State Key Laboratory of Numerical Modelling for Atmospheric Sciences
and Geophysical Fluid Dynamics(LASG)
Institute of Atmospheric Physics Chinese Academy of Sciences

East Asian summer monsoon changes:

From interannual to decadal time scales

Tianjun ZHOU

zhoutj@lasg.iap.ac.cn

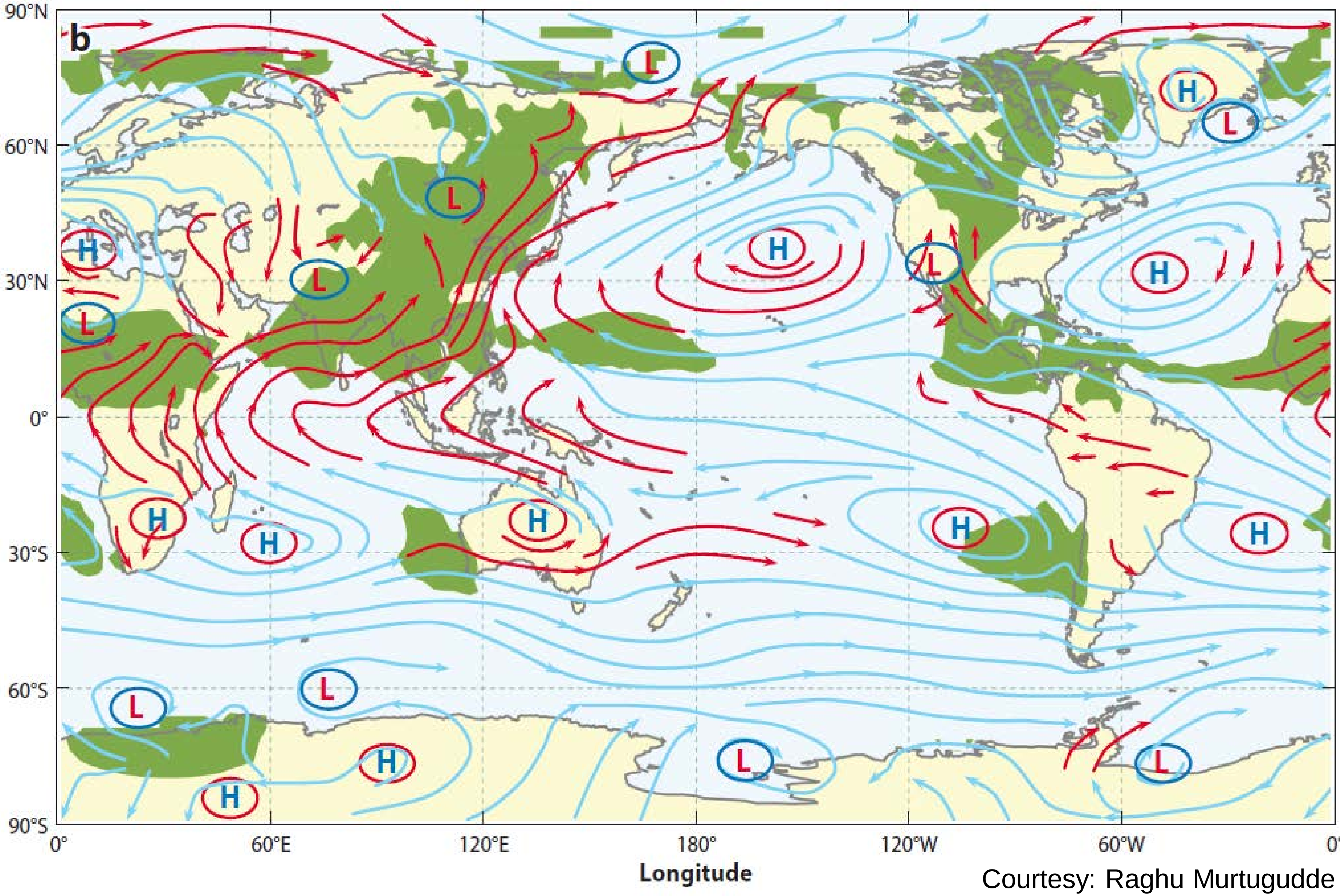
GOTHAM Summer School

18-22 September 2017, PIK, Potsdam, Germany

Outline

1. East Asian monsoon changes in the context of global monsoon
2. Understanding long term changes
3. Interannual variability
4. GMMIP for CMIP6
5. Concluding remarks

Boreal Summer monsoon



Courtesy: Raghu Murtugudde

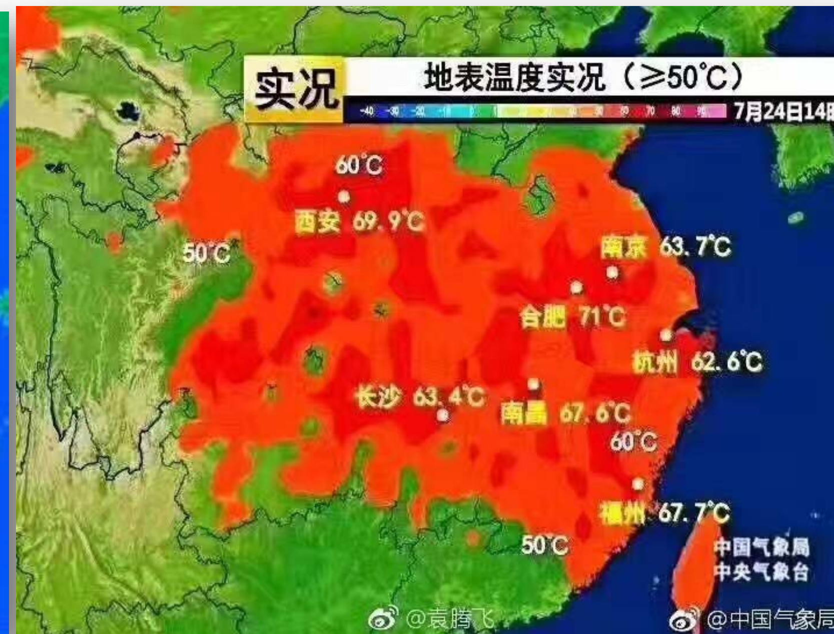
Indian Flood

http://assets-cdn.ekantipur.com/images/third-party/natural-disaster

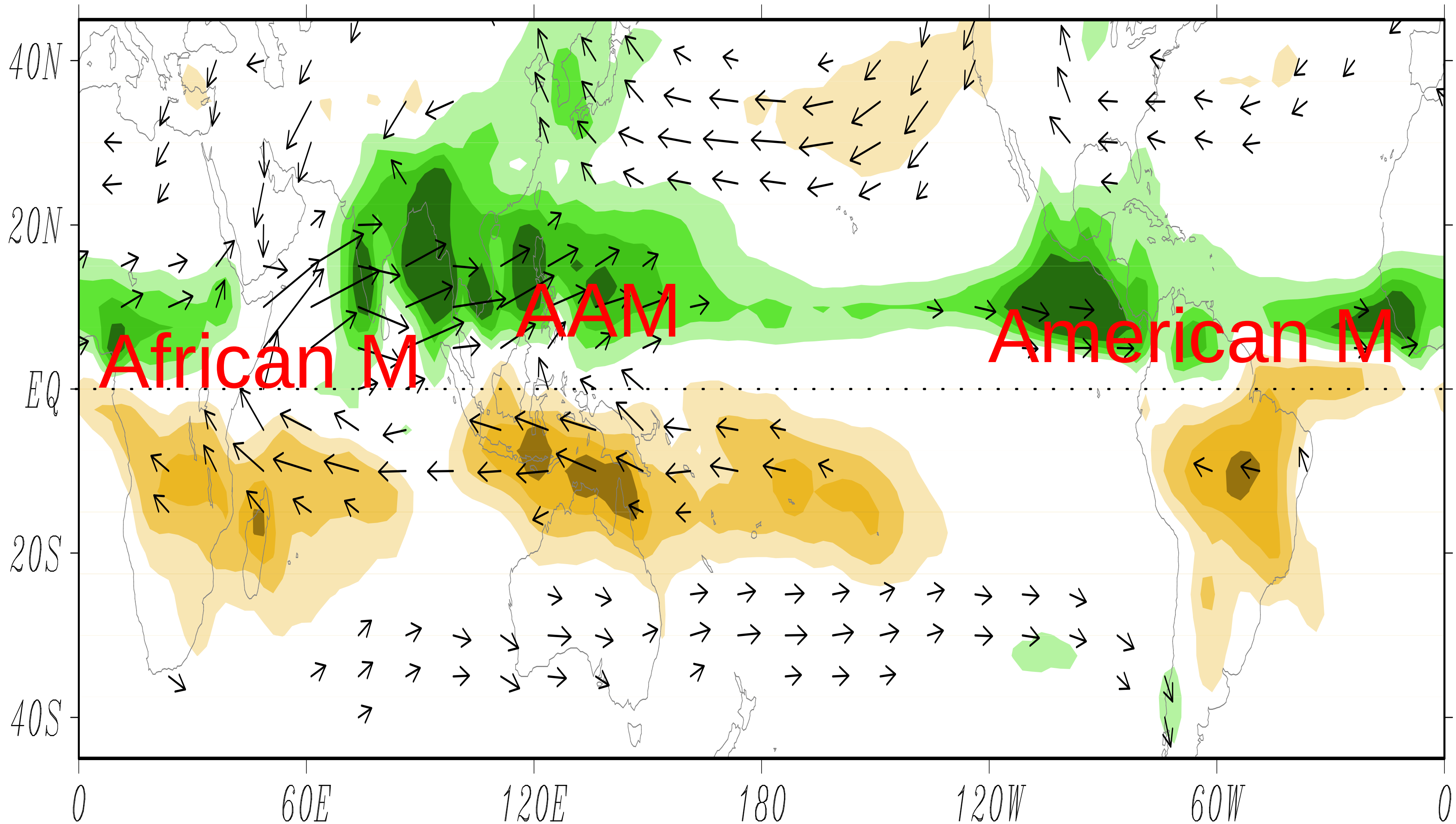
Wuhan Railway Station

04 pm, 08 July, 2016

Heat Wave in China : 20 July - Today, 31 July 2017



EASM is part of the Global Monsoon



JJA –DJF UV850 & Precipitation

Monsoon Prec. Intensity and Domain

1. Monsoon Prec. Intensity:

(a) Annual Range: Local summer Minus Local Winter Prec.

AR (Annual Range) = PR_{JJA}-PR_{DJF} (in North Hemisphere)

PR_{DJF}-PR_{JJA} (in South Hemisphere)

(b) Area averaged local summer Pr at each grid within the present monsoon domain

NHMI: NH-JJA "monsoon" precipitation

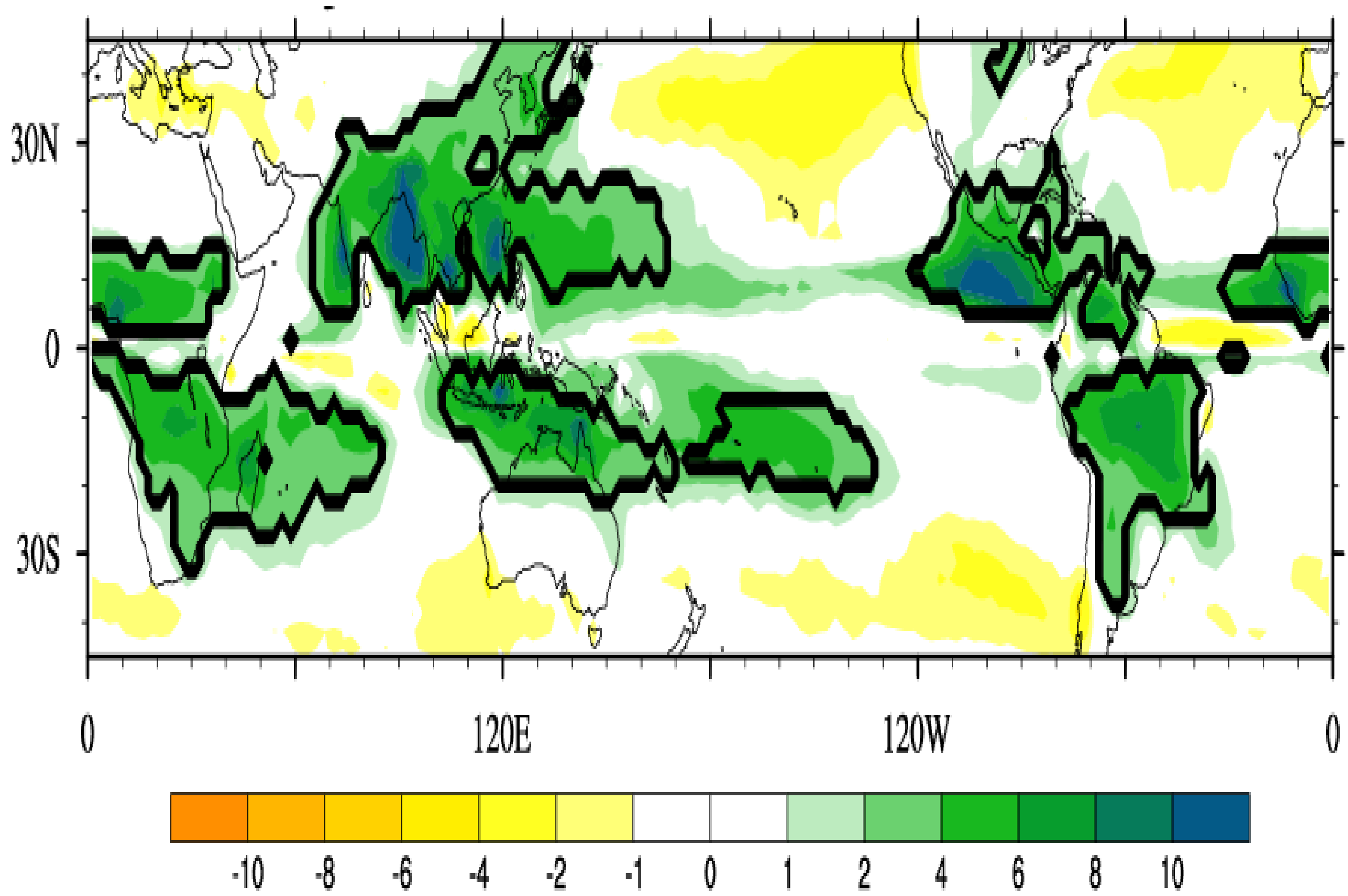
SHMI: SH-DJF "monsoon" precipitation

GMI: NHMI + SHMI

2. Monsoon Domain： AR >180mm and >35% Total annual rainfall

(Wang and Ding 2006 GRL)

Domain of global monsoons

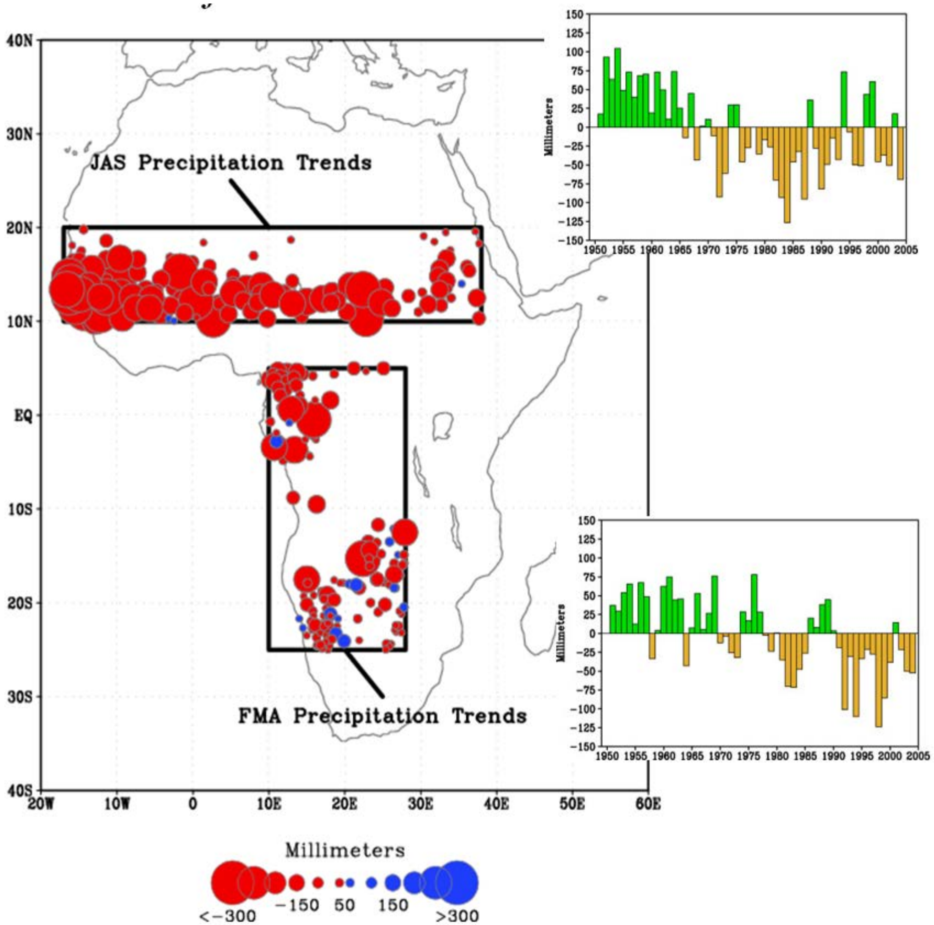


(Wang and Ding 2006 GRL)

Photo by Fu Yunfei

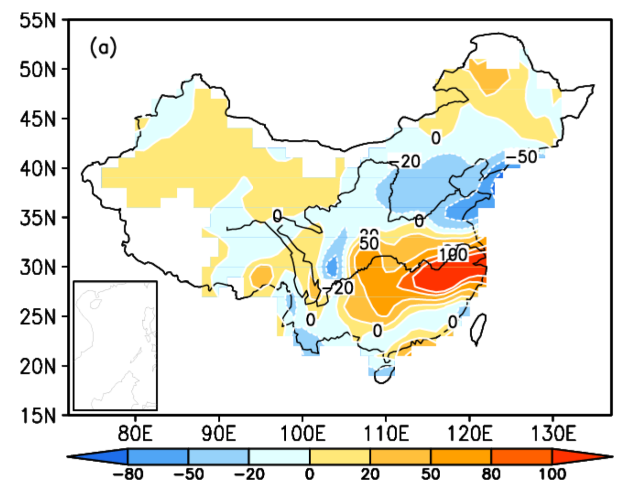
Coherent long term changes across different monsoons

