State Key Laboratory of Numerical Modelling for Atmospheric Sciences
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Ocean-Atmosphere interaction and Decadal monsoon variability

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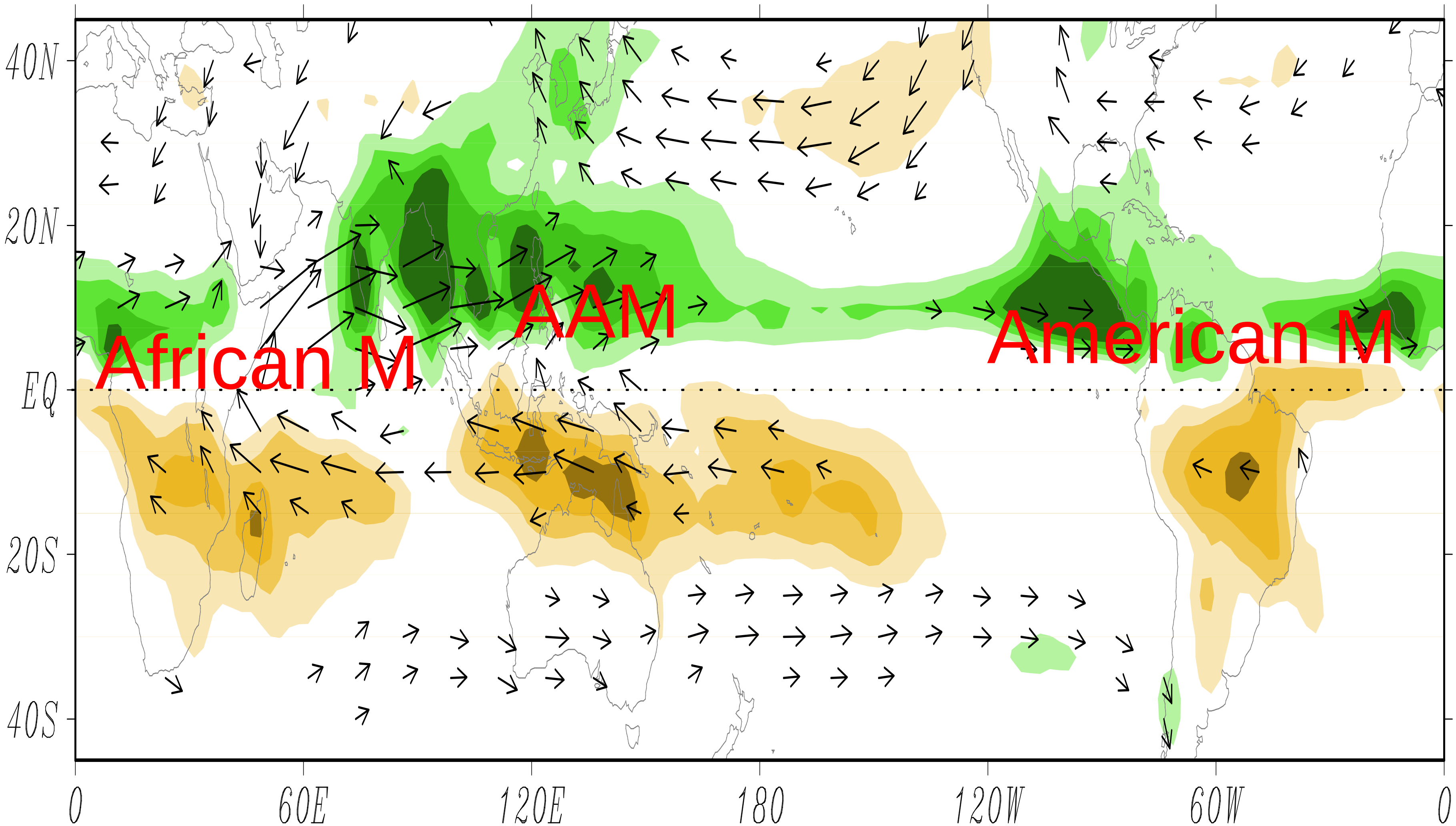
2nd ACAM Training School: Observation & modeling of atmospheric chemistry & aerosols in the Asian monsoon region

10-12 June 2017, Jinan University, Guangzhou China

Outline

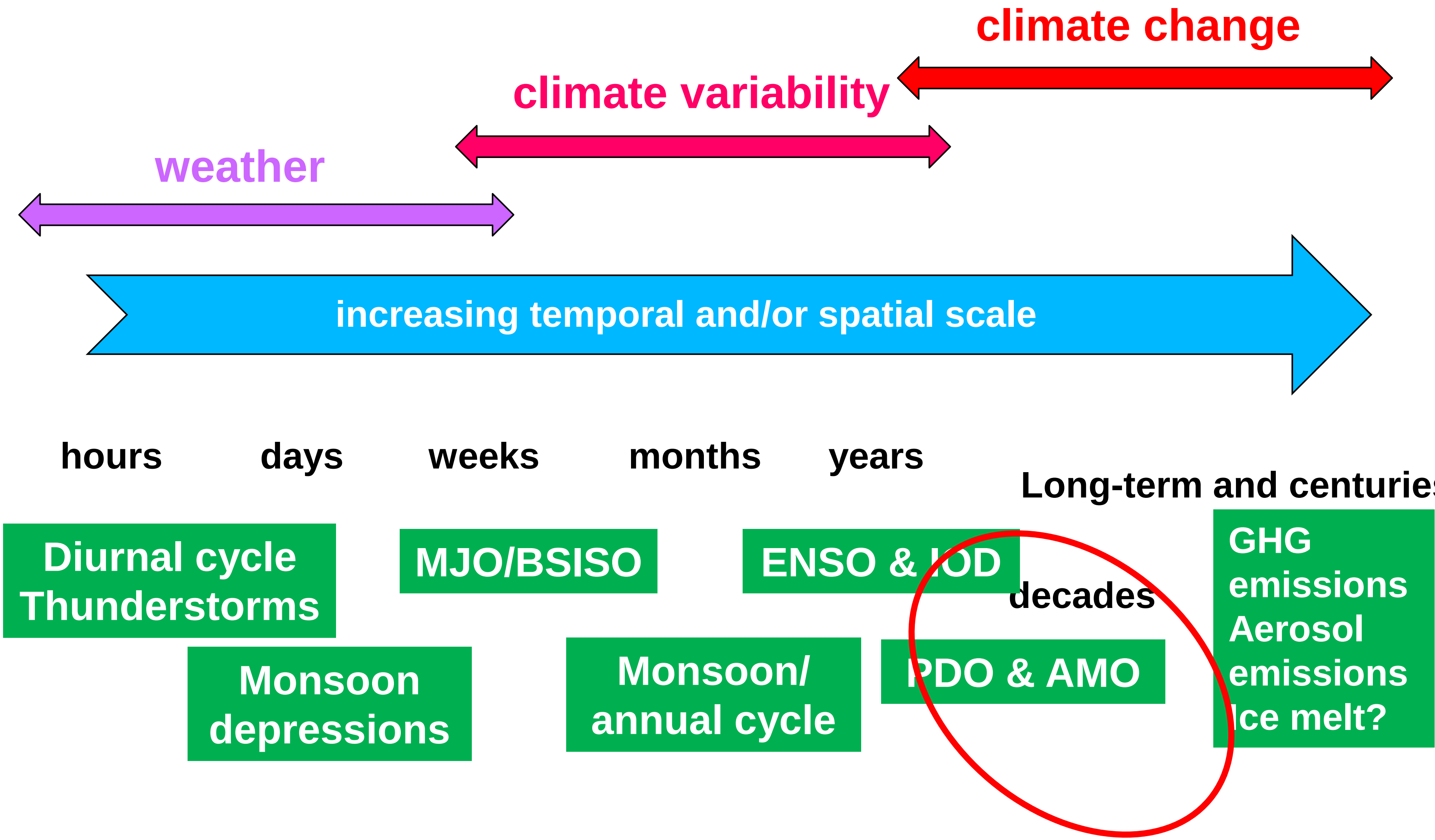
1. Background
2. GM and PDO
3. EASM and PDO
4. ISM and Indian Ocean warming
5. Indian Ocean warming
6. Concluding remarks

Global Monsoons



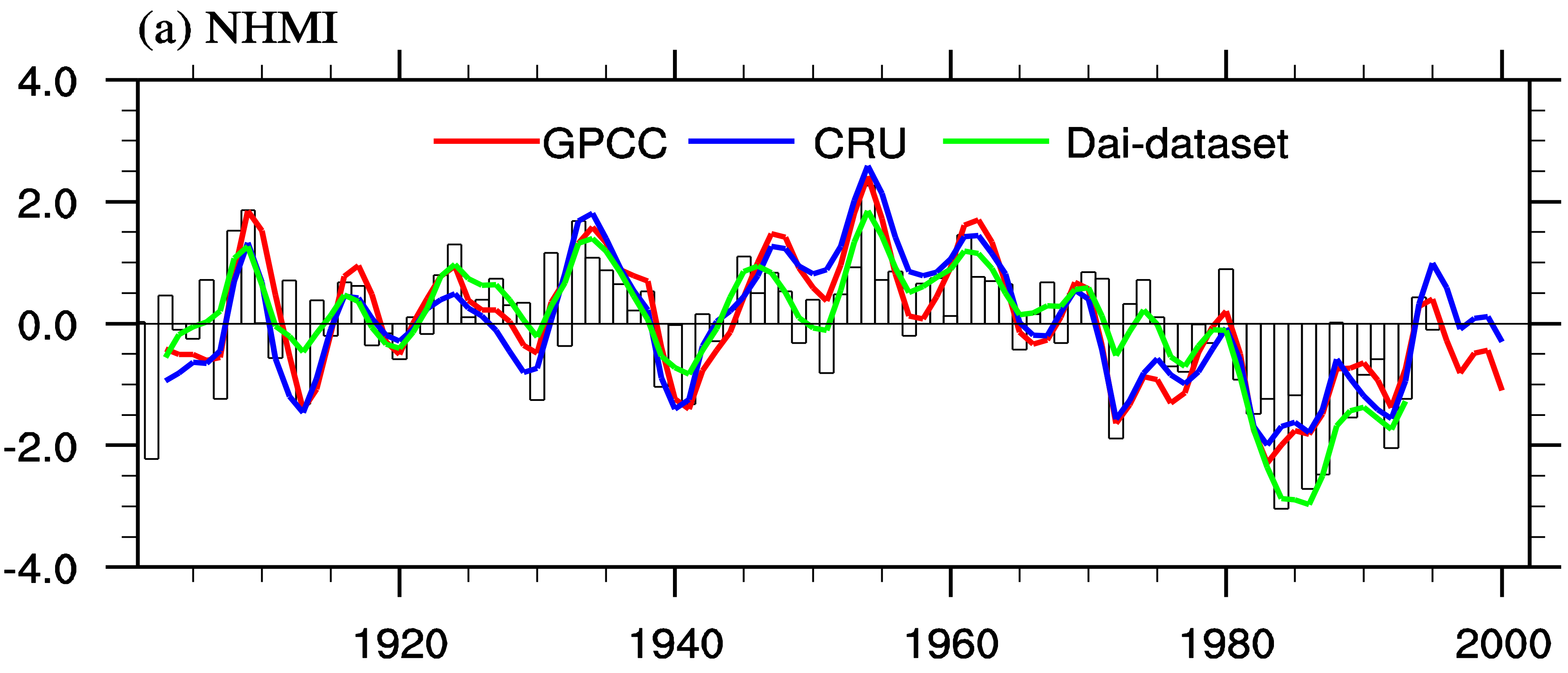
JJA –DJF UV850 & Precipitation

Space and time scales in the monsoon



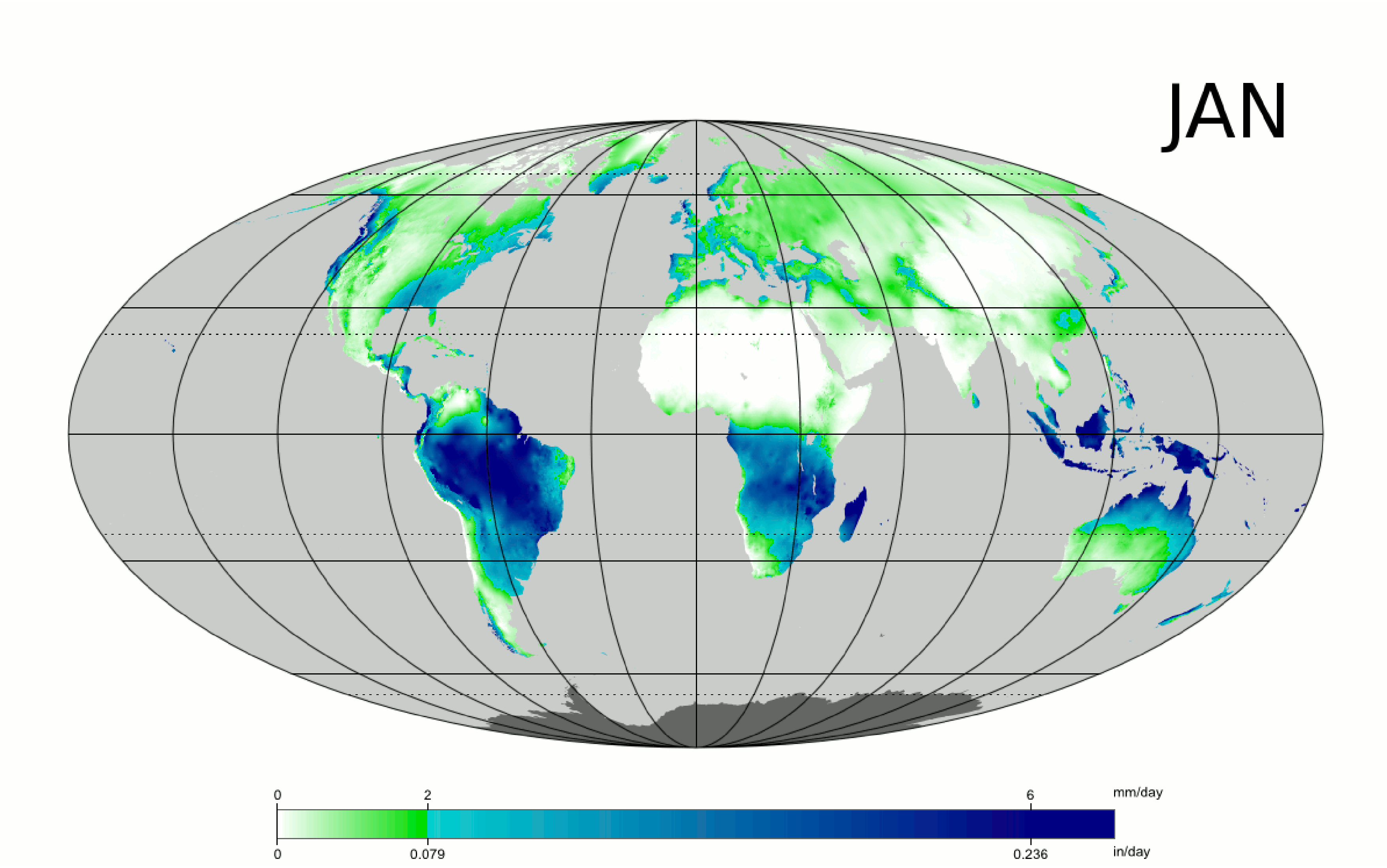
Courtesy: Andy Turner

Changes of NH land monsoon precipitation



*Zhang Lixia, Tianjun Zhou, 2011: An assessment of monsoon precipitation changes during 1901-2001, **Climate Dynamics**, 37, 279-296*

How to understand the observed changes at decadal scales?



