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Ocean-Atmosphere interaction and Interannual monsoon variability

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2nd ACAM Training School: Observation & modeling of atmospheric chemistry & aerosols in the Asian monsoon region

10-12 June 2017, Jinan University, Guangzhou China

Outline

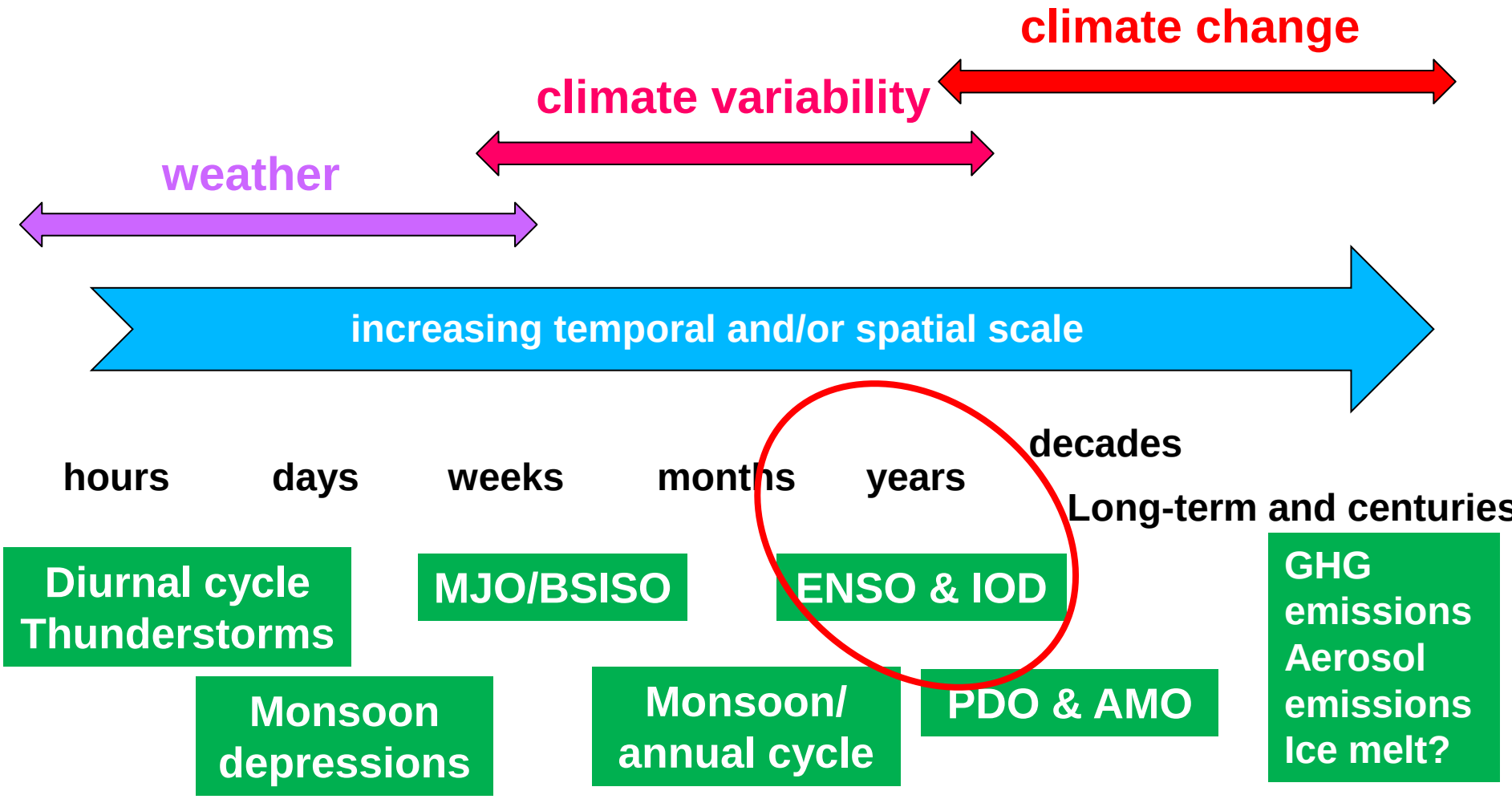
1. Background

2. EASM and ENSO

3. ISM and ENSO

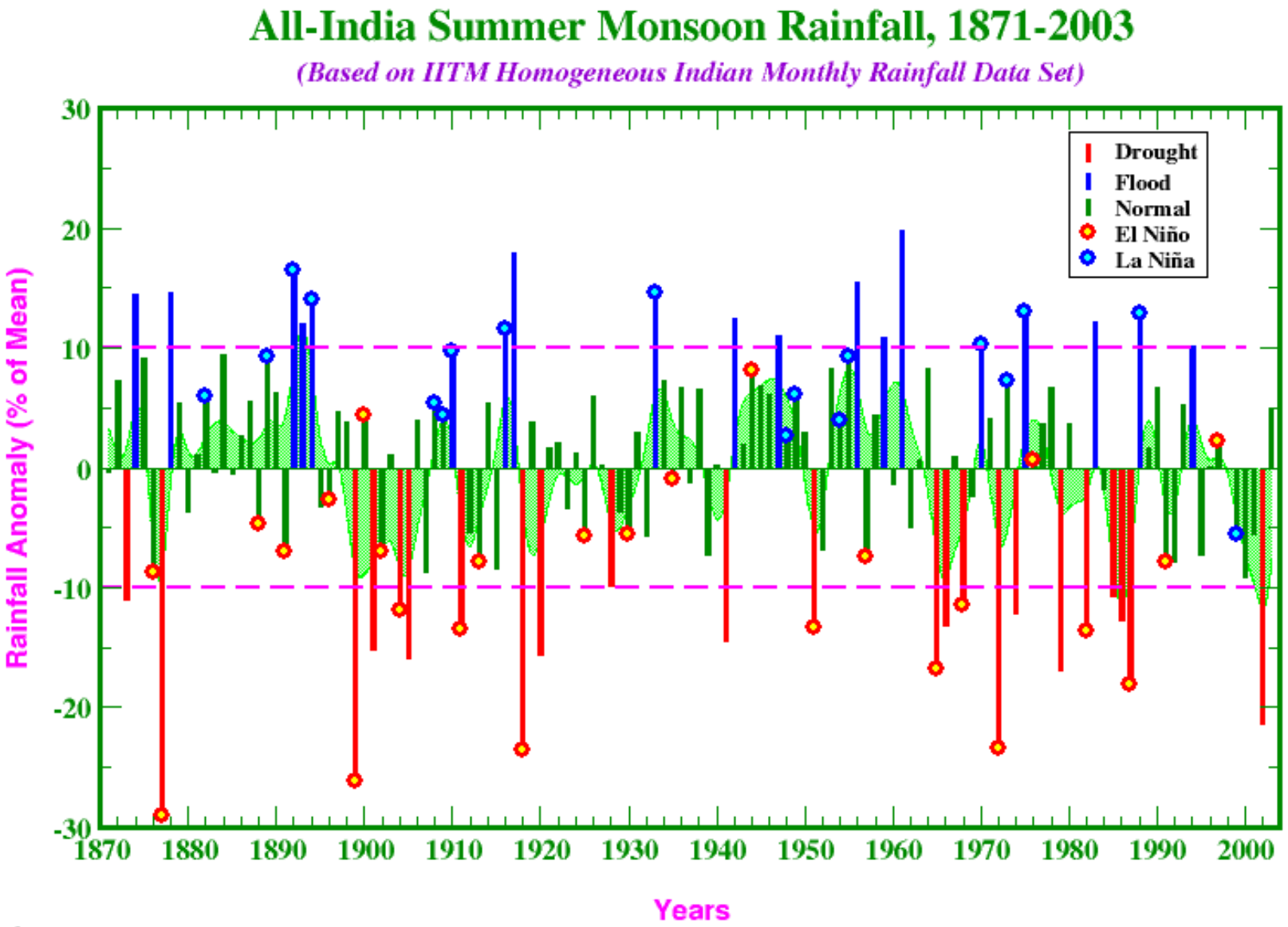
4. Concluding remarks

Space and time scales in the monsoon

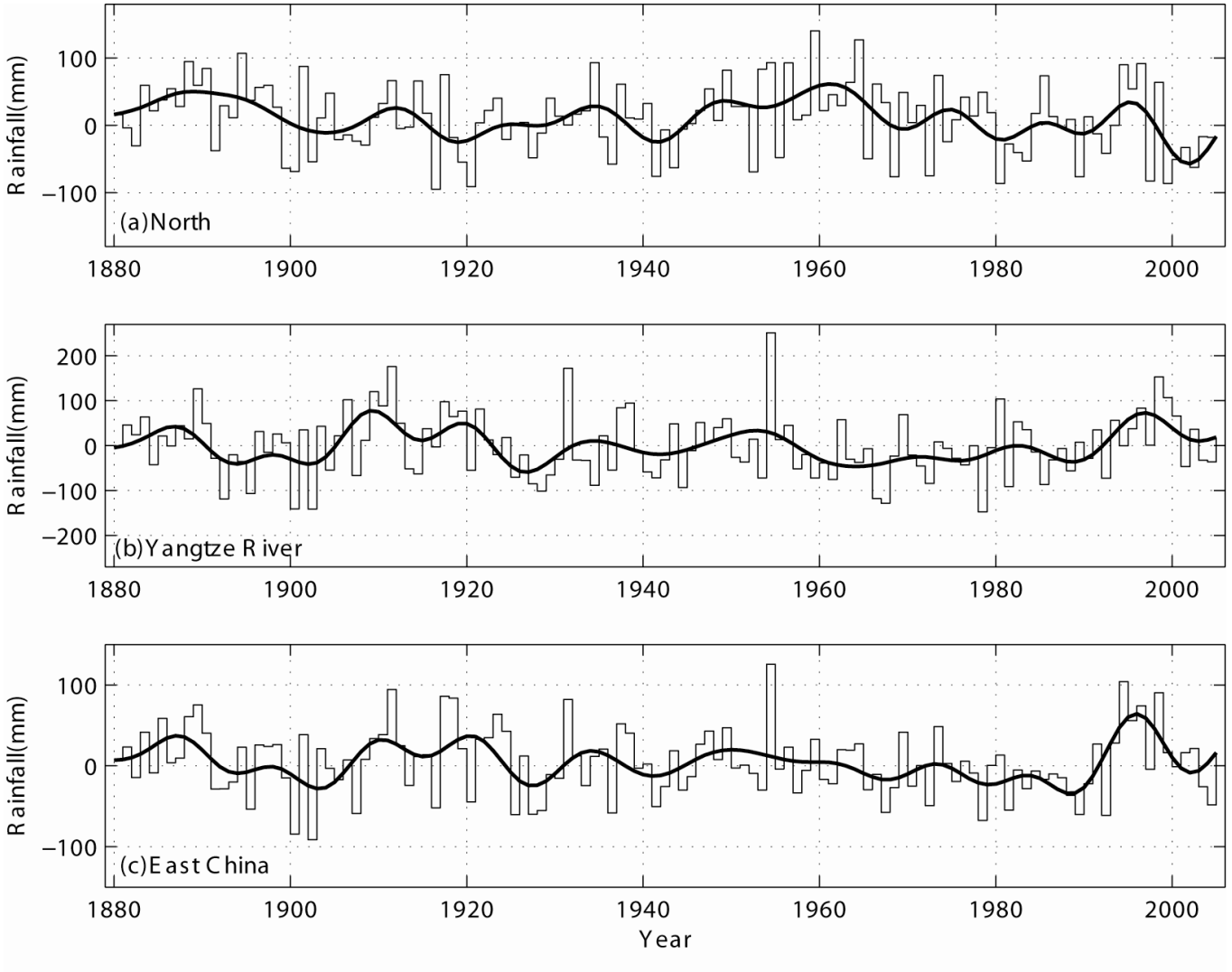


Courtesy: Andy Turner

Monsoon-ENSO co-variation

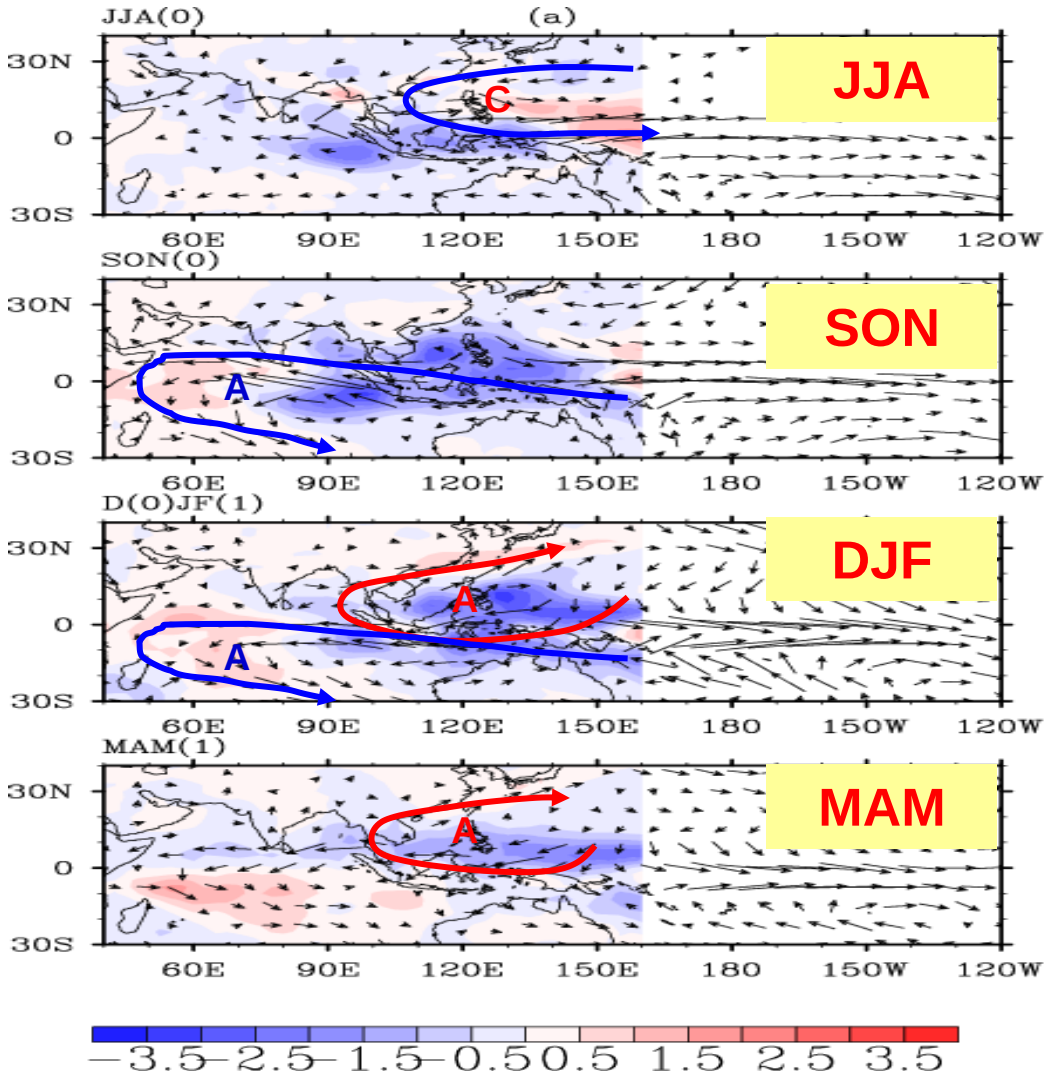


