Simulation and Prediction of IntraSeasonal Oscillation of Asian Monsoon

: Characteristics, Impacts, Predictability, and Prediction of Boreal Summer IntraSeasonal Oscillation

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1. Introduction: MJO vs BSISO

2. Characteristics and Impacts of BSISO

3. Predictability and Multi-Model Ensemble Prediction for BSISO and MJO

4. Real-time Monitoring and forecast for BSISO and MJO

5. Summary

1. Introduction: The Seamless Weather-Climate Prediction Problem

Physical Basis for Prediction	Initial Condition	Boundary Condition	Internal Variability vs External Forcing	Natural forcing vs Anthropogenic forcing

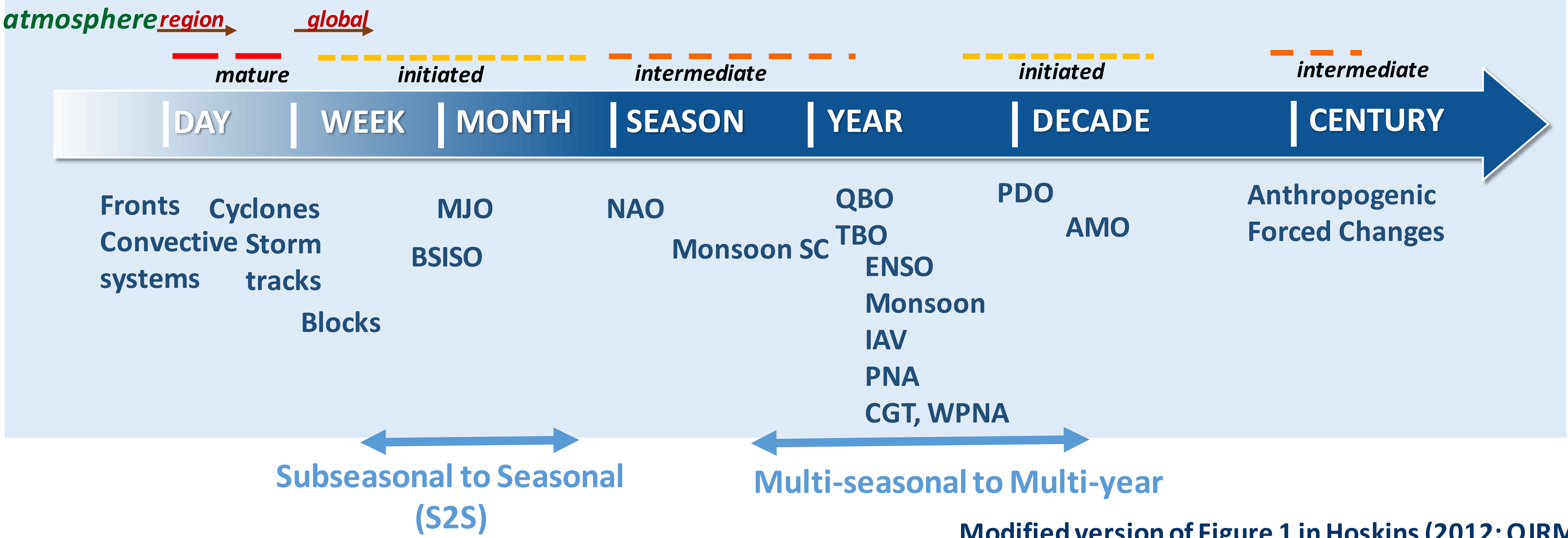
Physical Processes

Achieving a better understanding of intraseasonal variability, predictability, and its associated weather and climate impacts are of importance for extending forecast beyond its current limit and developing seamless suite of weather and climate prediction.

Current Status

Phenomena

Major Modes of Variability



Modified version of Figure 1 in Hoskins (2012; QJRM)

1. Introduction: International Intercomparison Projects

AGCM prediction with Perfect SST

AOGCM prediction

A-O-L-SI Coupled Prediction

ESM Prediction

1995 2000 2010 2015

Europe: PROVOST DEMETER ENSEMBLES EUROSIP

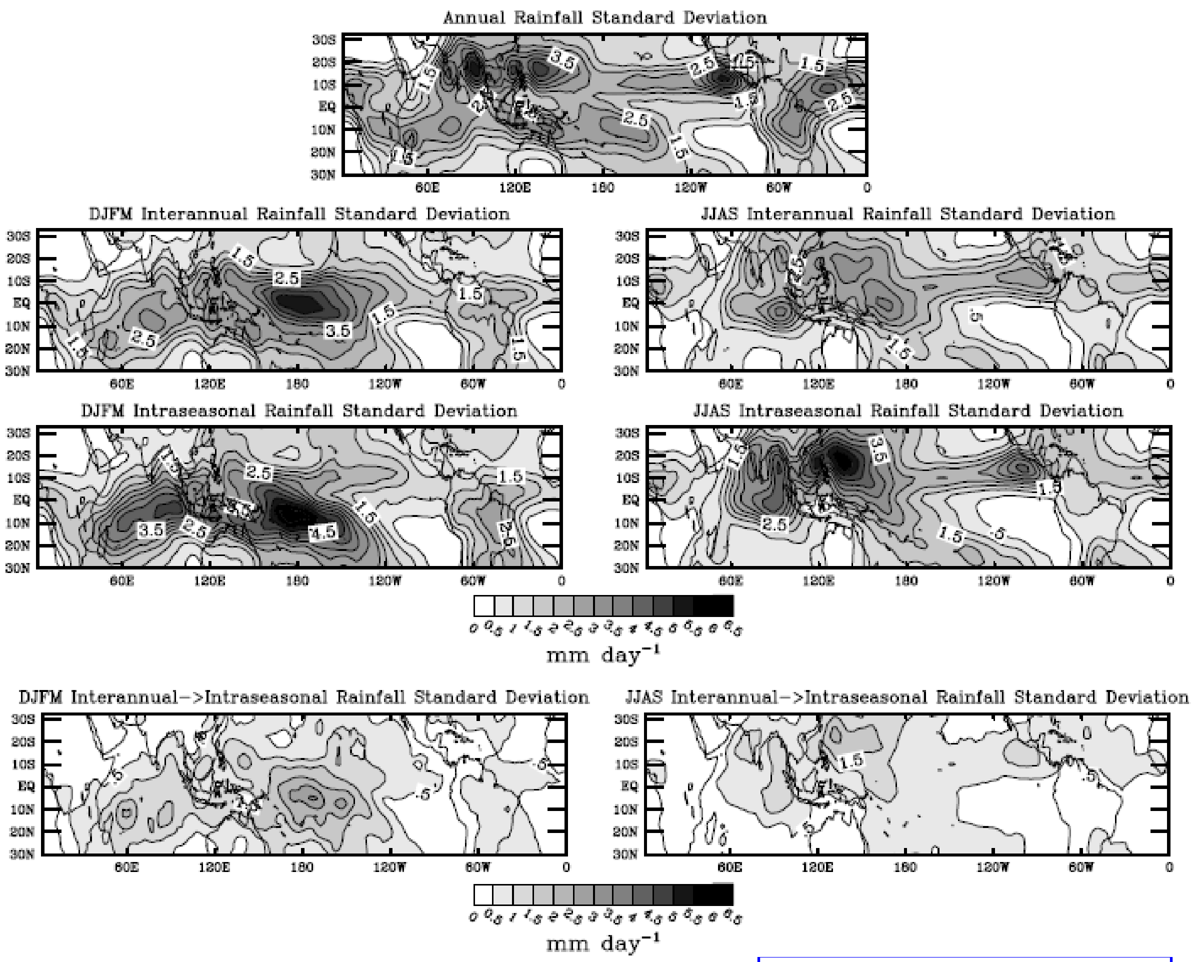
USA: DSP NMME

Asia-Pacific: AAMIP CliPAS

Global: ISVHE S2S CMIP5 Decadal Prediction CMIP6 Seamless Prediction

1. Introduction: Intraseasonal vs Interannual Variability

CMAP Rainfall



Intraseasonal : 30-90
Interannual : > 90

Waliser (2006 in *the Asian Monsoon*)

- While the defining variability of a monsoon system is its seasonal character, its variability about its typical seasonal evolution is often of most interest and importance. In the case of **the Asian and Australian summer monsoons**, their **intraseasonal character is especially prominent and unique**.
- The annual standard deviation exhibits strong variability on either side of the equator, which is a depiction of **the annual meridional migration of the tropical rainfall band** – **a fundamental manifestation of the monsoon**.
- The **IAV**, particularly in boreal winter, emphasizes **the connection to ENSO-related SST variability**.
- The **intraseasonal variability (ISV)** is as large or **larger than the interannual variability (IAV).**
- The ISV tends to be relatively **most prominent in the Asian monsoon sector during boreal summer** and **in the Australia monsoon sector during austral summer**.

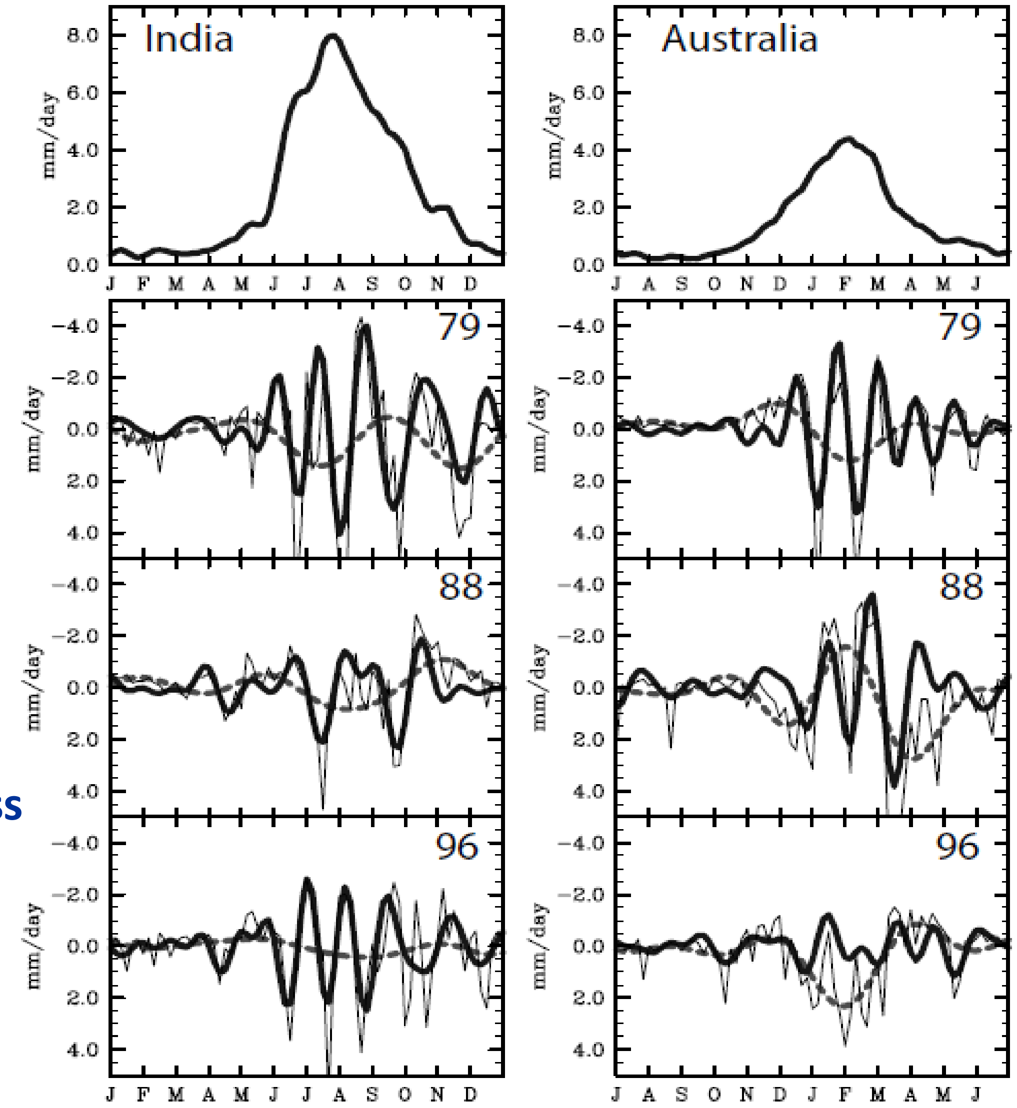
1. Introduction: Intraseasonal vs Interannual Variability

CMAP Rainfall

Climatological Annual Cycle

Solid line: 30-90-day filtered Anomaly (ISV)

Dashed line: 90-day low pass value (IAV)

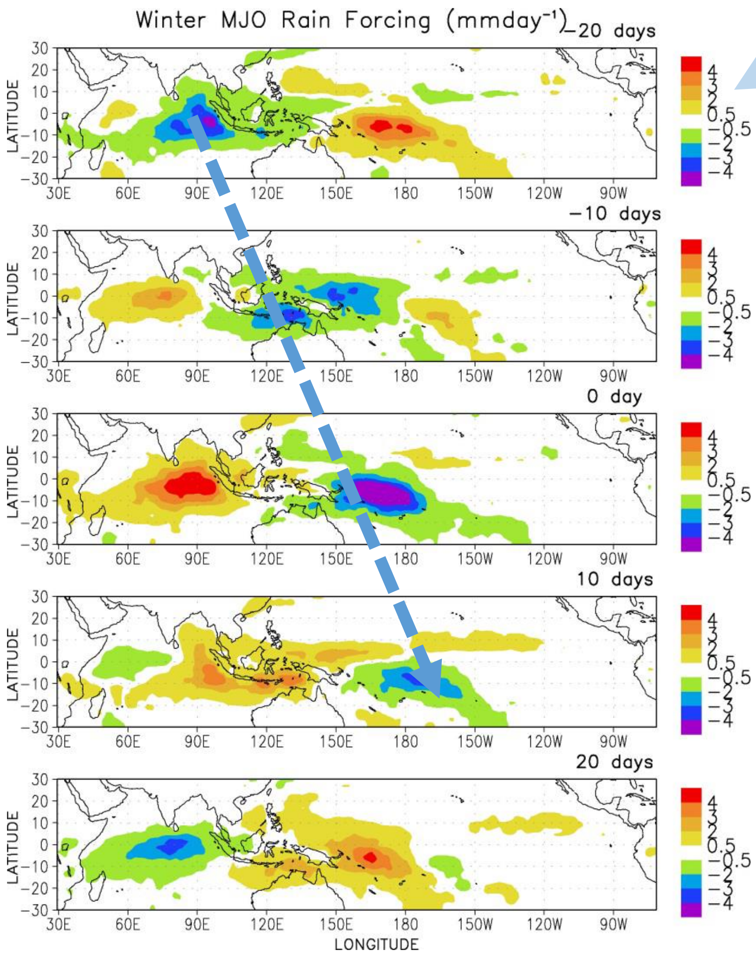


Waliser (2006 in *the Asian Monsoon*)

- Figure: the annual cycle of rainfall and the anomalous evolution of unfiltered and filtered rainfall over India and northern Australia
- It is shown the **overall dominance**, apart from the annual variation, **of the intraseasonal timescale** on these monsoon systems, including **its obvious role in dictating onset and break phases**. It is evident that **ISV is a fundamental component of these monsoon system**.

1. Introduction: MJO vs BSISO

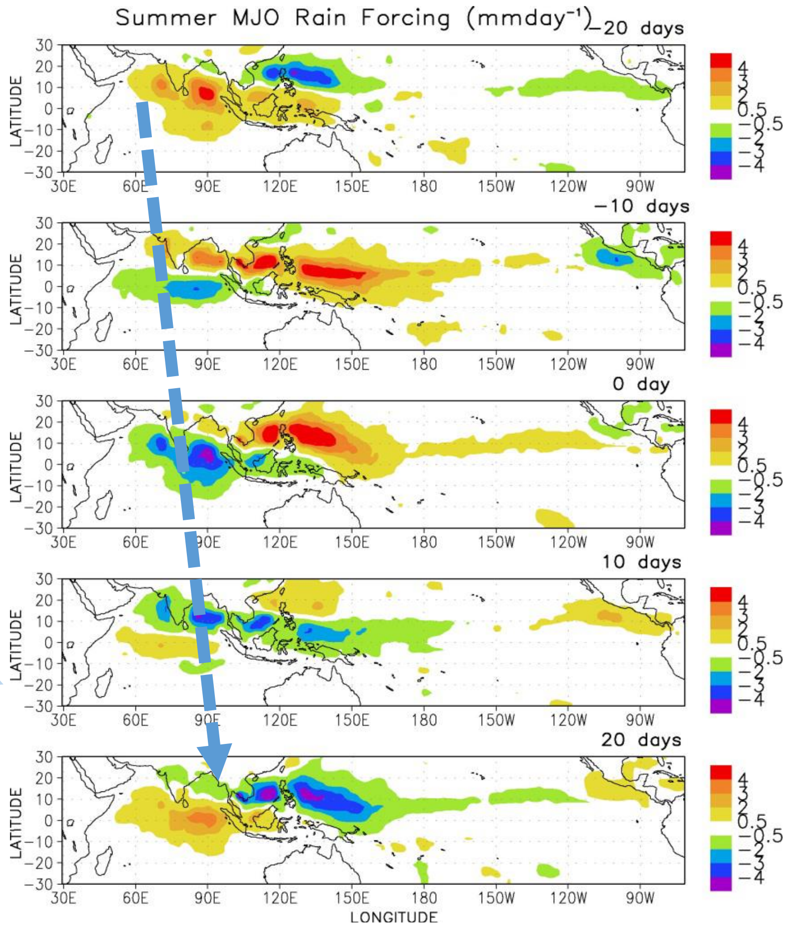
Madden-Julian Oscillation (MJO)



- **Boreal winter** mode
- **30-60-day** time scale
- Dominant **eastward** propagation along the equator
- Realtime Multivariate MJO (**RMM**) index (Wheeler and Hendon 2004)

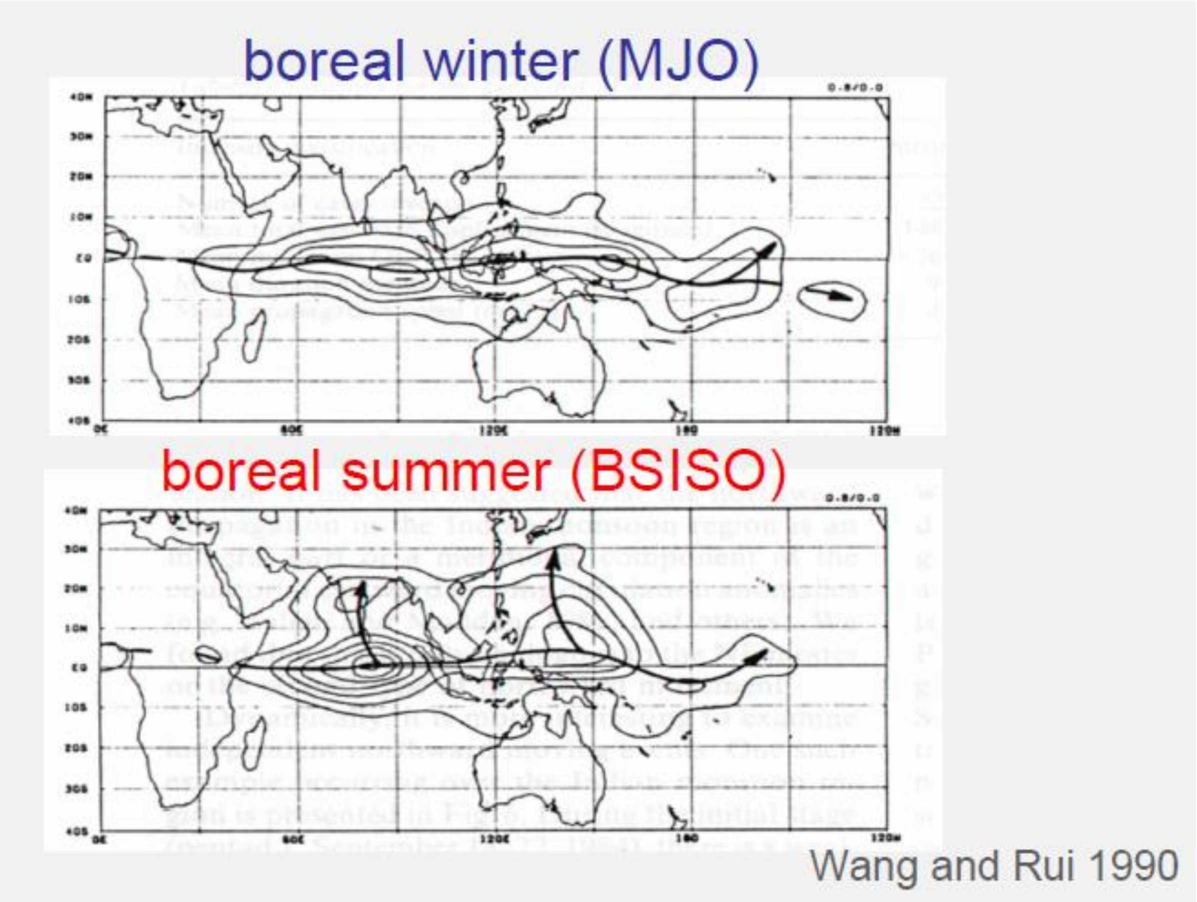
- **Boreal summer** mode
- **30-60-day** & **biweekly** time scale
- **northward/northwestward** propagation
- Affecting **monsoon onsets** (Wang and Xie 1997), **active/break phases** of monsoon (Annamalai and Slingo 2001), **monsoon seasonal mean** (Krishnamurthy and Shukla 2007)
- Possible source for **seasonal climate predictability** for precipitation (Lee et al. 2010) and extratropical atmospheric circulation (Ding and Wang; Lee et al. 2011)
- Realtime **BSISO indices** (Lee et al. 2013)

Boreal Summer Intraseasonal Oscillation (BSISO)



From MJO working group website

1. Introduction: Bimodal Representation of the Tropical ISO



ISV propagation vectors

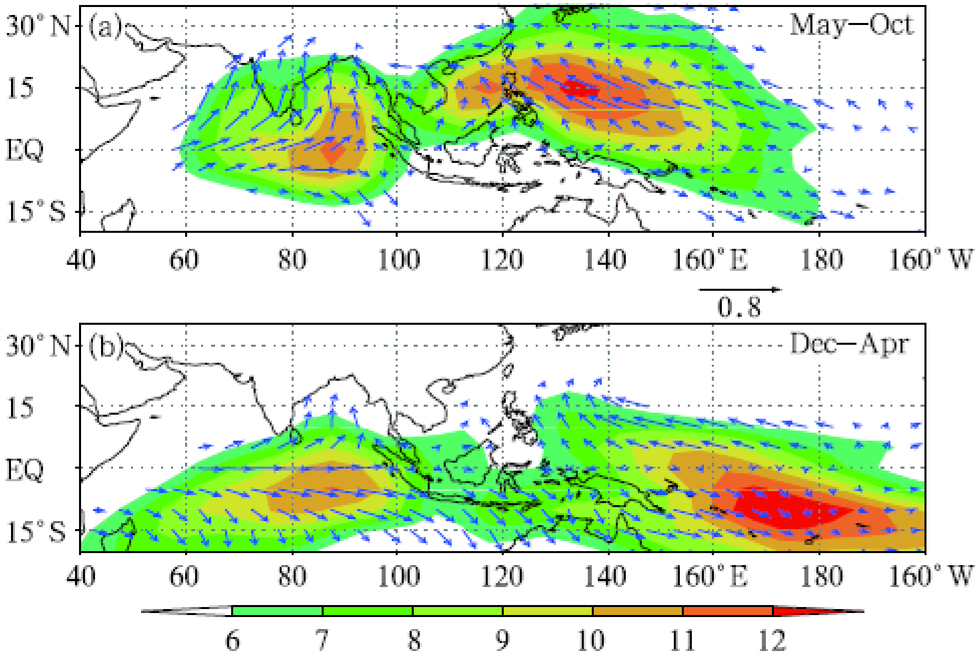
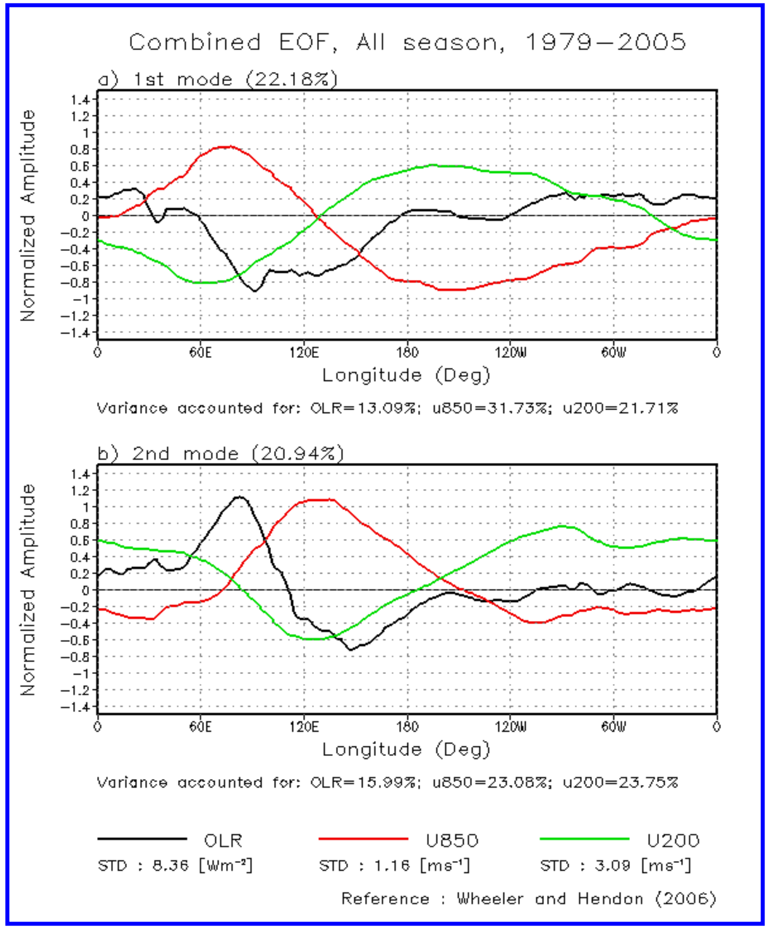
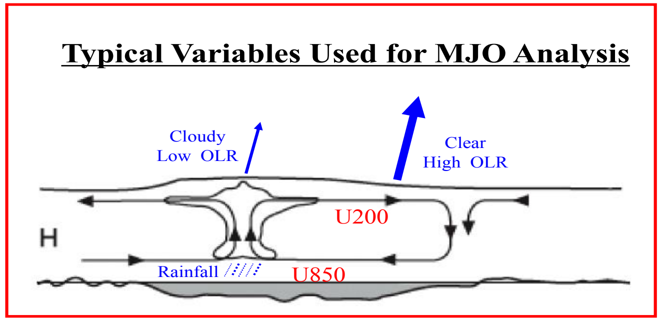