Ocean-Atmosphere Interaction

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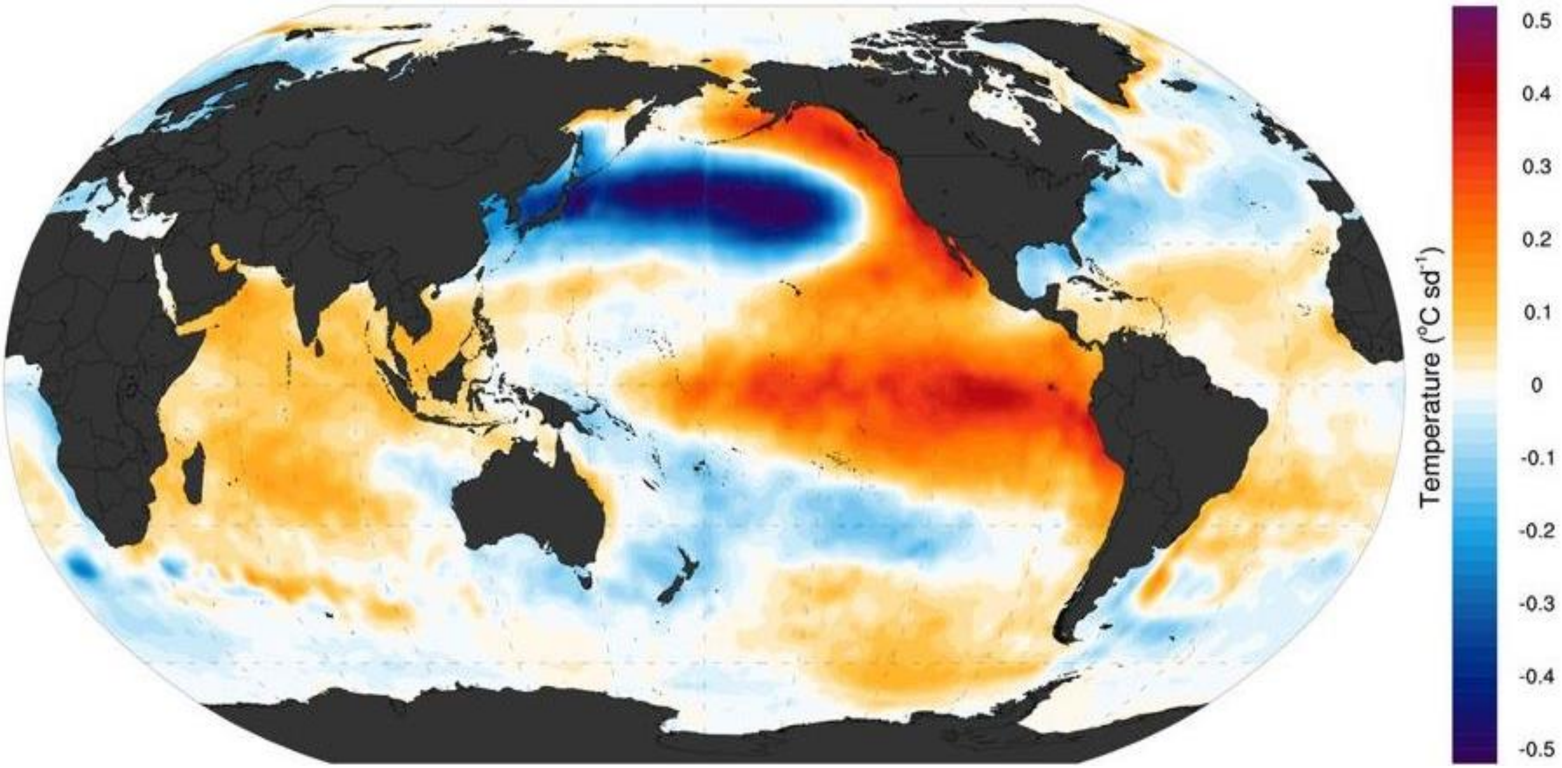
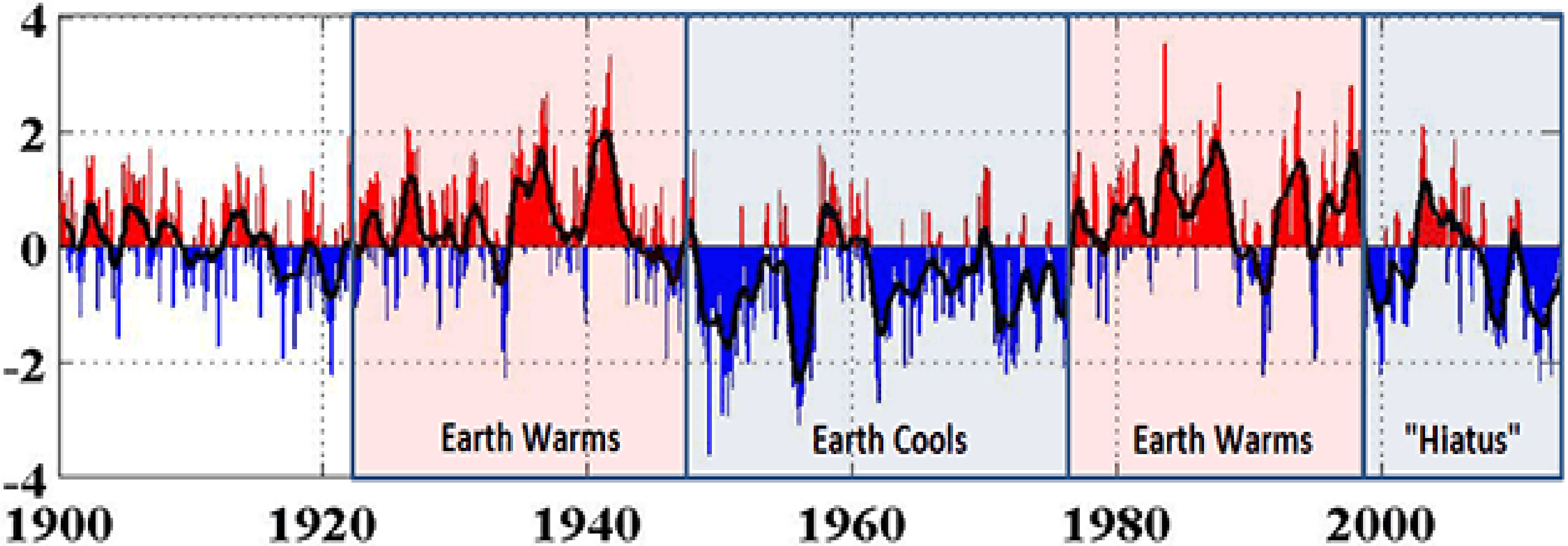
Pacific Decadal Oscillation

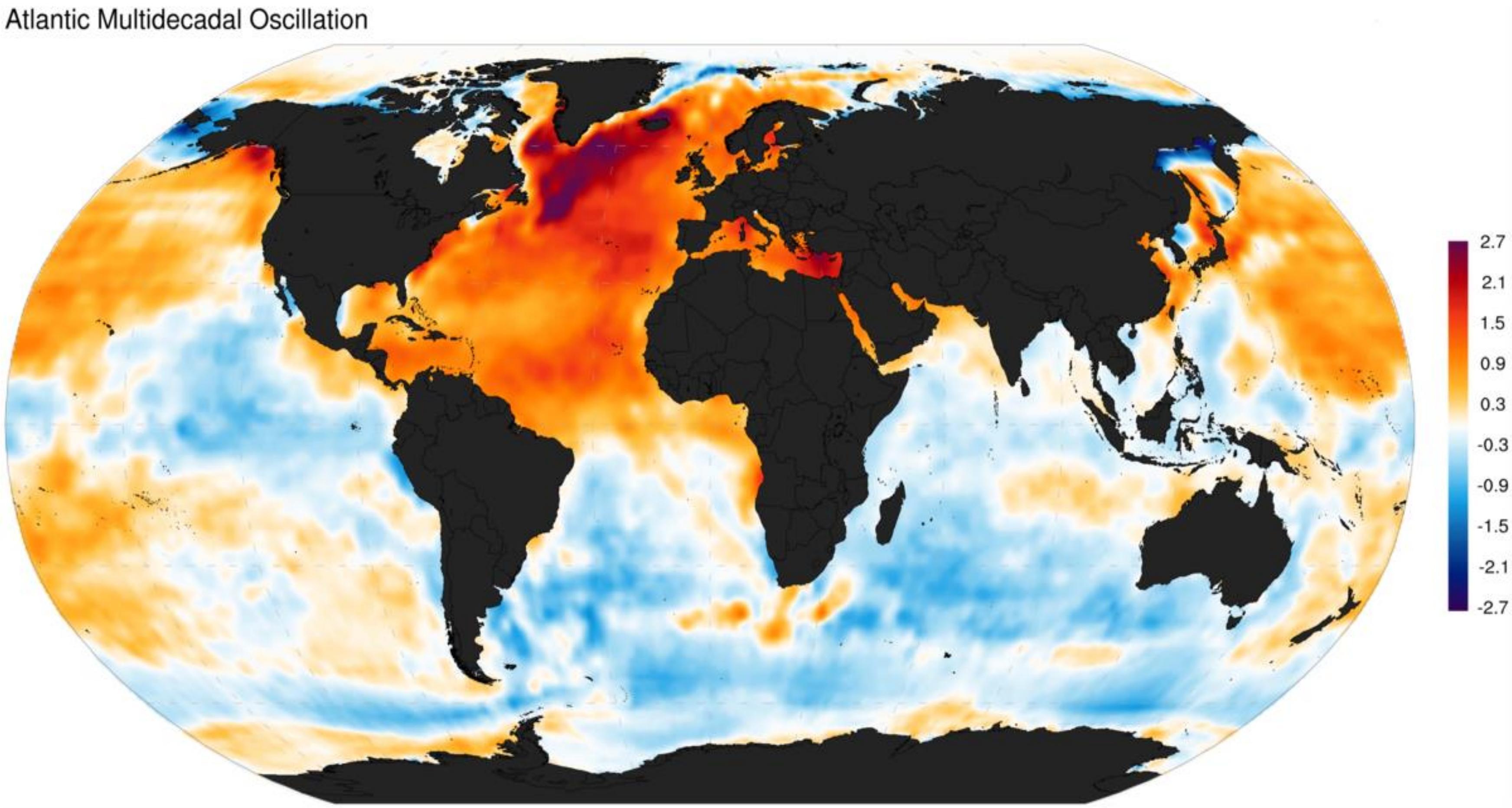


Pacific Decadal Oscillation Index

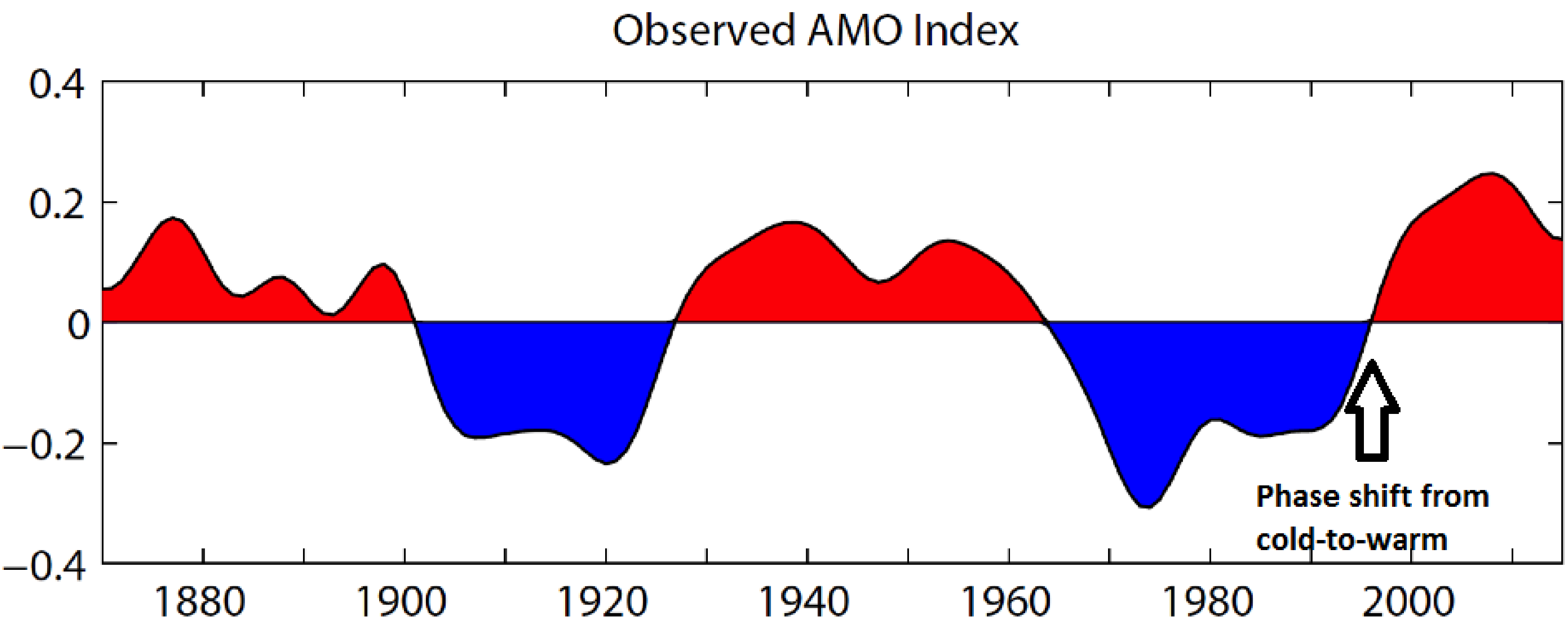
Monthly values for the PDO index: 1900-2013



Atlantic Multidecadal Oscillation



Atlantic Multidecadal Oscillation index



Contribution of IPO and AMO to GM changes

Northern Hemispheric summer monsoon (NHMI) circulation index (VMS) in relation to the mega-ENSO, AMO, and hemispheric thermal contrast (HTC).

IPO

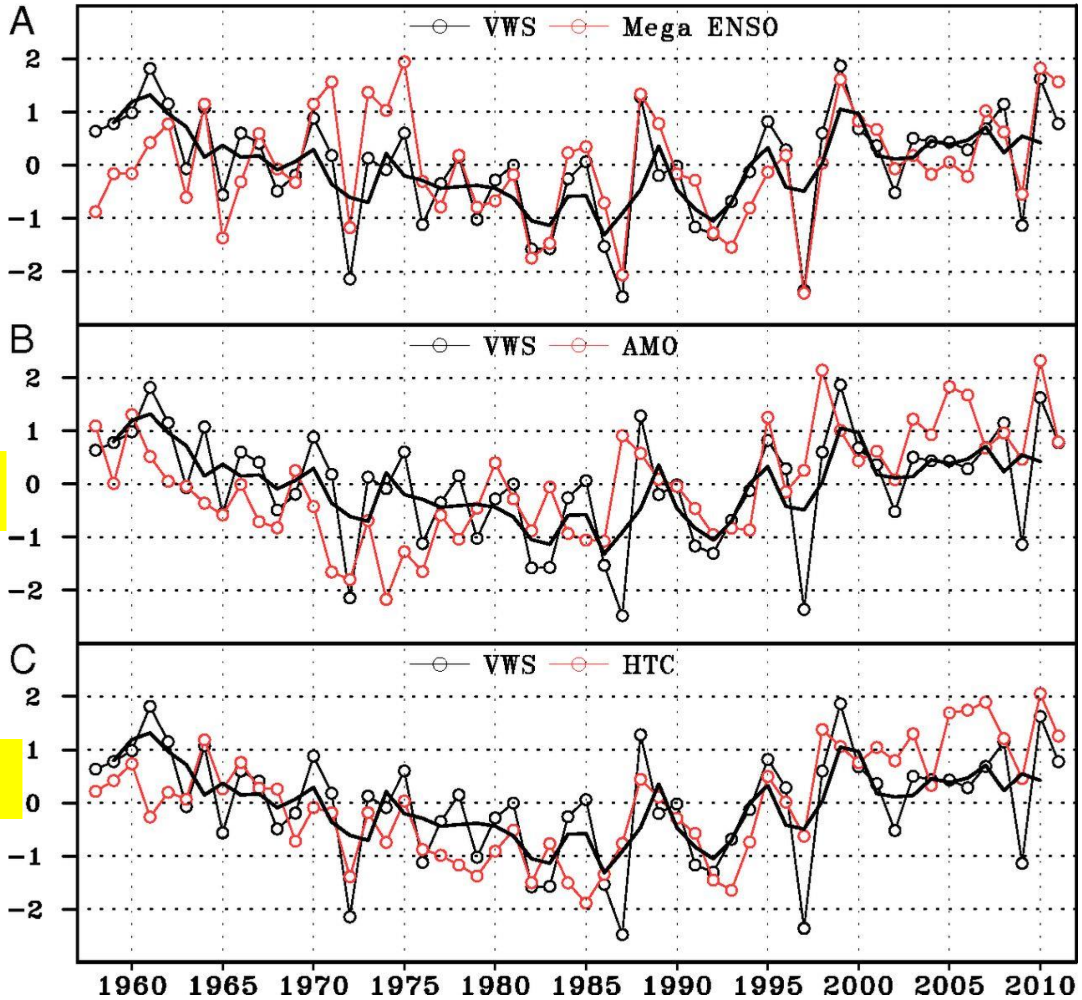
Cor=0.77

AMO

Cor=0.44

HTC

Cor=0.63



Wang et al. PNAS 2013;110:5347-5352

Is PDO forcing a mechanism for GM change?