East Asian summer rainfall



Zhou, T., D. Gong, J. Li, B. Li, 2009: Detecting and understanding the multi-decadal variability of the East Asian Summer Monsoon- Recent progress and state of affairs. Meteorologische Zeitschrift, 18 (4), 455-467

S-EOF modes of MME precipitation and the associated 850hPa wind



0.65

0.75

0.81

0.66

SEOF1(31.3%)

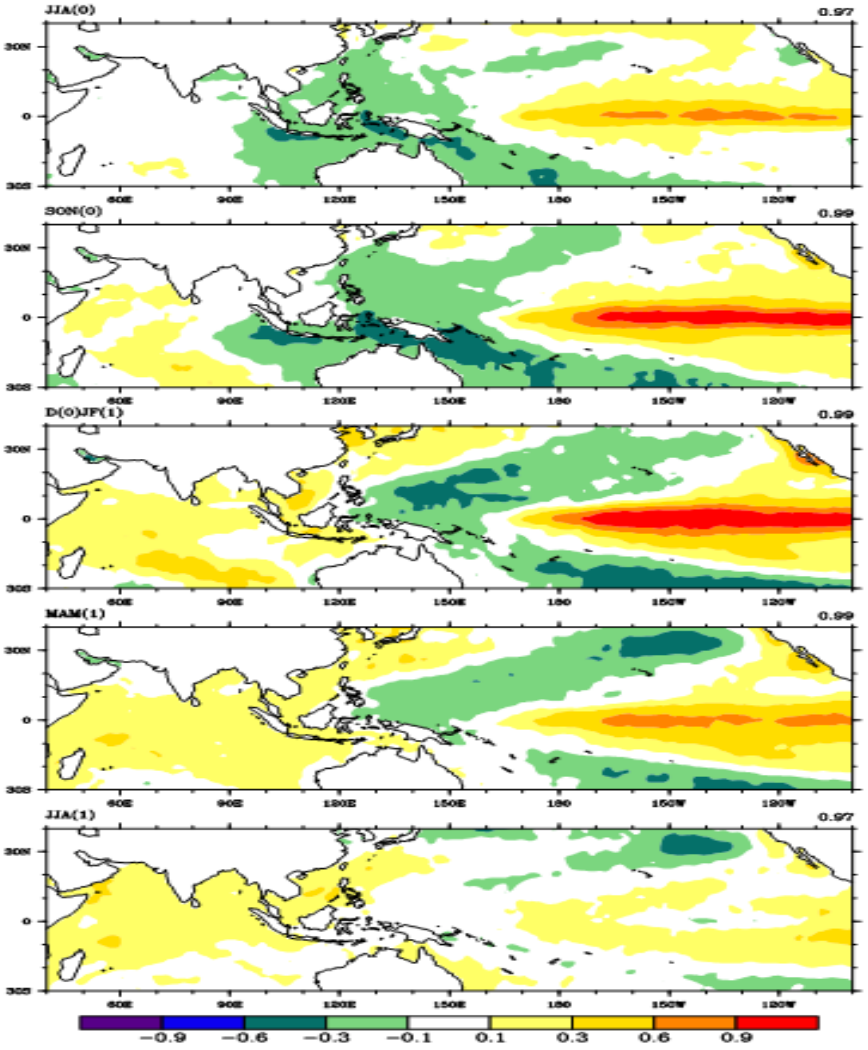
shading：precp

vector：UV850

AMIP MME

Zhou et al. 2009a How Well Do Atmospheric General Circulation Models Capture the Leading Modes of the Interannual Variability of the Asian-Australian Monsoon?, ***Journal of Climate***, 22, 1159-1173

SST anomalies in El Nino decaying year



JJA (0)

