The Abdus Salam
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1956-12

Targeted Training Activity: Seasonal Predictability in Tropical Regions to be followed by Workshop on Multi-scale Predictions of the Asian and African Summer Monsoon

4 - 15 August 2008

Predictability of ENSO and Monsoon.

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Predictability of ENSO and Monsoon

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Thanks to J. Shukla, J. Kinter, V. Krishnamurthy, J.-S. Kug, F.-F. Jin

COLA/GMU **Univ. of Hawaii**

Outline

- **Current Status of ENSO Predictability in CGCMs**
  - **Inherent limits to predictability**
  - **Model Flows**

- **Current Status of Monsoon Predictability in CGCMs**
  - **Intrasesasonal and seasonal predictability**
  - **ENSO-Monsoon relationship**

- **ENSO-Monsoon Relationship in GCM Experiments**
  - **Role of tropical Pacific SST anomalies**

Model Description and Experimental Design

APCC CLIPAS

5 CGCMs

- 1980 – 2004
- 4 case of initial time (Feb, May, Aug, Nov)
- 3-15 member
- 5-9 months duration

DEMETER

7 CGCMs

- 1980 – 2001
- 4 case of initial time (Feb, May, Aug, Nov)
- 9 ensemble member
- 6 months duration

	Lead month	run	Period	AGCM	OGCM
FRCGC SINTEX-F	6	9	82-04	ECHAM 4 T106 L19	OPA 8.2 2x2 L31
NASA	5	3	80-04	NSIPP 1 2x2.5 L34	Poseidon V4 1/3x1 L40
SNU	6	6	60-01	SNU T42 L21	MOM 2.2 1/3x1 L32
UH	6	10	83-03	ECHAM 4 T31 L19	UH Ocean 1x2 L2
NCEP CFS	9	15	81-03	GFS T62 L64	MOM 3 1/3x5/8 L27

	AGCM	OGCM
CERFACS	ARPEGE T63 L31	OPA 8.2 2.0x2.0 L31
ECMWF	IFS T95 L40	HOPE-E 1.4x0.3-1.429 L29
INGV	ECHAM 4 T42 L19	OPA 8.1 2.0x0.5-1.5 L31
LODYC	IFS T95 L40	OPA 8.2 2.0x2.0 L31
Meteo-France	ARPEGE T63 L31	OPA 8.0 192-152, L31
MPI	ECHAM-5 T42 L19	MPI-IM1 2.5x0.5-2.5 L23
UK Met Office	HadAM3 2.5x3.75 L19	GloSea OGCM 1.25x0.3-125 L40

What is limiting the ENSO predictability?

✓ **Model Flaws**
→ **mean error, phase shift, different amplitude, and wrong seasonal cycle, etc**

✓ **Flaws in the way the data is used**
→ **data assimilation and initialization; chaos within non-linear dynamics of the coupled system**

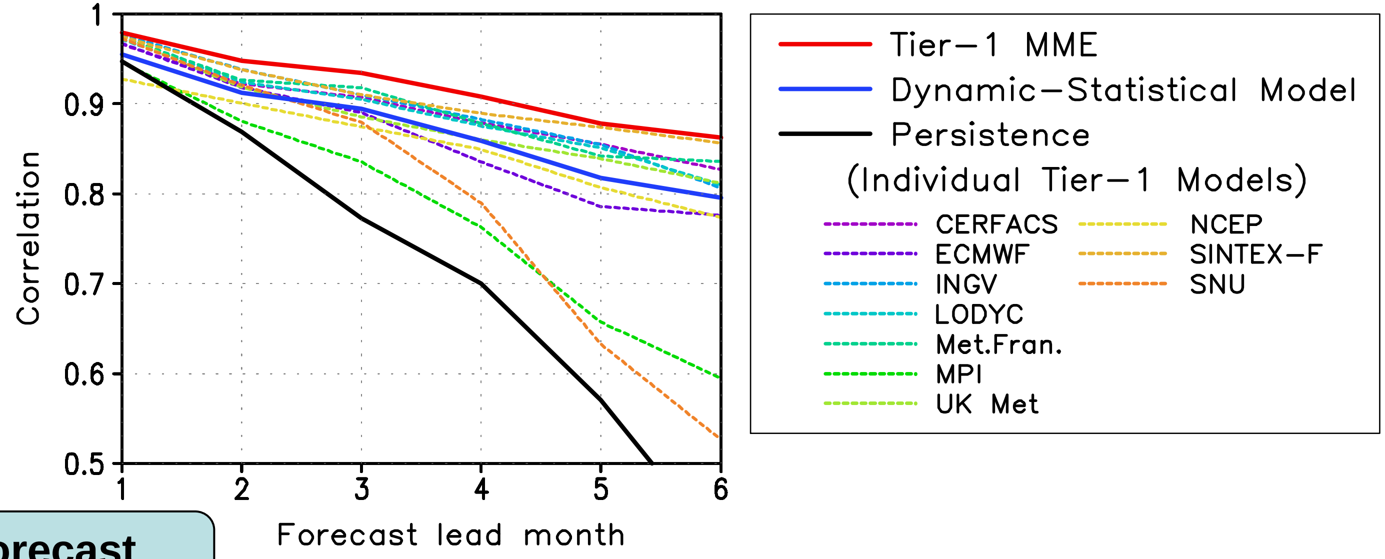
✓ **Inherent limits to predictability**
→ **some times are more predictable than others; amplitude of SST anomalies with respect to ENSO phase**

✓ **Gaps in the observing system**

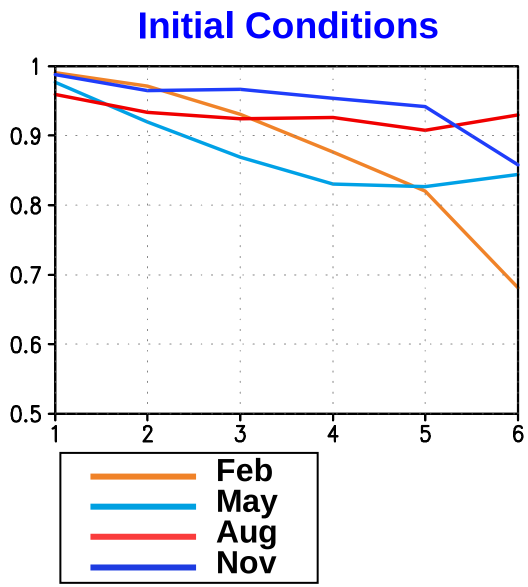
Thanks to Prof. Mark Cane (TTA/ICTP, 2008)

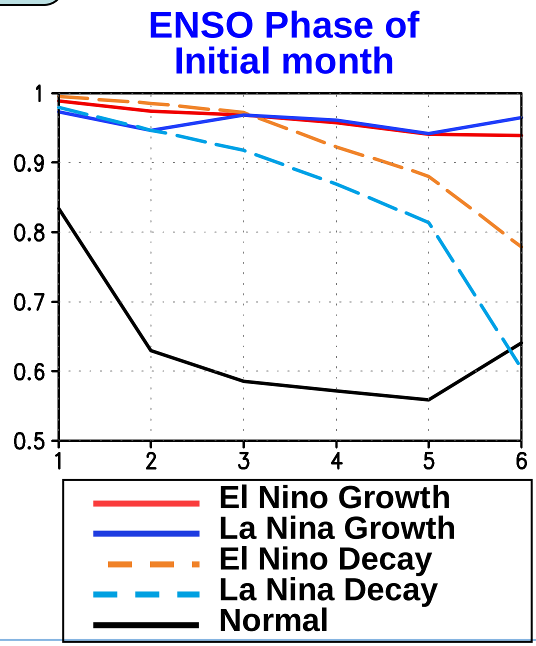
Forecast Skill of NINO3.4 Index

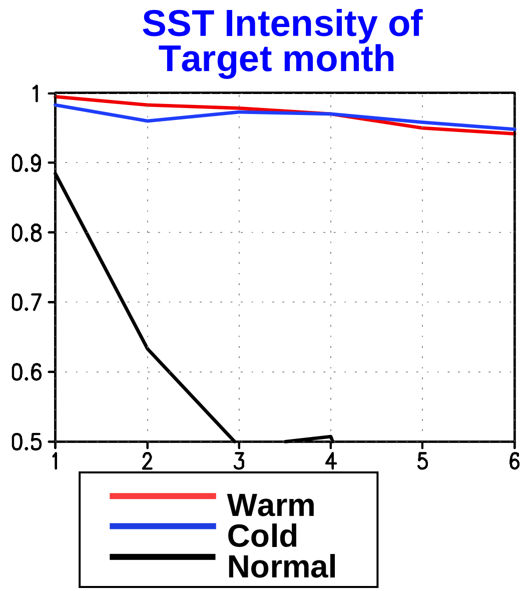
Overall Skill



Tier-1 MME Forecast







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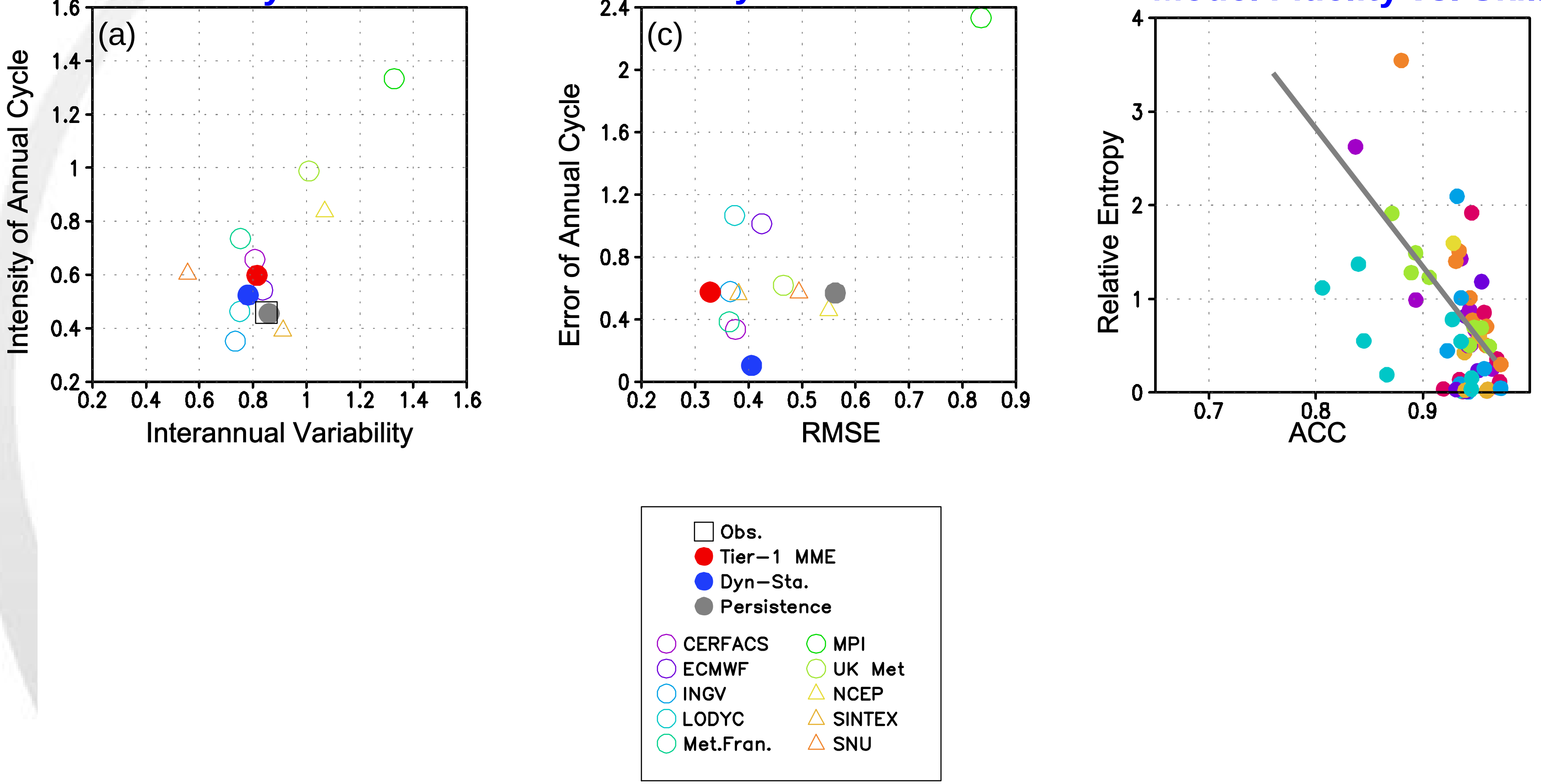
✓ Inherent limits to predictability
→ some times are more predictable than others, amplitude of SST anomalies with respect to ENSO phase

✓ Gaps in the observing system

ENSO Predictability (NINO3.4 index)

Annual Cycle vs. IAV | Annual Cycle Error vs. RMSE | Model Fidelity vs. Skill



- In CGCMs, the intensity of annual cycle and interanual variability show linear relationship.
- Models with better climatology tend to have better skill.

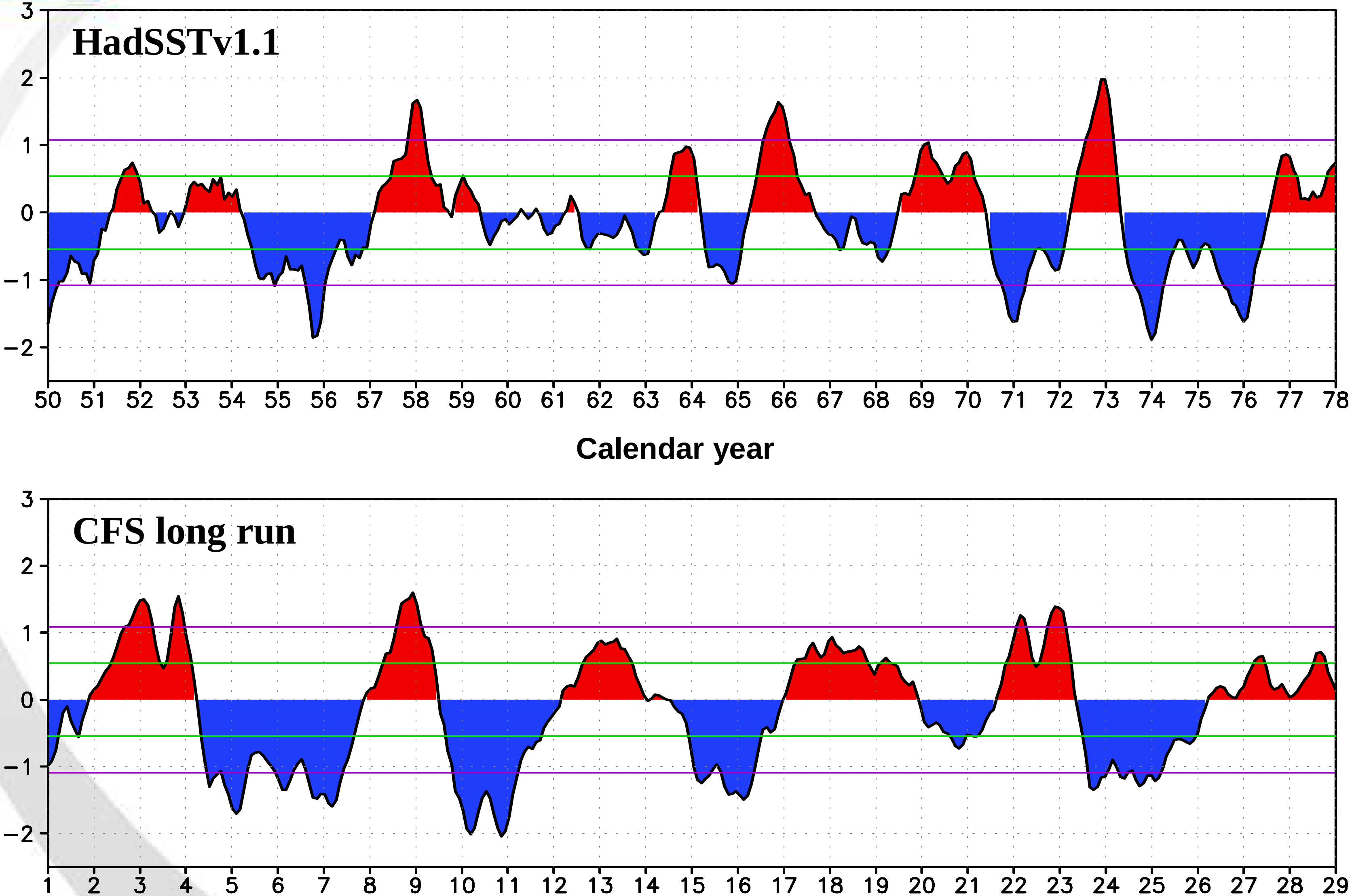
Experimental Design

→ To investigate the property of this model without influence of initial condition, long run simulation is analyzed and compared with forecast data.

	long run	forecast	
PRCGC SINTEX-F	• 202-year simulation • Analyzing last 200 years (200-yr climatology)	• 1982-2004 period • 9 members • May, Nov IC • 6 months lead	Luo *et al*. 2005
NCEP CFS	• 52-year simulation • Analyzing last 50 years (50-yr climatology)	• 1981-2003 period • 15 members • 12 calendar months • 9 months lead	Saha *et al*. 2005

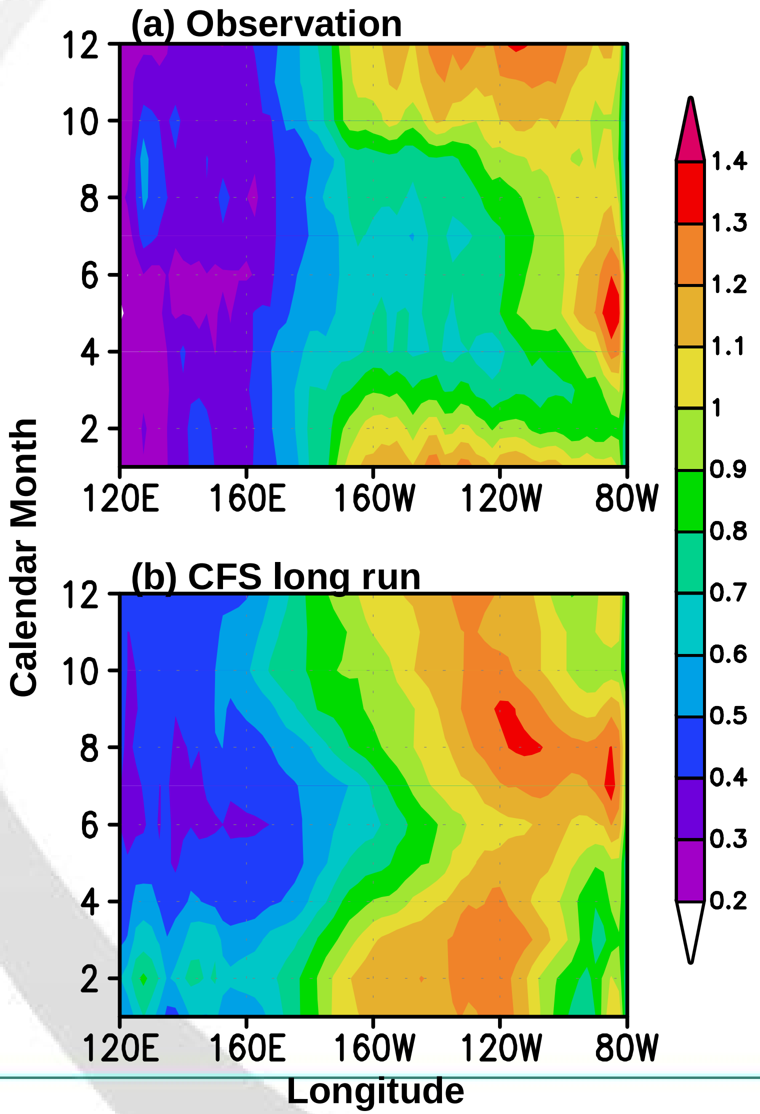
Thanks to T. Yamagata and J.-J. Luo (SINTEX-F), and Kathy Pegion (CFS)

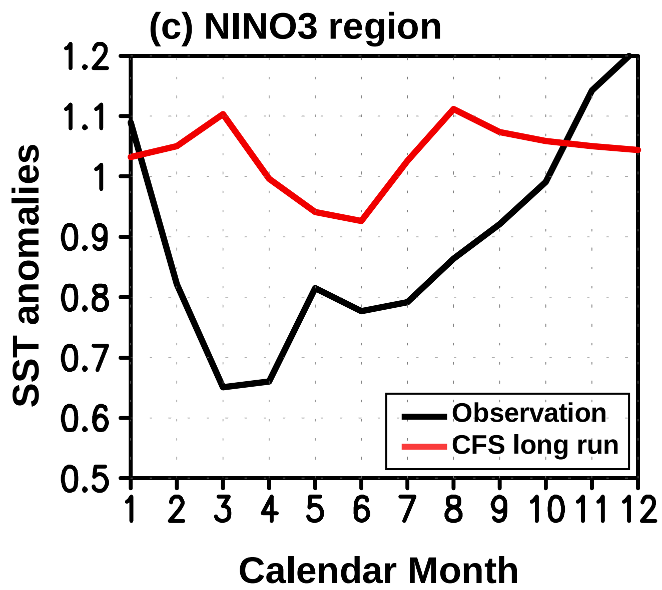
NINO 3.4 Index (Observed and CFS)