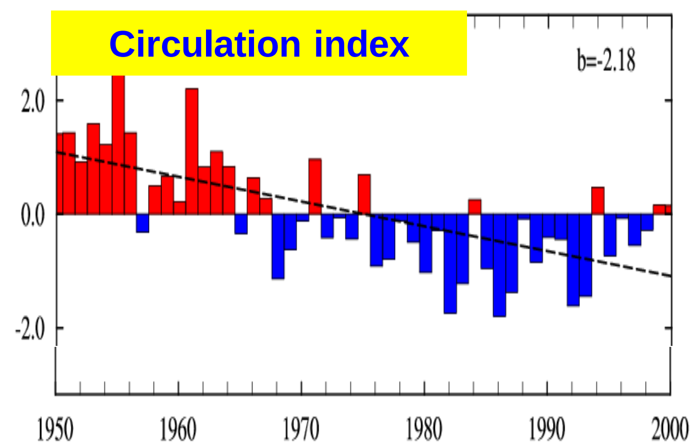
African rainfall



Hoerling et al. (2006) J. Climate

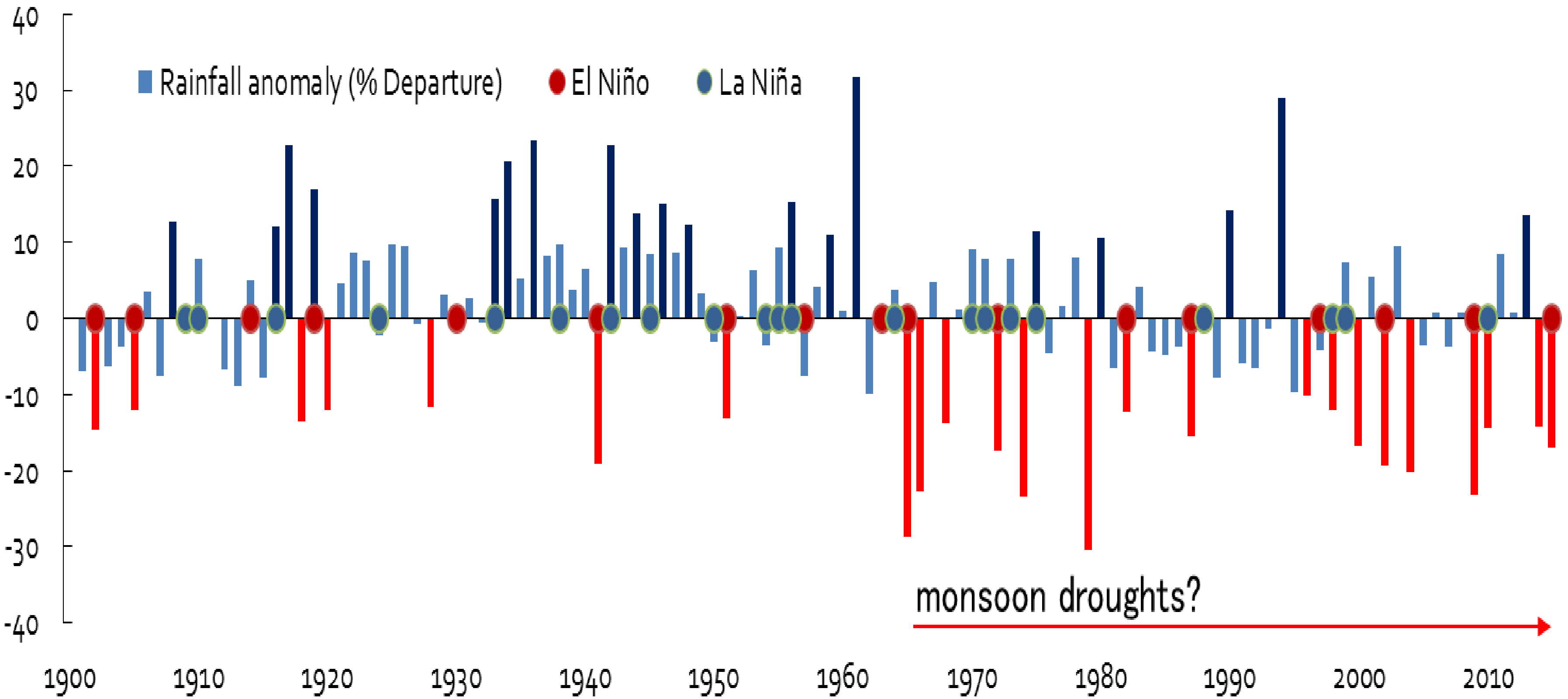
E Asian rainfall





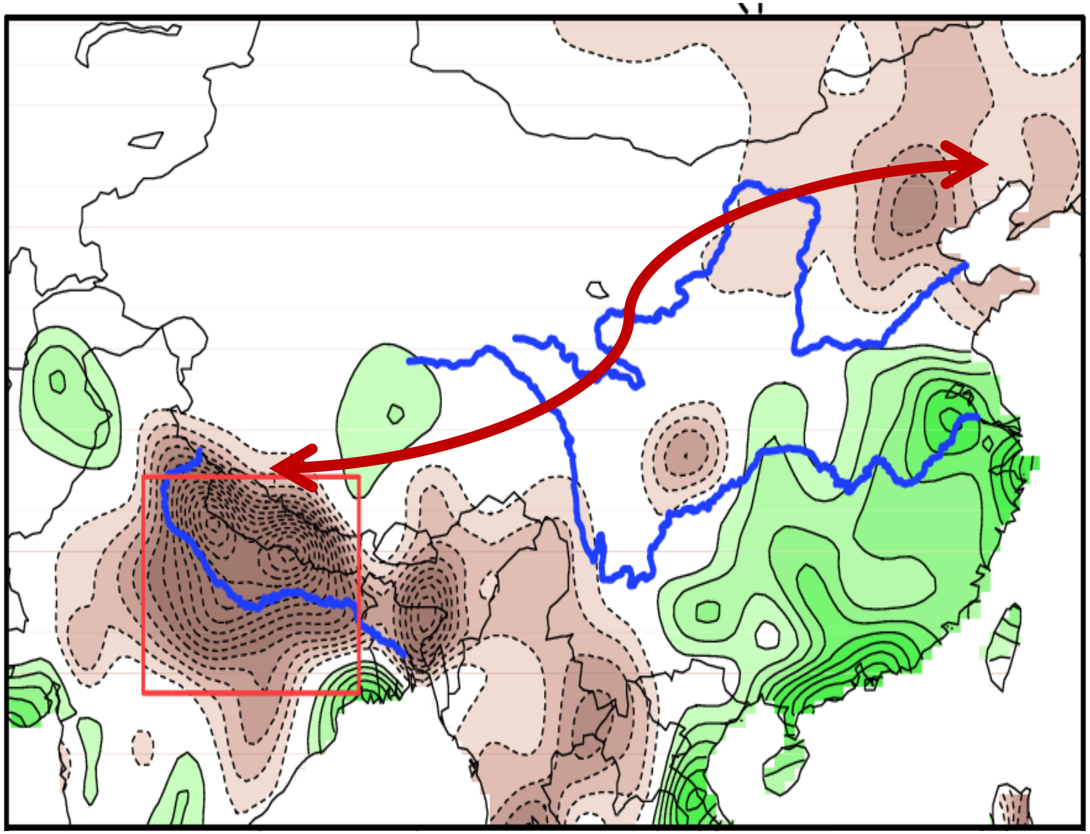
Zhou et al. (2009) Meteorologische Zeitschrift

The downward trend in the ISMR



Courtesy: Roxy Mathew Koll

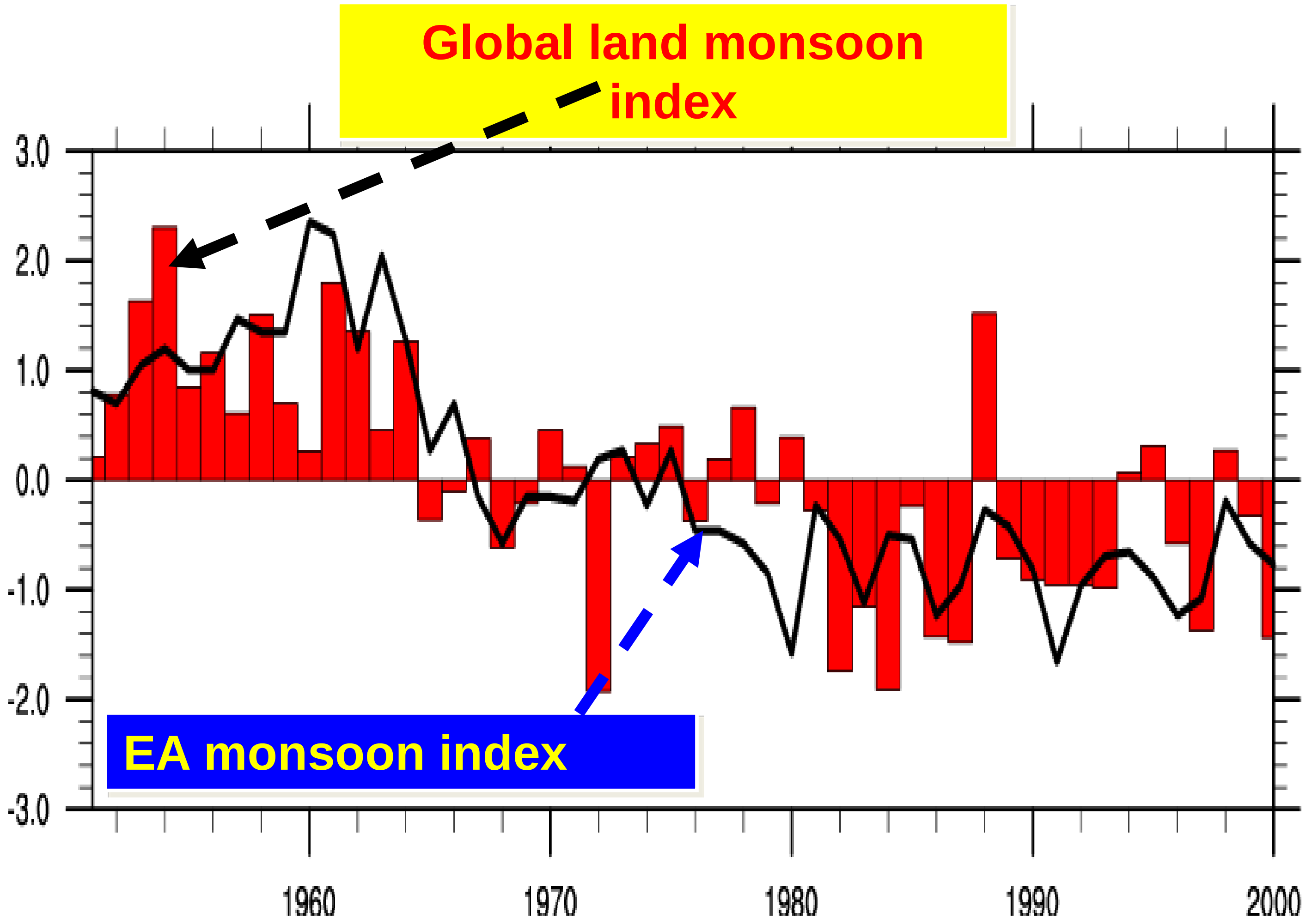
Changes of S. Asia and E. Asia summer rainfall



Linear trend in summer rainfall in the post--1950 period is plotted at 0.5 mm/day/century interval in the 0.5° resolution CRU TS 3.1 data; zero-contour is omitted. The South-Flood North-Dry pattern is manifest.

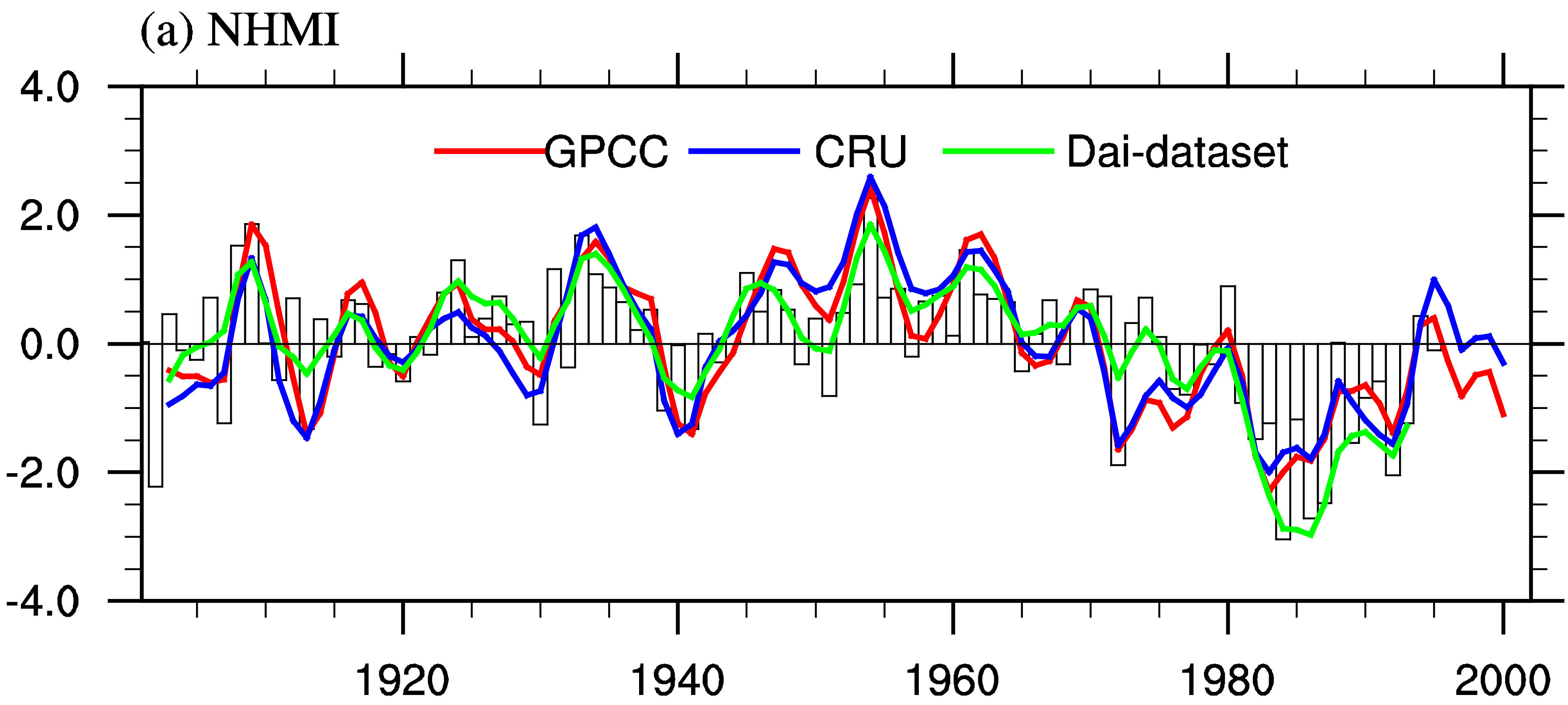
Nigam Sumant, Yongjian Zhao, Alfredo Ruiz-Barradas, **Tianjun Zhou**, 2015: The South-Flood North-Drought Pattern over Eastern China and the Drying of the Gangetic Plain, 437-359pp (Chapter 22) in: ***Climate Change: Multidecadal and Beyond***, edited by Chih-Pei Chang, Michael Ghil, Mojib Latif, John M. Wallace, 2015 World Scientific Publishing Co.

Changes of EASM: A Much Bigger Picture



Zhou T., L. Zhang, **Hongmei LI** 2008 Changes in global land monsoon area and total rainfall accumulation over the last half century, ***Geophysical Research Letters***, 35, L16707, doi:10.1029/2008GL034881

Changes of NH land monsoon precipitation



NH land monsoon:

1) upward trend during 1901-1950s (95% confidence)
2) downward trend from 1950s to 1980s(95% confidence)
3) Recovering since the 1980s

(Zhang and Zhou, 2011, Clim Dyn.)

Interim Summary 1

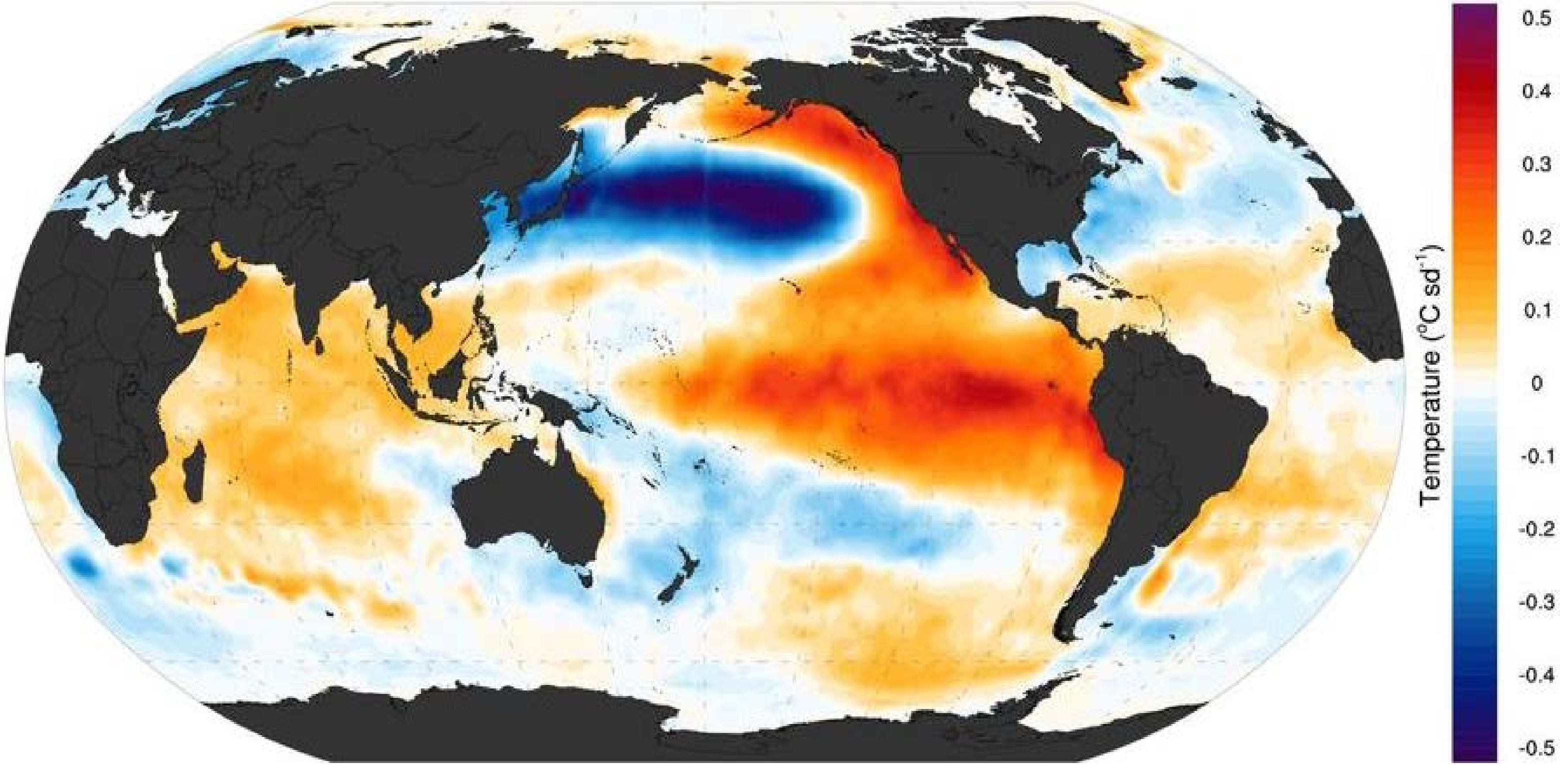
- The GM saw decadal variability in the 20^{th} century, with a strengthening trend prior to the 1950s, a weakening trend during the 2^{nd} half of the century.
- An enhanced trend of Global land monsoon is witnessed since the 1980s up to present.