We demonstrate the hypothesis by numerical modeling

Model & Experiments

◆NCAR CAM2: T42L26

◆Global SST-forced 15-member ensemble simulation.

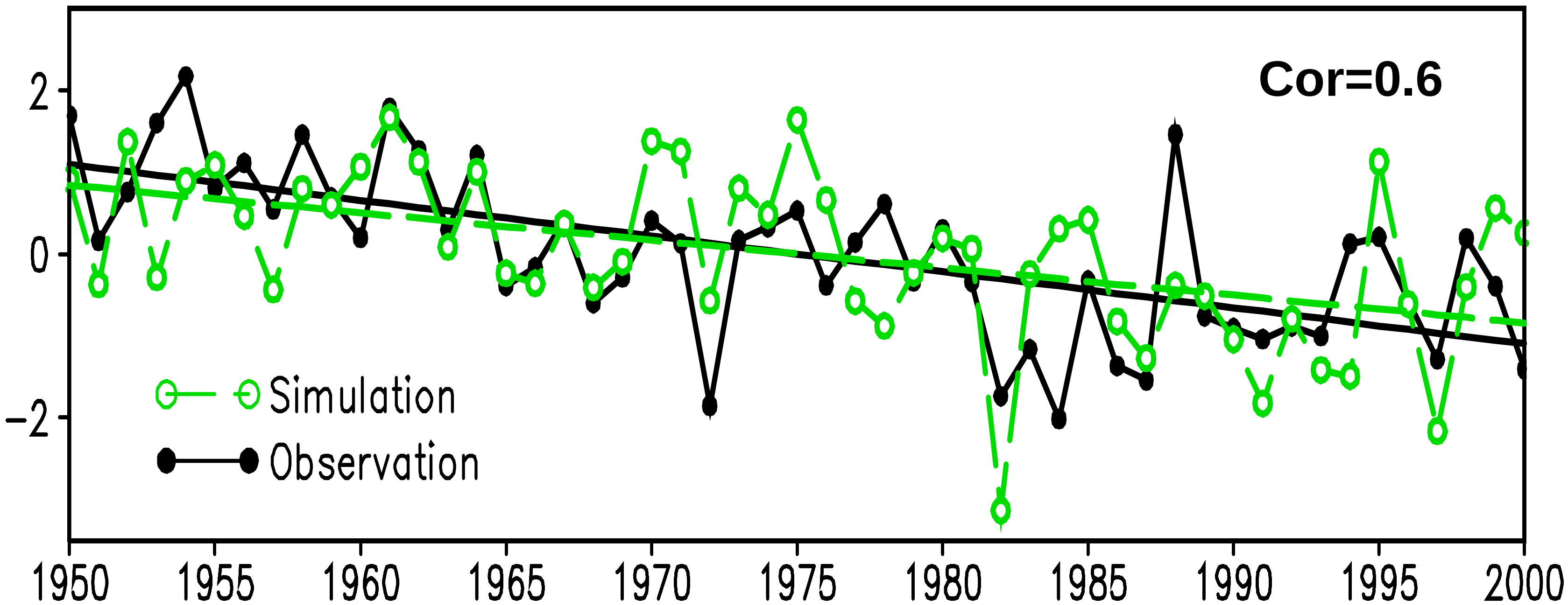
◆Time period:

January 1949 to October 2001

Observational SST changes are specified.

Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

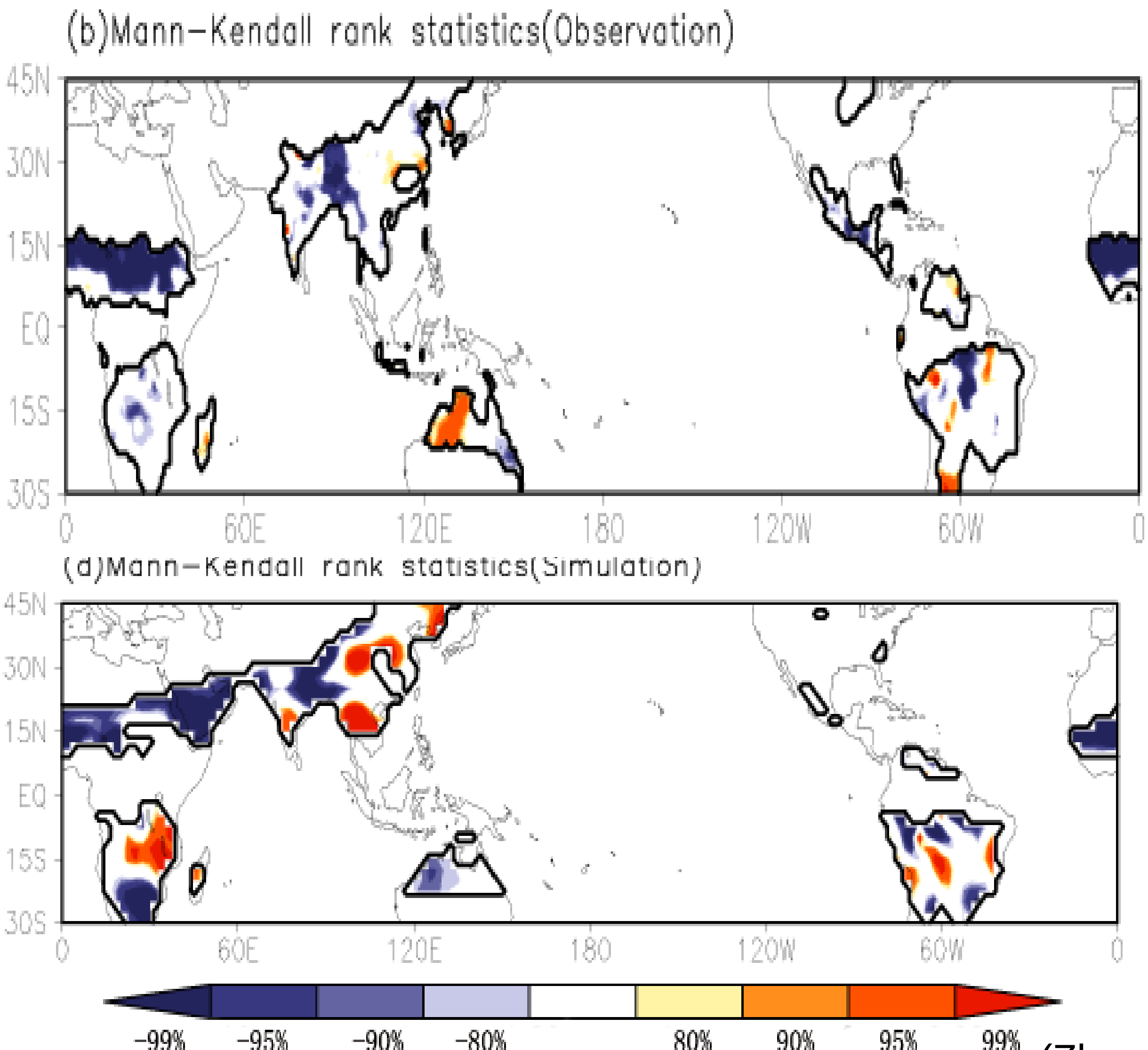
The observed and simulated Global Land monsoon index



SST-driven AGCM ensemble simulation, with 12 realizations

Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

The Mann-Kendall rank statistics of the observed and simulated AR trend within land monsoon domain



Observation

Simulation

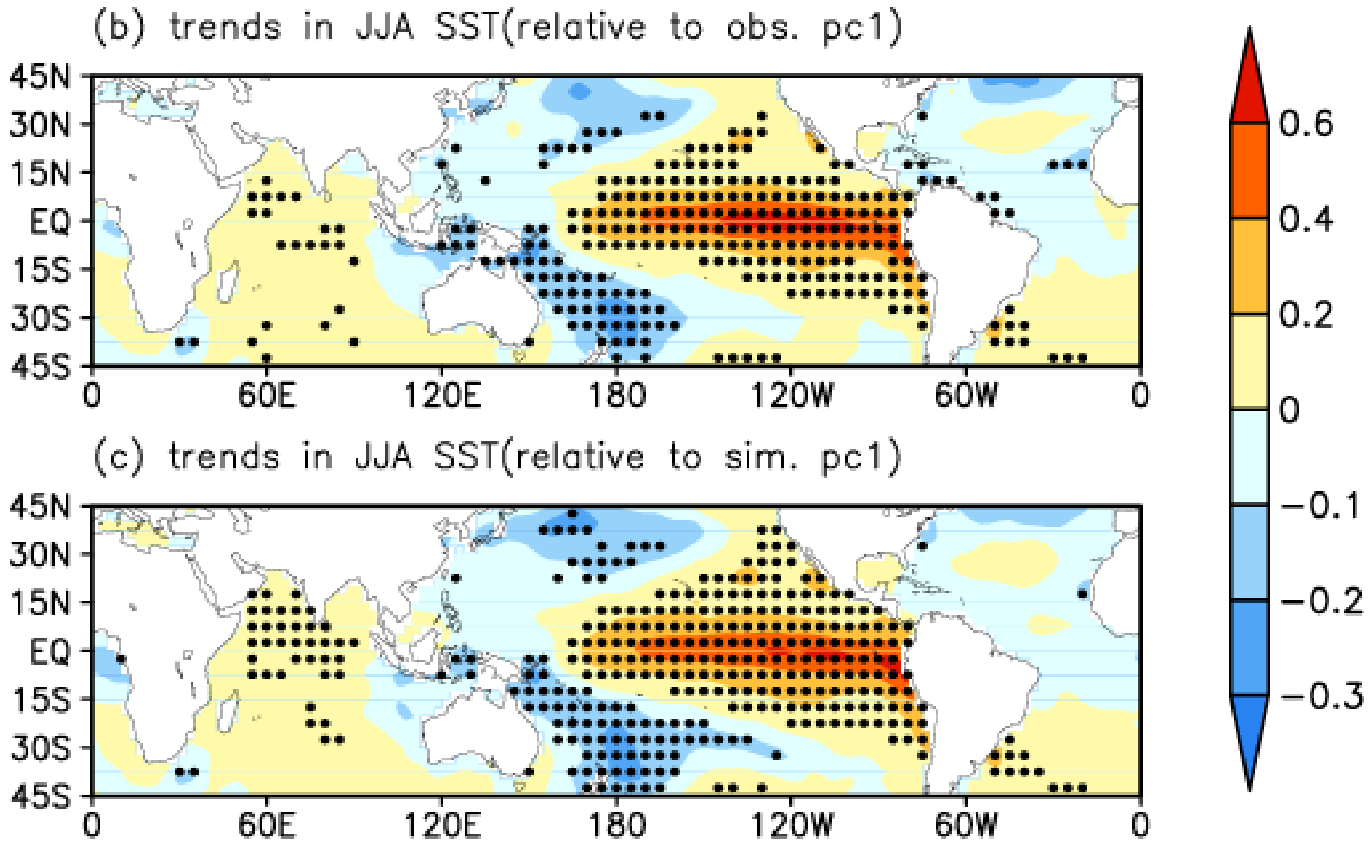
(Zhou et al. 2008 J. Climate)

SSTA congruent with the weakening trend of global land monsoon precipitation

Inter-decadal Pacific Oscillation: IPO/PDO

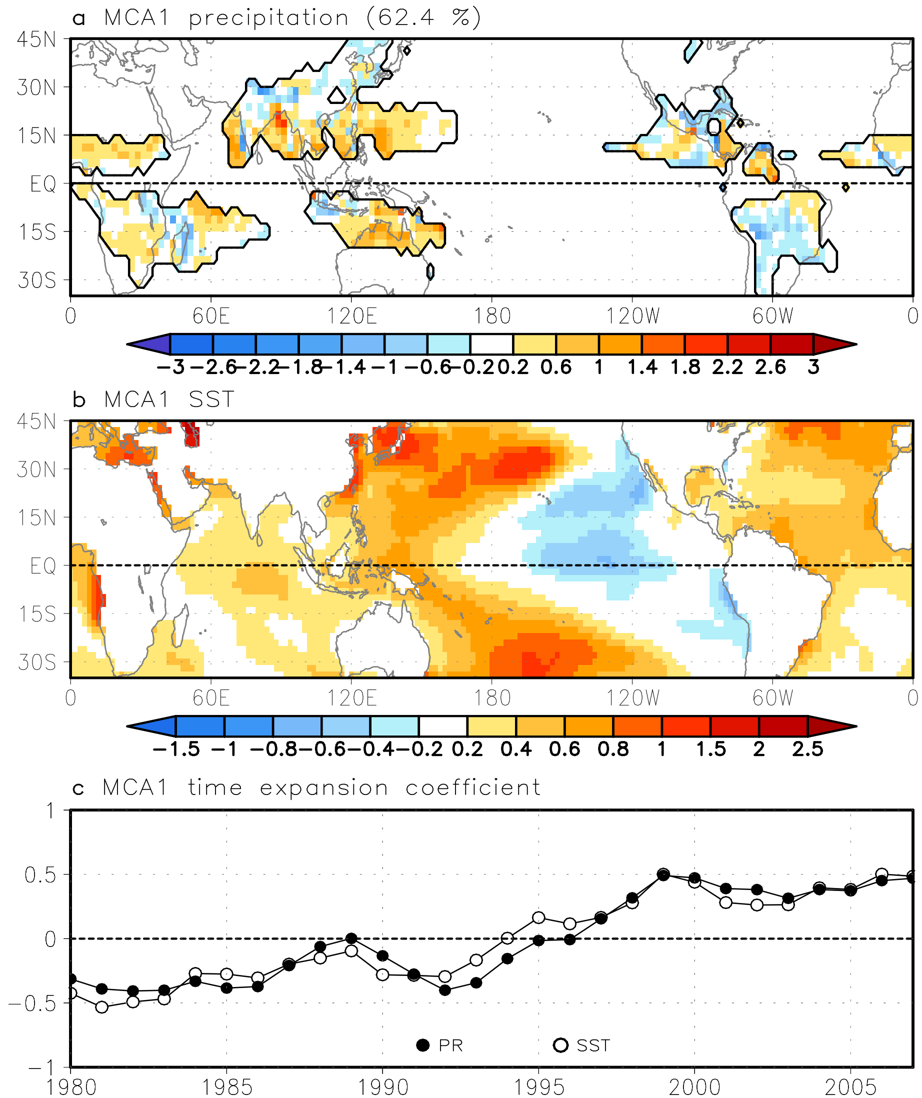
OBS

Model



Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

Recovery of Global Monsoon since early 1980s



Maximum Covariance Analysis (MCA) of Monsoon precipitation and SST

3-year running mean datasets of GPCP and ERSST.

Wang et al. 2012 CD; 2013, PNAS

Point # 1

- When forced by historical sea surface temperatures covering 1949-2001, the ensemble simulation with AGCM successfully reproduced the weakening tendency of global land monsoon precipitation.
- This decreasing tendency was driven by the warming trend over the central-eastern Pacific and the western tropical Indian Ocean, which is the tropical lobe of PDO/IPO.
- Similar mechanism applies to the recent recovery of GM.

Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

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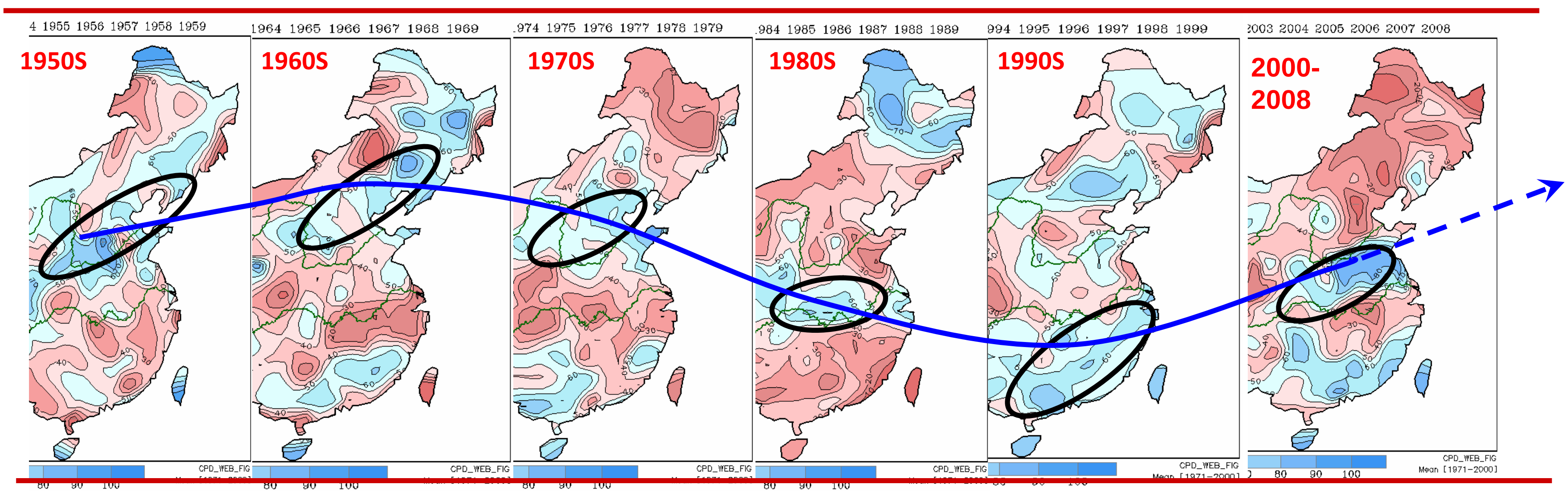
Decadal Changes of summer rainfall

20世纪 蓝色：降雨频次高；红色：降雨频次低 **21世纪**



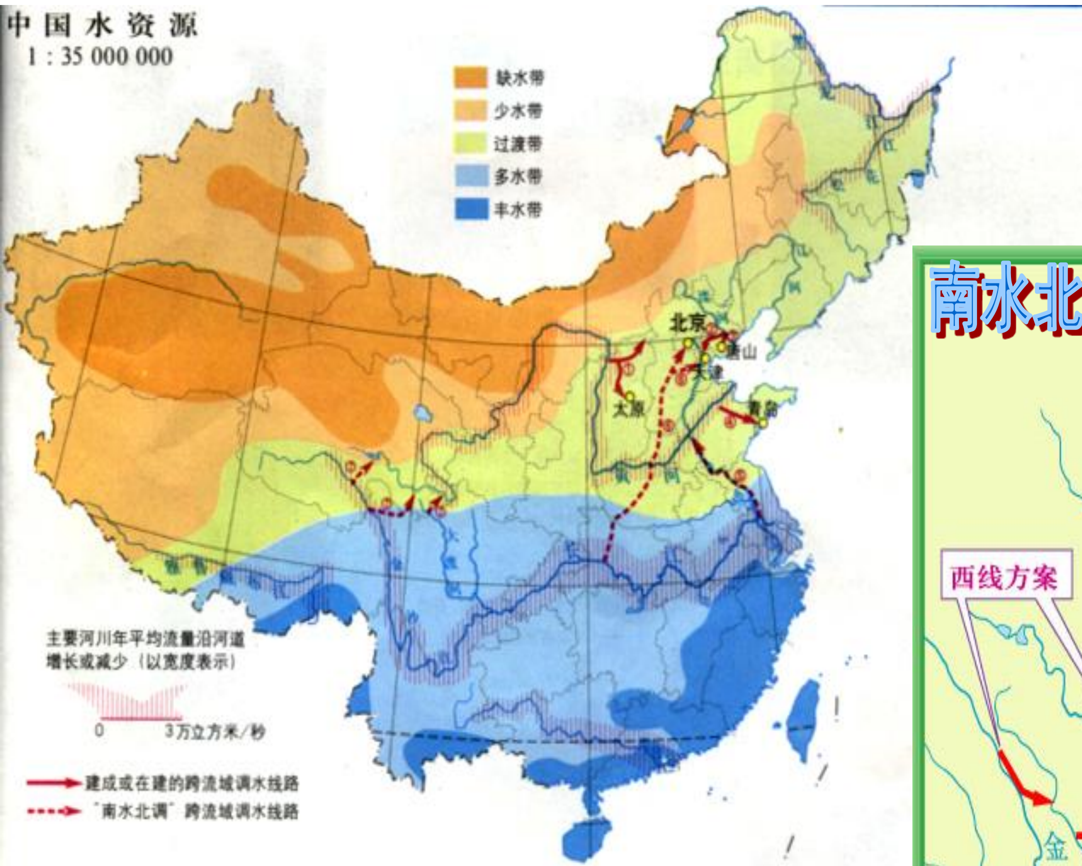
最高频次 90%	最高频次 80%	最高频次 60%	最高频次 60%	最高频次 70%

1970S **Monsoon Weakening**

(After BCC, 2010)

South-to-North Water Diversion Project

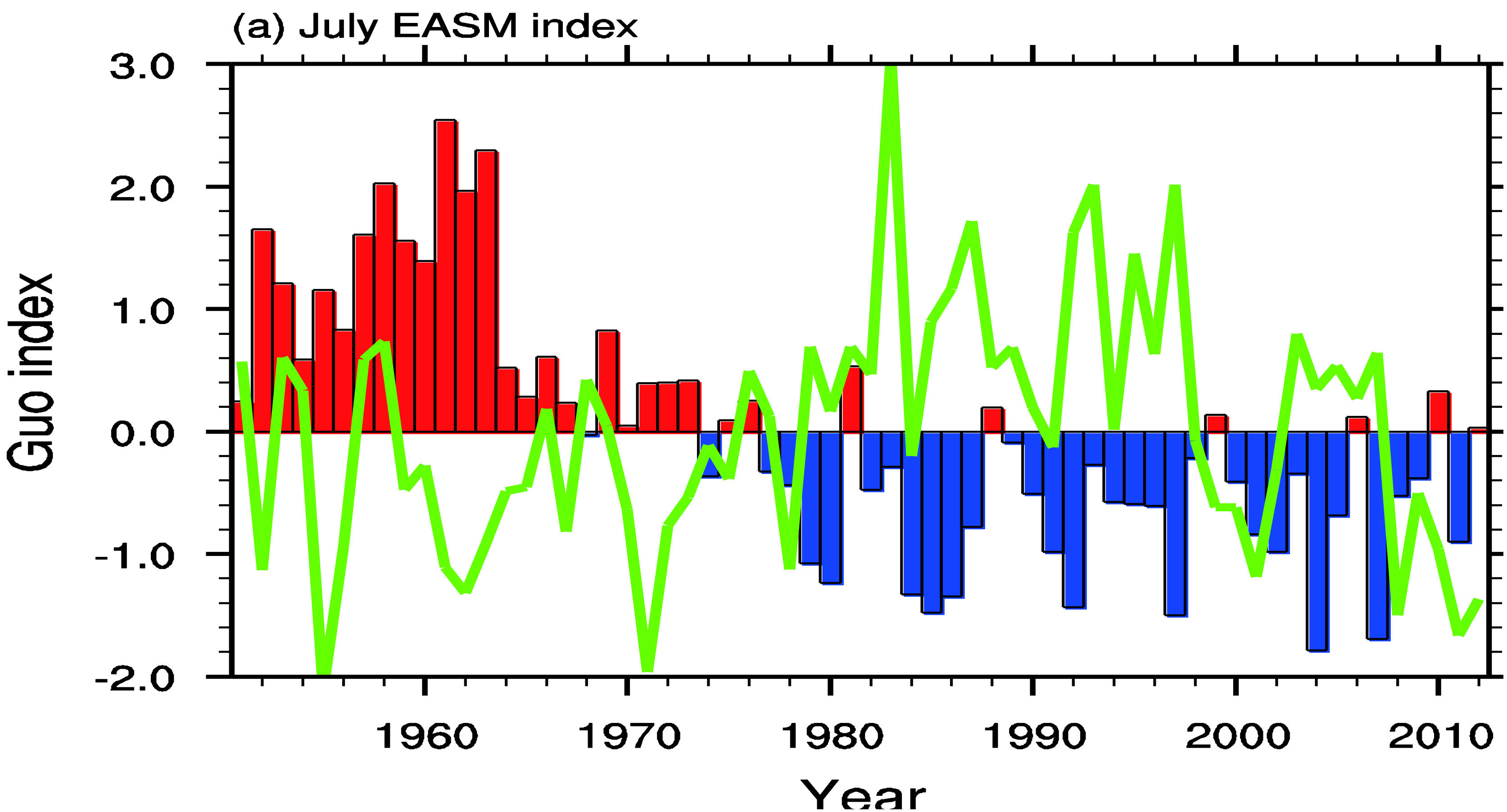
Transport water from YZ river to N. China by channels



http://www.nsbd.gov.cn/zx/english/

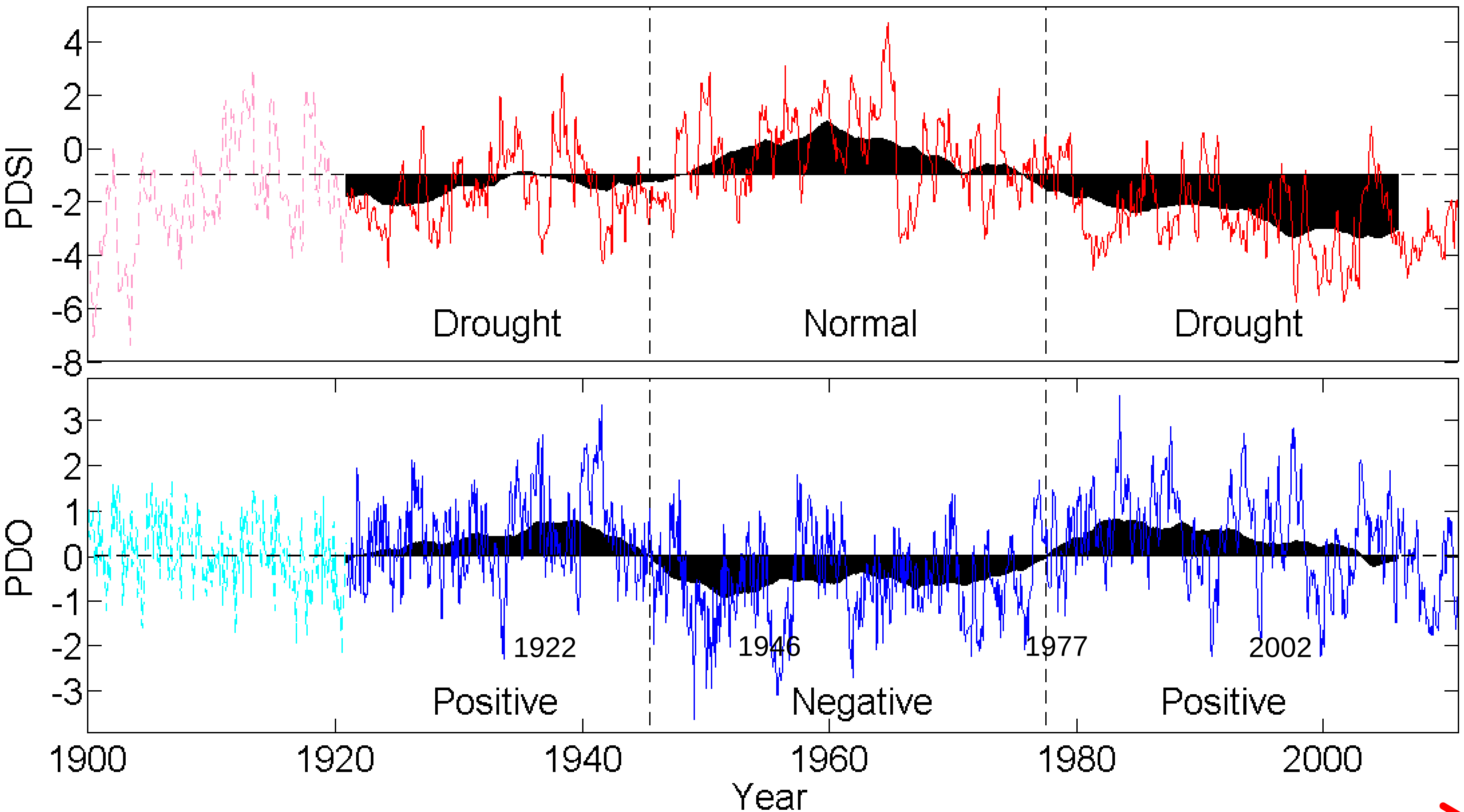
PDO and E. Asian monsoon

Monsoon index (bar)   Green: PDO index



Zhou, T., F. Song, R. Lin, X. Chen and X. Chen, 2013: The 2012 North China floods: Explaining an extreme rainfall event in the context of a long-term drying tendency [in "Explaining Extreme Events of 2012 from a Climate Perspective"]. ***Bulletin of the American Meteorological Society***, 94(9), S49-S51

PDSI index in N. China and PDO index over the 20th century



Shading: 11 yrs smoothing

Qian C. and T. **Zhou**, 2014: Multidecadal variability of North China aridity and its relationship to PDO during 1900-2010, ***J. Climate***, 27(3), 1210-1222

Again, we demonstrate the mechanism by numerical modeling

Model and Experiments

AMIP-type simulation is used to understand the driving of SST

	CAM3 (T85)	CAM3 (T42)	AM2.1 (FV)
GOGA	5	5	10
TOGA	5	5	N/A
ATM	N/A	10	N/A

Definition of EASM Index:

Normalized zonal wind shear between 850 and 200 hPa averaged within (20-40N,110-140E)   (After Han and Wang, 2007)