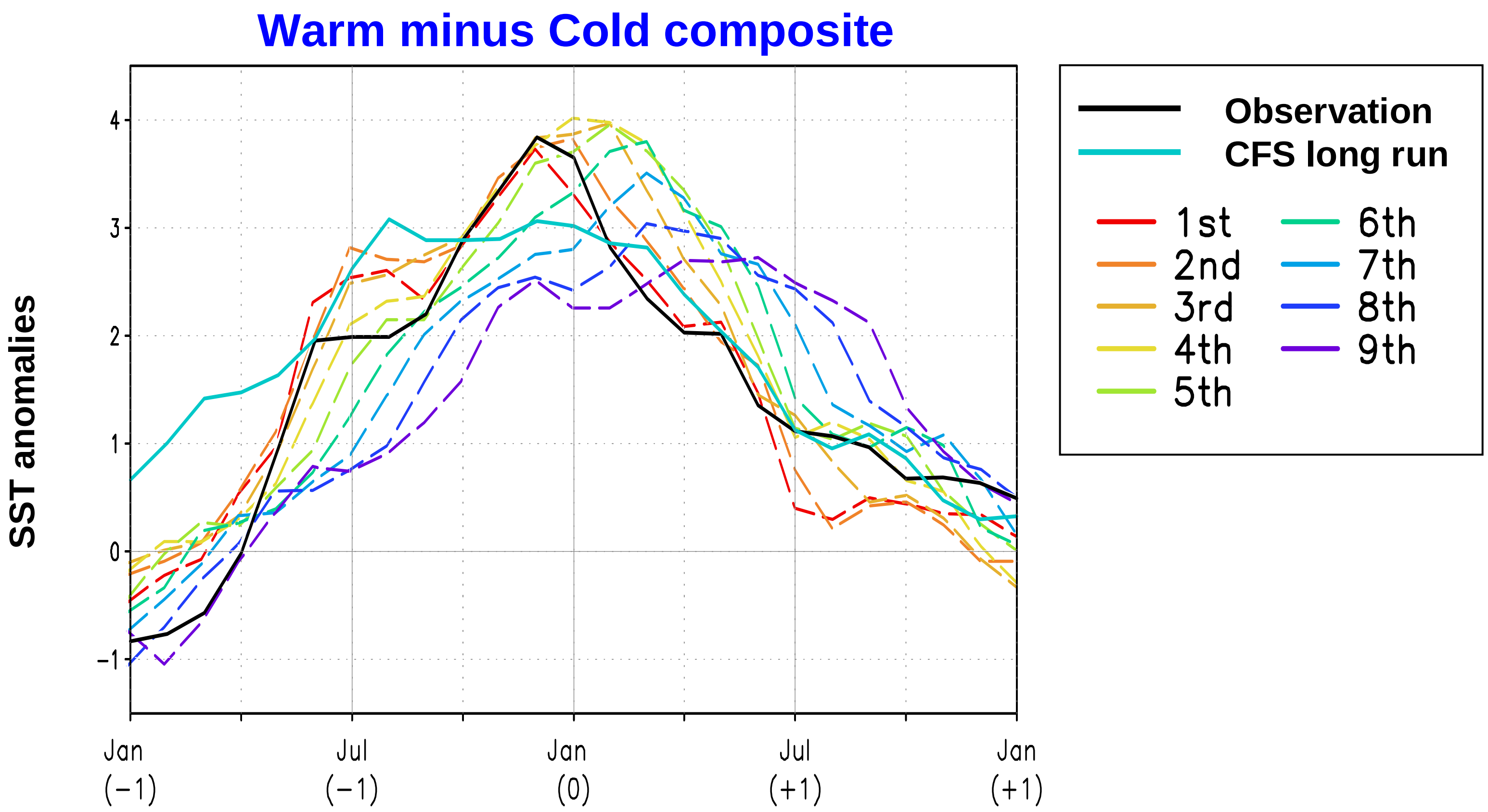
ENSO Characteristics in CFS CGCM

Standard Deviation of SST Anomalies over Tropics





NINO3 Index in CFS 52-yr simulation

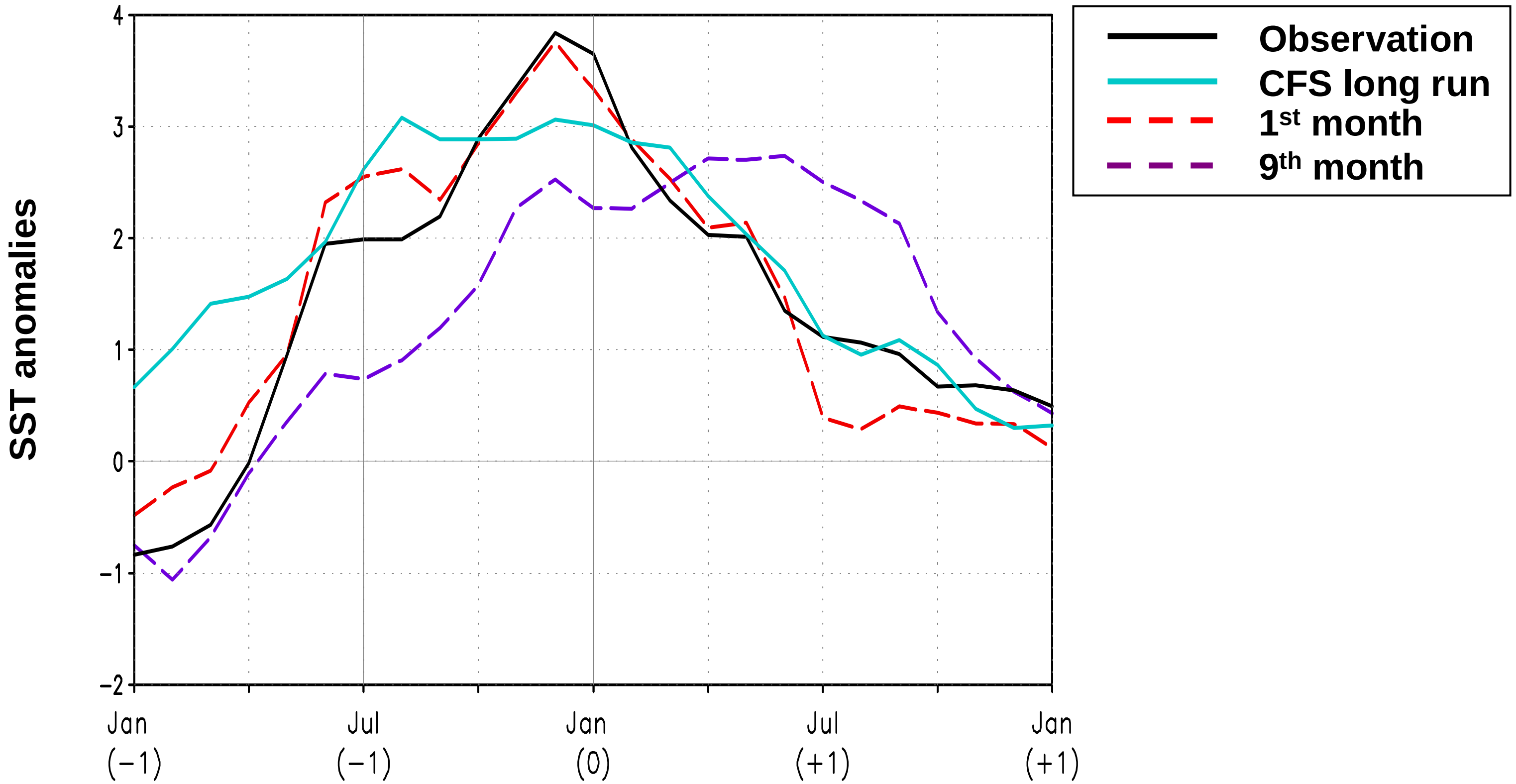


Reconstructed data with respect to lead time of 9-month forecast data starting from 12 calendar months (monthly forecast composite)

- **For observation and forecast, Warm composite (82/83, 86/87, 91/92, 97/98) - Cold composite (84/85, 88/89, 98/99, 99/00)**
- **For CFS 52-yr run, 7 cases for El Nino and 12 cases for La Nina based on one standard deviation definition of DJF Nino3 index**

NINO3 Index in CFS 52-yr simulation

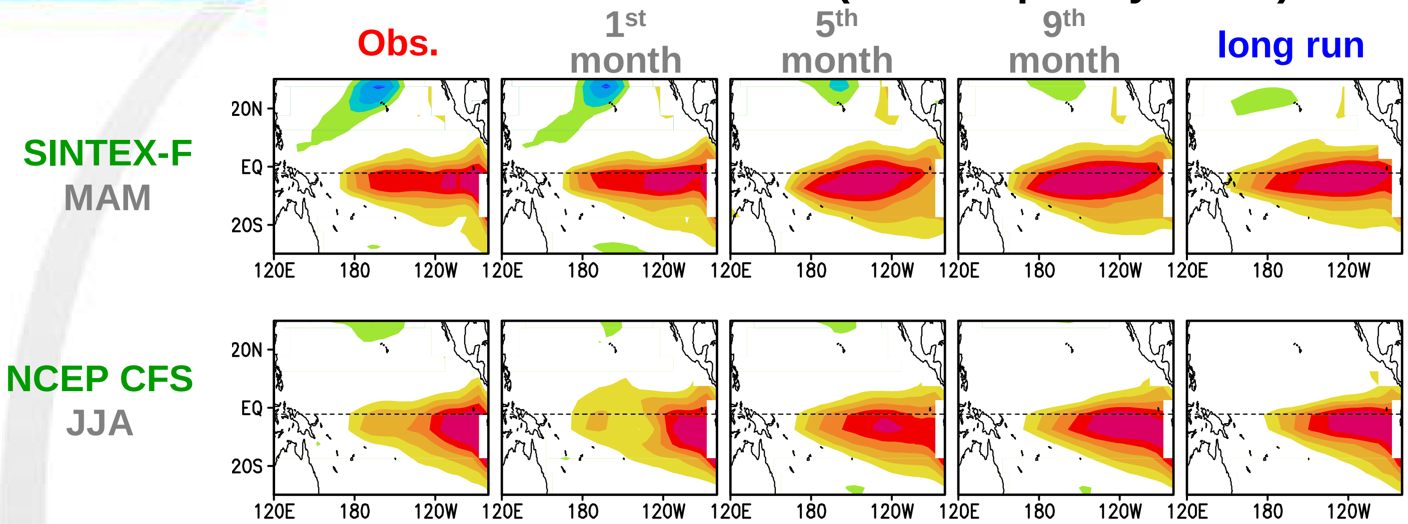
Warm minus Cold composite



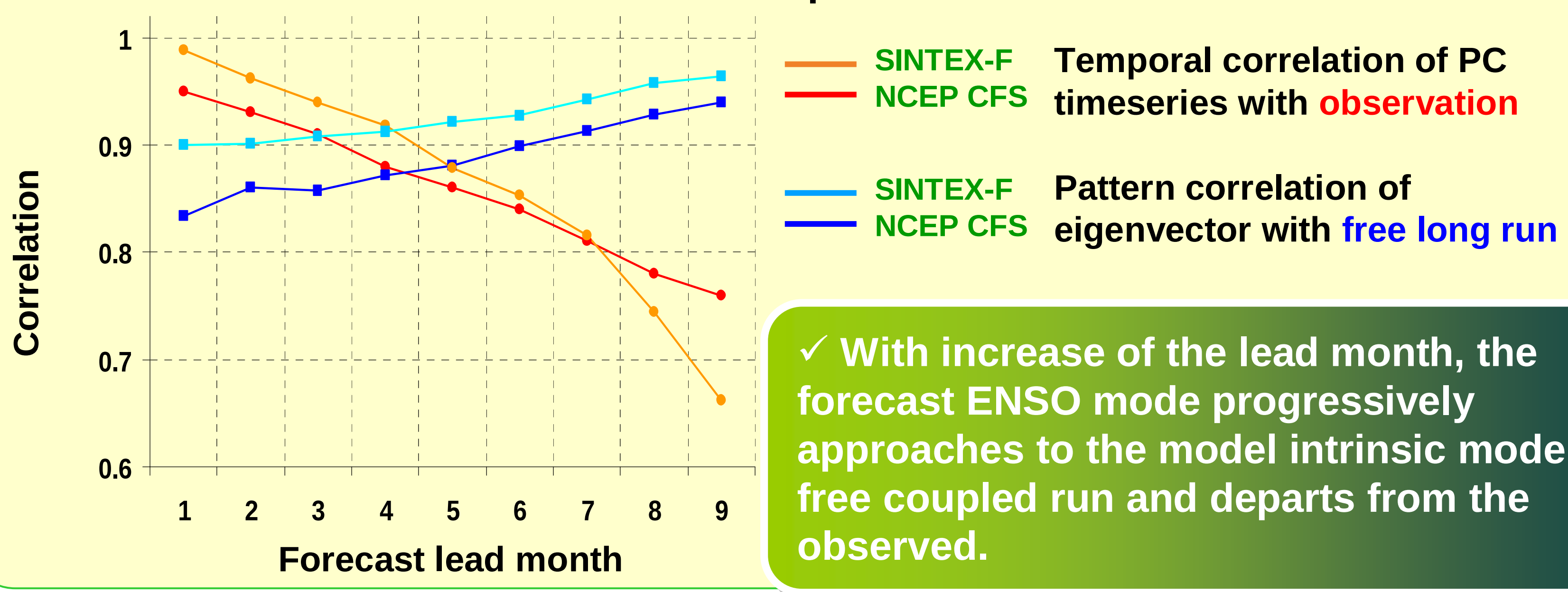
Reconstructed data with respect to lead time of 9-month forecast data starting from 12 calendar months (monthly forecast composite)

Impact of Coupled Model Error on Predictability

1st mode SEOF of SST (Low frequency mode)



Correlation coefficients with respect to lead month



✓ With increase of the lead month, the forecast ENSO mode progressively approaches to the model intrinsic mode in free coupled run and departs from the observed.

Model Flaw: Slow Coupled Dynamics

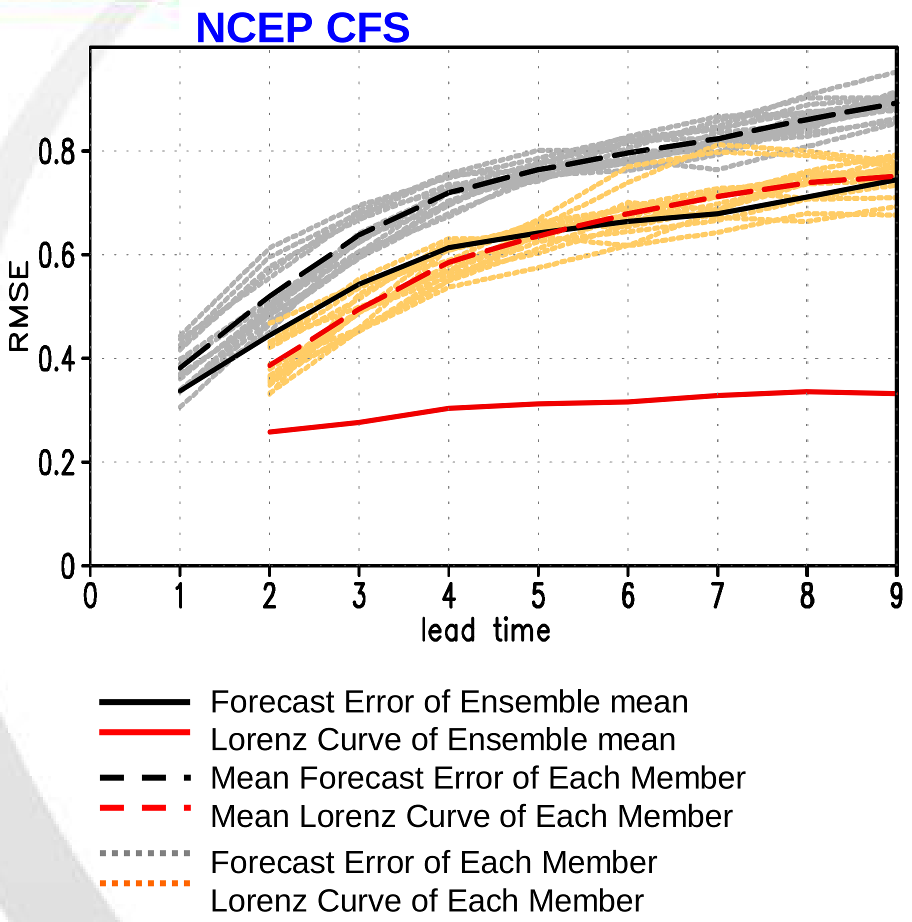
- **This is particular true for a long lead seasonal forecast, because as the forecast lead increases, the model forecast tend to be determined by the model ENSO behavior.**

- **Therefore, continuing improvement of the one-tier climate model's slow coupled dynamics in reproducing a realistic ENSO mode is a key for long-lead seasonal forecast.**

- **For example, precipitation forecast depends on accurate forecast of the amplitude, spatial patterns, and detailed temporal evolution of ENSO cycle**

RMS Error and Differences between Successive Forecasts

NINO3 SST in NCEP CFS forecasts



✓ Lorenz Curve of Ensemble Mean is not growing

→ Initial error growth is saturated within two months.

→ After that, error growth is following the identical model error for all initial cases. For NINO3 index, it will be the error of model ENSO dynamics.

✓ Lorenz Curve of Individual Member grows as fast as Forecast Error.

→ CFS has large ensemble spread due to instability of coupled system.

- ✓ Forecast error: lower bound of predictability, skill of "current" forecast
- ✓ Lorenz curve: upper bound of predictability (lower bound of error), growth of initial error defined as the difference between two forecasts valid at the same time (Lorenz 1982)

What is limiting the ENSO predictability?

✓ Model Flaws
→ mean error, phase shift, different amplitude, and wrong seasonal cycle, etc

✓ Flaws in the way the data is used
→ data assimilation and initialization, chaos within non-linear dynamics of the coupled system

✓ Inherent limits to predictability
→ some times are more predictable than others, amplitude of SST anomalies with respect to ENSO phase

✓ Gaps in the observing system

Different Flavors of El Nino in Nature

❑ Conventional El Niño

: "as a phenomenon in the equatorial Pacific Ocean characterized by a positive sea surface temperature departure form normal in the NINO 3.4 region greater than or equal in magnitude to 0.5C averaged over three consecutive months" (NOAA)

❑ Different flavors of El Niño

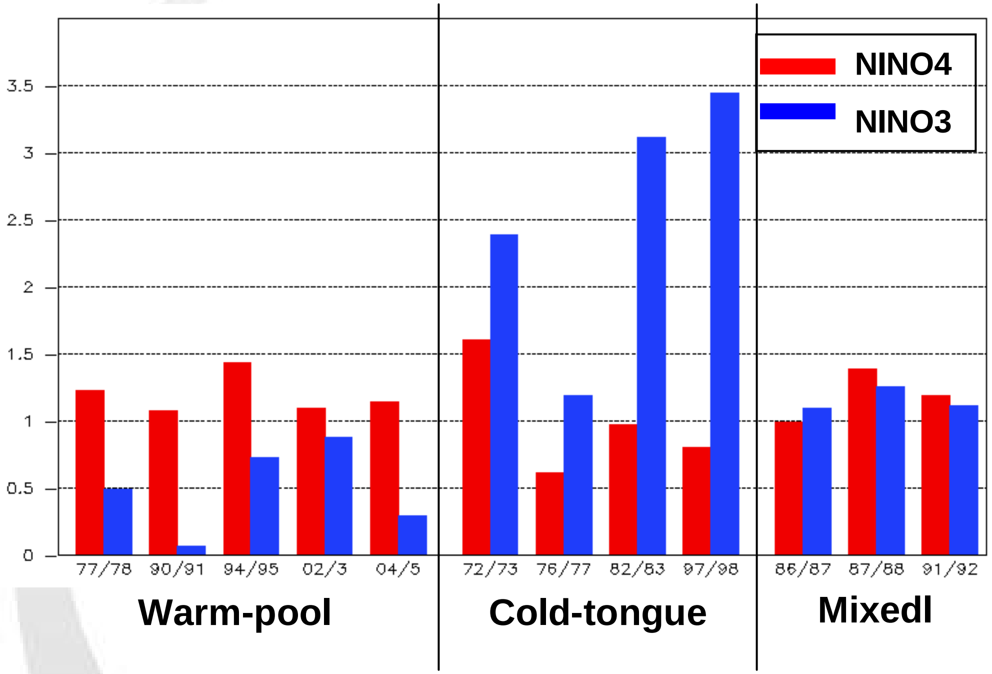
• Trans- Niño (Trenberth and Stepaniak, 2001), Dateline El Niño (Lakin and Harrison 2005), El Niño Modoki (Ashok et al. 2007), Non-canonical ENSO (Guan and NIgam, 2008), Warm pool El Niño (Kug et al. 2008), etc.

: Even though there are differences, the distinctive interannual SST variation over the central Pacific which becomes more active in recent year and significantly different global impact form conventional El Niño are common features.

❑ The transition mechanisms and dynamical structure of two-types of El Nino are significantly different (Kug et al. 2008).