Outline

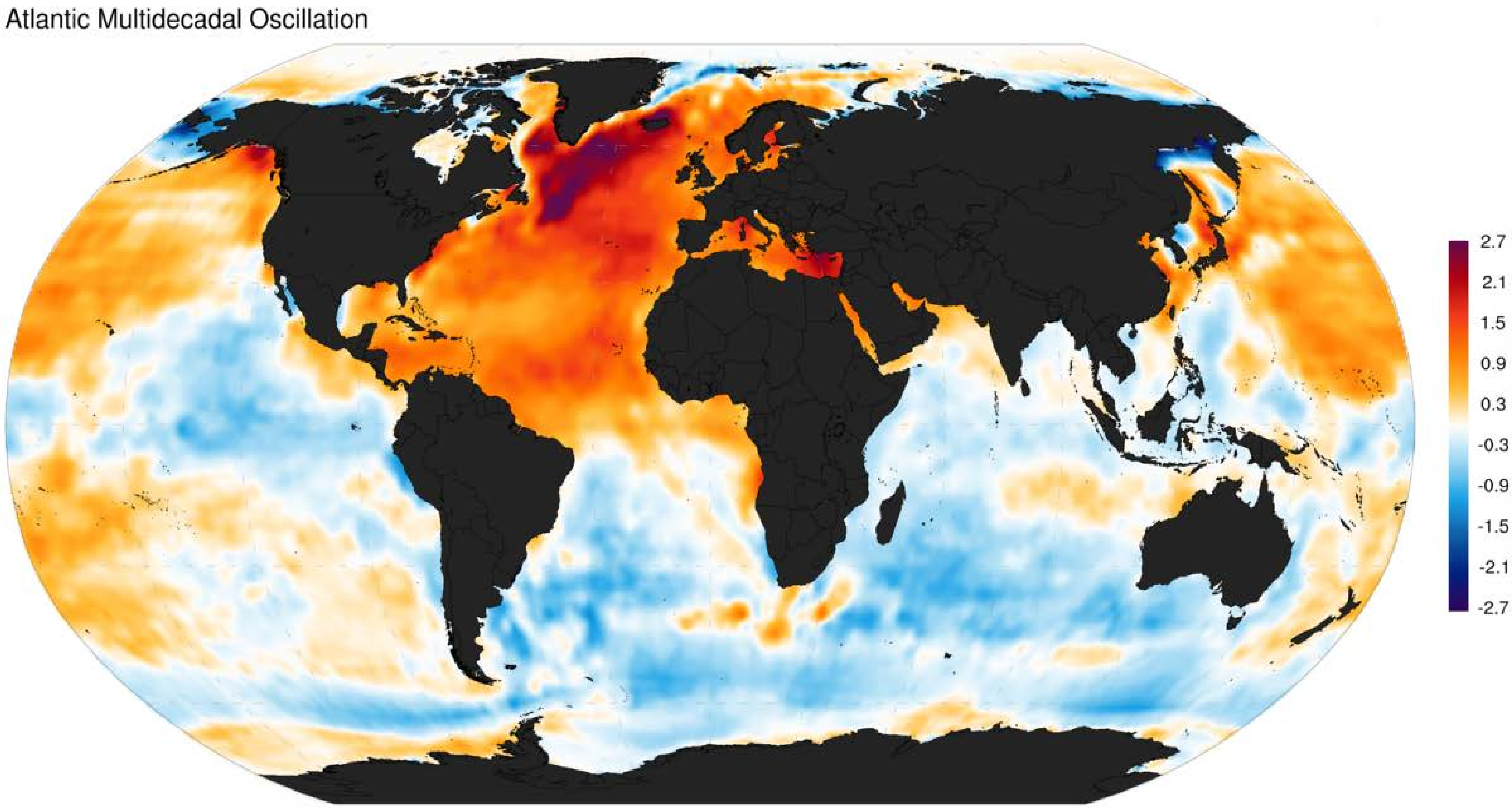
1. East Asian monsoon changes in the context of global monsoon
2. Understanding long term changes
3. Interannual variability
4. GMMIP for CMIP6
5. Concluding remarks

- Internal variability: PDO, AMO,ENSO
- Natural forcing: Solar radiation, volcanic aerosol
- External forcing: GHG, Aerosol, O3, Land use

Pacific Decadal Oscillation



Atlantic Multidecadal Oscillation



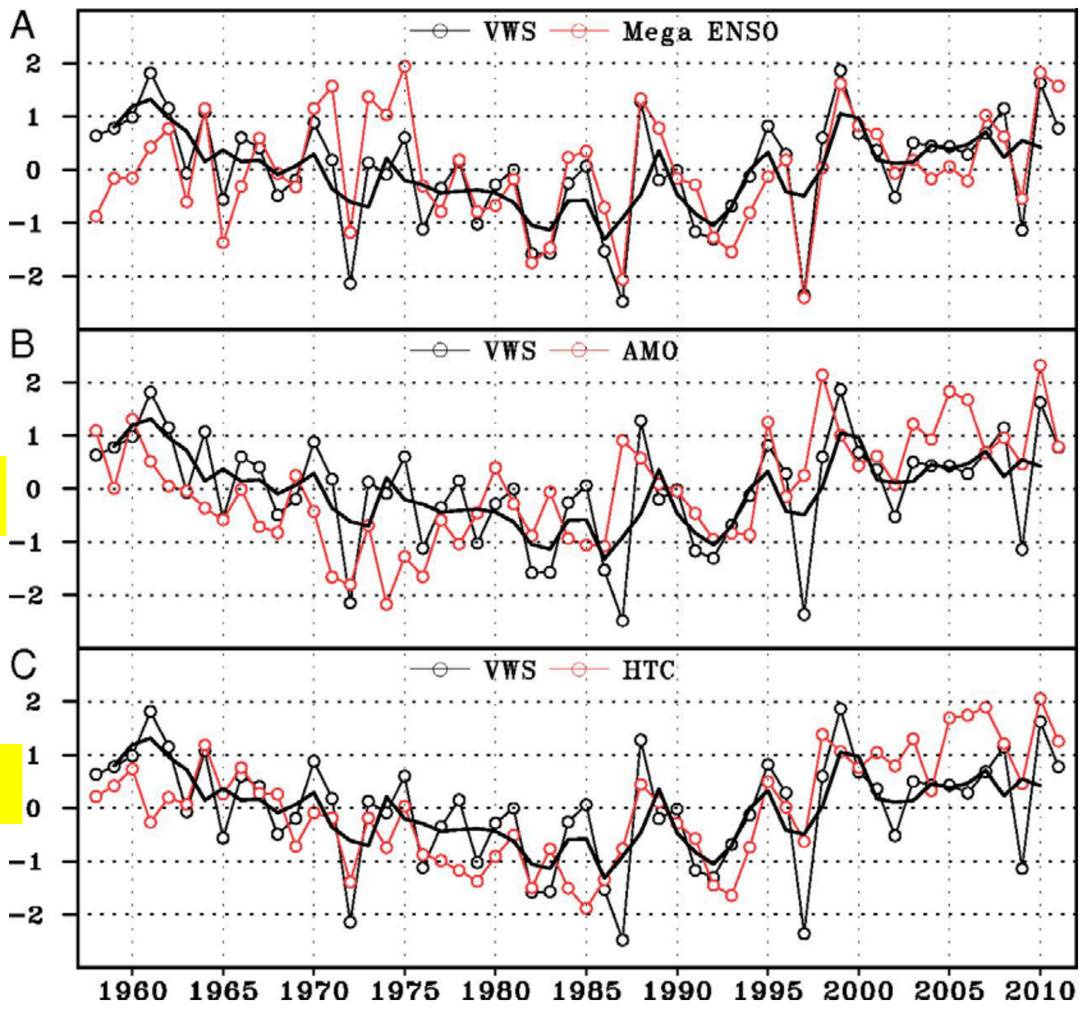
PDO, AMO and NH monsoon

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

PDO

AMO

HTC



Cor=0.77

Cor=0.44

Cor=0.63

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

We demonstrate the mechanism by numerical modeling

Model & Experiments

◆NCAR CAM2: T42L26

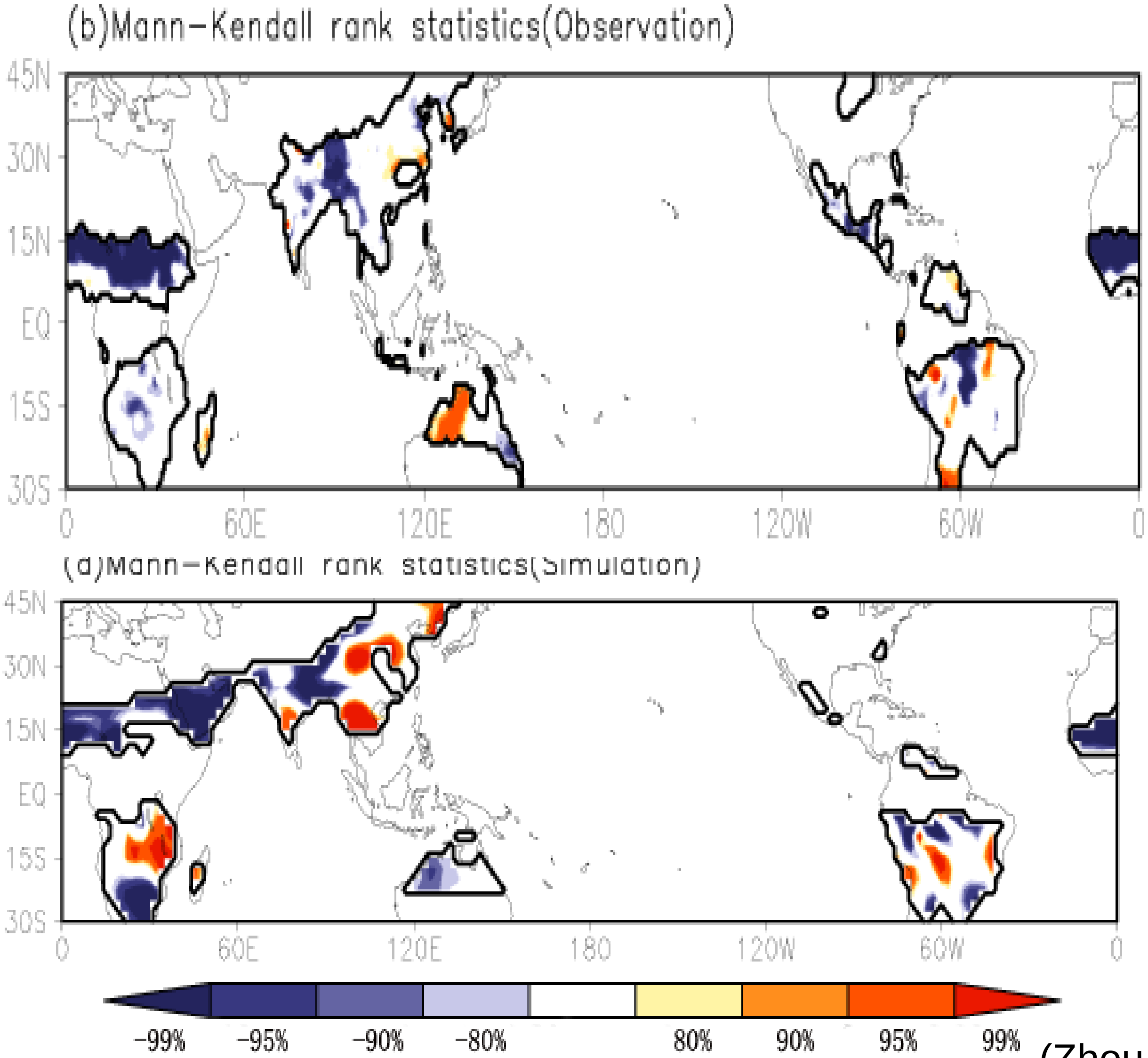
◆Global SST-forced 15-member ensemble simulation.

◆Time period:

January 1949 to October 2001

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

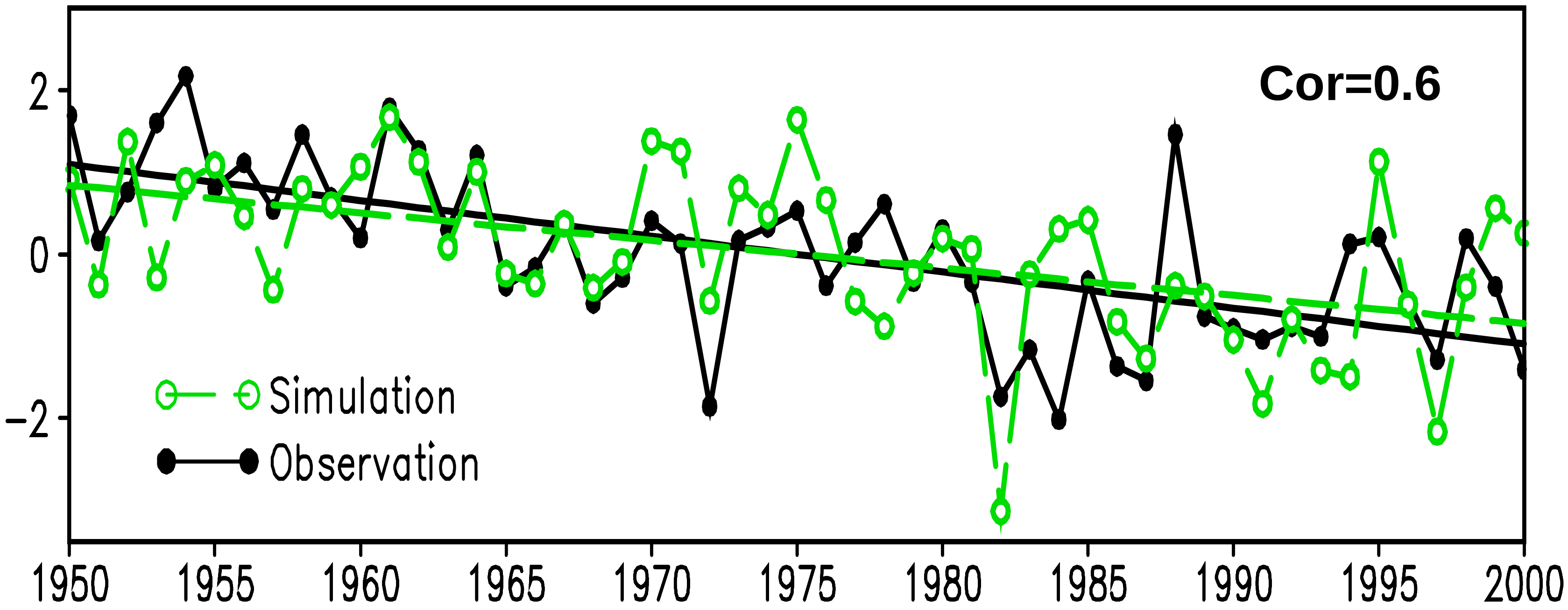


Observation

Simulation

(Zhou et al. 2008 J. Climate)

The observed and simulated Global Land monsoon index



SST-driven AGCM ensemble simulation, with 12 realizations

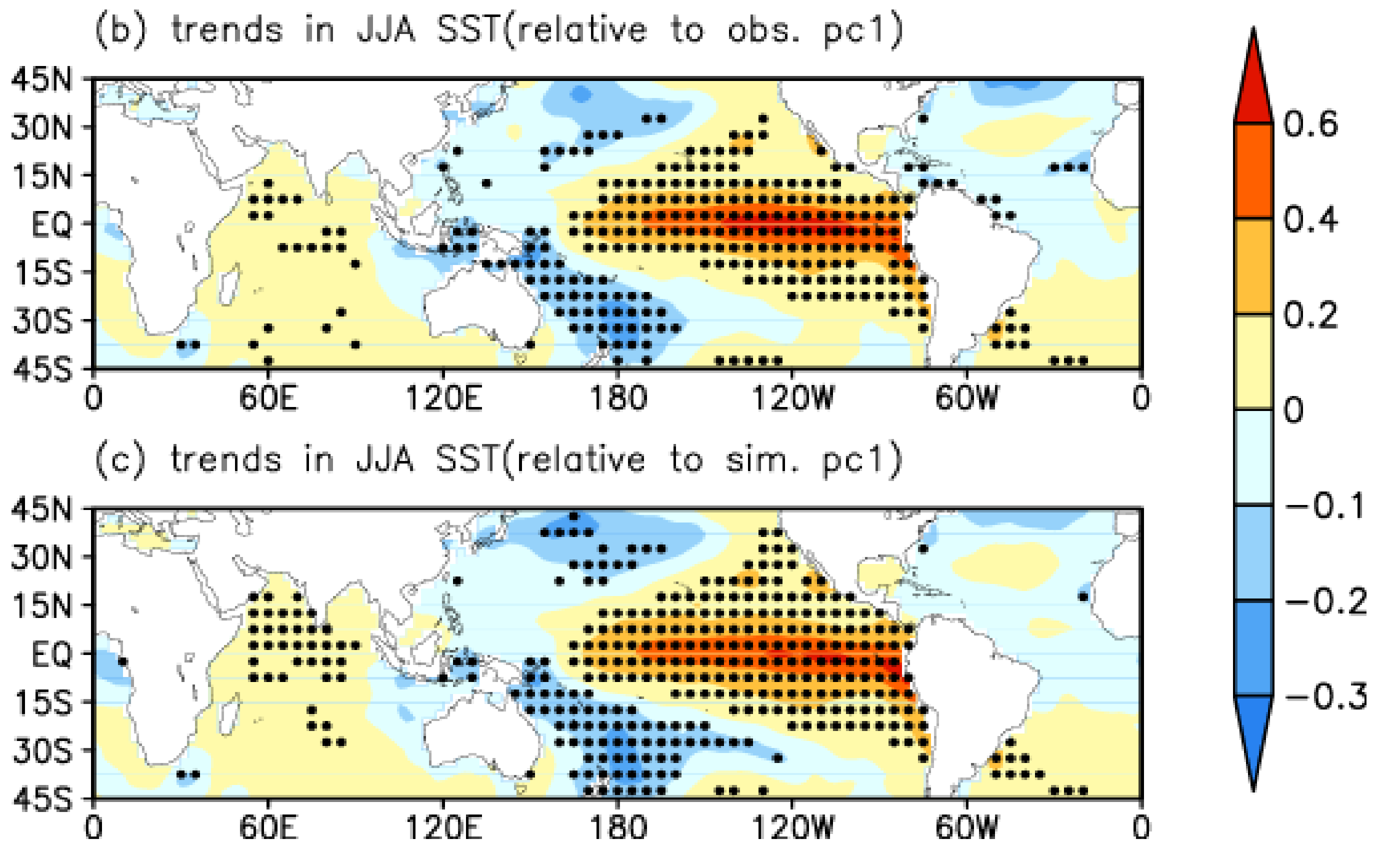
Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

