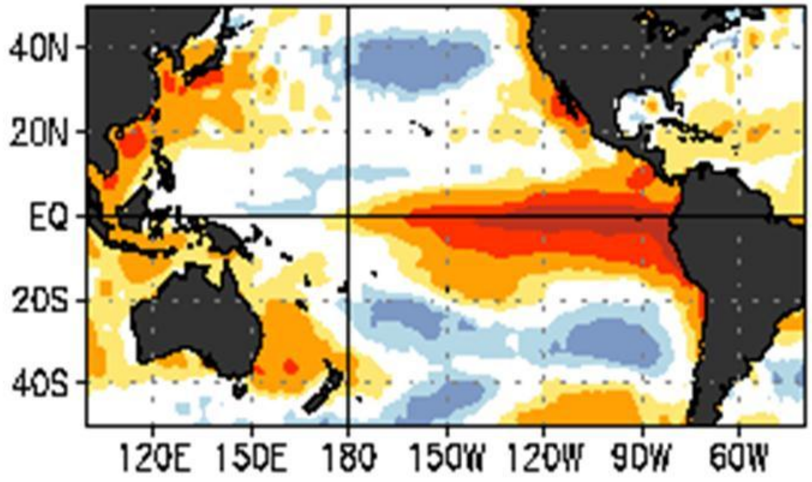
School of Earth and Atmospheric Science
Georgia Institute of Technology

Outline

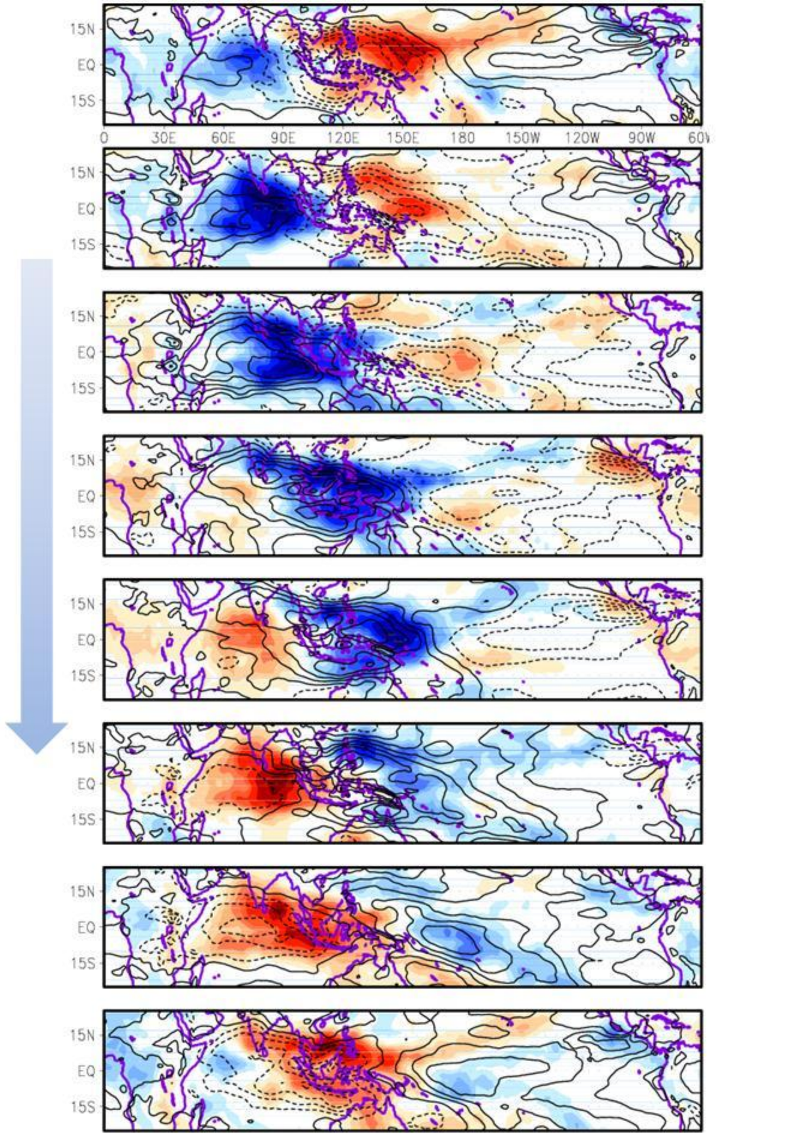
- Introduction to the ENSO and its impacts
- ENSO simulation and prediction
- Central Pacific El Nino
- Sub-seasonal (MJO) prediction
- Summary

Source of seasonal predictability

ENSO variability



MJO variability

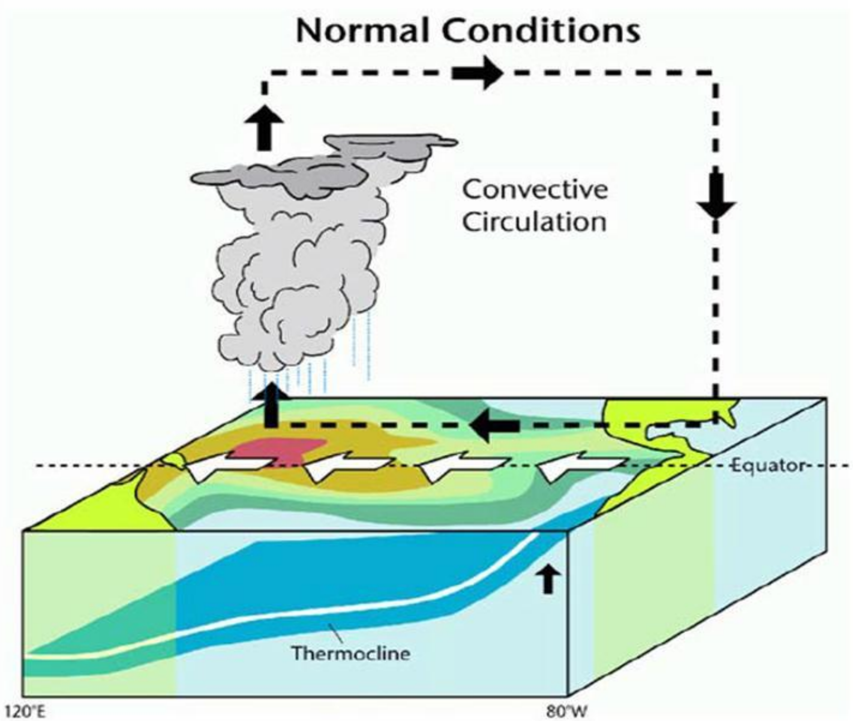


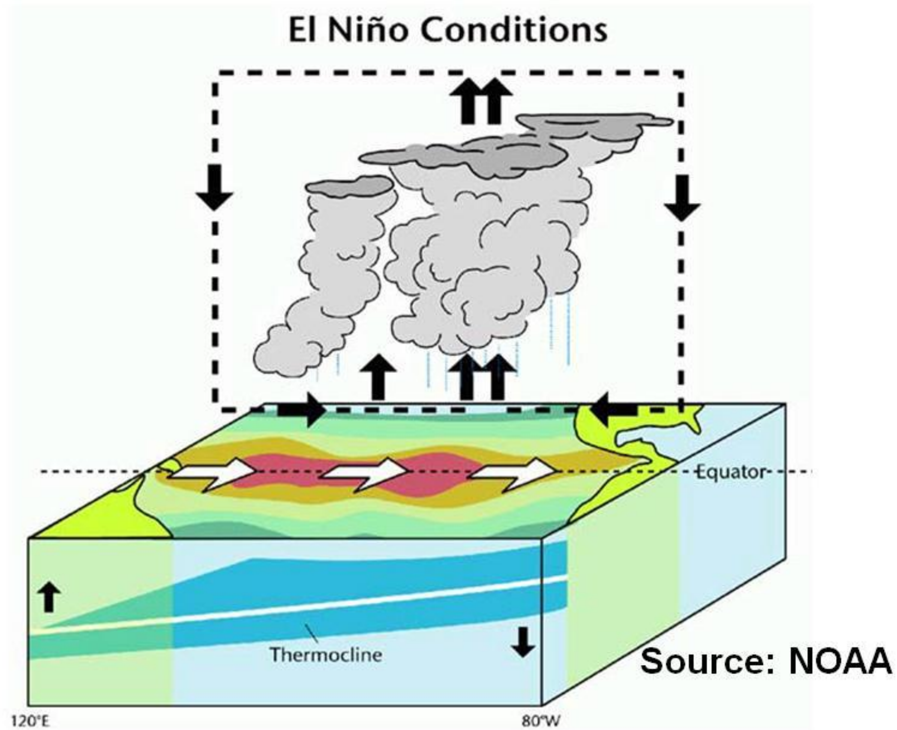
• El Nino Southern Oscillation (ENSO): the biggest single signal

• Madden-Julian Oscillation (MJO): an important source of extended-range prediction in the tropics/extratropics.

ENSO

- **ENSO** is one of the most significant **couplings** between the ocean and atmosphere on an **interannual** timescale occurs in the **tropical** Pacific.





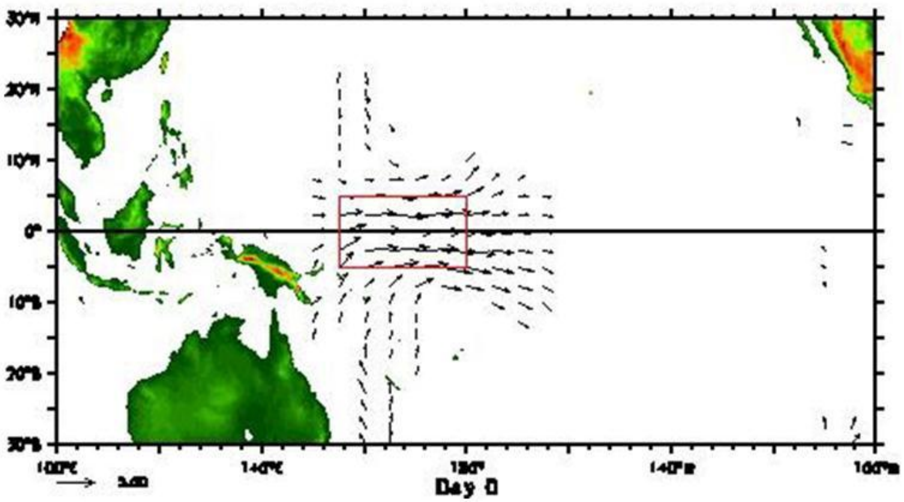
- Warm-pool extends to the east
- Convection is displaced eastward
- East-west SST gradient reduces
- Walker circulation weakens
- Upwelling in E Pacific reduces (thermocline relaxes)

What causes El Nino?

Triggering Mechanism

- Not well understood
- "**Westerly wind bursts**" (WWBs) over a period of several days may be one trigger
  - Most often associated with the MJO
  - Atmospheric Kelvin waves also generate sustained westerly winds
  - <u>Multiple sustained</u> WWBs decrease the equatorial easterlies.

    Less upwelling increases the central and eastern Pacific SSTs and lowers the thermocline depth and **initiates an El Nino event**



Anomalous surface winds
(i.e. a WWB)

* MD Eastin (UNCC)

Delayed Oscillator Theory

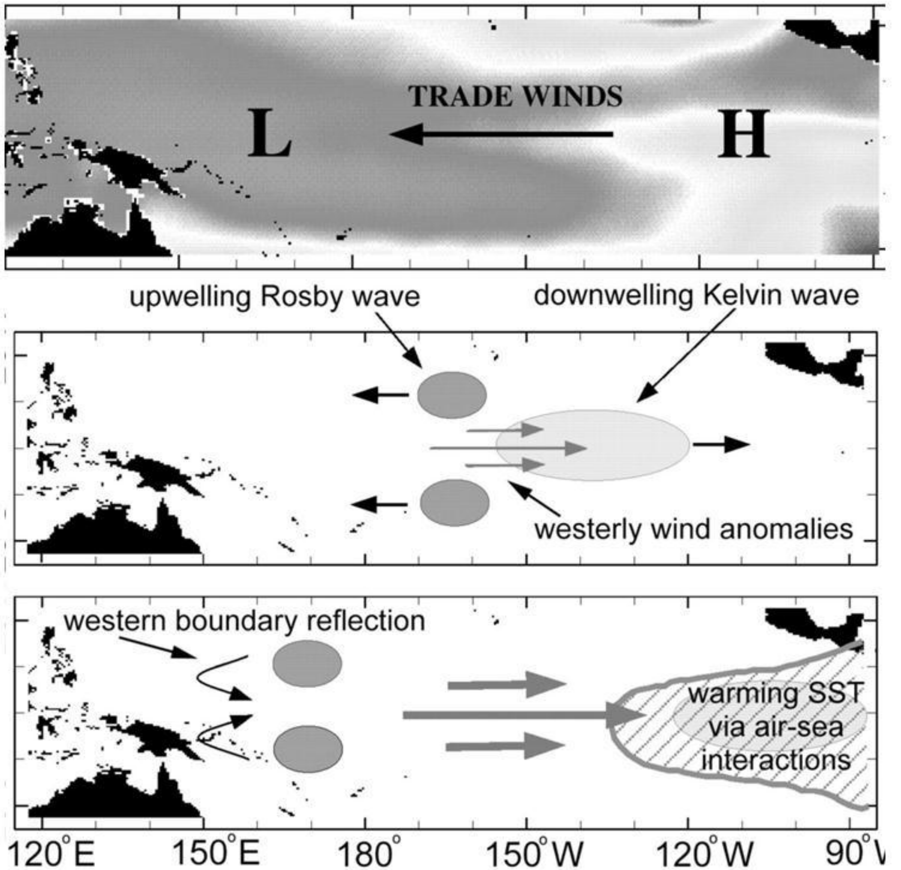
Delayed Oscillator Theory
(Suarez and Schopf 1988, Battisti and Hirst 1989)

Atmospheric WWBs generate equatorial Rossby and Kelvin waves **in the ocean**

Oceanic Kelvin waves:
Move eastward very rapidly
Induce downwelling (increases the thermocline depth)
Warm the ocean mixed layer and SSTs

Oceanic Rossby waves:
Move westward at slow speeds
Rossby wave is reflected back at the western boundary → upwelling Kelvin wave

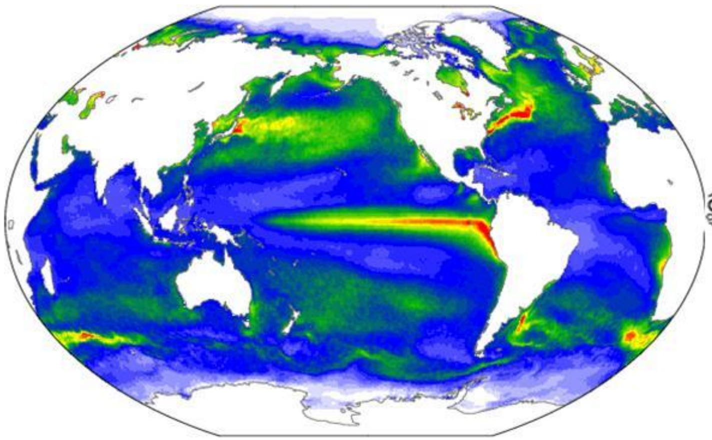
This theory provides an explanation for the ENSO every 4-5 years



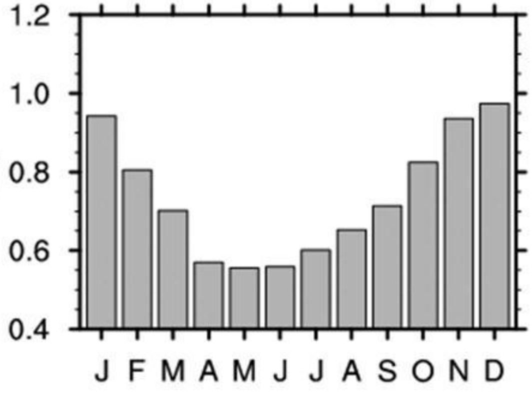
ENSO characteristics

- Large variability in the tropics
- Phase locking to the seasonal cycle (maximum in the boreal winter)
- 3-7 year timescale

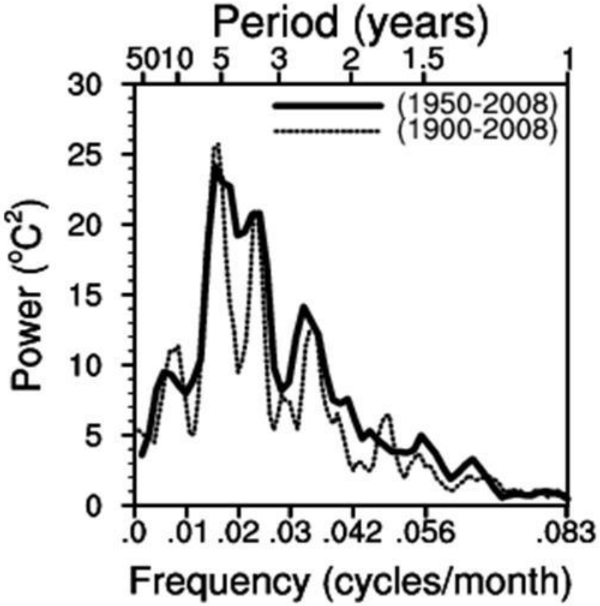
STD of SST



STD of monthly Nino3

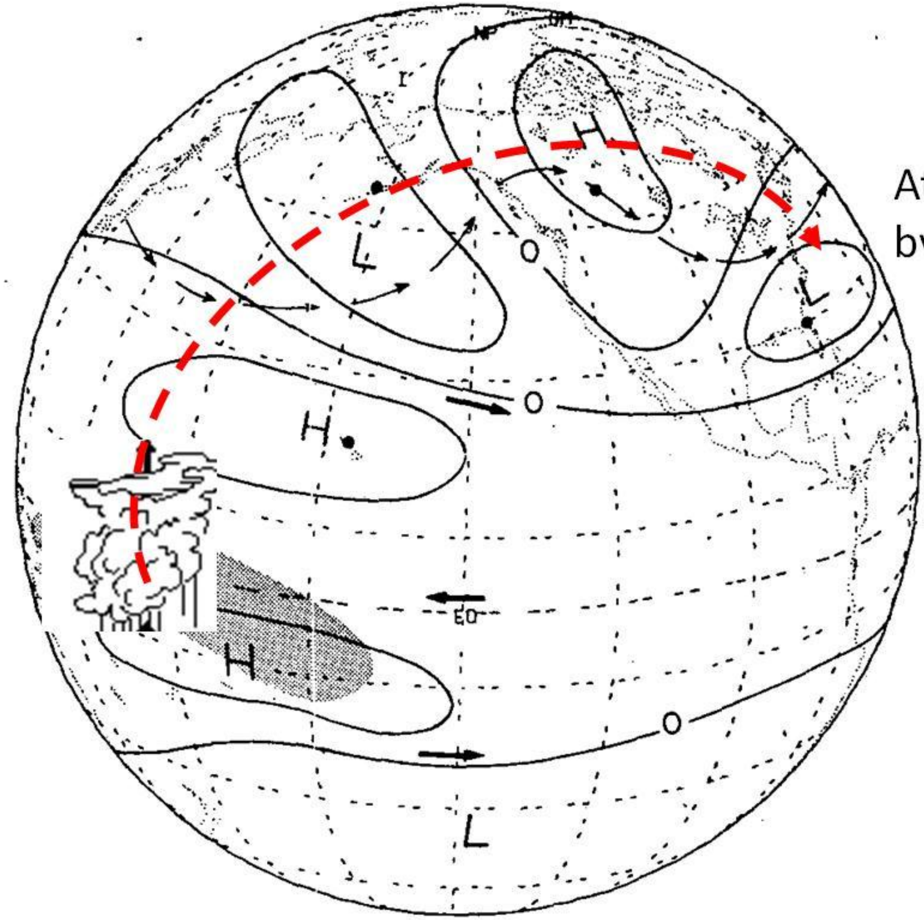


Nino3



ENSO teleconnection

Atmospheric Circulation Changes due to ENSO



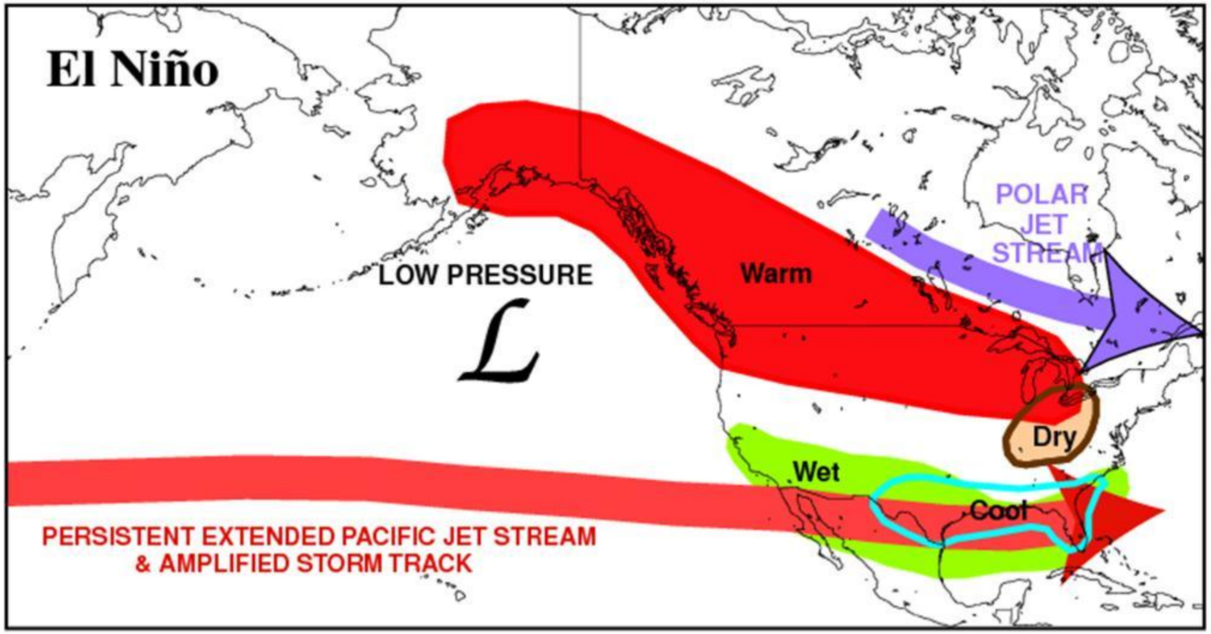
Atmospheric wave forced by tropical heating

Horel and Wallace (1981)
Wallace and Gutzler (1981)
Webster and Chang (1988)

- ENSO provides one of the strongest sources of interannual variability in the global climate.
- The anomalous diabatic heating in the tropical Pacific Ocean forces anomalies in tropical convection, which forces strong upper tropospheric divergence in the tropics and convergence in the subtropics → Standing Rossby wave with energy propagation from the tropics to midlat.