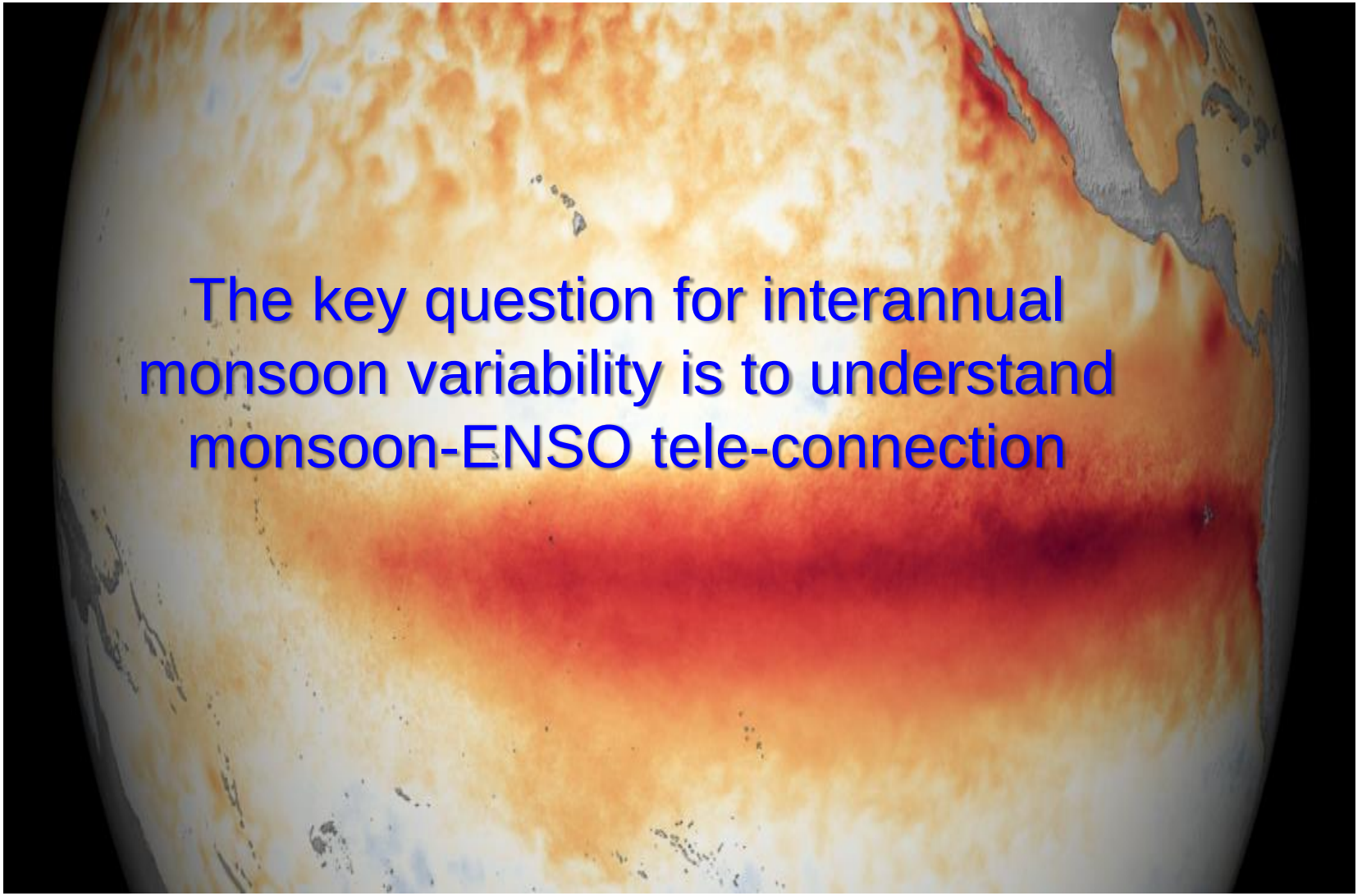
SON (0)

D(0)JF (1)

MAM (1)

JJA (1)

Zhou et al. 2009a How Well Do Atmospheric General Circulation Models Capture the Leading Modes of the Interannual Variability of the Asian-Australian Monsoon?, ***Journal of Climate***, 22, 1159-1173


The key question for interannual monsoon variability is to understand monsoon-ENSO tele-connection

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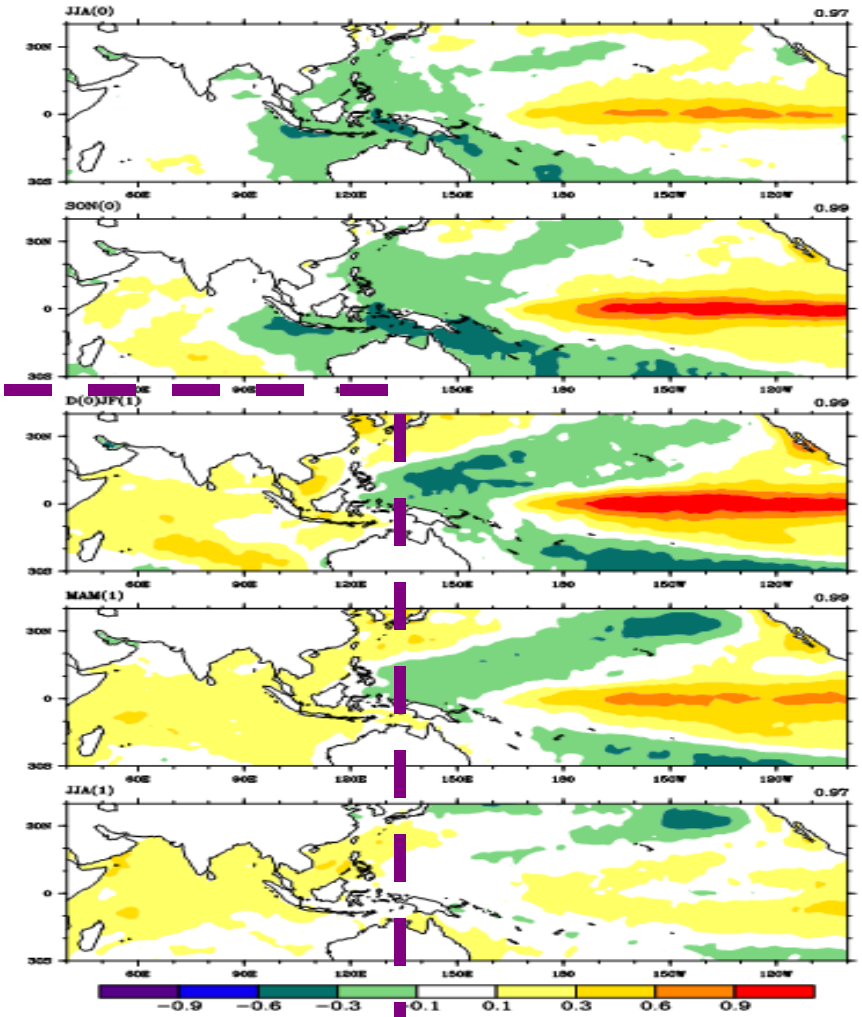
Indian Ocean SST anomalies versus Pacific SST



DJF

MAM

JJA

The following work highlight Indian Ocean SST forcing to EA climate:

Hu (1997 JGR)；

Guo Yufu (2004 AAS)；

Watanabe & Jin (2007 GRL)；

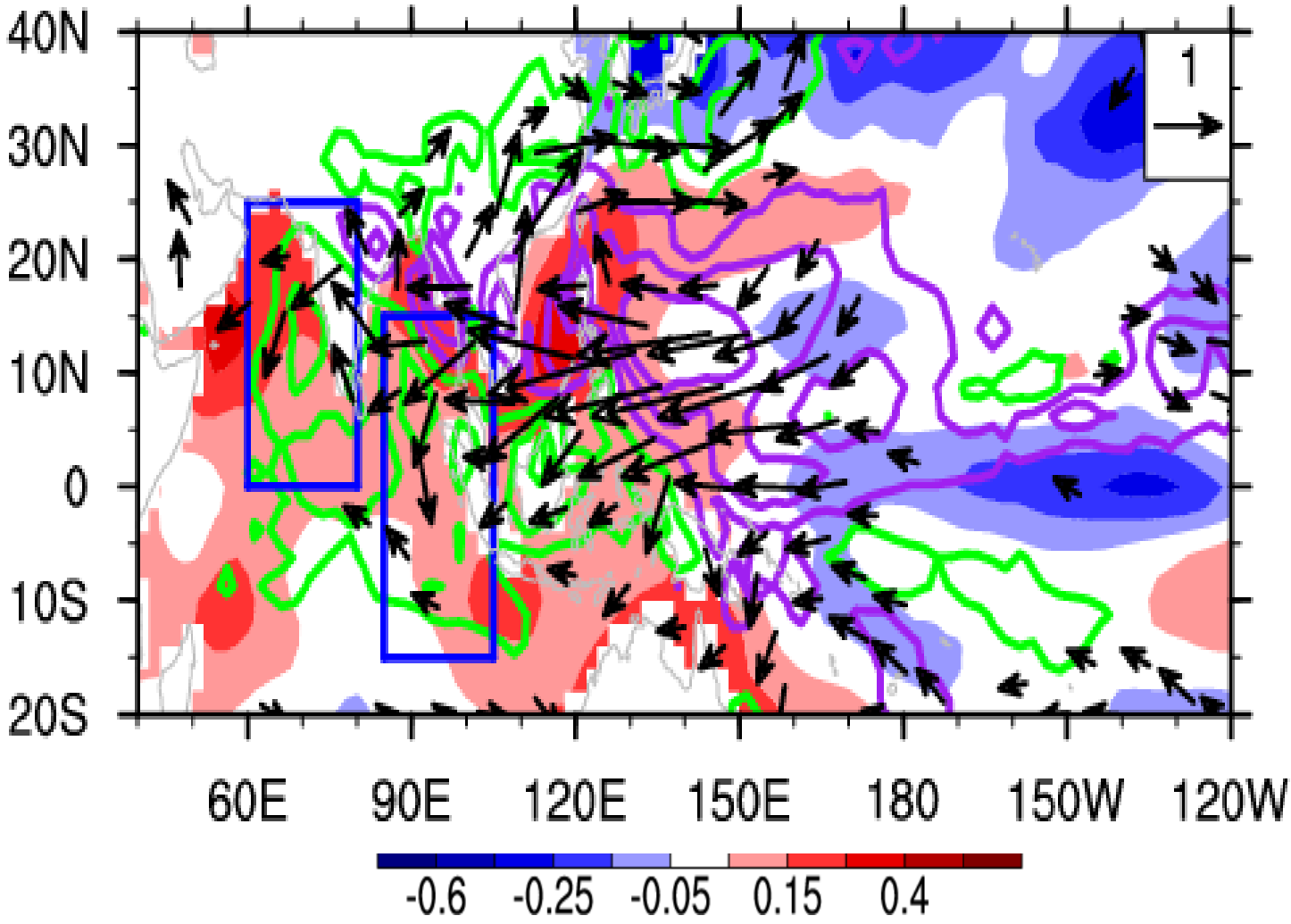
Yang et al. (2007)、Xie et al. (2009) Indian Ocean capacitor；

Wu et al. (2009) seasonal dependence of Indian and western Pacific SSTA

WU Bo, T. Zhou, Tim LI, 2009, Seasonally Evolving Dominant Interannual Variability Modes of East Asian Climate, ***Journal of Climate***, 22, 2992-3005.