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

East Asian summer monsoon: 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)

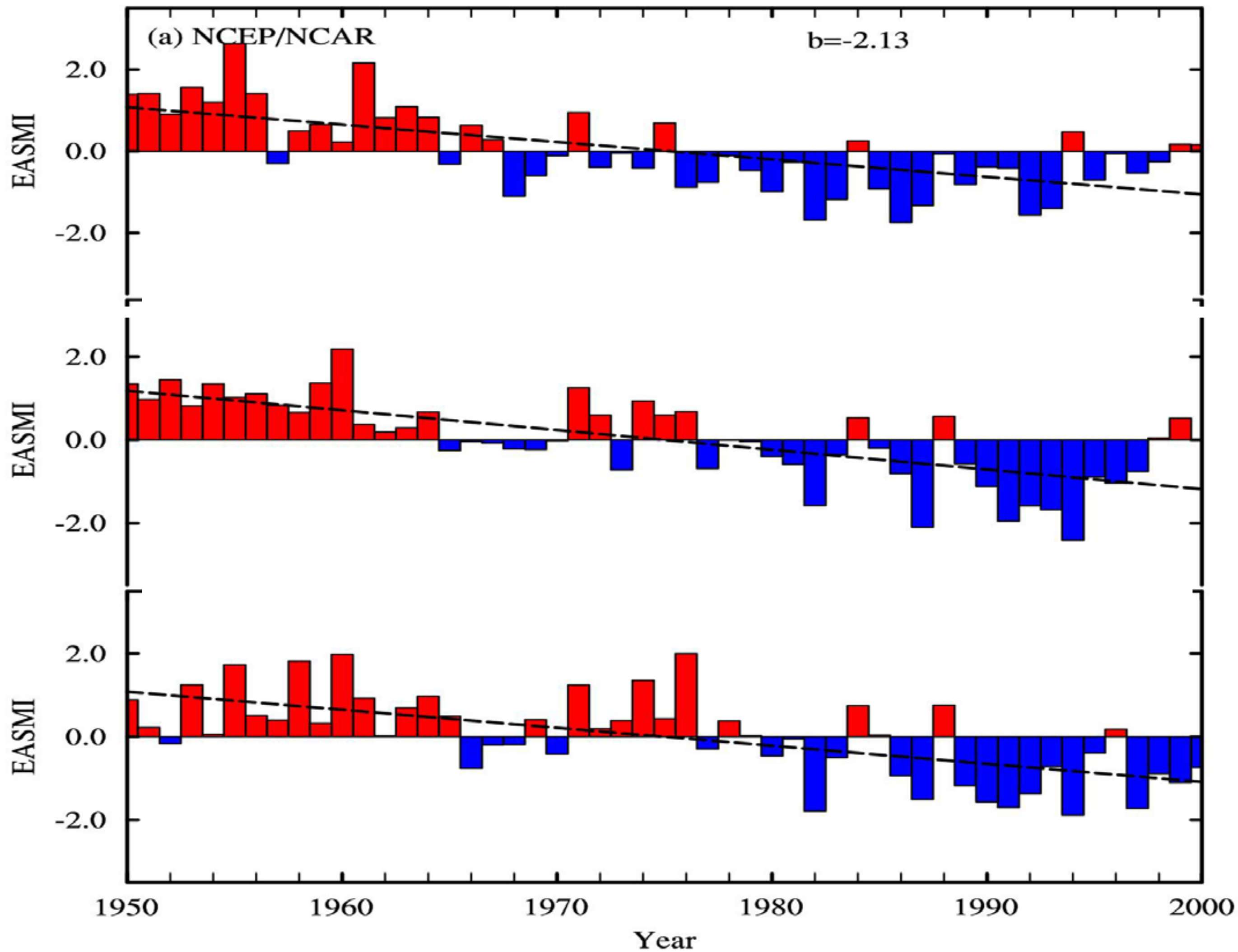
Li, Hongmei, A. Dai, **T. Zhou**, J. Lu, 2010: Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950-2000, ***Climate Dynamics*, 34**, 501-514

EASM index in AGCM driven by observed SST

Reanalysis

Global SST driven AGCM

Tropical SST driven AGCM



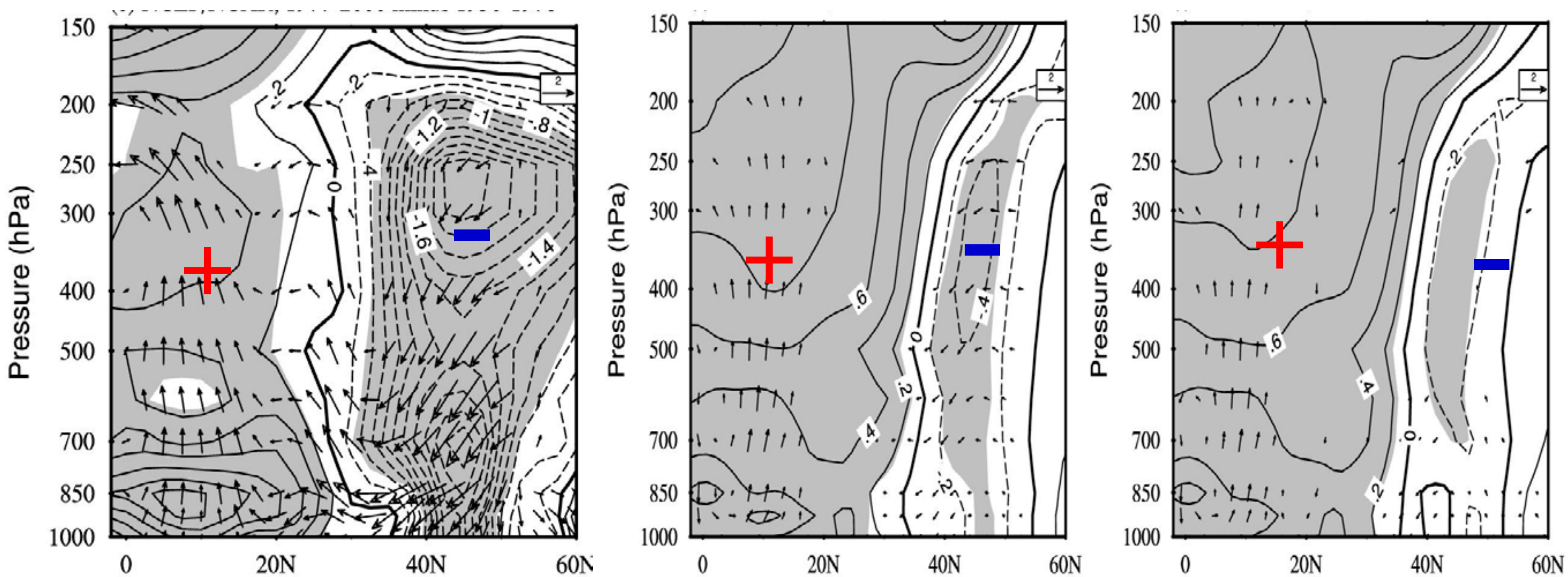
Li, Hongmei, A. Dai, **T. Zhou**, J. Lu, 2010: Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950-2000, ***Climate Dynamics*, 34**, 501–514

Land-Sea Thermal Contrast change

(105-122° E average）

(1980-99) －(1958-79)

Reanalysis | **Global SST-forcing** | **Tropical SST-forcing**



CLM

Cold Ocean ↑ **Warm Land**

Cold Ocean ↑ **Warm land**

Cold Ocean ↑ **Warm land**

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

Interim Summary 2

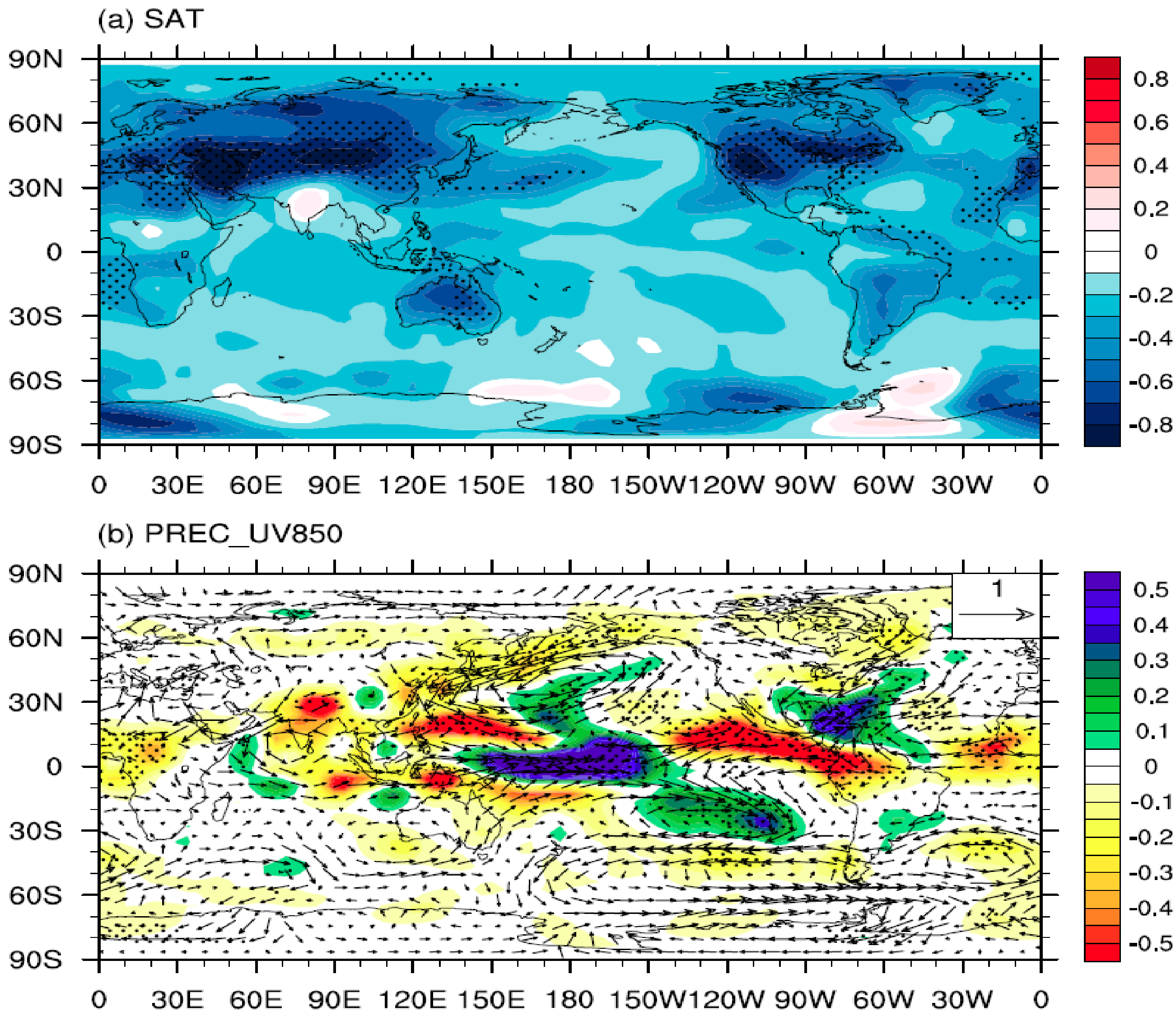
- The decreasing tendency of GM in the period of 1949-2001 was driven by the warming trend over the central-eastern Pacific and the western tropical Indian Ocean, which is the tropical lobe of PDO/IPO.
- The weakening tendency of E. Asian summer monsoon circulation is also dominated by the tropical lobe of PDO/IPO.

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

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


Volcanic aerosols

Summer climate after large volcanic eruptions.



Man, W., **T. Zhou,** , J. H. Jungclaus, 2014: Effects of Large Volcanic Eruptions on Global Summer Climate and East Asian Monsoon Changes during the Last Millennium: Analysis of MPI-ESM simulations, ***Journal of Climate***, 27, 7394-7409

GHG & Aerosols

SO2 and Black Carbon emission from the preindustrial to present

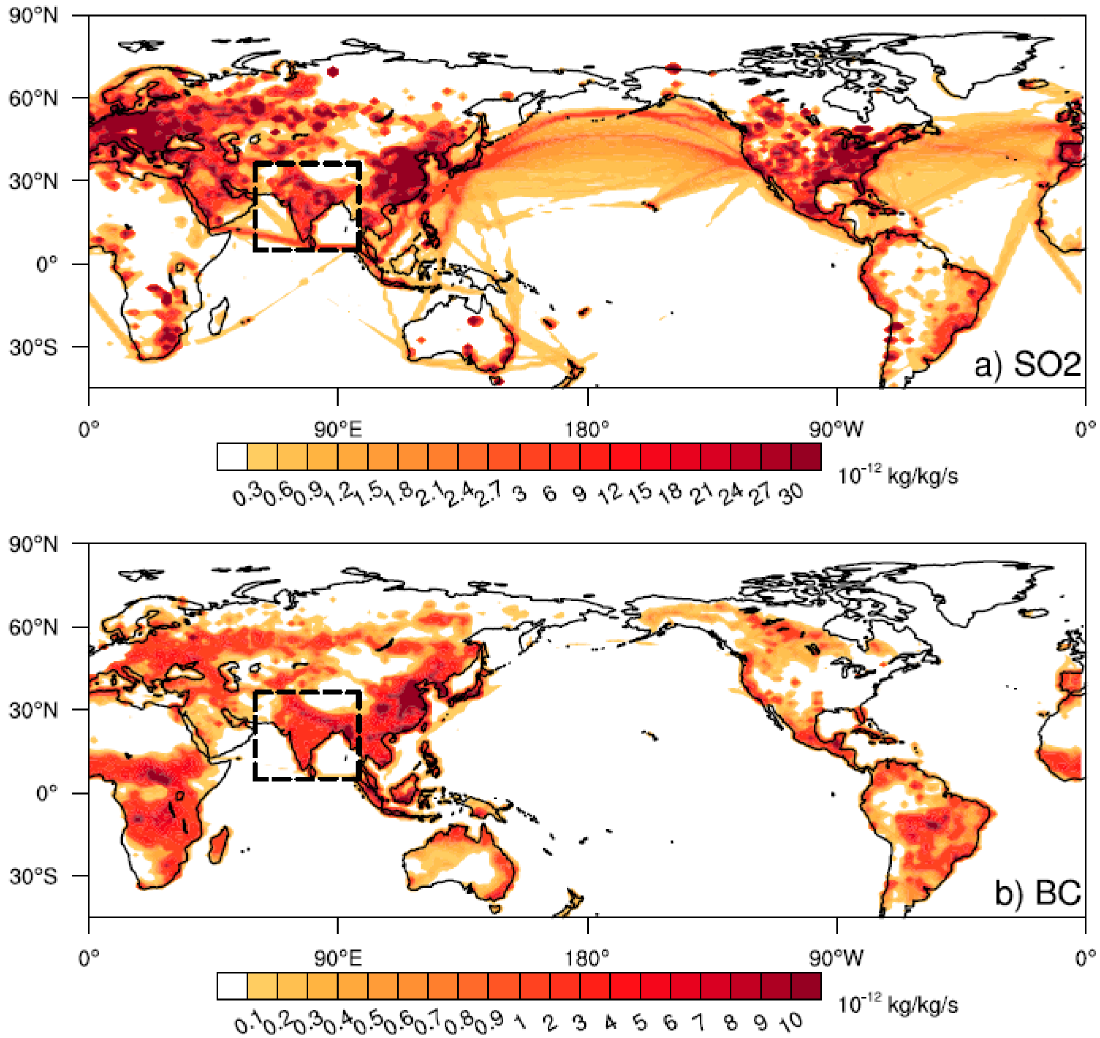
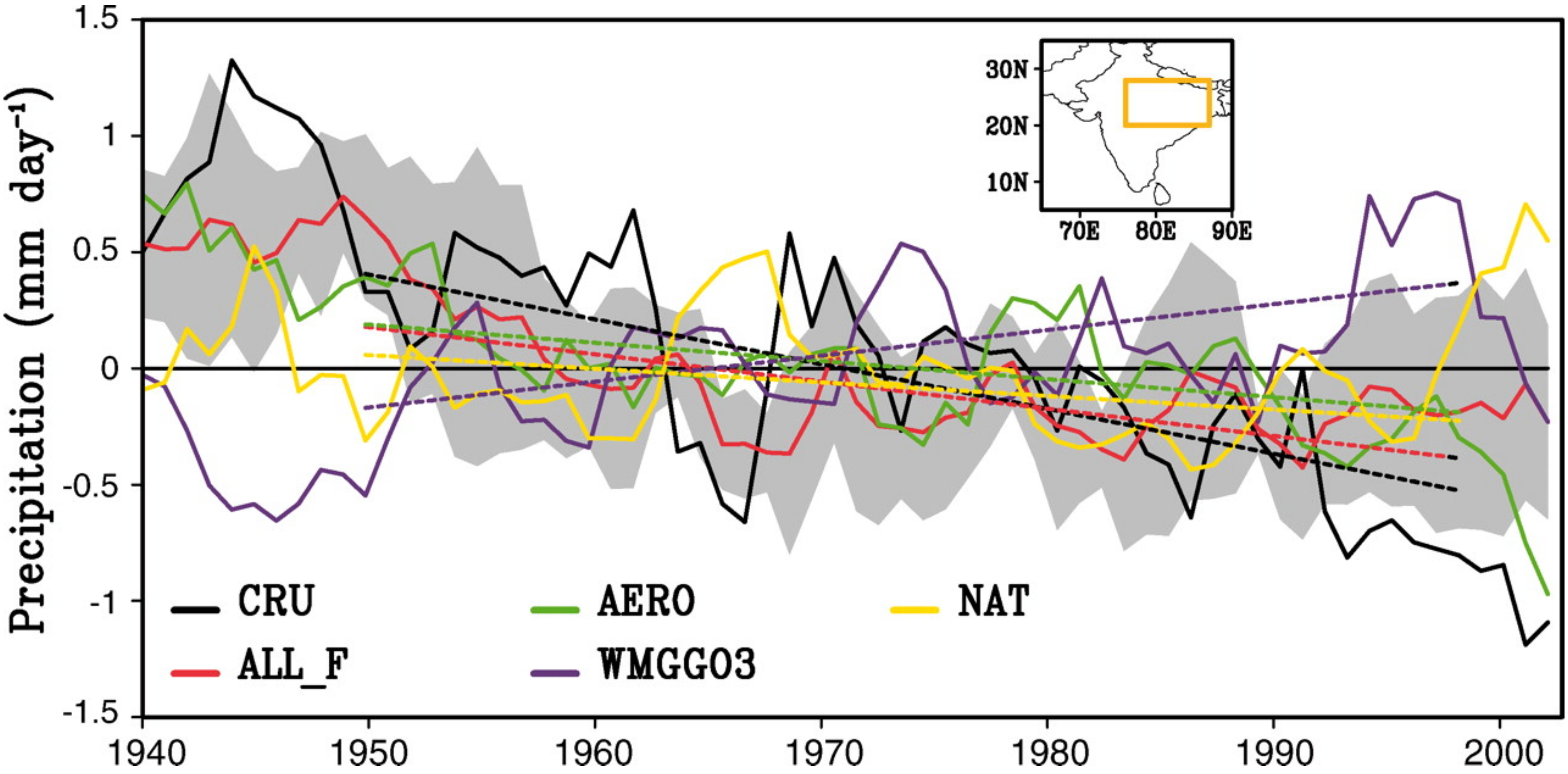


FIG. 1. Change of emissions (10^{-12} kg kg^{-1} s^{-1}) from the preindustrial (1860) to present-day (1976–2005) periods: (a) SO_2 and (b) BC. Data are from the RCPs database (Smith et al. 2001; Bond et al. 2007).