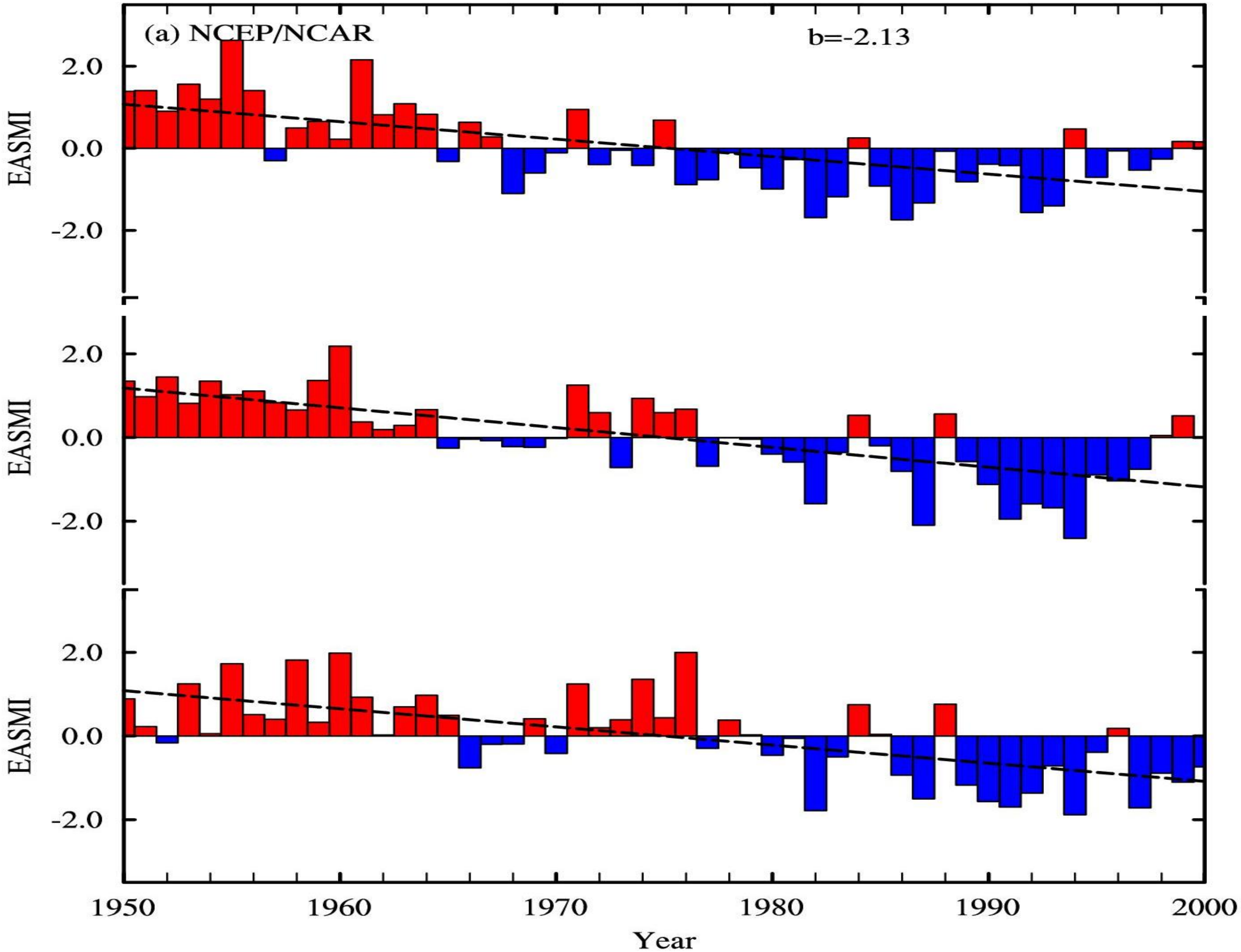
Li, Hongmei, A. Dai, **T. Zhou**, J. Lu, 2010: Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950-2000, ***Climate Dynamics*, 34**, 501-514

EASM index in AGCM driven by observed SST

Reanalysis

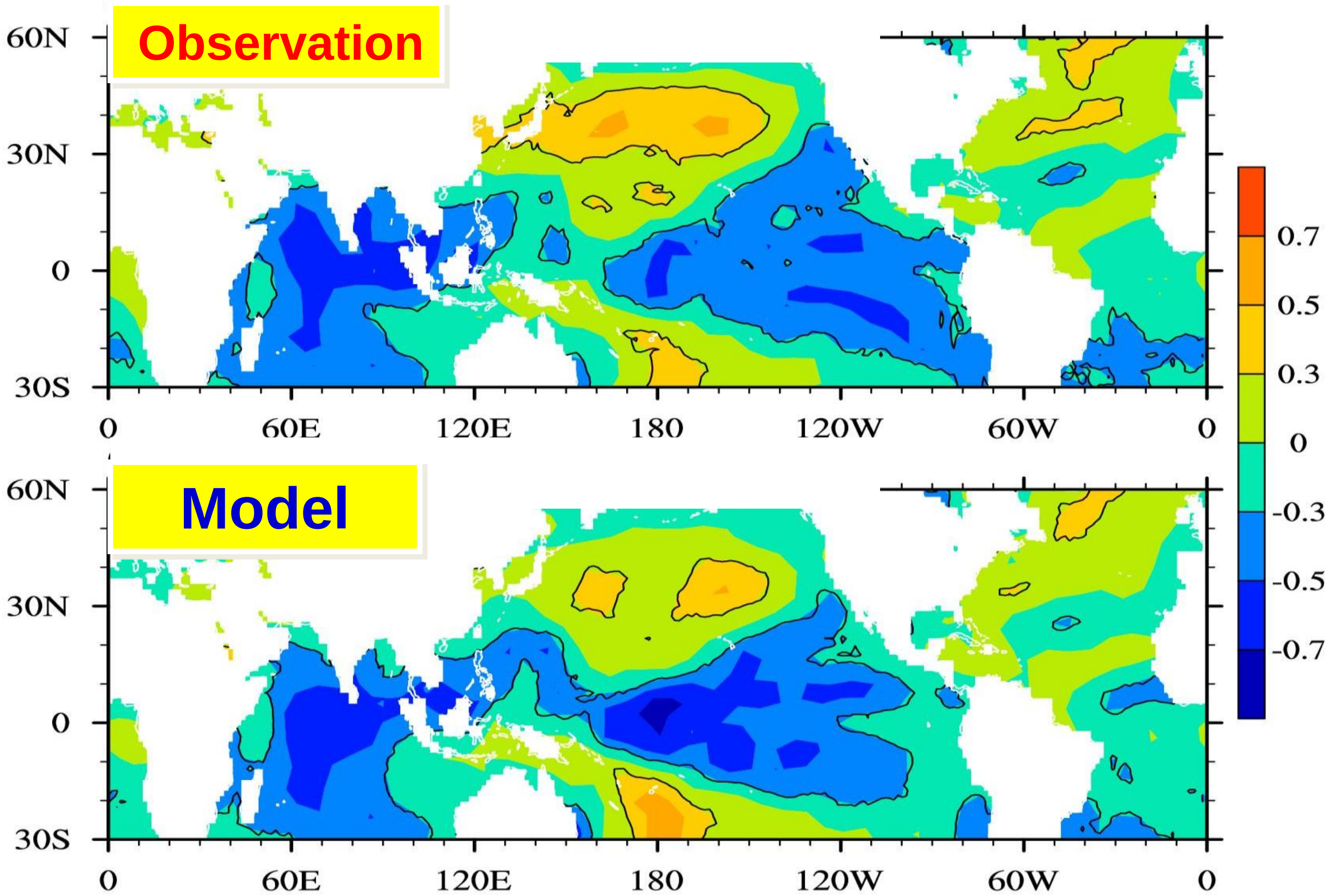
Global SST driven AGCM

Tropical SST driven AGCM



Li, Hongmei, A. Dai, **T. Zhou**, J. Lu, 2010: Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950-2000, ***Climate Dynamics*, 34**, 501–514

Correlations between SSTA and EASM



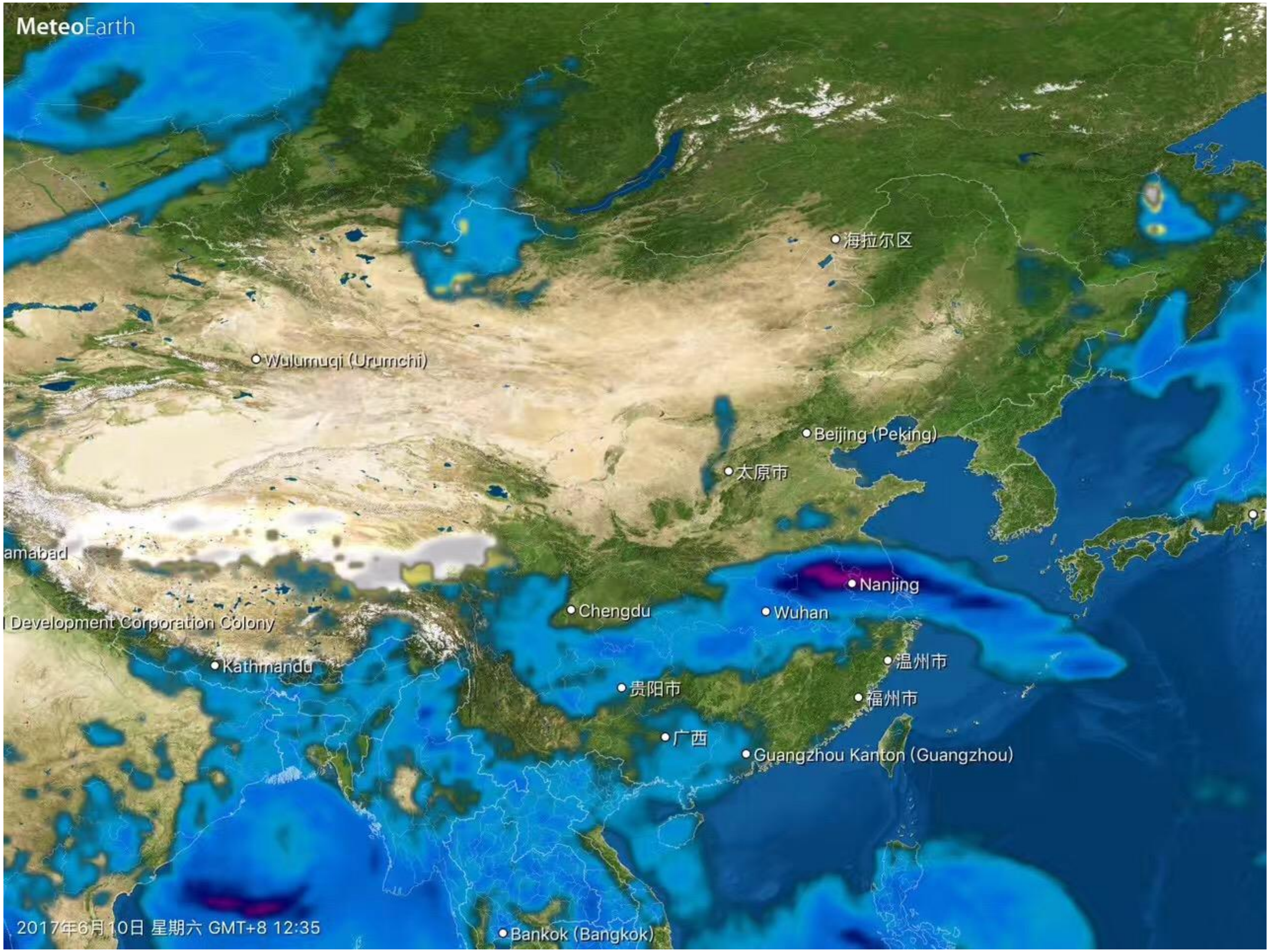
Li, Hongmei, A. Dai, **T. Zhou**, J. Lu, 2010: Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950-2000, ***Climate Dynamics*, 34**, 501–514, DOI 10.1007/s00382-008-0482-7

Point # 2

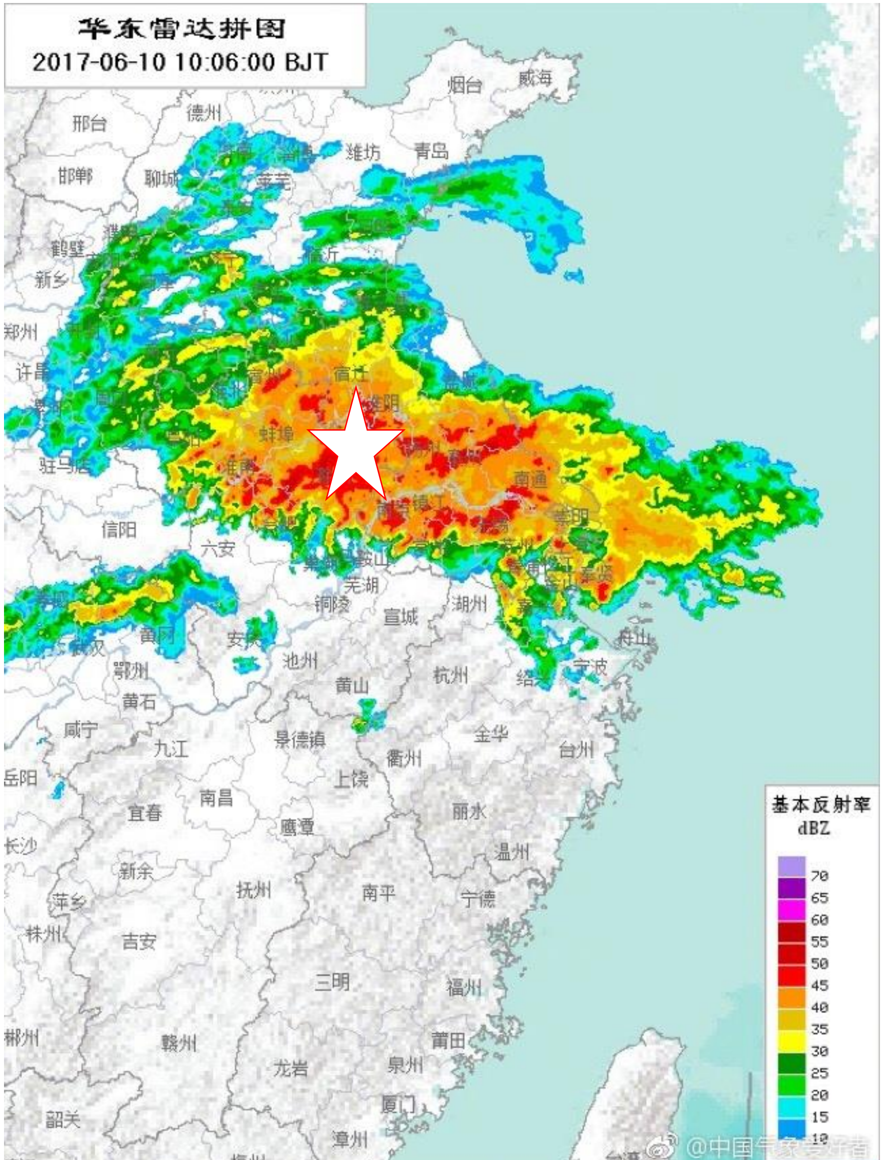
- Data diagnosis reveals an out of phase change of E. Asian summer monsoon circulation and PDO at inter-decadal time scale. This relationship is evident in both the past 50 yrs and the 20th century.
- When driven by historical SST, the AGCMs are able to reproduce to weakening tendency of E. Asian summer monsoon circulation. The response is dominated by the tropical lobe of PDO/IPO.
- *The simulation of monsoon rain band changes remains to be a challenge.*

Li, Hongmei, A. Dai, T. Zhou, J. Lu, 2010: Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950-2000, ***Climate Dynamics*, 34**, 501–514

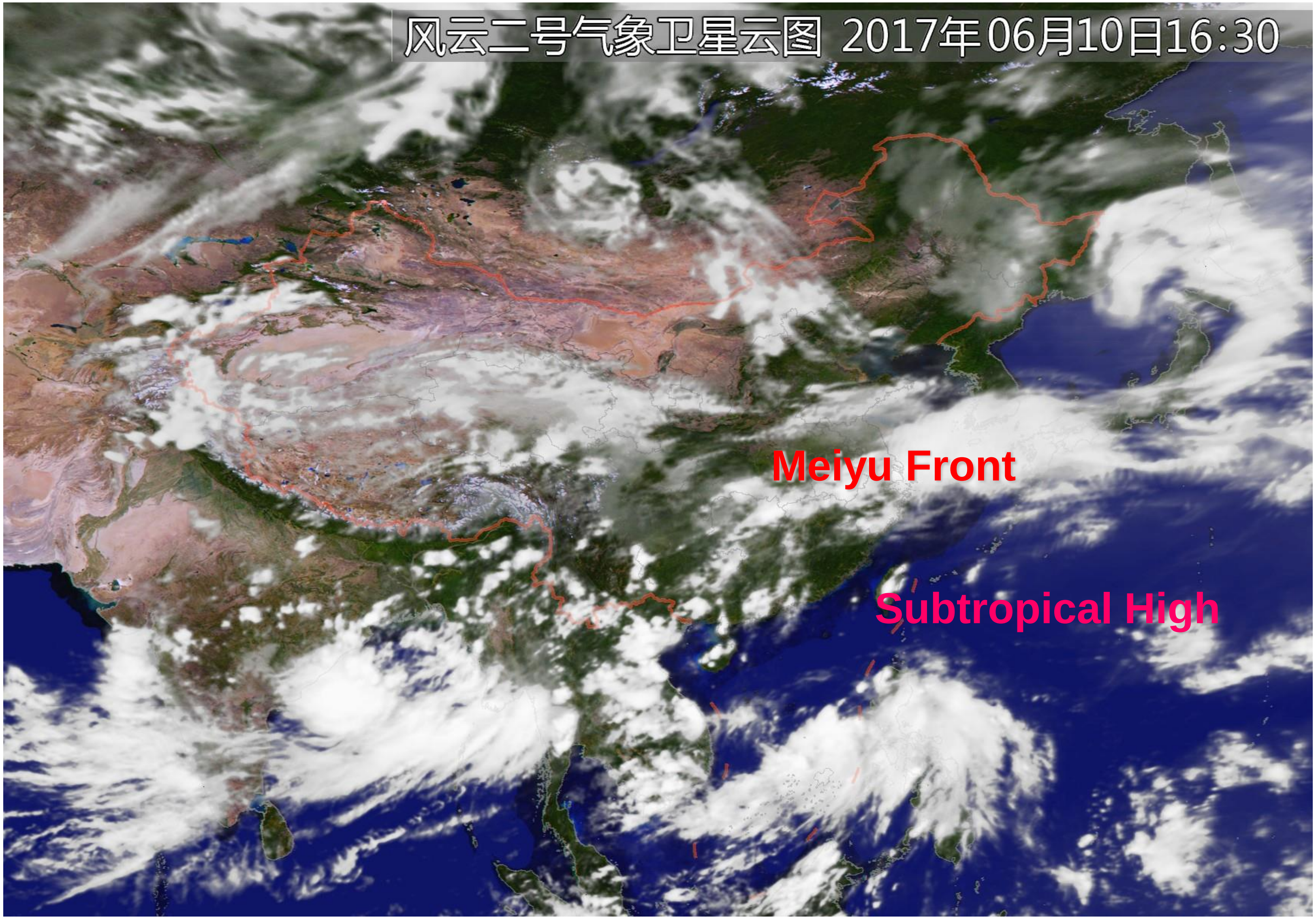
Monsoon rainband is controlled by Western Pacific Subtropical High