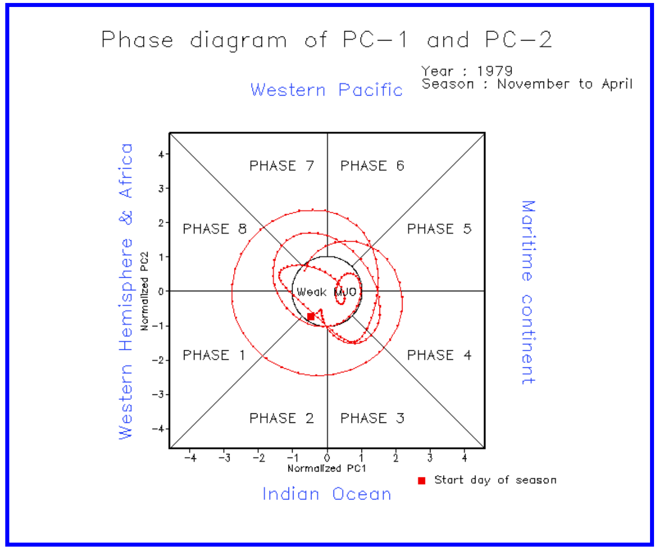
Fig. 9. The standard deviation of 20–80-day filtered CMAP rainfall anomalies (shaded) during 1979–1998 and propagation vectors for boreal (a) summer (May–October) and (b) winter (December–April).

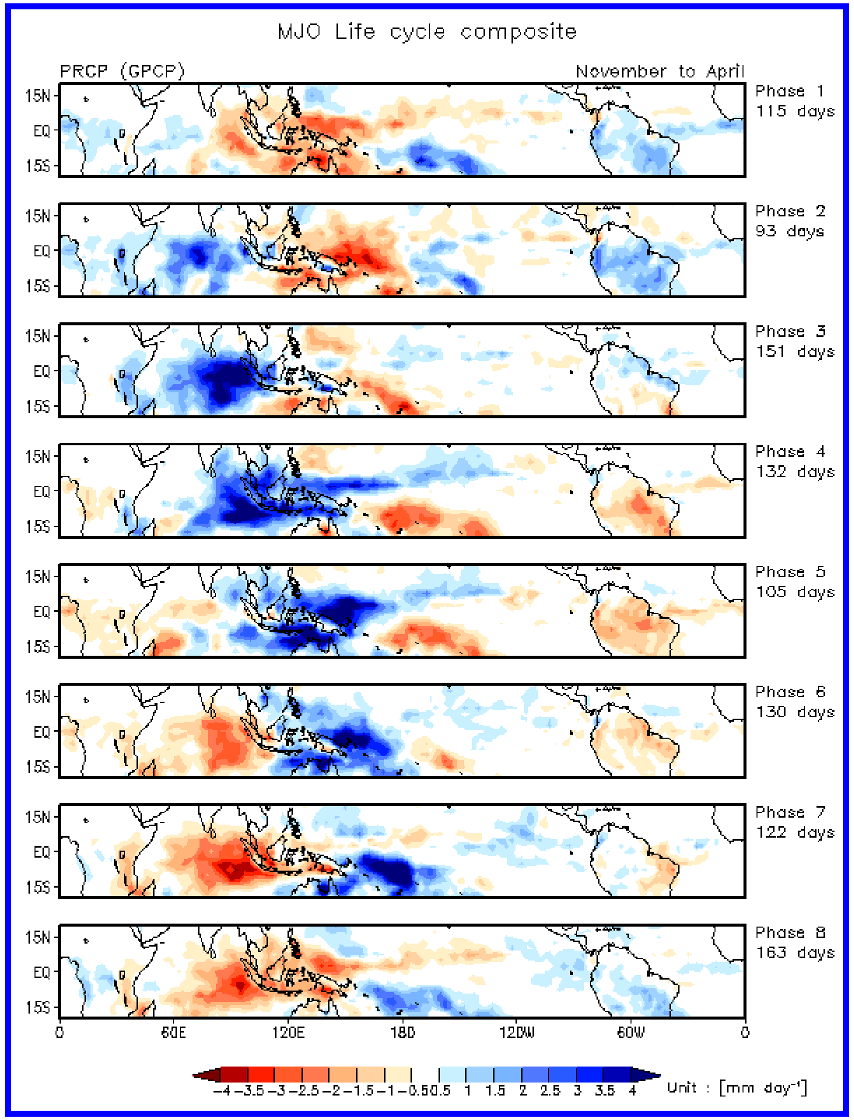
Li 2014 (JMR)

1. Introduction: Real-time Multivariate MJO Index





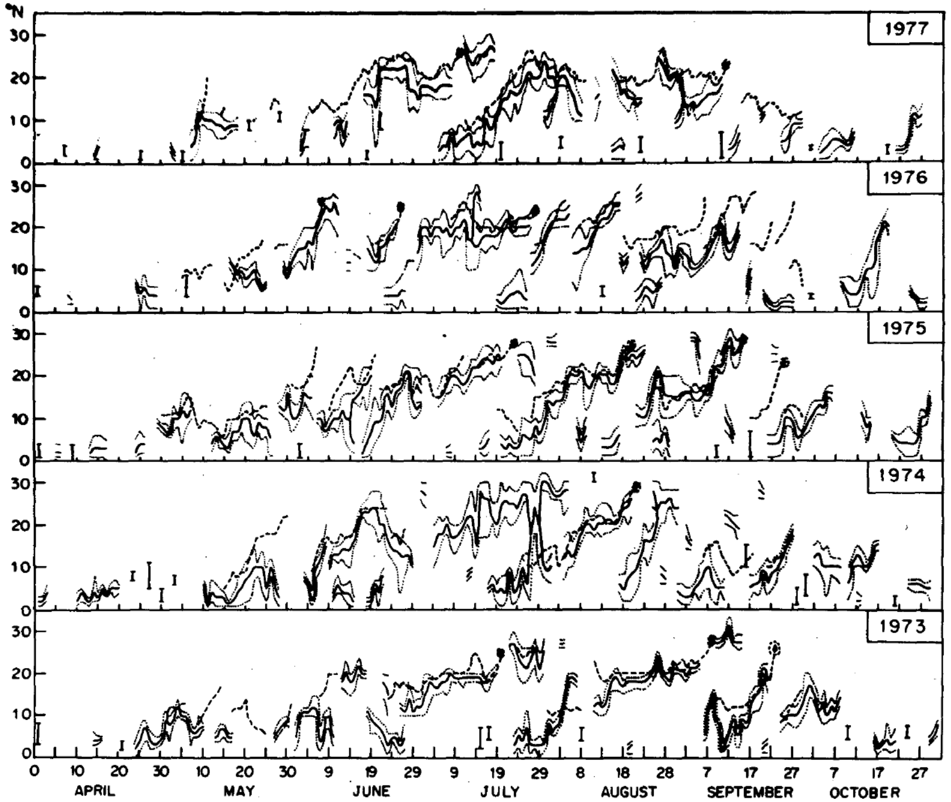




As a measure of the strength of the MJO, **Wheeler and Hendon (2004) Realtime Multivariate MJO (RMM) index** used the **first two leading multivariate EOF modes of the equatorial mean (between 15S and 15N) OLR, and zonal winds at 850 and 200 hPa**. This index captures equatorial eastward propagating mode, the MJO, very well and has been applied all year around to depict MJO activity

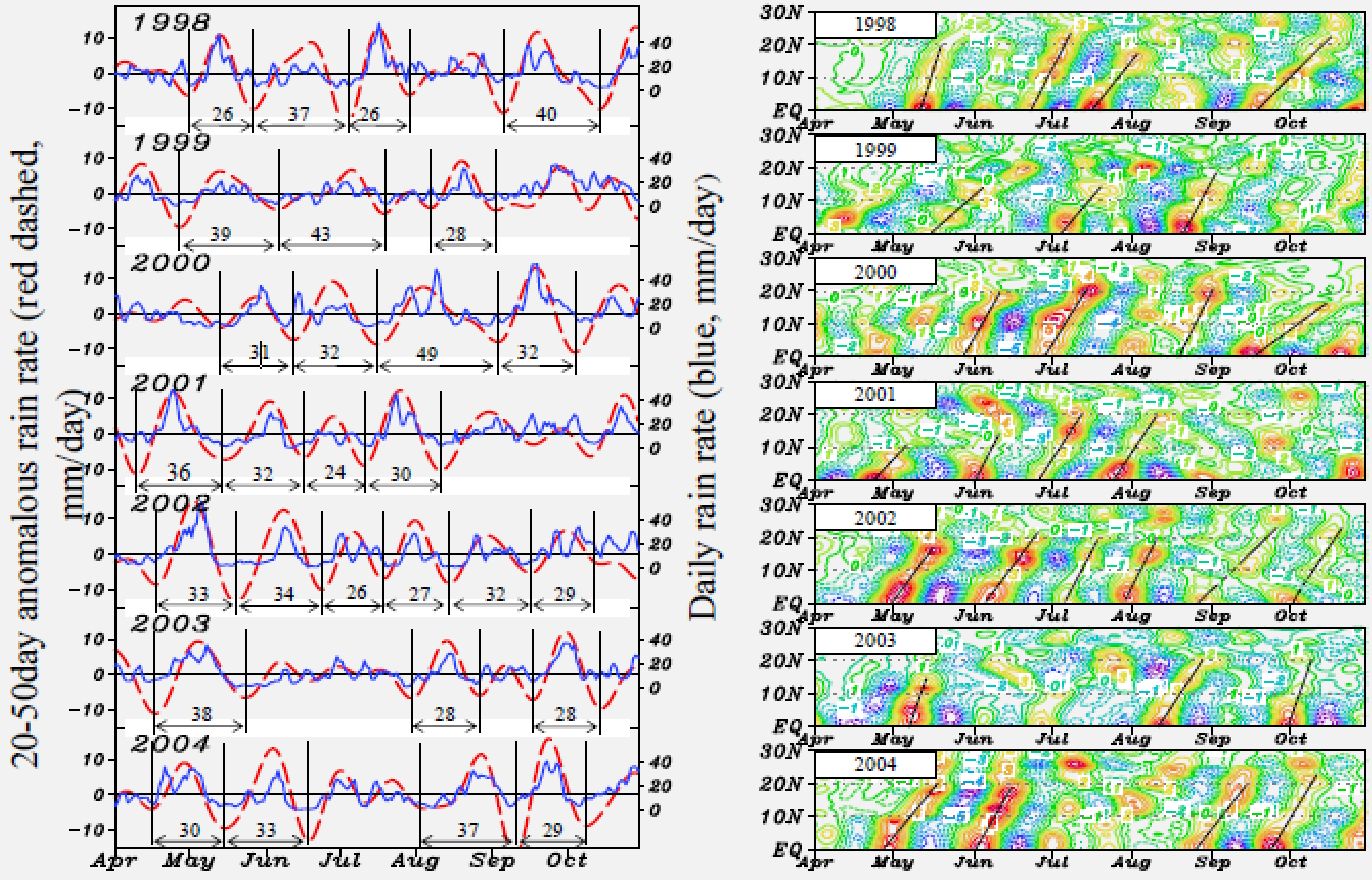
1. Introduction: Discovery of northward propagation

- Yasunari (1979 and 1980, JMSJ)
- Sikka and Gadgil (1980, MWR)



Time-latitude plots of the location and width of the maximum cloud zone at 90°E (Sikka and Gadgil 1980)

- Wang et al. (2005)

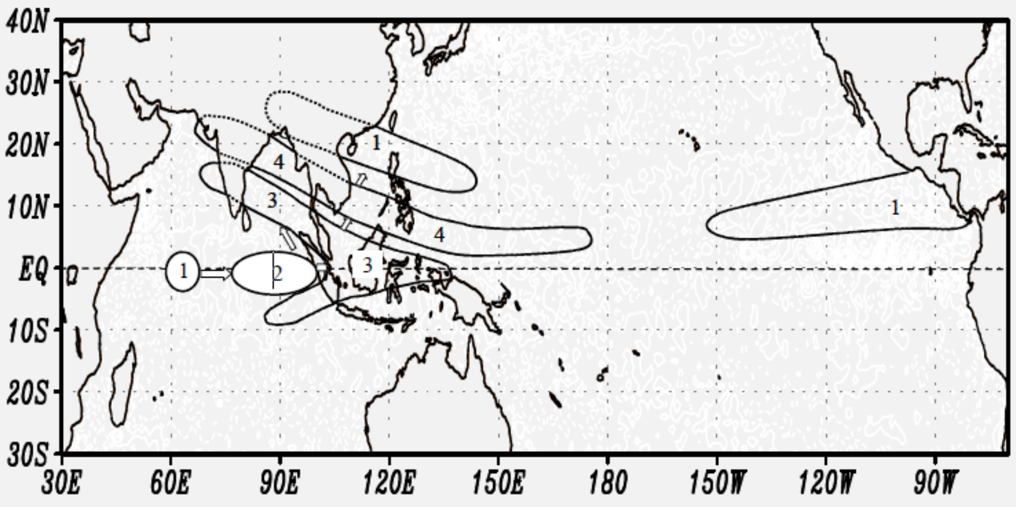


(a) TMI rain rate (75-100E,5S-5N)

(b) 20-50day 3B42 rain rate (75-100E)

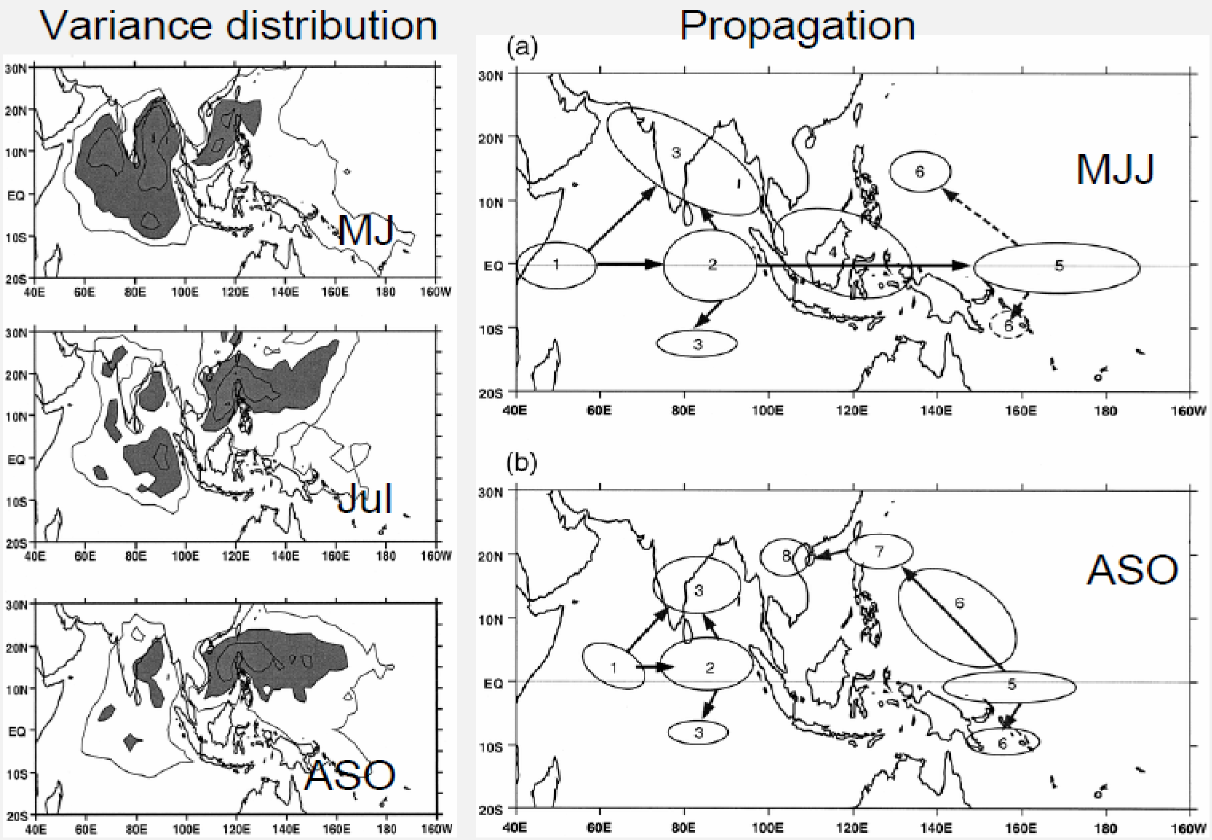
1. Introduction: Northward Propagation of BSISO

Schematic structure/movement of BSISO



Phase1: genesis in western EIO;
Phase 2: Intensification
Phase 3: Bifurcation, formation of tilted rain band
Phase 4:Northeastward propagation

Wang, Kikuchi and Webster 2005



Camball-Cook and Wang 2001

- Life Cycle: The BSISO tends to initiate in the western Equatorial Indian Ocean (EIO) and propagate eastward to the eastern EIO where it bifurcates forming northwest-southeast tilted rain band and propagates northward.
- The ISV is larger over the Indian monsoon region during early summer but over the western North Pacific-East Asia (WNP-EA) monsoon region during late summer and fall.

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2. BSISO: Identification on Dominant Modes

Lee, June-Yi, Bin Wang, Matthew C. Wheeler, Xiouhua Fu, Duane E. Waliser, and In-Sik Kang, 2013: **Real-time multivariate indices for the boreal summer intraseasonal oscillation over the Asian summer monsoon region**. Climate Dynamics, 40, 493-509

May-Oct daily OLR
(outgoing longwave radiation)

May-Oct daily U850
(850-hPa zonal wind)

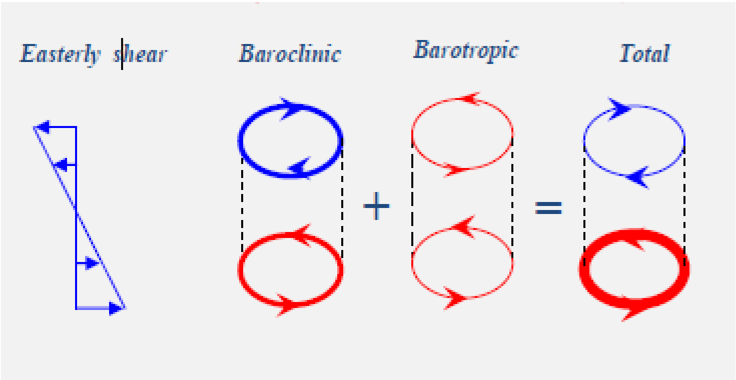
Removal of **slow annual cycle** & **interannual anomalies**

Normalization of each field
ASM Standard deviation is 27.58 W m^{-2} for OLR and 3.62 m s^{-1} for U850

Multivariate Empirical Orthogonal Function (EOF)

BSISO1: the first and second EOF modes
Canonical Northward Propagating Mode

BSISO2: the third and fourth EOF modes
The Asian Pre-Monsoon and Onset Mode



$$\frac{D\zeta_+}{Dt} = -v_+ + U_T\left(\frac{DD_-}{Dy} - \frac{D\zeta_-}{Dx}\right)$$

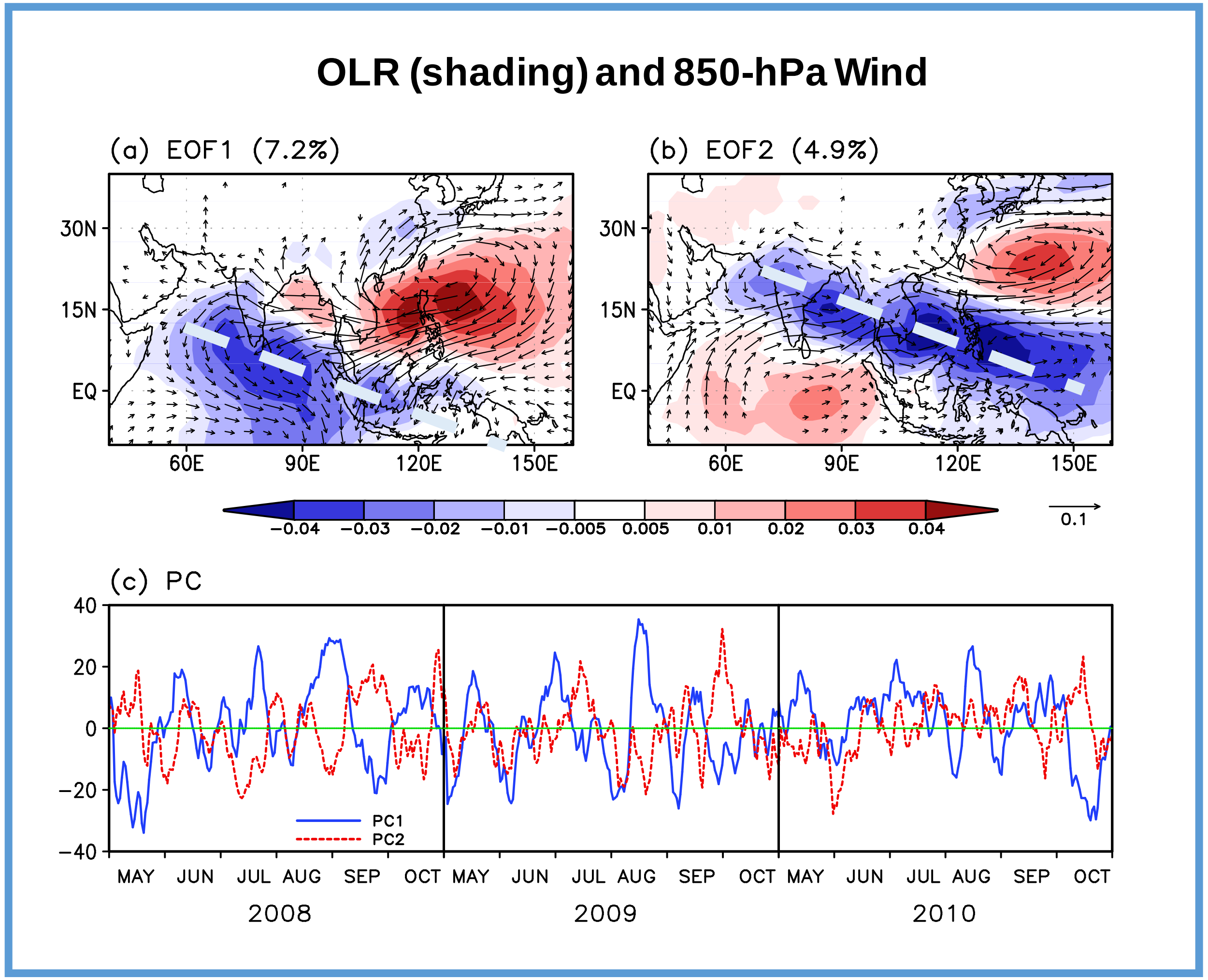
An easterly shear leads to the amplification of Rossby wave (RW) responses in the lower level (Wang and Xie 1996)

Filtering is not applied to define BSISO index for real-time monitoring and forecasting purpose.