Guo, Turner et al. 2016 JC

Five-year running mean June-September average precipitation anomalies over central-northern India

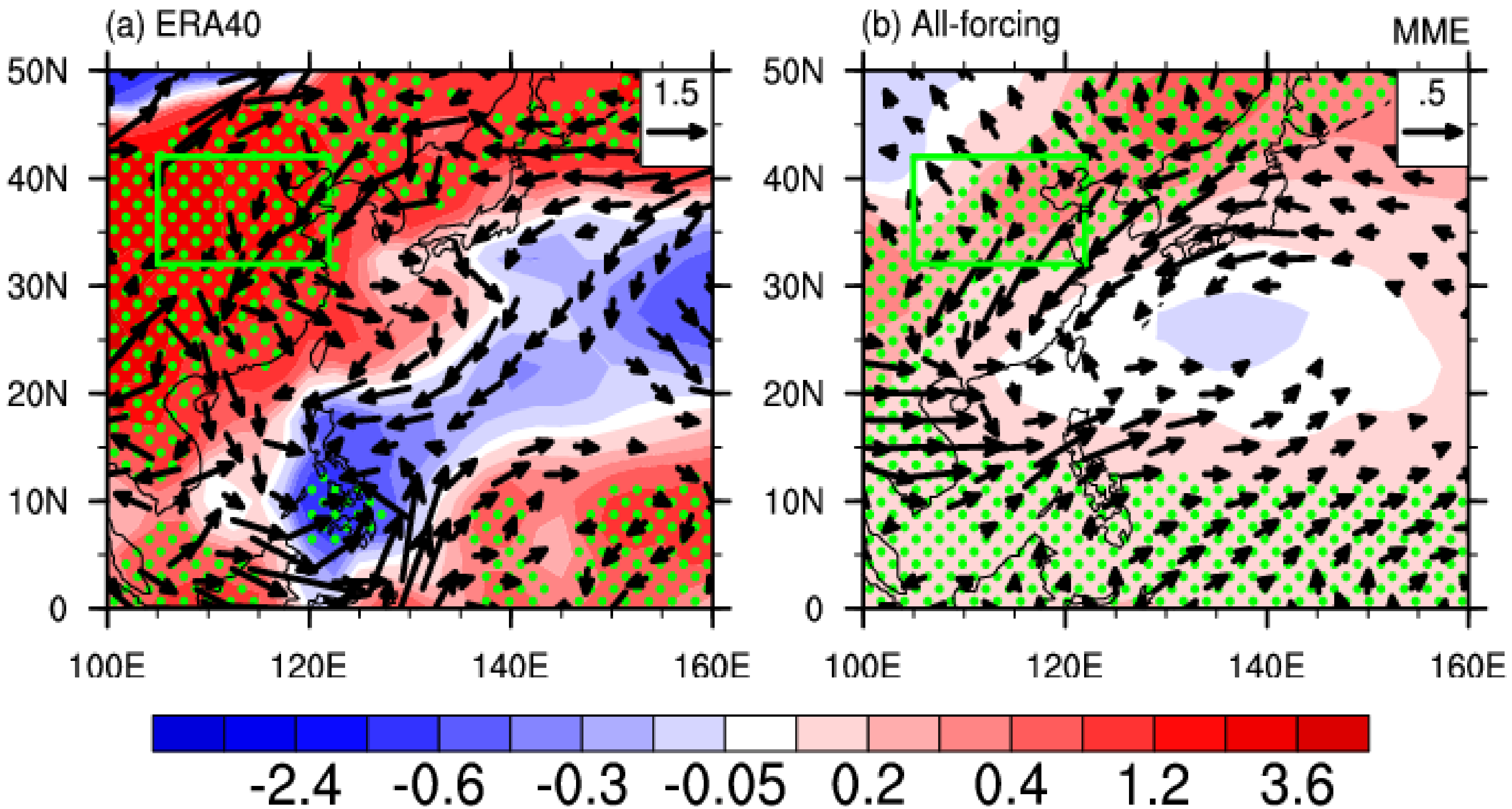


The red, green, blue, and yellow lines are for the ensemble-mean all-forcing (ALL_F), aerosol-only (AERO), greenhouse gases and ozone-only (WMGGO3), and natural forcing-only (NAT) CM3 historical integrations, respectively.

Bollasina et al. 2011 Science


How about the East Asian summer monsoon ?

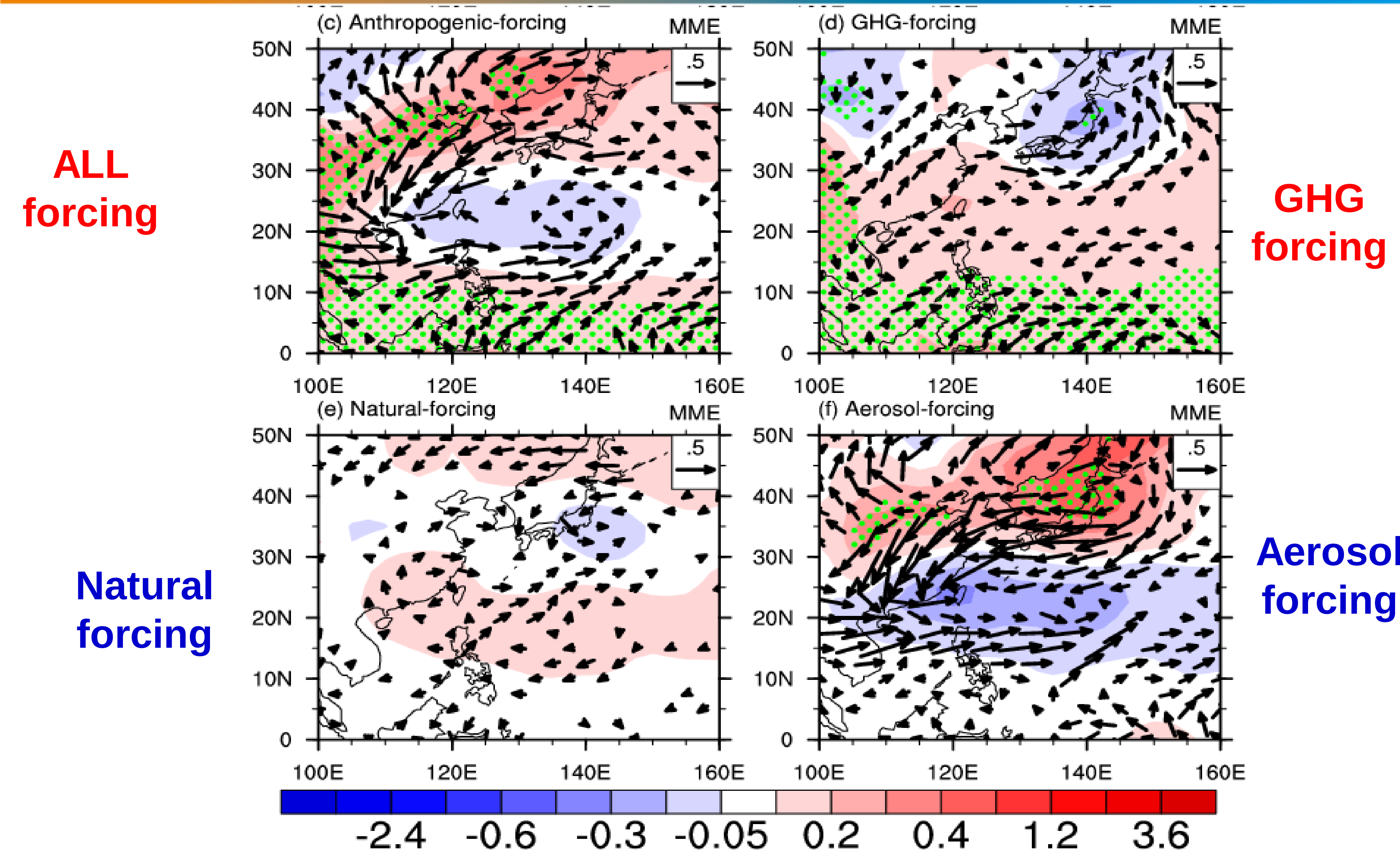
Linear trends of SLP and 850 hPa winds (1958-2001)



ERA40 **MME of CMIP5**

Song F., **T. Zhou**, and Y. Qian, 2013: Responses of East Asian summer monsoon to natural and anthropogenic forcings in the 17 latest CMIP5 models. *Geophysical Research Letters, 10.1002/2013GL058705*

Linear trends of SLP and 850 hPa winds (1958-2001)



Song F., **T. Zhou**, and Y. Qian, 2013: Responses of East Asian summer monsoon to natural and anthropogenic forcings in the 17 latest CMIP5 models. *Geophysical Research Letters, 10.1002/2013GL058705*

Interim Summary 3

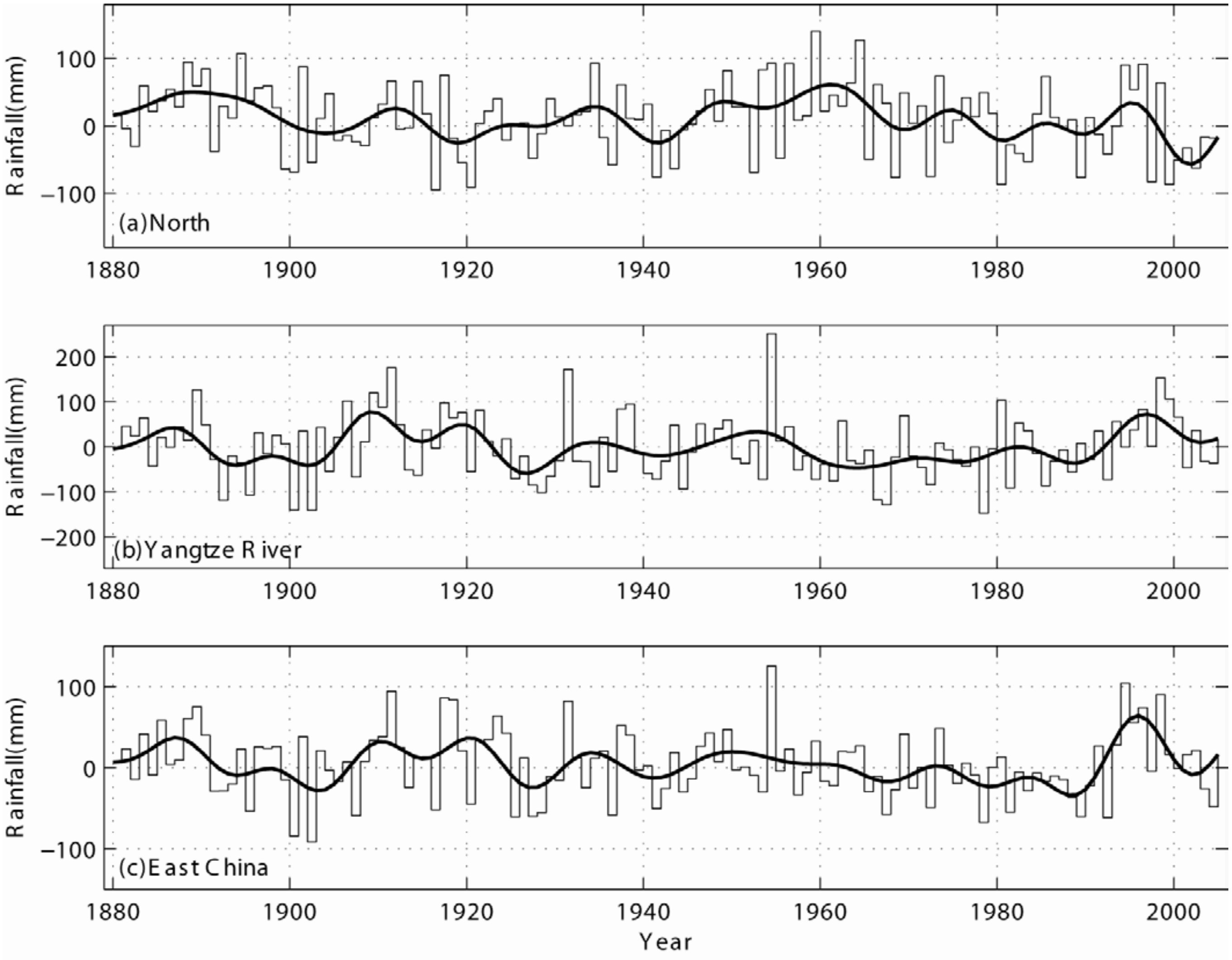
- External forcing such as volcanic aerosols is able to drive the GM changes.
- The specified anthropogenic aerosol forcing in CMIP5 models has driven a weakened low-level EA summer monsoon circulation during 1958-2001.
- The increasing GHG forcing is favorable for an enhanced monsoon circulation.

Song F., **T. Zhou**, and Y. Qian, 2013: Responses of East Asian summer monsoon to natural and anthropogenic forcings in the 17 latest CMIP5 models. *Geophysical Research Letters, 10.1002/2013GL058705*

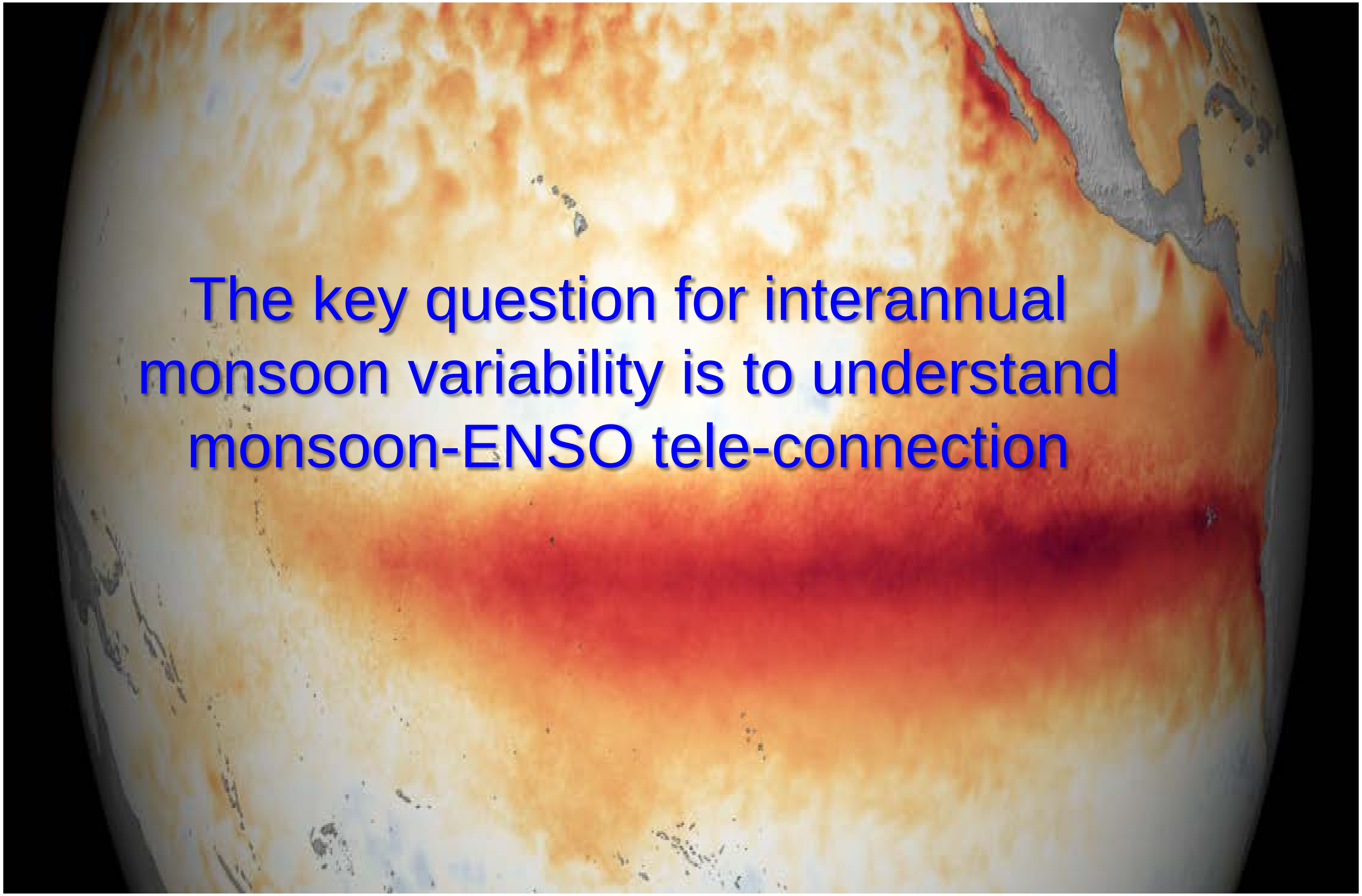
Outline

1. East Asian monsoon changes in the context of global monsoon
2. Understanding long term changes
3. Interannual variability
4. GMMIP for CMIP6
5. Concluding remarks