ENSO teleconnection

N. America (winter)



* NOAA/CPC

El Nino: Shift in sub-tropical jet brings storms into southern part US

- Warm in north, cool in south
- Southeast US experiences anomalous precipitation
- California coast experiences high precipitation
- Pacific NW and Midwest generally drier

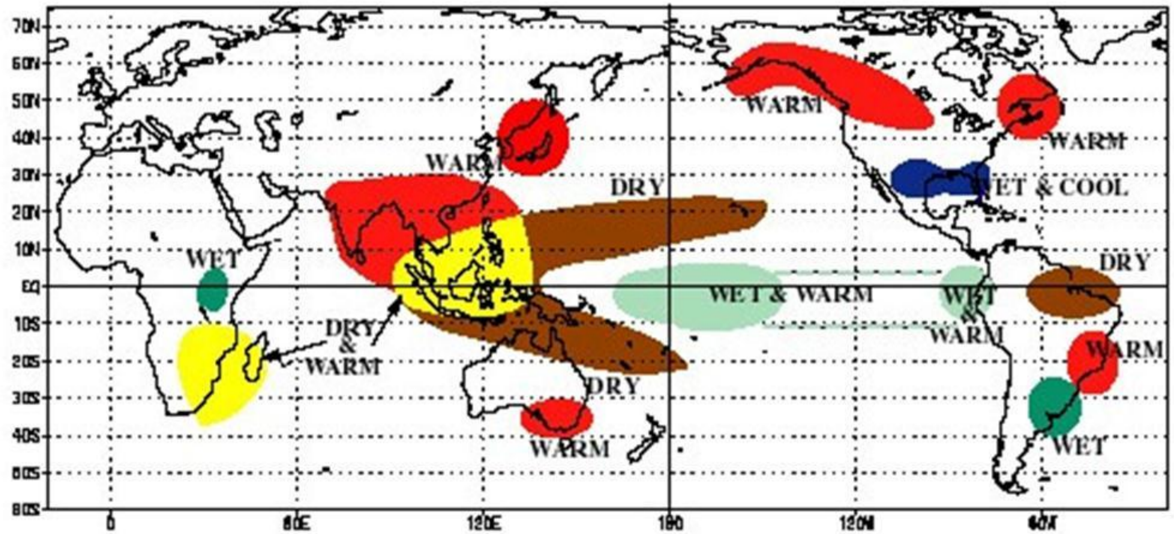
La Nina : generally opposite patterns

ENSO teleconnection

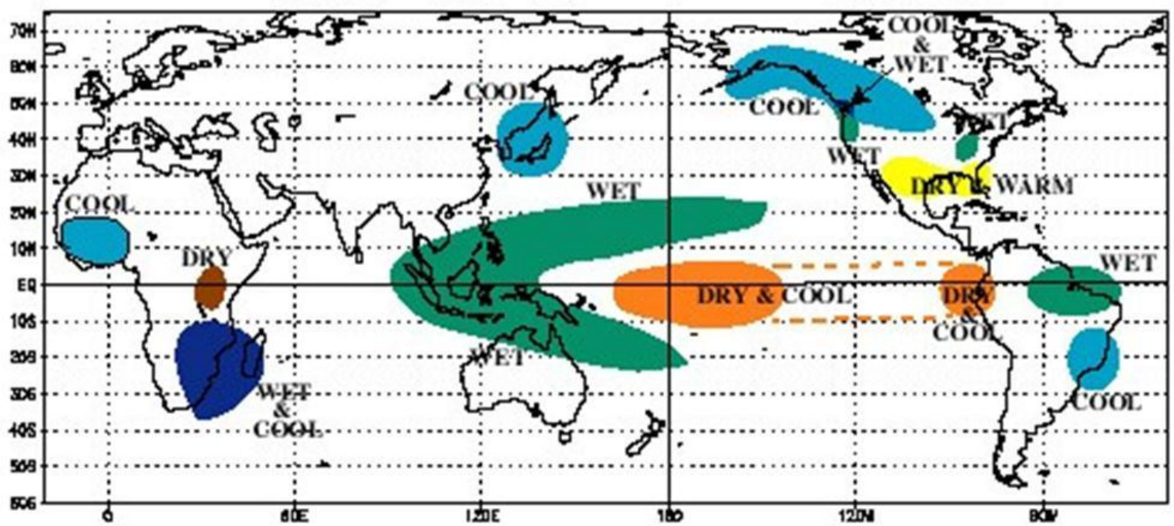
Global impact

NH Winter (DJF)

El Nino



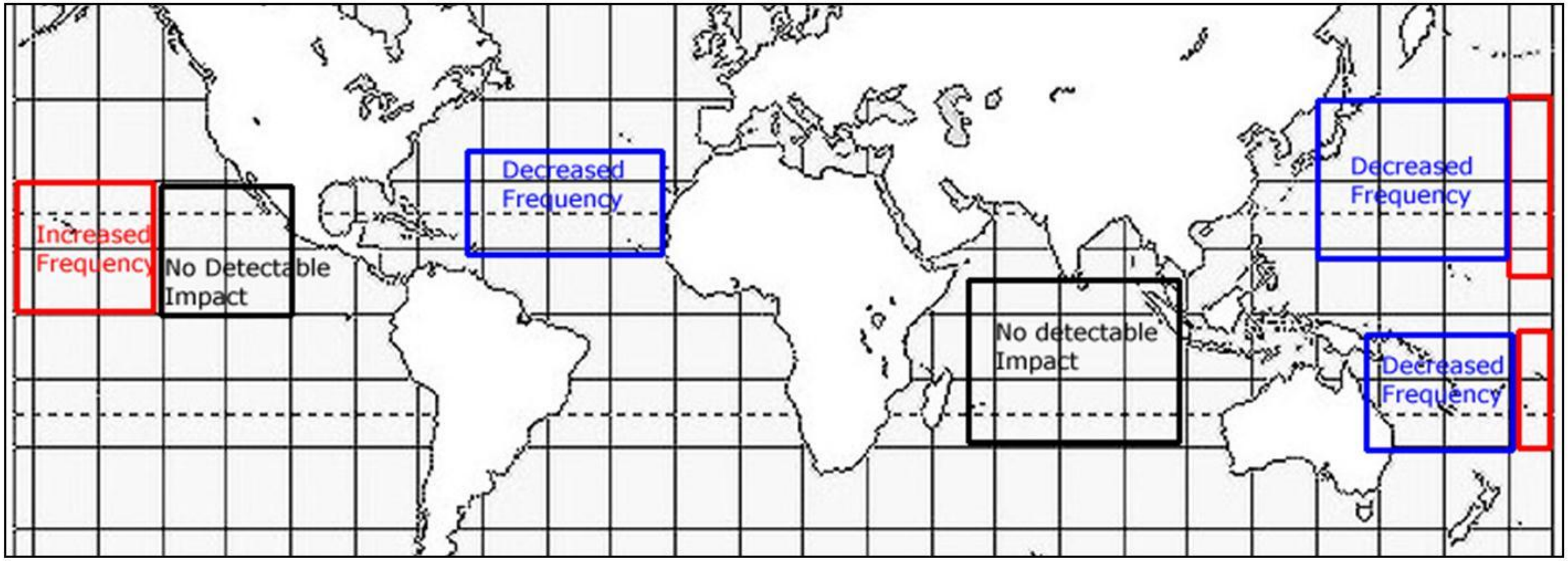
La Nina



* IRI

ENSO teleconnection

Tropical cyclone activity



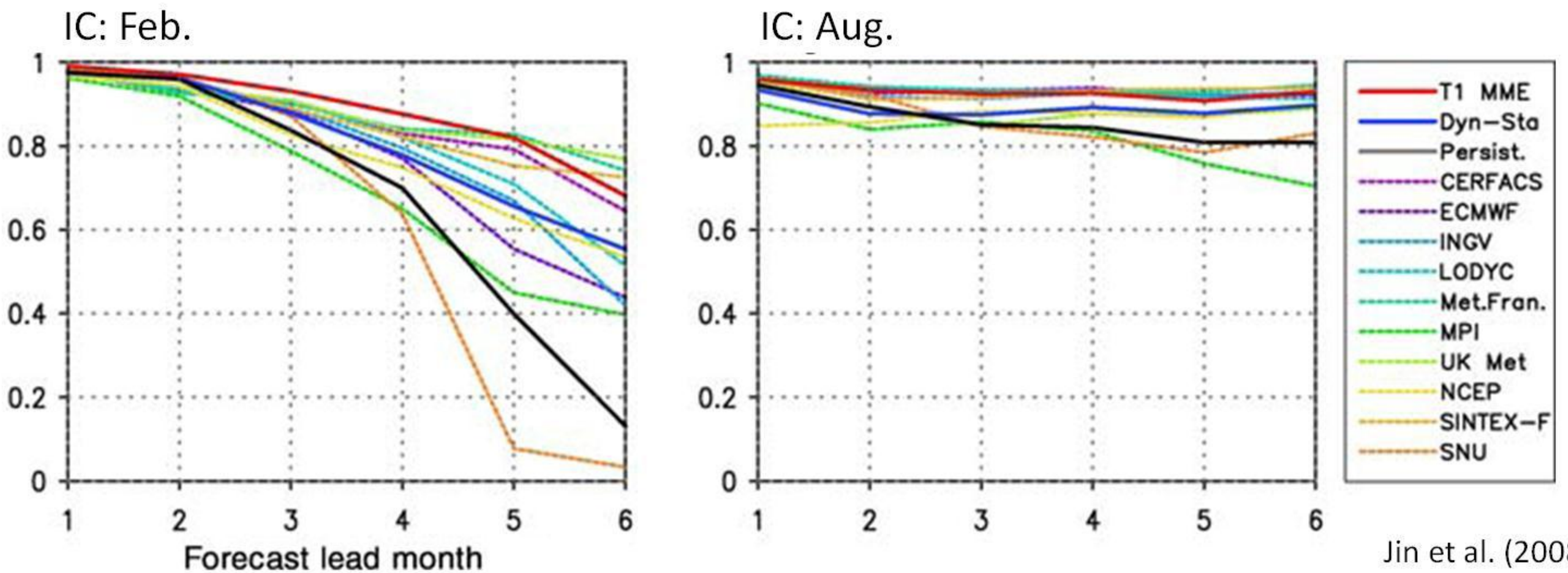
In El Nino year

- **Reduced** frequency :
  - Atlantic: Upper-level westerlies increase, increased vertical wind shear
  - Australia: Convection shifts east, monsoon trough weakens
  - Northwest Pacific (west of 160°E): Monsoon trough shifts away from area
- **Increased** frequency :
  - NW Pacific (east of 160E): Monsoon trough shifts into this area
  - NE Pacific (near Hawaii): Increased convection due to warmer SSTs

(Gray 1984, Chen et al. 1998; Chan 2000; Chia and Ropelewski 2002; Wang and Chan 2002; Wu et al. 2004; Kim et al. 2005; Camargo et al. 2007, …)

ENSO predictability

Nino 3 prediction skill



Jin et al. (2008)

- Very high levels of predictability even 6 months ahead
- Easier to forecast events from NH Summer

  (ENSO cycle is usually already established and persists until the following spring)
- ENSO forecasts are difficult from Feb.~April, called the "**spring predictability barrier**"
  - Relatively weak coupling between the ocean and atmosphere during boreal spring
  - Phase locking of the ENSO to the annual cycle

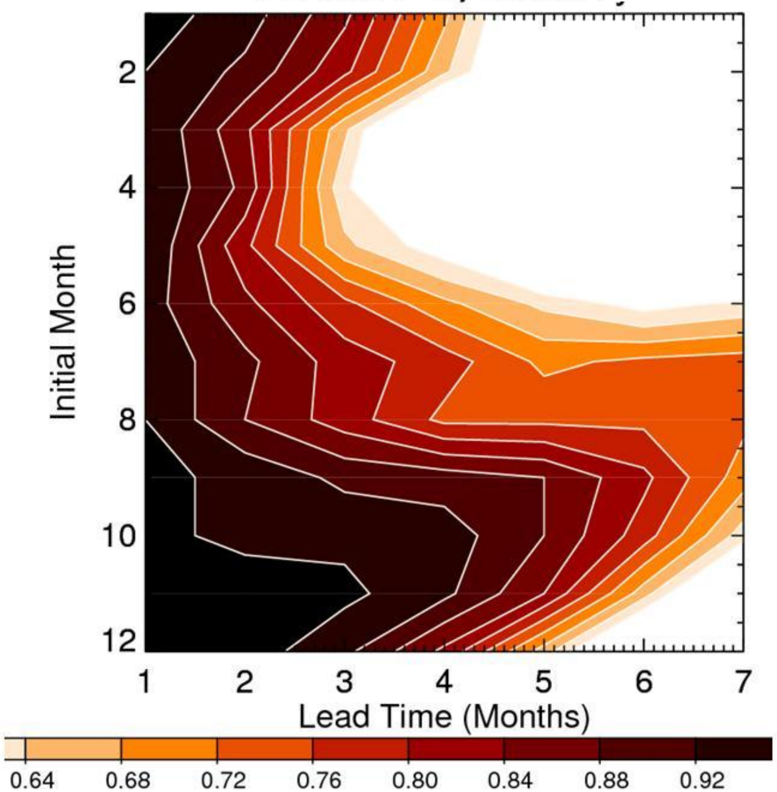
(Zebiak and Cane 1987; Battisti 1988; Goswami and Shukla 1991; Blumenthal 1991; Webster and Yang 1992, Webster 1995; Balmaseda et al 1995; Torrence and Webster 1998; An and Wang 2001; Jin et al. 2009)

ENSO predictability

<u>Spring predictability barrier</u>

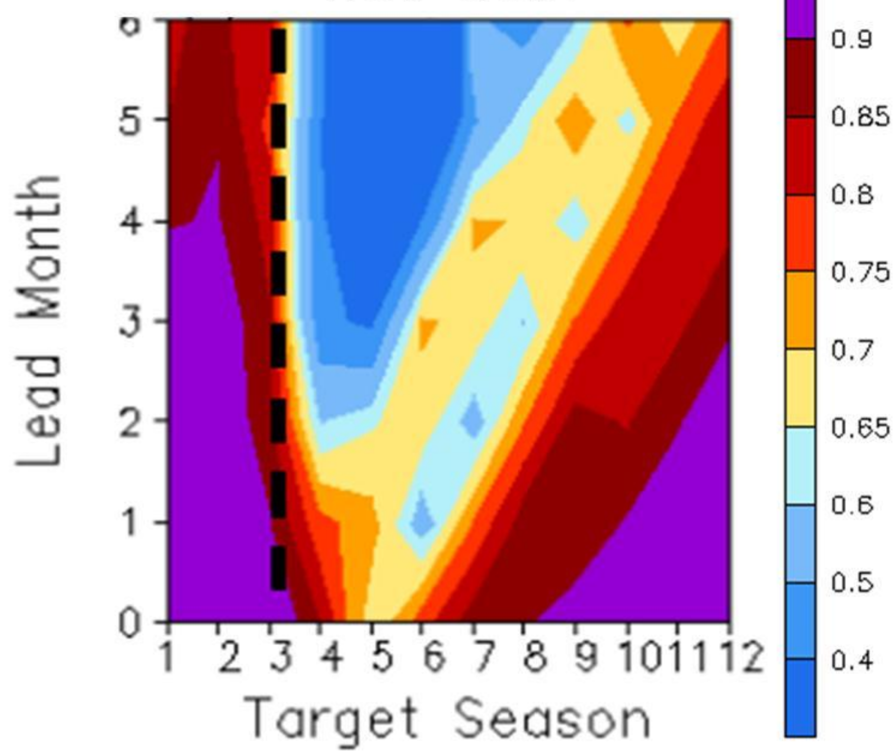
Nino3 prediction skill

ECMWF System4



* V. Toma, GATech

NCEP CFSv2



* Yan Xue, NOAA/CPC

Retrospective forecast system

	ECMWF Sys4	NCEP CFSv2
Hindcasts period	1981-2010	1982-2010
Initialized	1st of each month	Every 5th day
Ensembles	15/month	24~28/month
Forecast lead time	7 month	9 month
Atm. IC	ERA interim	CFS Reanalysis
NH Winter (DJF)	Nov 1st (15 ens)	Oct 23rd ~ Nov. 7th (16 ens)
NH Summer (JJA)	May 1st (15 ens)	April 21st ~ May 6th (16 ens)

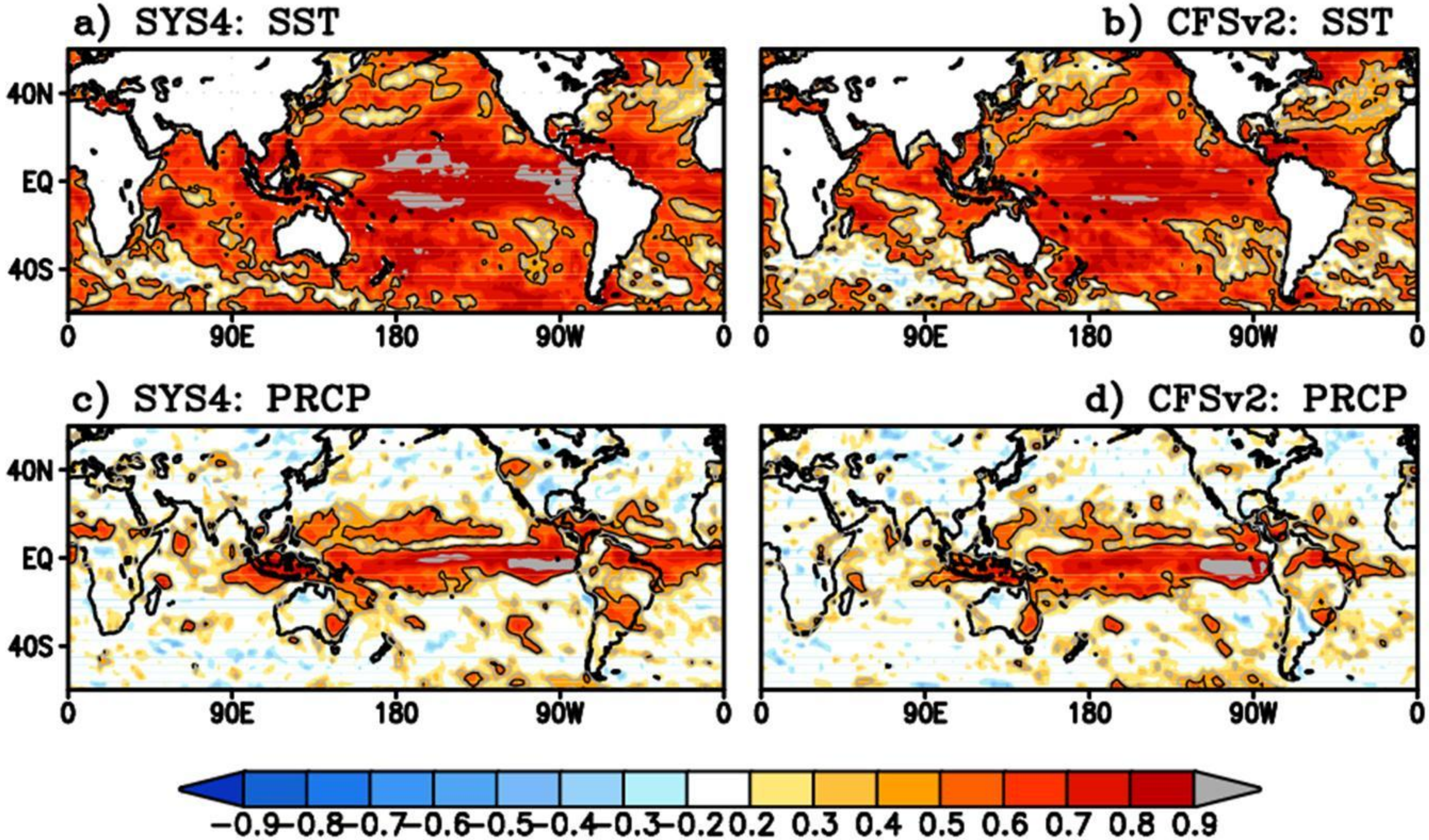
* Kim et al. (2012a,b, CD)

Seasonal prediction skill

NH Summer (JJA)

SST → OISSTv2

PRCP → GPCP



Correlation coeff.