2.1 BSISO1: Canonical Northward Propagating BSISO Mode

- **BSISO1, consisting of EOF1 and EOF2**, represents the **canonical northward and north-eastward propagating ISO** over the ASM region **during the entire warm season from May to October** with **quasi-oscillating periods of 30-60 days in conjunction with the eastward propagating MJO**.

- **Spatial Characteristics**: **Rossby wave like pattern** with a **northwest to southeast slope.** Out-of-phase relationship of convection between the ISM and WNPSM. Quadrupole pattern in EOF2.



Lee et al. (2013 Clim Dyn)

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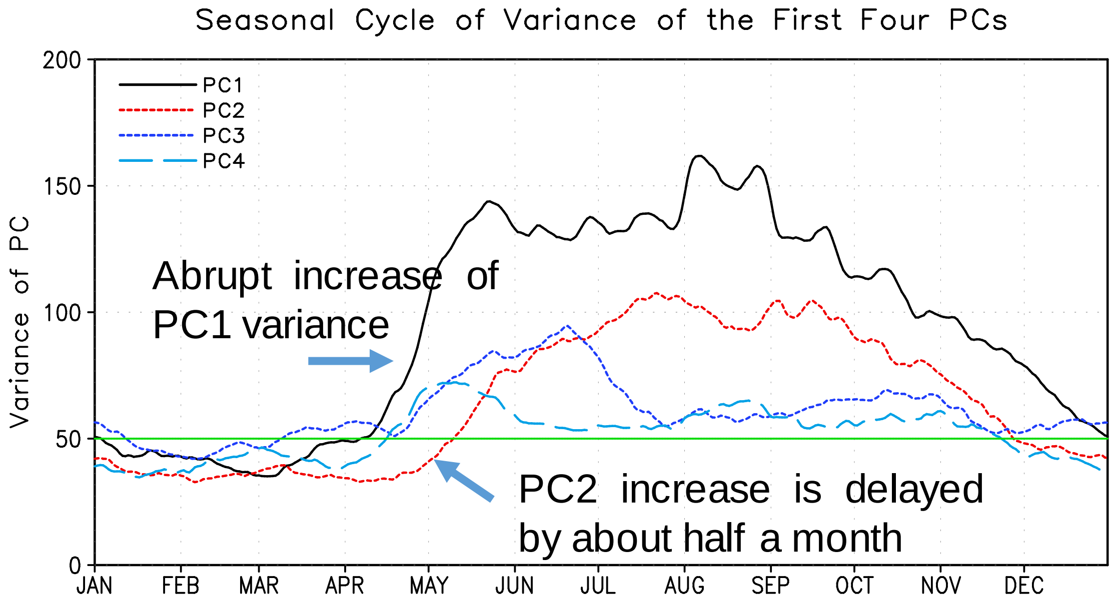
- **Seasonal cycle of variance:** Large overall variance from May to October. The PC1 has an abrupt increase of variance around late April and early May while the PC2 variance tends to be delayed by about half a month.



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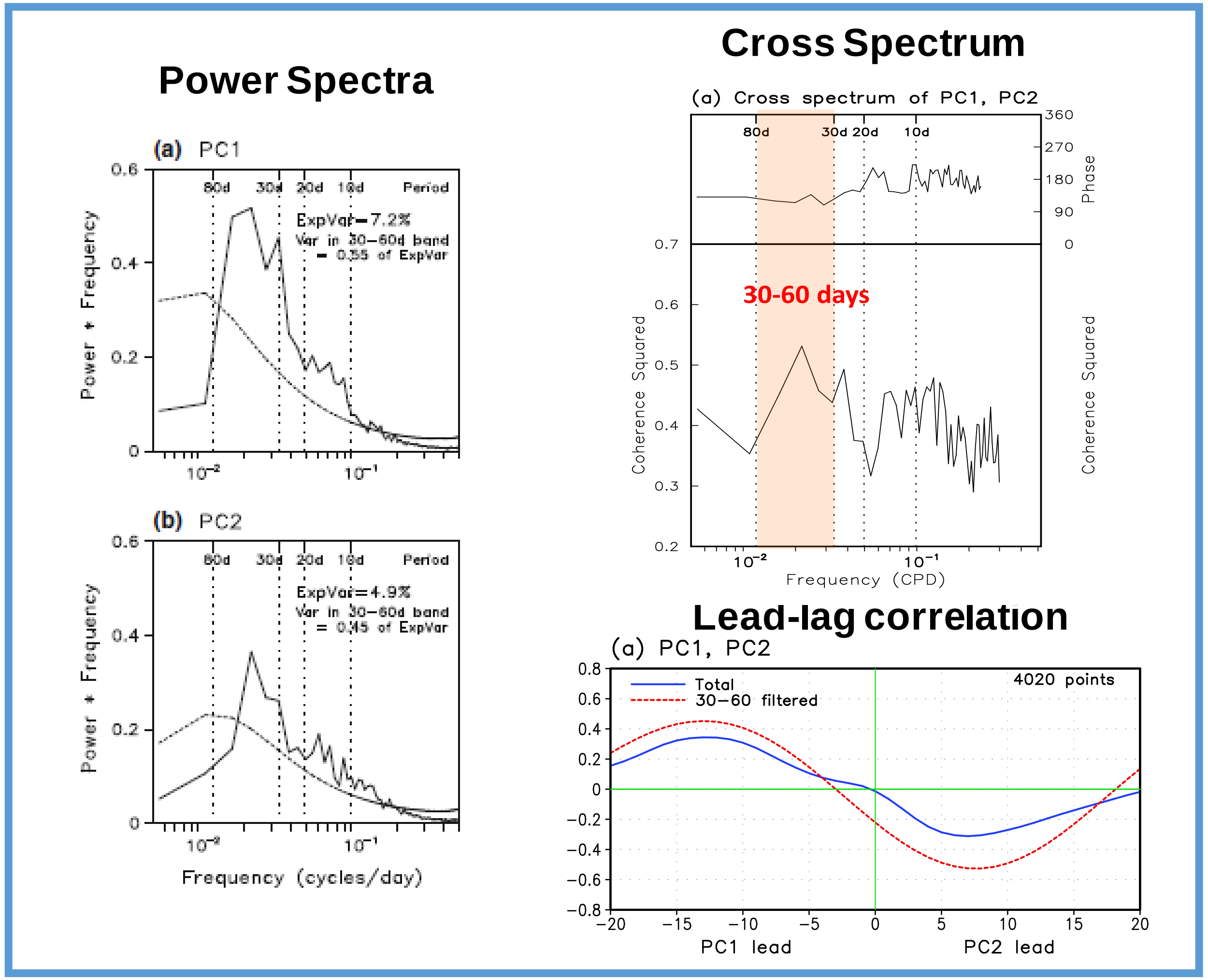
- **Coherence and lead-lag relationship:** The greatest coherence in the 30-60-day range between the PC1 and PC2 with a 90^{o} phase difference, indicating **the PC1 leads PC2 by a quarter cycle**. The PC1 tends to lead PC2 by about 13 days with a maximum correlation of 0.34 for non-filtered data, and 0.45 for 30-60-day filtered data.

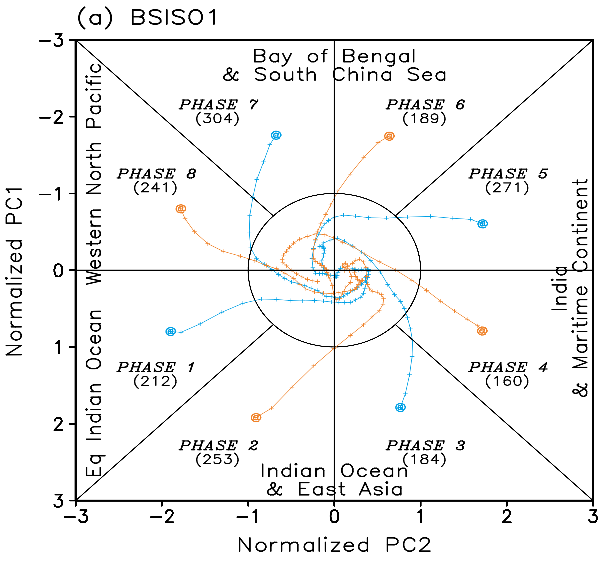


Lee et al. (2013 Clim Dyn)

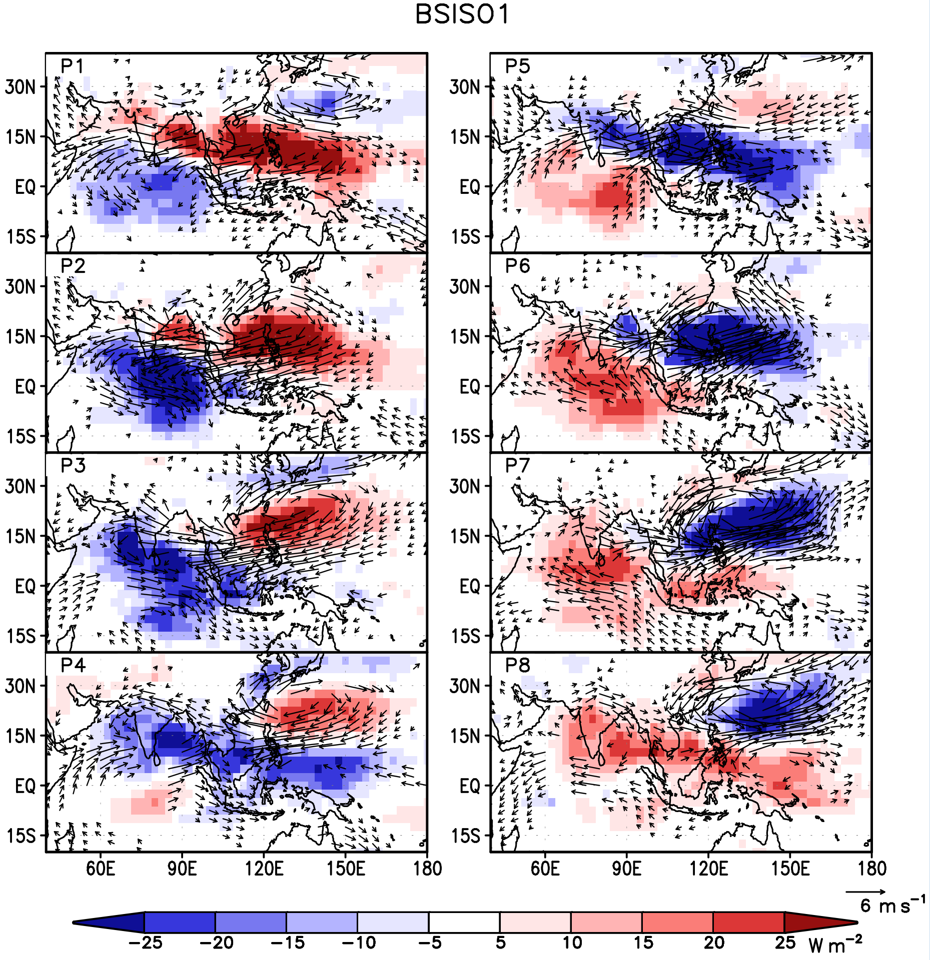
2.1 BSISO1: Its Life Cycle

- The BSISO1 convective activity **first appears over the equatorial Indian Ocean** in Phase 1, and then propagates northeastward reaching **the Indian Subcontinent in Phase 3** and **the Bay of Bengal in Phases 4-5**.
- The convection over the equatorial Indian Ocean also propagates eastward from Phase 1 and reaches the **Maritime Continent in Phases 3-4**. Then, the convection propagates northward reaching **the South China Sea in Phase 7**, the **WNP in Phase 8**.
- **Over East Asia, active convection occurs in Phases 3-4.**

Given the strong lead-lag behavior of PC1 and PC2, it is convenient to diagnose the state of BSISO1 as a point in the two-dimensional phase space.



Life cycle composite of OLR (shading) and 850-hPa wind anomalies



Lee et al. (2013 Clim Dyn)

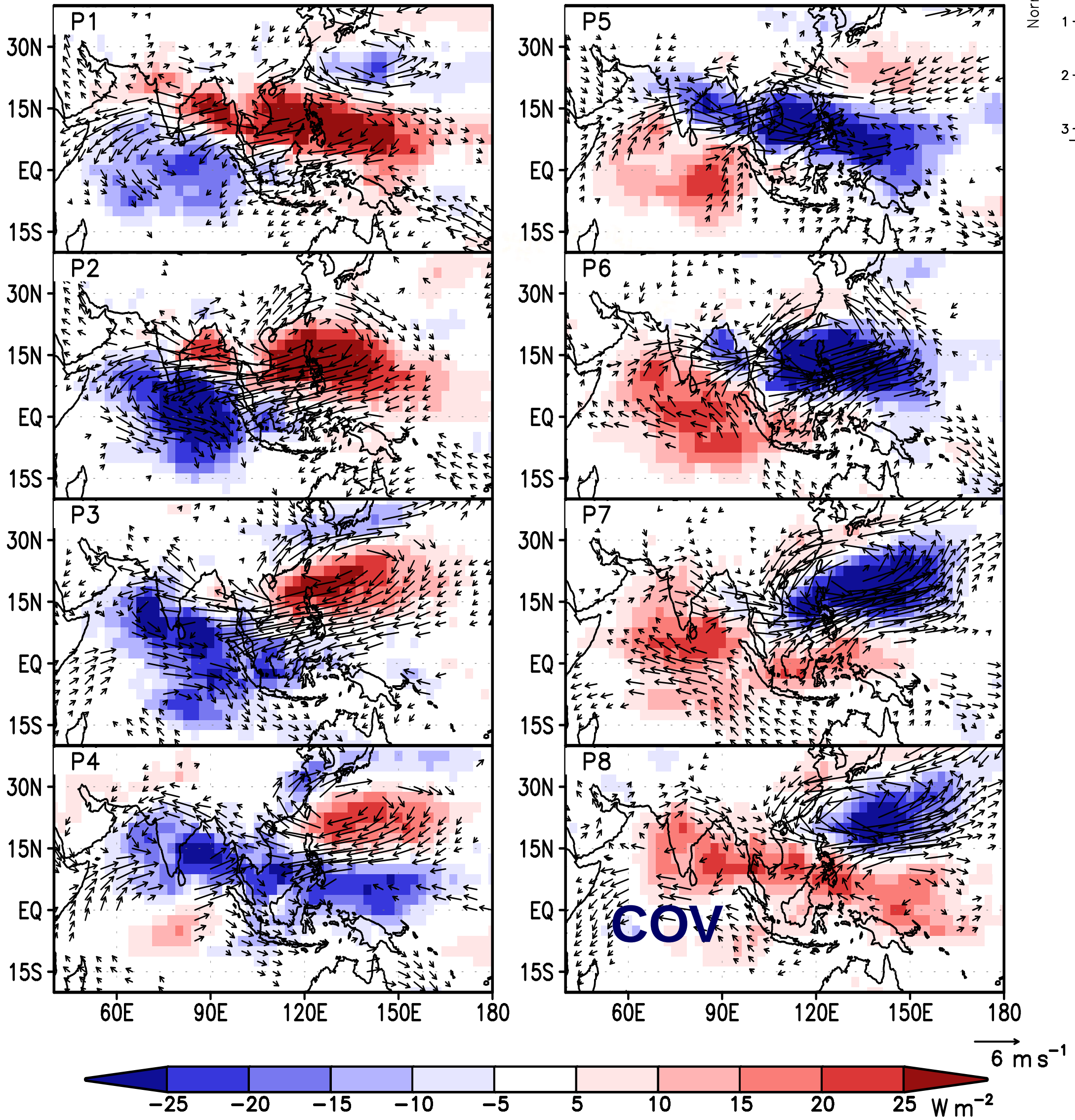
2.1 BSISO1: Dynamics

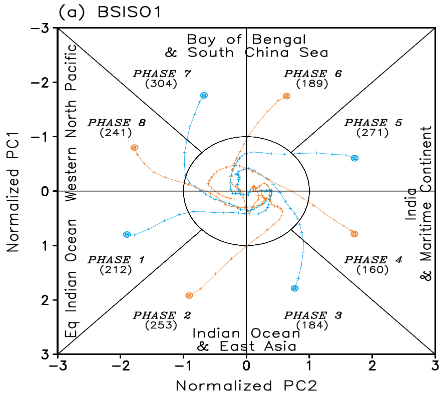
- **Intensification & eastward propagation: Kelvin wave (KW) dominate**
- **Bifurcation & formation of tilted rainband: Decoupling of KW-RW couplet and emanating moist RW**
- **Northward propagation in IM sector: Vertical shear mechanism & Moisture-convection feedback mechanism**

$$\frac{\partial \varsigma_+}{\partial t} = -\beta v_+ - U_T \left(\frac{\partial \omega}{\partial y} \right)$$

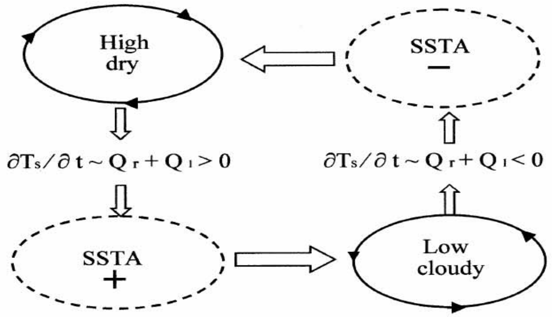
Jiang et al (2004)

Life cycle composite of OLR (shading) and 850-hPa wind anomalies





- **Northward propagation in WNP-EA sector: Cloud-radiation-SST & wind evaporation-SST feedbacks**

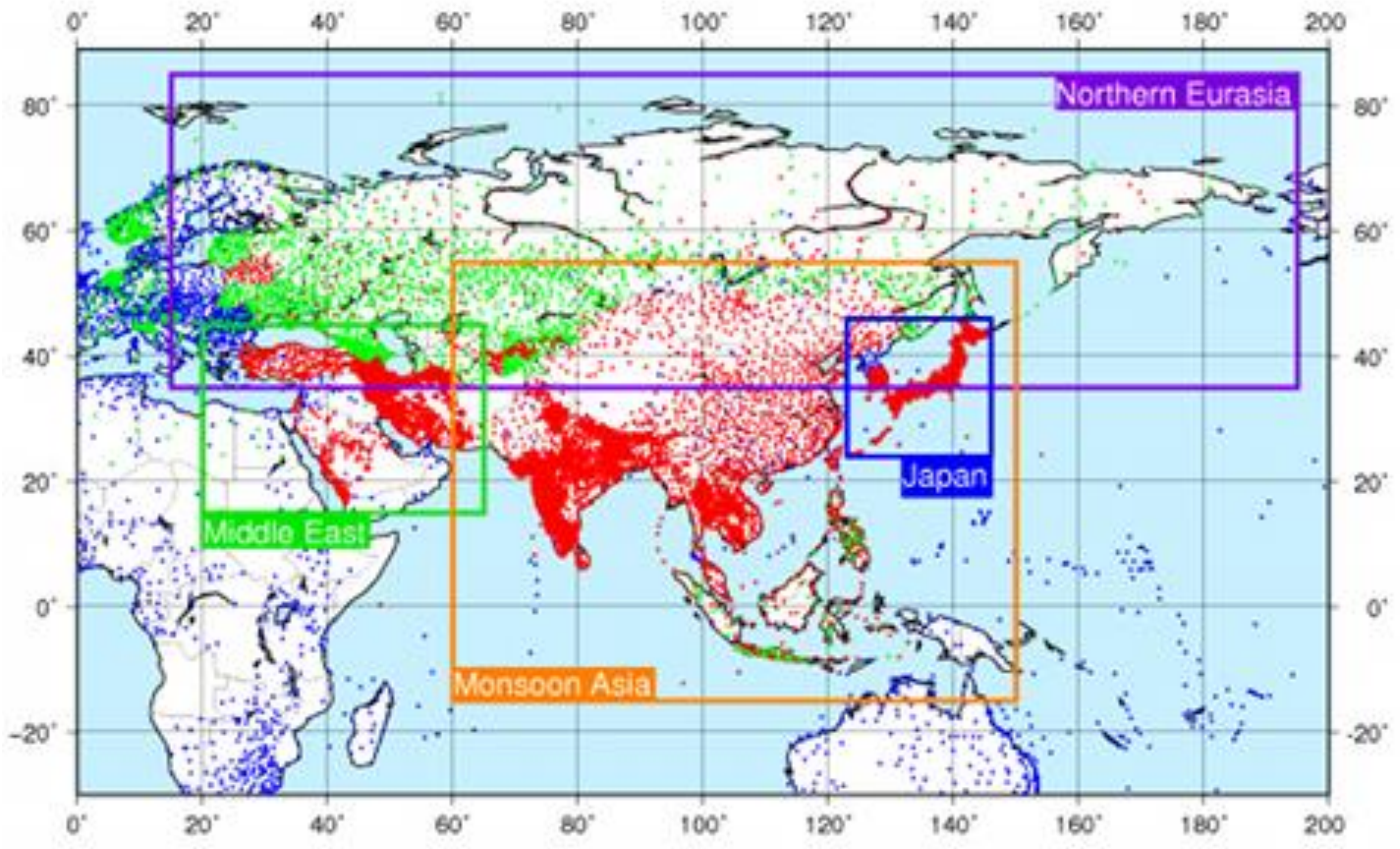


Wang and Zhang (2002)

- **Genesis in WIO: RW response to the suppressed convection**

2.1 BSISO1: Its Impact on Extreme Rainfall Occurrence

Data – APHRODITE's Precipitation



APHRODITE station distribution.
Source: http://www.chikyu.ac.jp/precip/products/index.html
Reference: Yatagai et al. 2012 Bull Am Meteorol Soc

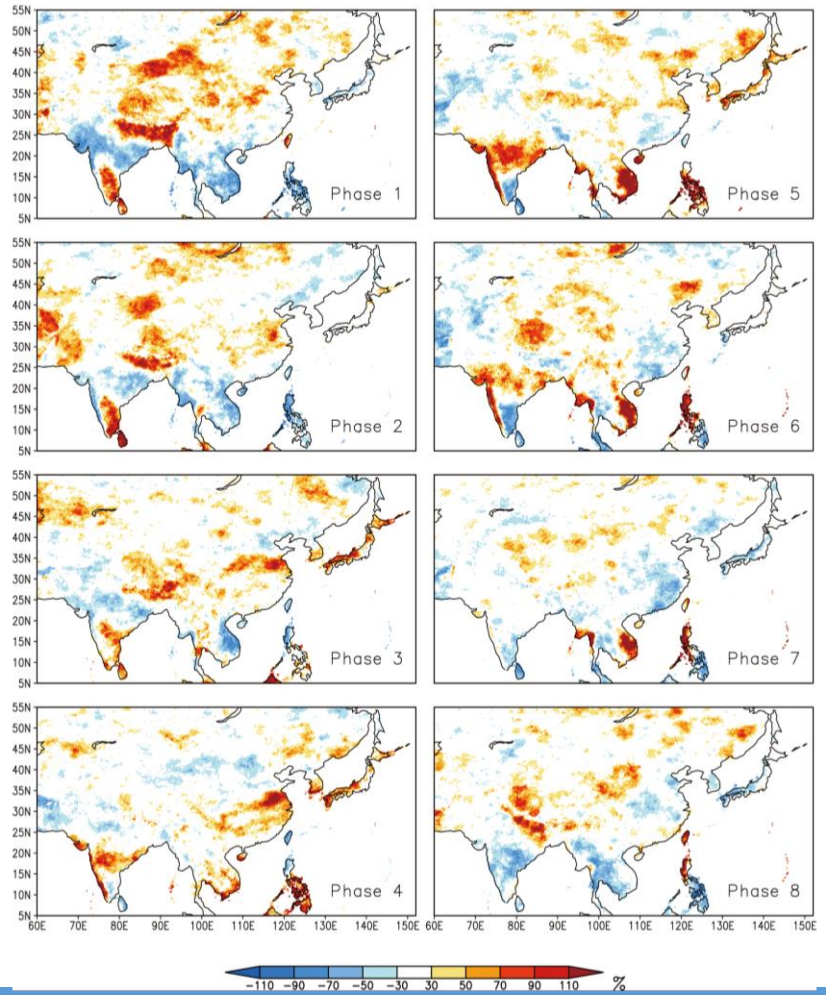
- **A**sian **P**recipitation- **H**ighly-**R**esolved **O**bservational **D**ata **I**ntegration **T**owards **E**valuation (**APHRODITE**)
- Long-term daily gridded precipitation dataset for Asia based on a **dense network of rain gauges**
- **1951-2007**
- Resolution for Asia: **0.25°x0.25°**

This study uses the **APHRODITE's daily precipitation over Asia** for **1981-2007** to investigate the BSISO impact on **extreme rainfall** over Asia

2.1 BSISO1: Its Impact on Extreme Rainfall Occurrence

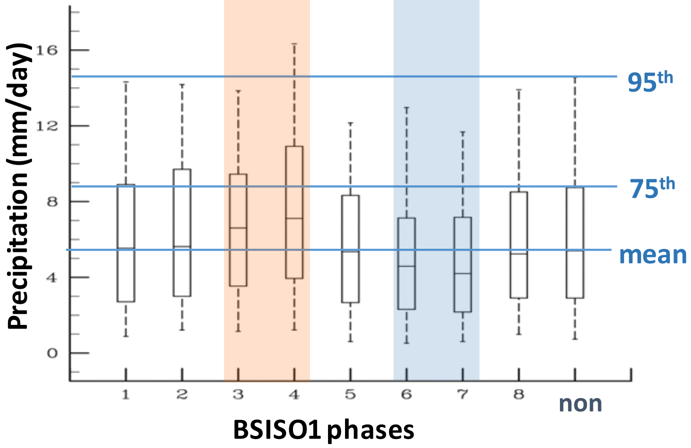
- **The BSISO strongly modulates extreme rainfall occurrence in Asia**.
- The **probability density function** of May-August rainfall in East Asia is skewed toward large values in **phases 2-4 of the BSISO1** life cycles, during which **the probability of extreme rainfall events at the 75th** (**90th**) percentile increases **30-50%** (**over 60%**) **relative to the non-BSISO periods**.
- The most devastating floods with prolonged extreme rainfall in Yangtze River during June 1998 occurred coincidently with the BSISO 4 phase.