Monsoon rainband is controlled by Western Pacific Subtropical High

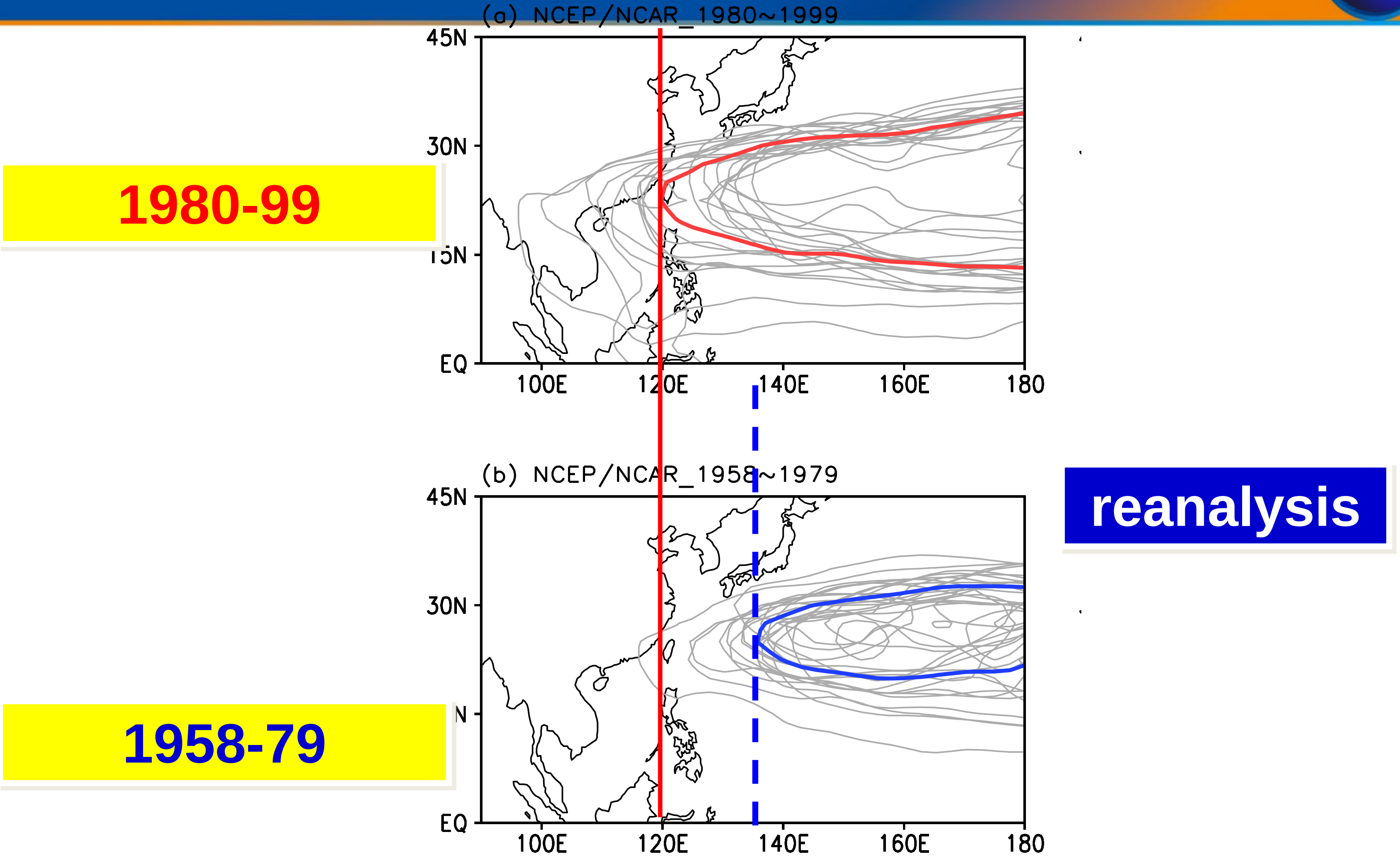


Monsoon rainband is controlled by Western Pacific Subtropical High



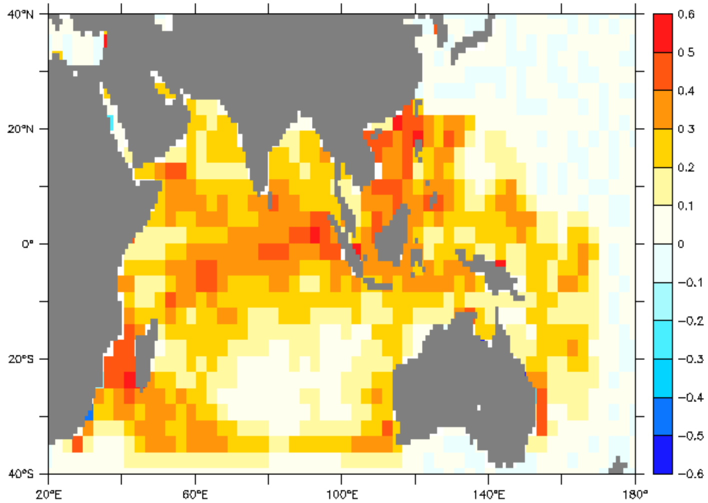
http://www.nmc.cn/publish/observations/china/dm/weatherchart-h000.htm

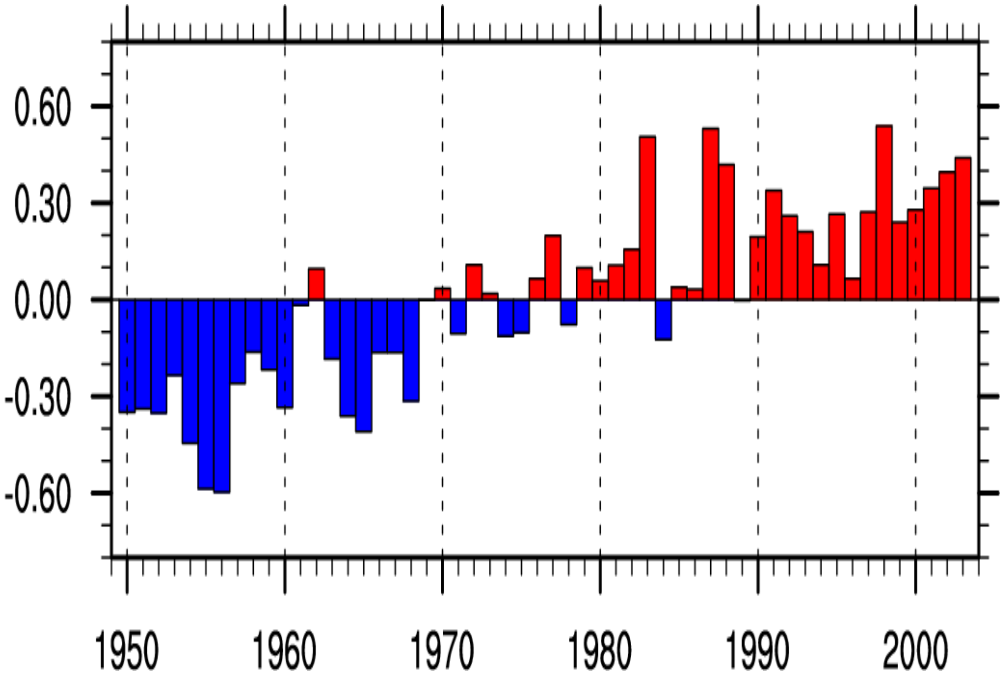
Westward Extension of WPSH



Zhou, T., R. Yu, J. Zhang, H. Drange et al. 2009, Why the Western Pacific Subtropical High has extended westward since the late 1970s**, *J. Climate***, 22, 2199-2215

The warming of IWP





SST [1976-2001] – SST[1960-1990]

SSTA time series

Zhou, T., R. Yu, J. Zhang, H. Drange et al. 2009, Why the Western Pacific Subtropical High has extended westward since the late 1970s**, *J. Climate***, 22, 2199-2215

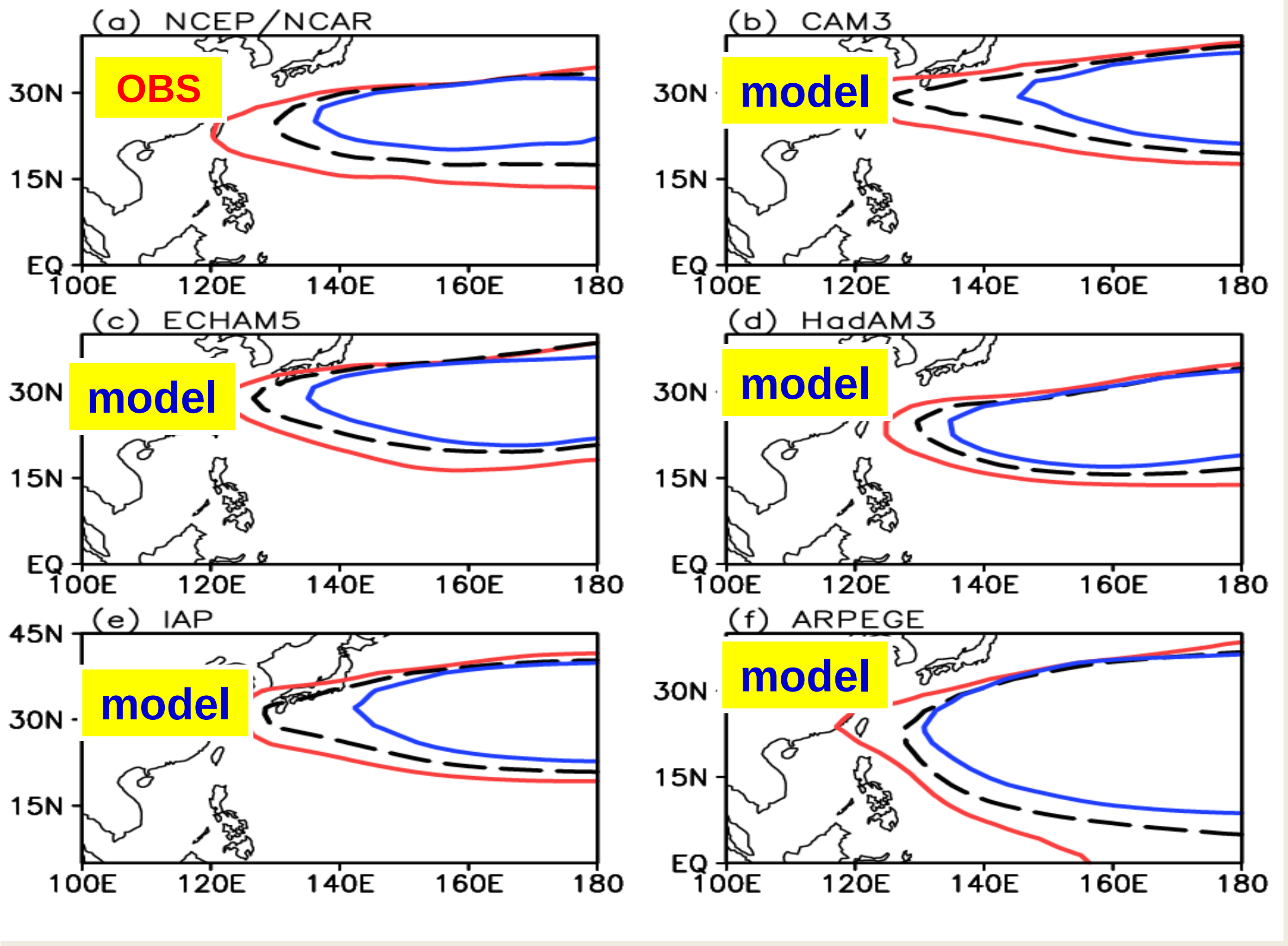
Description of 5 AGCMs

Institute	AGCM	Resolution	Convection scheme	Reference
NCAR	CAM3	T85L26	Deep convection is parameterized following Zhang and McFarlane (1995). Shallow and upper-level convection uses Hack (1994).	Boville et al. (2006)
MPI	ECHAM5	T63 L31	Tiedtke(1989) with modifications for deep convection according to Nordeng (1994).	Hagemann et al. (2006)
UKMO	HadAM3	2.5^{o} lat X 3.75^{o} lon L19	Gregory and Rowntree (1990) with the addition of convective downdrafts (Gregory and Allen 1991)	Pope et al. (2000)
IAP	GAMIL	2.8^{o} lat x2.8^{o} lon L26	Zhang-McFarlane(1995)	Wang et al.(2004)
CNRM	ARPEGE	T63 L31	Deep convection is represented by a mass flux scheme with detrainment as proposed by Bougeault (1985). The stratiform and shallow convection cloud formation is evaluated via a statistical method described in Ricardand Royer (1993)	Cassou et al. (2001)

Zhou, T., R. Yu, J. Zhang, H. Drange et al. 2009, Why the Western Pacific Subtropical High has extended westward since the late 1970s**, *J. Climate***, 22, 2199-2215