* Solid black line represents statistical significance of correlation coeff. at 99% confidence level.

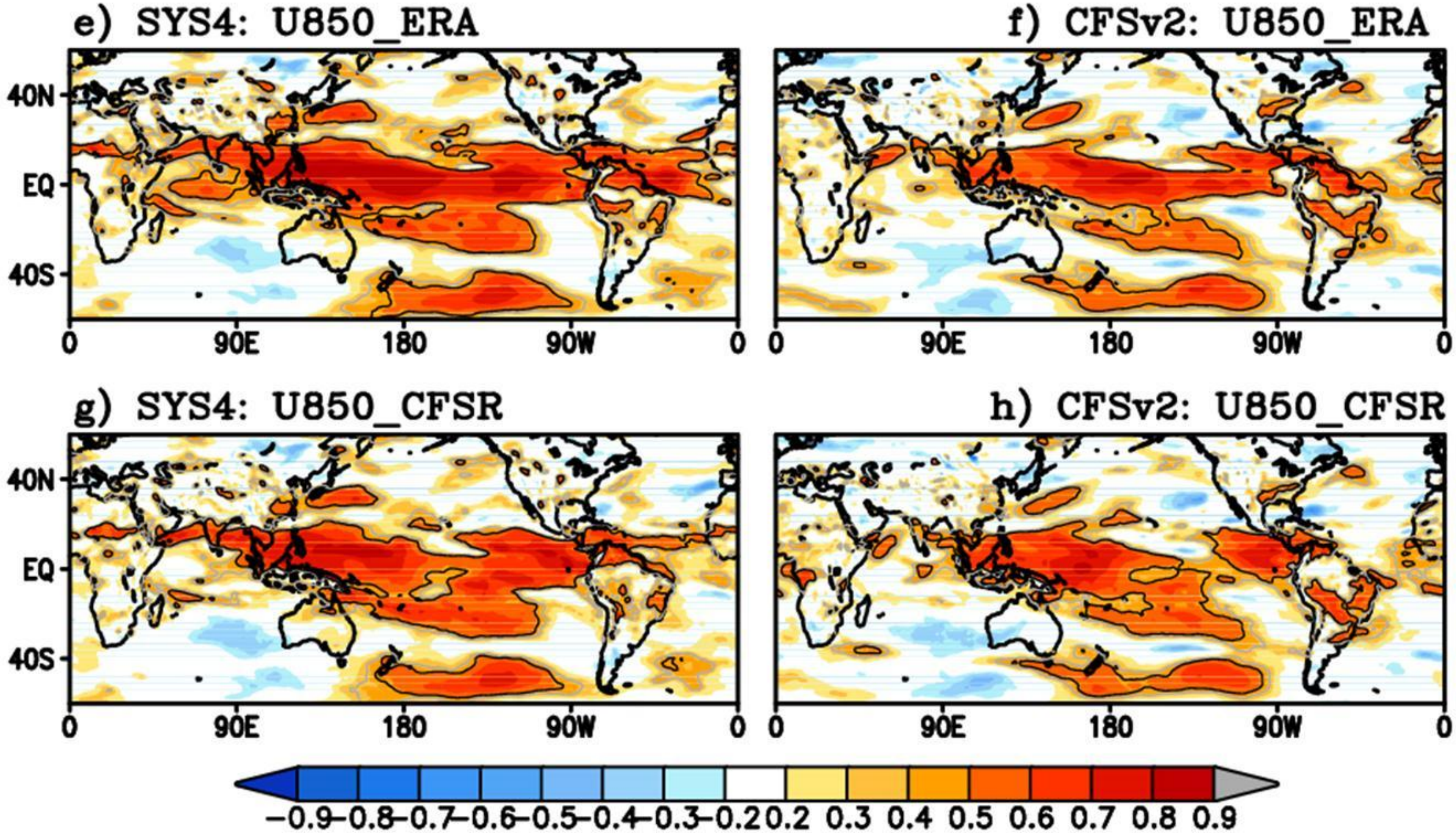
* Kim et al. (2012)

Seasonal prediction skill

NH Summer (JJA)

U850 →
ERA interim

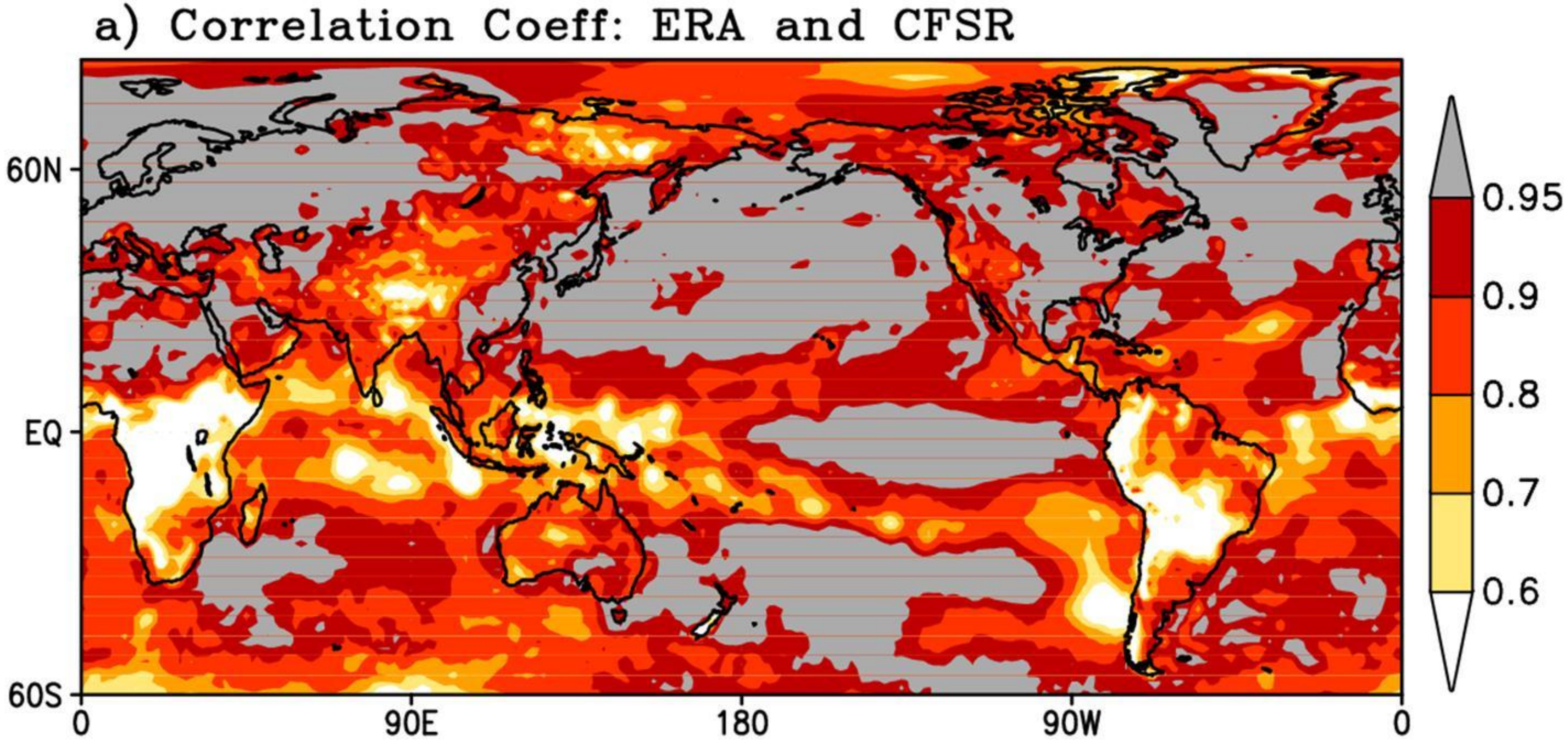
U850 →
CFSR



* Kim et al. (2012)

ERA interim and CFSR

Correlations: 2m Temperature (DJF, 1982-2009)

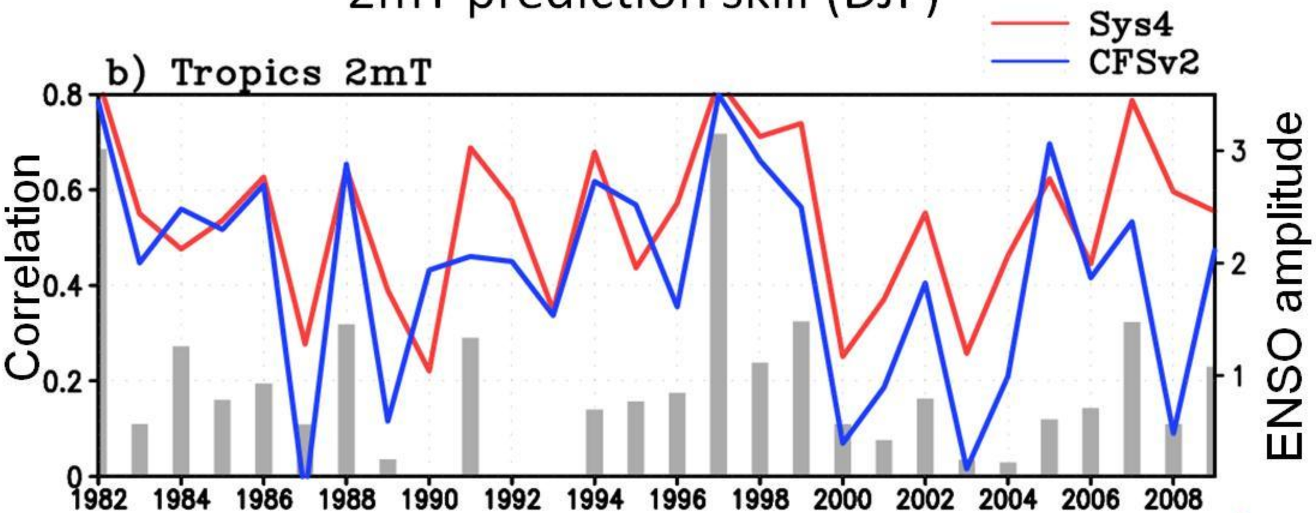


- This comparison illustrates the uncertainty in the reanalysis datasets, which by extension contributes to uncertainty in the prediction analysis.

* Kim et al. (2012)

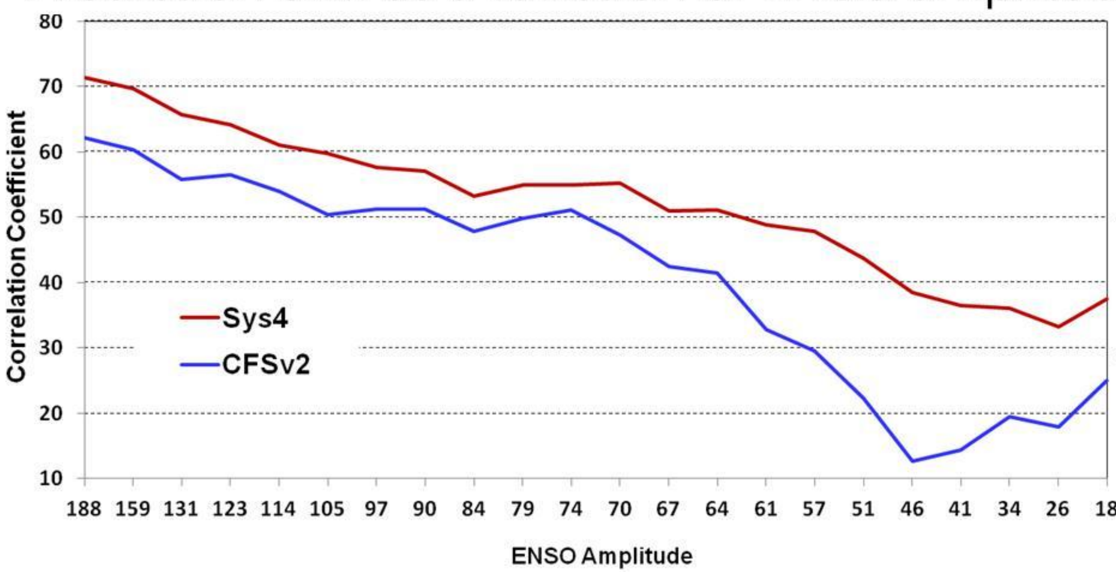
Seasonal prediction and ENSO

2mT prediction skill (DJF)



* Pattern correlation over the Tropical Pacific (40E-300E, 20S-20N)

Prediction skill as a function of ENSO amplitude

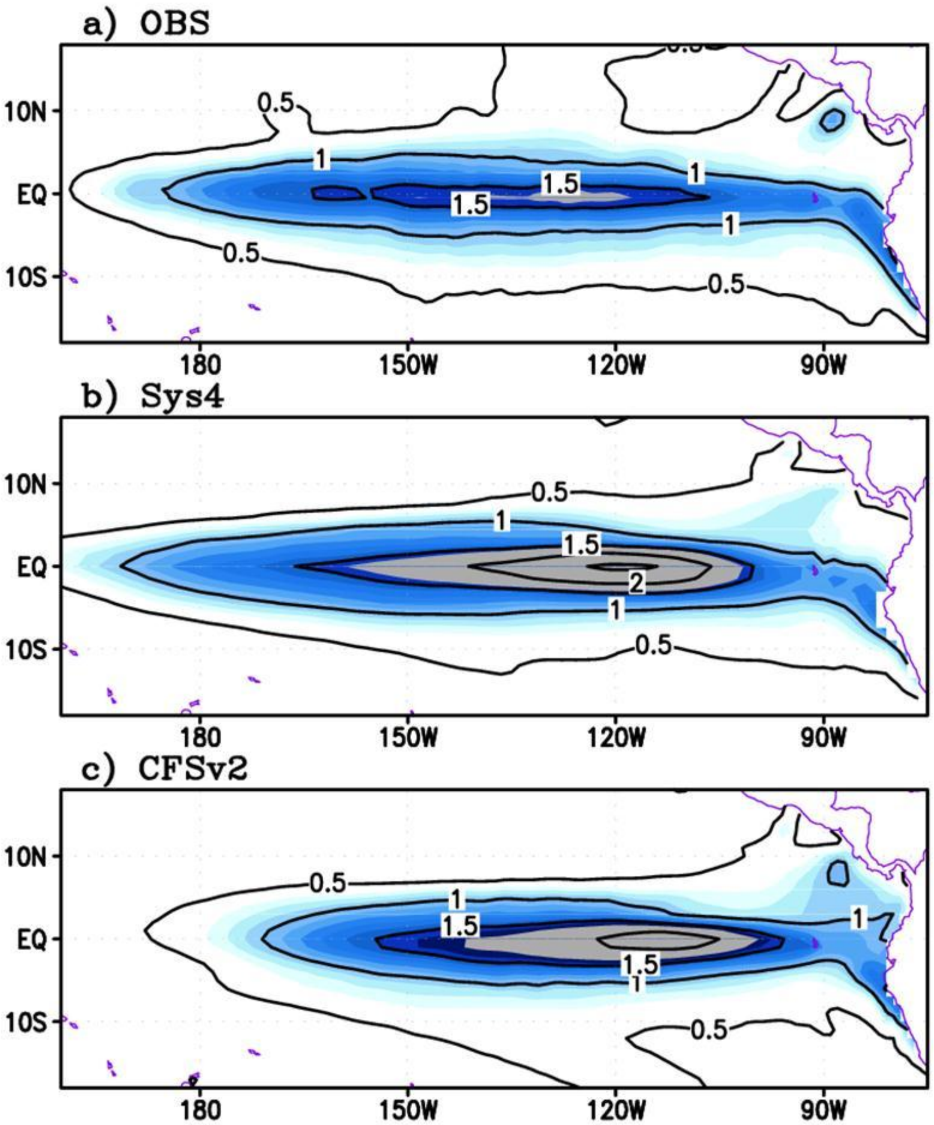


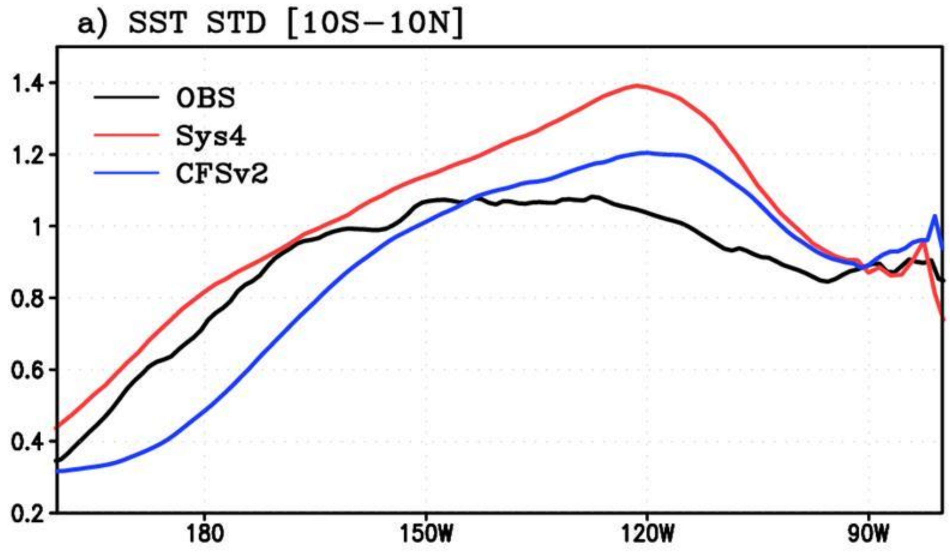
The prediction skill of tropical 2mT is greater in **strong ENSO** winter than in weak ENSO winter.

* Kim et al. (2012)

ENSO prediction

SST variability (DJF)



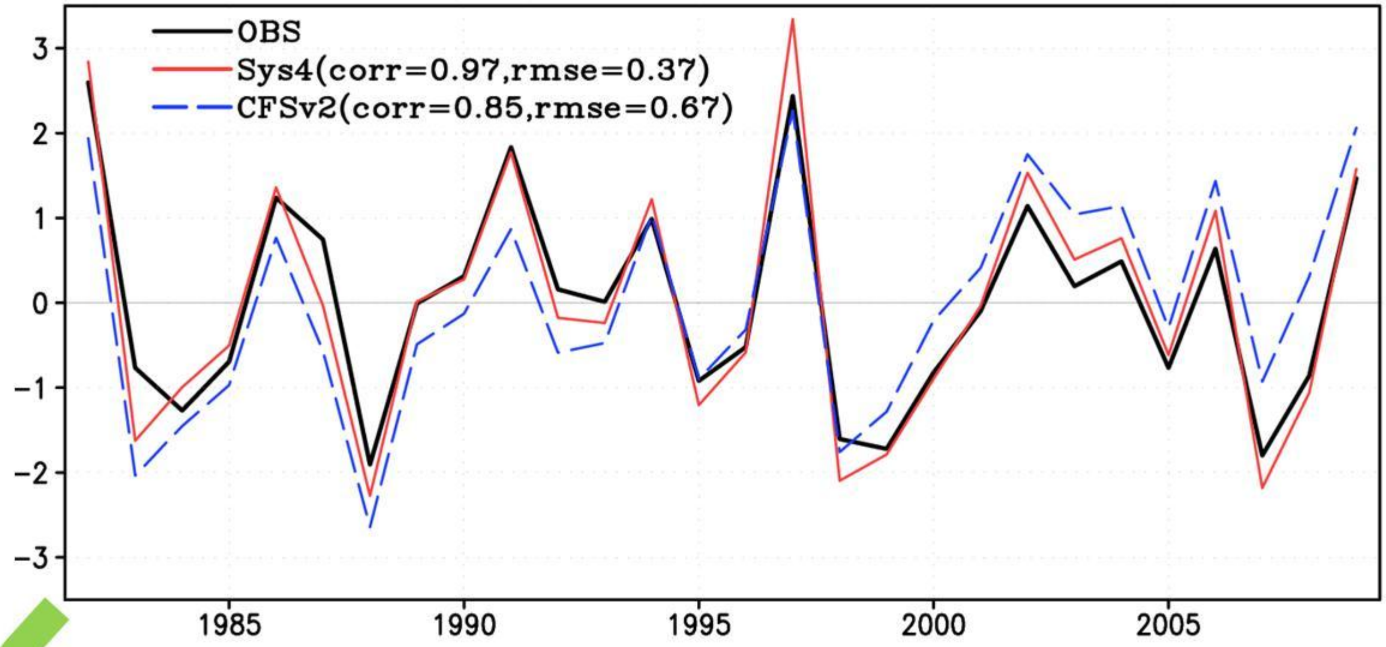


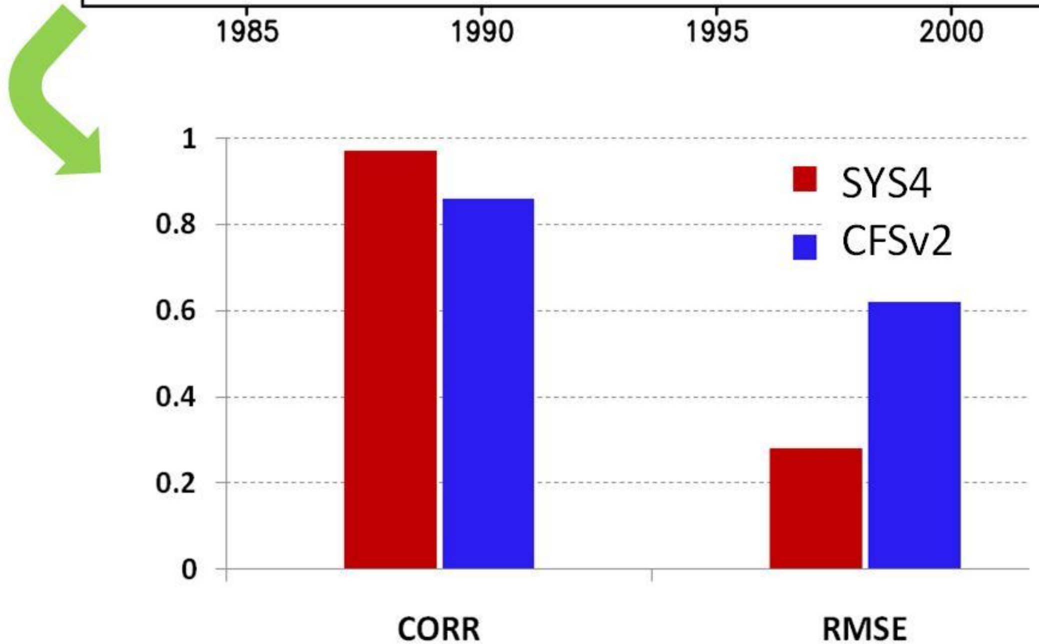
- Both system overestimates the amplitude of SST variability in ENSO region.