Changes in probability of 90th extreme rainfall occurrence

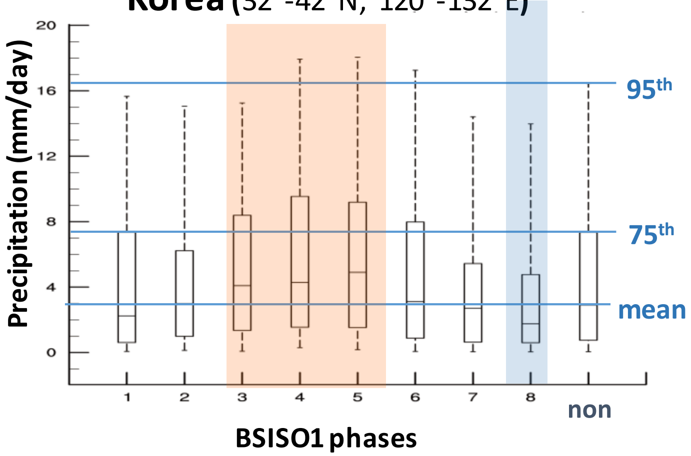


Box Plot: PDFs of Rainfall

SE China (20°-32.5°N, 105°-122°E)



Korea (32°-42°N, 120°-132°E)

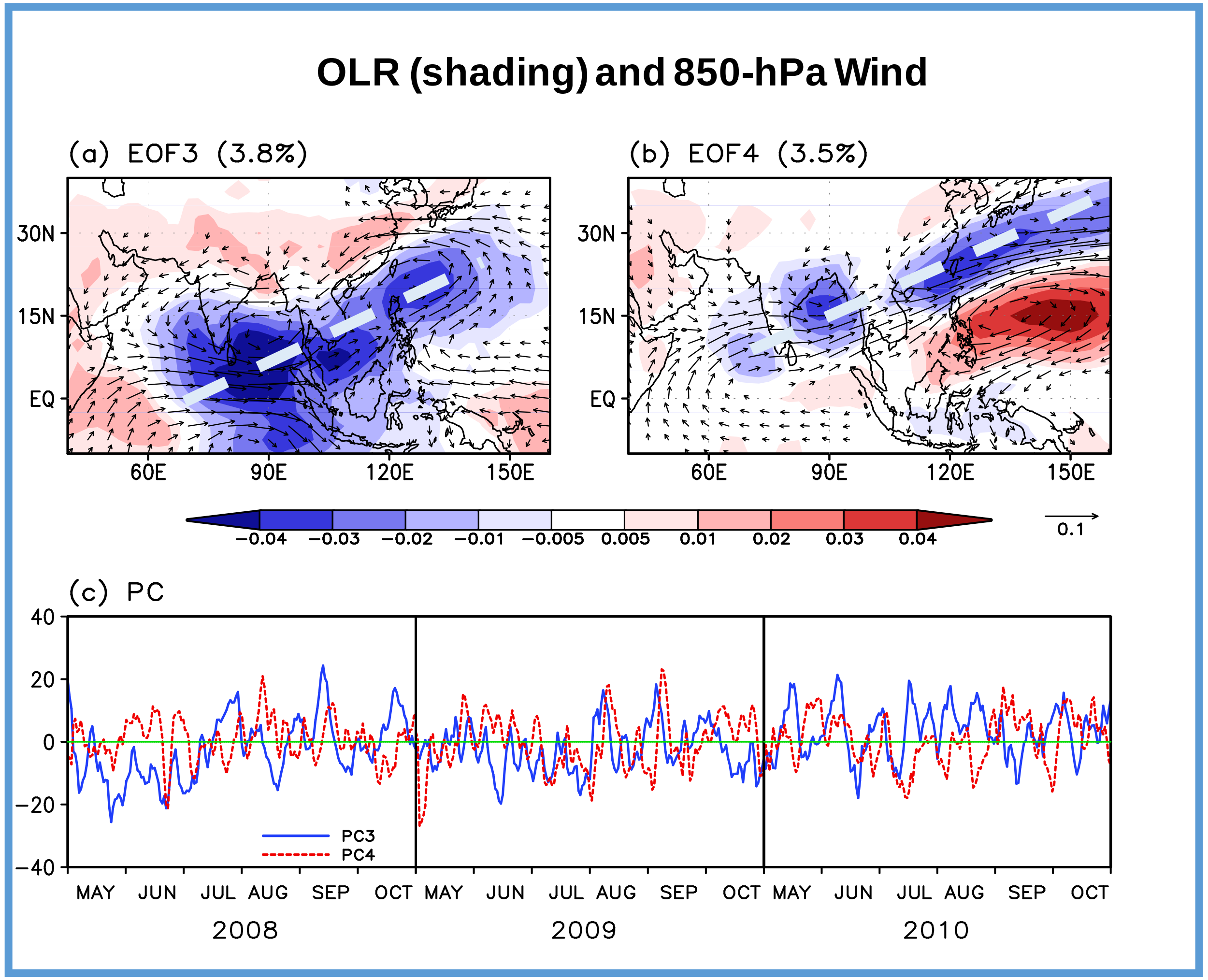


Hsu et al. (2015 I J Climatol accepted)

2.2 BSISO2: The Asian Pre-Monsoon and Onset Mode

- **BSISO2, consisting of EOF3 and EOF4**, captures the **northward/northwestward propagating** variability with periods of **10-30 days** during primarily the **pre-monsoon and monsoon-onset season** that is not related with the eastward propagating MJO.

- **Spatial Characteristics**: **Elongated and front-like pattern** with a **southwest to northeast slope**. In-phase relationship of convection between the ISM and WNPSM.



Lee et al. (2013 Clim Dyn)

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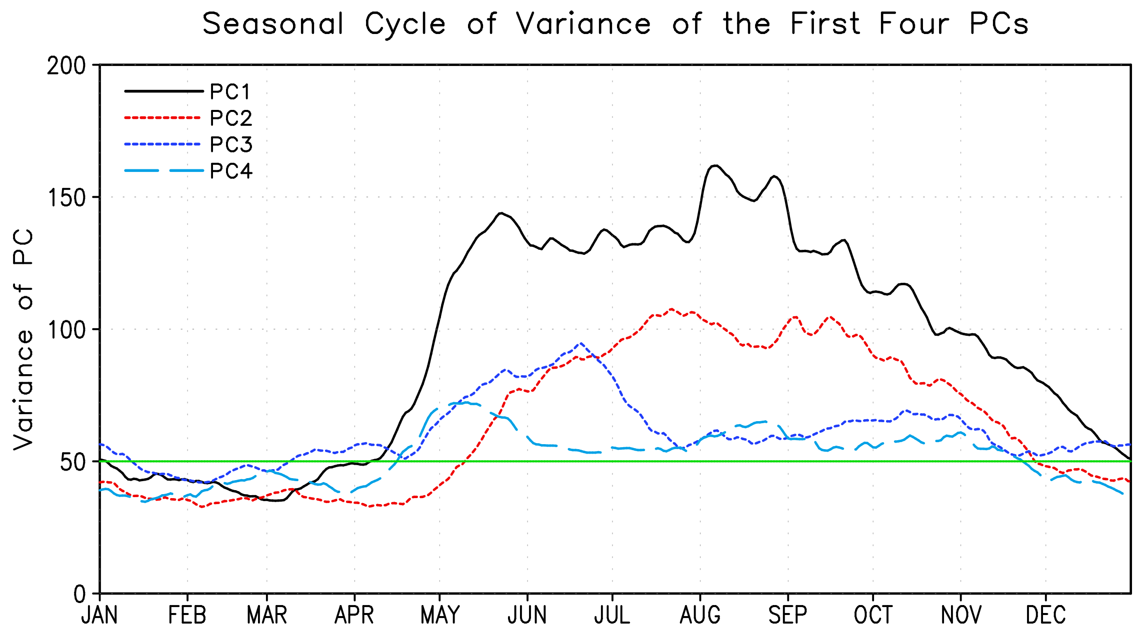

Lee et al. (2013 Clim Dyn)

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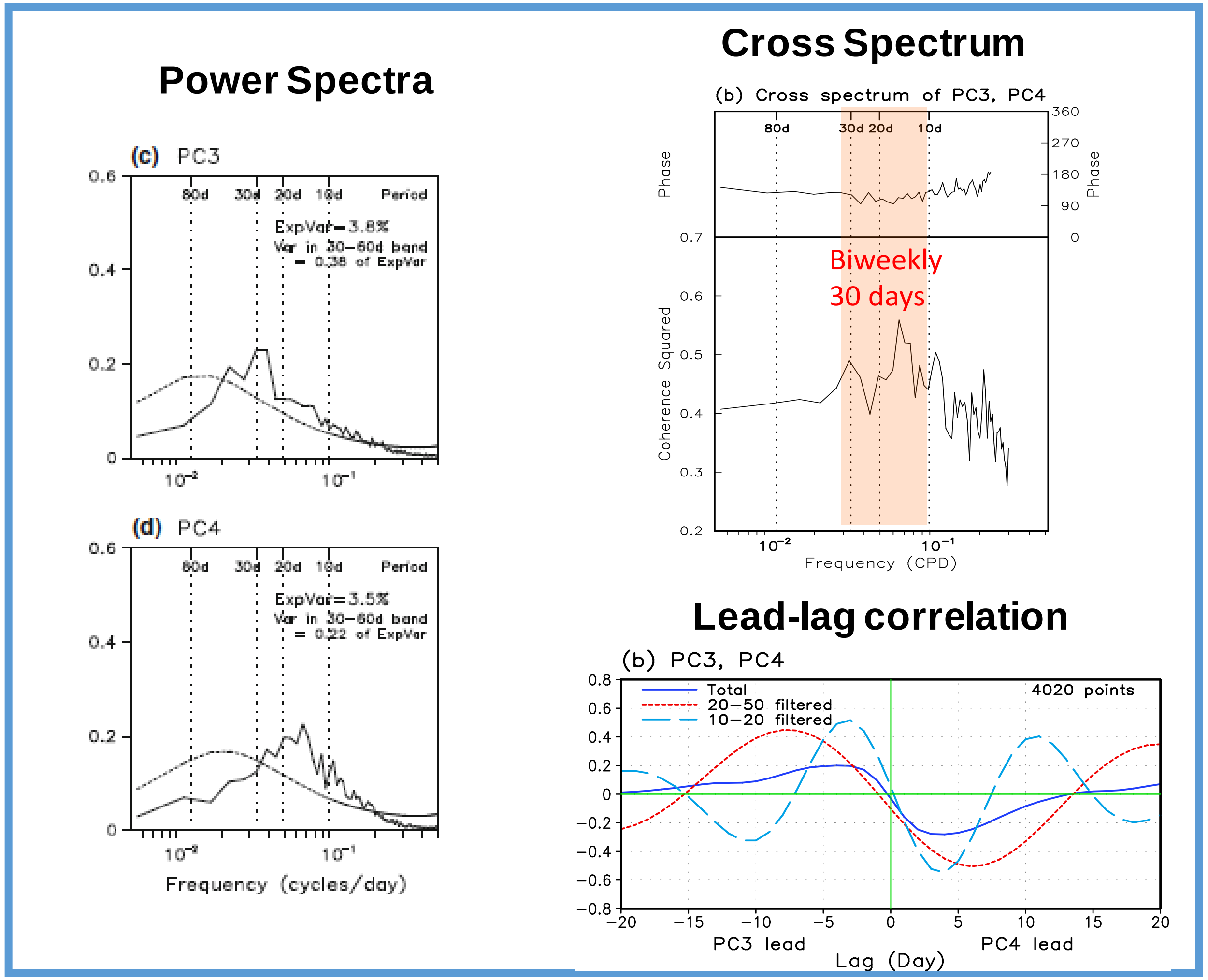
- **Coherence and lead-lag relationship:** High coherence in the 10-20 days (biweekly) range and around 30 days with 90° phase difference between the PC3 and PC4, indicating PC3 leads PC4 by quarter cycle. PC3 tends to lead PC4 by about 3-4 days for 10-20 period and 7-8 days for 30 day period.

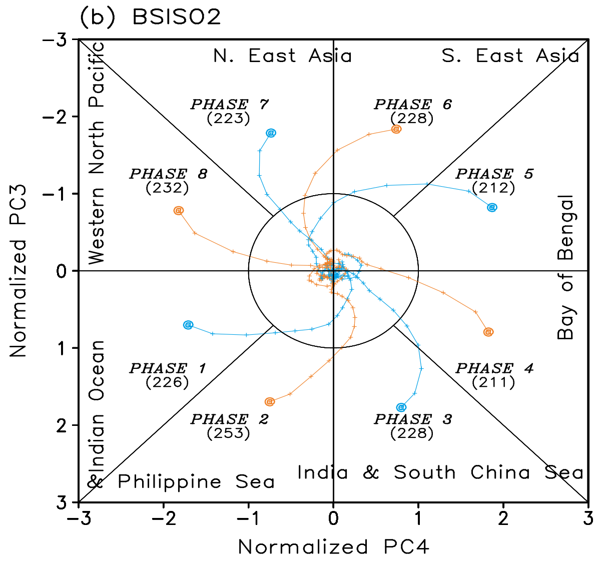


Lee et al. (2013 Clim Dyn)

2.2 BSISO2: Its Life Cycle

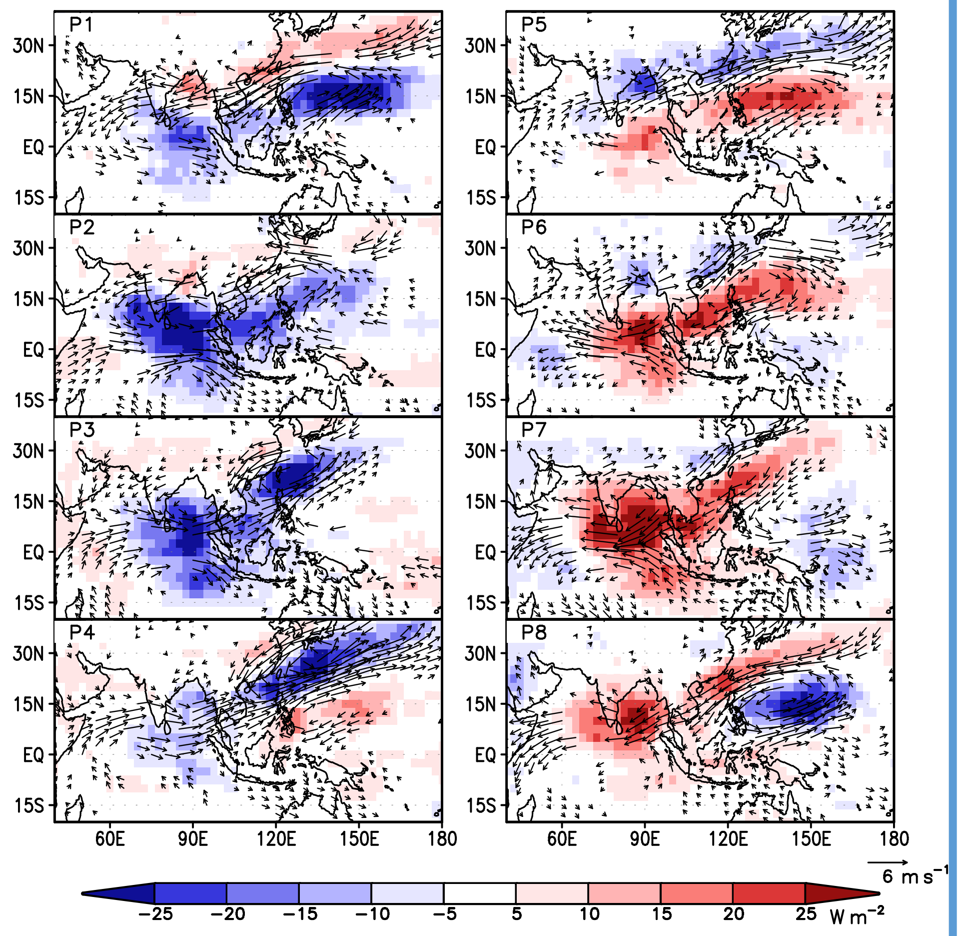
- The life cycle of BSISO2 is shorter than BSISO1.
- The BSISO2 **initiates at the equatorial western Pacific.** The convection is located in the equatorial Indian Ocean and **Philippine Sea in Phase 1** and then propagates northwestward over the Indian longitude as well as the WNP-EA region.
- The BSISO2 may represent **stepwise monsoon onset** over the ASM region.

Given the strong lead-lag behavior of PC3 and PC4, it is convenient to diagnose the state of BSISO2 as a point in the two-dimensional phase space.



Life cycle composite of OLR (shading) and 850-hPa wind anomalies

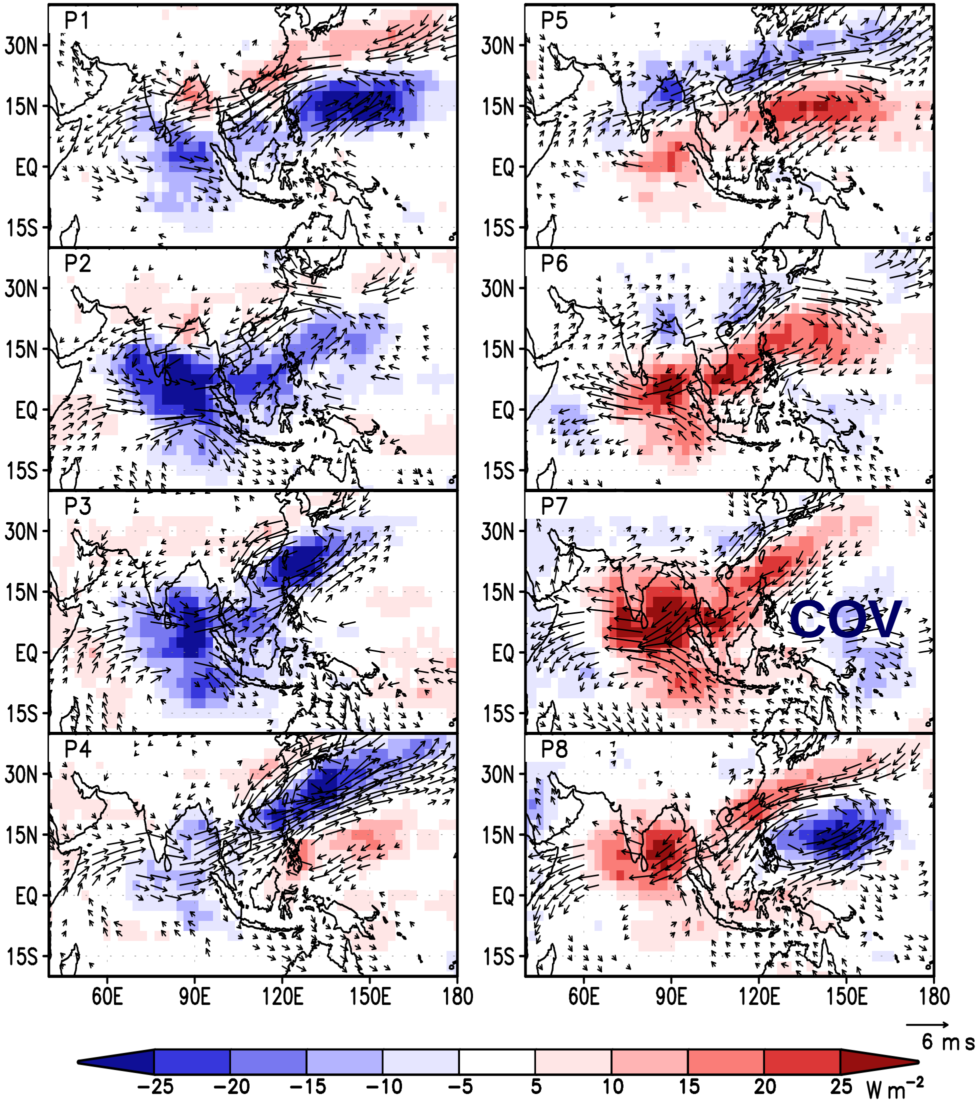
BSISO2

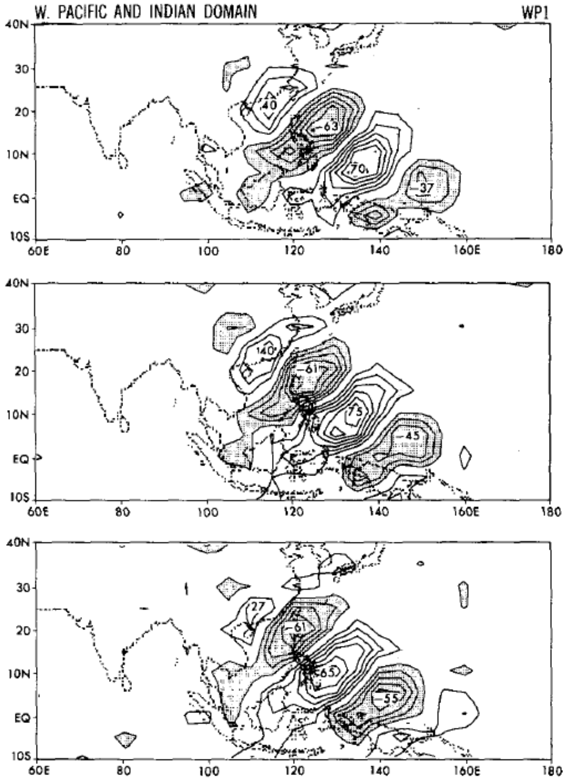


Lee et al. (2013 Clim Dyn)