East Asian summer rainfall

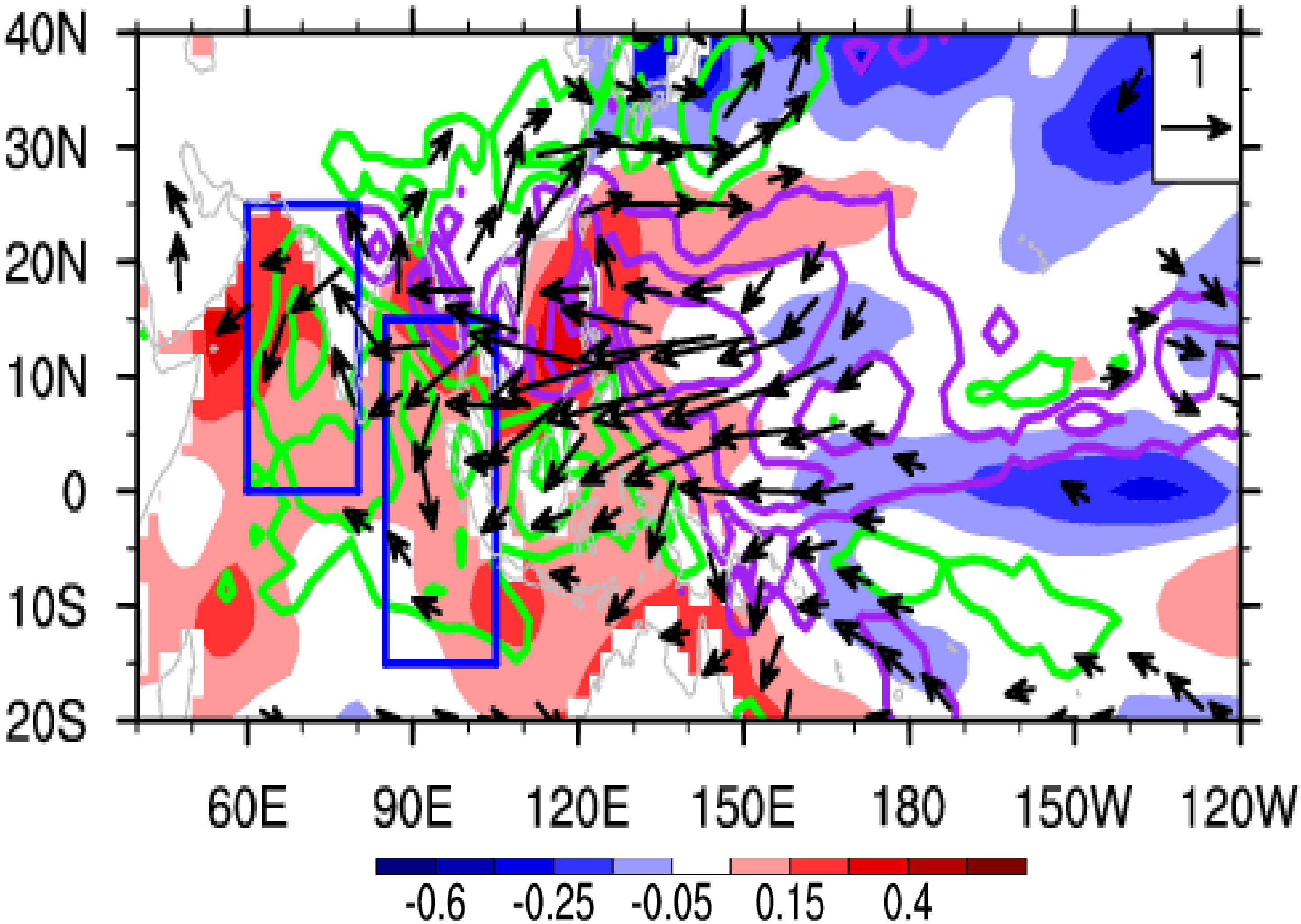


Zhou, T., D. Gong, J. Li, B. Li, 2009: Detecting and understanding the multi-decadal variability of the East Asian Summer Monsoon- Recent progress and state of affairs. *Meteorologische Zeitschrift*, 18 (4), 455-467


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

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

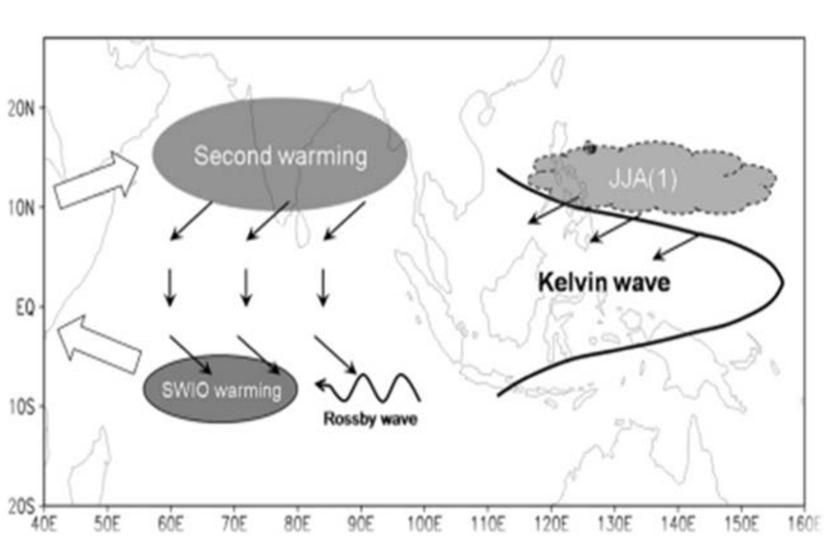
SST (shading), UV850 hPa (Vector), precipitation (contour)



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.

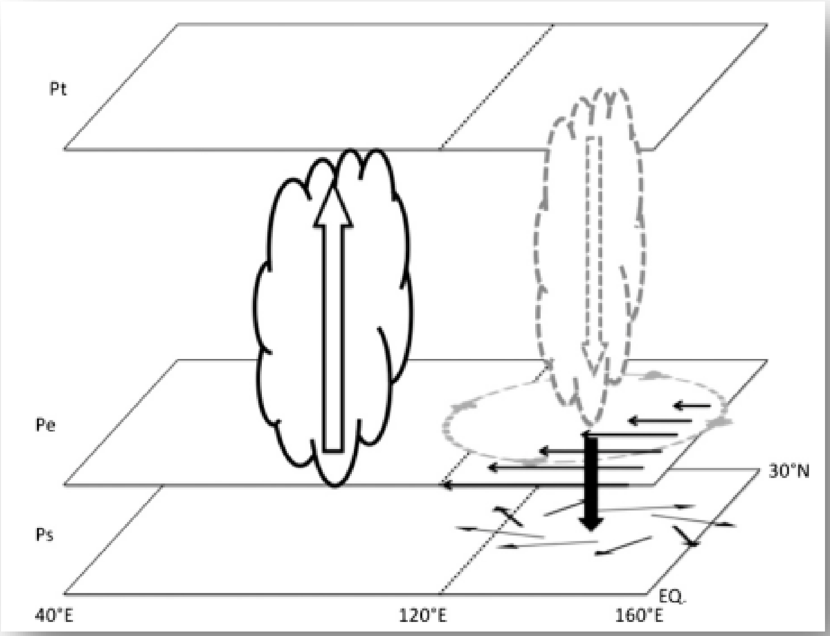
Indian Ocean warming –western North Pacific Anticyclone

Indian Ocean capacitor effect



(Xie et al. 2009 JC)

Ekman pumping



(Wu et al. 2009 JC)

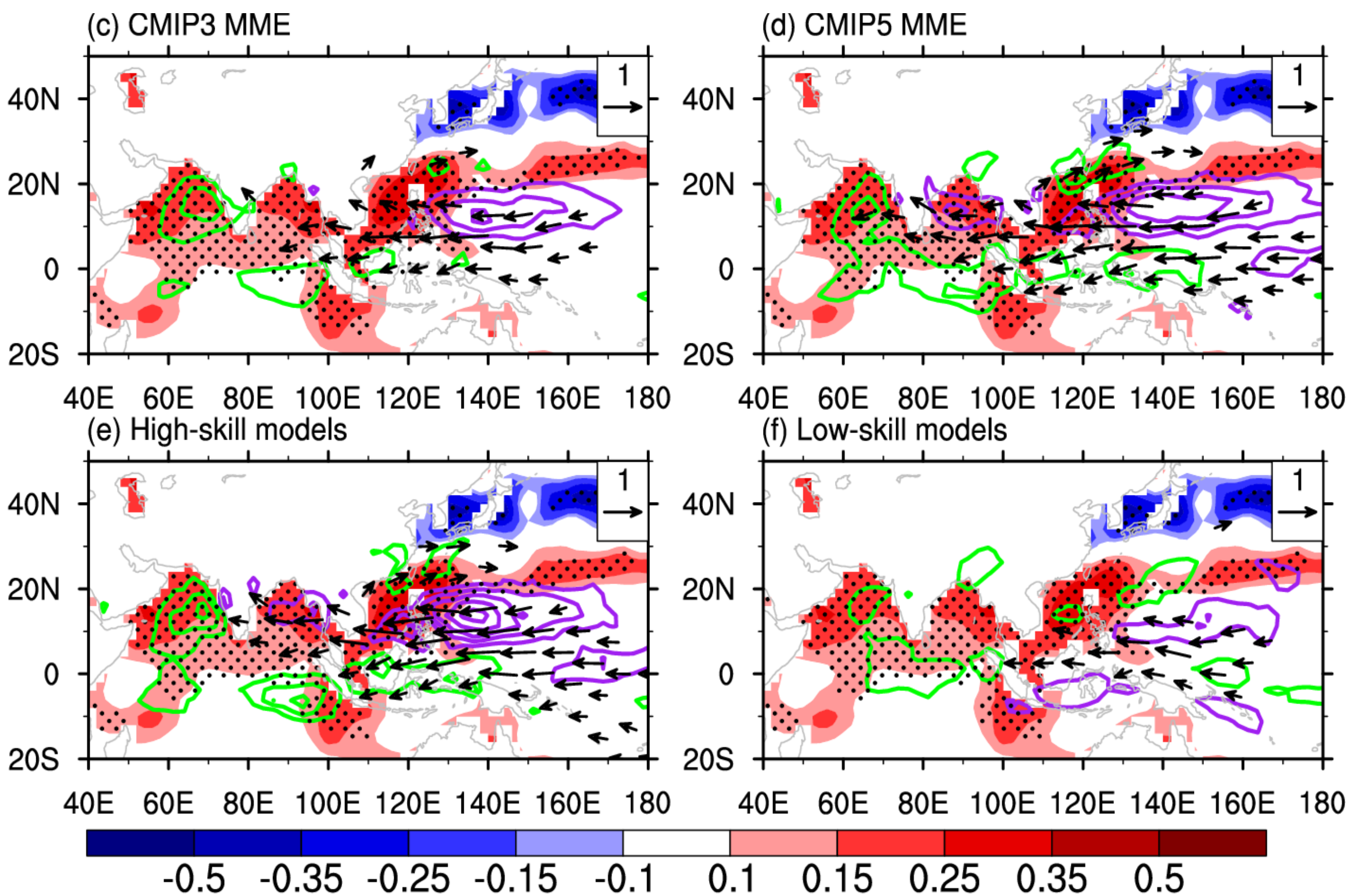
See Bo WU's talk later for details

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

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

Interim Summary 4

- The impact of El Nino on EA monsoon is significant in El Nino decaying year summer through Indian Ocean-Western Pacific tele-connection.
- The teleconnection is maintained by the combined effects of the local forcing of the negative SSTA in the WNP and the remote forcing from the IOBM.
- CMIP3 versus CMIP5 models:

  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

Outline

1. East Asian monsoon changes in the context of global monsoon
2. Understanding long term changes
3. Interannual variability
4. GMMIP for CMIP6
5. Concluding remarks

What is GMMIP?

◆GMMIP:

Global Monsoons Model Inter-comparison Project

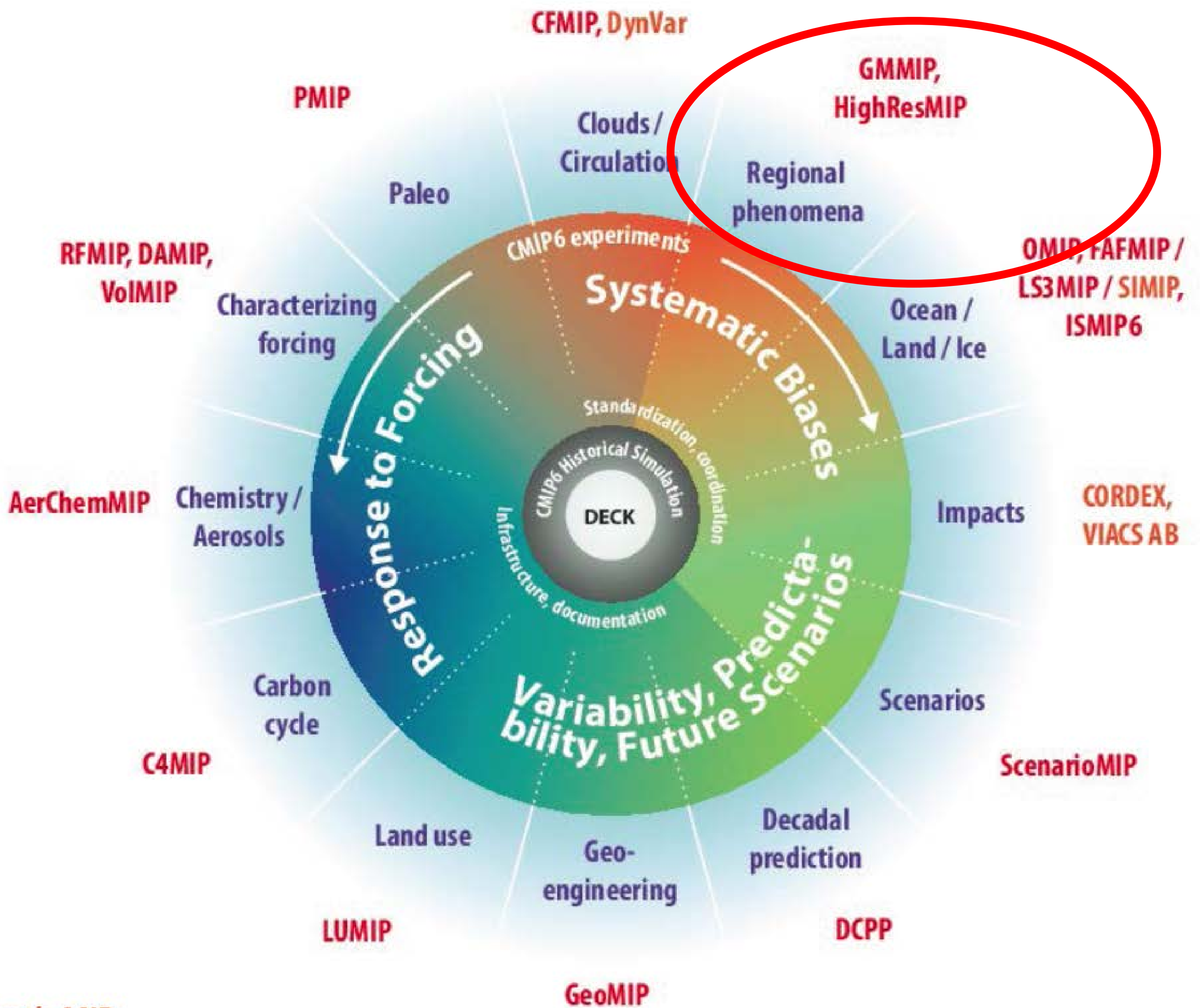
◆One of the 18(21) MIPs for WCRP CMIP6

◆Proposed by former CLIVAR AAMP, now CLIVAR/GEWEX Monsoons Panel & CLIVAR/C20C+

◆Co-chairs: Tianjun Zhou, Andy Turner, James Kinter III

◆Secretariat: IAP,CAS

21 CMIP6-Endorsed MIPs

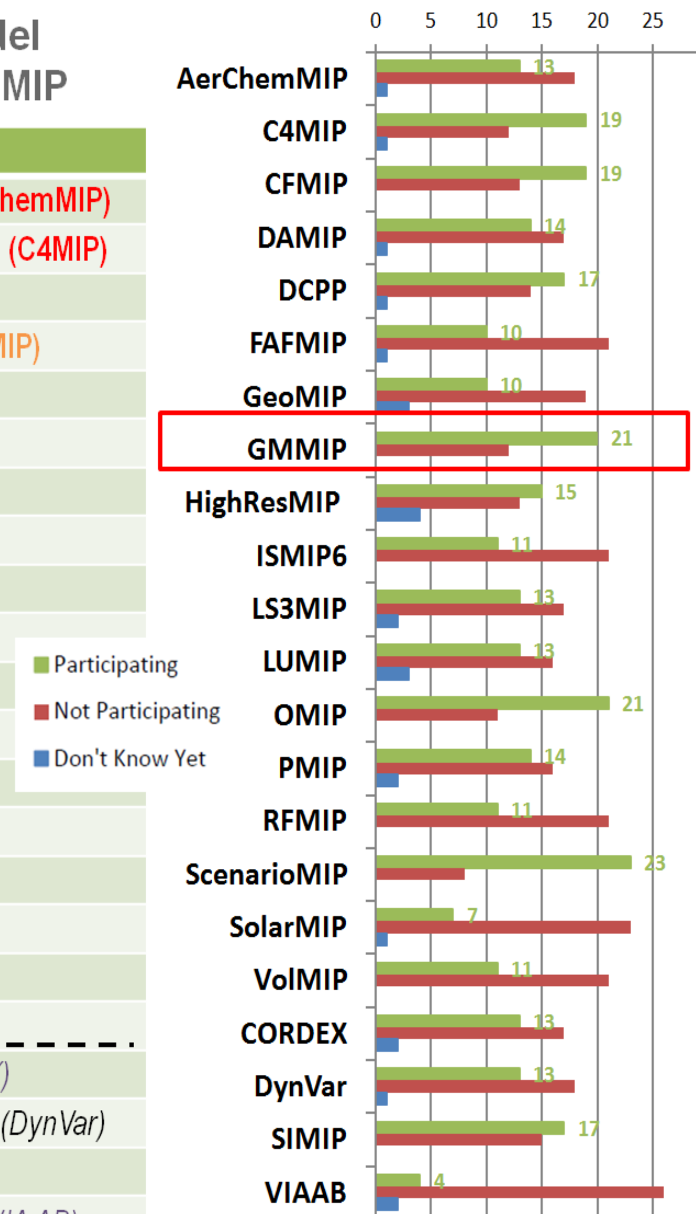


Diagnostic MIPs

Model Groups' Commitments to participate in each MIP

Proposals from CMIP6-Endorsed MIPs & Model Groups' Commitments to Participate in each MIP