* Kim et al. (2012)

ENSO prediction

Nino 3.4 index (DJF)

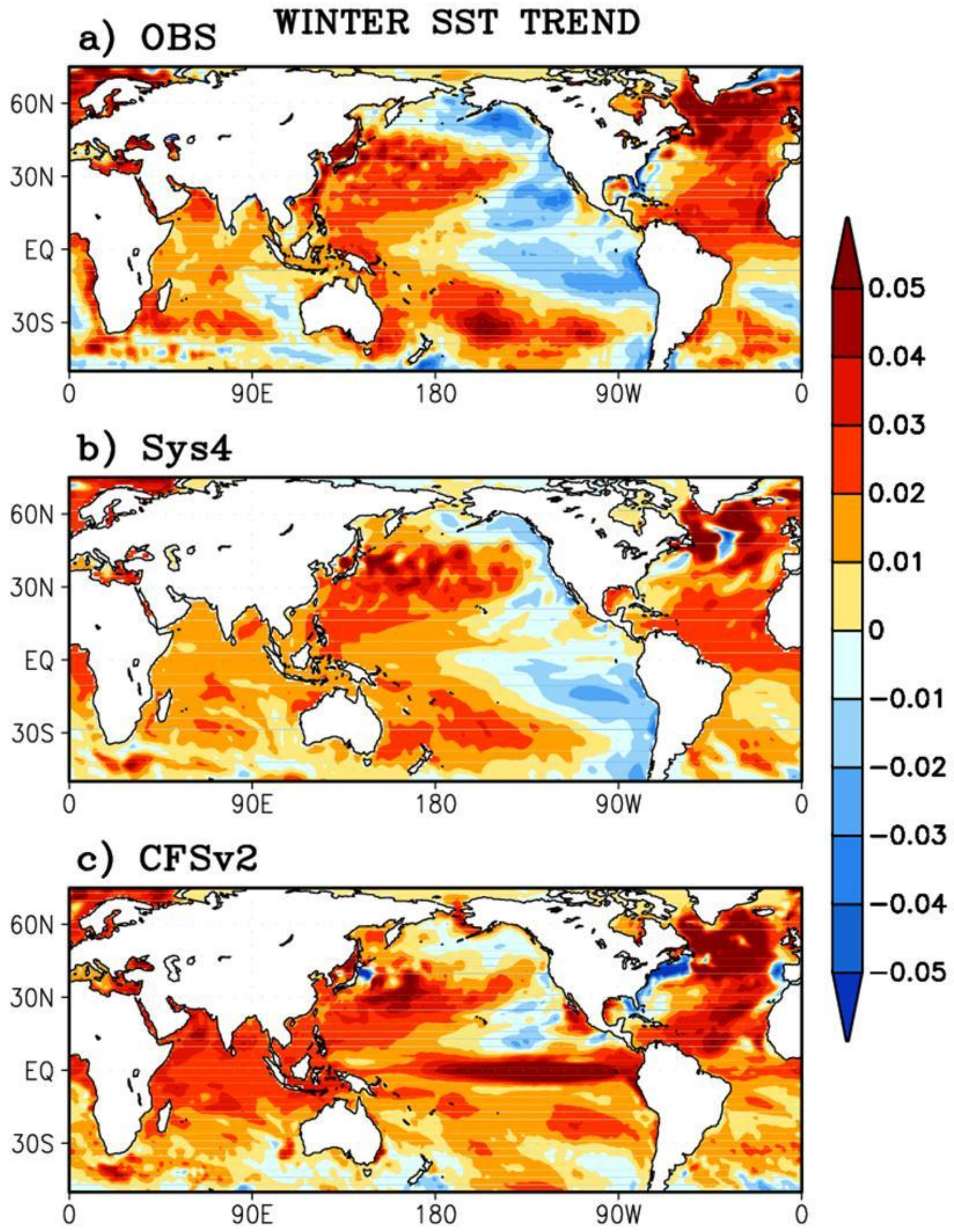




* Kim et al. (2012)

ENSO prediction

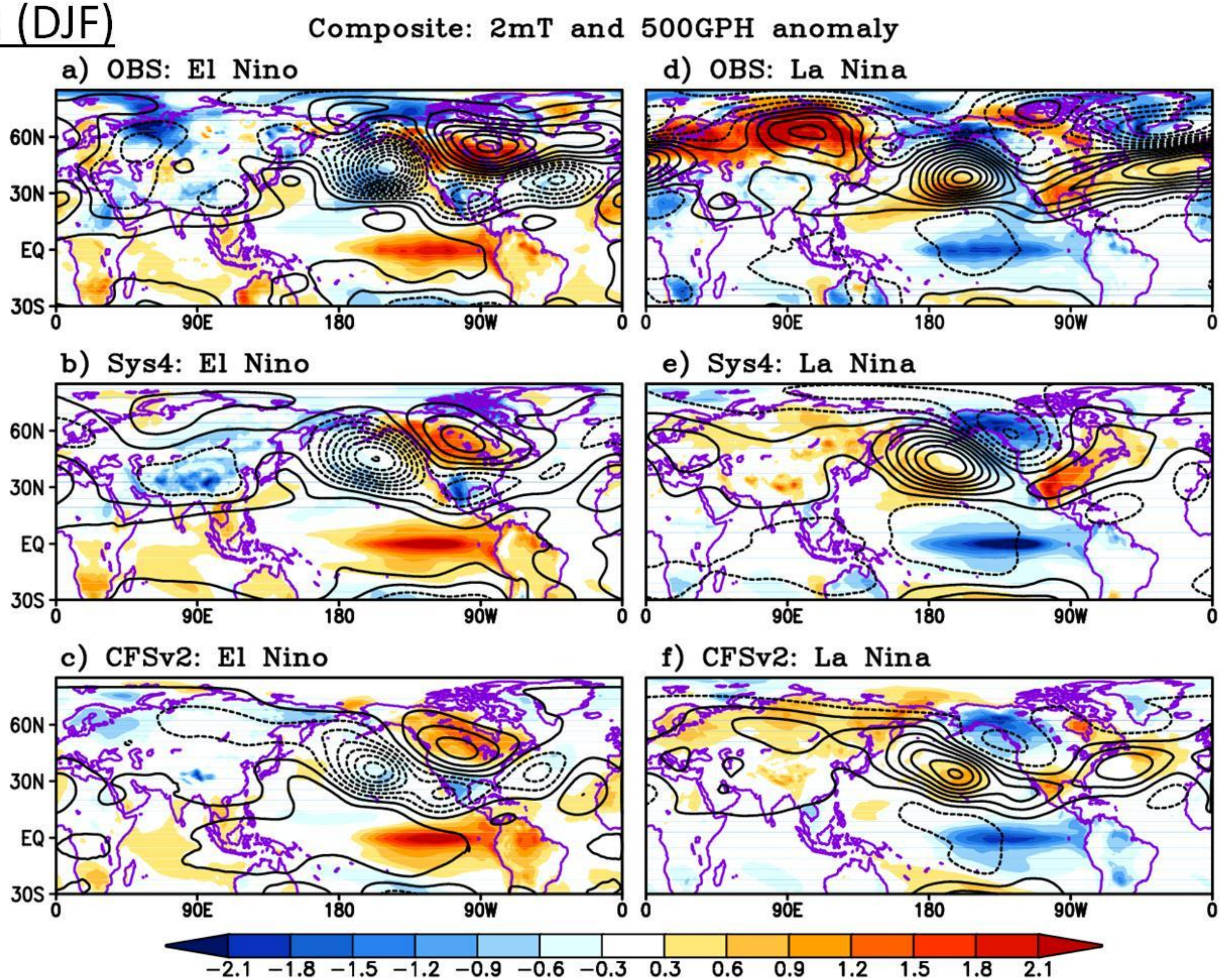
Temperature changes [K/year]



CFSv2: The large warming trend in the eastern Pacific SST is primarily associated with **changes in satellite observing system** that occurred in 1998/1999 period that were assimilated in the CFSR (Xue et al. 2011; Wang et al. 2011).

ENSO teleconnection

ENSO Composites (DJF)



El Nino winters: 82/83, 91/92, 97/98 and 2009/10

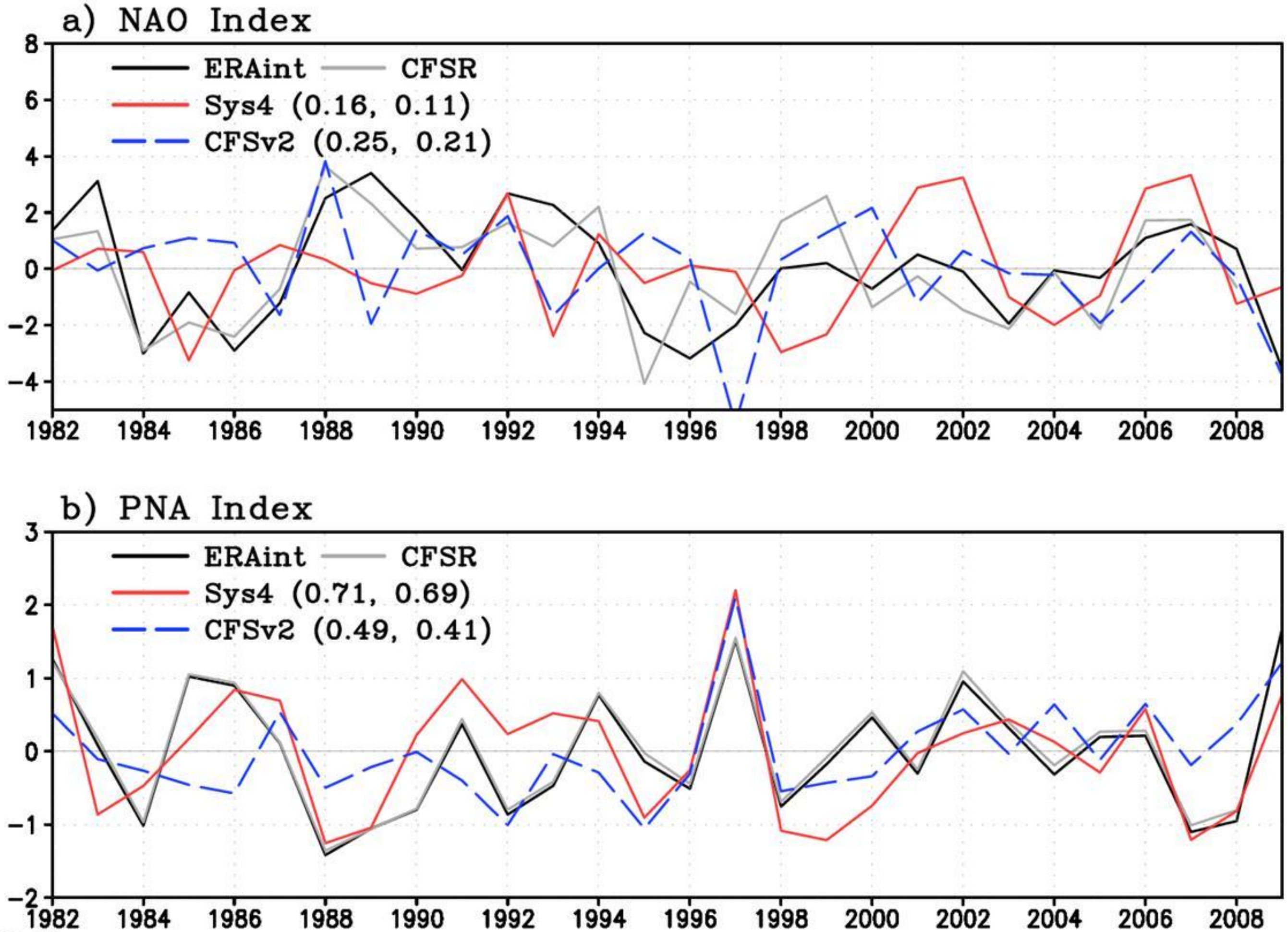
La Nina winters: 88/89, 98/99, 99/00 and 2007/08

* Kim et al. (2012)

Teleconnection

NAO and PNA index (DJF)

- Large scale regimes in the North Atlantic controlling European surface temperatures.
- NAO responsible for > 30% of variance in winter surface air temperature (Hurrell 1995).
- How well do the models predict the dominant winter climate oscillation?



NAO: Li and Wang (2003)
PNA: Wallace and Gutzler (1981)

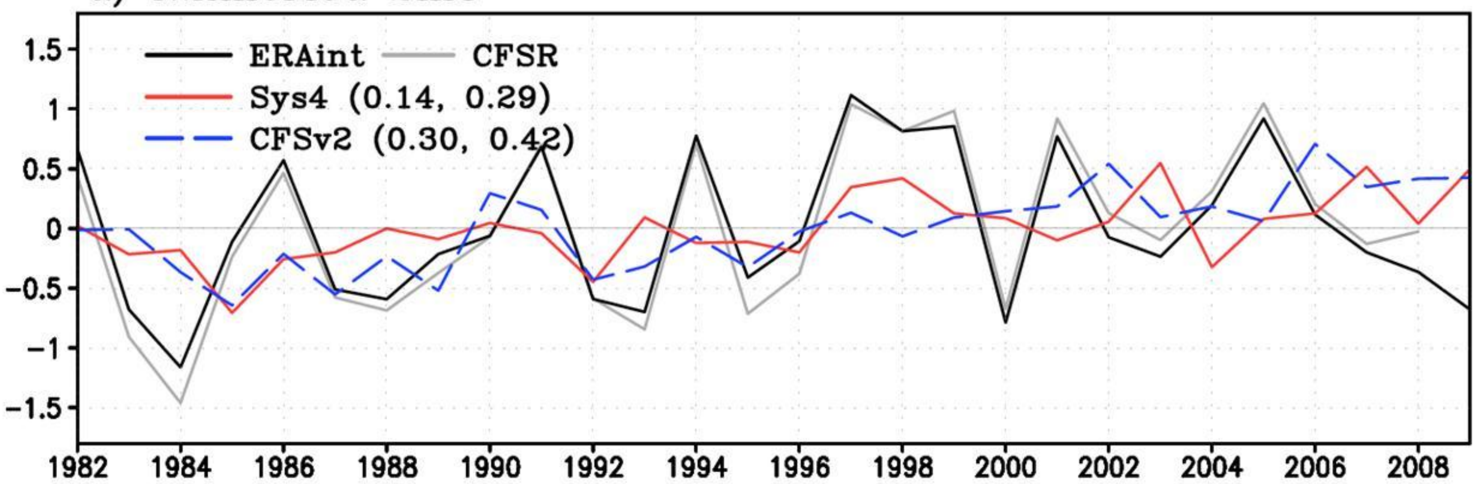
* Kim et al. (2012)

Teleconnection

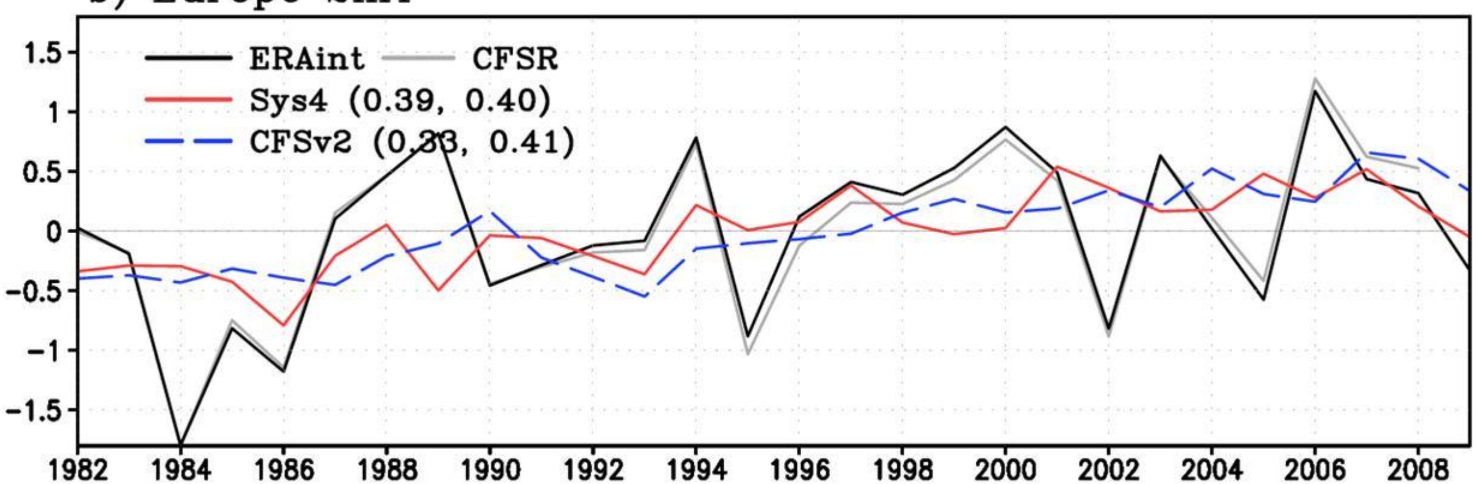
2mT anomaly (DJF)

- How well do the models predict the winter temp. over the N. America and northern Europe?

a) N.America 2mT



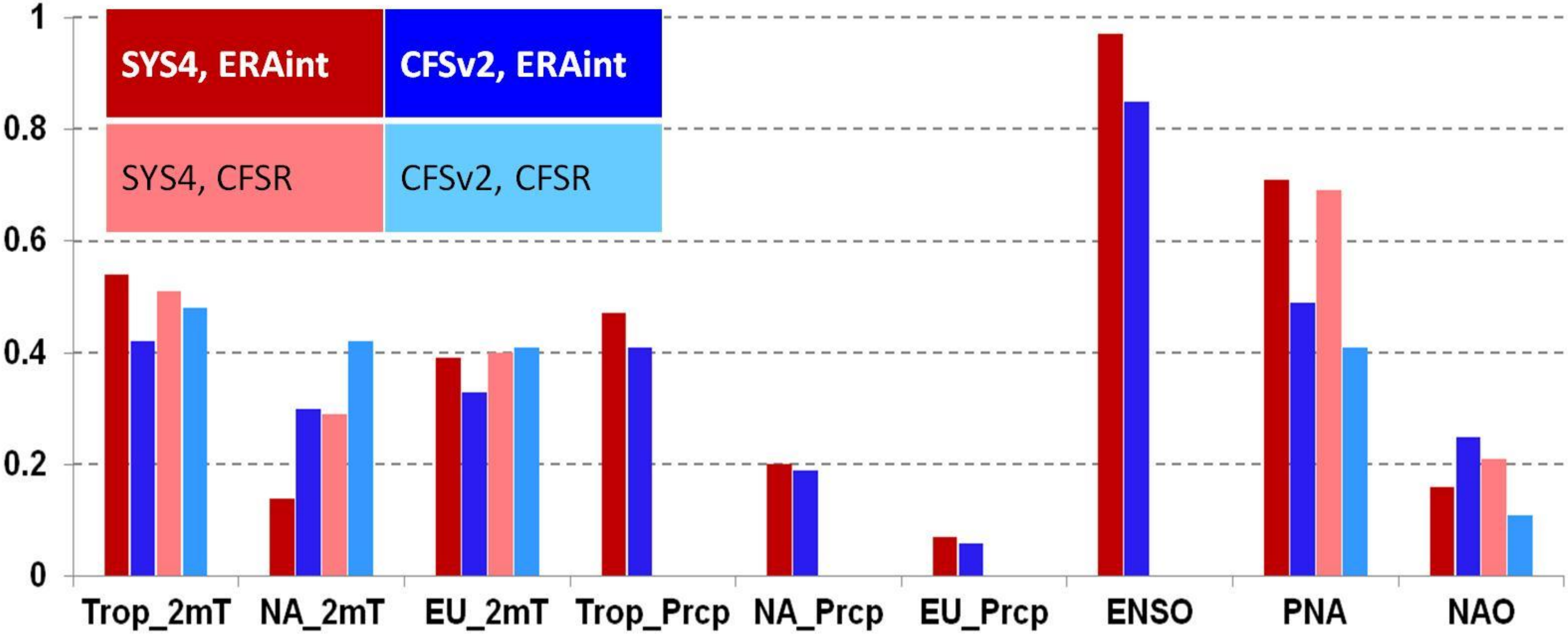
b) Europe 2mT



* Kim et al. (2012)