2.2 BSISO2: Dynamics

Life cycle composite of OLR (shading) and 850-hPa wind anomalies

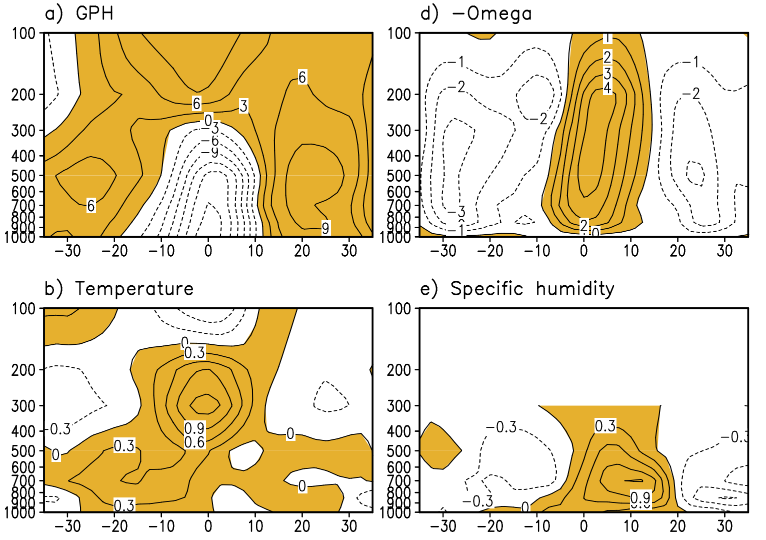




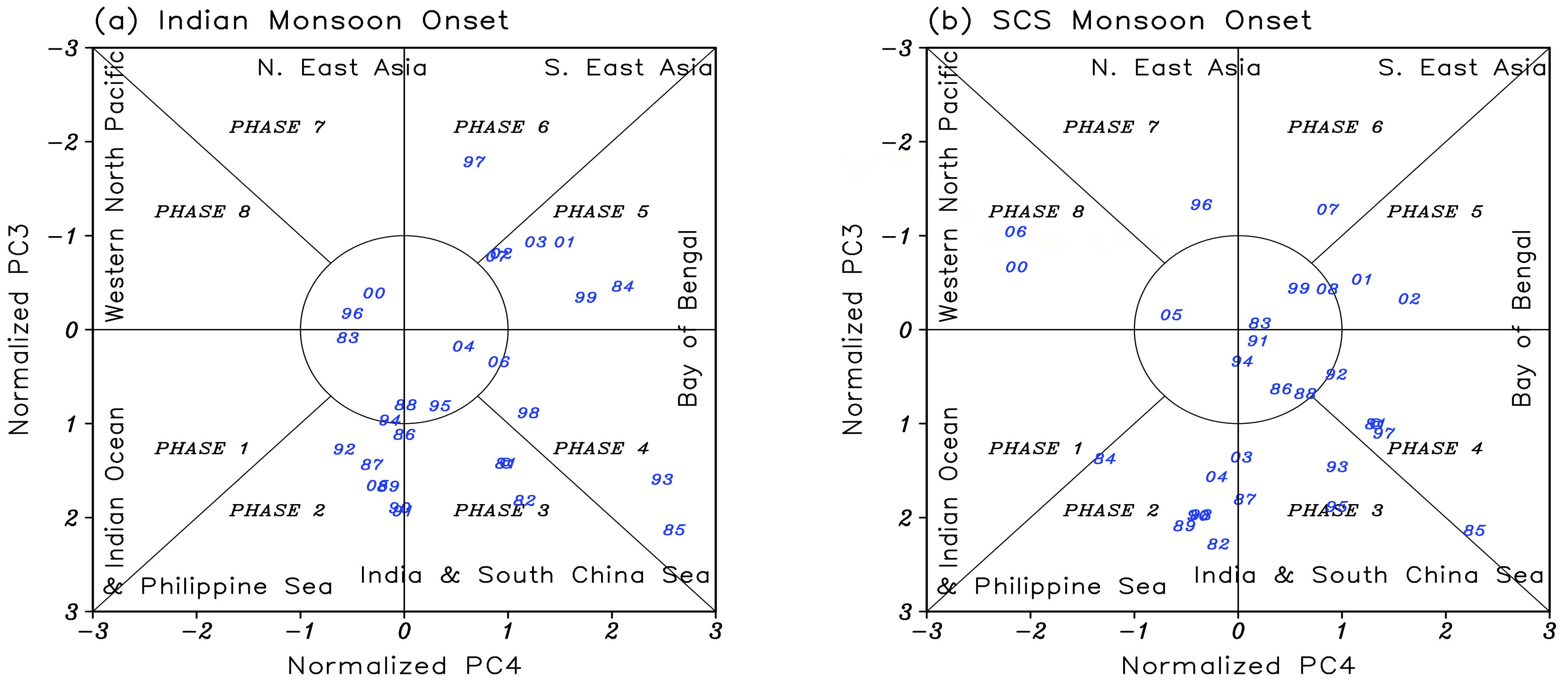
Lau and Lau (1990)

- **The initiation and structure of BSISO2 resemble to the synoptic-scale wave train in the WNP.**
- **The synoptic-scale wave train with time scale of 2~8 days has a southwest-northeast tilted structure initiated at the equatorial western Pacific.**

Structure of Moist Baroclinic Waves under Easterly Wind Shear



2.2 BSISO2: Relationship with Monsoon Onset

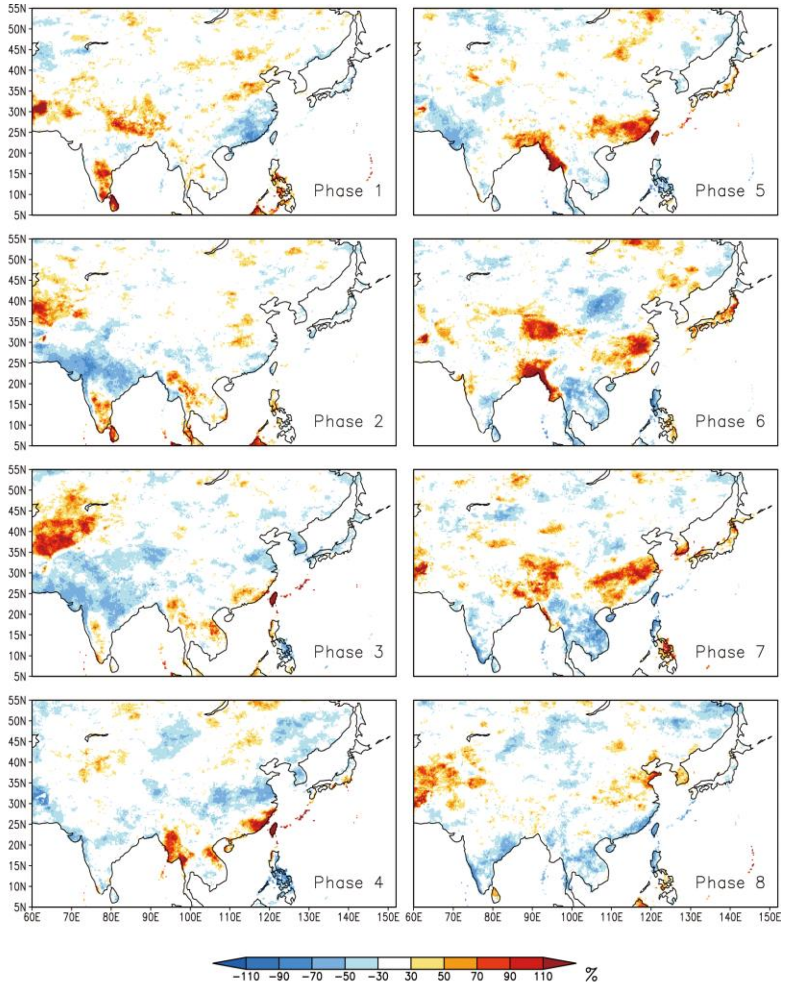


68 % (**70%**) of the o**nset dates for the Indian monsoon (South China Sea)** occurred in **phases 2-4 of BSISO2** for 1981-2010.

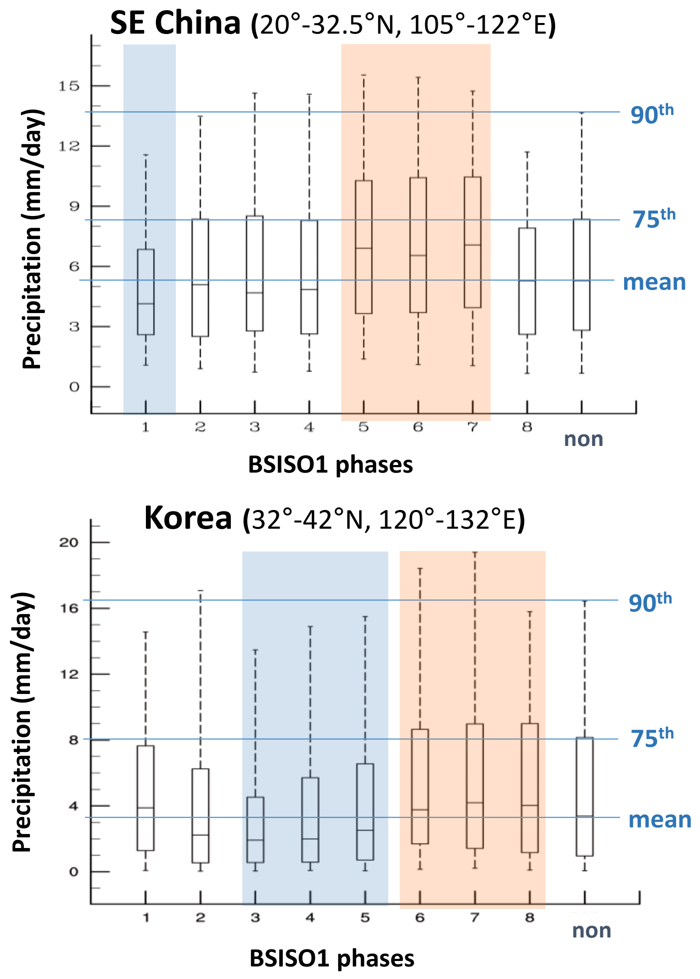
2.2 BSISO2: Its Impact on Extreme Rainfall Occurrence

- **The BSISO strongly modulates extreme rainfall occurrence in Asia**.
- The **probability density function** of May-August rainfall in East Asia is skewed toward large values in **phases 5-7 of the BSISO2** life cycles, during which **the probability of extreme rainfall events at the 75th** (**90th**) percentile increases **30-50%** (**over 60%**) **relative to the non-BSISO periods.**

Changes in probability of 90th extreme rainfall occurrence



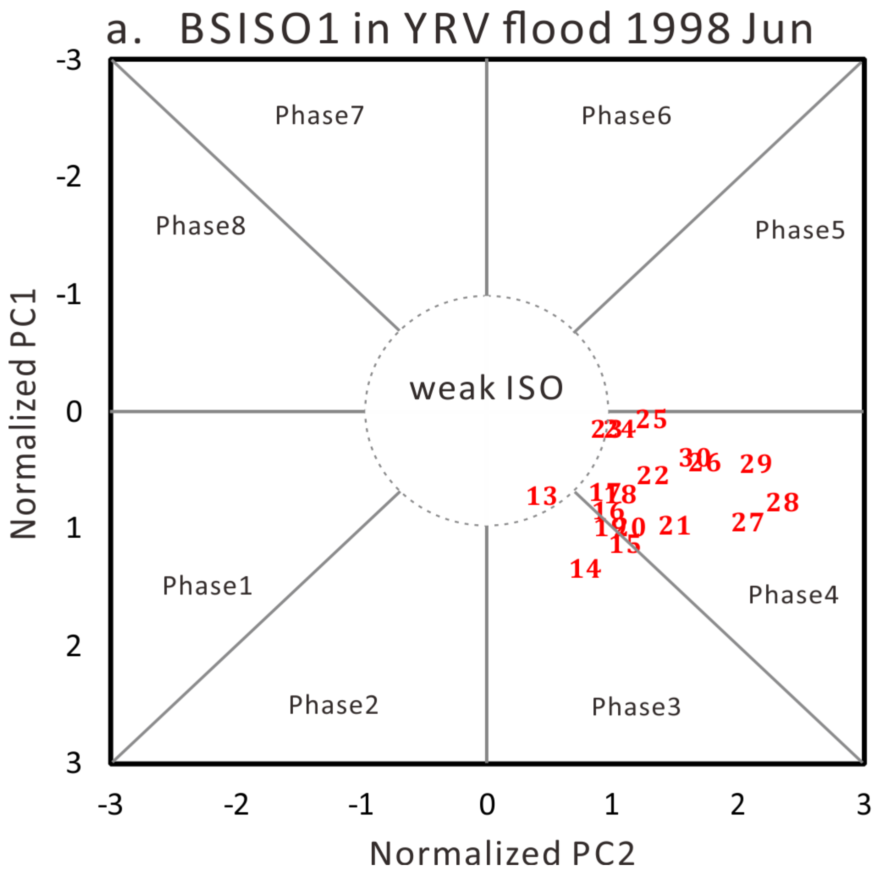
Box Plot: PDFs of Rainfall



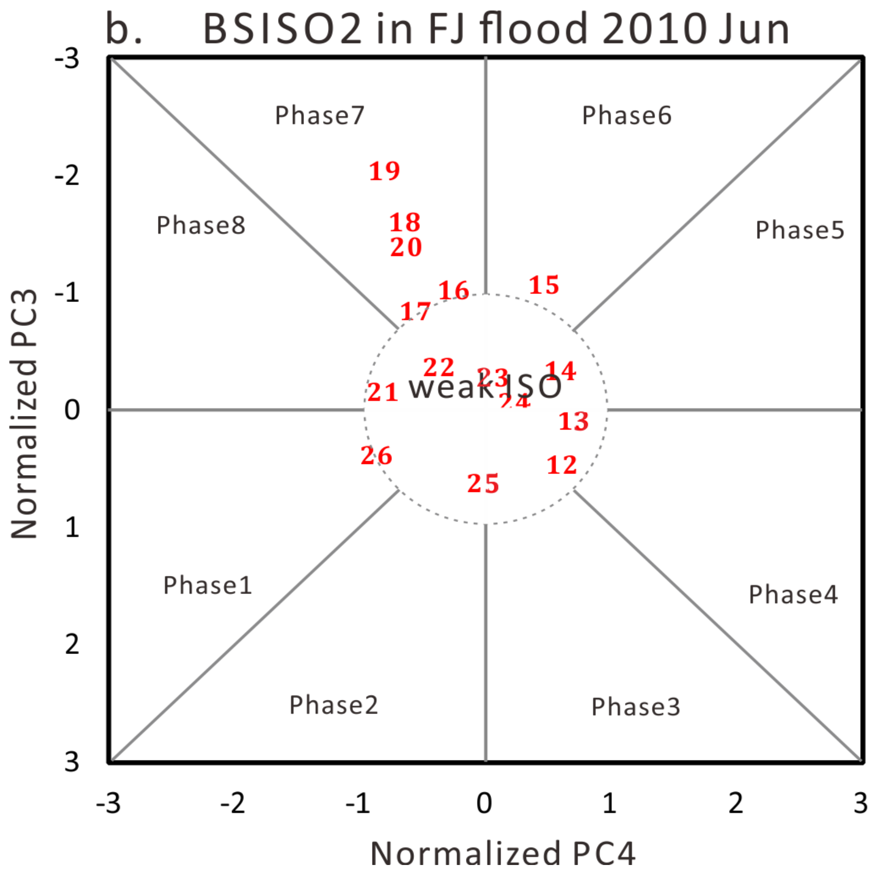
Hsu et al. (2015 I J Climatol accepted)

Cast Study: The Two Most Devastating Floods in China

Yangtze River flood
13-30 June, 1998
Phase 4 of BSISO1



Fujian Flood
15-19 June, 2000
Phase 7 of BSISO2



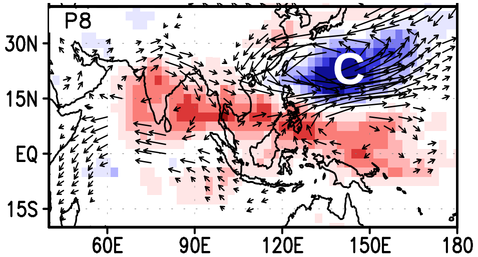
2.3 BSISO Teleconnection associated with convective anomalies over the SCS & WNP

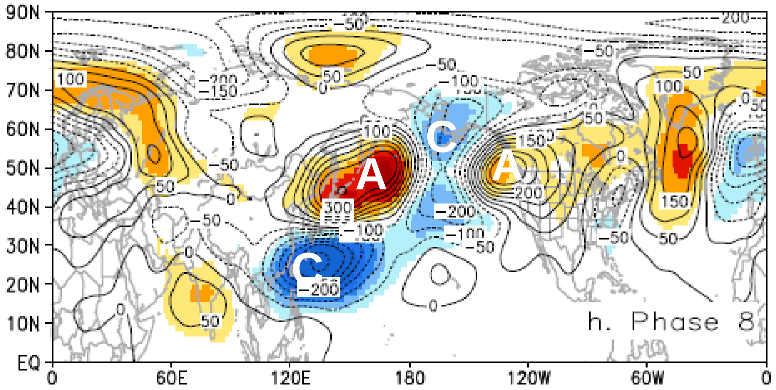
850-hPa (shading) & 200-hPa (contour) GPH Composite Anomalies

Active Phase

BSISO1

Phase 8

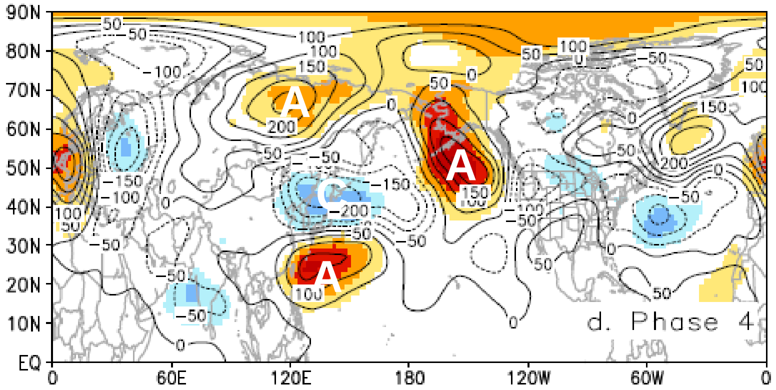


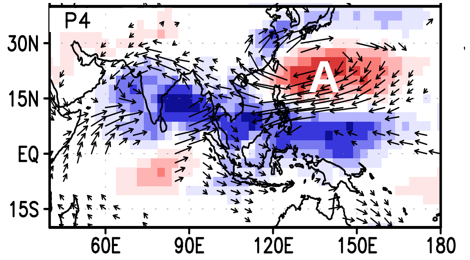


Break Phase

BSISO1

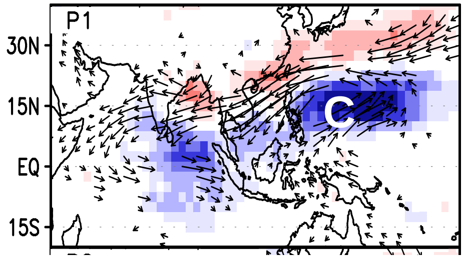
Phase 4

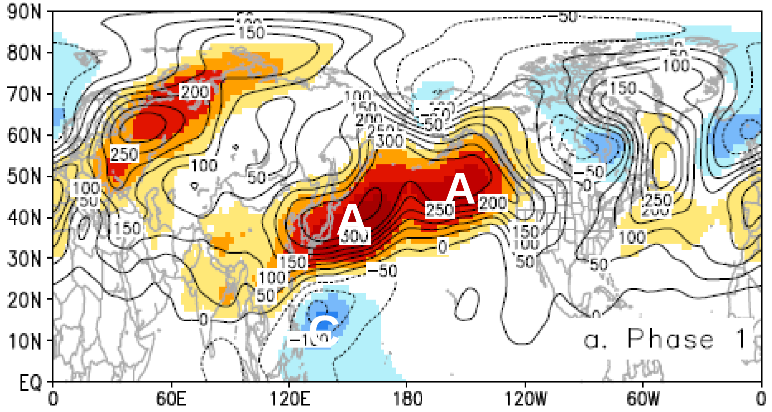




BSISO2

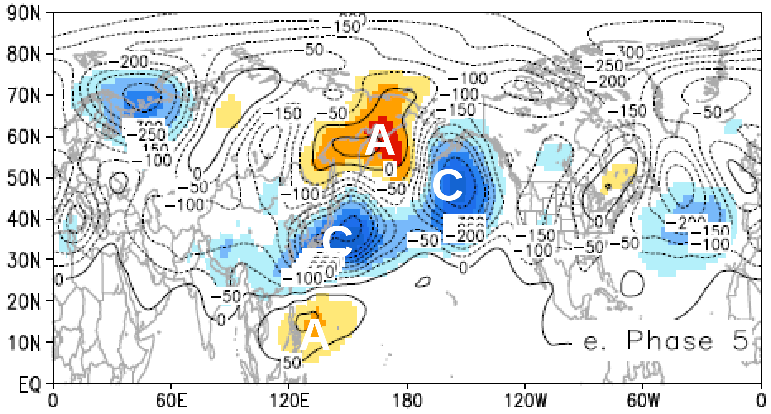
Phase 1

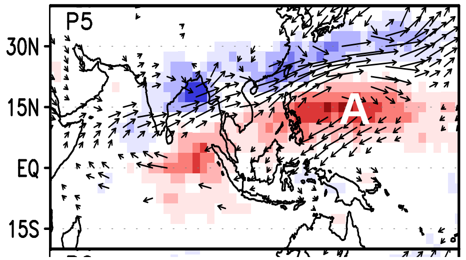


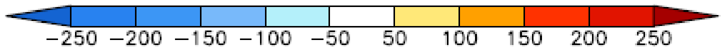


BSISO2

Phase 5





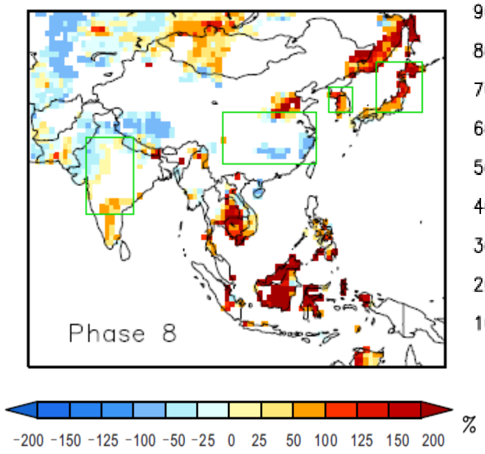


BSISO1 Teleconnection

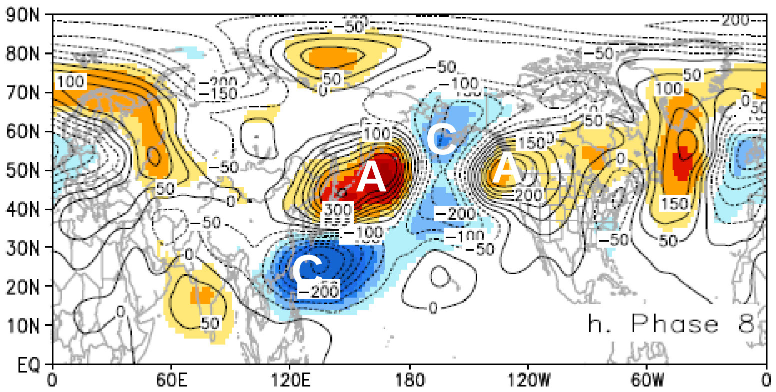
850-hPa (shading) & 200-hPa (contour) GPH

Probability of 75th extreme occurrence (APHRODITE Data)