Metric: Observed changes of monsoon in El Nino decaying year summer

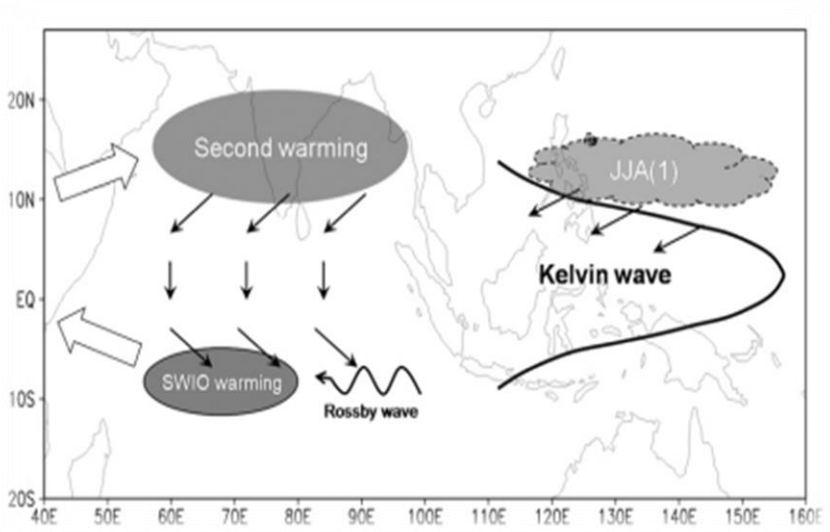
SST (shading), UV850 hPa (Vector), precipitation (contour)



Song, F., **T. Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679-1697.

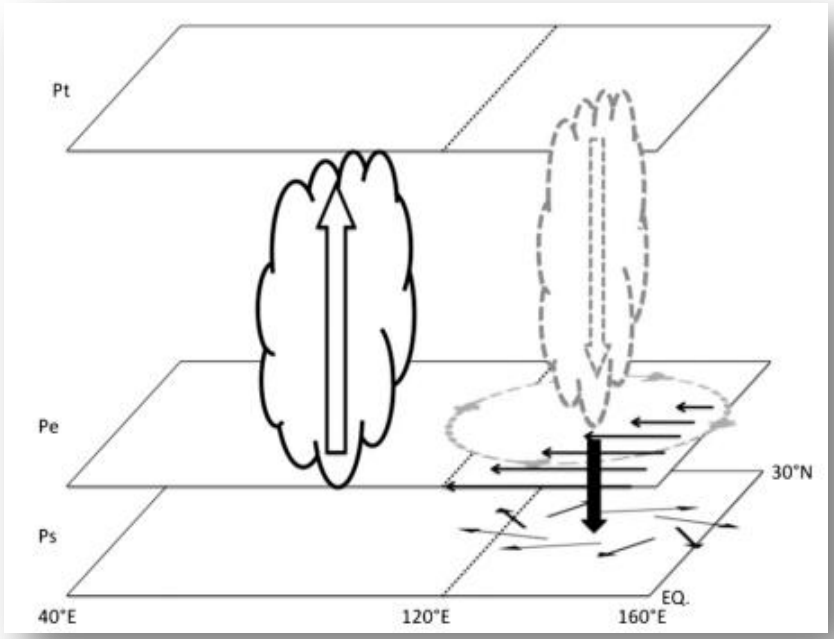
Indian Ocean warming –western North Pacific Anticyclone

Indian Ocean capacitor effect



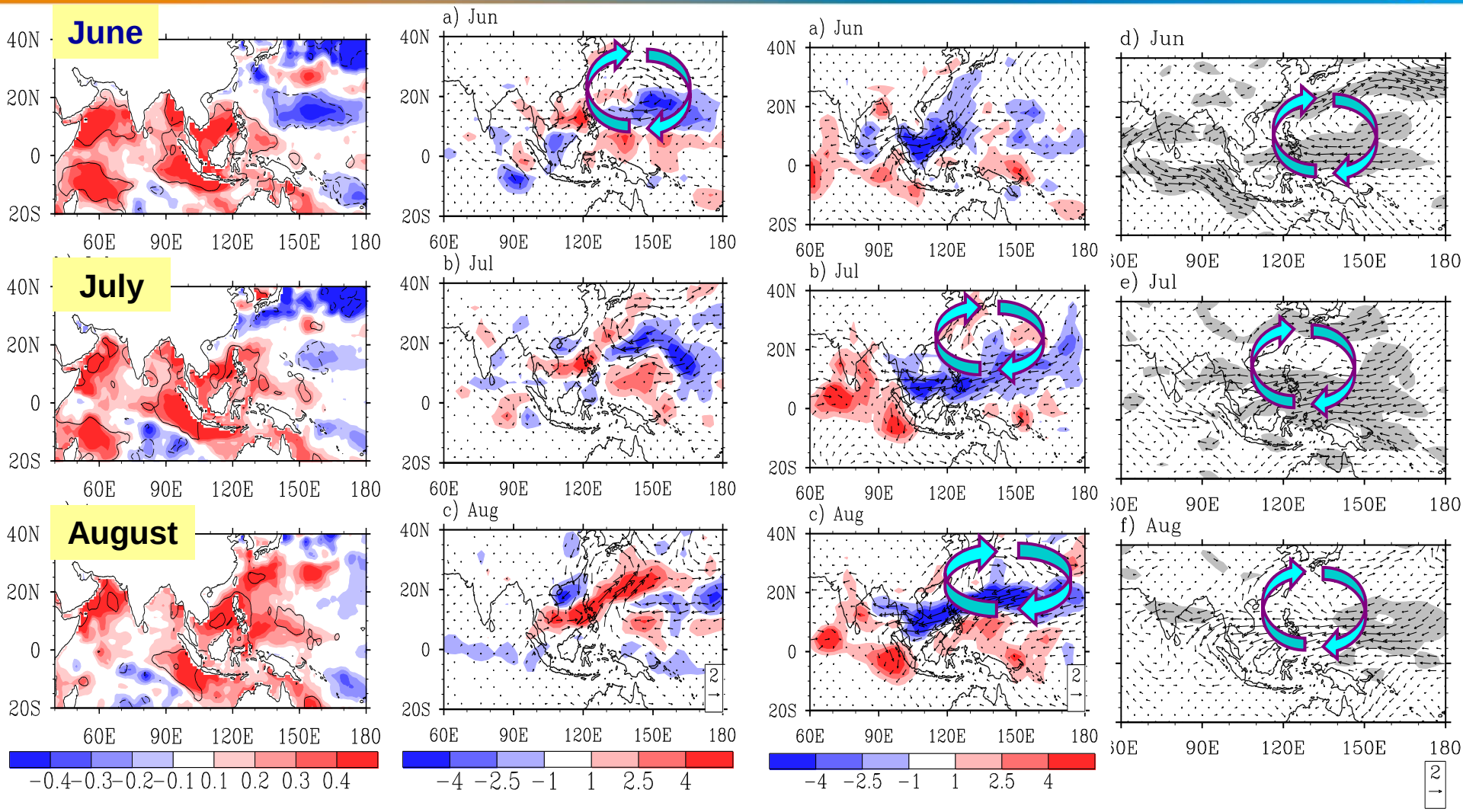
(Xie et al. 2009 JC)

Ekman pumping



(Wu et al. 2009 JC)

Contributions of Indian Ocean and western Pacific SSTA



SST in El Nino decaying year

W. Pac forcing

Indian Ocean forcing

Obs

Wu B et al. 2010. ***Journal of Climate***, 23, 2974-2986

Point # 1

- the WNPAC is maintained by the combined effects of the local forcing of the negative SSTA in the WNP and the remote forcing from the IOBM.
- The former (latter) contribution gradually weakens (enhances) from June to August. The negative SSTA in the WNP is crucial for the maintenance of the WNPAC in early summer.
- The IOBM plays a crucial role in late summer via the Kelvin wave induced anticyclonic shear and boundary layer divergence.

Wu B., T.Li, and T. Zhou, 2010: Relative contributions of the Indian Ocean and local SST anomalies to the maintenance of the western North Pacific anomalous anticyclone during El Nino decaying summer. *Journal of Climate*, 23, 2974-2986

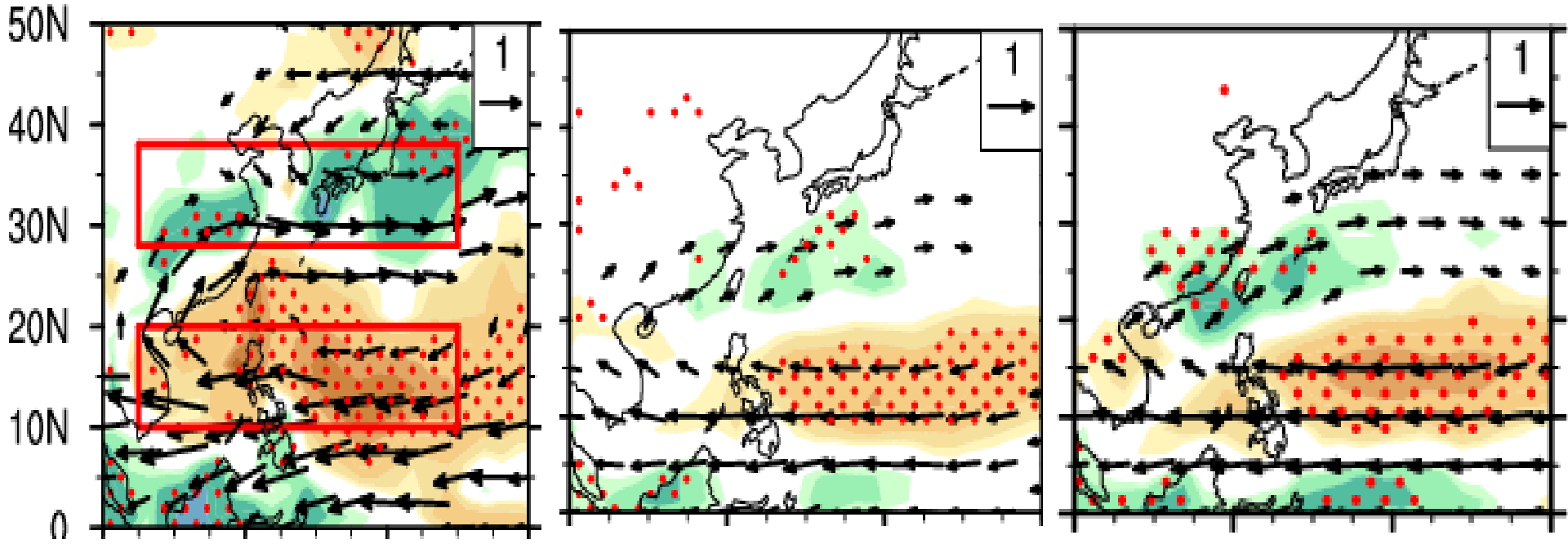
How about climate models' performances?