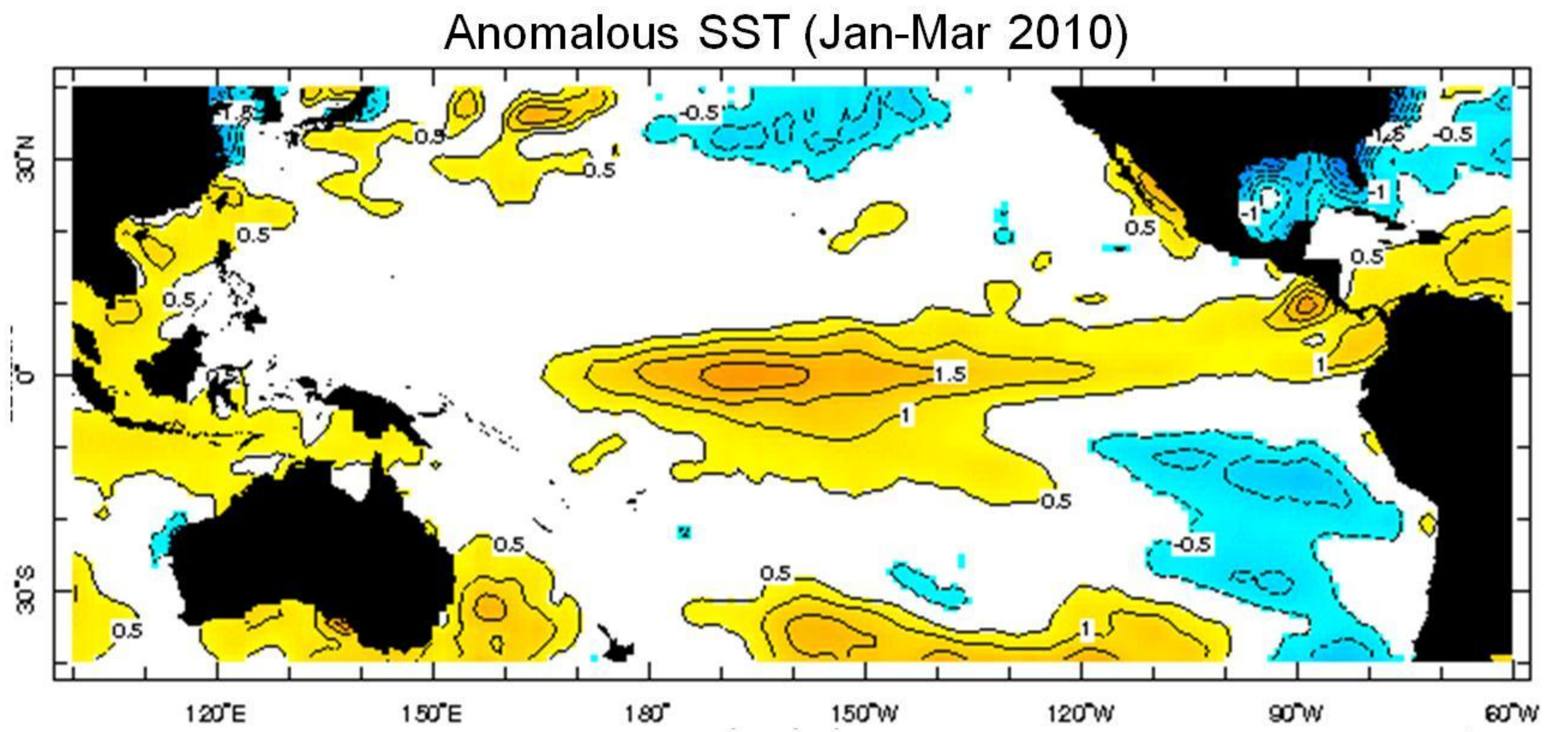
Seasonal prediction skill

System 4 and CFSv2 (DJF)



* Kim et al. (2012)

Central Pacific El Nino



* NCEP, EMC

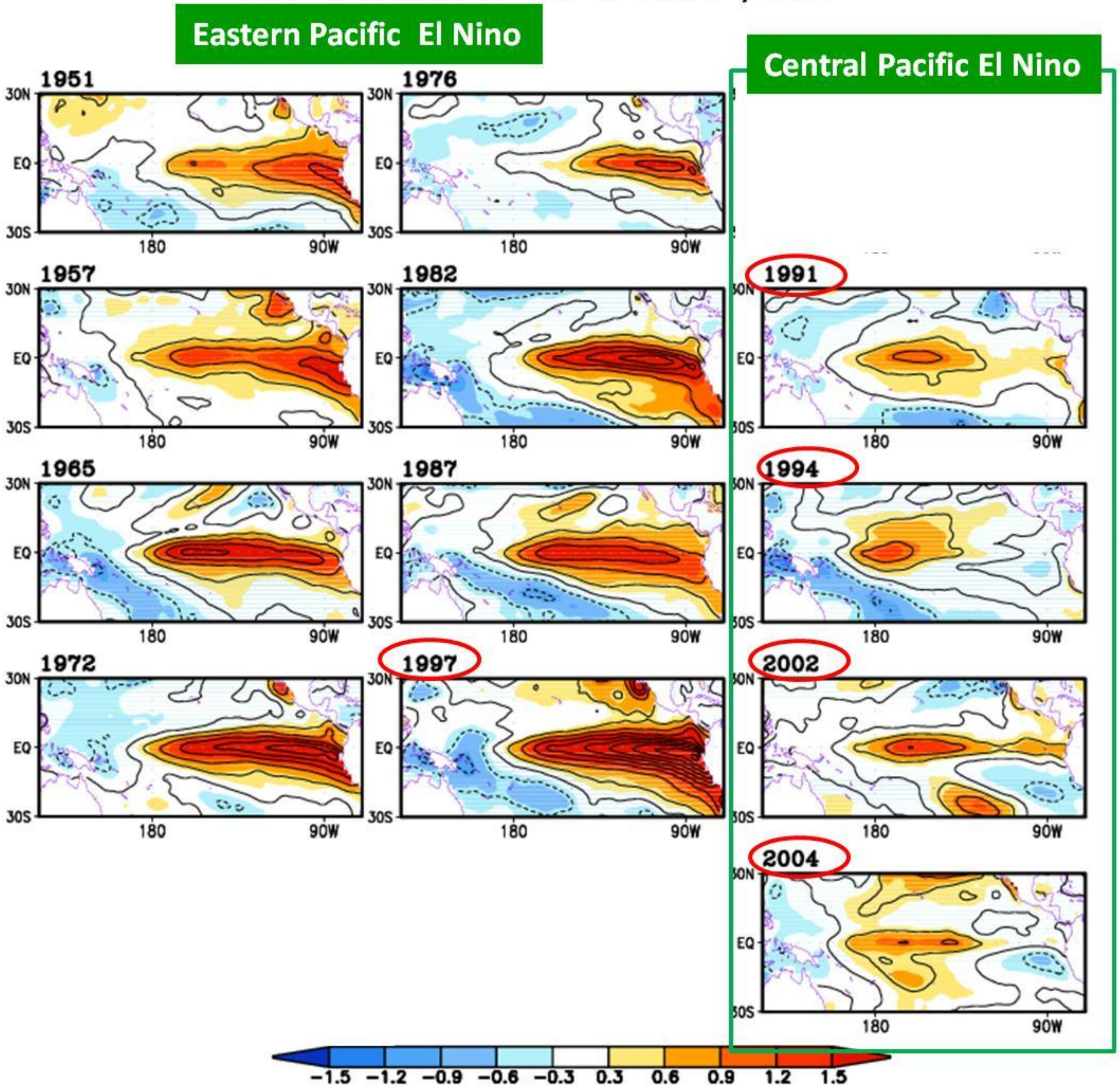
"Central Pacific El Nino, Dateline El Nino, Modoki El Nino, Warm pool El Nino, Central Pacific Warming"

- The **zonal shift of SST anomaly pattern** between the eastern and central Pacific is one of the most obvious differences between the two types El Nino.
- **Global impact** is quite different from the conventional El Nino
- CP El Nino exhibits **stronger variance** in recent decades.

(Trenberth and Stepaniak 2001, Lakin and Harrison 2005, Ashok et al. 2007, Kug et al. 2009, Kim et al. 2009, Weng et al. 2007, 2009, Taschetto and England 2009, Yeh et al. 2009, Kao and Yu 2009, …)

Central Pacific El Nino

SST anomalies for El Nino years



El Nino after 1990s

Most of the CP El Nino happened in and after 1990, indicating that this types of El Nino is very active in recent decades

* Kim et al. (2009)

Central Pacific El Nino

EP-El Nino

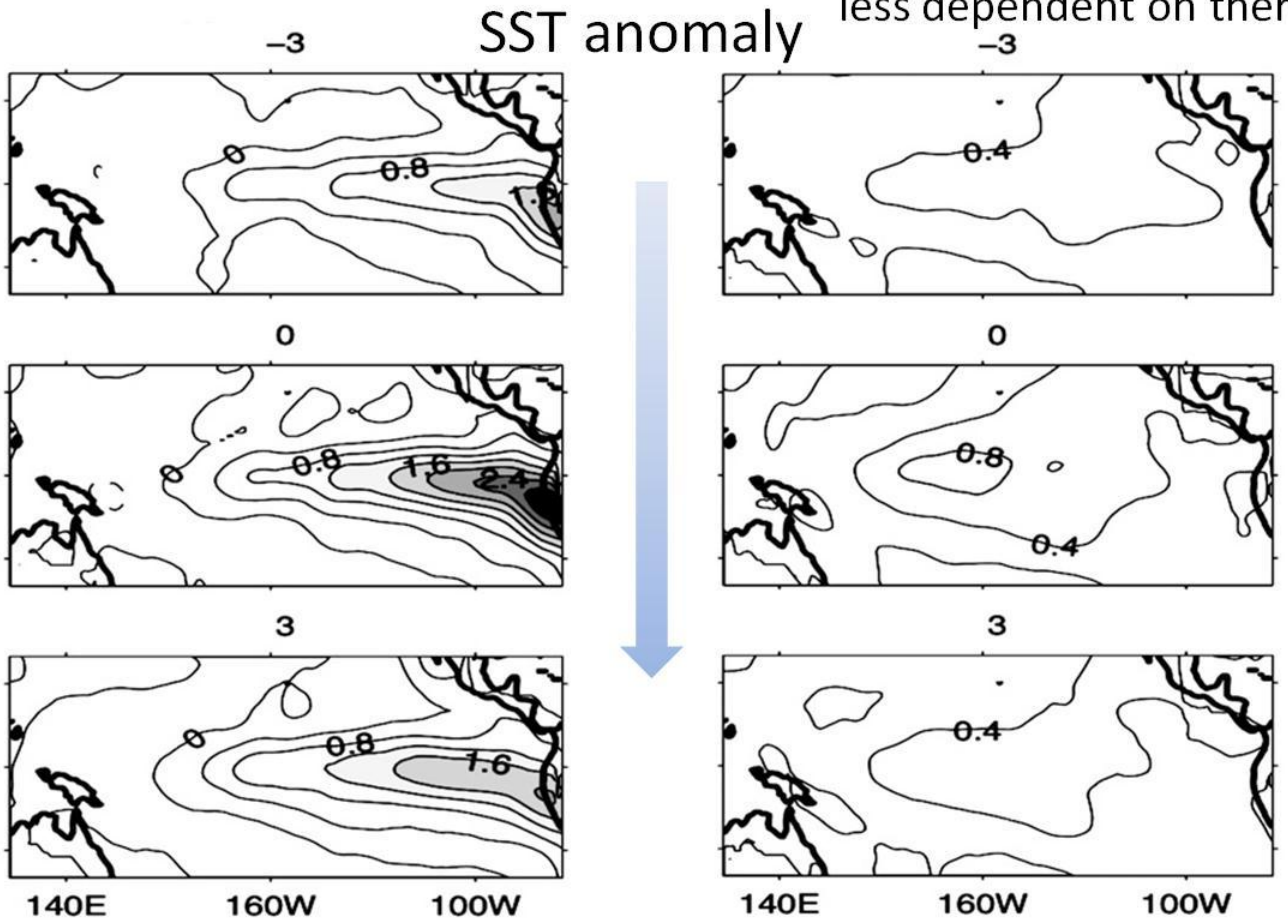
Large scale variability:

Basin-wide thermocline and surface wind variations

CP-El Nino

Local scale variability:

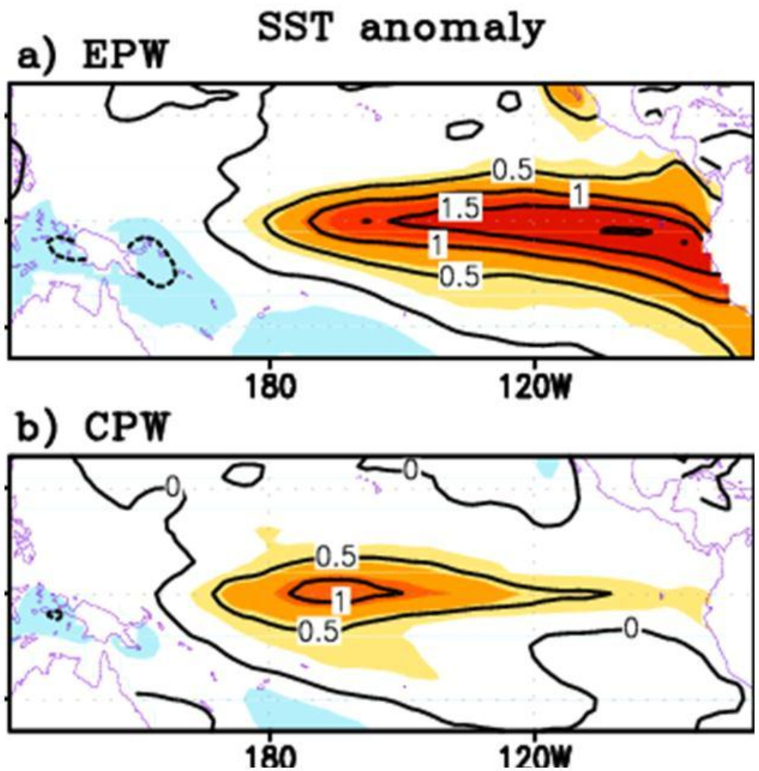
- Confined in the central Pacific and tends to onset, develop, and decay **in situ** in the CP.
- The underlying dynamics of the CP ENSO seems less dependent on thermocline variations.



* Kao and Yu (2009)

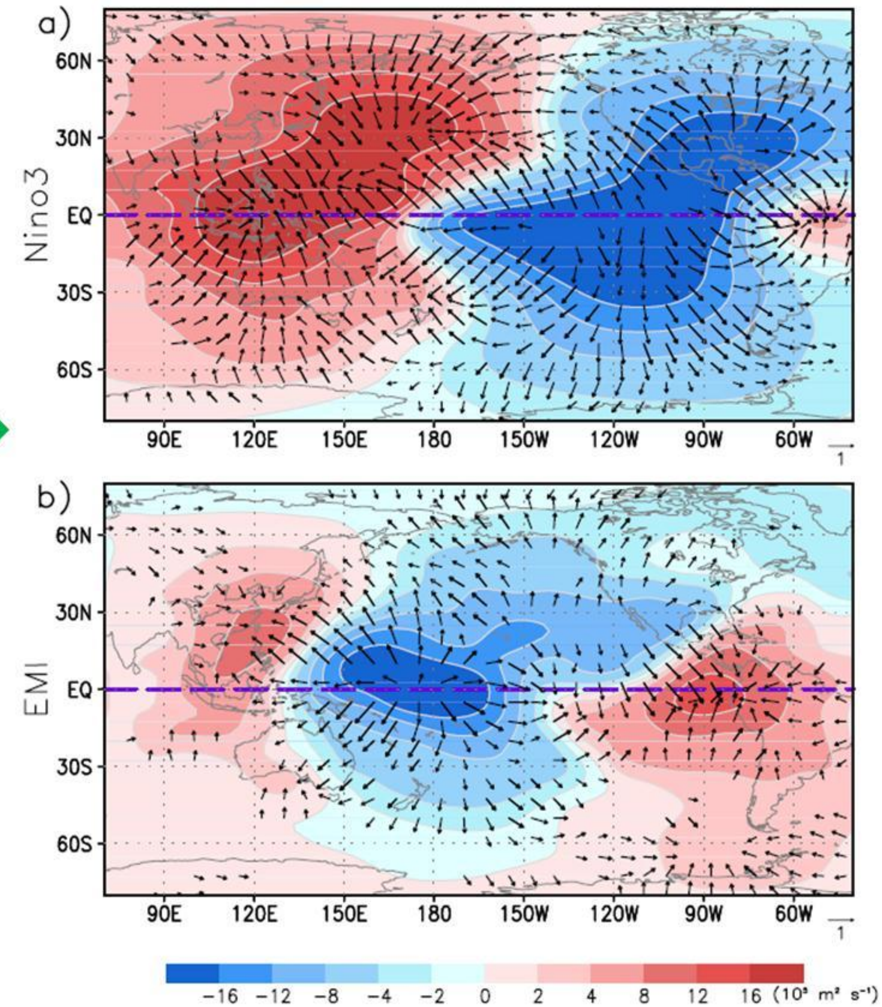
Teleconnection: CP El Nino

Distinct teleconnection pattern



EP

Anomalous 200 hPa velocity potential



CP

* Weng et al. (2009)