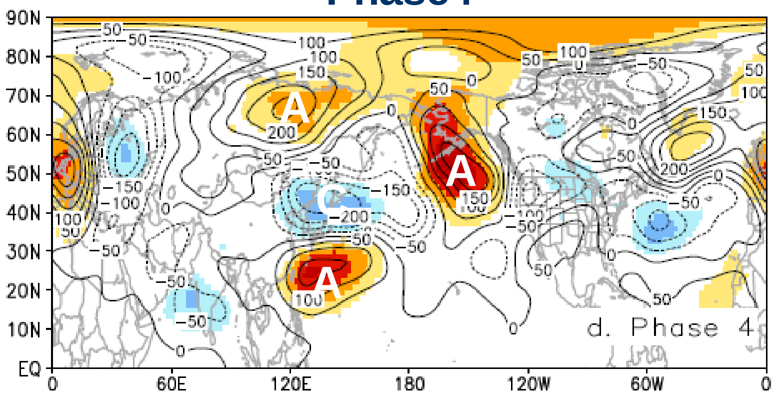
Heat Wave



Active Phase
Phase8

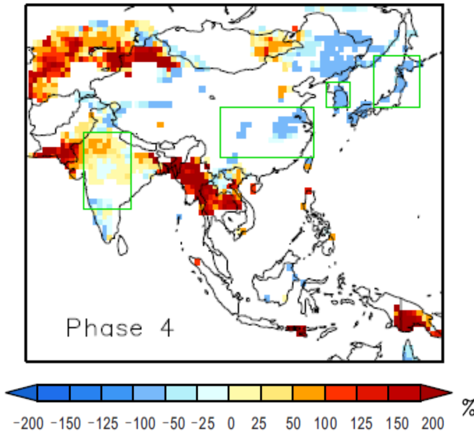


Active Phase
Phase4



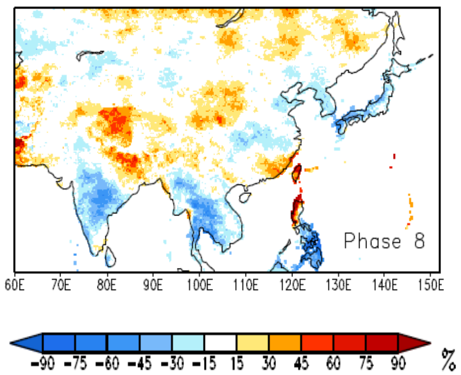
Probability of 75th extreme occurrence (APHRODITE Data)

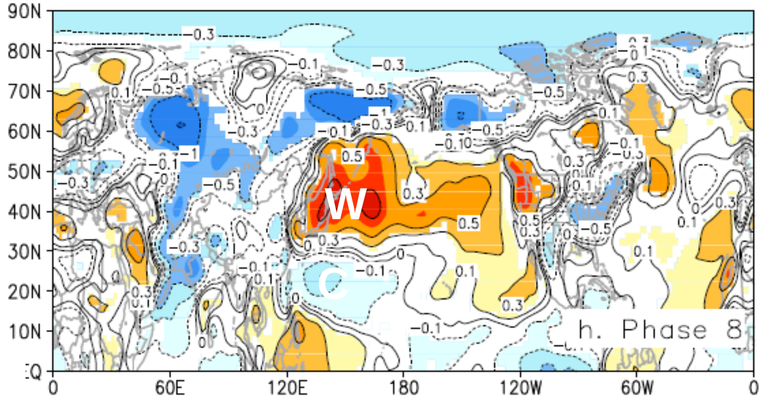
Heat Wave

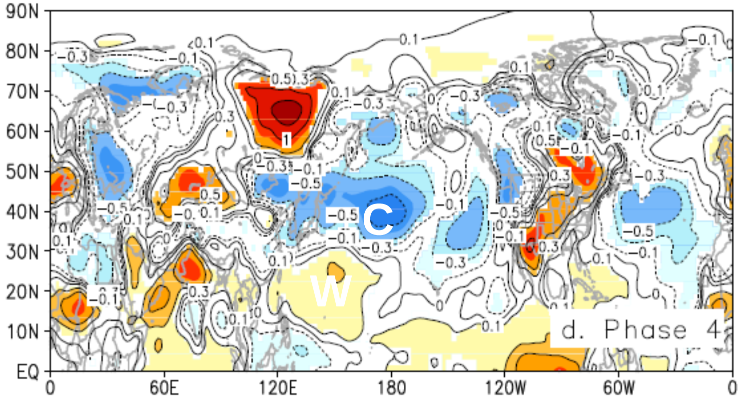


2m Air Temperature

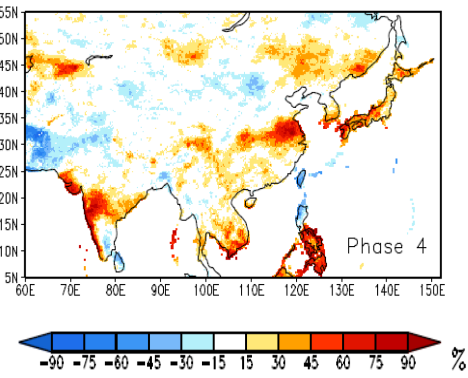
Extreme Rainfall







Extreme Rainfall

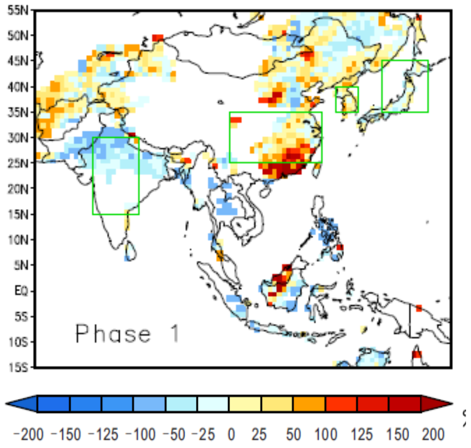


BSISO2 Teleconnection

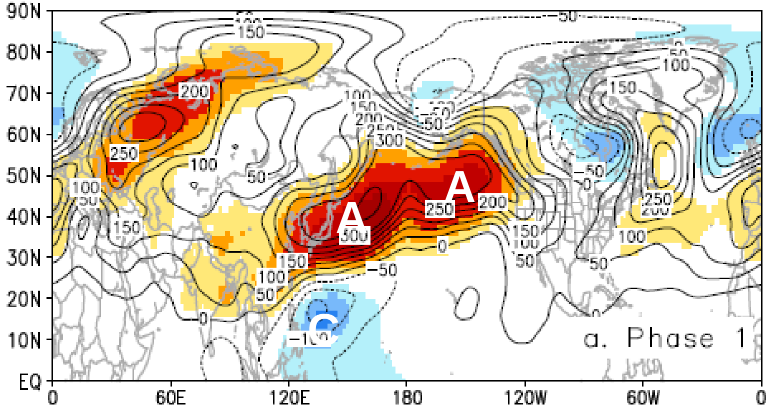
850-hPa (shading) & 200-hPa (contour) GPH

Probability of 75th extreme occurrence (APHRODITE Data)

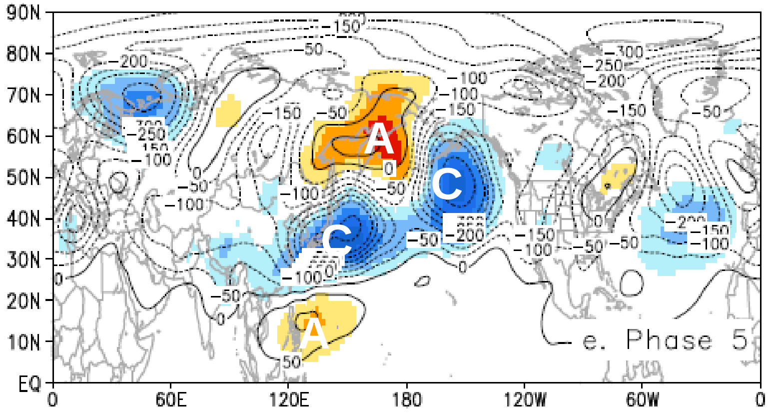
Heat Wave



Active Phase Phase1

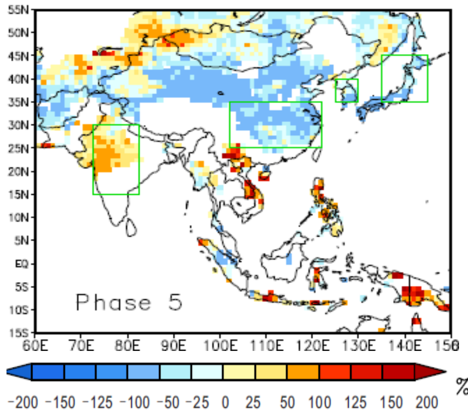


Active Phase Phase5



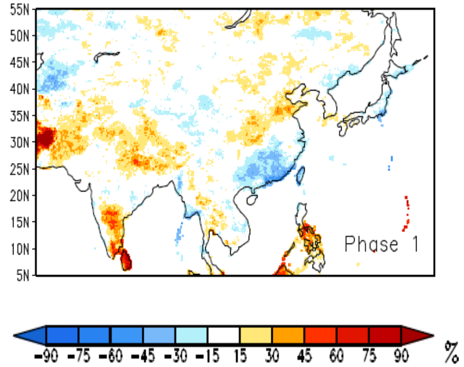
Probability of 75th extreme occurrence (APHRODITE Data)

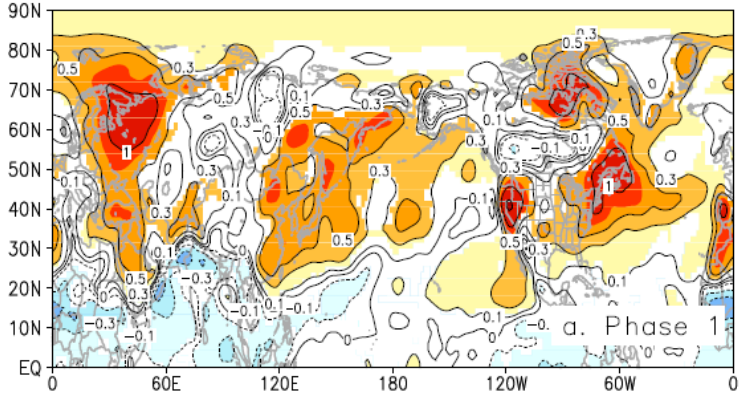
Heat Wave

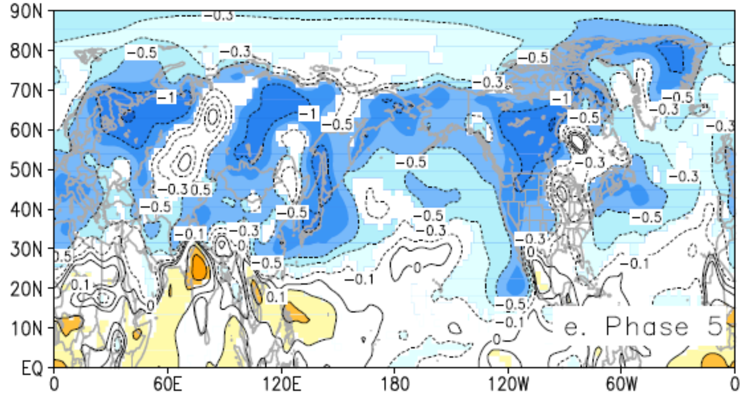


2m Air Temperature

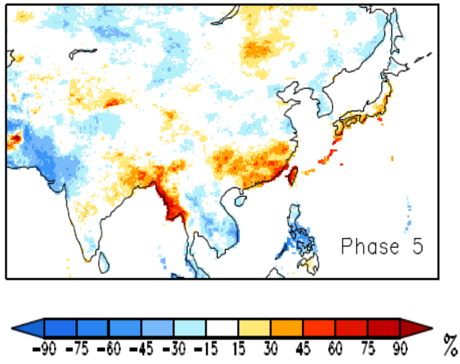
Extreme Rainfall







Extreme Rainfall



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3. Predictability and Prediction for BSISO and MJO

Description of Models and Experiments in ISVHE

ISVHE

The ISVHE Project

Intraseasonal Variability Hindcast Experiment

The **ISVHE** is a coordinated multi-institutional ISV hindcast experiment supported by **APCC, NOAA CTB, CLIVAR/AAMP, YOTC/MJO TF, and AMY.**

ONE-TIER SYSTEM

	Model	Control Run	ISO Hindcast		
			Period	Ens No	Initial Condition
ABOM	POAMA 1.5 & 2.4 (ACOM2+BAM3)	CMIP (100yrs)	1980-2006	10	The first day of every month
CMCC	CMCC (ECHAM5+OPA8.2)	CMIP (20yrs)	1989-2008	5	Every 10 days
ECMWF	ECMWF (IFS+HOPE)	CMIP(11yrs)	1989-2008	15	Every 15 days
GFDL	CM2 (AM2/LM2+MOM4)	CMIP (50yrs)	1982-2008	10	The first day of every month
JMA	JMA CGCM	CMIP (20yrs)	1989-2008	6	Every 15 days
NCEP/CPC	CFS v1 (GFS+MOM3) & v2	CMIP 100yrs	1981-2008	5	Every 10 days
PNU	CFS with RAS scheme	CMIP (13yrs)	1981-2008	3	The first day of each month
SNU	SNU CM (SNUAGCM+MOM3)	CMIP (20yrs)	1989-2008	1	Every 10 days
UH/IPRC	UH HCM	CMIP (20yrs)	1994-2008	6	Every 10 days

TWO-TIER SYSTEM

	Model	Control Run	ISO Hindcast		
			Period	Ens No	Initial Condition
CWB	CWB AGCM	AMIP (25yrs)	1981-2005	10	Every 10 days
MRD/EC	GEM	AMIP (21yrs)	1985-2008	10	Every 10 days

3. Predictability and Prediction for BSISO and MJO

The Progress of the MJO Prediction

Milestone: Discovery of the MJO
(Madden and Julian 1971, 1972)

Phase I ~2004

► Empirical era

- Empirical forecasts
- Beginning of dynamical forecast

Phase II ~2010

► Dynamical era

- Definition of the RMM index
- MJO WG
- MJO Experimental Prediction Project

Phase III 2010~

► Multi-Model era

- ISVHE
- WWRP/WCRP S2S project
- DYAMO/CINDY
- Multi-institutional realtime MJO Forecast at NCEP CPC
- BSISO Experimental Prediction at APCC

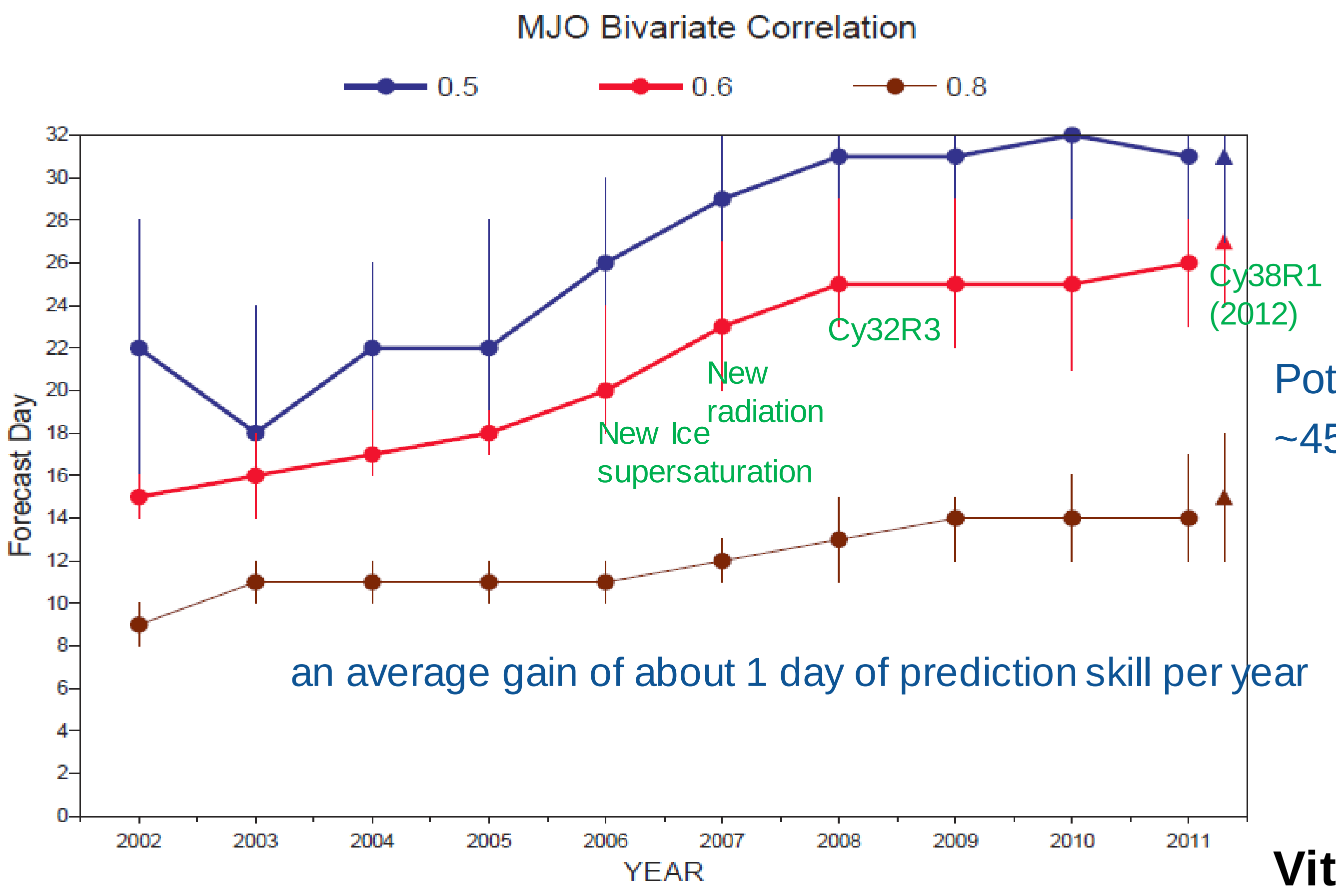
3. Predictability and Prediction for BSISO and MJO

The Current Status of MJO Forecast

Model	Initial conditions	Day 0.5 ACC	Reference
CCCma GCM3	NCEP/NCAR R1	6 days	Lin et al. 2008
RPN GEM	NCEP/DOE R2	10 days	Lin et al. 2008
NCEP CFSv1	NCEP/DOE R2	10 – 15 days	Seo et al. 2009
NCEP CFSv2	CFSR	20 days	Wang et al. 2014
GFDL CM	Coupled initialization	27 days	Xiang et al. 2015
GloSea5	ERA-Interim	20 days	MacLachlan et al. 2015
POAMA 1.5b	ERA-40 relaxation	21 days	Rashid et al. 2011
ECMWF Cy32r3	ERA-40, Operational analysis	23 days	Vitart and Molteni 2010
ECMWF Cy38r1	ERA-Interim	Above 27 days	Vitart 2014; Kim et al. 2014
SNU CGCM	NCEP/DOE R2	20 days	Kang and Kim (2011)

3. Predictability and Prediction for BSISO and MJO

Evolution of ECMWF MJO Forecast Skill Score



Cy41R1 (2015) ?

an average gain of about 1 day of prediction skill per year

Reforecast period: 1995 – 2011

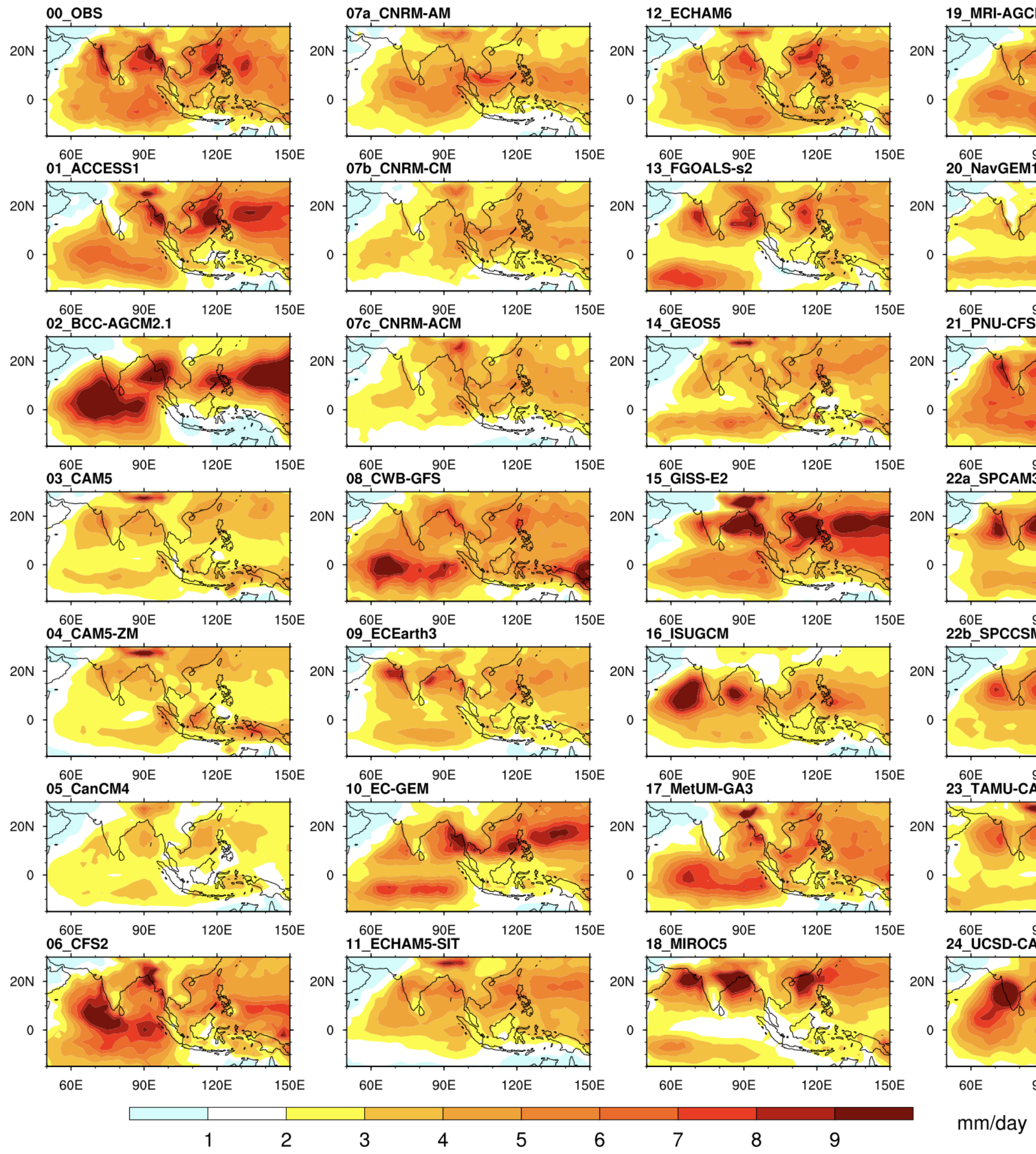
Bivariate Correlation Skill

$$\mathrm{COR}(\tau) = \frac{\sum_{i=1}^{N} [a_{1i}(t) b_{1i}(t) + a_{2i}(t) b_{2i}(t)]}{\sqrt{\sum_{i=1}^{N} [a_{1i}^2(t) + a_{2i}^2(t)]}\sqrt{\sum_{i=1}^{N} [b_{1i}^2(t) + b_{2i}^2(t)]}},$$

Potential predictability: ~45 days

Vitart (2014 QJRMS)

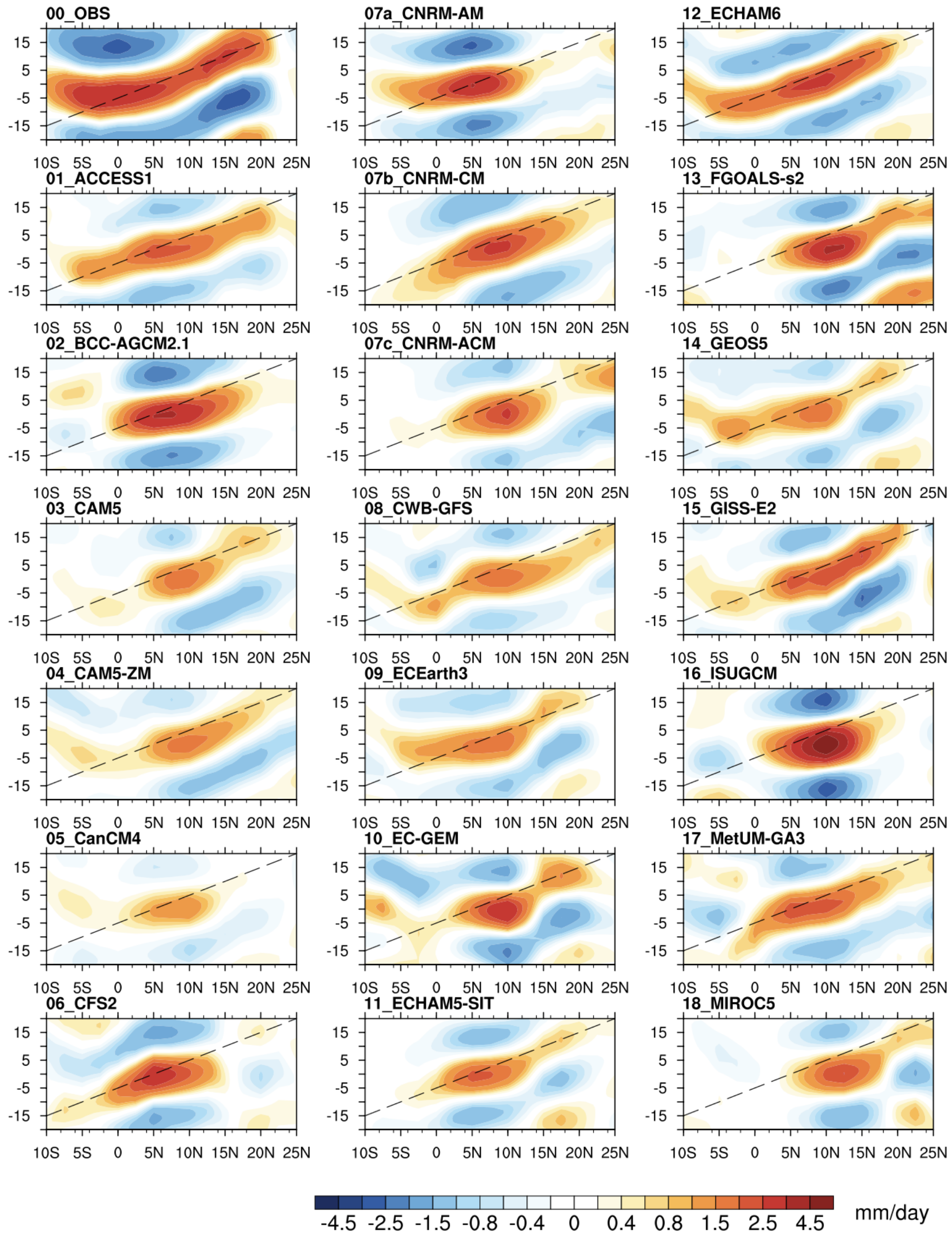
3. Simulation of BSISO



Standard deviation of daily 20-90 day band-pass-filtered rainfall anomalies during boreal summer (May-Oct) based on observation and model simulations.