Model and Data

- **13 CMIP3** and **19 CMIP5 AMIP experiments**.
- Observational and reanalysis data:
  - NCEP2: 850 hPa wind, air temperature;
  - GPCP: precipitation;
  - ERSST: SST;
- Period: 1980 to 1997.
- All the datasets are interpolated onto common grid 2.5°x2.5°

Song, F., **T. Zhou,** 2014a: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean-Western Pacific Anticyclone Teleconnection. ***Journal of Climate***, 27, 1679-1697

UV850 and precipitation in El Nino decaying year summer



Observation

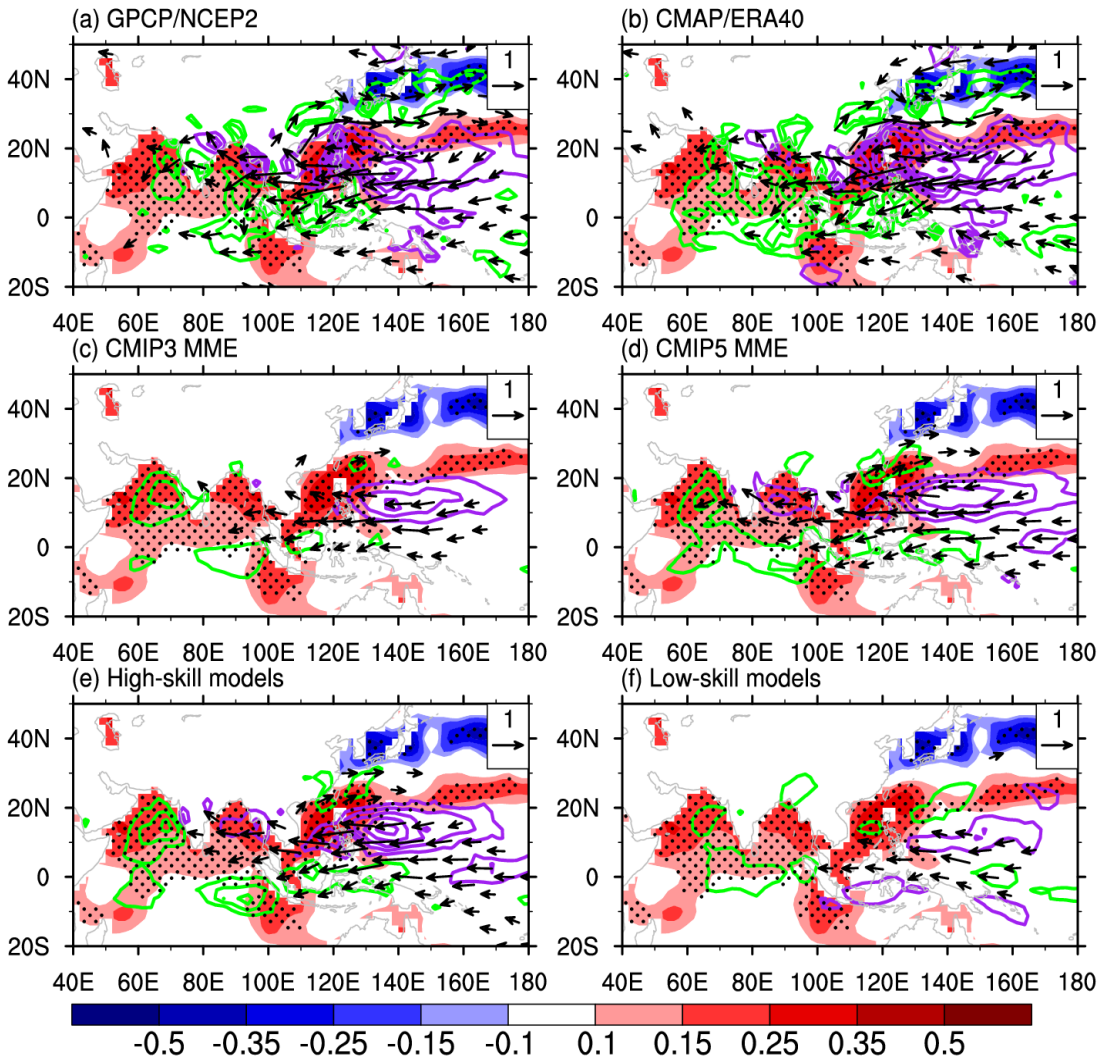
CMIP3 MME

CMIP5 MME

- **Southward shifts of the W. Pacific Anticyclone and the associated rainfall anomalies over EA; Similar bias in CMIP3 & CMIP5 models**

Song, F., **T. Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679-1697.

Indian Ocean-western Pacific anticyclone tele-connection



- Better Indian ocean positive precp, better Kelvin wave response.
- CMIP5 MME better than CMIP3 MME

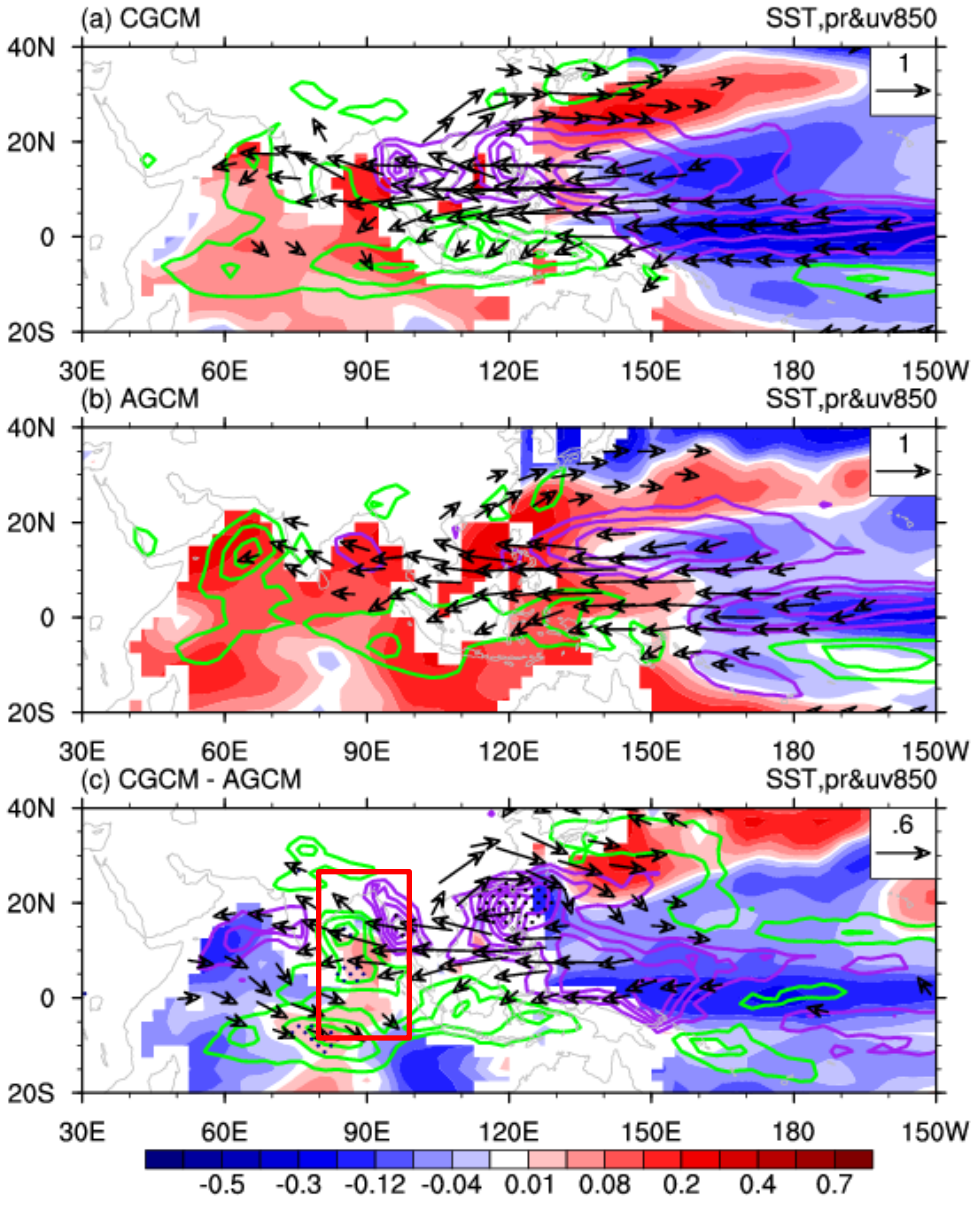
Song Fengfei, Tianjun Zhou, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679–1697

Model and Data: air-sea coupling

- **17 CMIP5 AGCMs and corresponding CGCMs are analyzed**
- **Observational and reanalysis data:**
  - **NCEP2&ERA40; GPCP&CMAP; ERSST**
- **the period for the comparison between AGCMs and CGCMs is 1979-2005**
- **All the datasets are interpolated into common grid 2.5°x2.5°**

Song F., **T. Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

Anomalies of SST, precipitation, and 850 hPa winds in El Nino decaying year summer



Shading: SST
Green contour: positive precipitation
Purple contour: negative precipitation
Vector: 850 hPa winds