	Long Name of MIP (Short Name of MIP)
1	Aerosols and Chemistry Model Intercomparison Project (AerChemMIP)
2	Coupled Climate Carbon Cycle Model Intercomparison Project (C4MIP)
3	Cloud Feedback Model Intercomparison Project (CFMIP)
4	Detection and Attribution Model Intercomparison Project (DAMIP)
5	Decadal Climate Prediction Project (DCPP)
6	Flux-Anomaly-Forced Model Intercomparison Project (FAFMIP)
7	Geoengineering Model Intercomparison Project (GeoMIP)
8	Global Monsoons Model Intercomparison Project (GMMIP)
9	High Resolution Model Intercomparison Project (HighResMIP)
10	Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6)
11	Land Surface, Snow and Soil Moisture MIP (LS3MIP)
12	Land-Use Model Intercomparison Project (LUMIP)
13	Ocean Model Intercomparison Project (OMIP)
14	Palaeoclimate Modelling Intercomparison Project (PMIP)
15	Radiative Forcing Model Intercomparison Project (RFMIP)
16	Scenario Model Intercomparison Project (ScenarioMIP)
17	Solar Model Intercomparison Project (SolarMIP)
18	Volcanic Forcings Model Intercomparison Project (VolMIP)
19	*Coordinated Regional Climate Downscaling Experiment (CORDEX)*
20	*Dynamics and Variability of the Stratosphere-Troposphere System (DynVar)*
21	*Sea-Ice Model Intercomparison Project (SIMIP)*
22	*Vulnerability, Impacts, and Adaptation Advisory Board for CMIP6 (VIA AB)*



CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

Primary Scientific Questions of GMMIP

1. What are the relative contributions of internal processes and external forcings that have driven the 20th century historical evolution of global monsoons?
2. To what extent and how does the ocean-atmosphere interaction affect the interannual variability and predictability of monsoons?
3. How well can developing high-resolution models and improving model dynamics and physics help to reliably simulate monsoon precipitation and its variability and change?
4. What are the effects of Eurasian orography, in particular the Himalaya/Tibetan Plateau, on the regional/global monsoons?

GMMIP Exps and related other MIPs

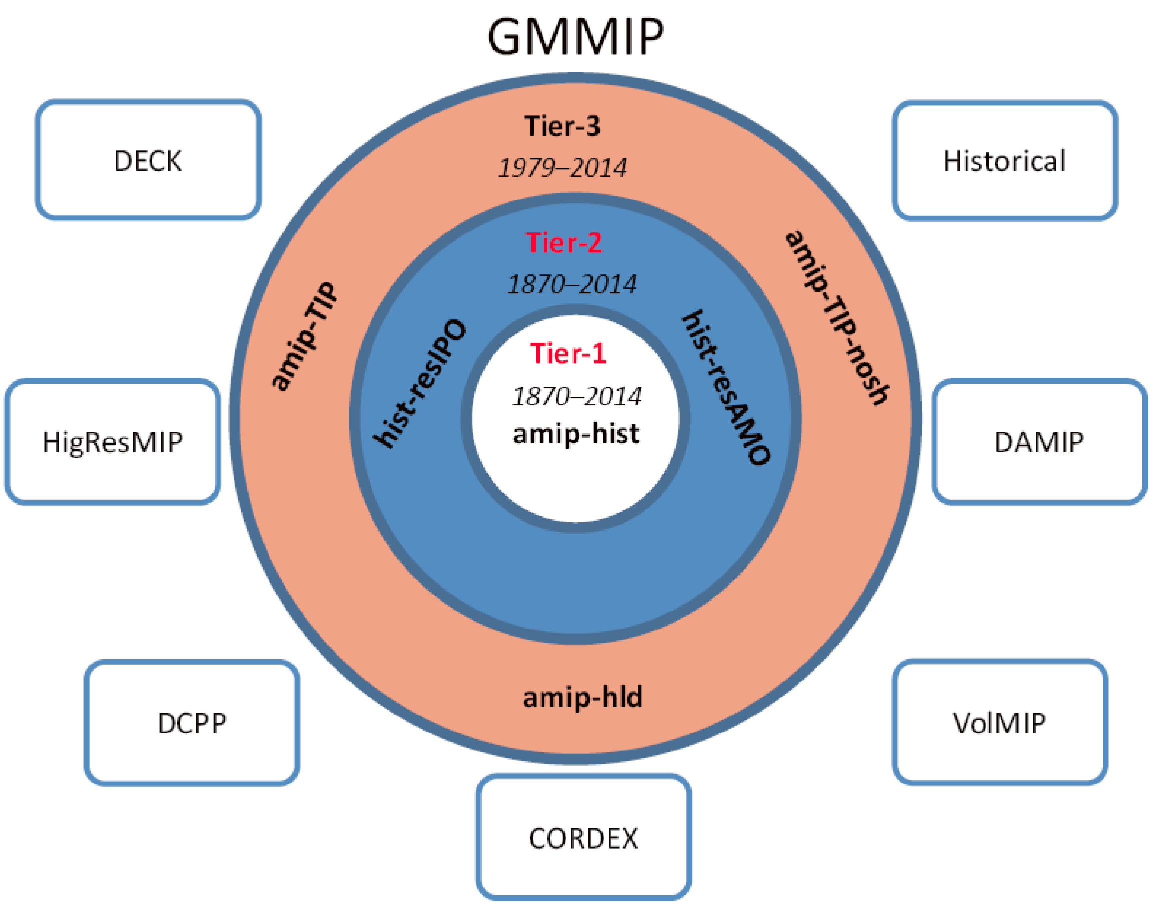
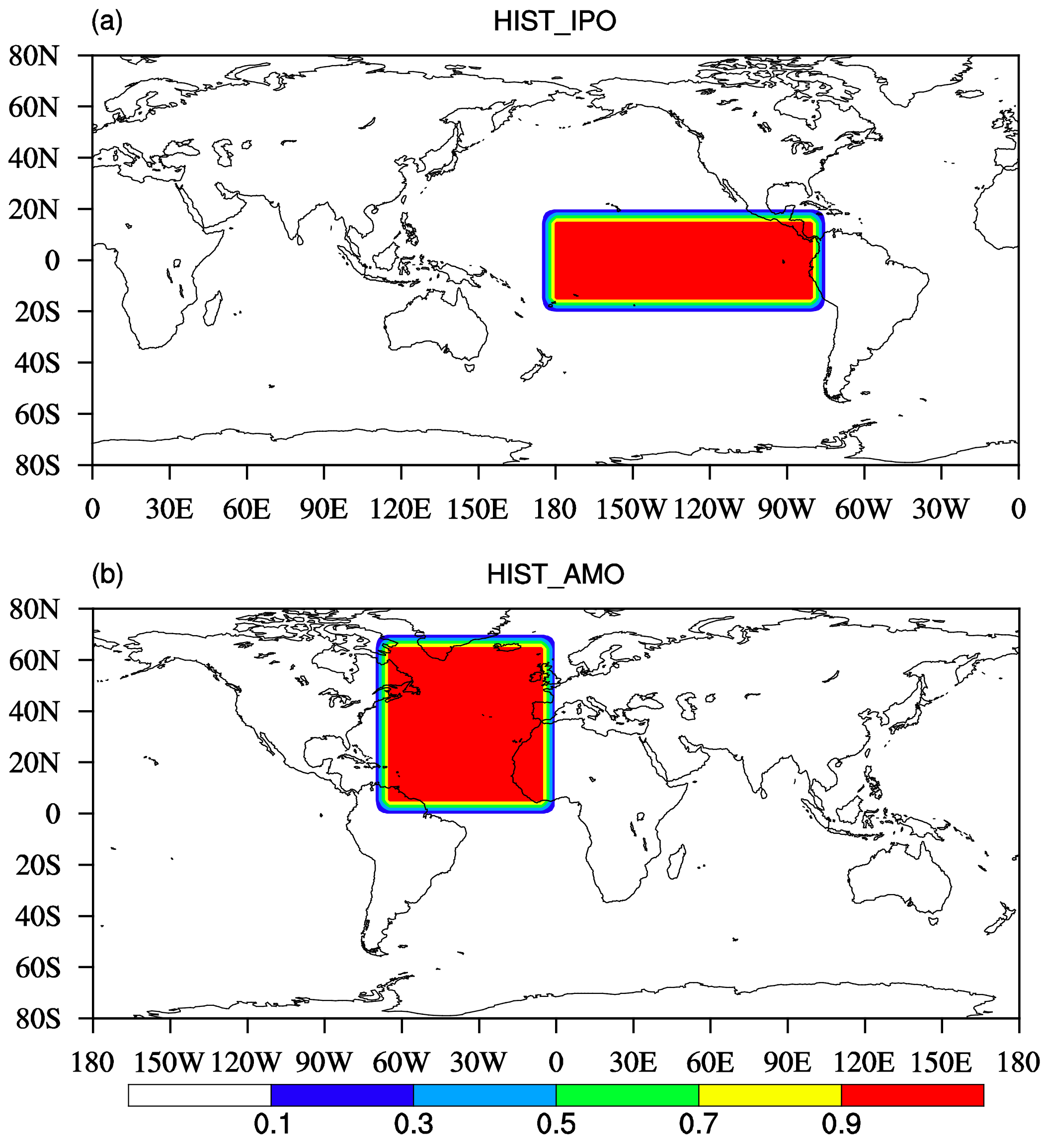
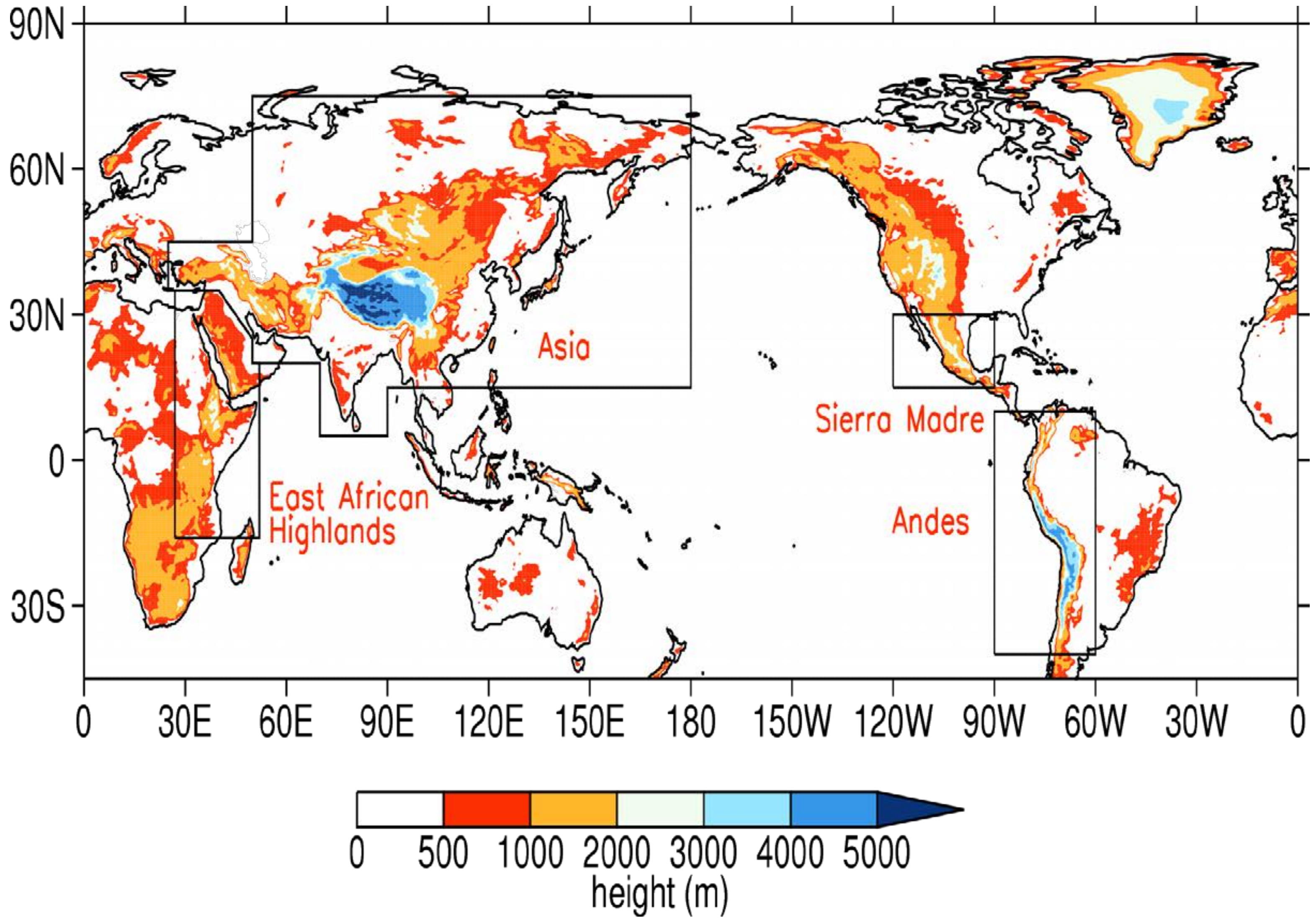


Figure 3. Three-tier experiments of GMMIP and its connections with DECK, historical simulation and endorsed MIPs.

IPO、AMO Pacemaker Exps



Orography regions specified for the Tier-3 experiments



Concluding Remarks

- East Asian monsoon change is part of the global monsoon.
- Both the internal (IPO and AMO) and the external forcing (GHG, aerosol) contributes to the EA and GM changes, but their relative contributions remain unclear.
- GMMIP will focus on the understanding of dynamical & physical processes dominating the changes of global monsoon systems.
- It provides a good platform for the climate modeling community in monsoon studies.

Geosci. Model Dev., 9, 1–16, 2016
www.geosci-model-dev.net/9/1/2016/
doi:10.5194/gmd-9-1-2016

Geoscientific Model Development
Open Access
EGU

GMMIP (v1.0) contribution to CMIP6: Global Monsoons Model Inter-comparison Project

Tianjun Zhou[1], Andrew G. Turner[2], James L. Kinter[3], Bin Wang[4], Yun Qian[5], Xiaolong Chen[1], Bo Wu[1], Bin Wang[1], Bo Liu[1,6], Liwei Zou[1], and Bian He[1]

[1]LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China
[2]NCAS-Climate and Department of Meteorology, University of Reading, Reading, UK
[3]Center for Ocean-Land-Atmosphere Studies & Dept. of Atmospheric, Oceanic & Earth Sciences, George Mason University, Fairfax, Virginia, USA
[4]Department of Meteorology, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii, USA
[5]Atmospheric Sciences & Global Change Division, Pacific Northwest National Laboratory, Richland, Washington, USA
[6]College of Earth Science, Graduate University of the Chinese Academy of Sciences, Beijing 100049, China

Correspondence to: Tianjun Zhou (zhoutj@lasg.iap.ac.cn)

Received: 30 March 2016 – Published in Geosci. Model Dev. Discuss.: 11 April 2016
Revised: 3 September 2016 – Accepted: 14 September 2016 – Published:

THANKS

http://www.lasg.ac.cn/gmmip

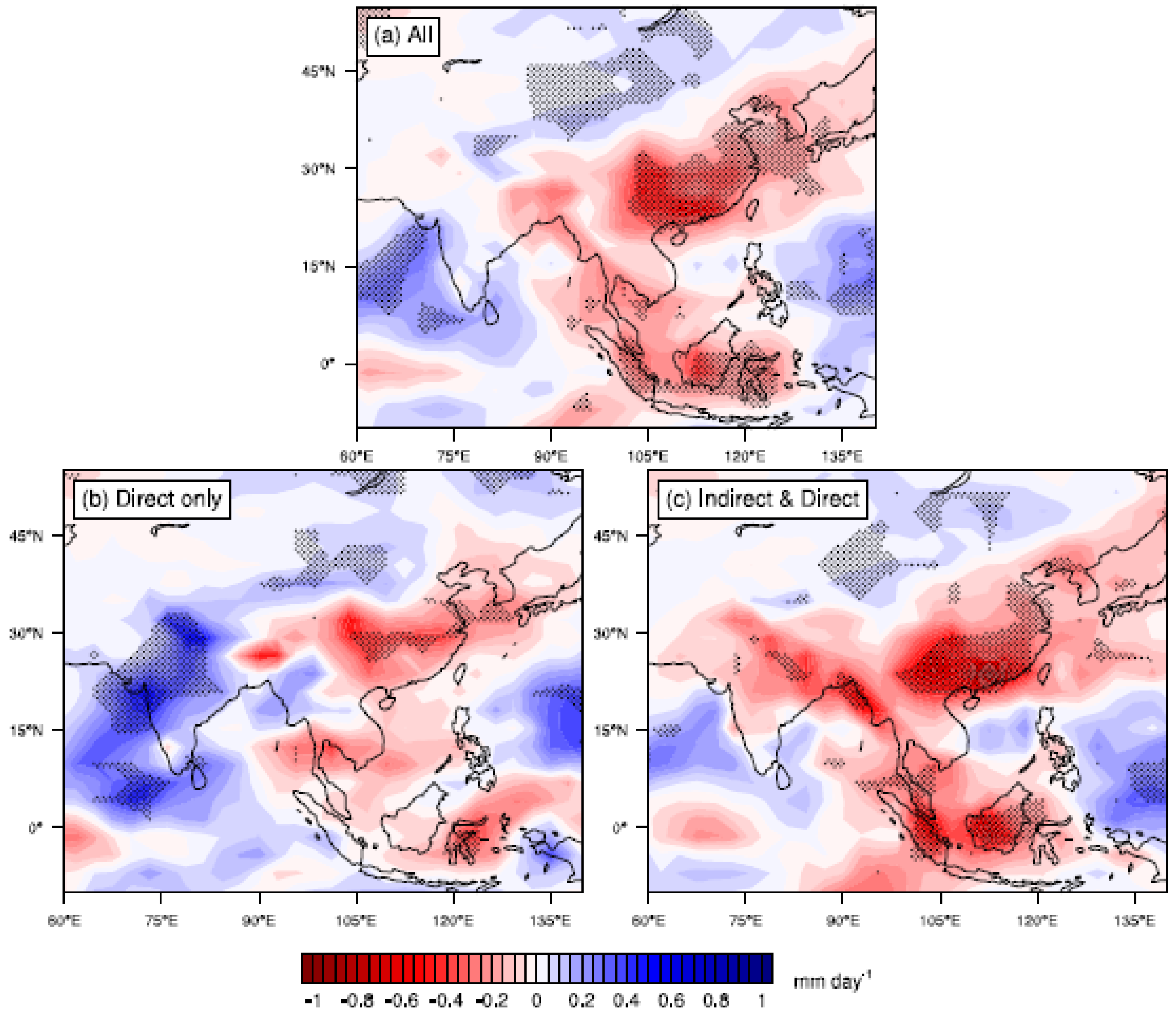
Details of three sets of CMIP5 experiments