Neena et al. Clim Dyn 2015

3. Simulation of BSISO

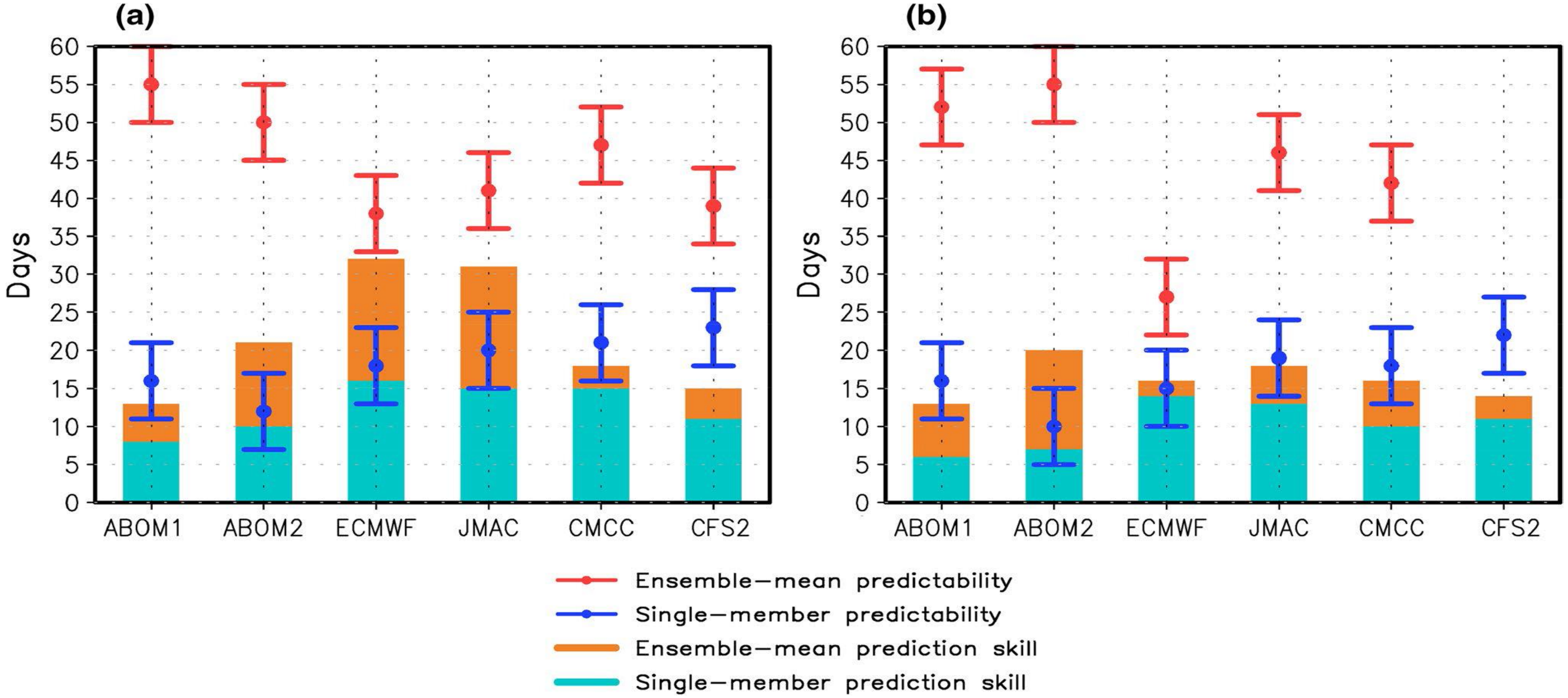


Latitude-time evolution of 20-90 day band-pass-filtered rainfall anomalies regressed against itself averaged over a near equatorial box (85°-90°E, 5°-10°N). Regressed anomalies are averaged over 80-100E. Dashed lines in each panel denote the 1° latitude/day northward propagation phase speed.

Neena et al. Clim Dyn 2015

3. BSISO Predictability and Prediction

The Predictability and prediction skill in BSISO in (a) strong and (b) weak BSISO initial condition



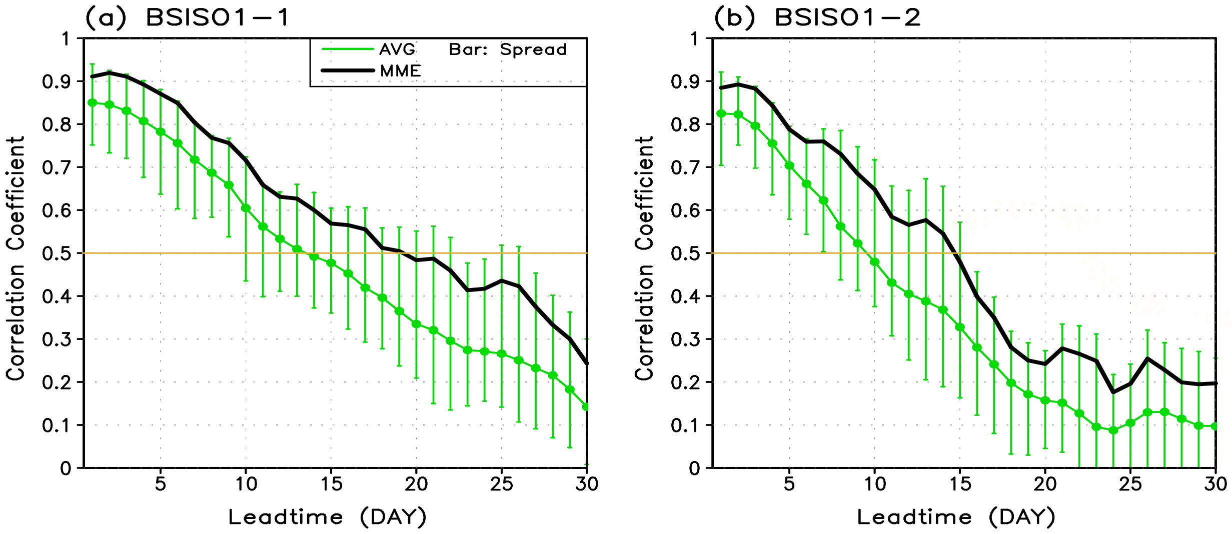
	Strong BSISO IC	Weak BSISO IC
Prediction skill	~ 3 weeks	~2 weeks
Predictability	~ 6weeks	~6 weeks

Lee et al. 2015 Clim Dyn

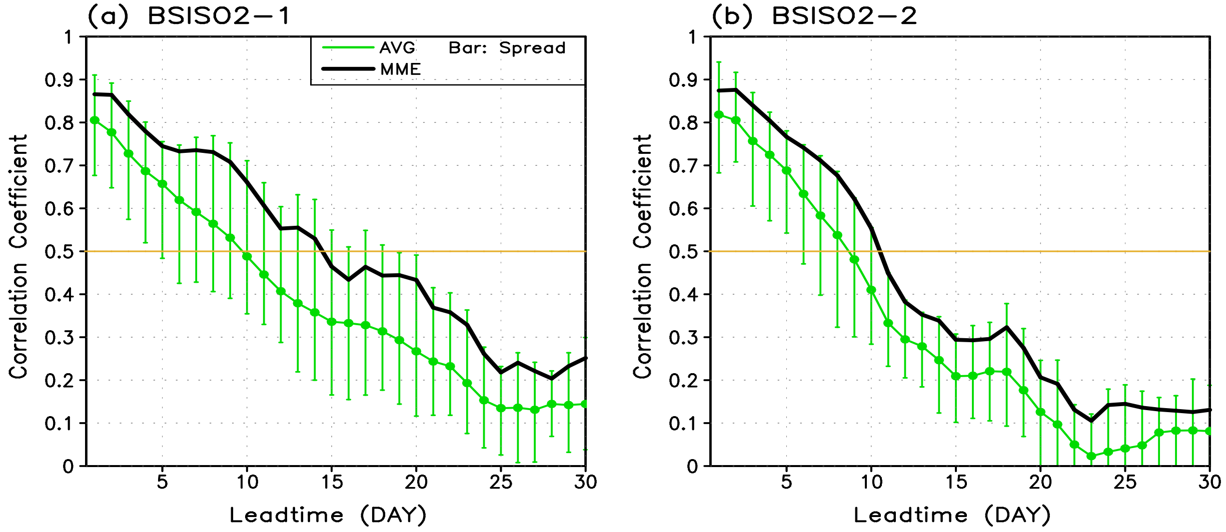
3. BSISO Predictability and Prediction

Anomaly Correlation Coefficients (1989-2008, MJJASO)

BSISO1



BSISO2



Common Period: 1989-2008
Initial Condition: 1st day of each month from Oct to March

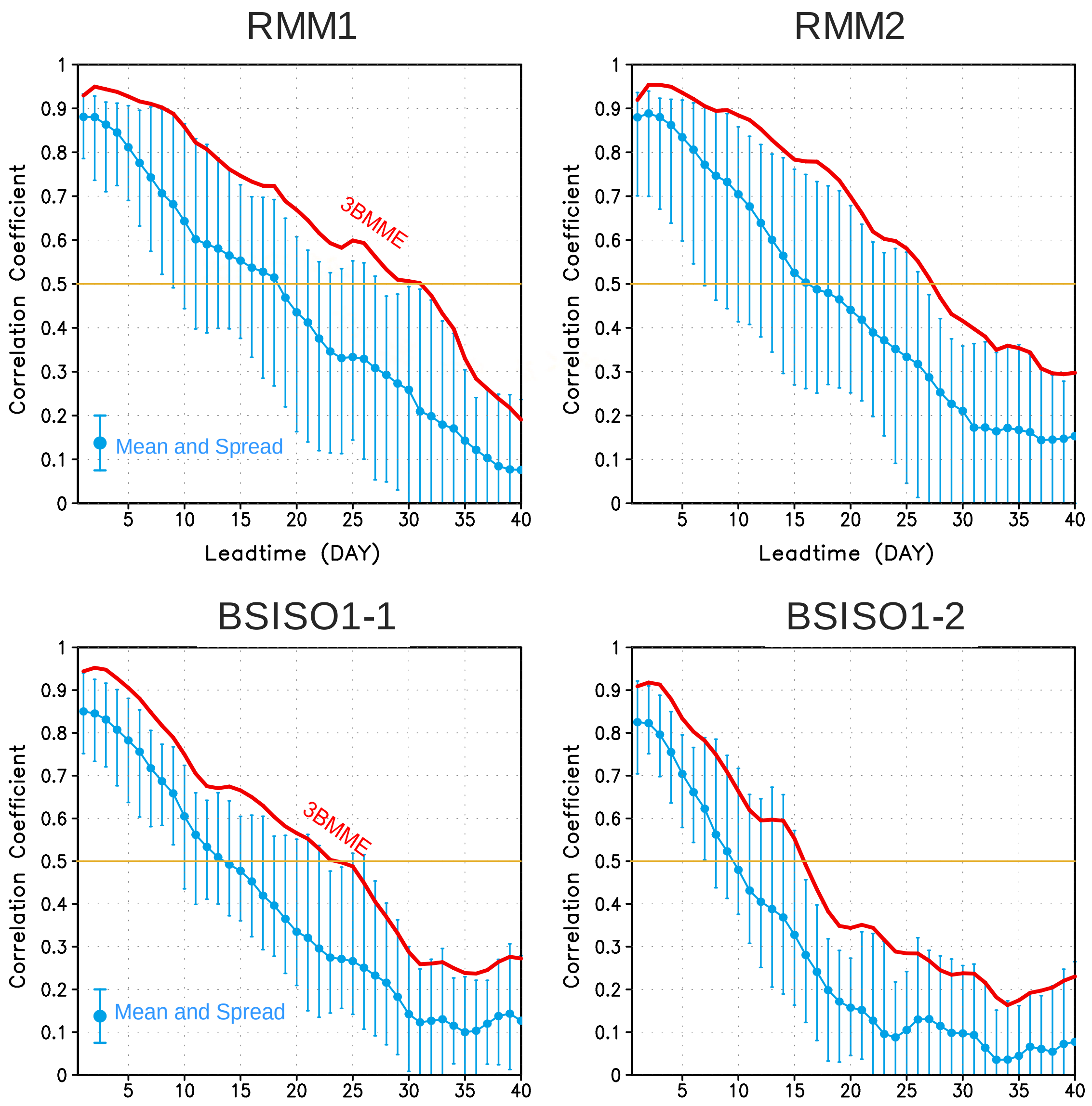
MME: Simple composite with all models

Using the MME, forecast skill for BSISO1 reaches 0.5 at 15 to 20-day forecast lead and for BSISO2 at 10- to 15-day forecast lead.

3. BSISO Predictability and Prediction

- The RMM index for eastward propagating ISO mode during NDJFMA (Wheeler and Hendon 2004)
- The MME skill up to 25 ~ 30 days

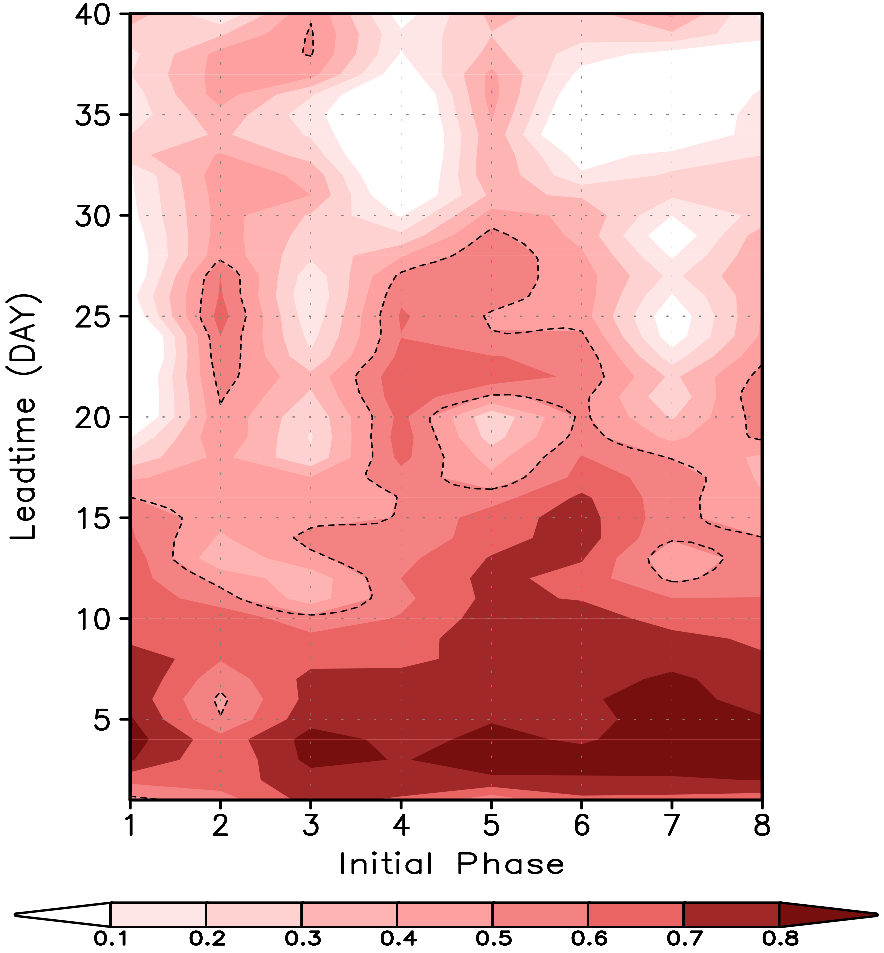
- The BSISO index for northward propagating ISO during MJJASO (Lee et al. 2013)
- The MME skill up to 15 ~ 25 days



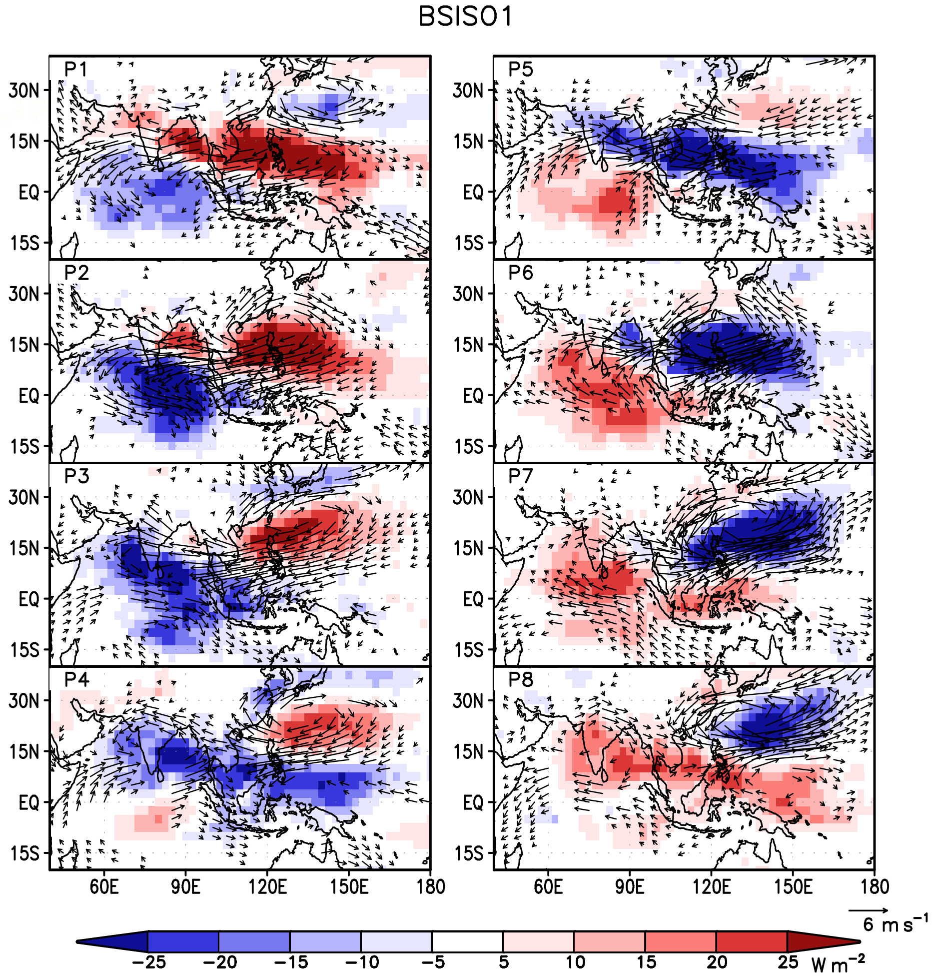
3. BSISO Predictability and Prediction

Initial Phase Dependency of BSISO Forecast Skills

Temporal Correlation Coefficient Skill of the MME for BSISO1

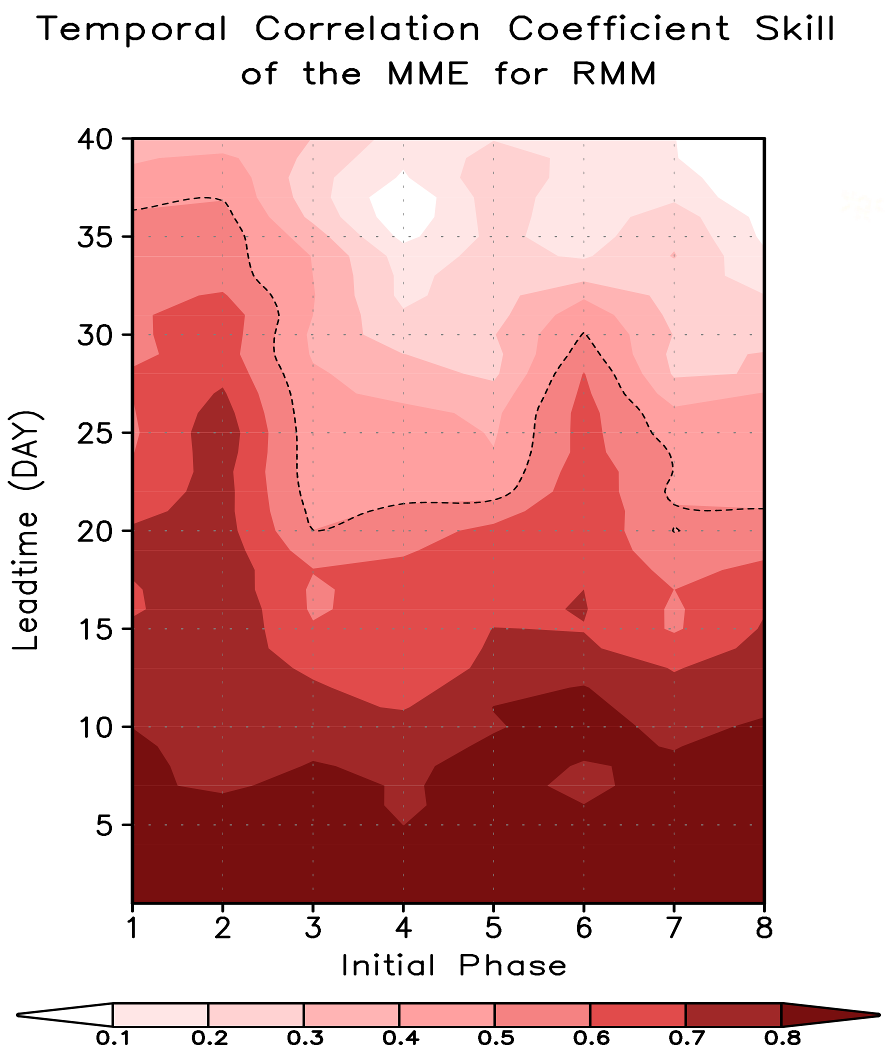


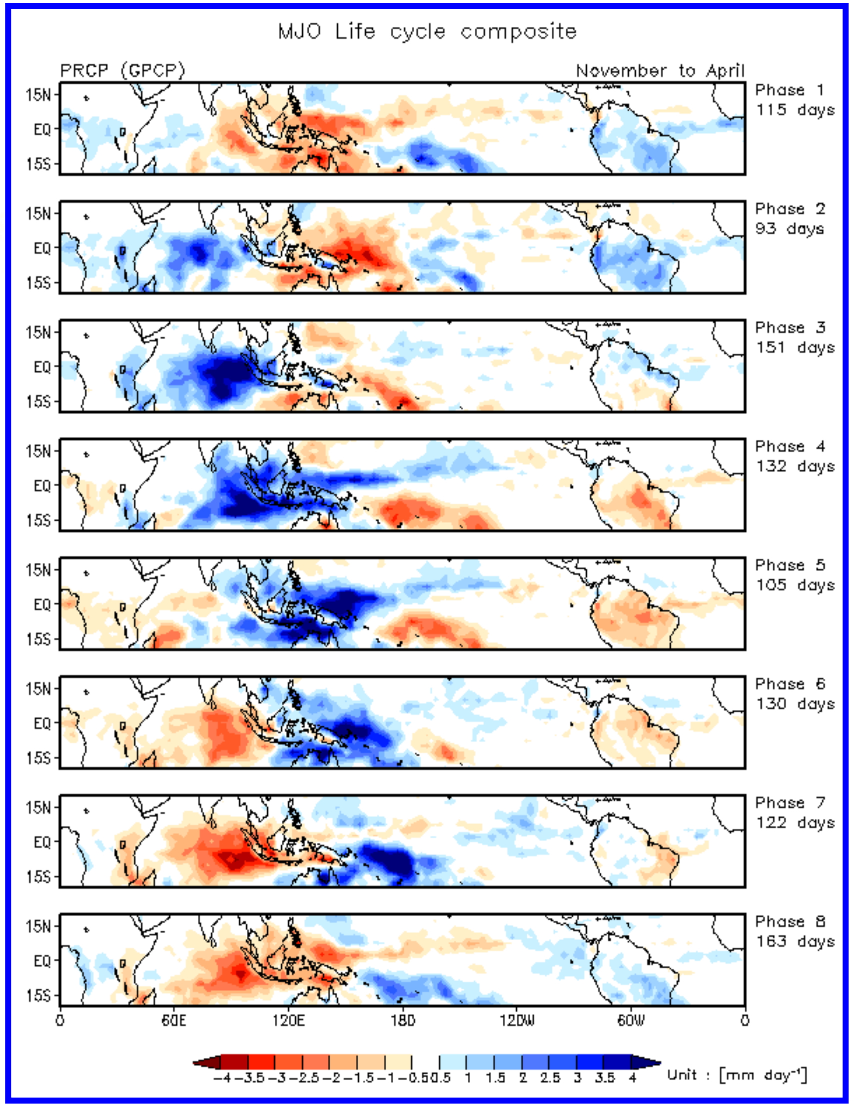
Life cycle composite of OLR (shading) and 850-hPa wind anomalies