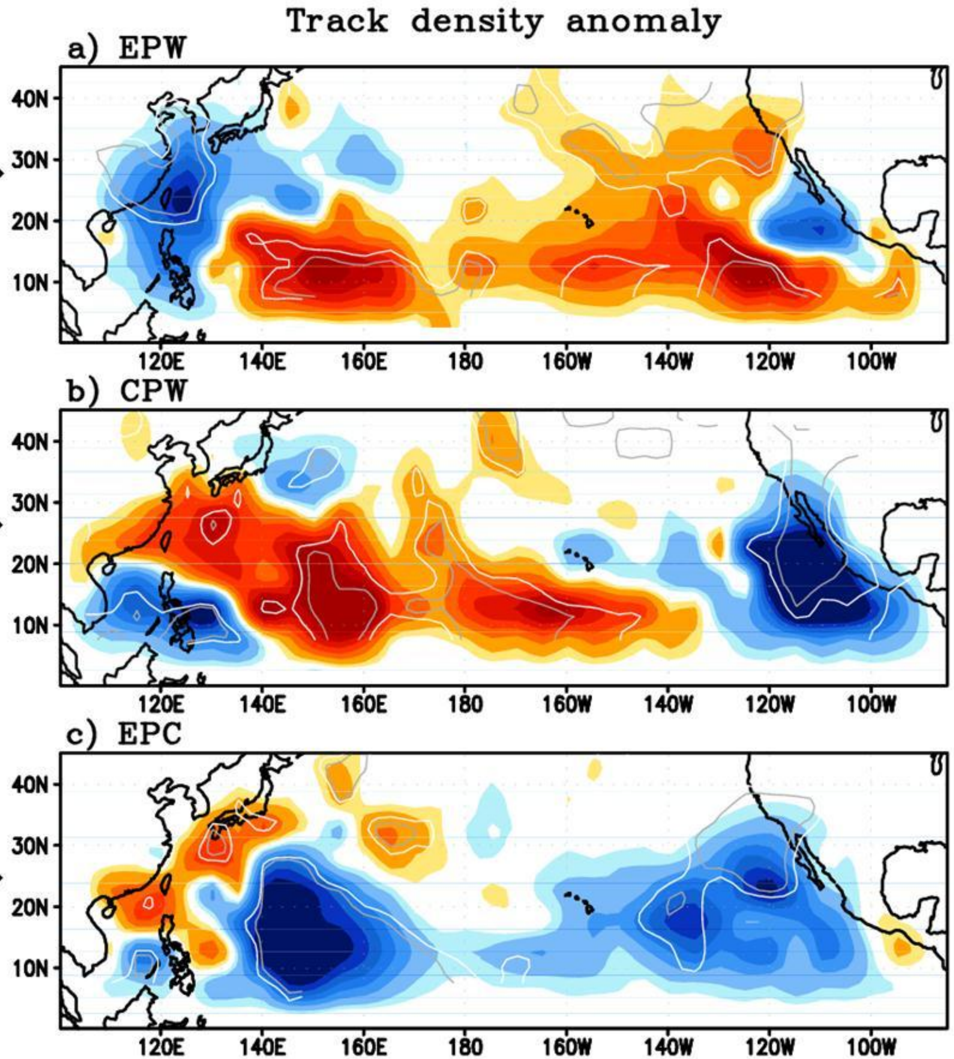
Teleconnection: CP El Nino

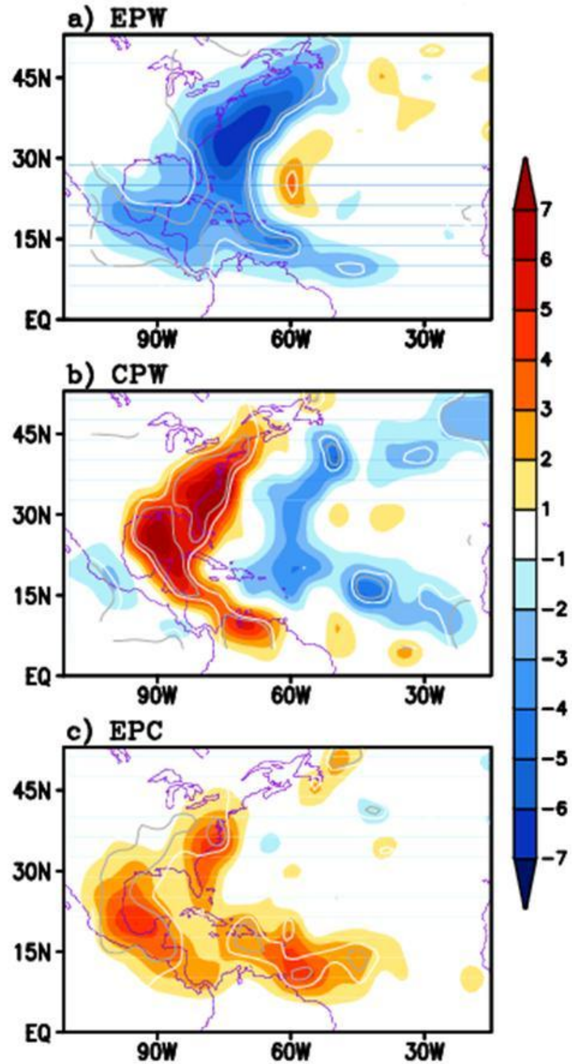
Tropical cyclone activity

EP-El Nino →

CP-El Nino →

La Nina →





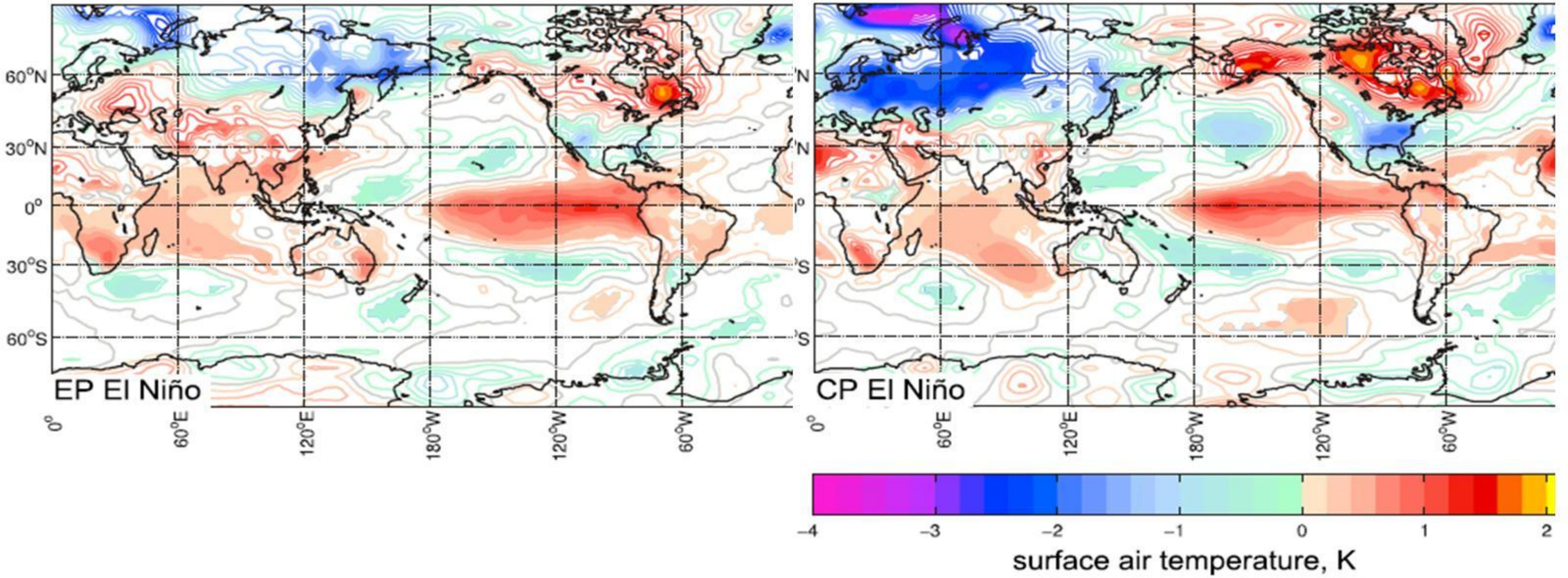
* Kim et al. (2009, 2011)

Teleconnection: CP El Nino

NH Winter sfc. Temperature (NCEP/NCAR Rean)

EP-El Nino

CP-El Nino

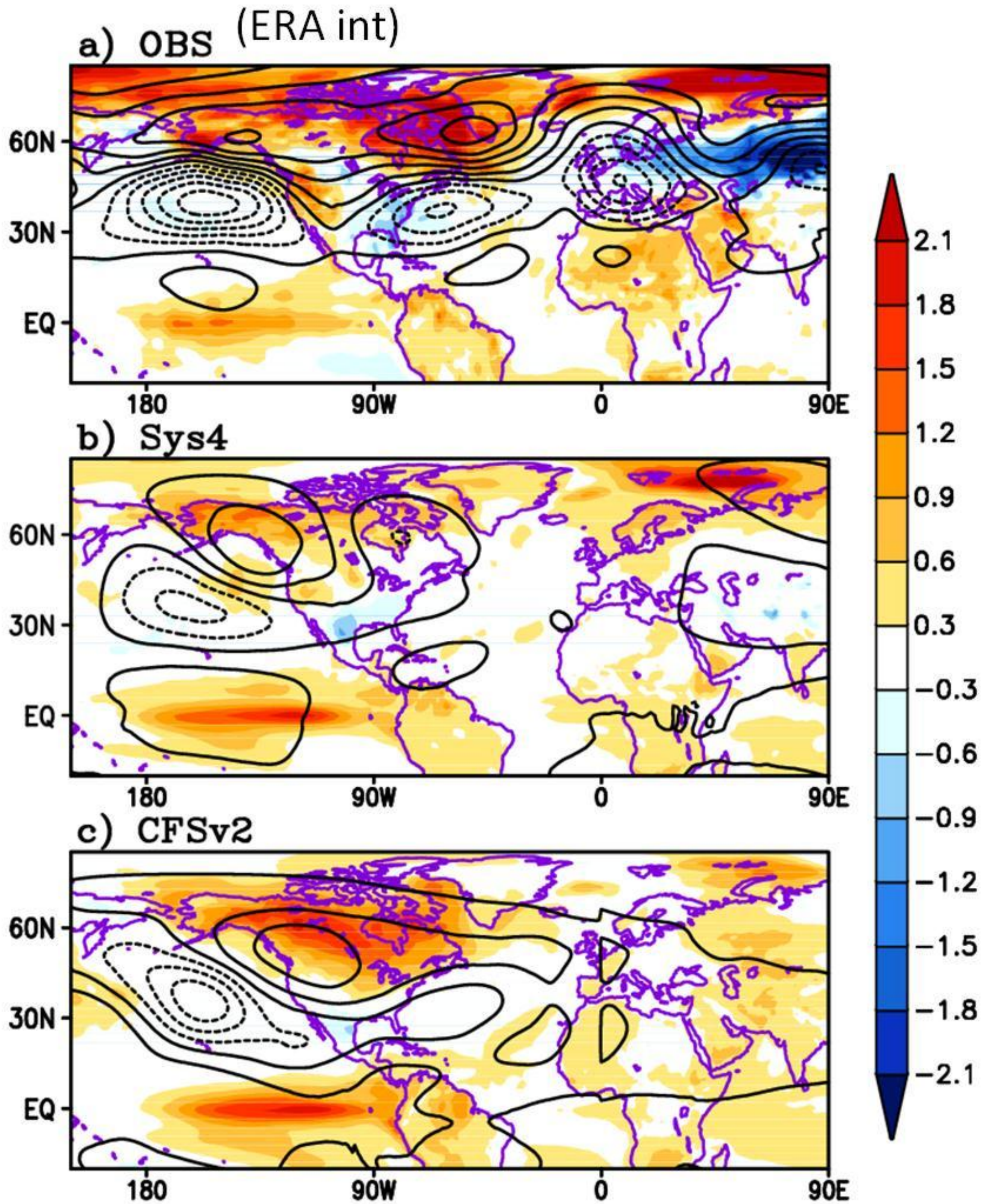


EP El Niños start in 1951, 1957, 1965, 1972, 1976, 1997, 2008
CP El Niños start in 1968, 1977, 1986, 1994, 2002, 2009

Graf and Zanchettin (2012),
"Central Pacific El Nino, the "subtropical bridge", and Eurasian climate (2012, JGR)

Prediction for CP El Nino

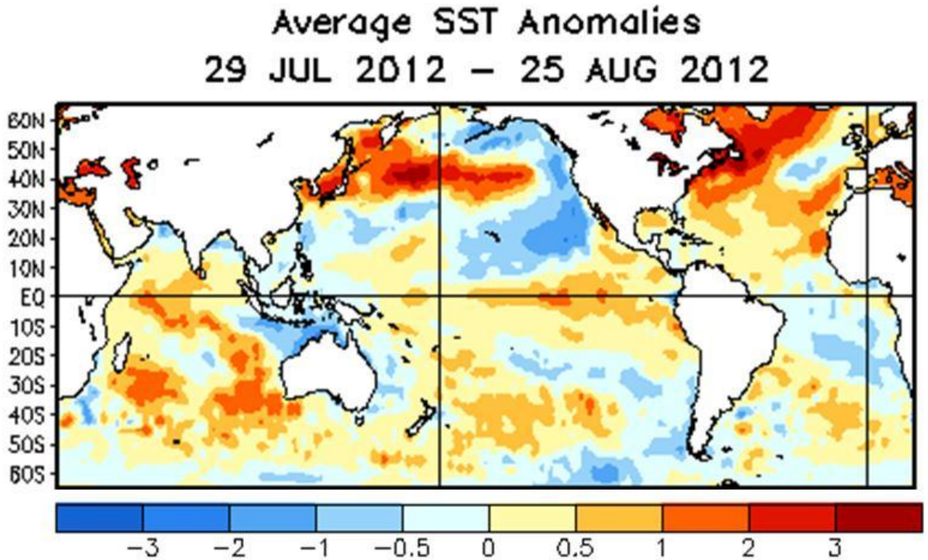
NH Winter 2mT



CP El Nino winters: 1994, 2002, 2004, 2009

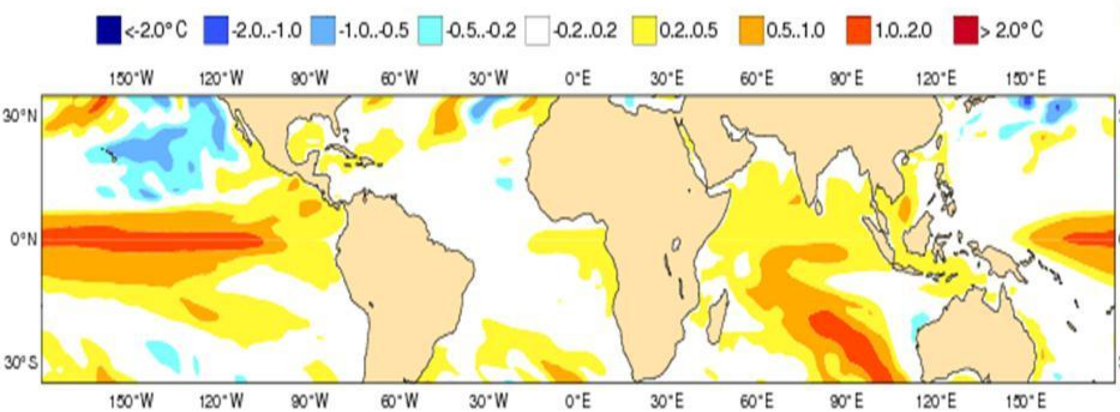
Current SST condition and outlook

- **Current condition →**

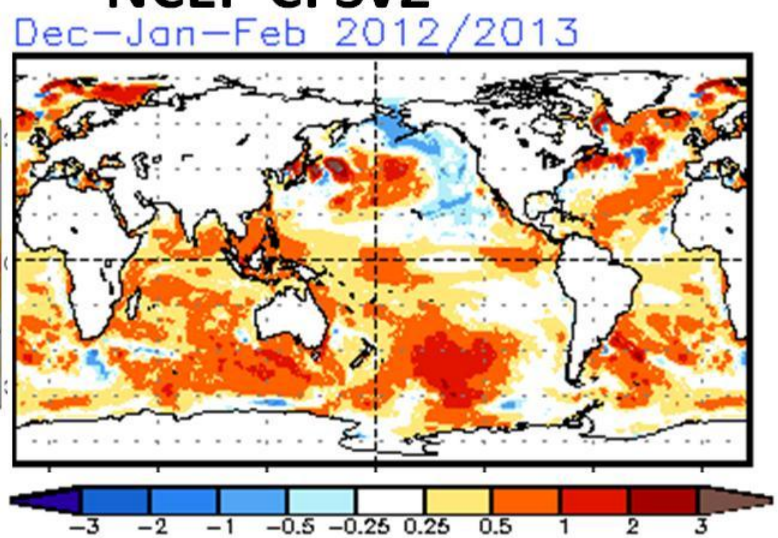


DJF 2012/13 SST forecast (issued Aug 2012)

System 4



NCEP CFSv2



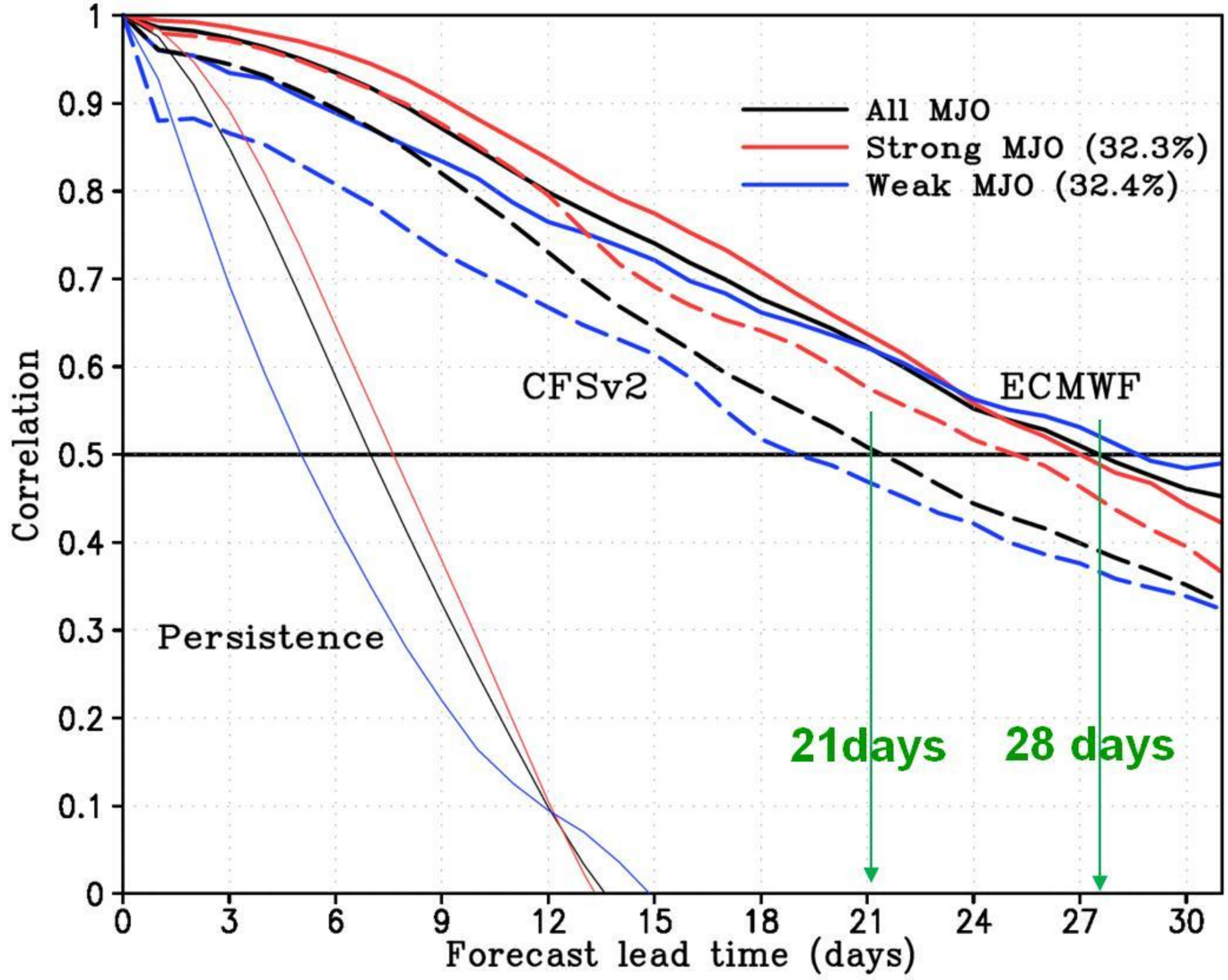
MJO Prediction

	ECMWF Monthly Forecasting system (Hindcast)	NCEP CFSv2
Ensembles	5	3
Forecast lead time	32 days	
Initialization	Once per week	Every day
Hindcast period	2000-2009, Jan-Dec.	
Sample	Total 1080 MJO events	

- Wheeler and Hendon (2004) MJO index (**RMM**, Real-time Multivariate MJO)
- OBS: NOAA OLR, ERA interim (wind)

MJO Prediction

RMM prediction skill

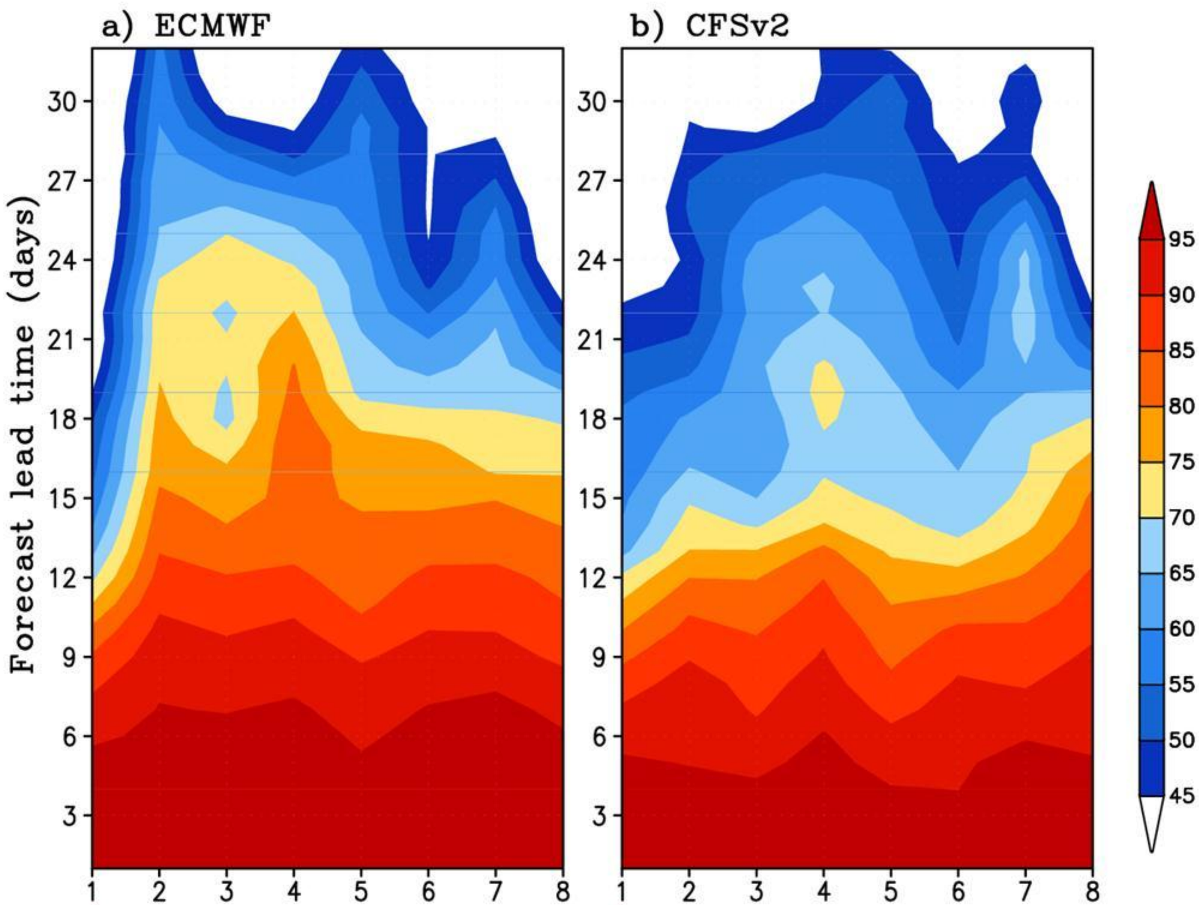


- **Models have higher skill than persistence prediction**
- **For 'All MJO' cases, the useful skill is 28 days for EC and 21 days for CFSv2**
- **The predictive skill is higher when the MJO is strong in the initial condition**