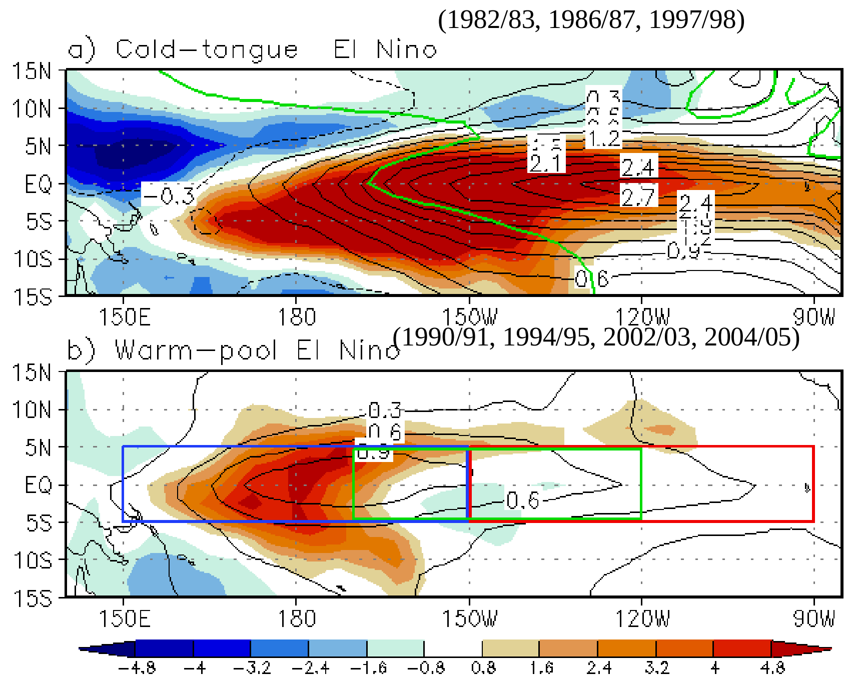
Observed Different Flavors of El Nino

Normalized NINO3 and NINO4 SST



Either NINO3 SST or NINO4 SST is greater than their standard deviation

Composite of SST (Contour) and Rainfall (Shaded)

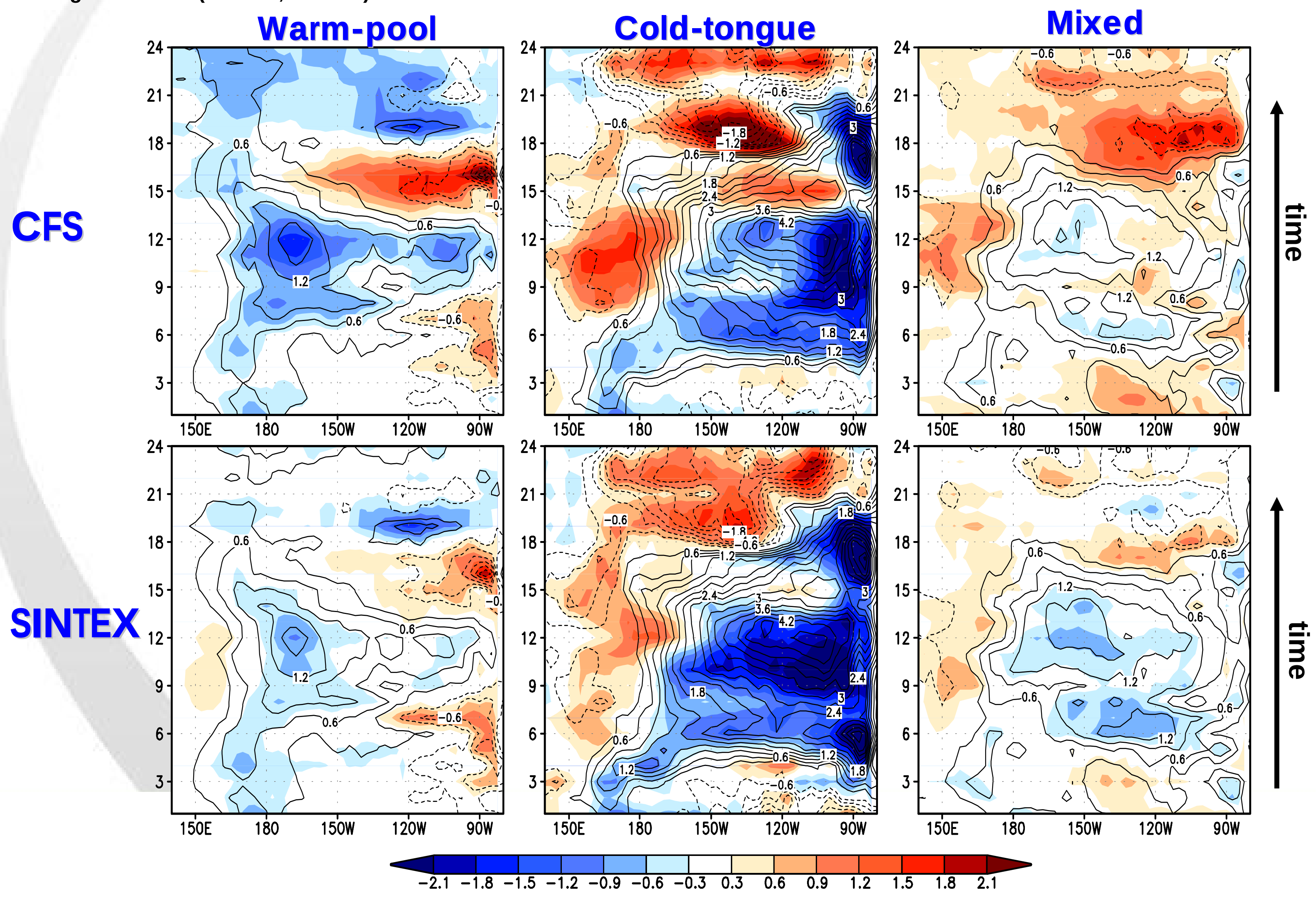


Composite of SST Anomalies along the Equator

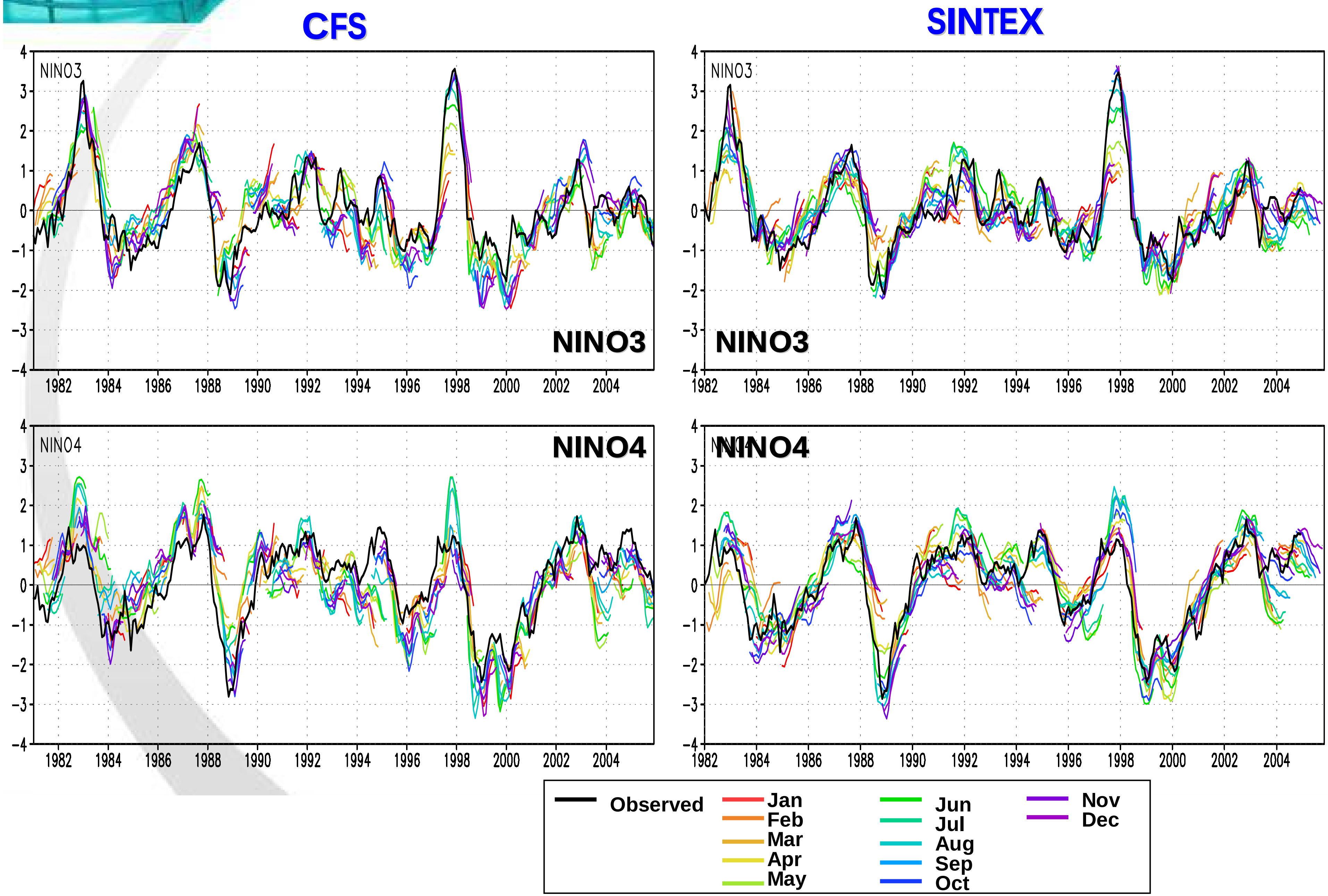
Forecast lead month 7

Composite of seasonal mean SST anomalies
- **Warm-pool: 4 cases (1990/91, 1994/95, 2002/03, 2004/05)**
- **Cold-tongue: 2 cases (1982/83, 1997/98)**

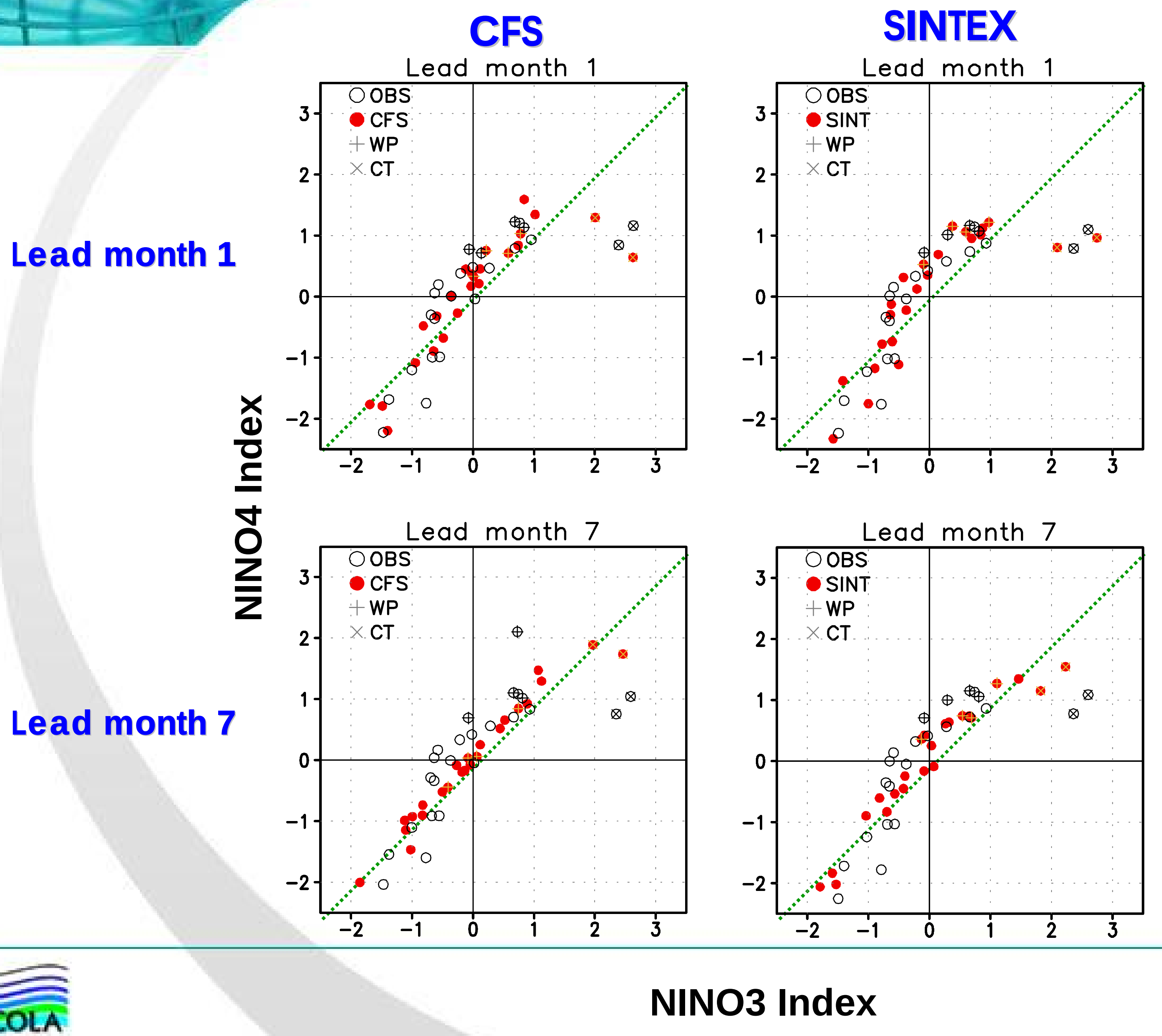
Shading is for model bias, contour is for observed composite



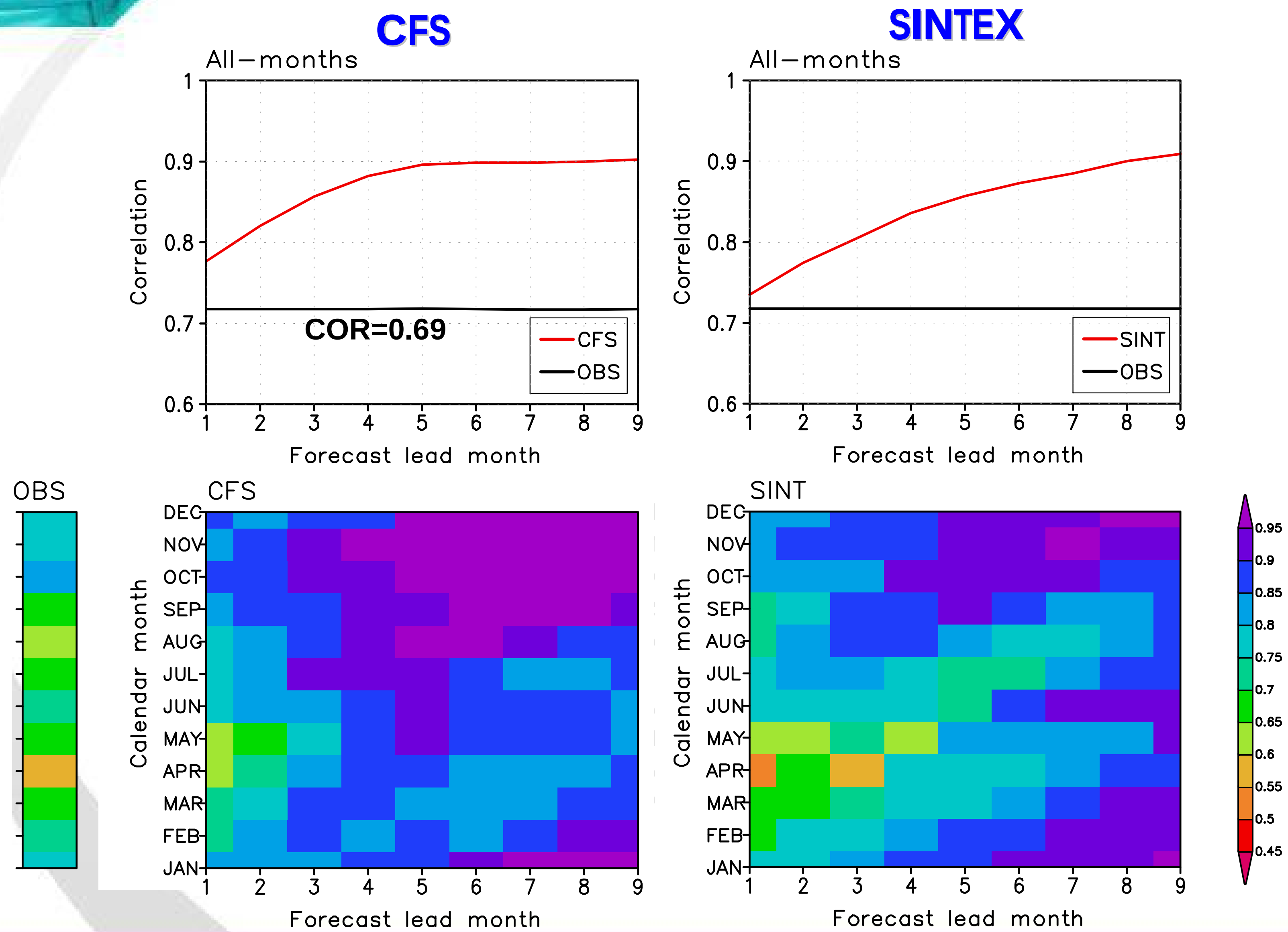
Interannual Variability of NINO3 and NINO4



Scatter Diagram of Normalized DJF NINO3 vs. NINO4

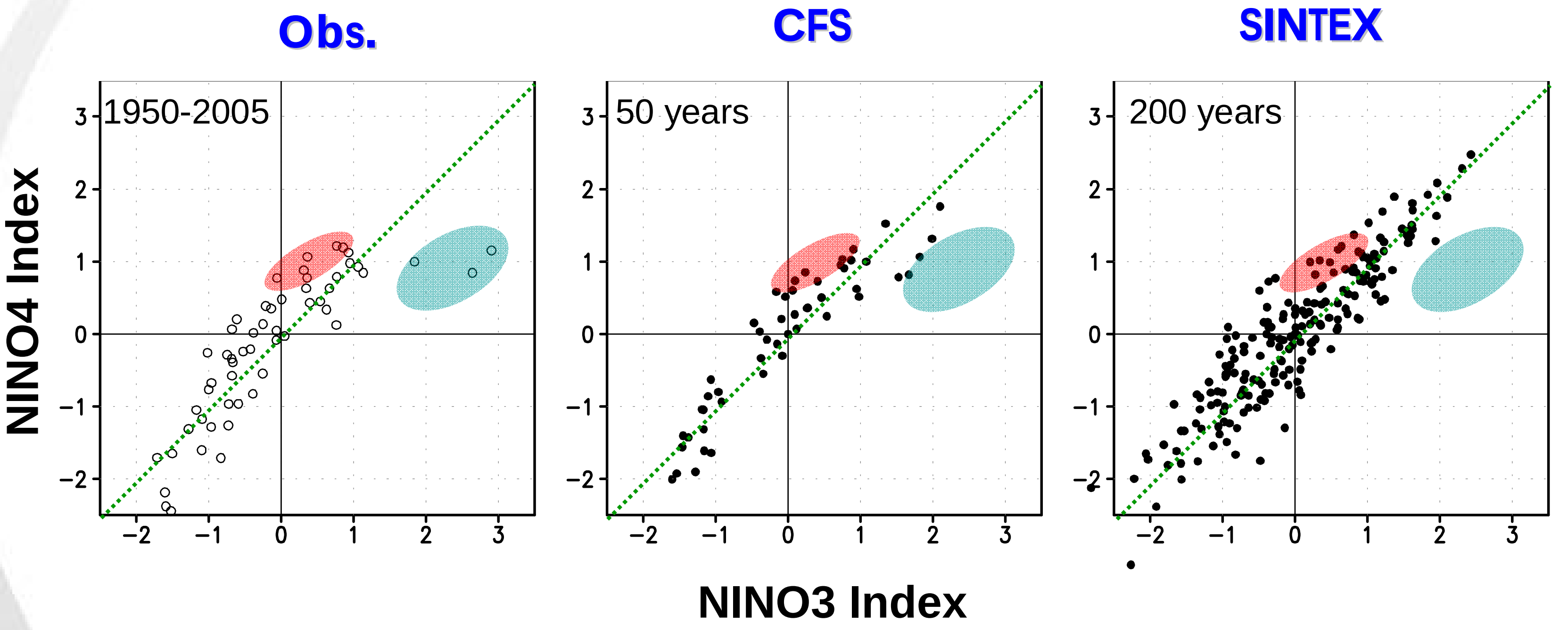


Relationship between NINO3 and NINO4



Scatter Diagram of Normalized DJF NINO 3 vs. NINO 4

From free long run of two CGCMs



COR=(NINO3, NINO4)	0.69	0.82	0.86

→ **Model Flaw: One Flavor of El Nino**

Outline

- Current Status of ENSO Predictability in CGCMs
  - Inherent limits to predictability
  - Model Flows

- Current Status of Monsoon Predictability in CGCMs
  - **Intrasesasonal and seasonal predictability**
  - **ENSO-Monsoon relationship**

- ENSO-Monsoon Relationship in GCM Experiments
  - Role of tropical Pacific SST anomalies

Background and Objective

Observed dominant modes of intraseasonal variability of summer South Asian monsoon (Krishnamurthy and Shukla 2007, 2008)

1. Two intraseasonal oscillatory patterns

- **45 and 28-day modes**
- **Their average cycles of variability are correspond to the life cycles of active/break periods of monsoon rainfall over India**

2. Two large-scale standing patterns

- **ENSO mode and Indian Ocean Dipole mode**
- **They persist through out the monsoon season, and seasonal mean monsoon is mainly determined by the two standing patterns.**

→ In this study, the space-time evolution of convection over the monsoon region containing the Indian subcontinent, the Indian Ocean, and the Western Pacific and its role on seasonal predictability is investigated in 7 CGCM forecast dataset.