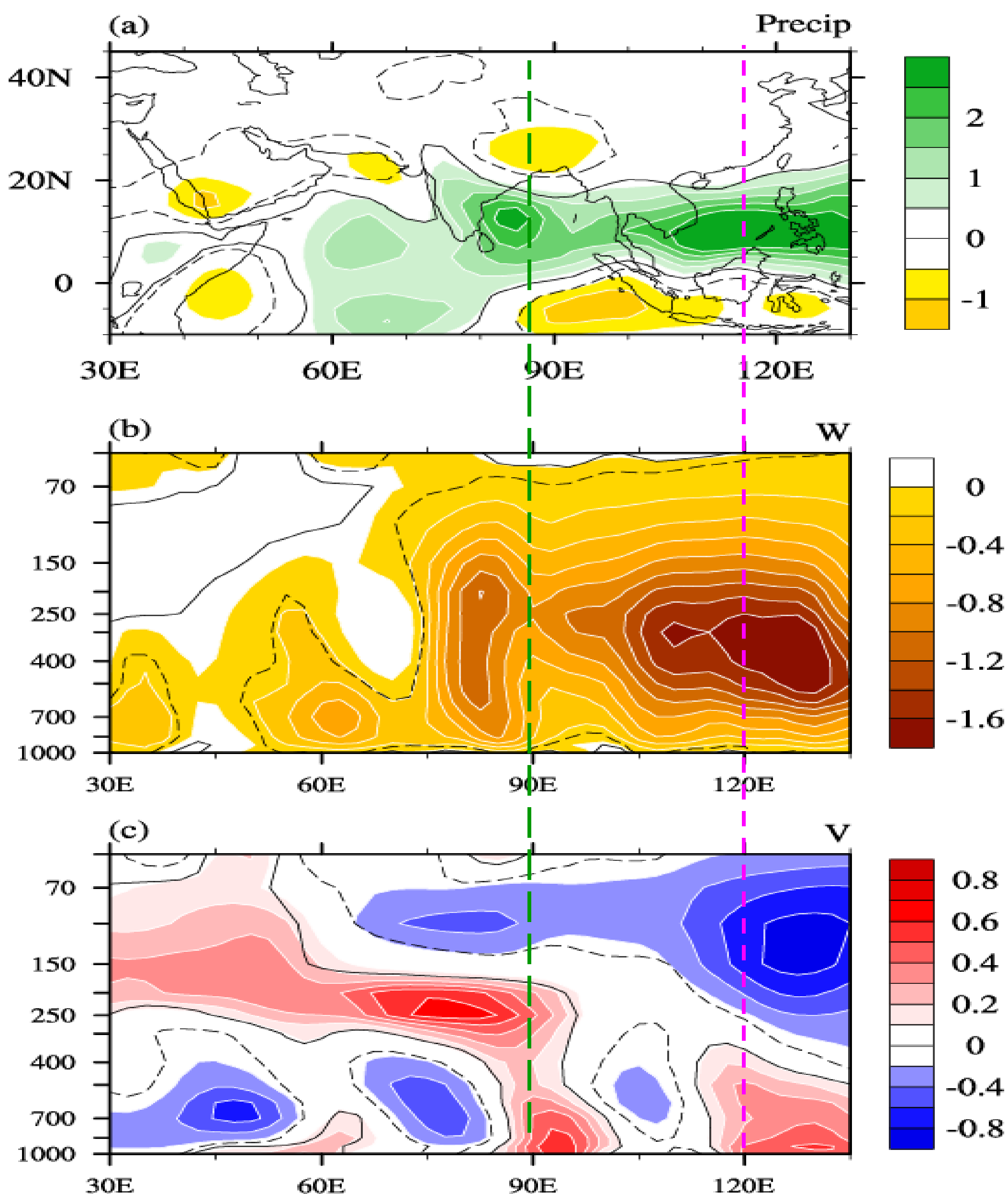
WPSH in the simulation

Warm、Cold、Normal SST-driven runs



Zhou, T., R. Yu, J. Zhang, H. Drange et al. 2009, Why the Western Pacific Subtropical High has extended westward since the late 1970s**, *J. Climate***, 22, 2199-2215

Sverdrup Vorticity-balance in the model



Multi-Model Ensemble

Rainfall

$$\beta v \approx f \frac{\partial \omega}{\partial p}$$

Vertical velocity

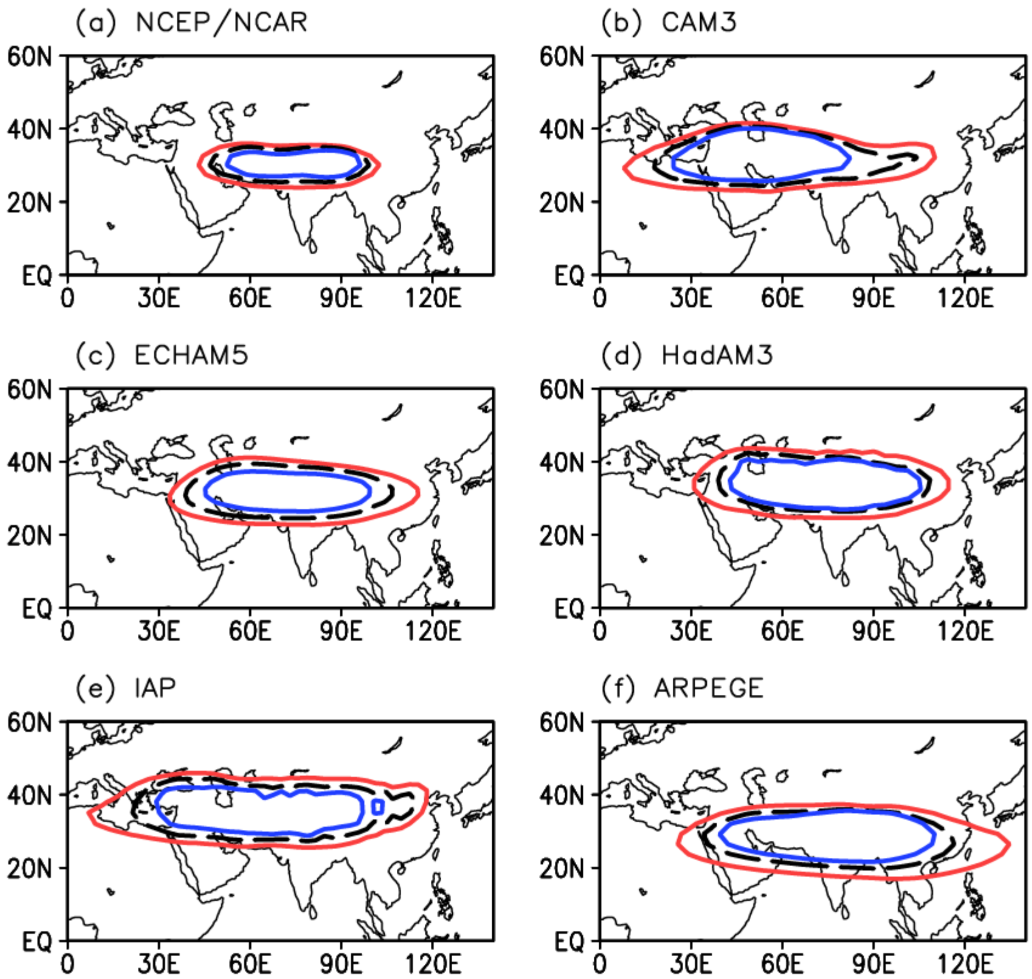
Meridional wind

0-20N average

(Zhou et al. 2009a J.

South Asian High is getting fatter

SAH in IWP warming, cooling and *control* runs



Zhou, T., R. Yu, J. Zhang, H. Drange et al. 2009, Why the Western Pacific Subtropical High has extended westward since the late 1970s**, *J. Climate***, 22, 2199-2215

Point # 3

- The westward extension of WPSH and zonal expansion of South Asian High were driven by Indo-Western Pacific warming.
- Both the negative heating in the equatorial central Pacific and Sverdrup vorticity balance are the underlying forcing mechanisms.

Zhou, T., R. Yu, J. Zhang, H. Drange et al. 2009, Why the Western Pacific Subtropical High has extended westward since the late 1970s**, *J. Climate***, 22, 2199-2215

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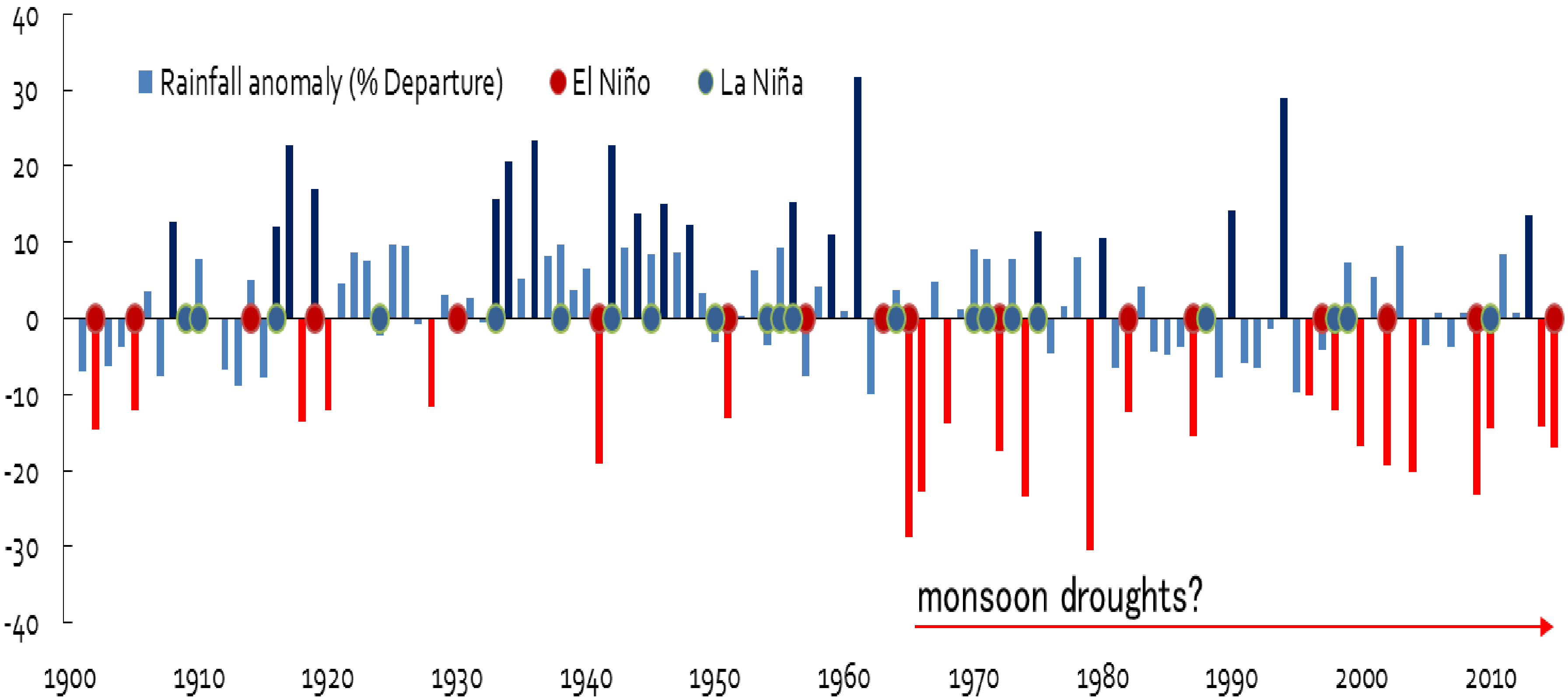
But, a downward trend in the ISMR is witnessed



Courtesy: Roxy Mathew Koll

The downward trend in the ISMR

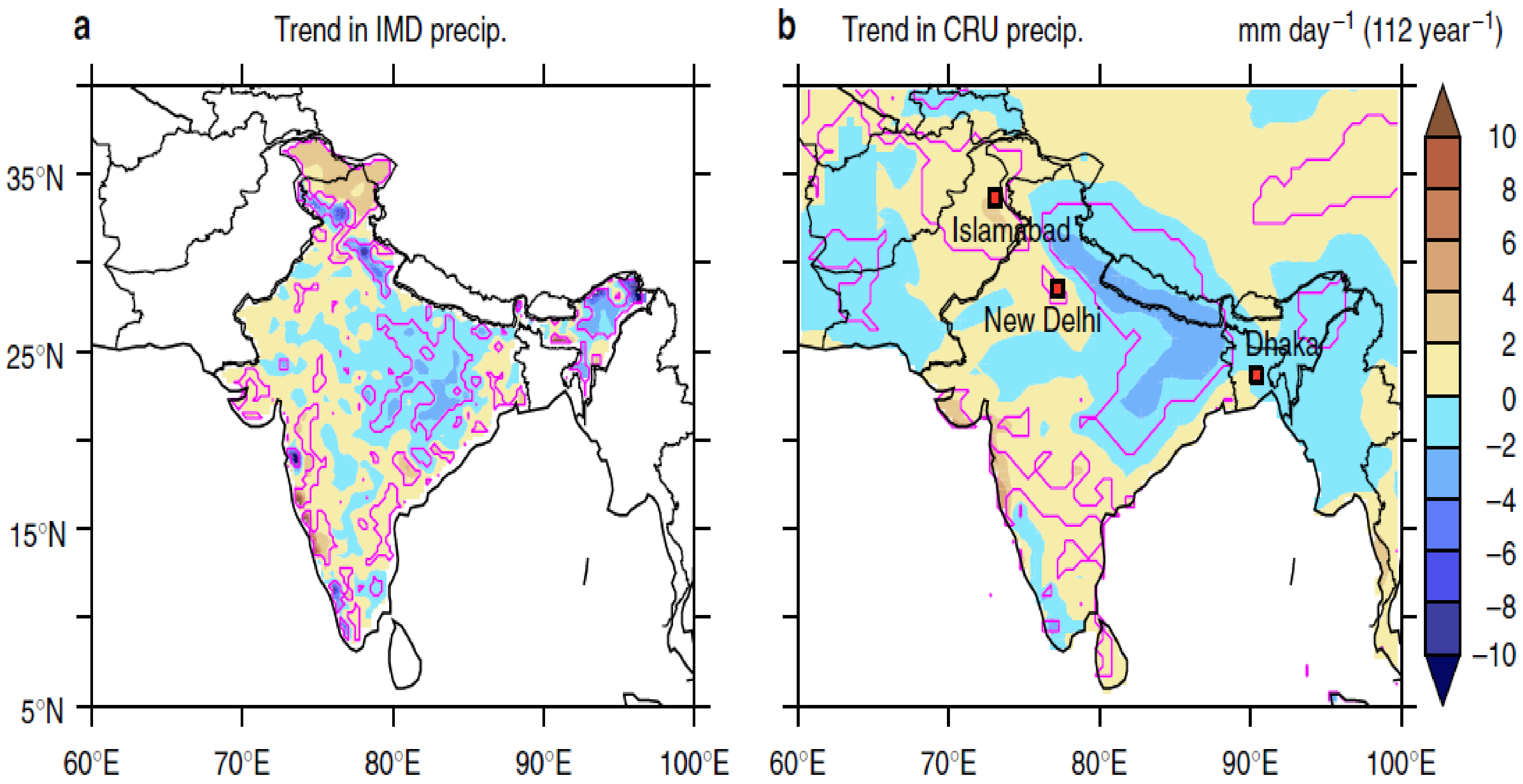


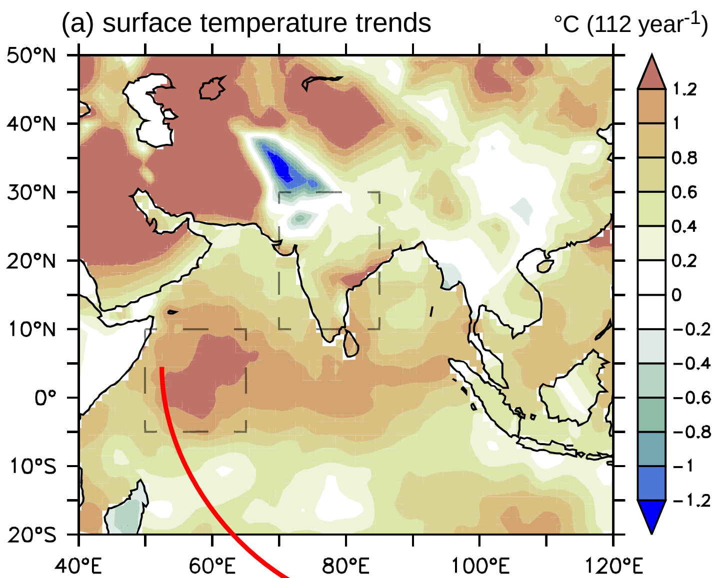
Figure 1 | Summer monsoon precipitation trends for the years 1901-2012. Observed trend in precipitation (mm day^{-1} 112 year^{-1}) in (**a**) IMD and (**b**) CRU datasets, during June-September, for the years 1901-2012. Contours denote regions significant at the 95% confidence level.