* Kim and Webster (in prep)

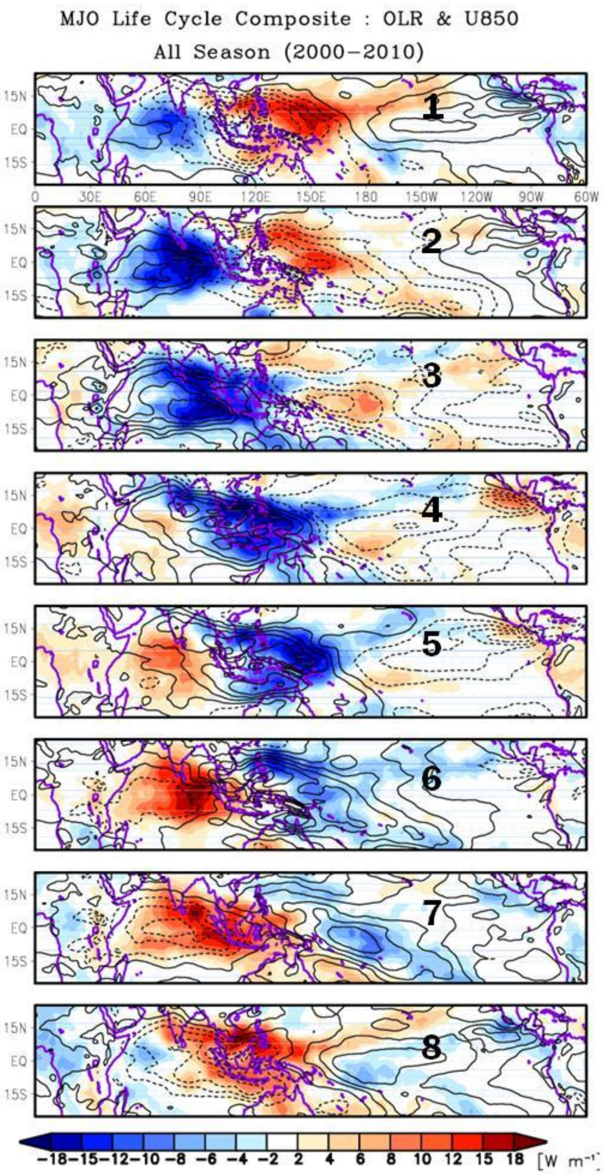
MJO Prediction

RMM prediction skill



(Strong MJO)

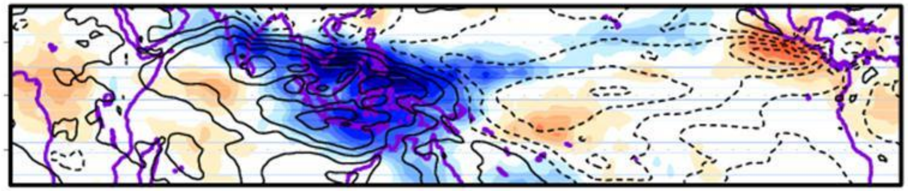
Initial phase



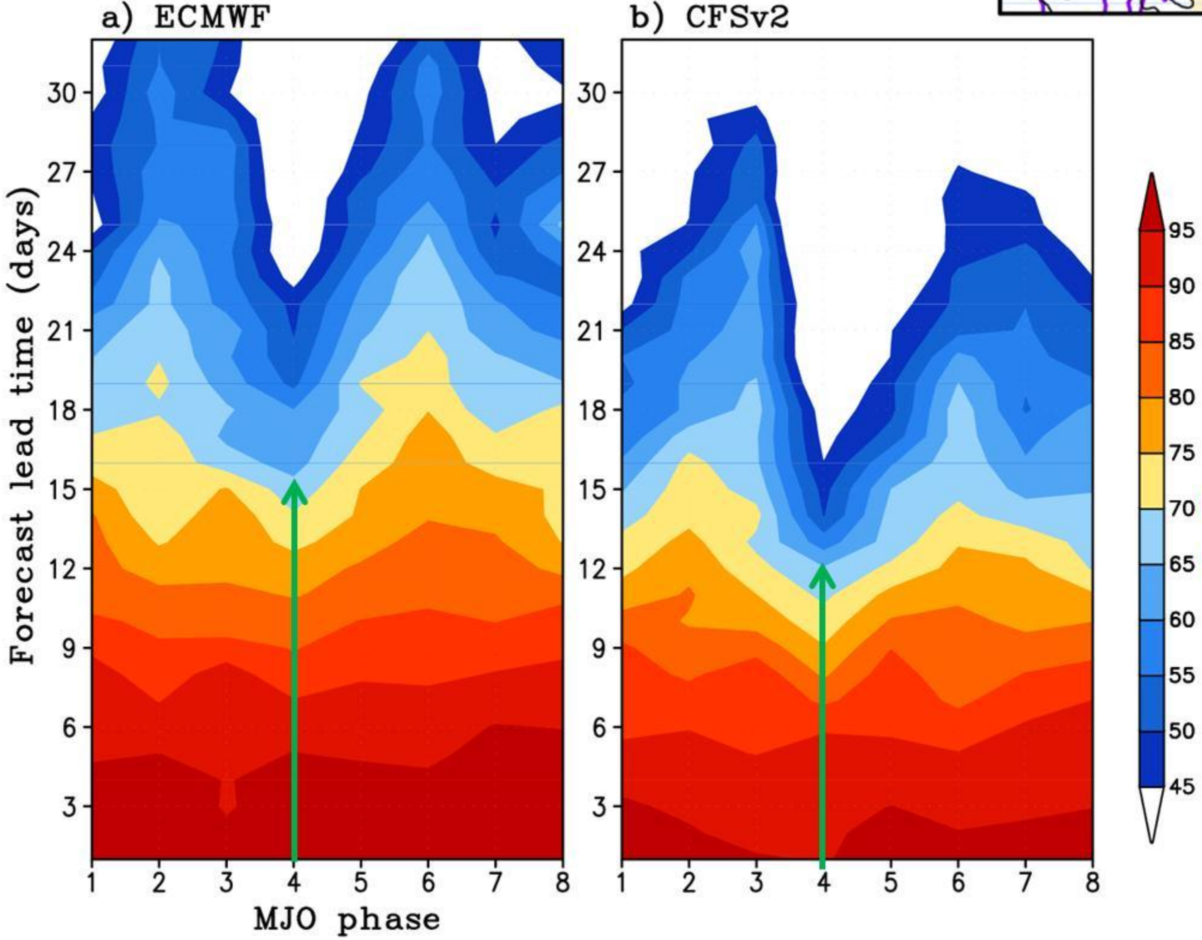
- **Prediction skill drops quickly when MJO is initialized in the Indian Ocean (Phase 1)**

MJO Prediction

RMM prediction skill



Phase 4

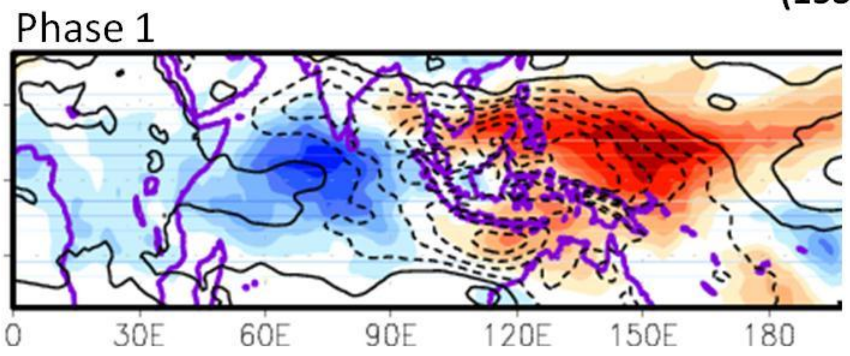


Target phase

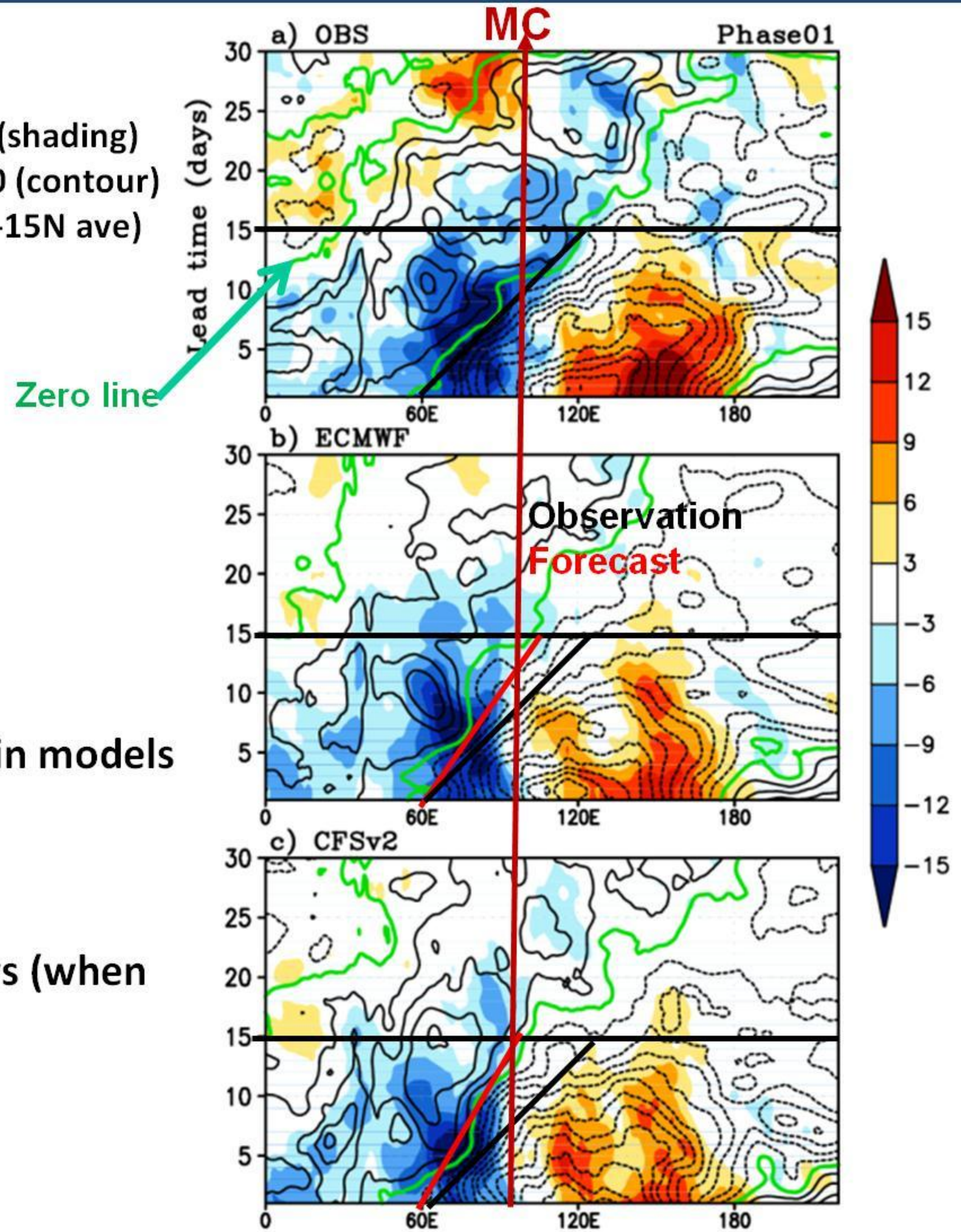
- Current MJO predictions suffer from low skill when enhanced convection is over the Indian Ocean in IC and enters the Maritime Continent ("Maritime Continent prediction barrier")

Evolution of MJO

Composite from initial phase 1

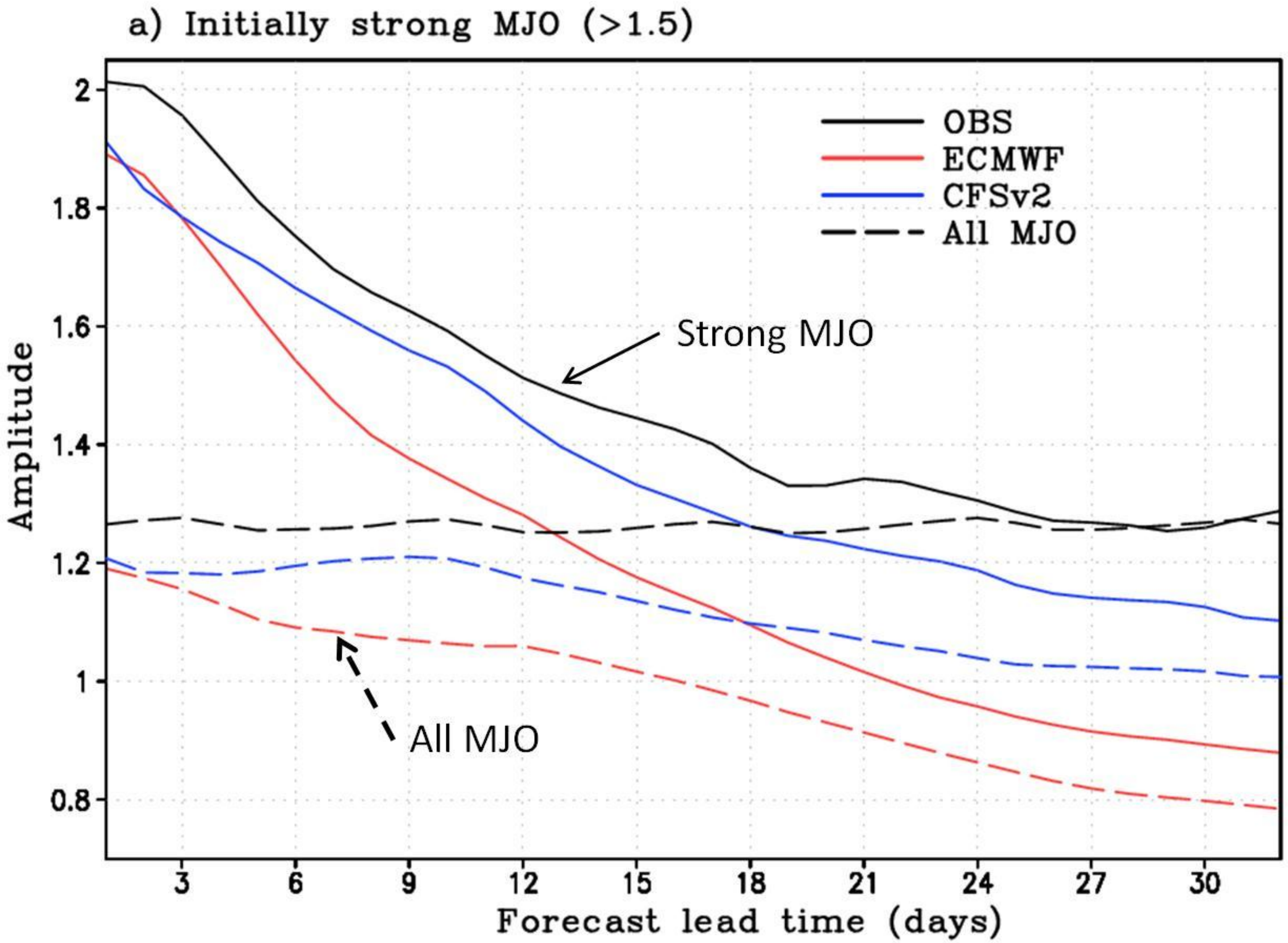


OLR (shading)
U850 (contour)
(15S-15N ave)



- The MC acts as a barrier for propagation in models
- Slow propagation speed in models
- Weaker amplitude in models after 15 days (when MJO is supposed to propagate across MC)

MJO amplitude



- **In forecasts, the MJO amplitude is weaker than observed and decreases faster than observation.**

Summary (I)

- ENSO provides one of the strongest sources of interannual variability in the global climate

- Seasonal climate prediction skill (tropics) depends on the ENSO amplitude: Greater in strong ENSO winter than in weak ENSO winter.

- Seasonal predictability of ENSO and ENSO teleconnection signal is handled well in both systems (System4 and CFSv2).

- However, both systems exhibit a strong ENSO spring predictability barrier.

Summary (II)

- Northern Hemisphere extra-tropical climate oscillation (NAO) and seasonal mean surface temperature in extra-tropics are poorly reproduced in both systems.

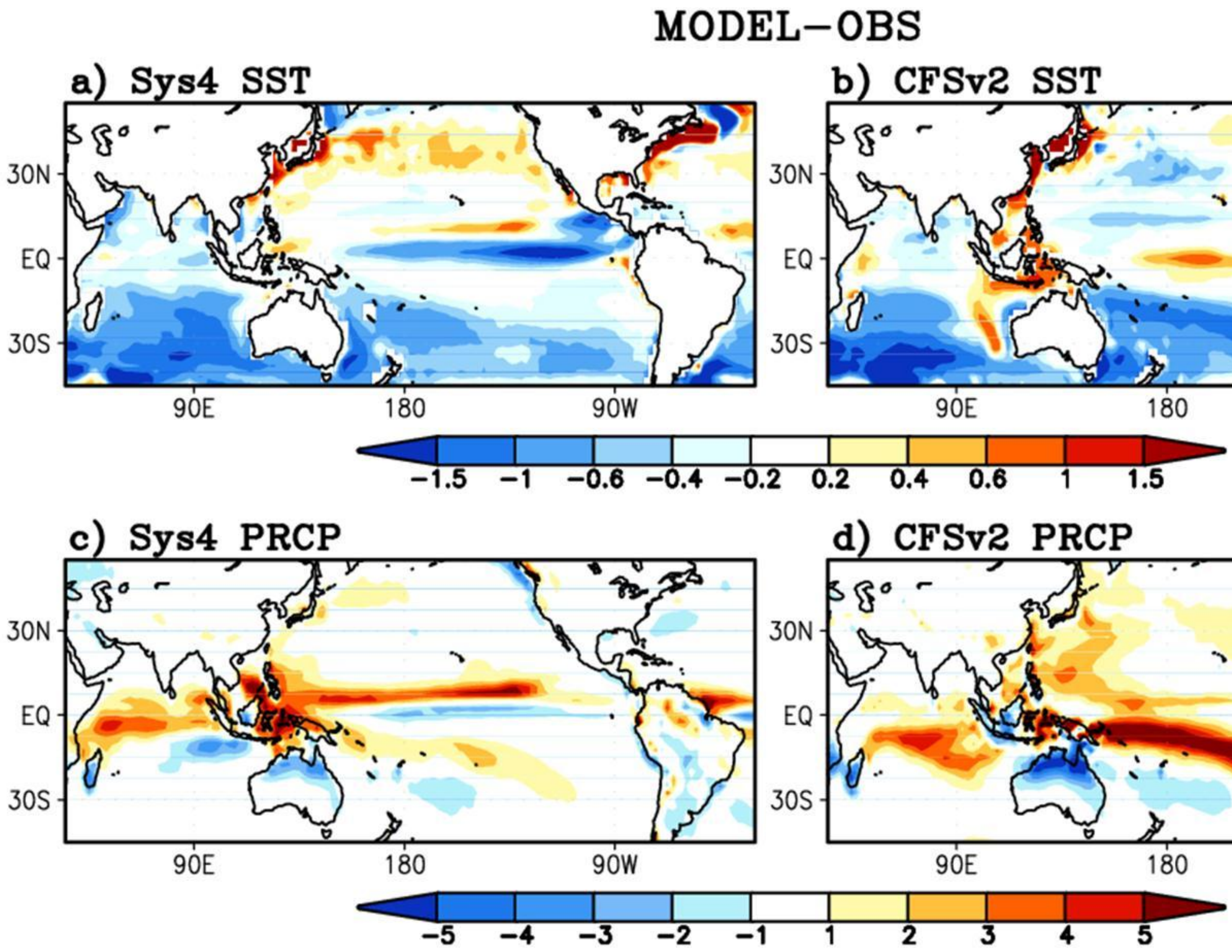
- EP/CP El Nino have very different resulting teleconnections to the global climate.