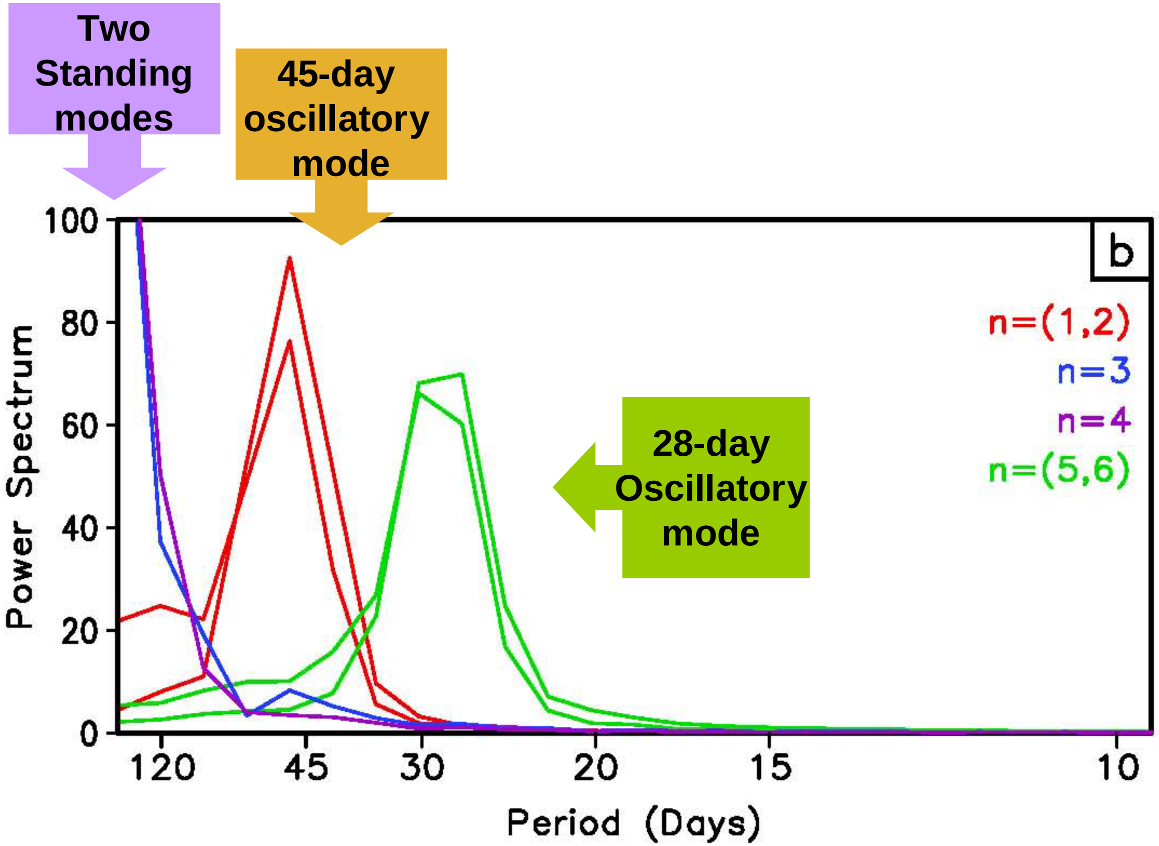
Dominant Modes of Observation

Multi-channel singular spectrum analysis

• Data: daily OLR anomalies for JJAS 1985-2002

•Region: 40-160E, 20S-35N

Power spectra of the space-time principal component



• Data: Reconstructed component (RC) which is constructed from the corresponding ST-EOF and ST-PC as the original field

→ The time length and sequence are exactly those of the original time series (Ghil et al. 2002)

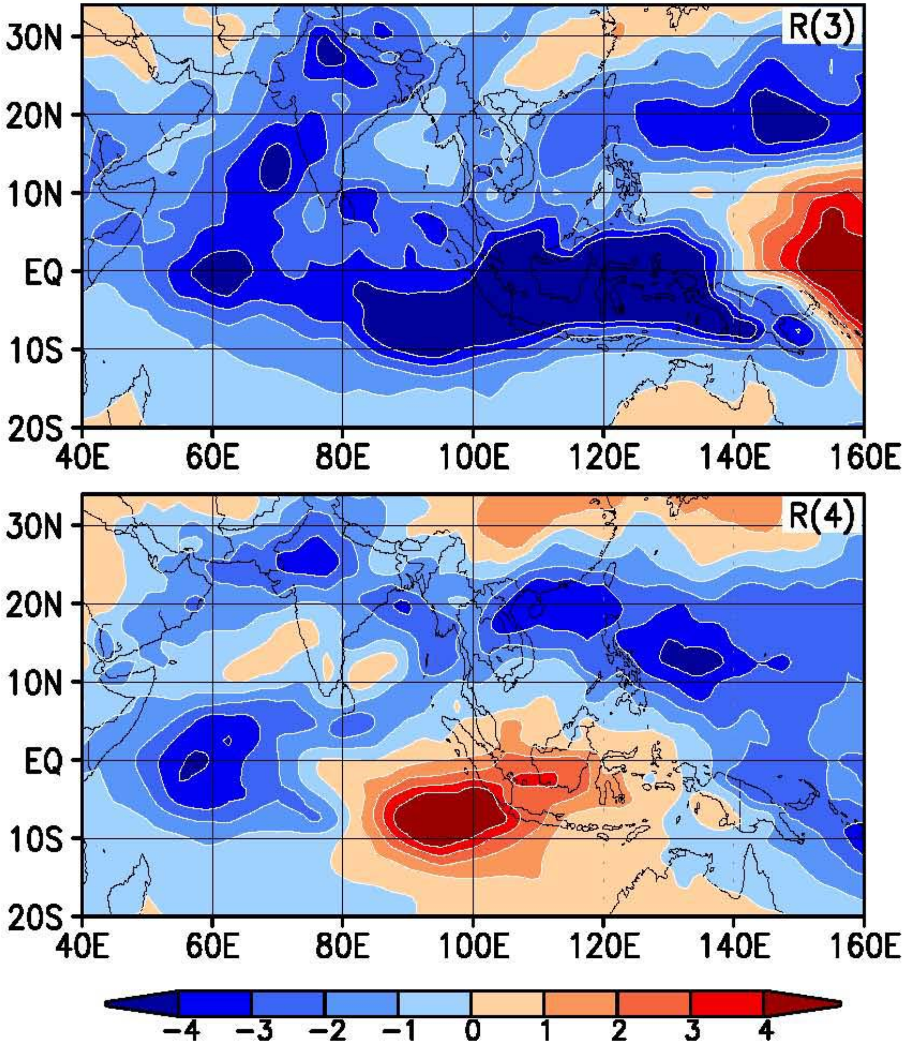
Krishnamurthy and Shukla, 2008

Dominant Modes of Observation

Standing modes

ENSO mode

IOD mode



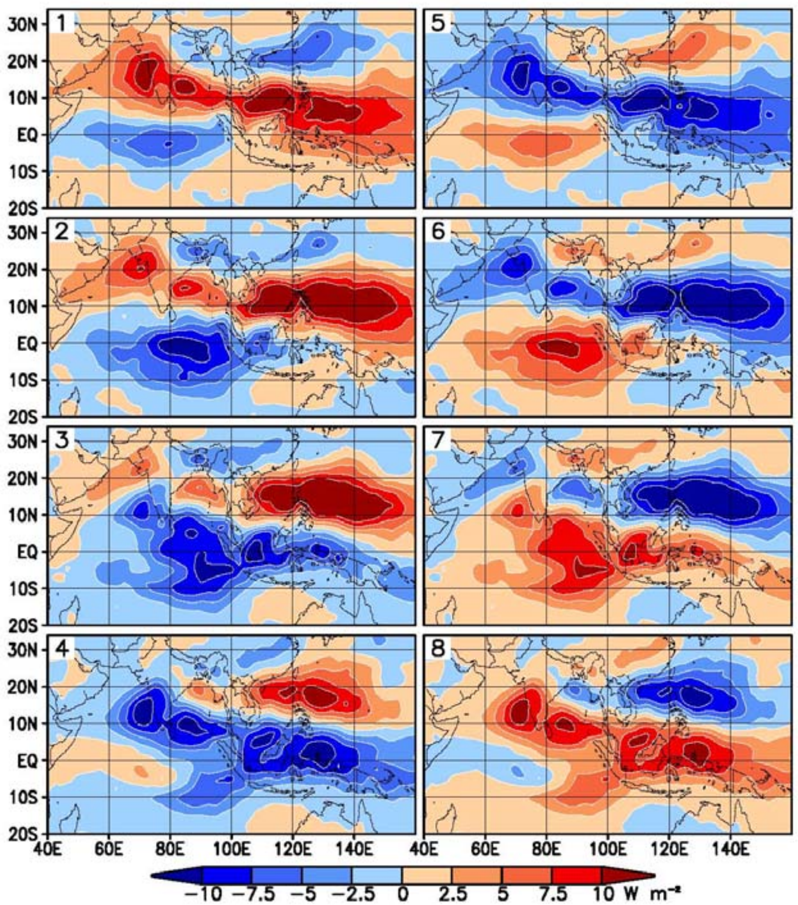
1st Spatial EOF of daily RC

The seasonal mean monsoon is mainly determined by the two standing patterns, without much contribution from the oscillatory modes.

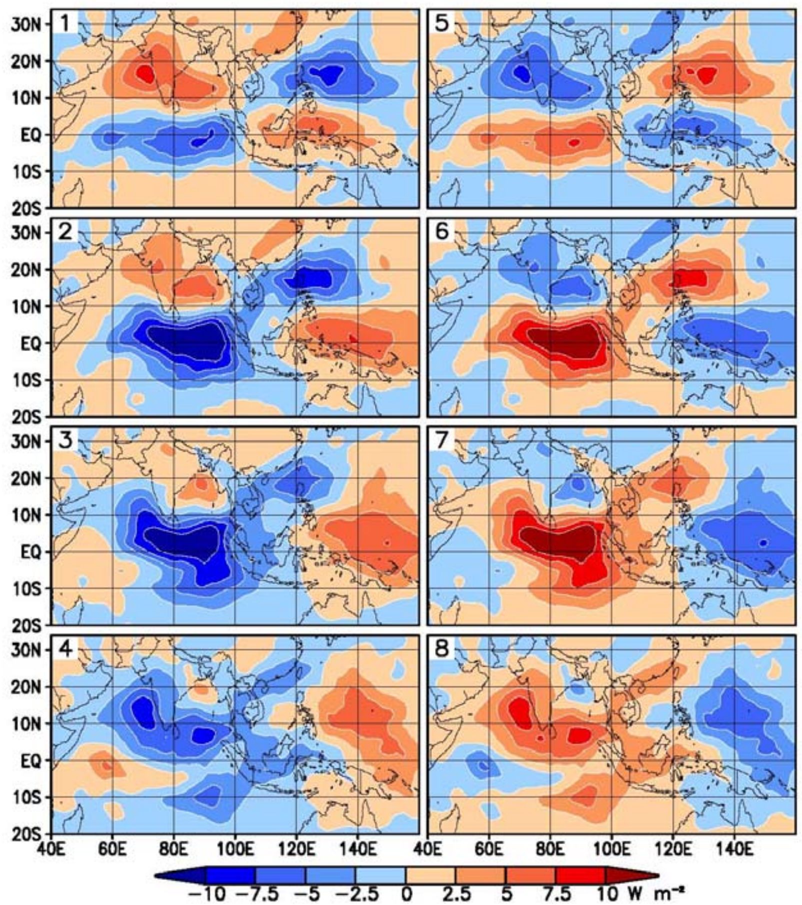
Dominant Modes of Observation

Oscillatory modes

45-Day



28-Day



Composites of eight phases of a cycle of oscillatory mode
: Their average cycles of variability are shown to correspond to the life cycles of active and break periods of monsoon rainfall over India.

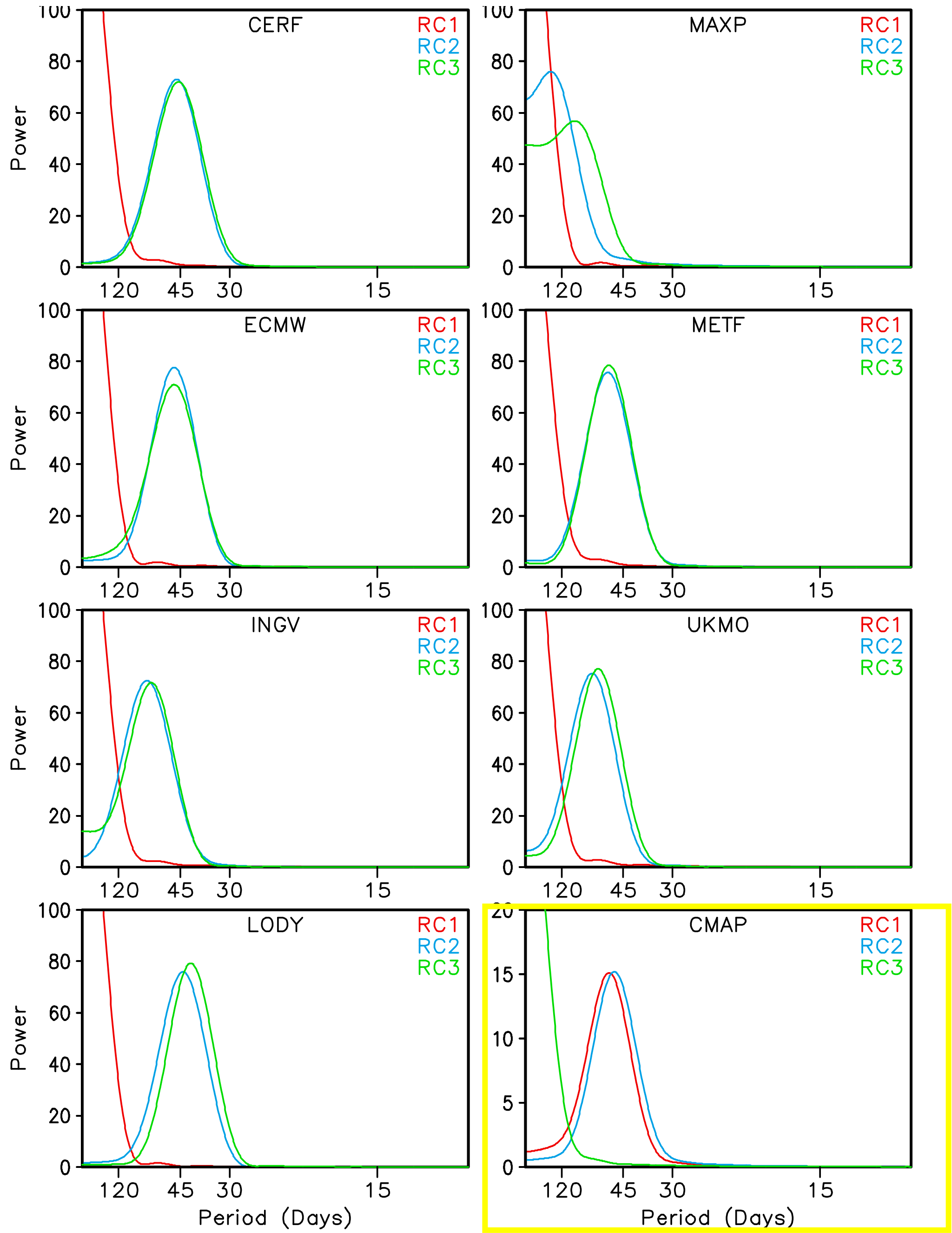
Dominant Modes of 7 CGCMs

Multi-channel Singular Spectrum Analysis

- **Data: daily rainfall anomalies for JJAS 1981-2002 (only daily climatology is removed.)**
- **Region: 40-160E, 20S-35N**
- **Reference: CMAP pentad rainfall**

Power spectra of the reconstructed component

→ It shows the dominant standing mode and 45-day mode in one member of each model.



Dominant Modes of 7 CGCMs

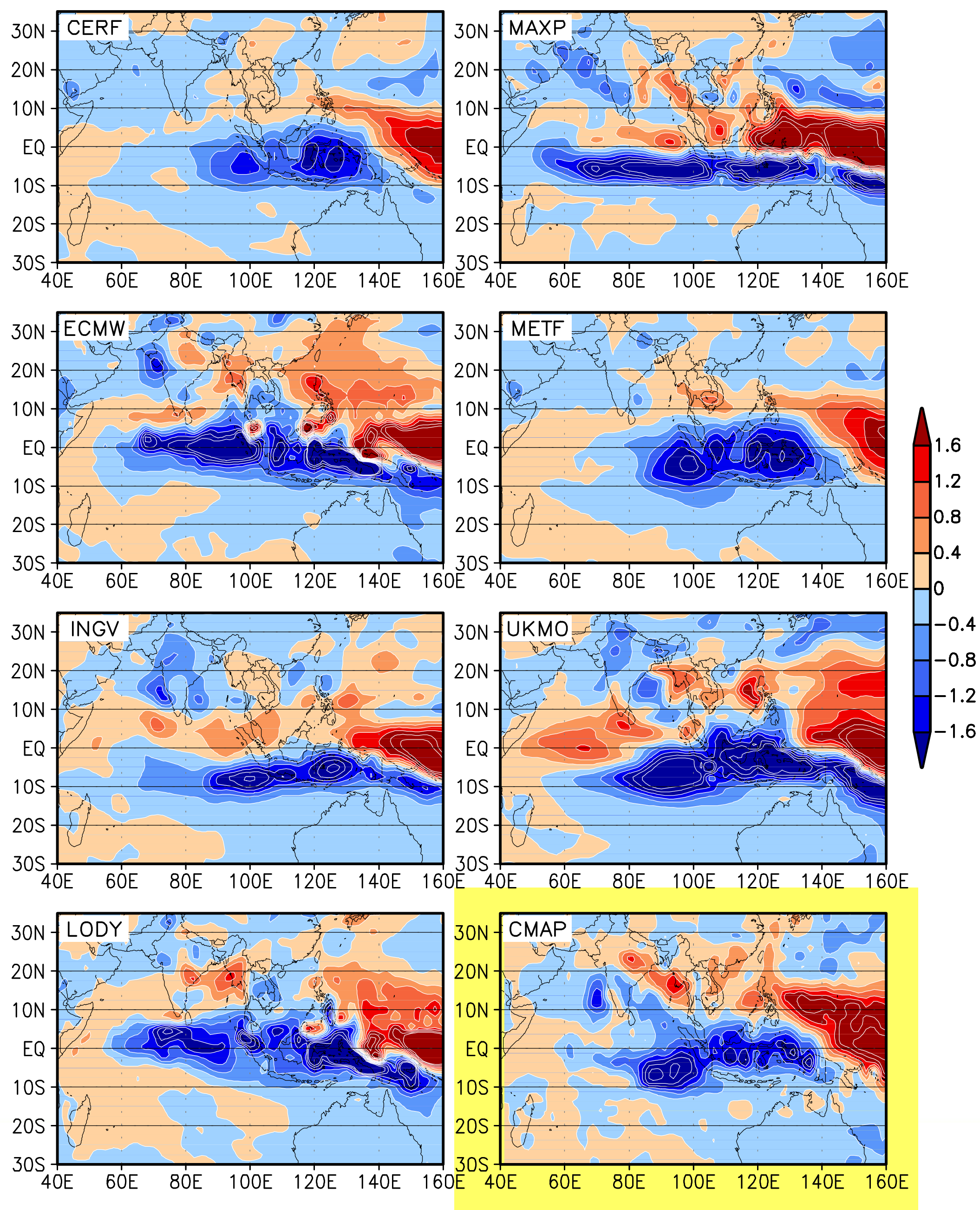
Standing ENSO mode

- They persist through out the monsoon season.

- Most of models show indifferent pattern to observed over the Indian continent.