3. BSISO Predictability and Prediction

Initial Phase Dependency of MJO Forecast Skills





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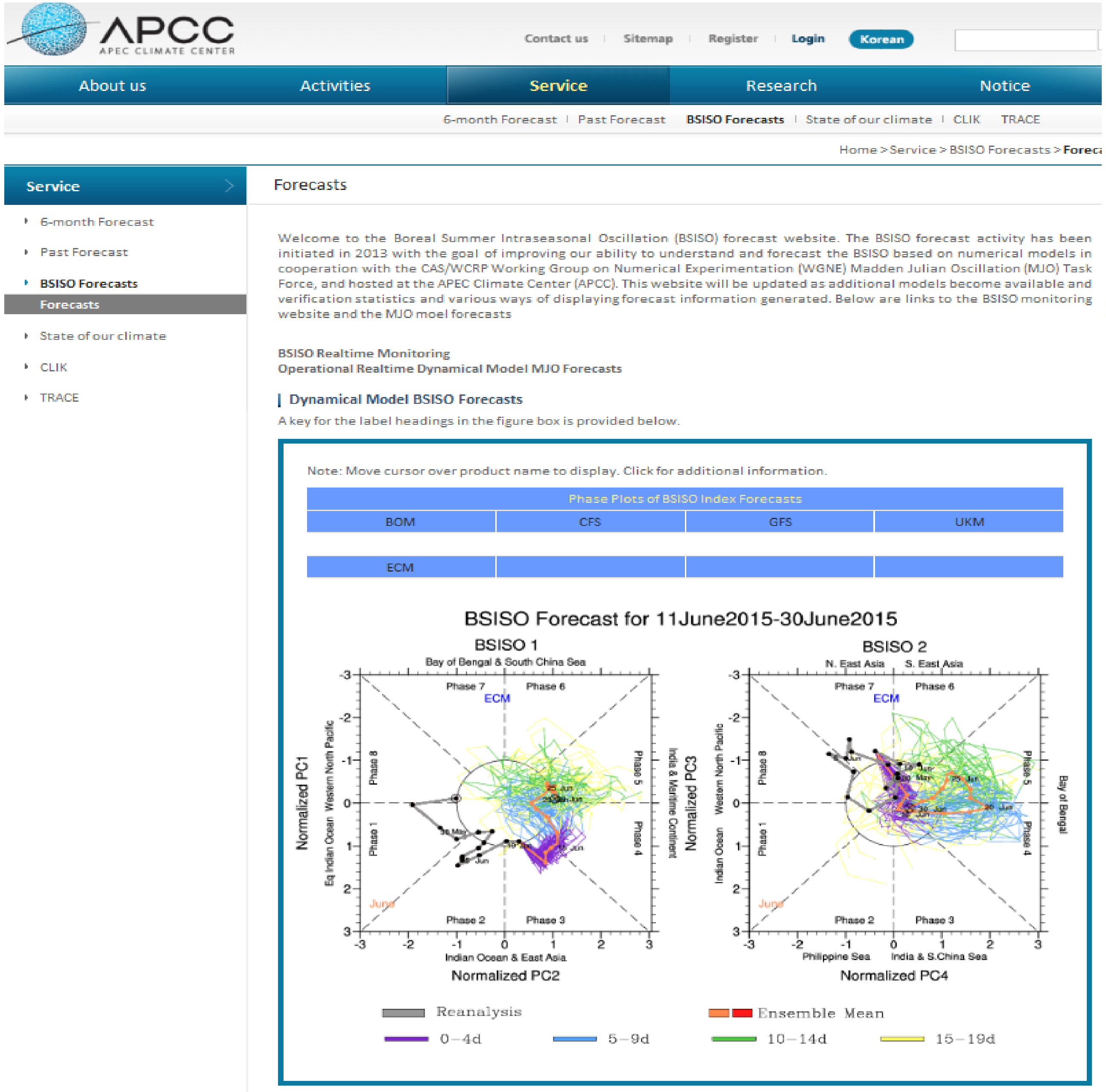
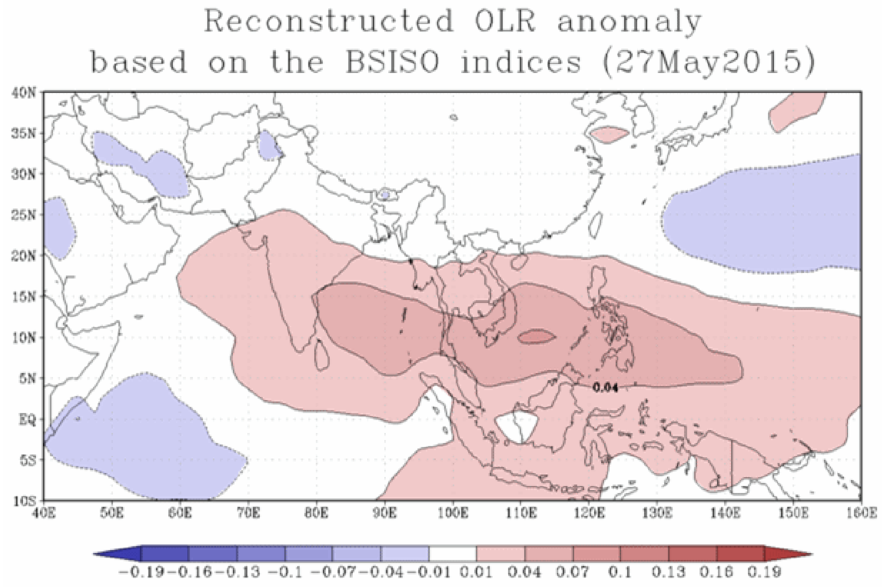


BSISO Monitoring and Real-time forecast hosted by APCC and endorsed by WMO WGNE and MJOTF

Forecast are from five operational models in ECMWF and UKMO in Europe, NCEP in USA, and CWB in Taiwan



4. Real-time Monitoring and forecast

In cooperation with the WGNE MJO TF, APCC has hosted real-time monitoring and forecast of BSISO indices since 2013 summer.

Participating Institutes

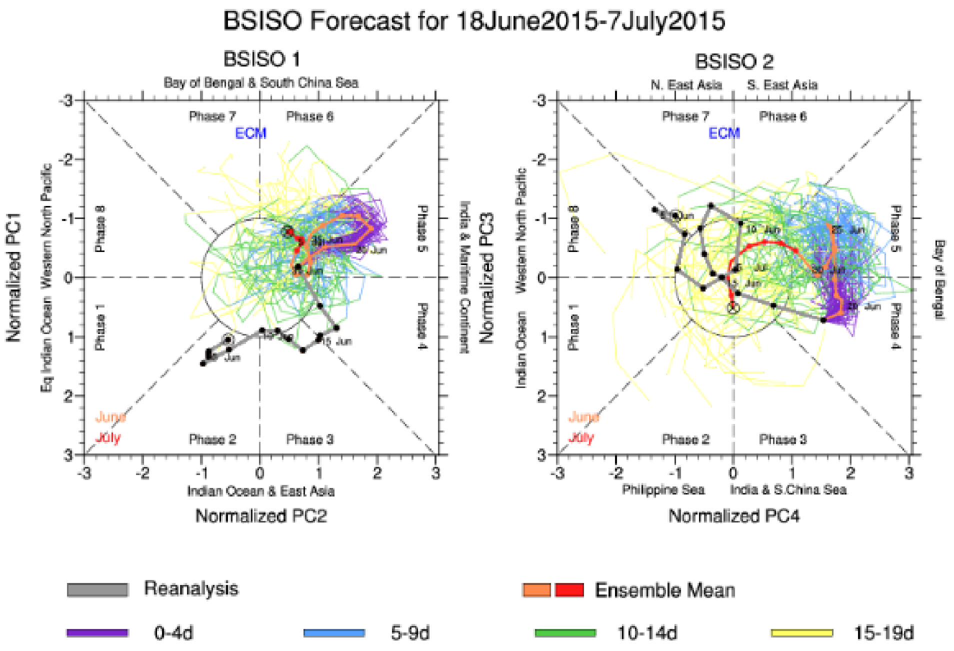
Institute	Model	Ensemble Size	Forecast Period	Update frequency	Resolution
NCEP	Climate Forecast System	4	40 days	Once a day	T126 L64
	Global Forecast System	1	16 days	Once a day	T574, T190 L64
	Global Ensemble Forecast System	*20*	*35 days*	*ASAP*	
Australia	POAMA 2.4 multi-week model	33	40 days	Twice per week	T47 L17
ECMWF	ECMWF Ensemble Prediction System	51	32 days	Twice per week	T639, T319 L62
UK Met Office	MOGREPS-15	24	15 days	Once a day	60km L70
Taiwan CWB	*CWB EPS T119*	*1*	*40 days*	*From 2015*	
CMC	*GEMDM_400x200*	*20*	*15 days*	*ASAP*	

4. Real-time Monitoring and forecast

ECMWF Forecast

Note: Move cursor over product name to display. Click for additional information.

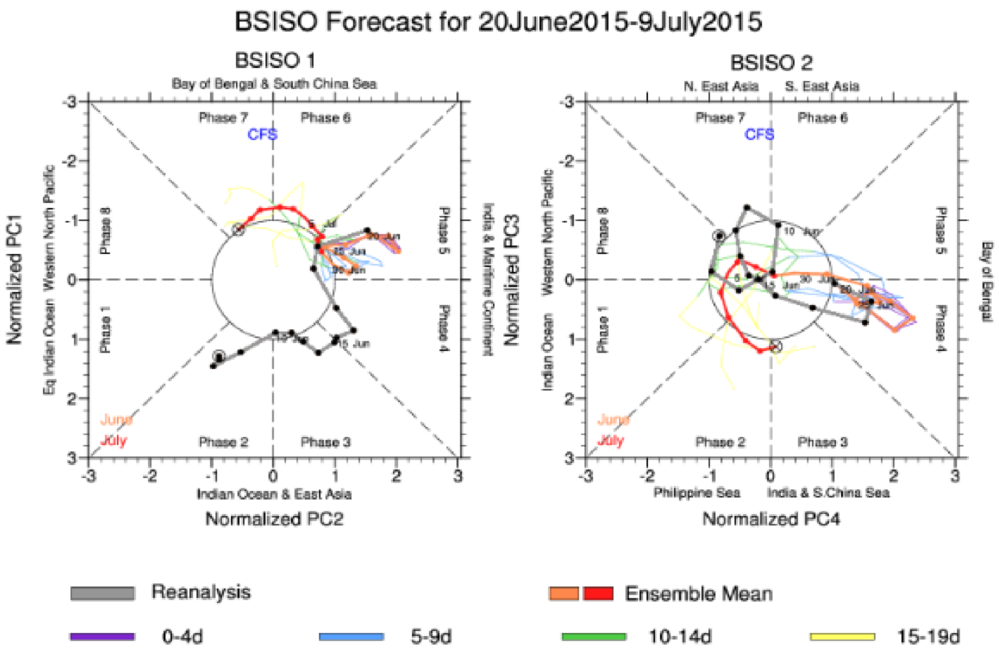
Phase Plots of BSISO Index Forecasts			
BOM	CFS	GFS	UKM
ECM	CWB		



NCEP CFS Forecast

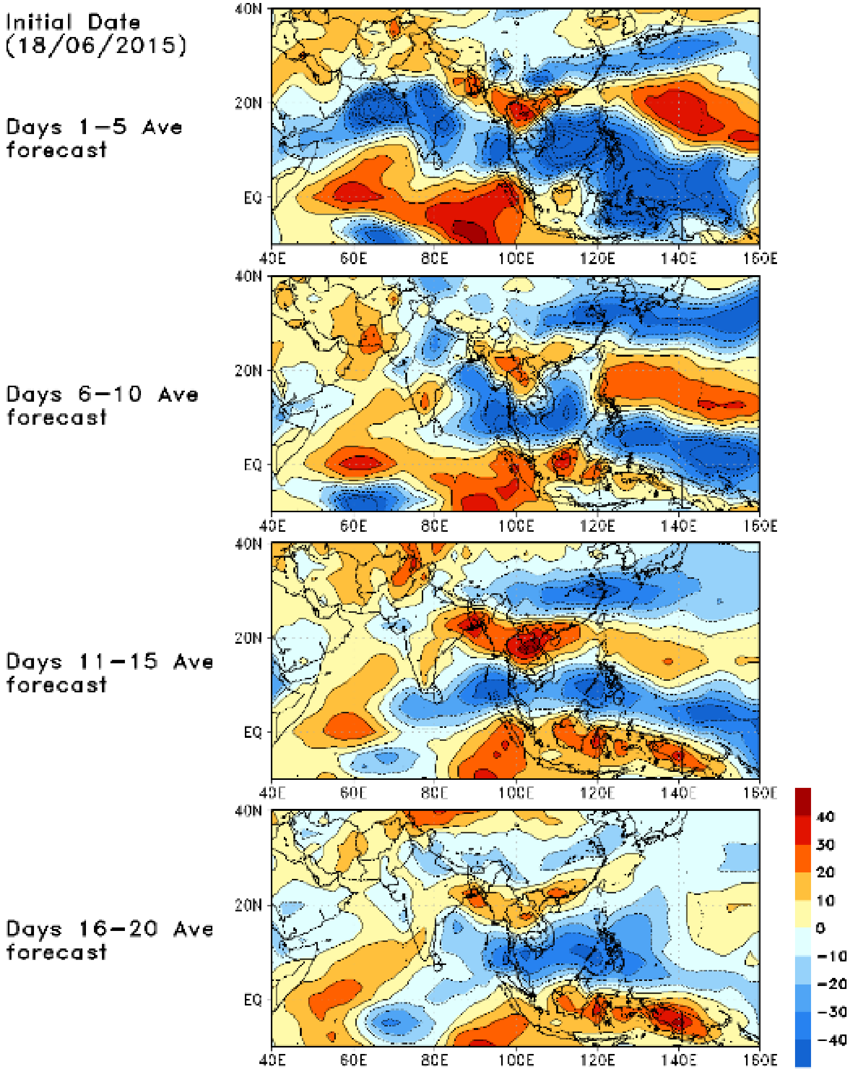
Note: Move cursor over product name to display. Click for additional information.

Phase Plots of BSISO Index Forecasts			
BOM	CFS	GFS	UKM
ECM	CWB		

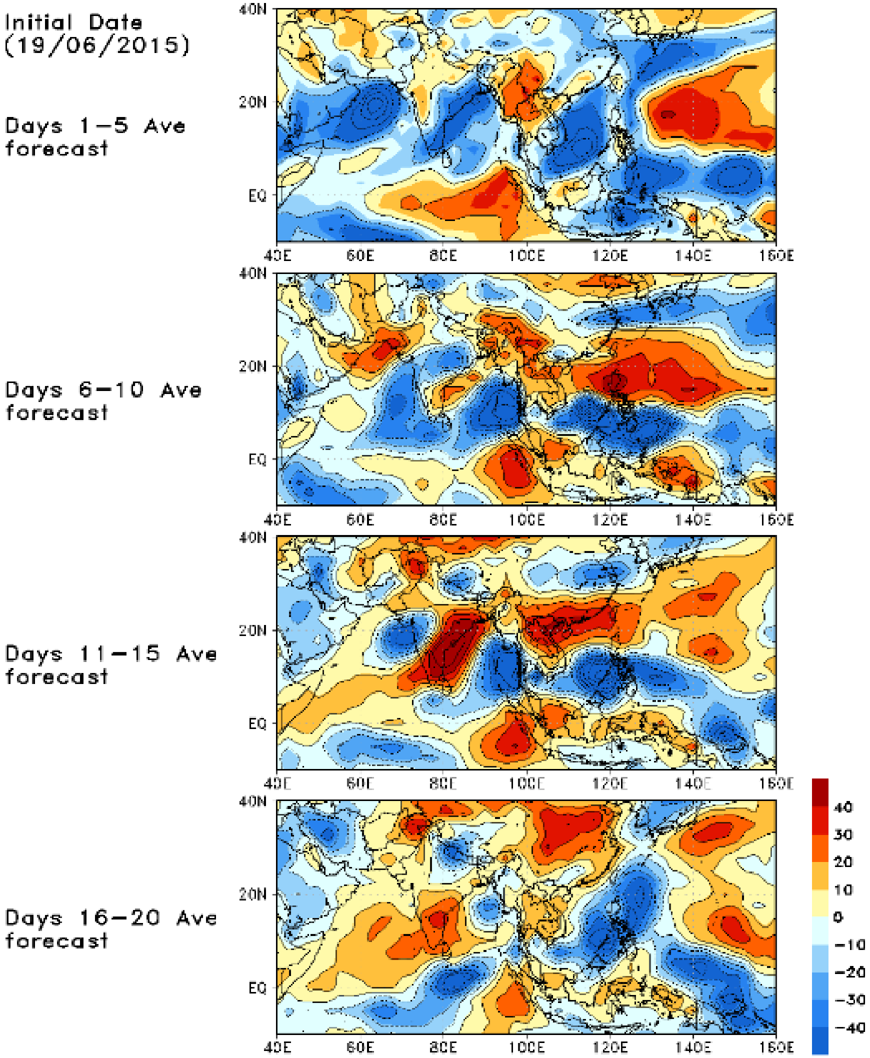


4. Real-time Monitoring and forecast

ECMWF Forecast

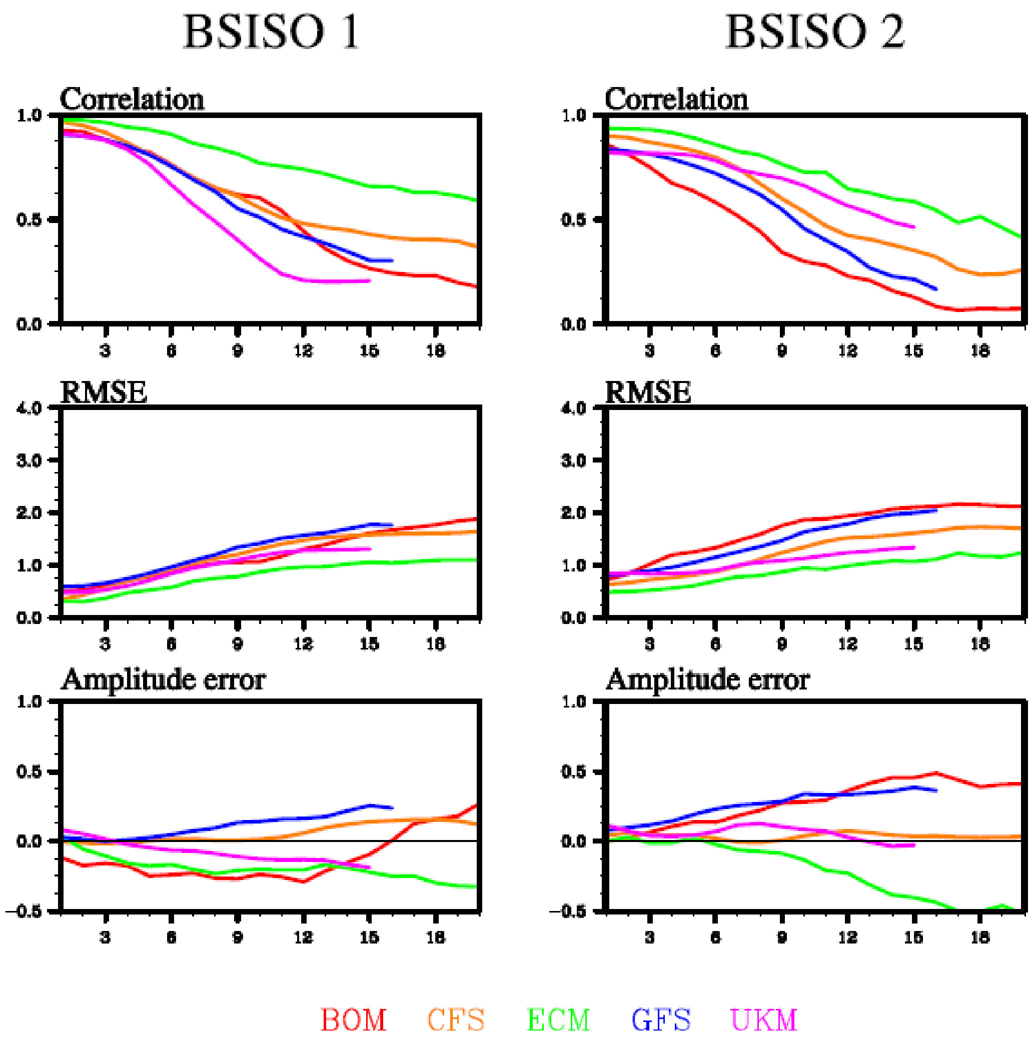


NCEP CFS Forecast



4. Real-time Monitoring and forecast

Assessment of real-time forecast skill for the BSISO1 and BSISO2 during May-October for 2013-2014



Models have a useful forcast skill of 0.5 for BSISO1 (BSISO2) up to 10-20 days (10-16 days) for the two years of 2013-2014.

5. Summary

- Given the extreme importance of the BSISO, we have made an effort to define new indices to assist in real-time monitoring and forecast applications of the BSISO. The BSISO indices proposed in this study were designed to better represent fractional variance and the observed northward/northwestward propagating ISO over the ASM region than the RMM index.

- **BSISO1, consisting of EOF1 and EOF2**, represents **the canonical northward and north-eastward propagating ISO over the ASM region** during the entire warm season from May to October with quasi-oscillating periods of 30-60 days in conjunction with the eastward propagating MJO.

- **BSISO2, consisting of EOF3 and EOF4**, captures **the northward/northwestward propagating variability with periods of 10-30 days** during primarily the pre-monsoon and monsoon-onset season.

- The **probability density function** of May-August rainfall in East Asia is skewed toward large values in **phases 2-4 of the BSISO1** and **phases 5-7 of the BSISO2** life cycles, during which **the probability of extreme rainfall events at the 75th** (**95th**) percentile increases **30-50%** (**over 60%**) **relative to the non-BSISO periods**.

- The ISVHE has been coordinated to better understand the physical basis for prediction and determine predictability of ISO. Analysis of ISVHE data indicates that the **BSISO1 is predictable up to 6 weeks** but the state-of-the-art coupled models have a useful skill of 0.5 for **the BSISO1 and BSISO2 up to 15-20 days and 10-15 days**, respectively.

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THANK YOU