- MJO prediction shows extended skill (3-4 weeks) in both systems, especially when the MJO is strong in the initial condition. However, MJO amplitude is weaker than the observation.

- The MC acts as a barrier for propagation of the convective component from the Indian Ocean into the western Pacific in model.

Backup slides

Model bias


MODEL−OBS
a) Sys4 SST
b) CFSv2 SST
30N
EQ
30S
90E
180
90W
−1.5
−1
−0.6
−0.4
−0.2
0.2
0.4
0.6
1
1.5
c) Sys4 PRCP
d) CFSv2 PRCP
−5
−4
−3
−2
−1
1
2
3
4
5

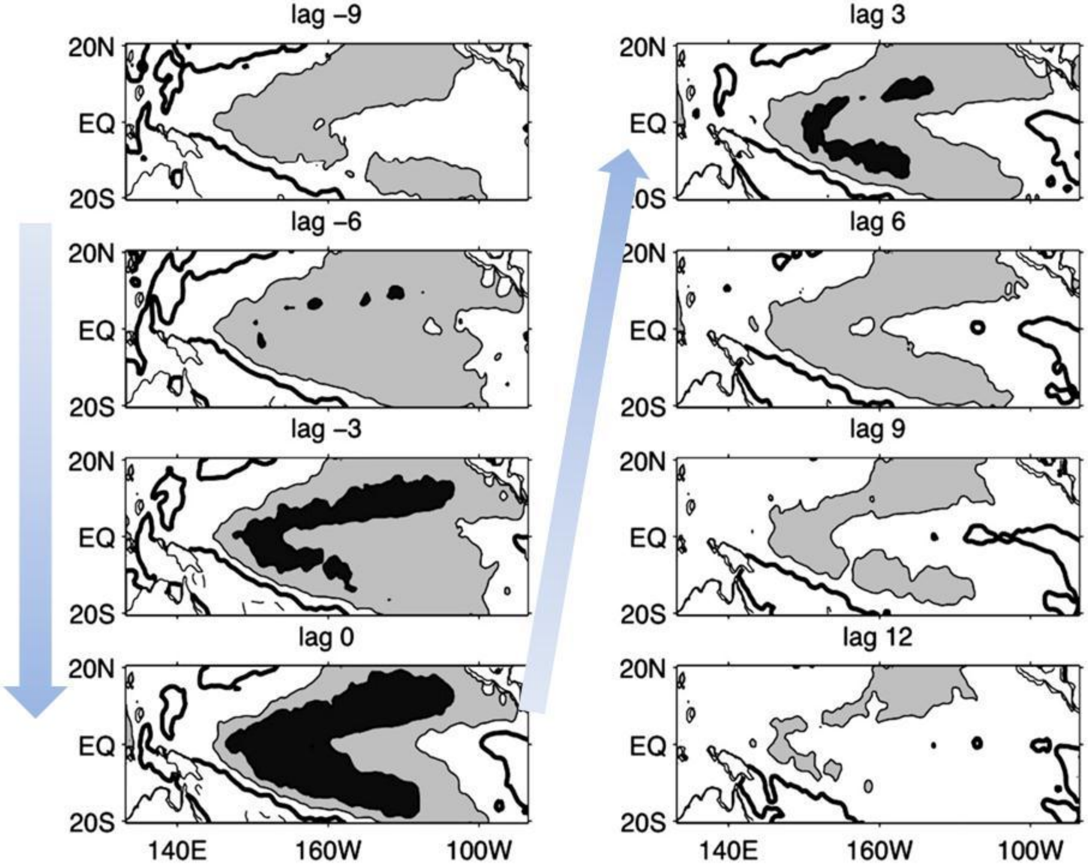
Dynamics of the Central Pacific Warming

Evolution of a CPW

- SST anomalies first **appear** around the dateline
- **Develop** and **mature** in a v-shaped structure with anomalies extending into the subtropics of both hemispheres
- **Decay** in the equatorial central Pacific
- Below the surface, the CPW is associated with ocean temperature anomalies that develop **in-situ** in the central Pacific
- Both the initiation and termination of the CPW occur in the central Pacific.

→ In contrast to the EP ENSO, the underlying dynamics of the CP ENSO seems **less dependent on thermocline variations**

SST anomaly



Kao and Yu (2009)

Dynamics of the Central Pacific Warming

Evolution of a CPW

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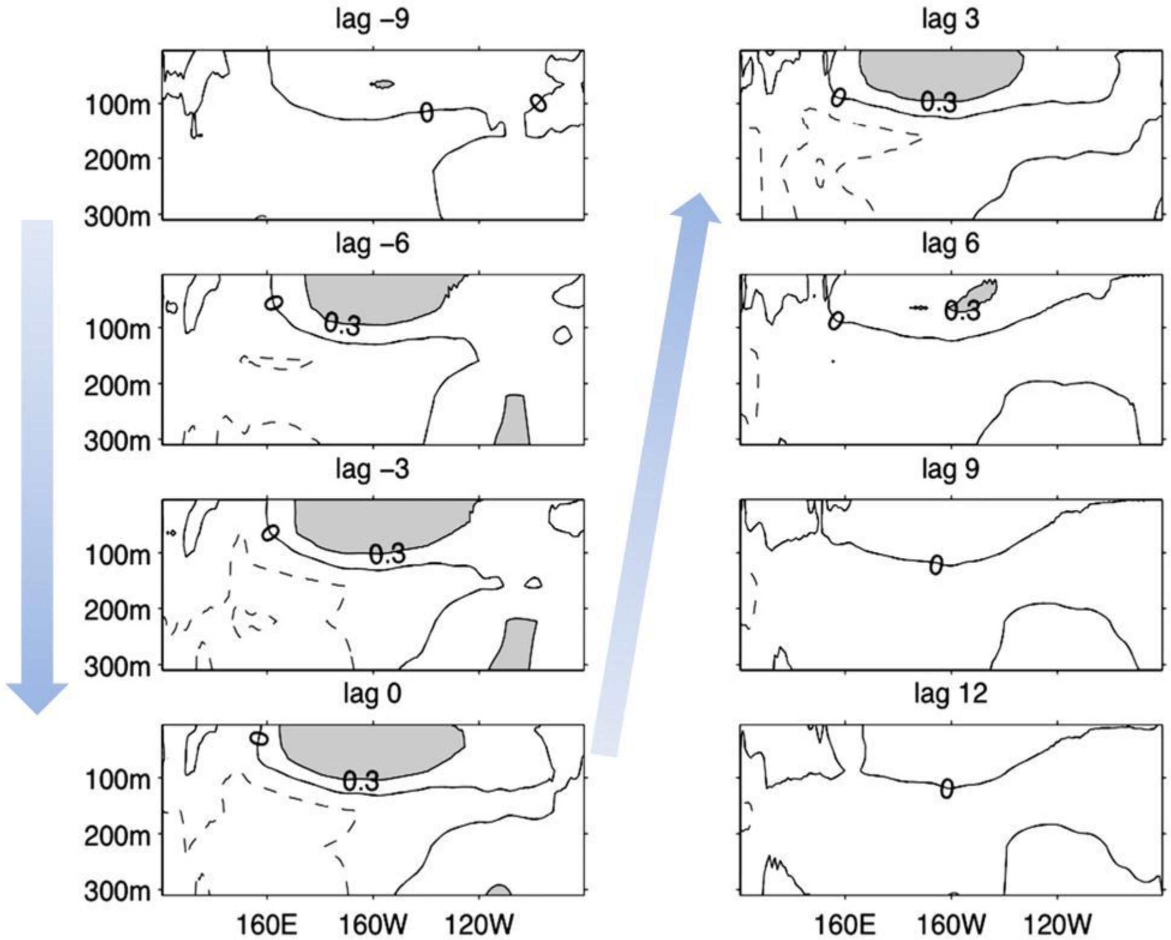
Subsurface Ocean Temperature



Kao and Yu (2009)

Three Theories for the CP ENSO Dynamics

- ❑ **Thermocline Dynamic Theory**: The same thermocline dynamics as the EP ENSO but with the location of upwelling shifted westward (Ashok et al. 2007).
- ❑ **Equatorial Ocean Advection Theory**: Grown by the zonal ocean advection along the equatorial Pacific (Kug et al. 2009).
- ❑ **Extratropical Forcing Theory**: Excited by extratropical forcing and then grown by the equatorial ocean advection (Kao and Yu 2009, Yu et al. 2010, Yu and Kim 2011).

Why does CPW happen?

• **Global warming**: The recent increase in the occurrence of the CPW is related to a weakening of the mean Walker circulation and a flattening of the mean thermocline in the equatorial Pacific, which might be a result of global warming
(Yeh et al. 2009, Vecchi et al. 2007)

• **Natural multidecadal variability** (Newman et al. 2011, McPhaden et al. 2011)

-Extratropical SLP variations can be precursors to CPW.
-Extratropical forcing is particularly important to the generation of the CPW (Yu and Kim 2011).

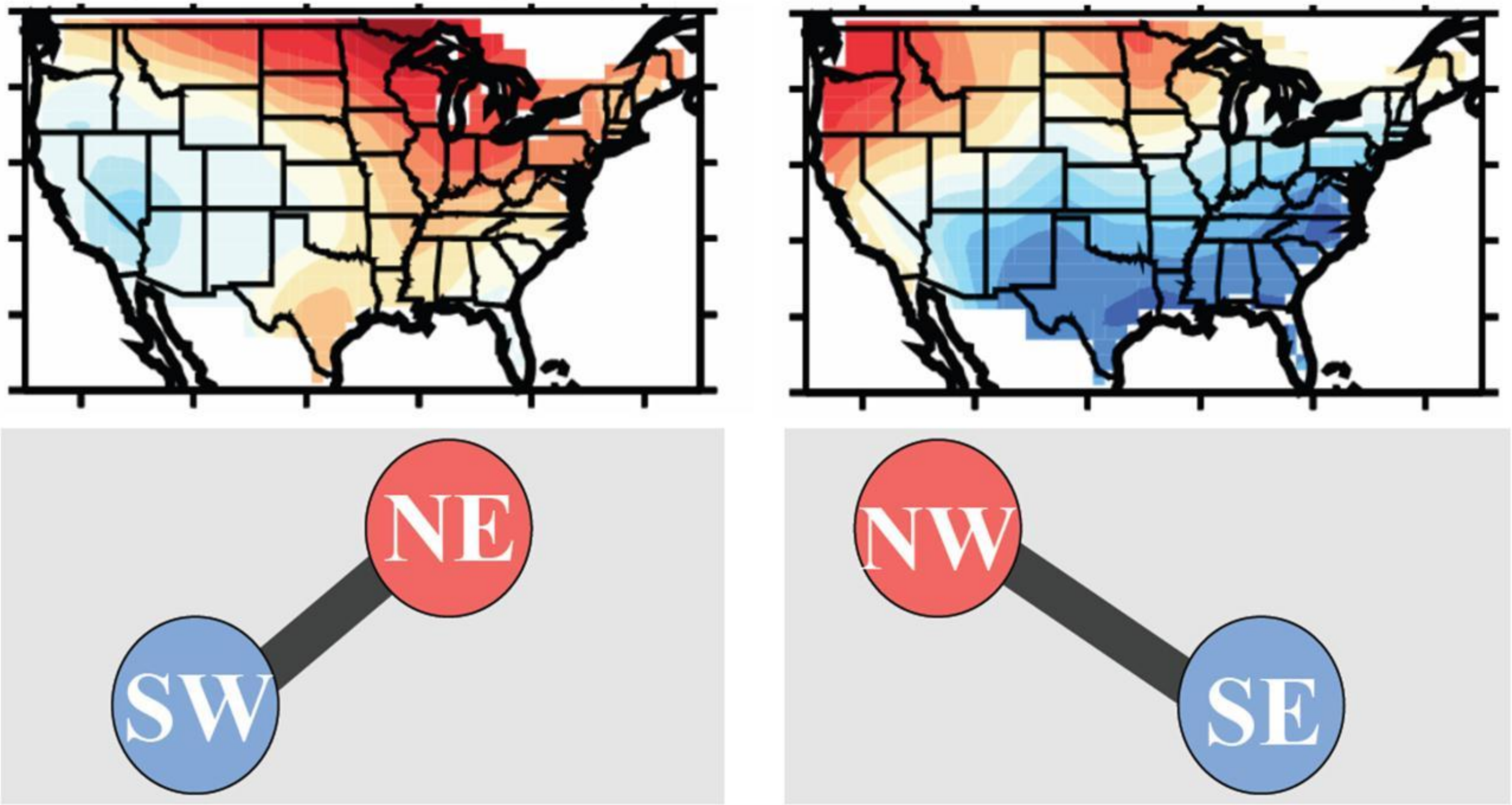
Teleconnection: CP El Nino

Regressed US Winter (JFM) Temperature

(1948-2010)

With EP El Nino Index

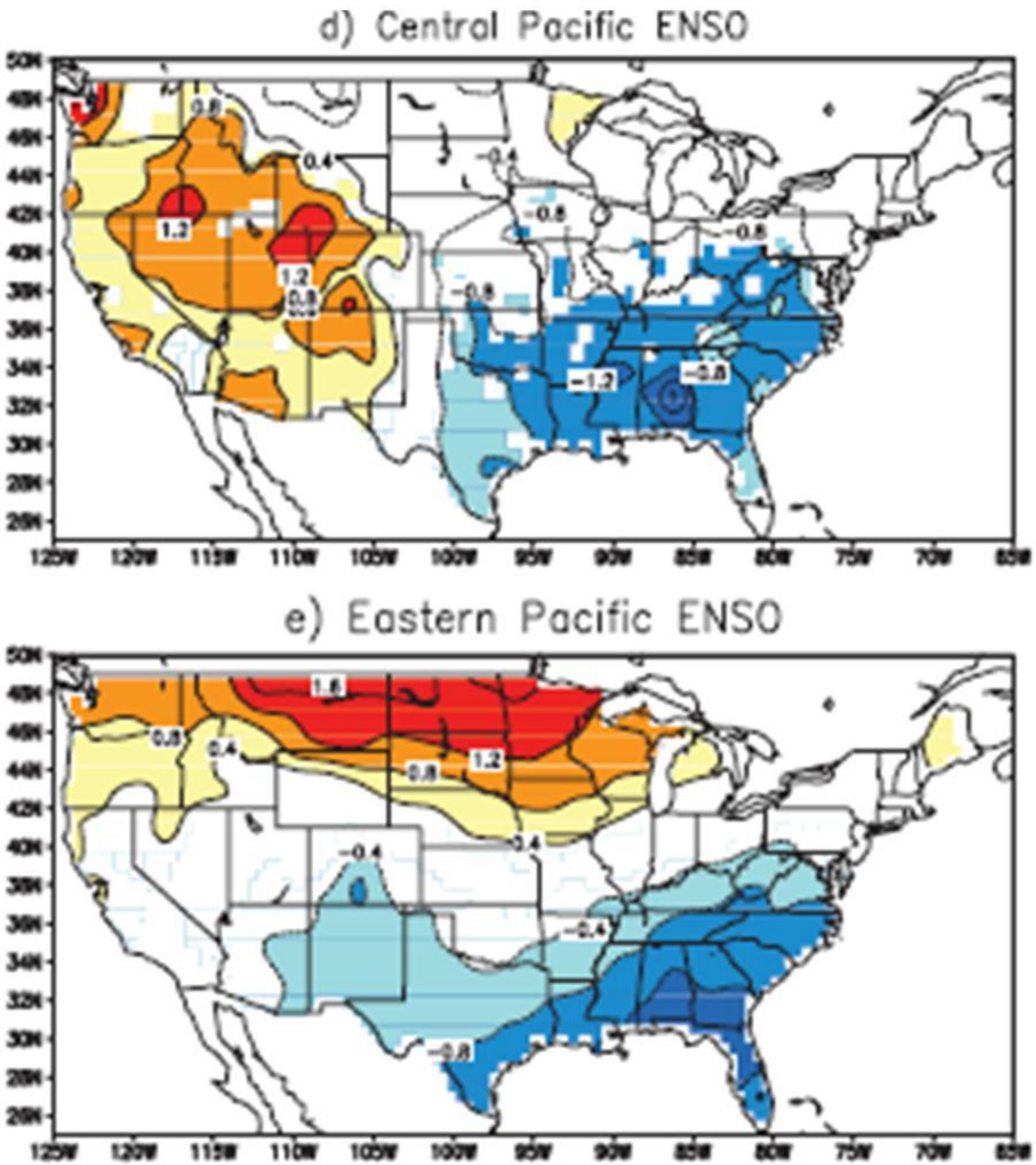
With CP El Nino Index



* Jin-Yi Yu et al.

Teleconnection: CP El Nino

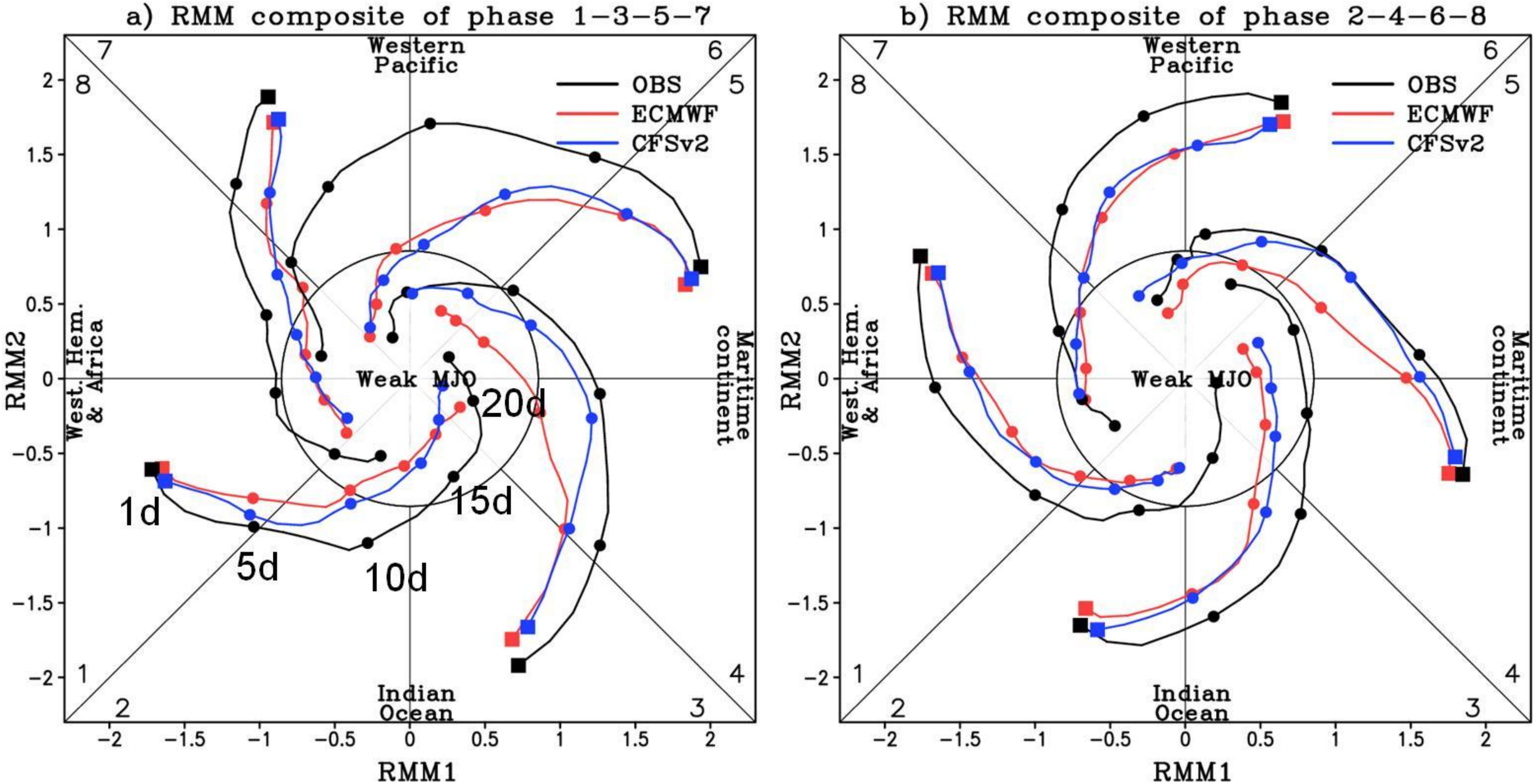
US Temperature



*** Mo (2010)**

Evolution of MJO phase and amplitude

20 day prediction



• Models has weaker amplitude when MJO is initialized in phase 1, but strong amplitude in phase 5 compared to other phases (similar to the observation)

• In ECMWF, the MJO amplitude is weaker than observation throughout the entire phases