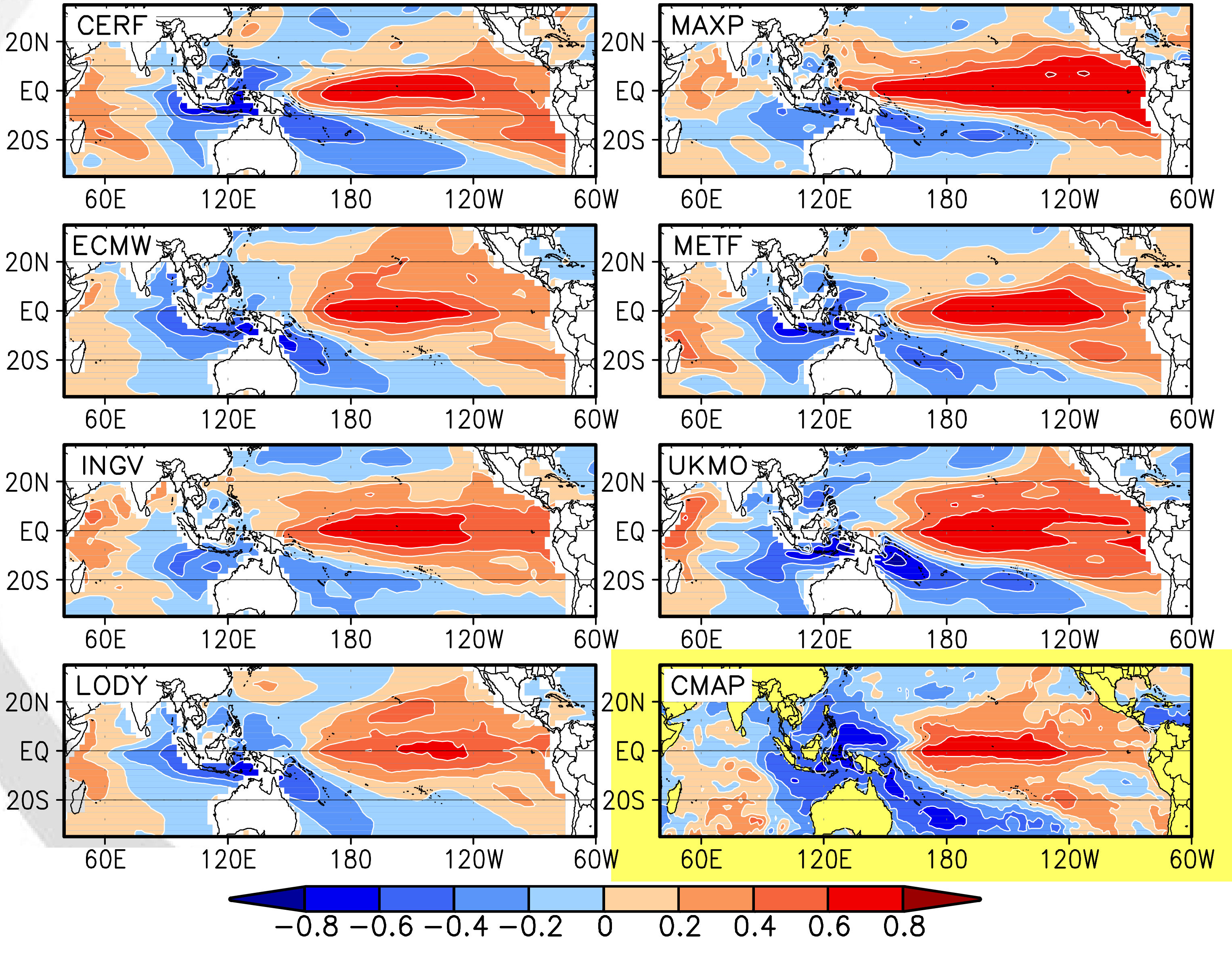
- 1st EOF of MSSA RC explains more than 90 % of variance.

1st EOF of MSSA ENSO mode RC



Relationship with SST Anomalies

Correlation of ENSO mode with daily SST

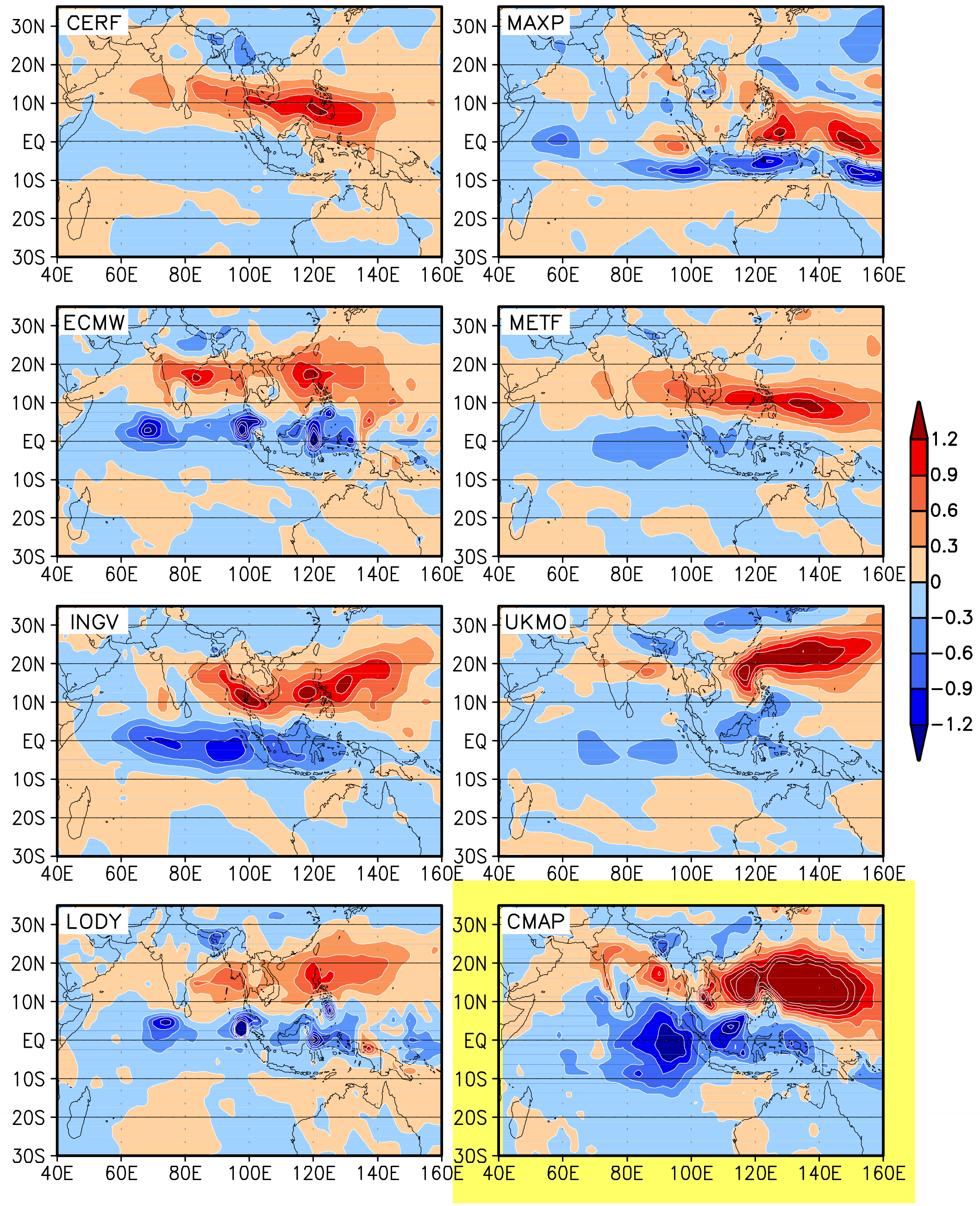


Dominant Modes of 7 CGCMs

Oscillatory 45-day mode

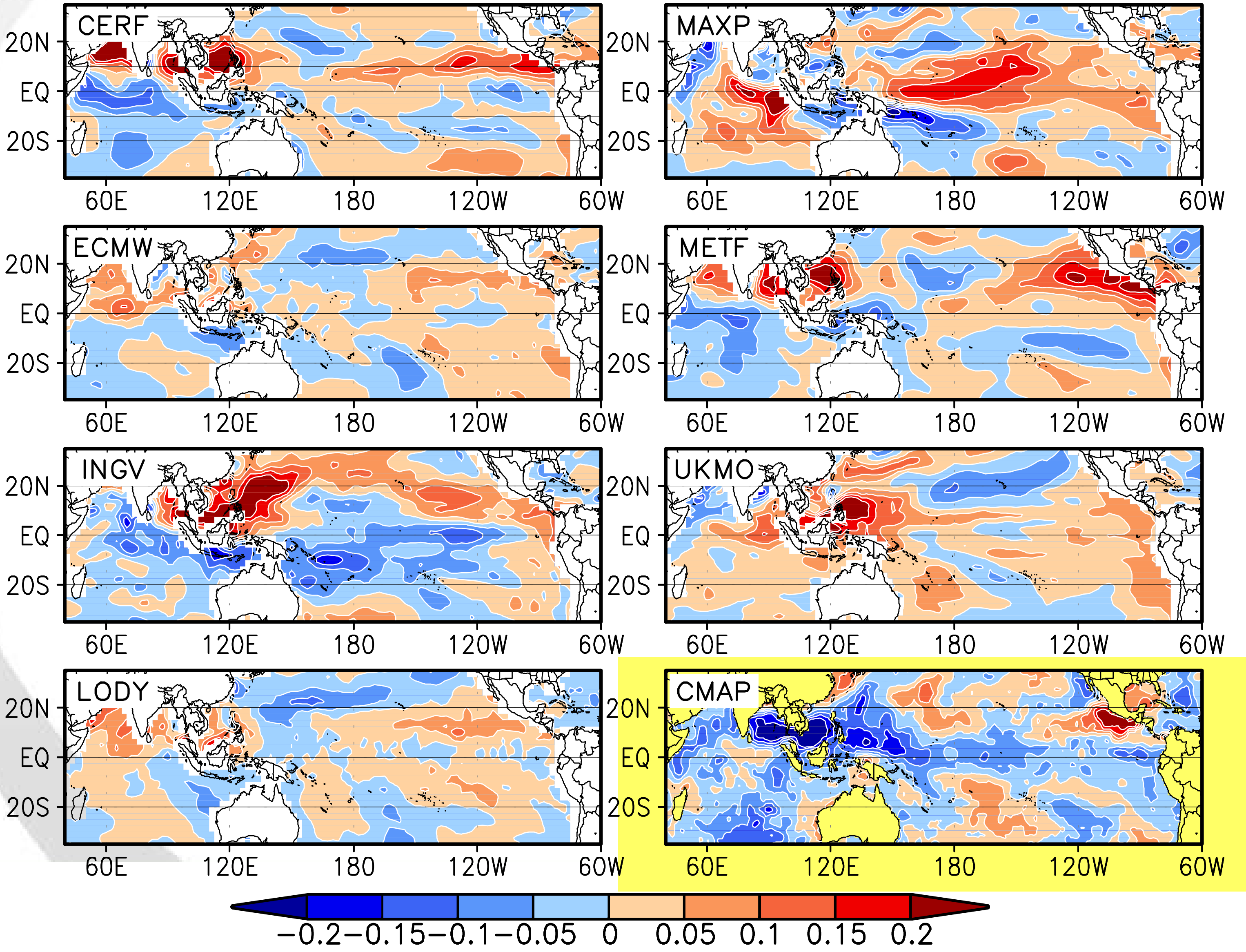
- **It is associated with the life cycles of active and break periods of monsoon rainfall with 45 days period.**
- **Some eastward and northward movements are found to be associated with this oscillatory mode.**

1st EOF of MSSA Oscillatory mode RC

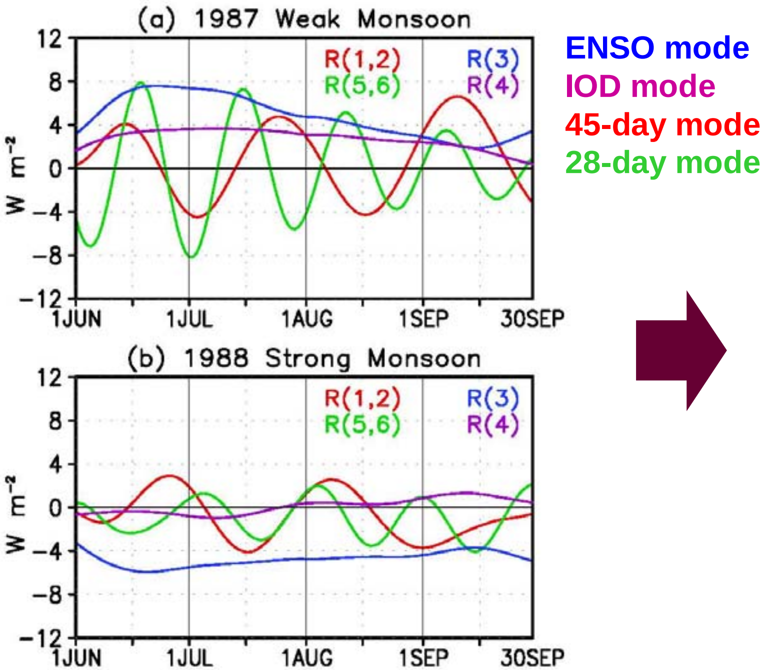


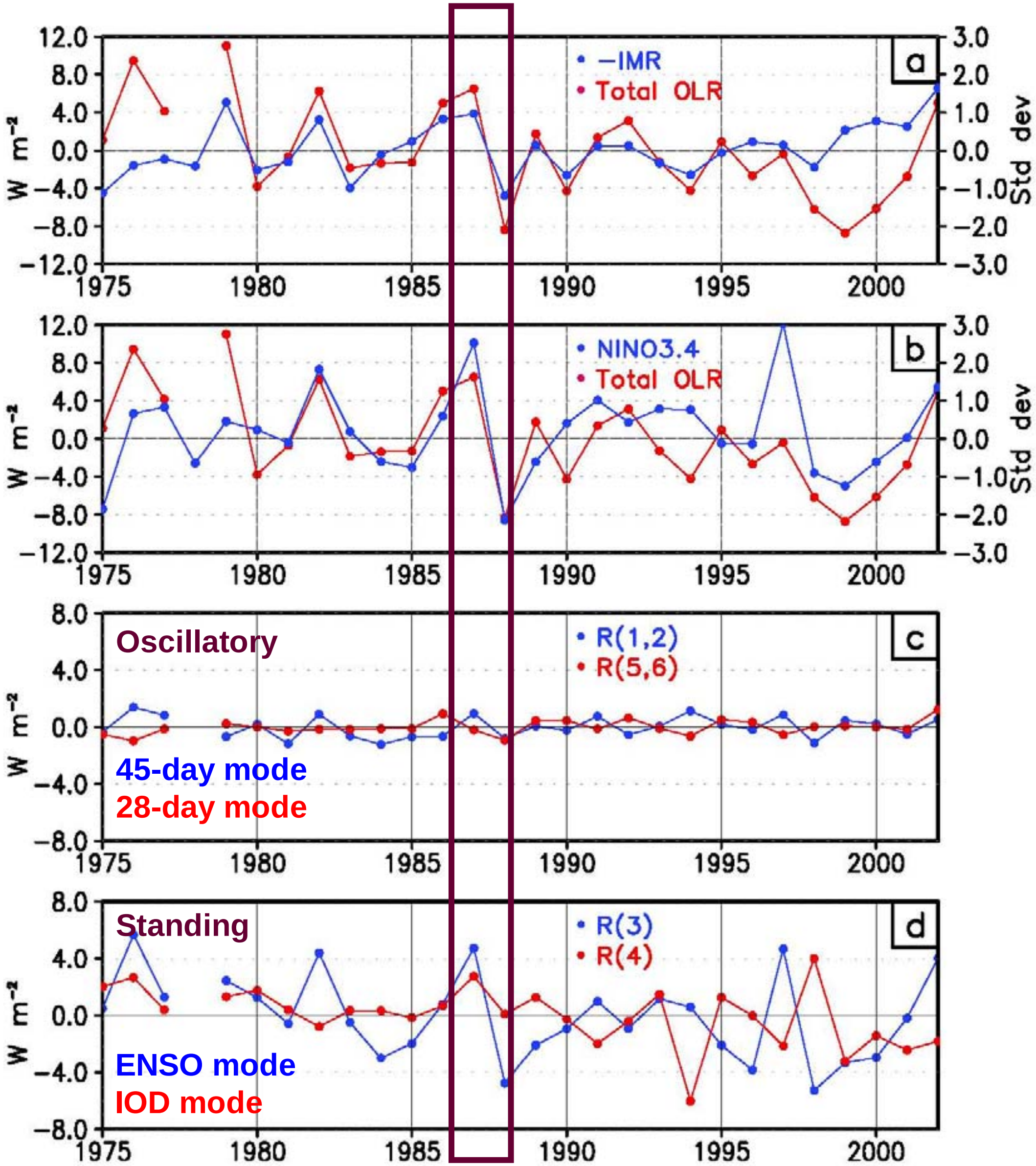
Relationship with SST Anomalies

Correlation of Oscillatory 45-day mode with daily SST



Role of Intraseasonal Variability on Seasonal Predictability of Indian Monsoon Rainfall



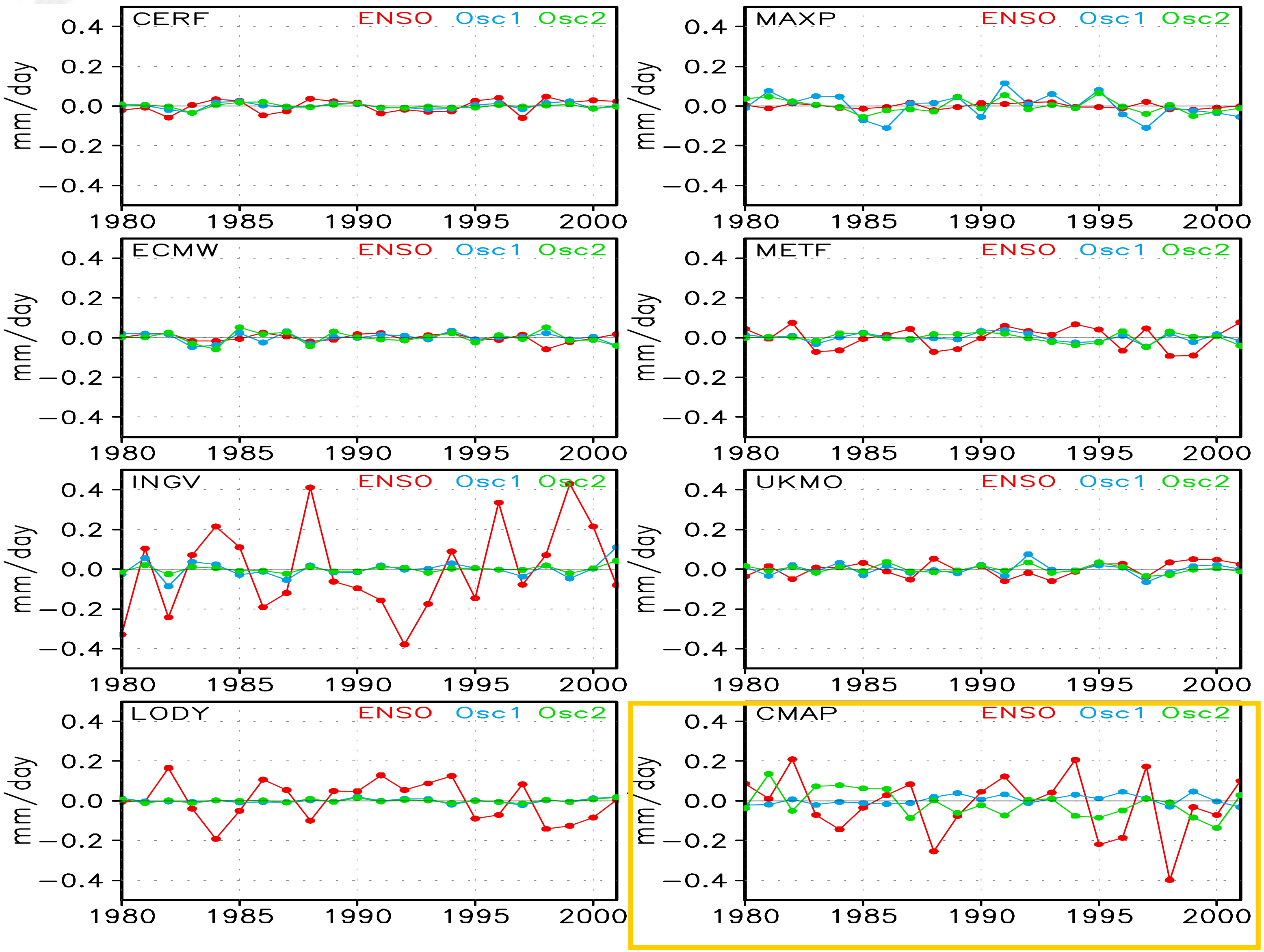


The strength of the JJAS seasonal mean OLR anomalies is mainly determined by the two persisting standing patterns while the contribution from the oscillatory modes is small.