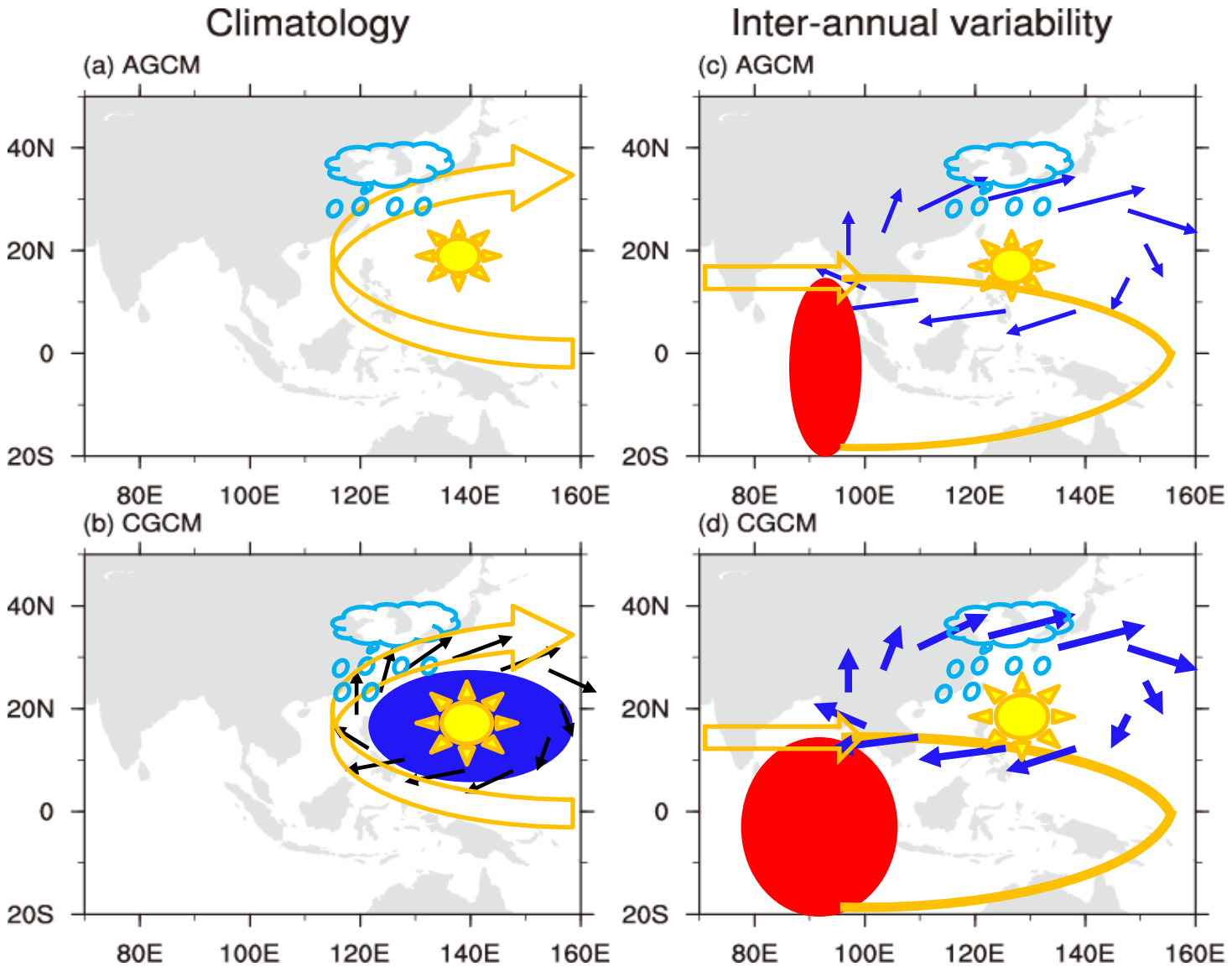
◆ CGCM: SSTA over TEIO is warmer than the OBS.

◆ Warmer TEIO SSTA -> more precipitation -> stronger Kelvin wave response as W. Pac AC -> enhanced EASM simulation.

◆ Local colder SST over the W. Pac also enhances the W. Pac AC

Song, F., **T. Zhou,** 2014b, ***Journal of Climate***

Schematic plot of the air–sea coupling's role in the EASM simulation



Song F., T. Zhou, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

Point # 2

- Biases of AGCM:

  Northward shift of the WP subtropical high in mean state;

  Southward shift of the WP AC in interannual variability.

- Improvements of CGCM

  Mean state: Better WPSH at a cost of colder local SST.

  Interannual variability: Improvements in WP AC location and intensity of monsoon rainfall anomaly, due to the enhanced IO-WPAC tele-connection through the air-sea coupling.

- Dynamics:

  More rainfall over the Indian Ocean associated with a warmer SST, and a stronger equatorial Kelvin wave response in the W. Pacific.

Song F., **T. Zhou**, 2014: The climatology and inter-annual variability of East Asian summer monsoon in CMIP5 coupled models: Does air-sea coupling improve the simulations ? ***Journal of Climate***, 27, 8761-8777

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(V. Old) Indian monsoon statistical forecasting

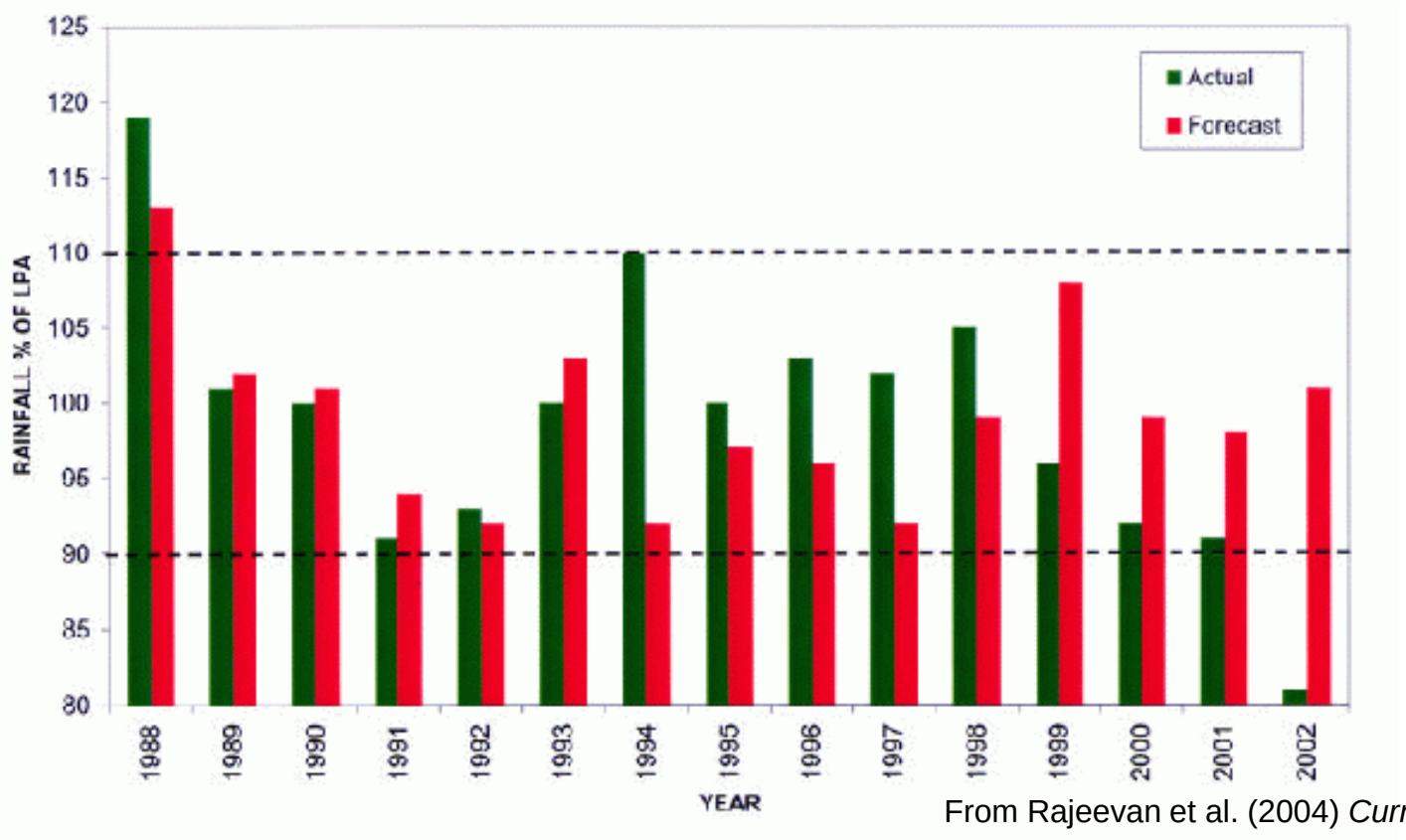
The 10 parameters (and their correlation coefficients with AIR*) are:

1. Arabian Sea SST (Jan and Feb) 0.55
2. Eurasian snow cover (Dec) -0.46
3. NW Europe Temperature (Jan) 0.46
4. NINO3 SST anomaly (Jul-Sep previous year) 0.42
5. South Indian Ocean SST (Mar) 0.47
6. East Asia Pressure (Feb and Mar) 0.61
7. Northern Hemisphere 50 hPa wind pattern (Jan) -0.51
8. Europe Pressure Gradient (Jan) 0.42
9. South Indian Ocean 850 hPa zonal wind (Jun) -0.45
10. NINO3.4 SST tendency (between Jan and Jun) -0.46

*AIR = All India Rainfall

Courtesy: Andy Turner

Statistical forecast performance



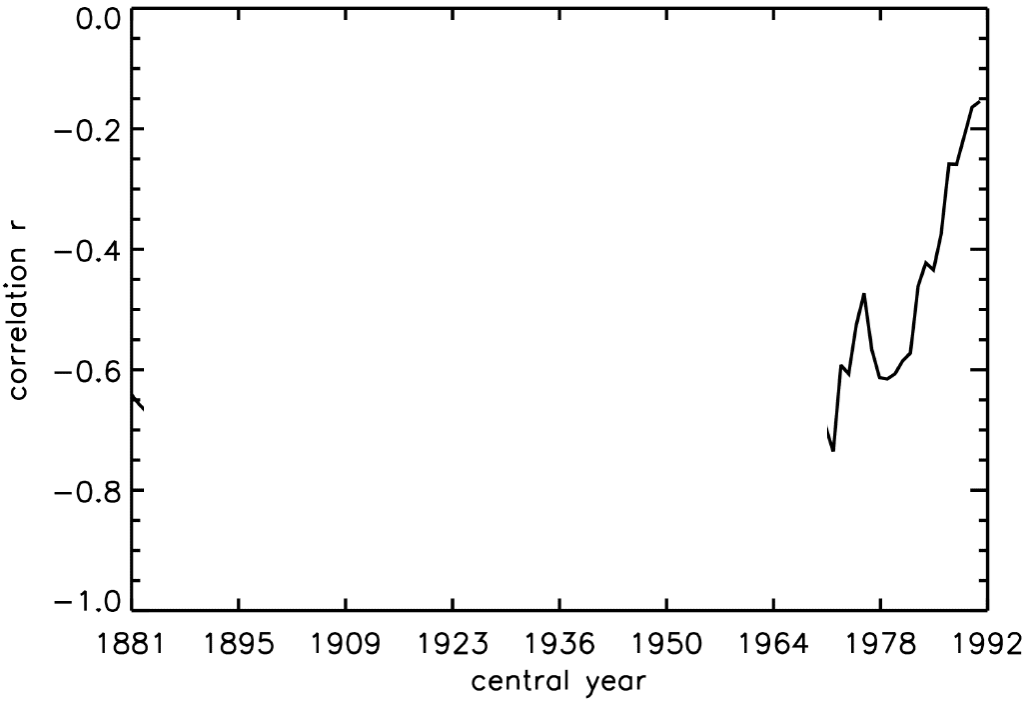
From Rajeevan et al. (2004) *Current Science*

- Performance of the previous IMD model (16 parameter power regression)
- Note the gradual deterioration in skill and the failure to predict the 2002 drought
- The correlations between *predictors* and *predictands* are not necessarily stationary in time, so dynamical models (coupled ocean-atmosphere GCMs) are beginning to be used for seasonal forecasting of the monsoon

Courtesy: Andy Turner

Modulation of the ENSO-monsoon teleconnection: apparent weakening?