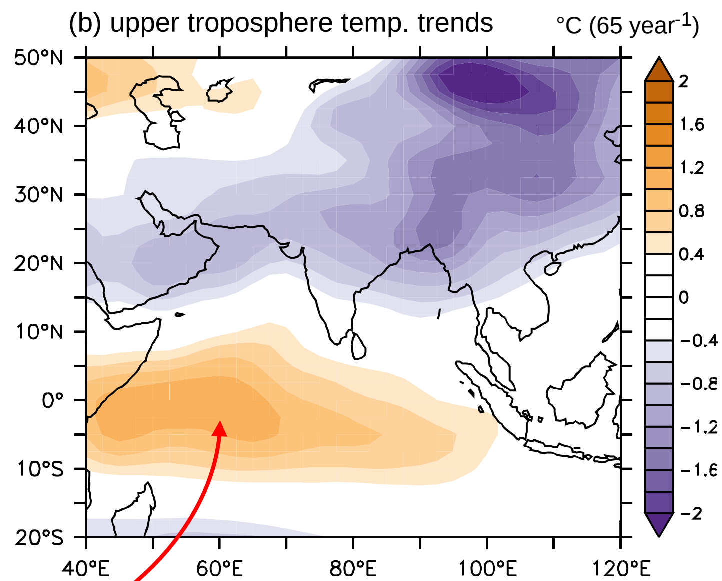
Decreasing trend in precipitation from Pakistan through central India to Bangladesh. Significant over central Indian subcontinent (horse-shoe pattern)

Guhathakurta and Rajeevan, IJOC, 2008; Roxy et al. 2015, Nature Communications

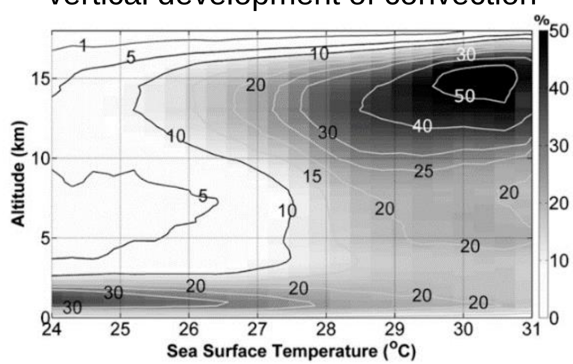
Land-sea thermal contrast over South Asian domain

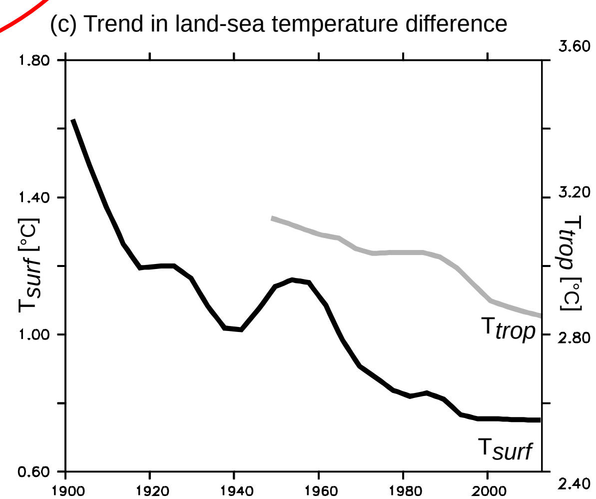
Indian Ocean-large warming, Subcontinent-suppressed warming





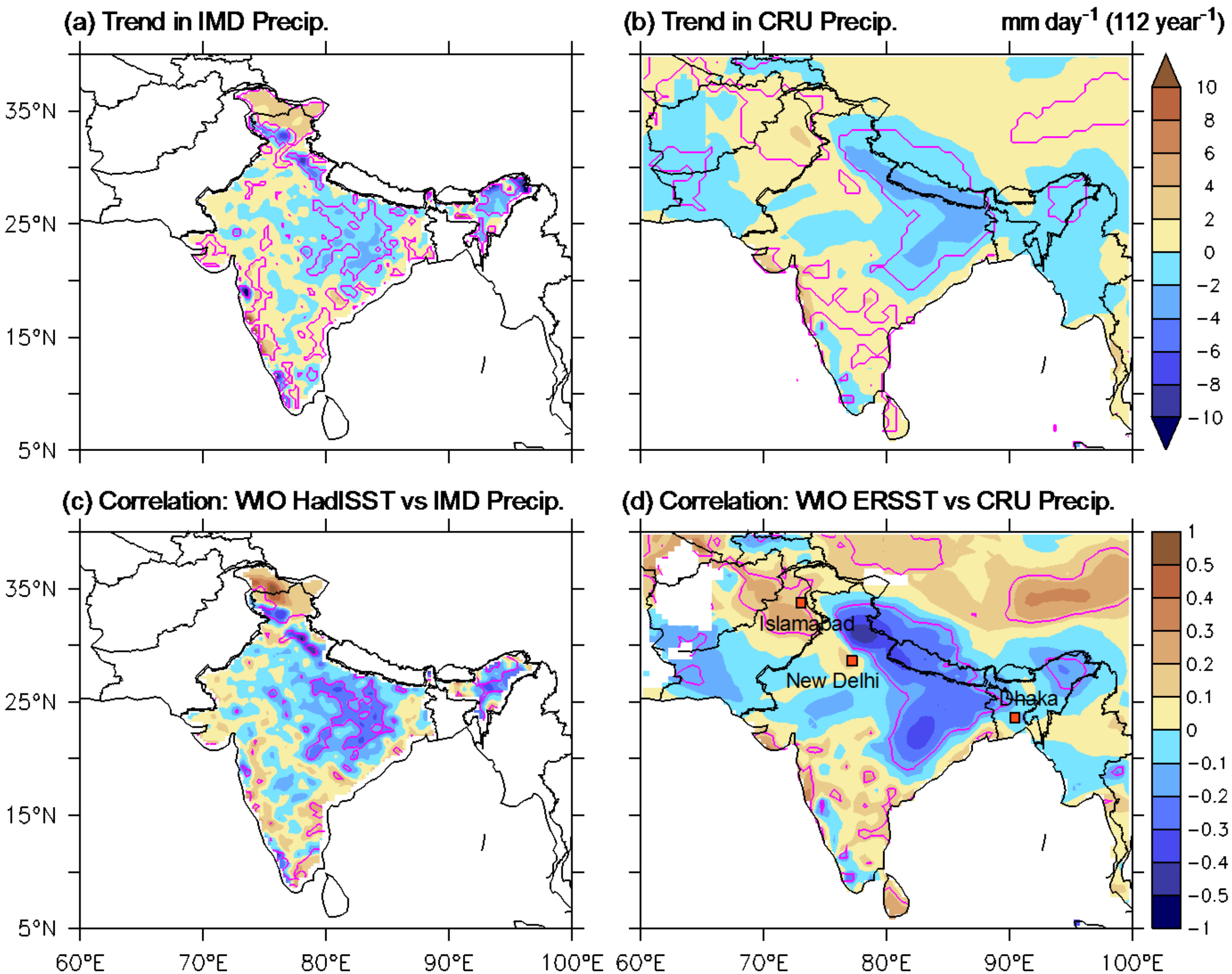
Increased SST results in intense vertical development of convection





Roxy et al. 2015, Nature Communications

Indian Ocean warming well correlated with weak Precip



(a) & (b)
Decreasing trend in precipitation from Pakistan through central India to Bangladesh. Significant over central Indian subcontinent (horse-shoe pattern)

(c) & (d)
Trend and correlation with western Indian Ocean warming has similar patterns.

Roxy et al. 2015, Nature Communications

Point # 4

- The Indian summer monsoon has seen a weakening tendency since the 1970s.
- The WIO warming is the driving mechanism.
- SST warming extends the warm pool, increases ocean rainfall …but results in decreased rainfall over the subcontinent

Roxy et al. 2015, Nature Communications

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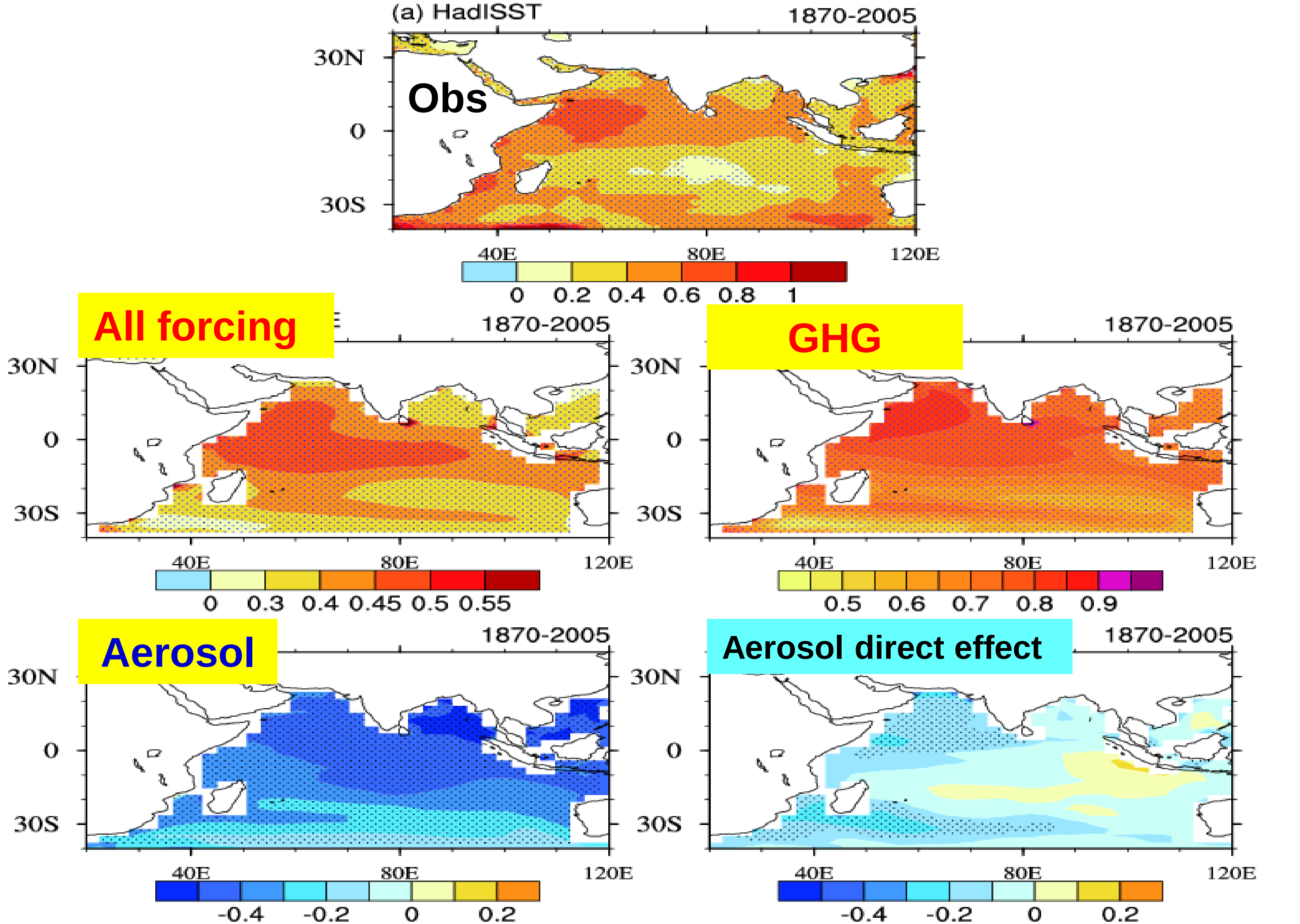
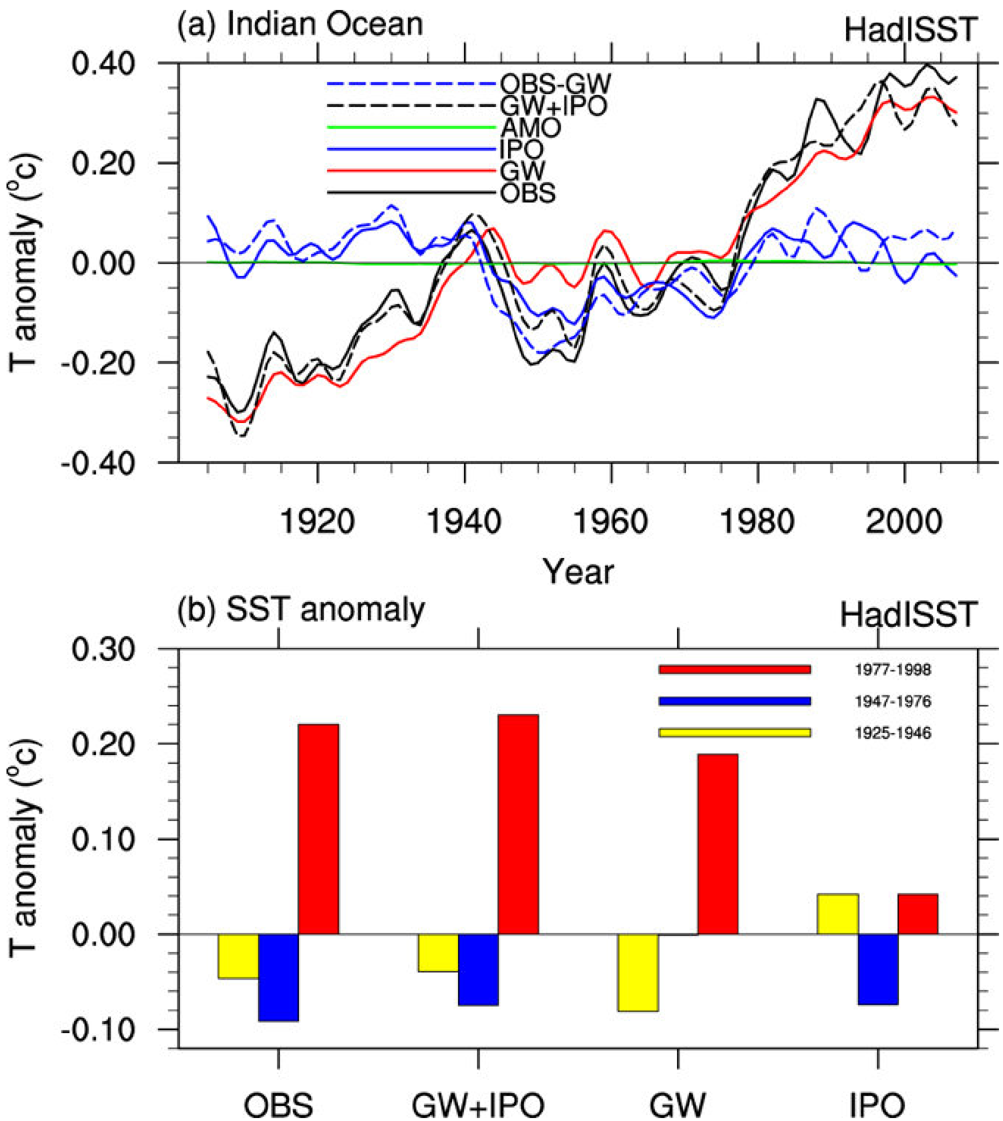
Indian Ocean Warming in 17 CMIP5 models



Dong, L., and T. Zhou , 2014: The Indian Ocean Sea Surface Temperature Warming Simulated by CMIP5 Models during the 20th Century: Competing Forcing Roles of GHGs and Anthropogenic Aerosols, *Journal of Climate*, 27, 3348–3362

The Footprint of PDO on Indian Ocean SST changes



- Decadal change of Indian Ocean SST is driven by PDO from the Pacific
- The global warming hiatus was driven by cold phase of PDO, while the Indian Ocean cooling induced by PDO has a contribution of 10%

Dong Lu, Tianjun Zhou*, Aiguo Dai, Fengfei Song, Bo Wu, Xiaolong Chen, 2016: The Footprint of the Inter-decadal Pacific Oscillation in Indian Ocean Sea Surface Temperatures, ***Scientific Report***s,6:21251, DOI:10.1038/srep2125

Concluding Remarks

1. Decadal variability of GM was driven by the phase change of PDO.
2. Both the weakening trend of East Asian summer monsoon since the 1970s and its recent recovery were driven by the phase shift of PDO.
3. The weakening of ISM since the 1970s is directly driven by the warming of WIO.
4. The Indian Ocean warming is dominated by the GHG forcing and offset by the aerosol cooling.
5. The PDO has a footprint in the Indian Ocean.

THANKS

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