Krishnamurthy and Shukla, 2008

Seasonal Predictability of Indian Monsoon Rainfall

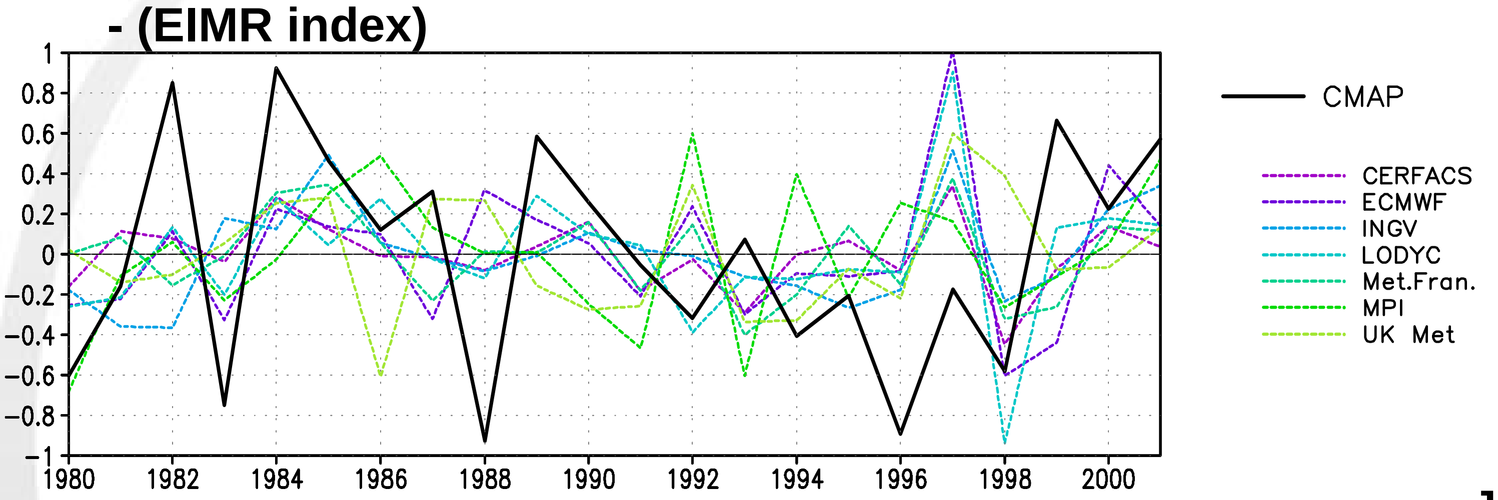
JJAS Extended IMR Indices of RC

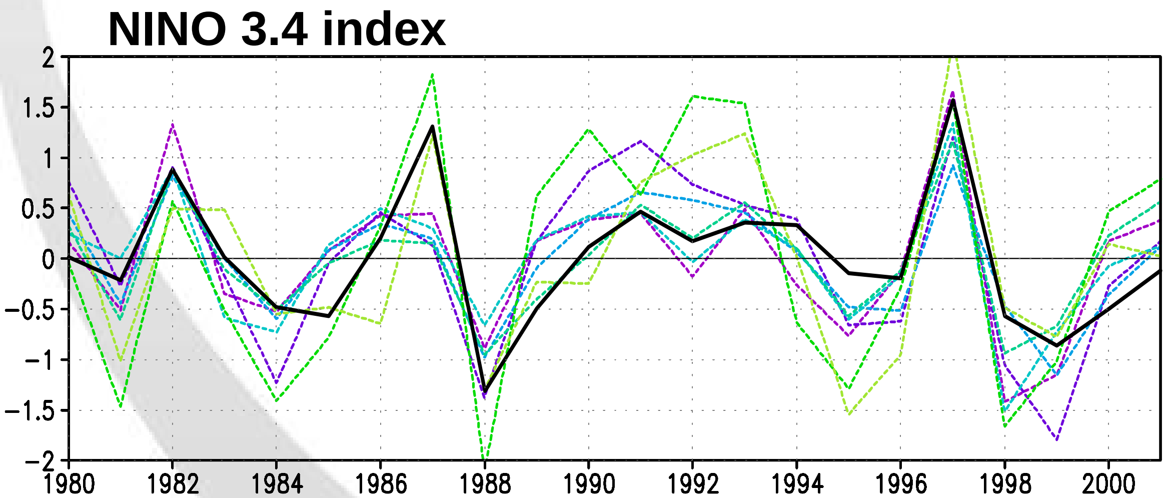


Extended IMR: Rainfall over 70-110E, 10-30N

Seasonal Predictability of Indian Monsoon Rainfall

JJA Indices





JJA ACC

	EIMR	NINO 3.4
CERFACS	0.43	0.78
ECMWF	0.15	0.77
INGV	0.23	0.81
LODYC	0.49	0.73
Meteo-France	0.17	0.82
MPI	0.15	0.74
UK Met Office	0.07	0.77

Commentary

- The most dominant obstacle in realizing the potential predictability of intraseasonal and seasonal variations is inaccurate models, rather than an intrinsic limit of predictability.

Thanks to Prof. Jagadish Shukla (TTA/ICTP, 2008)

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    - ENSO-Monsoon relationship

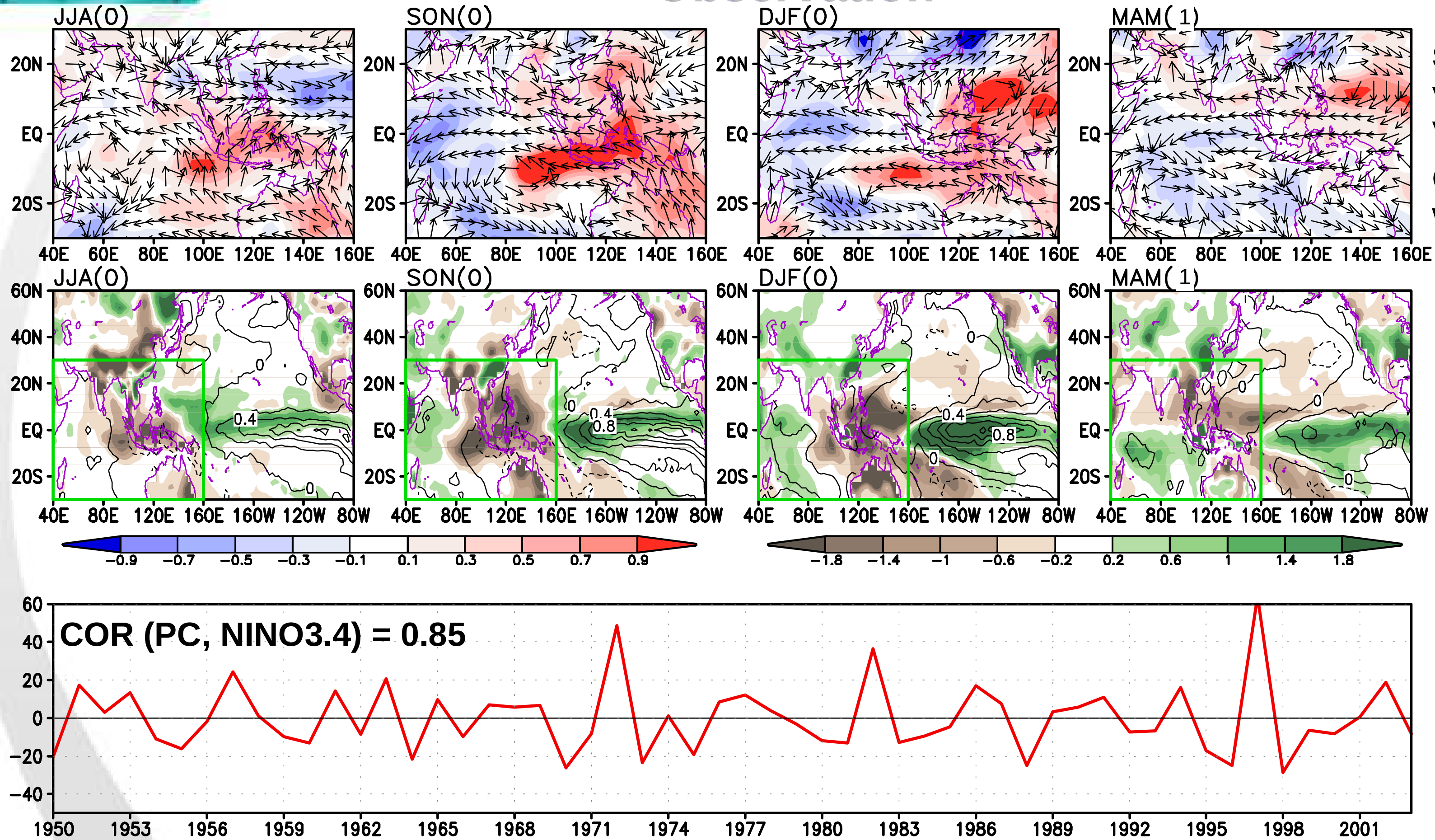
- **ENSO-Monsoon Relationship in GCM Experiments**
    - **Role of tropical Pacific SST anomalies**

ENSO-Monsoon Relationship in GCM Experiments

- ENSO-monsoon relationship in NCEP/CFS forecasts
- The role of ocean forcing in coupled systems: CGCM vs. “Pacemaker”
- The role of air-sea interaction on ENSO-monsoon relationship
- Shortcoming in “Pacemaker”: Decadal change of ENSO-Indian monsoon relationship

Regressed field of 1st SEOF of 850 hPa zonal wind

Observation



Shading: 500 hPa vertical pressure velocity

Contour: 850 hPa winds

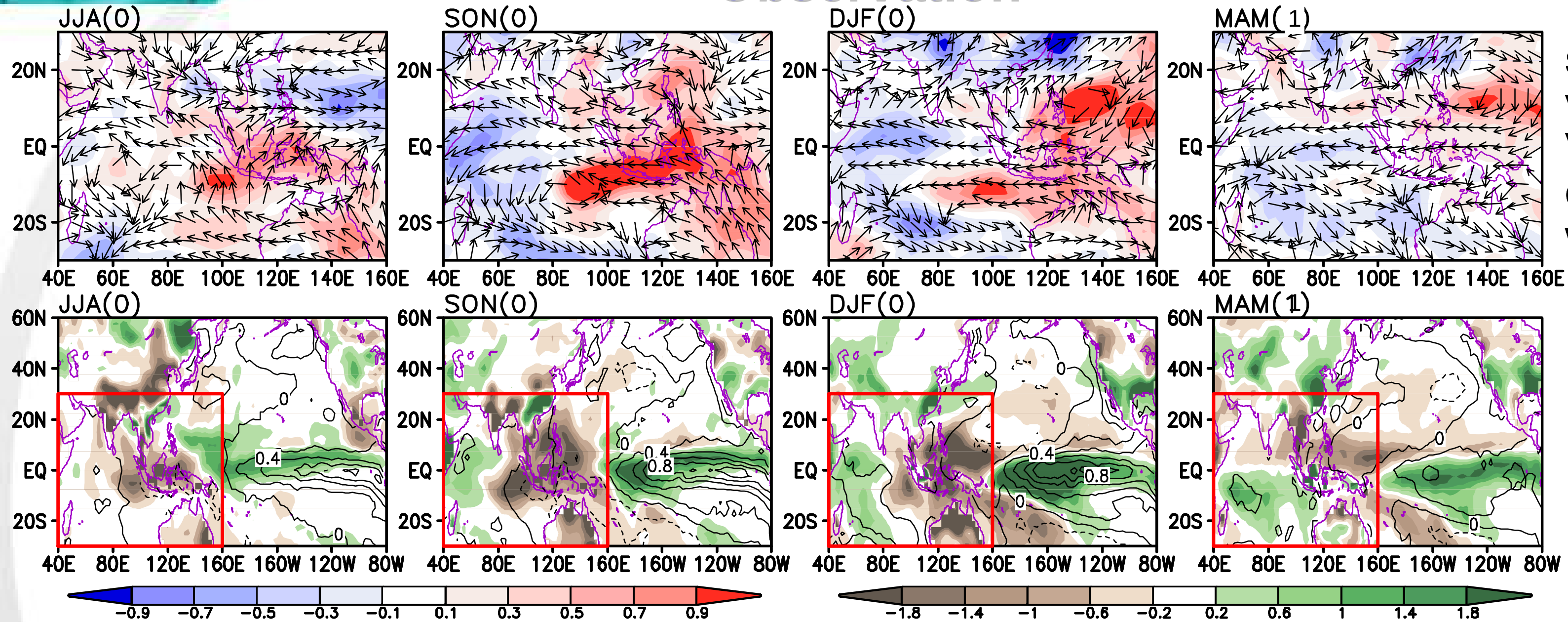
Shading: Rainfall (CMAP and PREC/L)

Contour: SST

- From the summer of Year 0, referred to as JJA(0), to the spring of the following year, called MAM(1), a covariance matrix was constructed using four consecutive seasonal mean anomalies for each year.
- SEOF (Wang and An 2005) of 850 hPa zonal wind over 40E-160E, 40S-40N
- High-pass filter of eight years
- The seasonally evolving patterns of the leading mode concur with ENSO's turnabout from a warming to a cooling phase (Wang et al. 2007).

Regressed field of 1st SEOF of 850 hPa zonal wind

Observation



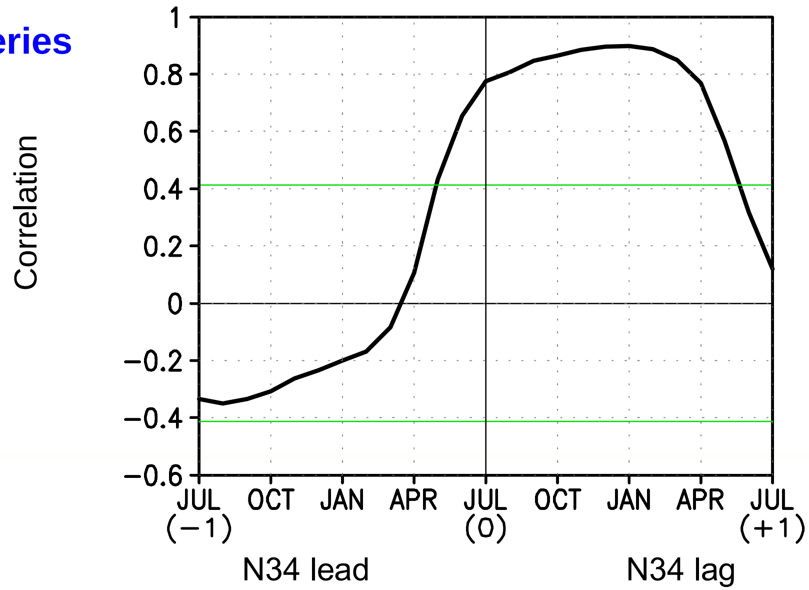
Shading: 500 hPa vertical pressure velocity

Contour: 850 hPa winds

Shading: Rainfall (CMAP and PREC/L)

Contour: SST

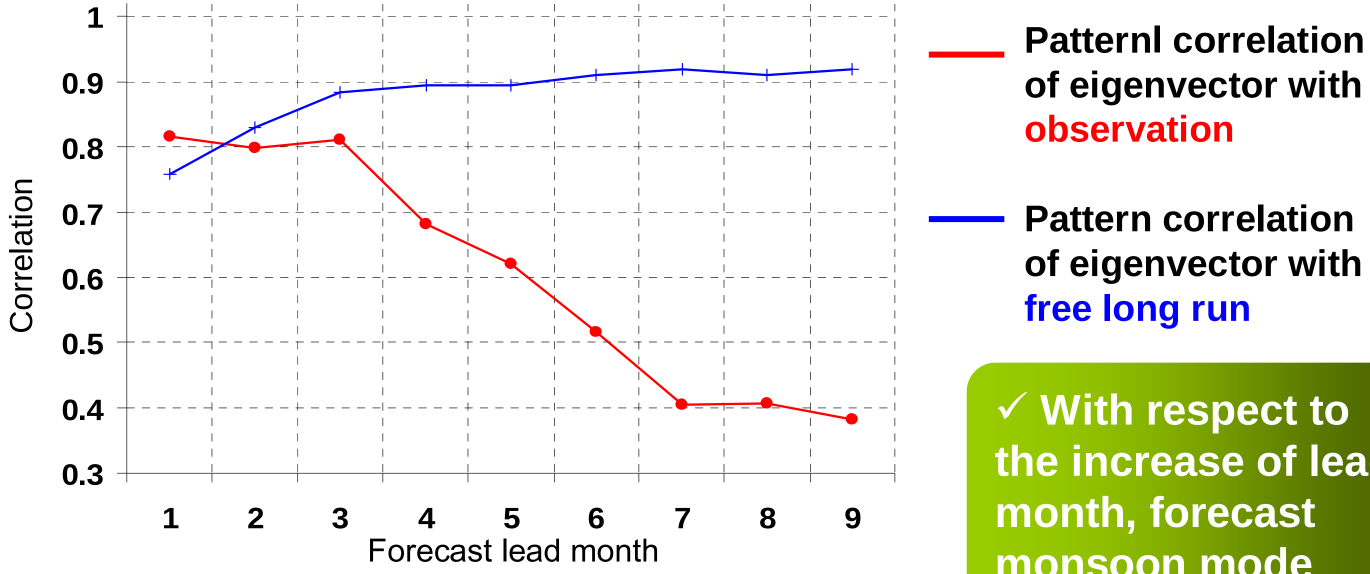
COR (1st PC timeseries of SEOF, N34)



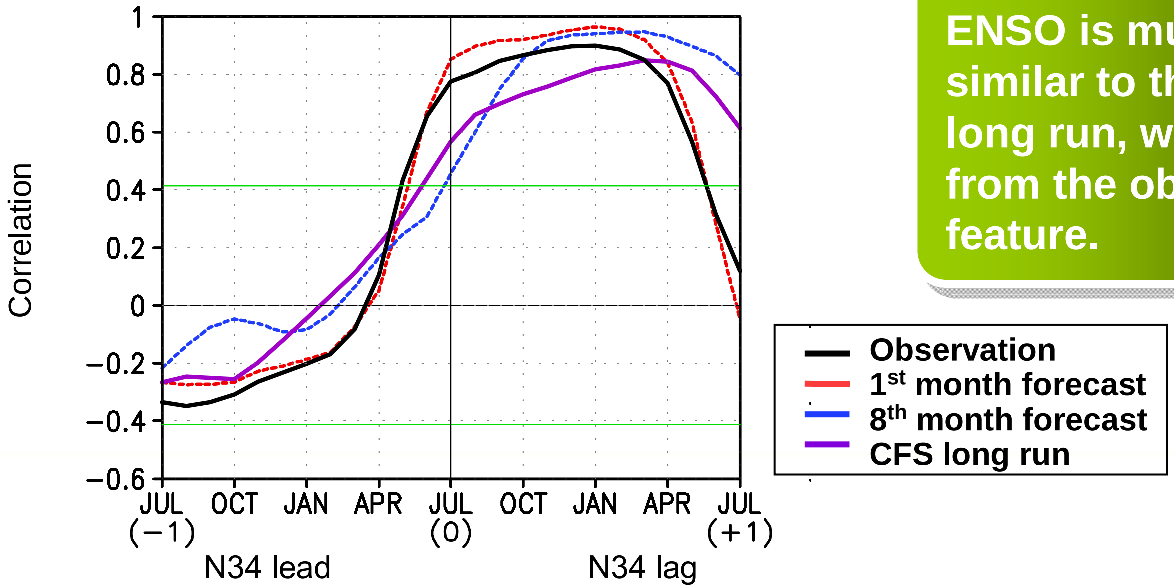
Impact of the Model Systematic Errors on Forecasts

❖ NCEP CFS Retrospective forecast
- 15 members
- 9 month lead
- 1981-2003 (23yrs)

Pattern Corr. of SEOF Eigenvector



COR (1st PC timeseries of SEOF, N34)



✓ With respect to the increase of lead month, forecast monsoon mode associated with ENSO is much similar to that of long run, while far from the observed feature.

In CFS coupled GCM, what is responsible to drop the predictability of ENSO – monsoon relationship?

- ✓ **Ocean forcing?**
- ✓ **Atmospheric response?**
- ✓ **Air-sea interaction?**

…..

“Pacemaker” Experiments

- The challenge is to design numerical experiments that reproduce the important aspects of this air-sea coupling while maintaining the flexibility to attempt to simulate the observed climate of the 20th century.

- “Pacemaker”: tropical Pacific SST is prescribed from observations, but coupled air-sea feedbacks are maintained in the other ocean basins (e.g. Lau and Nath, 2003).

- Anecdotal evidence indicates that pacemaker experiments reproduce the timing of the forced response to El Niño and the Southern Oscillation (ENSO), but also much of the co-variability that is missing when global SST is prescribed.

- In this study, we use NCEP/GFS T62 L64 AGCM.