Moving correlation between AIR and Niño-3 SST during JJAS



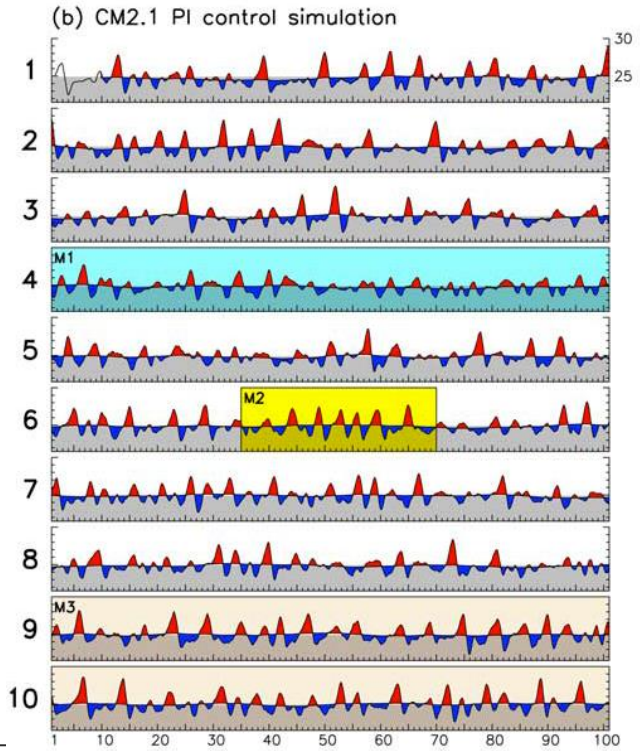
- The monsoon-ENSO teleconnection has been characterized by apparent recent weakening, but…
- Considerable interdecadal variability in the past
- Recent El Niño events (2002, *2004*, 2009) have again been related to monsoon droughts of (81%, 87%, 78% LPA AIR)

Is recent “weakening” related to warming (e.g. Krishna Kumar *et al.,*1999)?

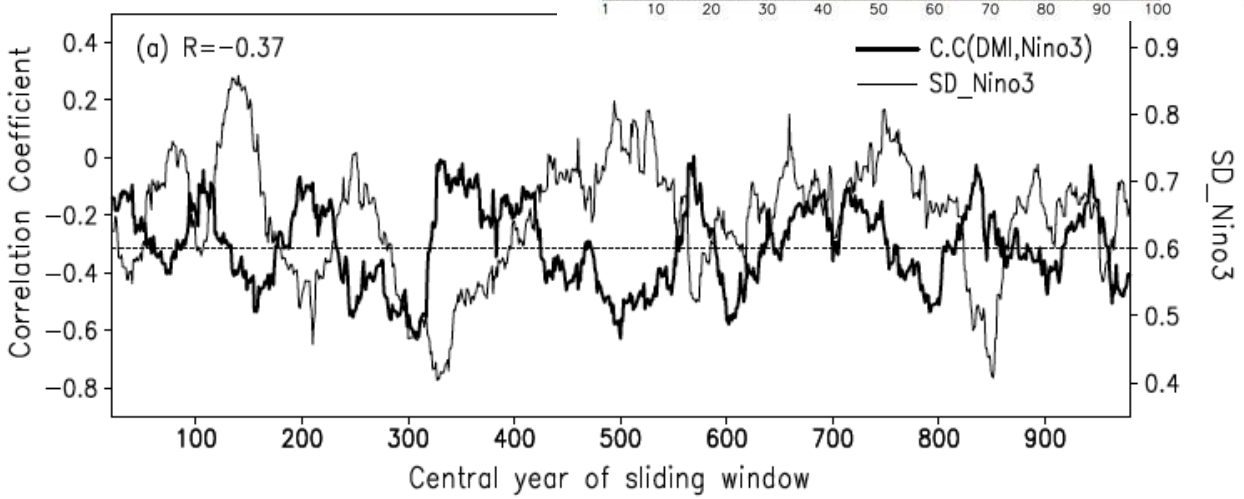
Courtesy: Andy Turner

ENSO variance and variations in the monsoon-ENSO teleconnection

- Ability of ENSO to vary internally
- Modulation of ENSO variance can alter teleconnection



Wittenberg (2009) *GRL*



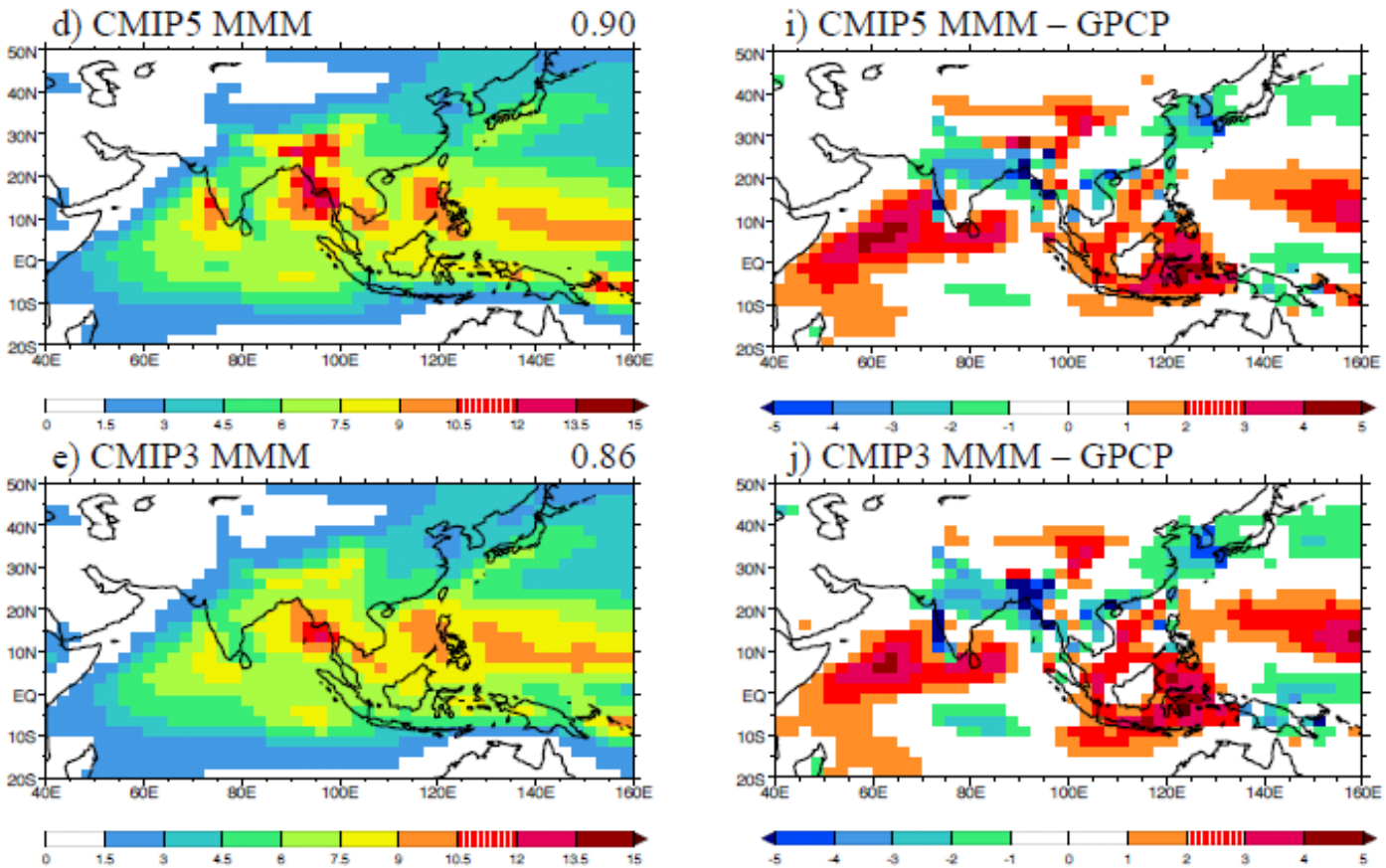
Chen et al. (2010) *GRL*

← remember: negative correlation=strong mE teleconnection

CMIP5 and operational models' performances?

Multi-model mean monsoon precipitation biases in CMIP/5

Mean JJAS precipitation (left) and bias versus GPCP obs (right)

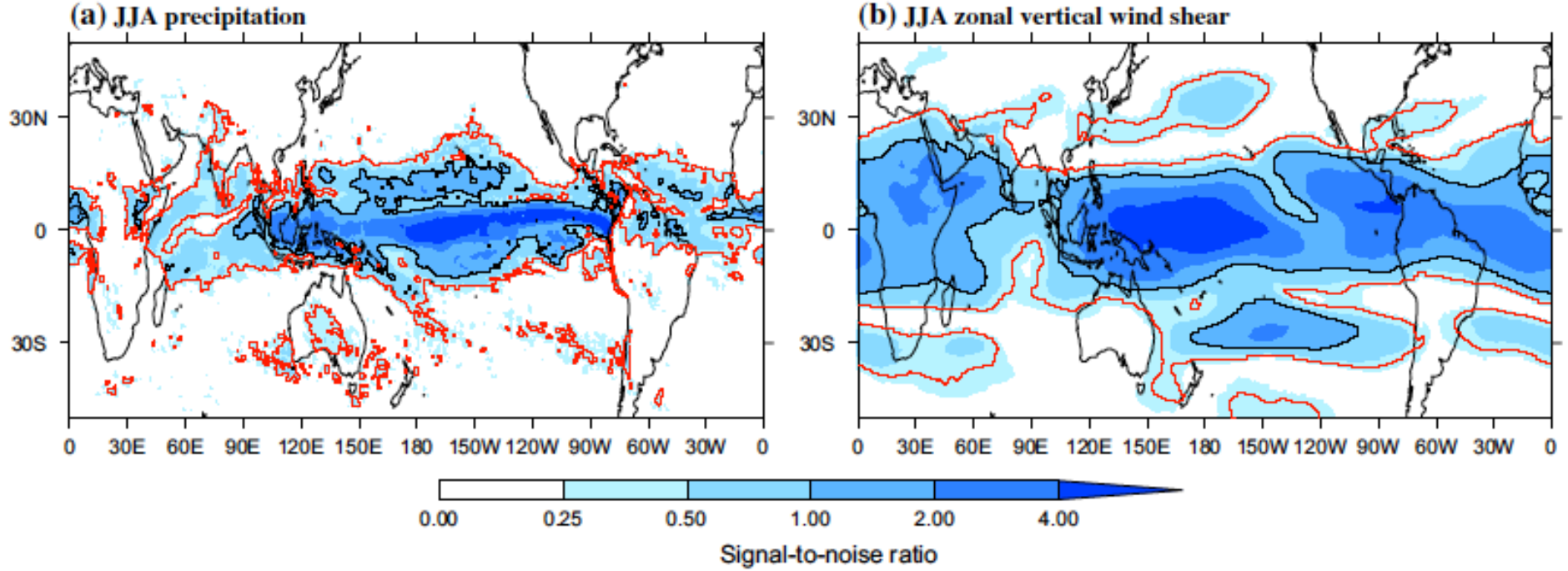


Large biases in CMIP3 and CMIP5 models

See Sperber *et al.* (2013) *Climate Dynamics*

Performance in the MetUM GloSea5

MetUM shows more signal in Asian monsoon region for circulation



S/N defined as ratio of variance of interannual timeseries of ensemble mean to time-mean of variances of ensemble for each year

From Johnson *et al.* (2016) *Clim. Dyn*.