"Pacemaker" Experimental Design

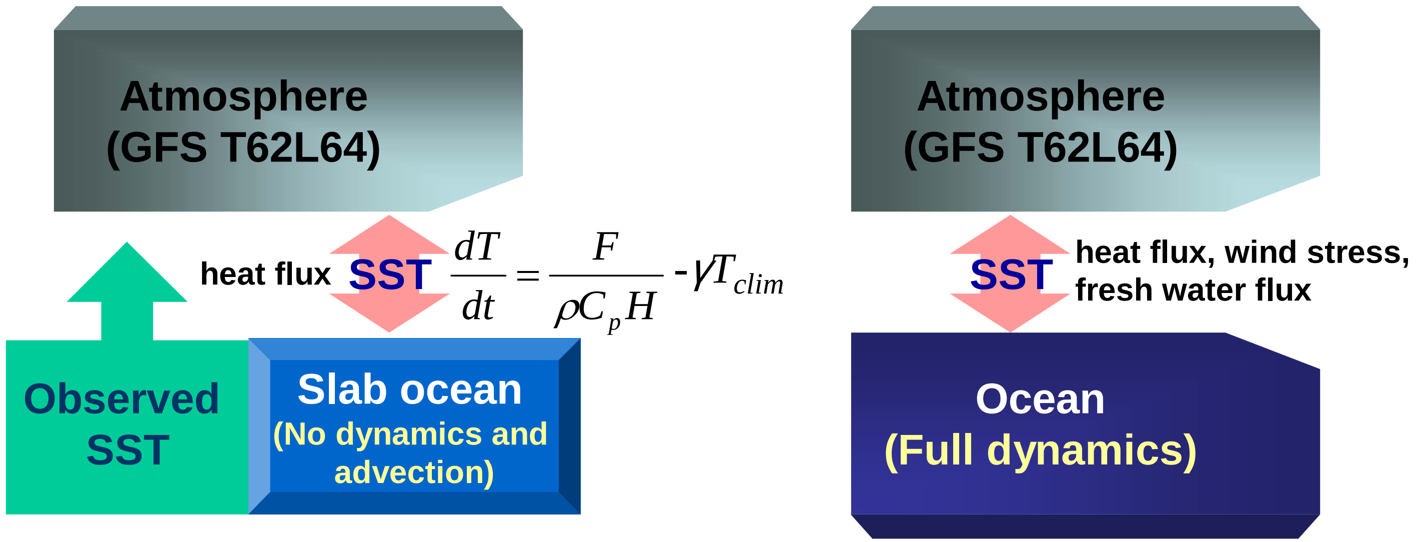
In this study, the deep tropical eastern Pacific where coupled ocean-atmosphere dynamics produces the ENSO interannual variability, is prescribed by observed SST.

Pacemaker region	165E-290E, 10S-10N
To merge the pacemaker and non-pacemaker regions	No blending
Outside the pacemaker region	Slab ocean mixed-layer
To handle model drift	Weak damping of 15W/m^2/K to observed climatology
Mixed-layer depth	Zonal mean monthly Levitus climatology

Model and Experimental Design

Pacemaker
Local air-sea interaction

CGCM
Fully coupled system



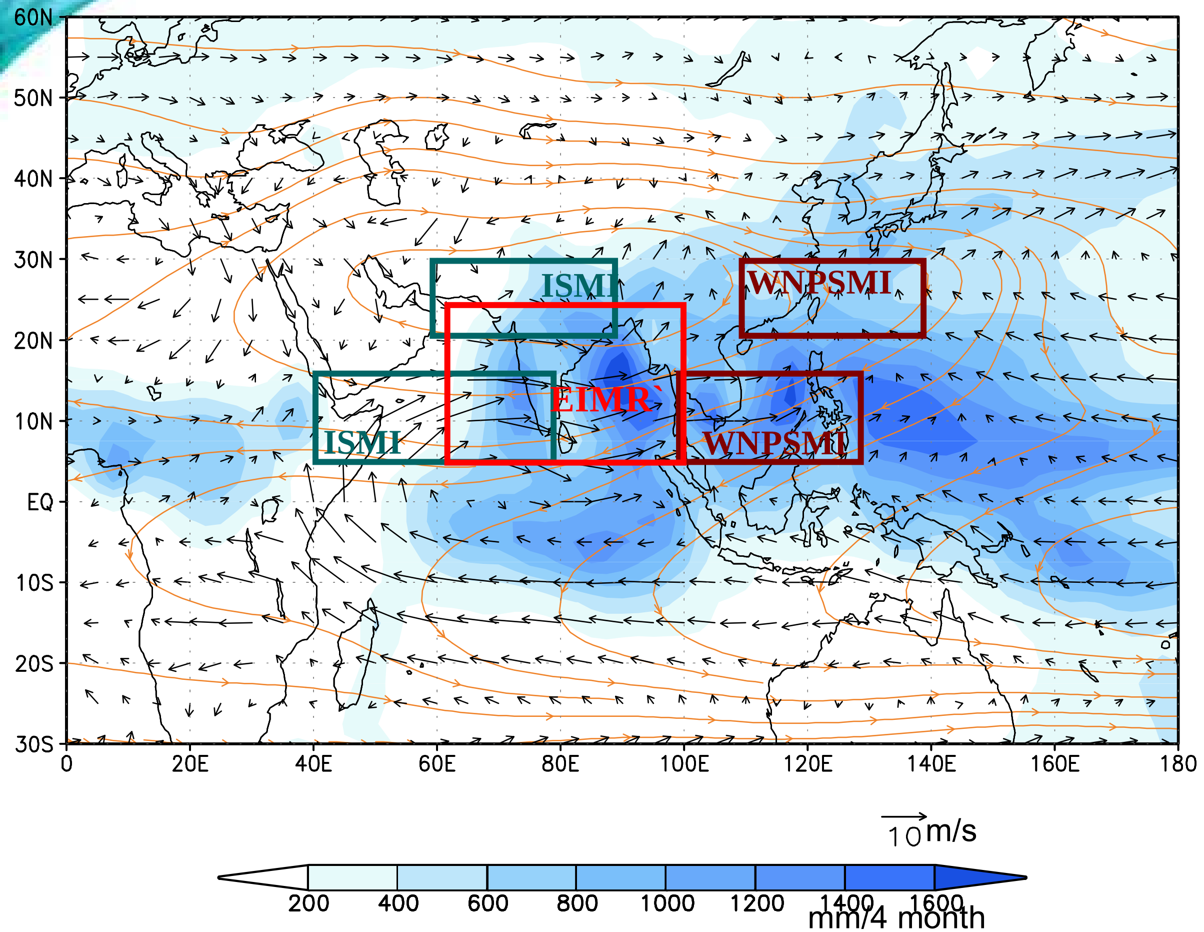
$$\frac{dT}{dt} = \frac{F}{\rho C_p H} - \gamma T_{clim}$$

Mixed layer model + AGCM (1950-2004, 4runs)

CGCM (52 yrs)

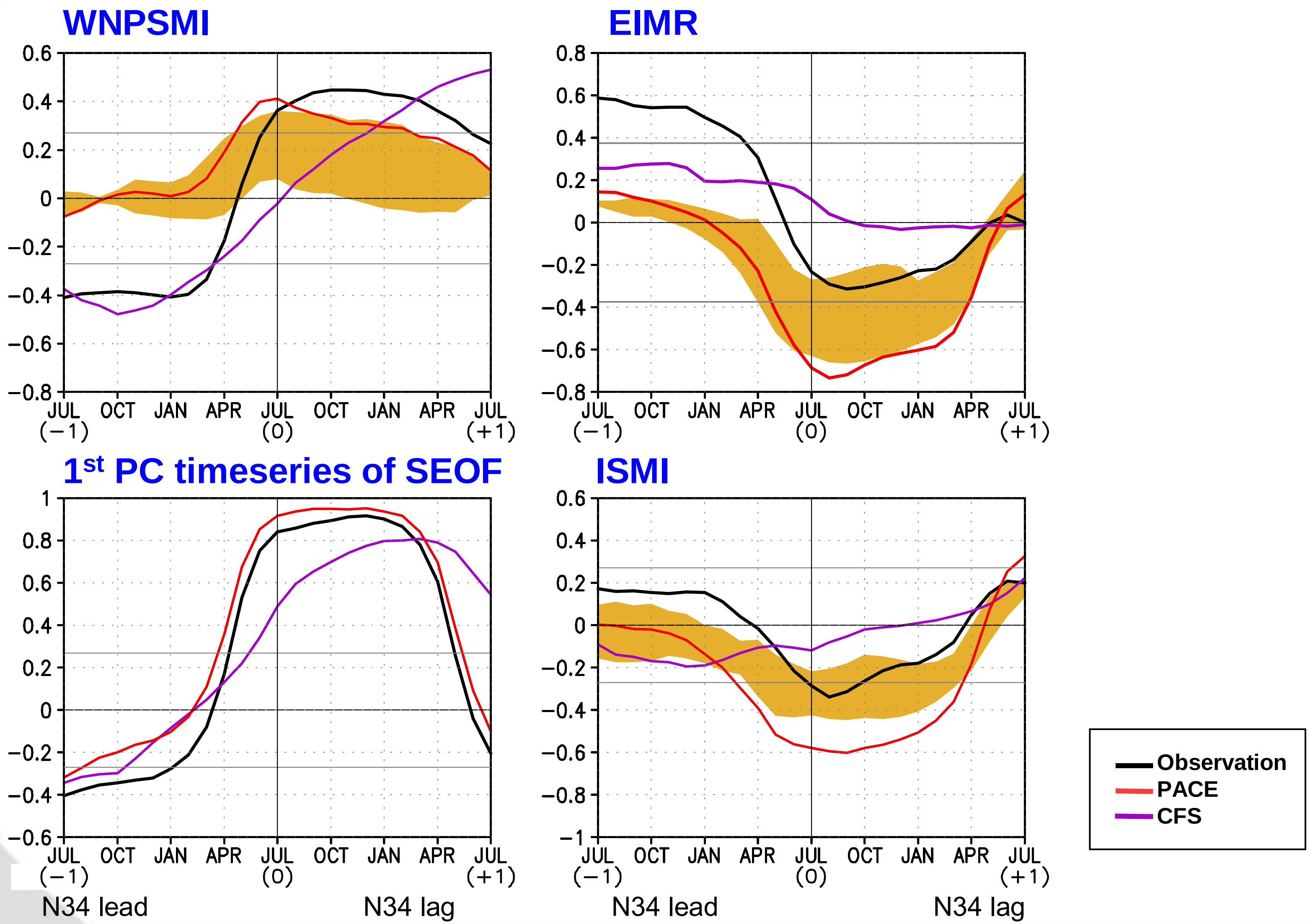
Experiment	Extratropics	Tropics	Mixed-layer depth	Period	Member
Pacemaker	Slab ocean mixed-layer with weak damping of 15W/m^2/K	Observed interannual SST	Zonal mean monthly Levitus climatology except Eastern Pacific (reduced as 1/3)	55 yr (1950-2004)	4
CGCM (CFS)	MOM3			52 yr	1

Definition of Monsoon



- Western North Pacific Summer Monsoon Index (Wang and Fan, 1999)
  WNPSMI : U850(5ºN–15ºN, 100ºE–130ºE) minus U850(20ºN–30ºN, 110ºE–140ºE)
- Extended Indian Monsoon Rainfall Index (Wu and Kirtman 2004)
  EIMR: Rainfall (5ºN–25ºN, 60ºE–100ºE)
- ISMI: U850(5ºN–15ºN, 40ºE–80ºE) minus U850(20ºN–30ºN, 70ºE–90ºE)

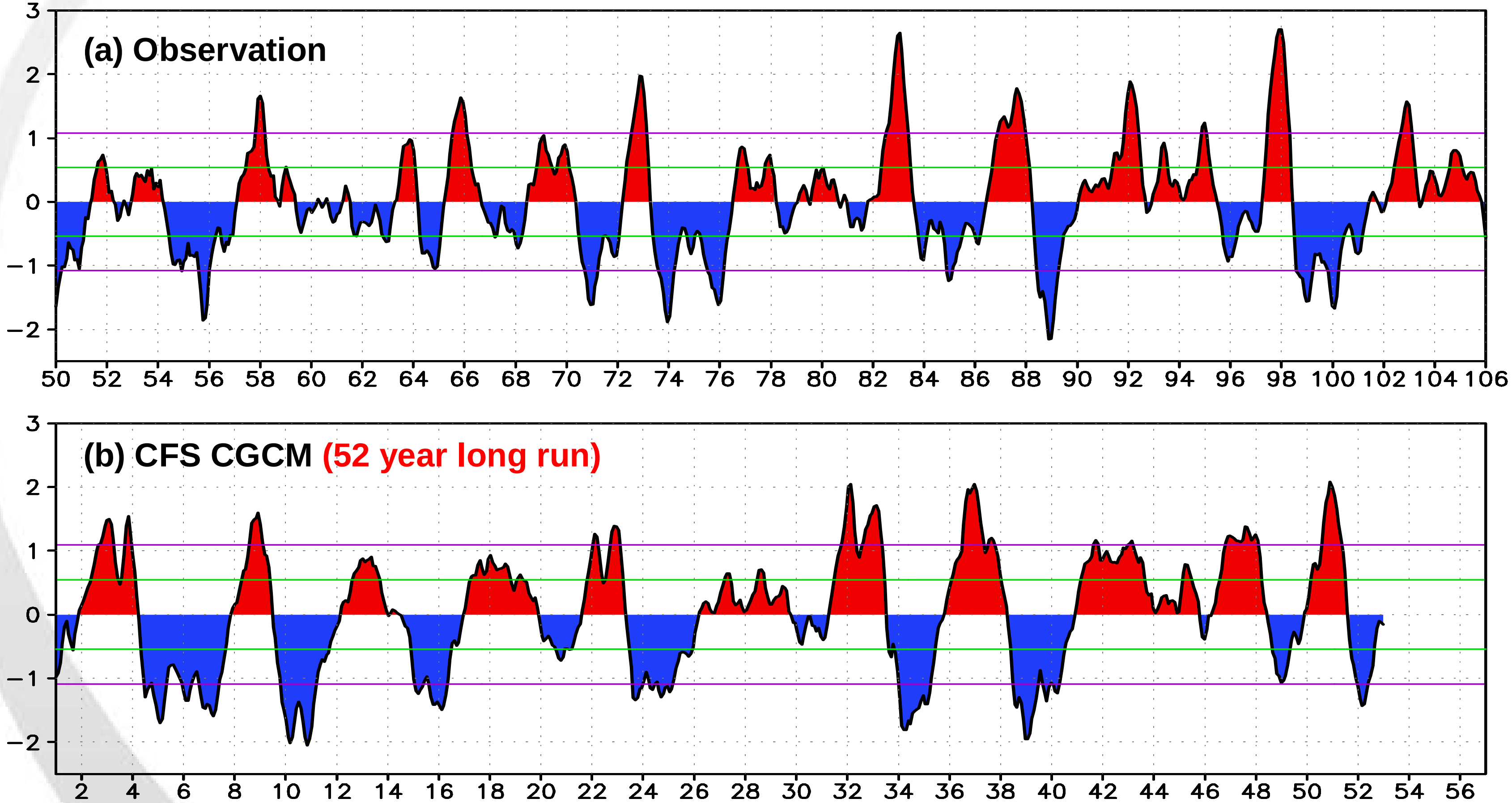
Lead-lag correlation with Nino3.4 Index



Ensemble spread of 4 members of Pacemaker exp.

ENSO Characteristics in CFS CGCM

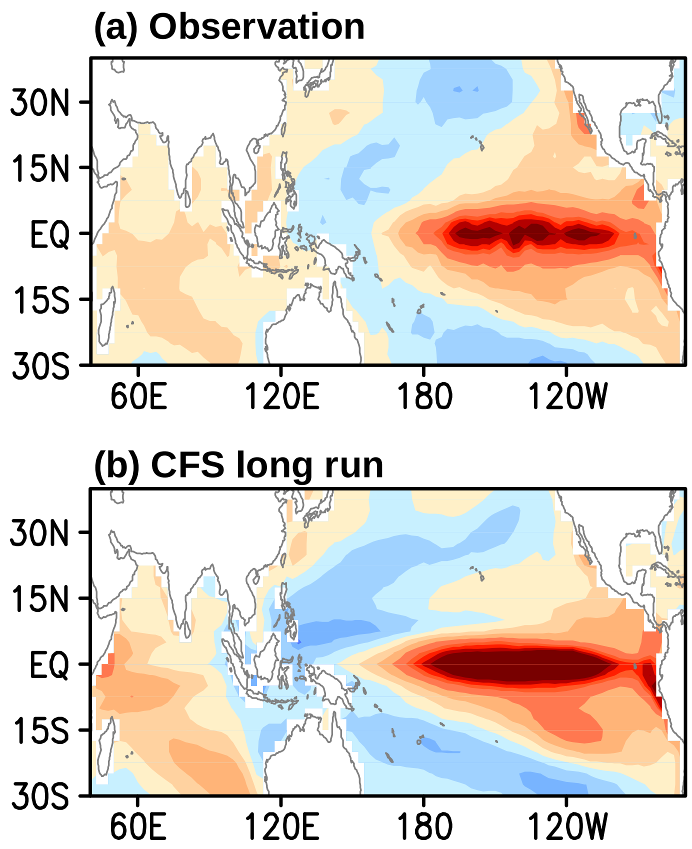
NINO3.4 Index during 1950-2005



NCEP CFS has long life cycle of ENSO and associated summer peak. This slow coupled dynamics of model must be responsible for the delay of relationship.

ENSO Characteristics in CFS CGCM

Regression of DJF NINO3.4 Index to SST anomalies



- **In CGCM, ENSO SST anomalies show westward penetration with narrow band comparing to the observed.**

JJA Regression map of 1st SEOF of 850 hPa zonal wind

Total field — 850 hPa zonal wind and rainfall

Difference from Obs. — 850 hPa zonal wind and SST

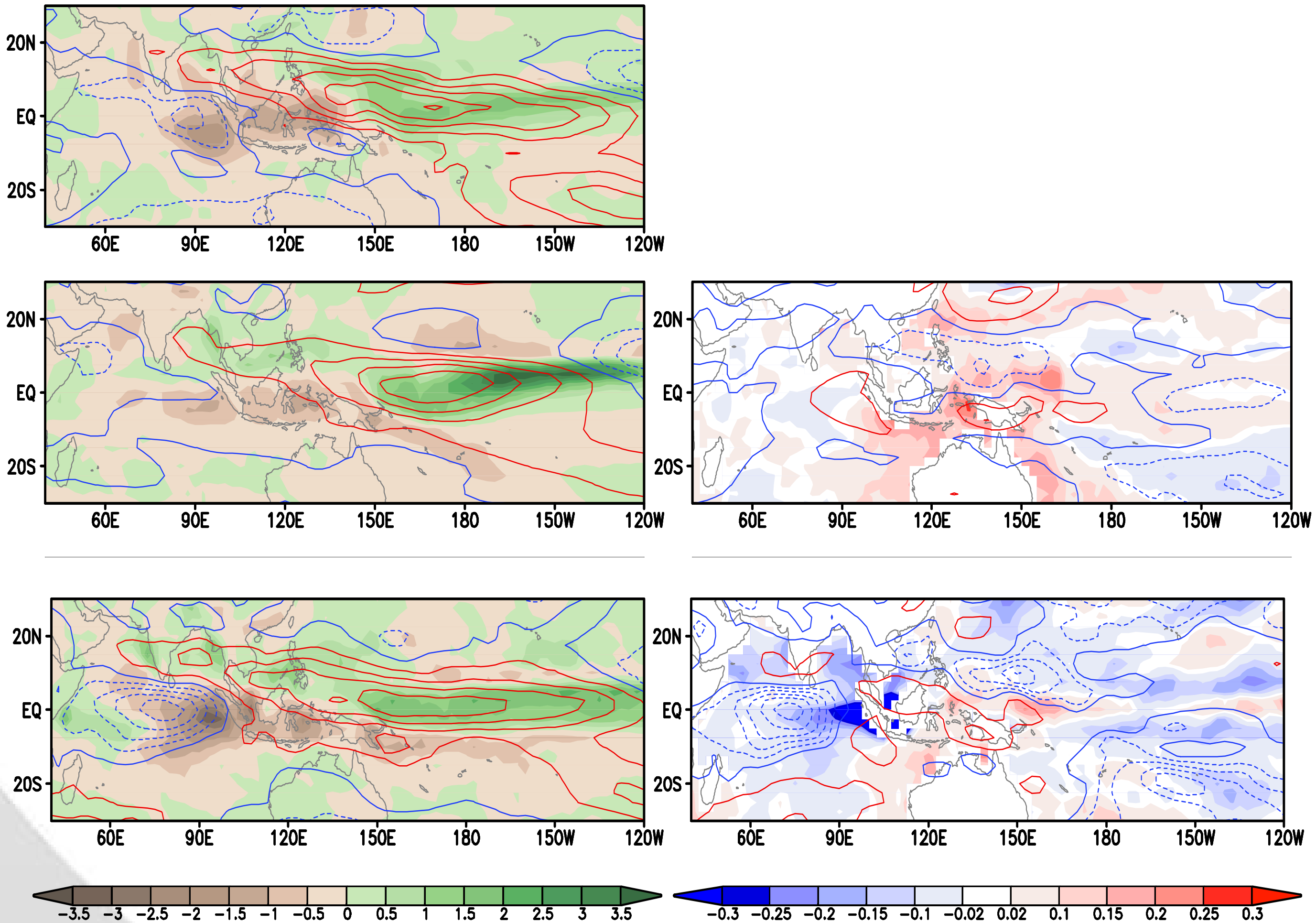
Obs.

Pace

CFS

Pace-Obs.

CFS-Obs.

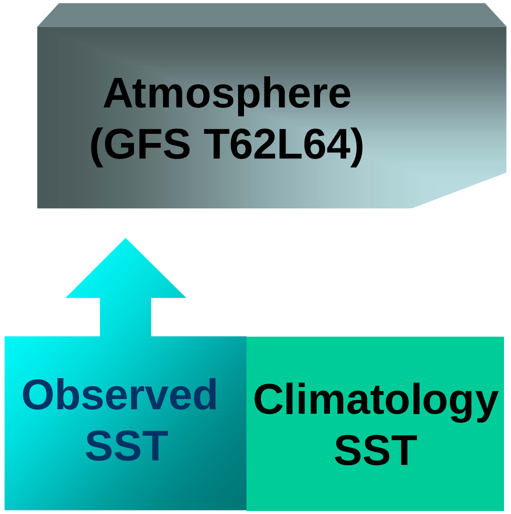


Contour: zonal wind
Shading: rainfall

Contour: zonal wind
Shading: SST

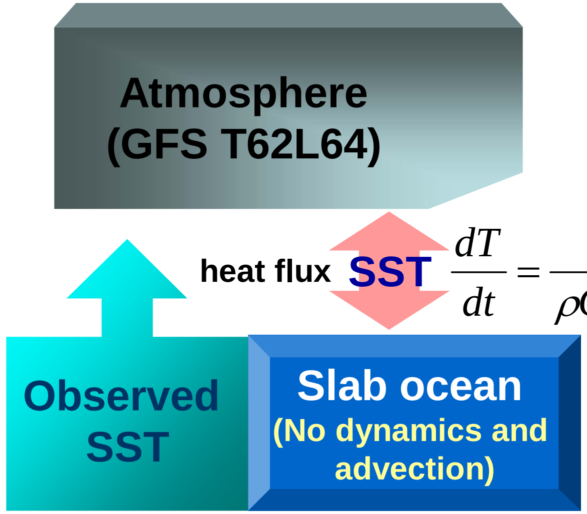
Model and Experimental Design

Control
No air-sea interaction



AGCM
(1950-2004, 4runs)

Pacemaker
Local air-sea interaction

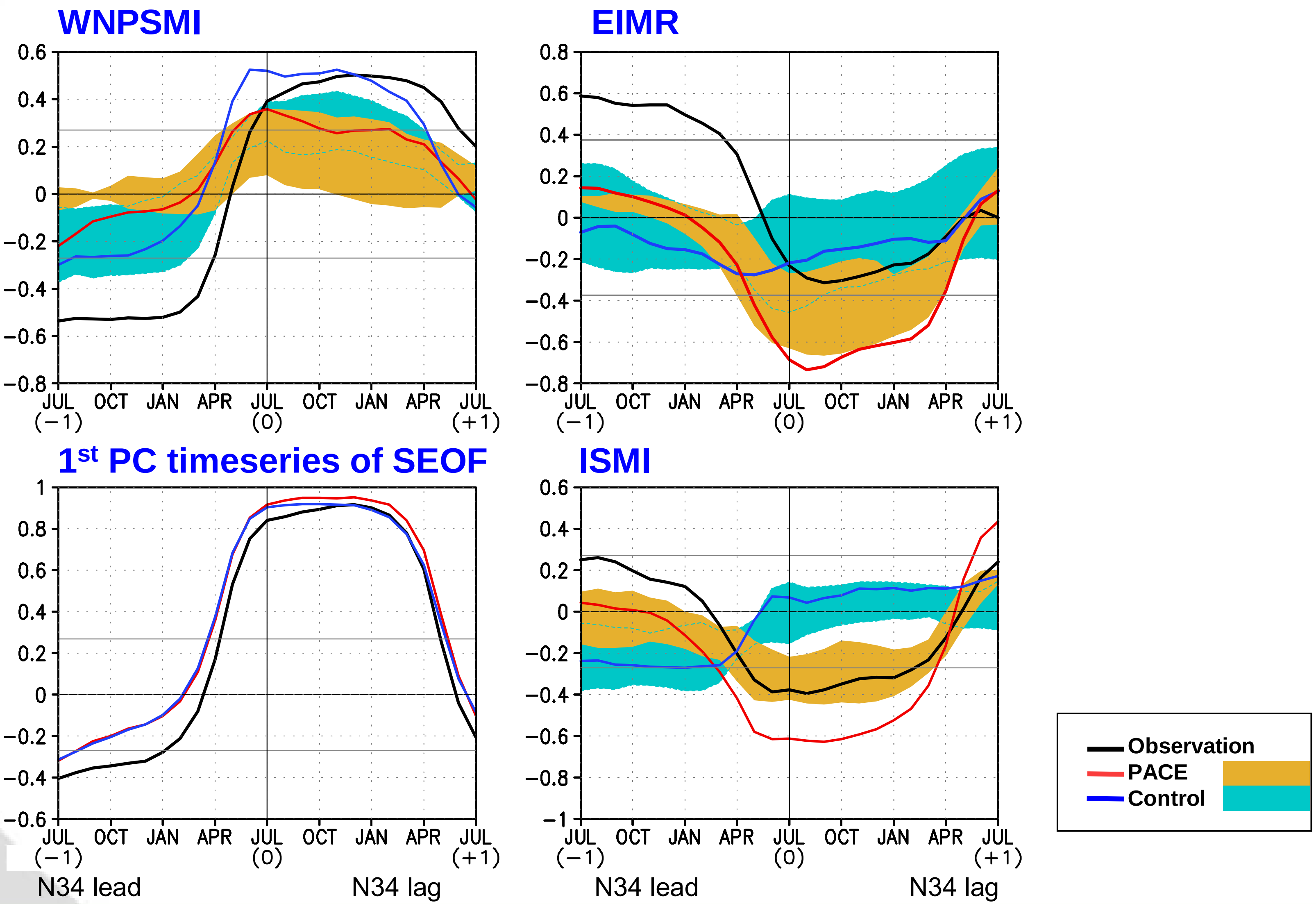


$$\frac{dT}{dt} = \frac{F}{\rho C_p H} - \gamma T_{clim}$$

Mixed layer model + AGCM
(1950-2004, 4runs)

Experiment	Extratropics	Tropics	Mixed-layer depth	Period	Member
Pacemaker	Slab ocean mixed-layer with weak damping of 15W/m^2/K	Observed interannual SST	Zonal mean monthly Levitus climatology except Eastern Pacific (reduced as 1/3)	55 yr (1950-2004)	4
Control	Climatological SST	Observed interannual SST	none	55 yr (1950-2004)	4

Lead-lag correlation with Nino3.4 Index



ISMI: U850(5ºN–15ºN, 40ºE–80ºE) minus U850(20ºN–30ºN, 70ºE–90ºE)

Ensemble spread of 4 members of Pacemaker exp.

JJA Regression map of 1st SEOF of 850 hPa zonal wind

Total field
850 hPa zonal wind and rainfall

Difference from Obs.
850 hPa zonal wind and SST

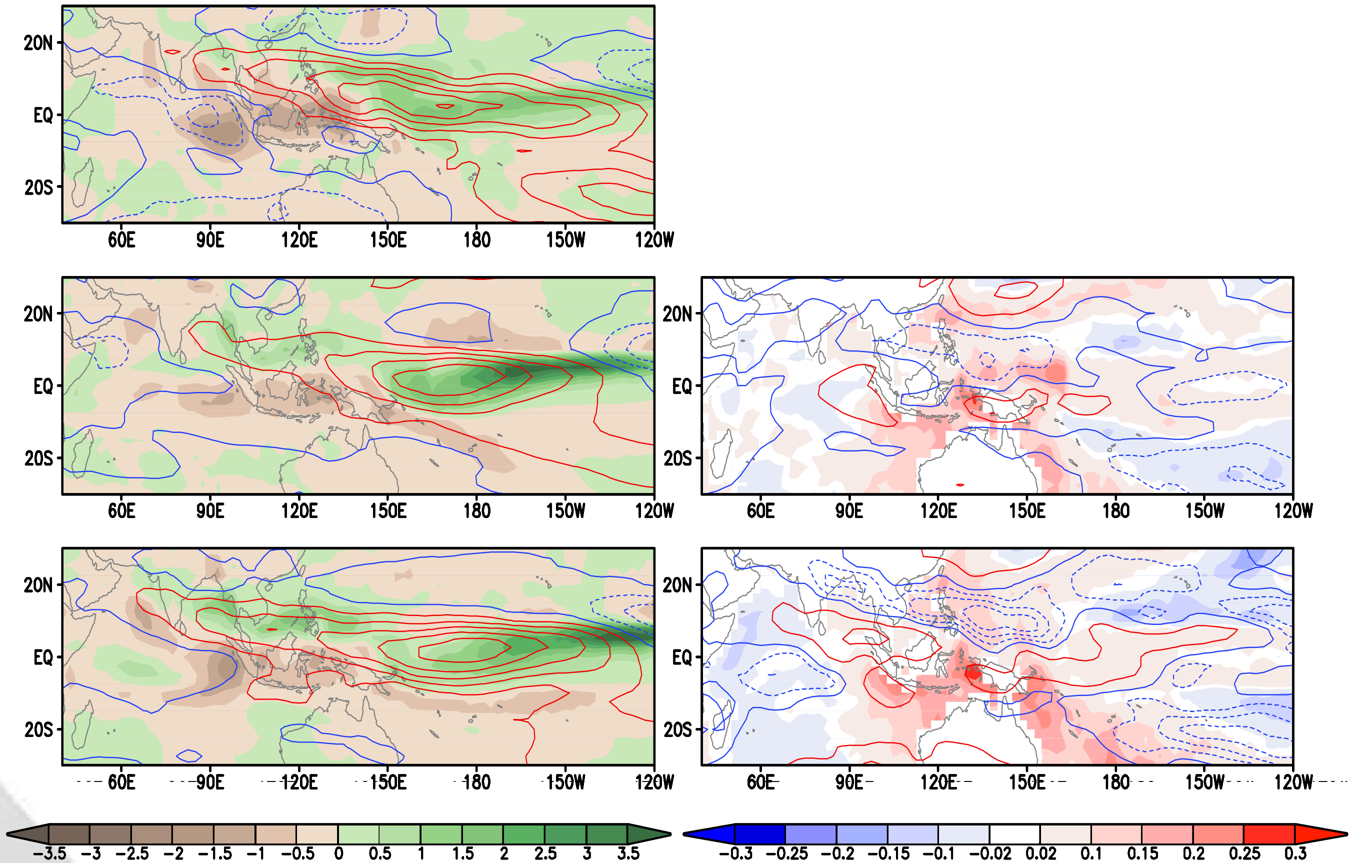
Obs

Pace

Ctl

Pace-Obs.

Ctl-Obs.

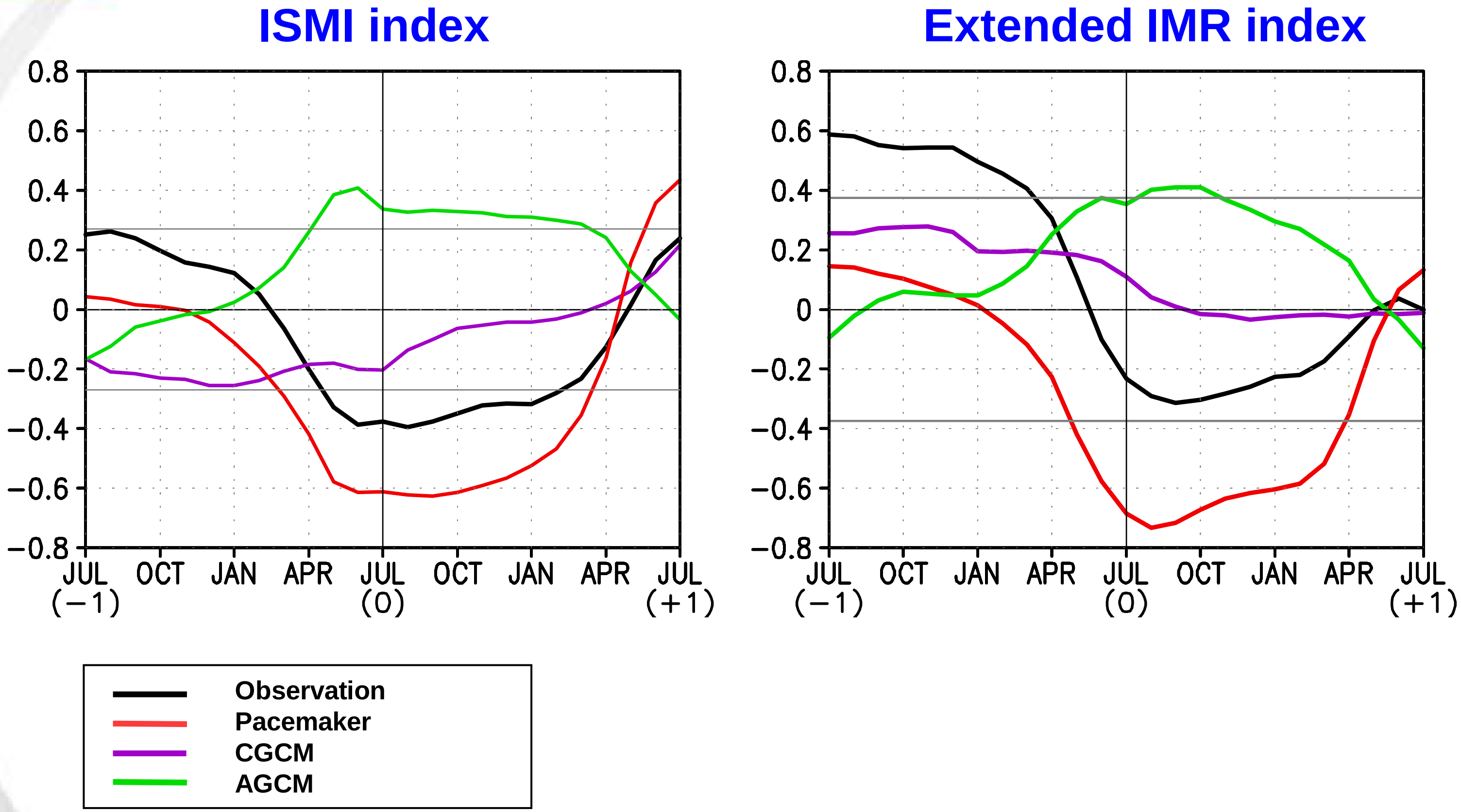


Contour: zonal wind
Shading: rainfall

Contour: zonal wind
Shading: SST

Relationship between NINO3.4 and Indian Monsoon Indices

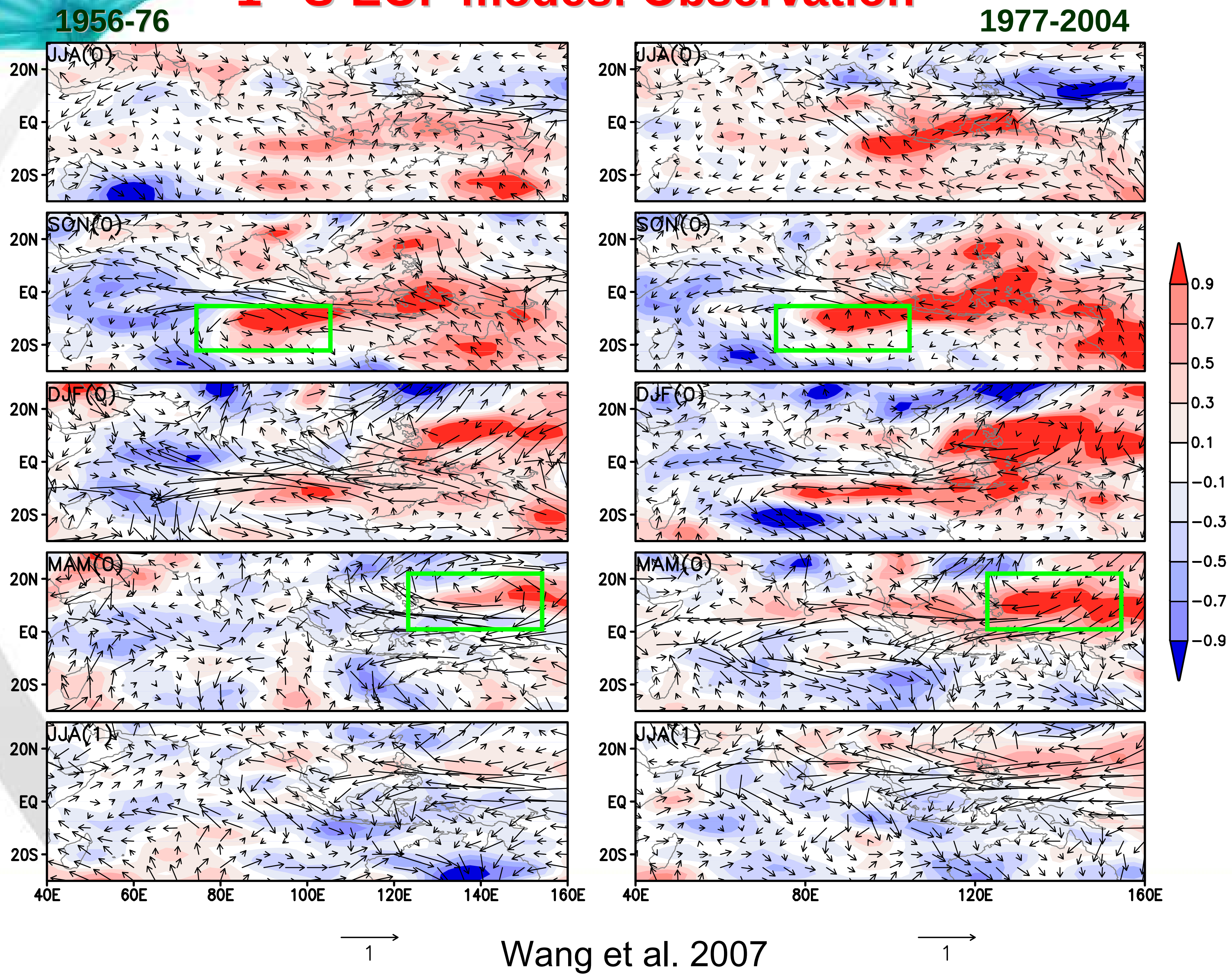
Pacemaker, CGCM, and AGCM



Indian Summer Monsoon Index (Wang and Fan, 1999):
U850(5ºN–15ºN, 40ºE–80ºE) - U850(20ºN–30ºN, 70ºE–90ºE)

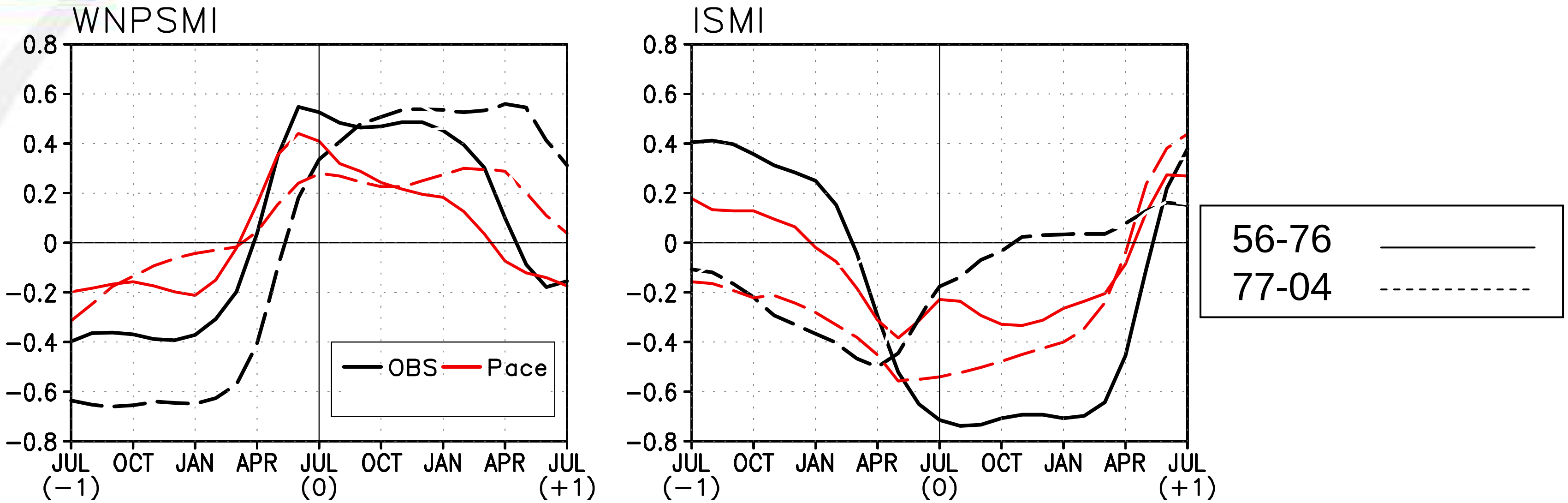
Extended Indian Monsoon Rainfall index
(Wu and Kirtman, 2004): Rainfall (5-25N, 60E-100E)

1st S-EOF modes: Observation



Wang et al. 2007

Lead-lag Correlation between NINO3.4 and Monsoon indices



Decadal change of ENSO-Monsoon relationship based on SEOF analysis (Wang et al. 2007)

1. Remote El Niño/La Niña forcing is the major factor that affects A-AM variability.

→ The mismatch between NINO3.4 SST and the evolution of the two major A-AM circulation anomalies suggests that El Niño cannot solely force these anomalies.

2. The monsoon-warm pool ocean interaction is also regards as a cause (a positive feedback between moist atmospheric Rossby waves and the underlying SST dipole anomalies)

→ The enhanced ENSO variability in the recent period has increased the strength of the monsoon-warm pool interaction and the Indian Ocean dipole SST anomalies, which has strengthened the summer westerly monsoon across South Asia, thus weakening the negative linkage between the Indian summer monsoon rainfall and the eastern Pacific SST anomaly.

→ However, in pacemaker, the strengthen of the Indian Ocean dipole SST anomalies is not shown due to fixed mixed-layer depth and SST climatology.

THANK YOU!

ANY QUESTIONS?