Performance in the MetUM GloSea5

MetUM shows more signal in Asian monsoon region for circulation

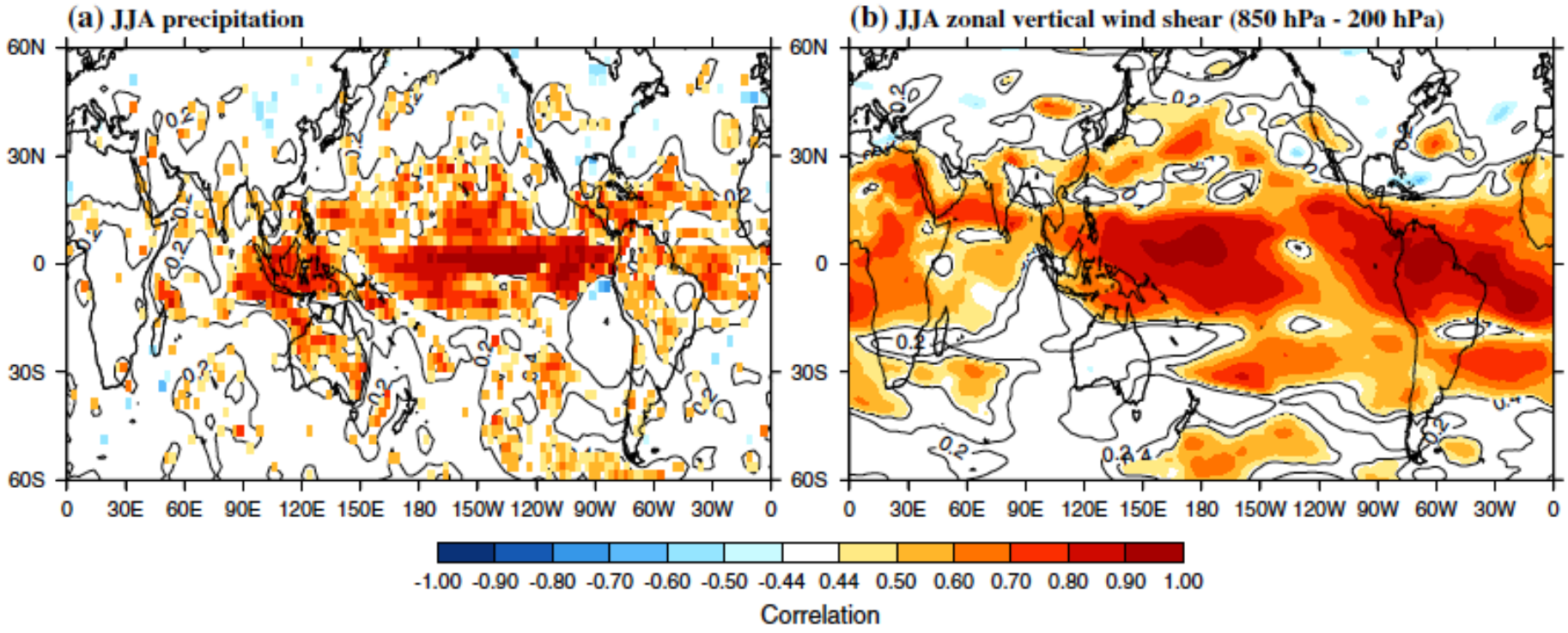
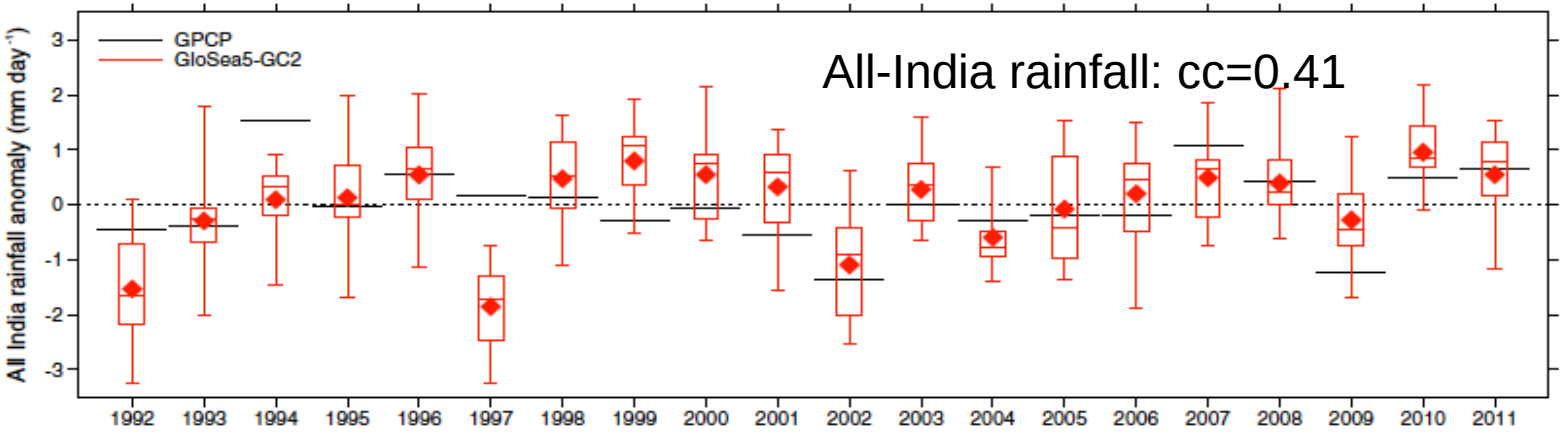


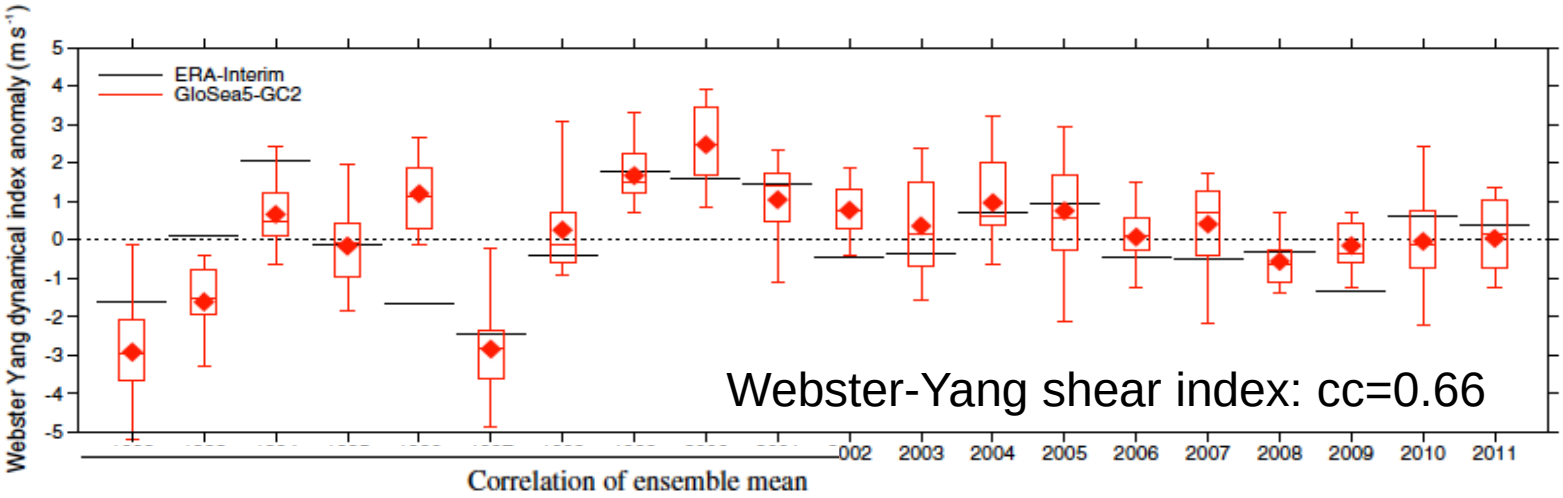
Fig. 3 Grid-point anomaly correlations of GPCP JJA precipitation and ERA-Interim JJA vertical wind shear with their GloSea5-GC2 ensemble mean equivalents. Significant skill (0.44, $p < 0.05$) is shaded, while lower skill is contoured at 0.2 and 0.4

From Johnson *et al.* (2016) *Clim. Dyn*.

Performance in the MetUM GloSea5

Large-scale circulation measures outperform localized rainfall





Correlation of ensemble mean

AIR	0.41
Wang–Fan index	0.36
Webster–Yang index	0.66

From Johnson *et al.* (2016) *Clim. Dyn.*

Point # 3

- The Indian summer monsoon prediction traditionally relies on statistical model, but the recent decades witnessed a gradual deterioration in skill and the failure to predict the 2002 drought.
- The monsoon-ENSO teleconnection has been characterized by apparent recent weakening. Modulation of ENSO variance can alter the monsoon-ENSO teleconnection.
- CMIP models show large biases in monsoon rainfall simulation. There exists intimate connection between biases in monsoon circulation and precipitation.
- MetUM GloSea-5 shows more signal in Asian monsoon region for circulation.

Courtesy: Andy Turner

THANKS

http://www.lasg.ac.cn/staff/ztj