Experiment description	CMIP5 label	Major purposes	Short name
Past ~1.5 centuries (1850–2005)	historical	Evaluation	**All-forcing**
historical simulation but with GhG forcing only	historicalGHG	Detection and attribution	**GHG-forcing**
historical simulation but with natural forcing only	historicalNat	Detection and attribution	**Natural-forcing**

- **According to Taylor et al. (2009), anthropogenic-forcing is estimated by All-forcing run minus Natural-forcing run.**
- **Aerosol-forcing is estimated by Anthropogenic-forcing run minus GHG-forcing run. 105 realizations are analyzed.**

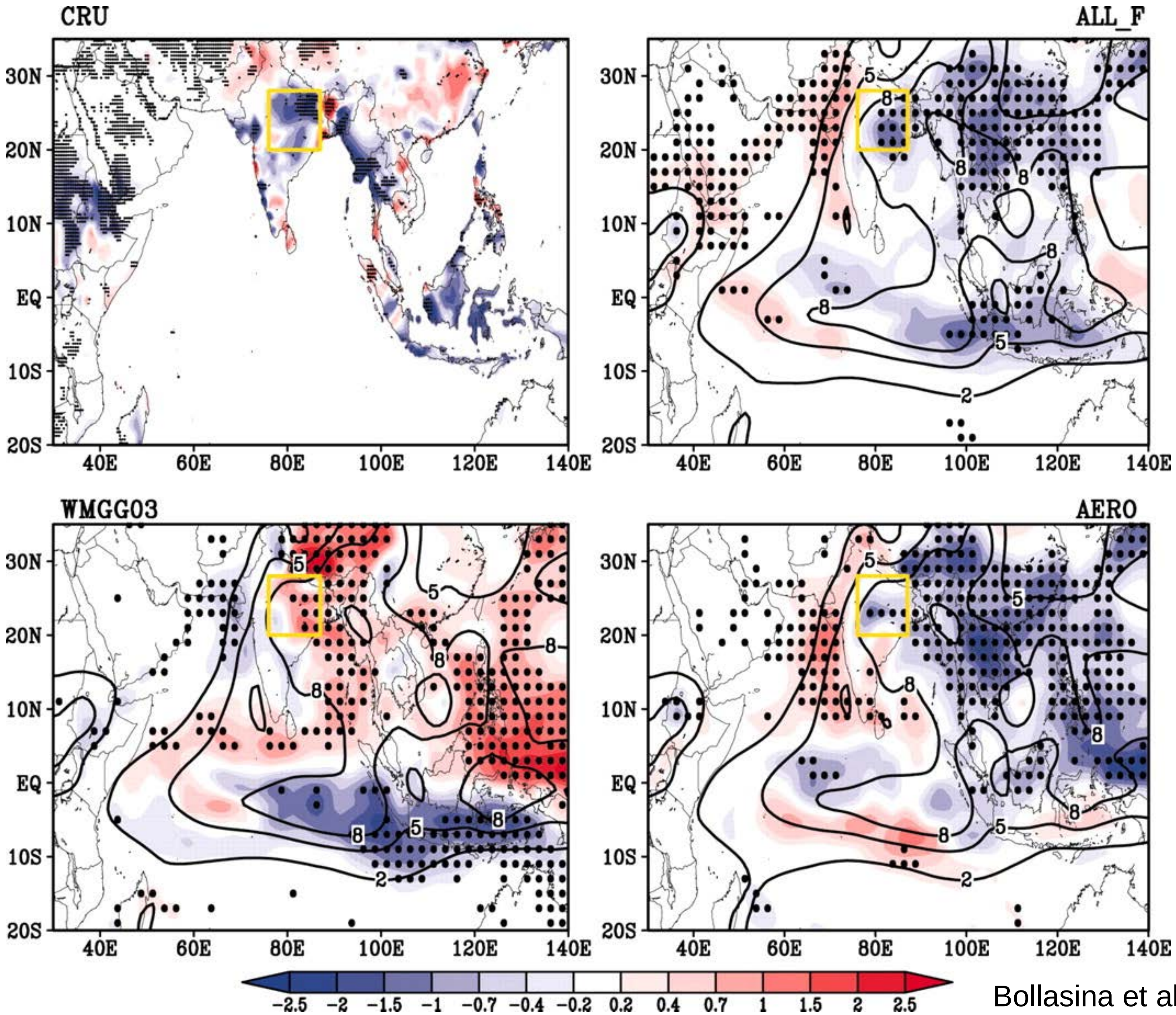
Song F., **T. Zhou**, and Y. Qian, 2013: Responses of East Asian summer monsoon to natural and anthropogenic forcings in the 17 latest CMIP5 models. *Geophysical Research Letters, 10.1002/2013GL058705*

Changes of JJAS rainfall between present-day and preindustrial periods (1986–2005 minus 1861–1880) in MME-means of the CMIP5



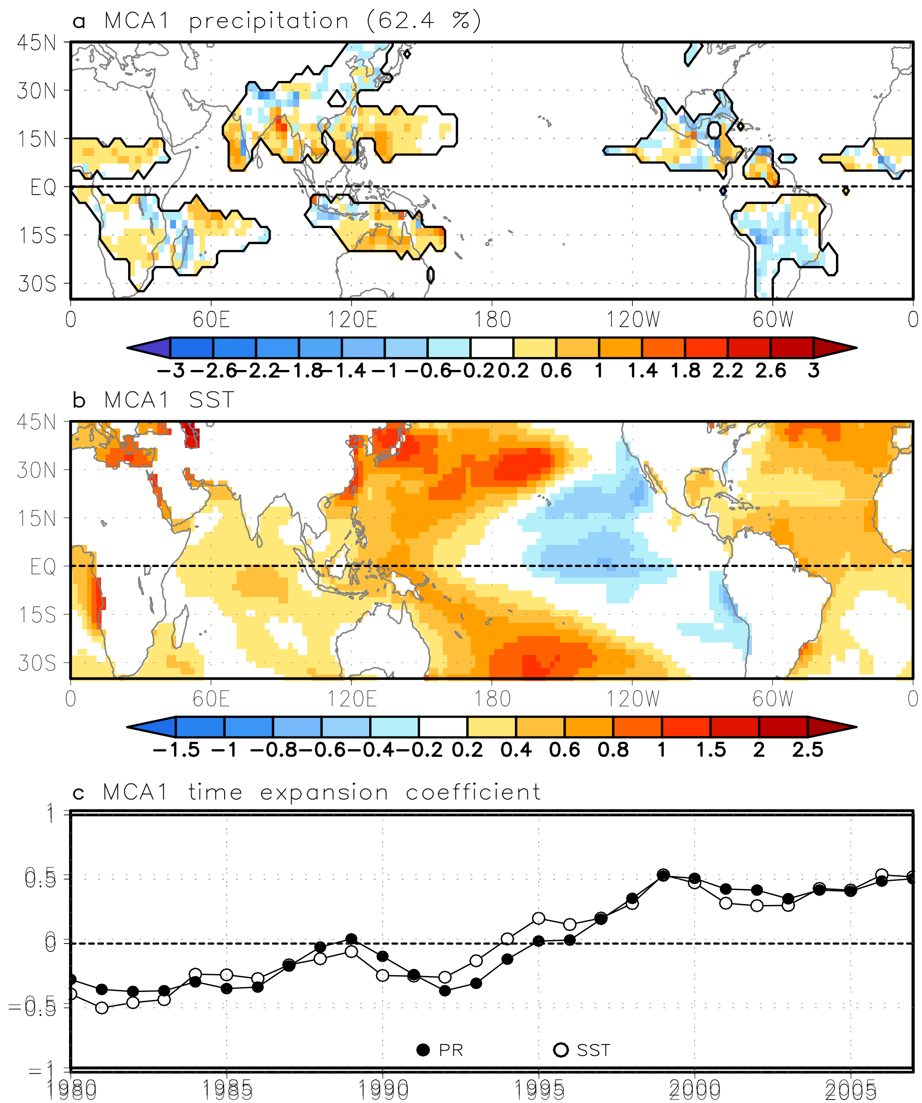
Guo et al. 2015 ACP

Spatial patterns of the 1950–1999 least-squares linear trends of the June-September average precipitation [mm day^{-1} (50 years)$^{-1}$]



Bollasina et al. 2011 Science

Recovery of Global Monsoon since early 1980s



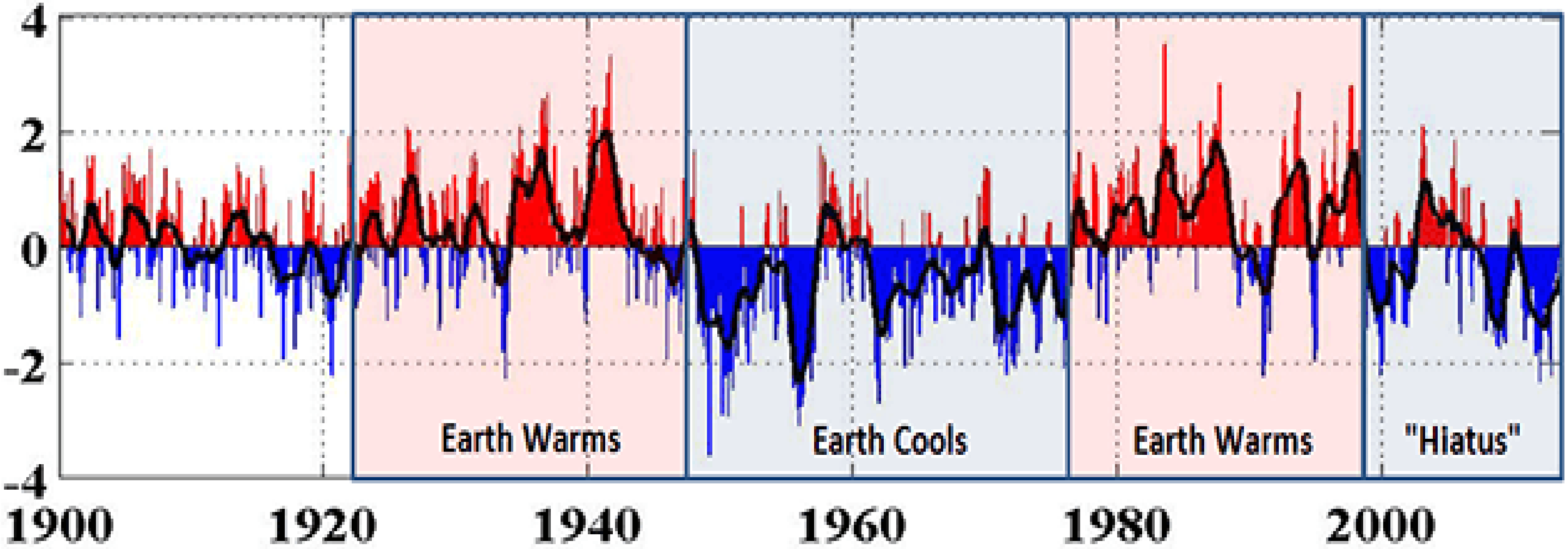
Maximum Covariance Analysis (MCA) of Monsoon precipitation and SST

3-year running mean datasets of GPCP and ERSST.

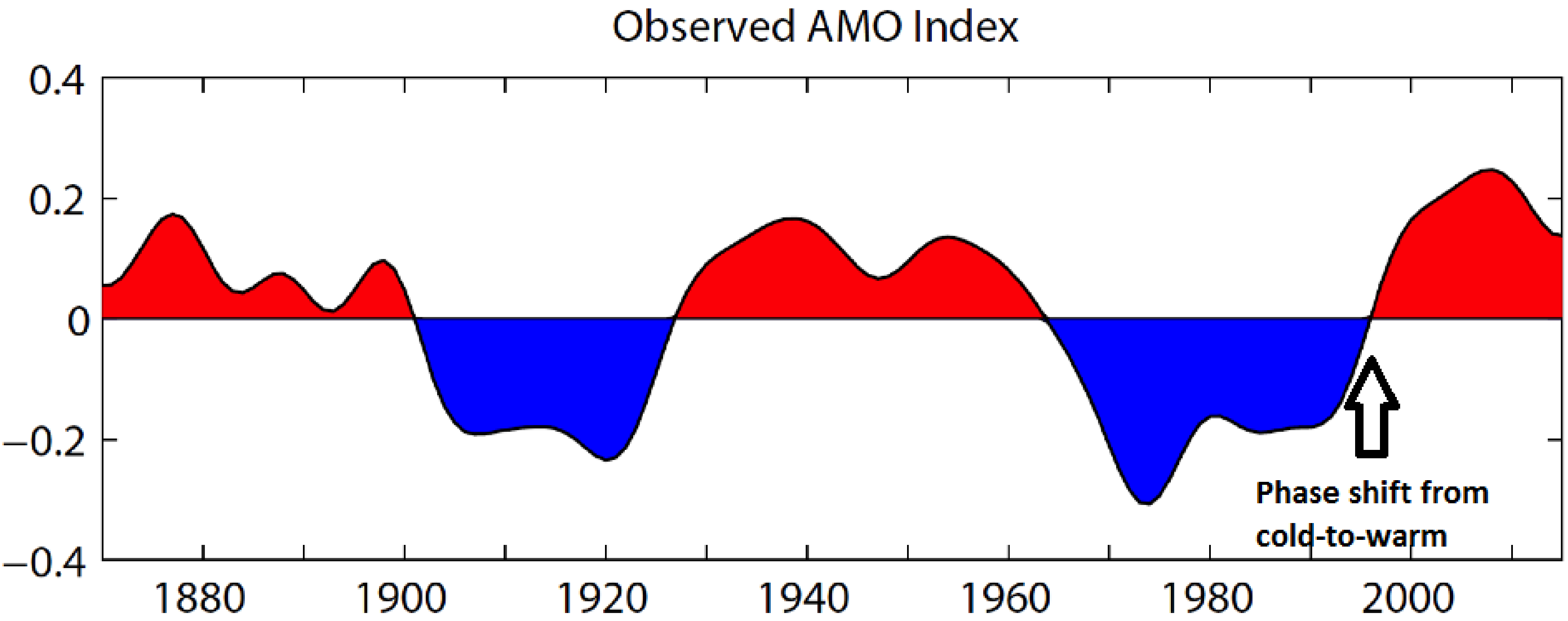
Wang et al. 2012 CD; 2013, PNAS

Pacific Decadal Oscillation Index

Monthly values for the PDO index: 1900-2013



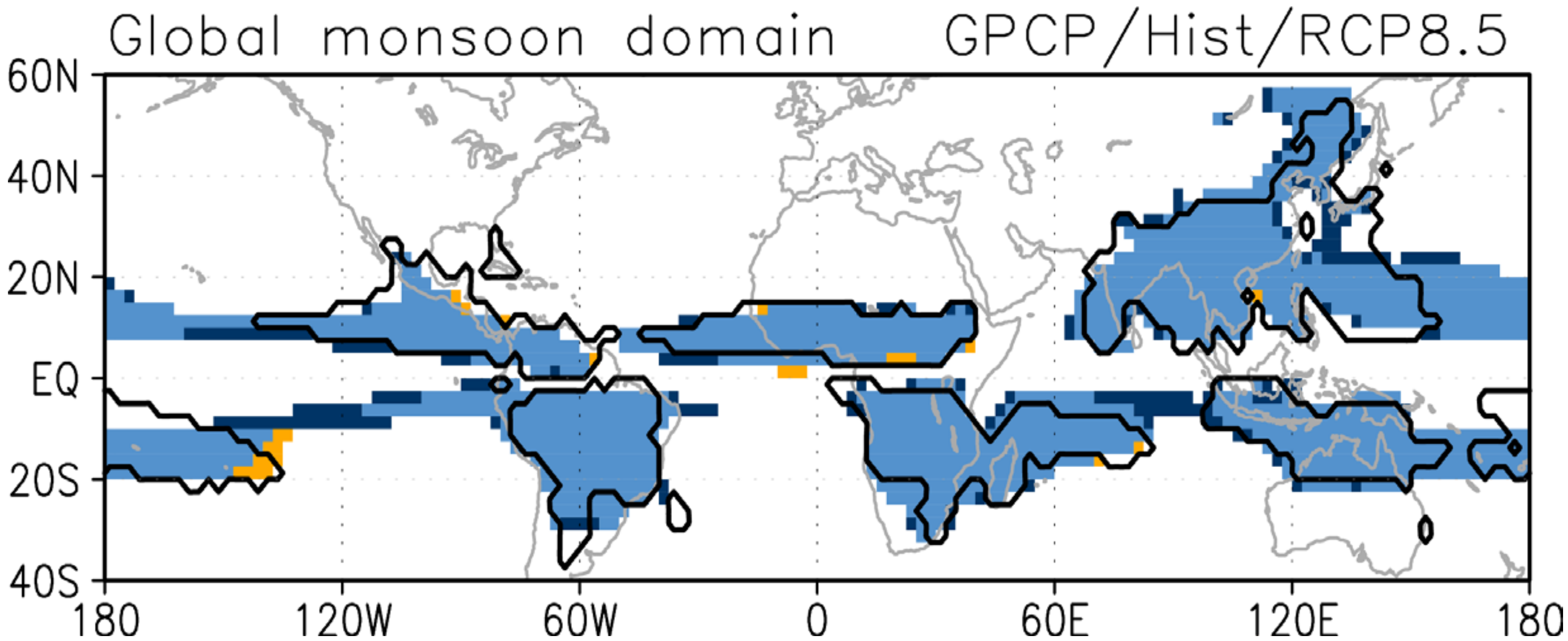
Atlantic Multidecadal Oscillation index



Global Monsoon: Area (GMA)

Black Contour: GPCP **Shading: MME of 29 CMIP5 models**

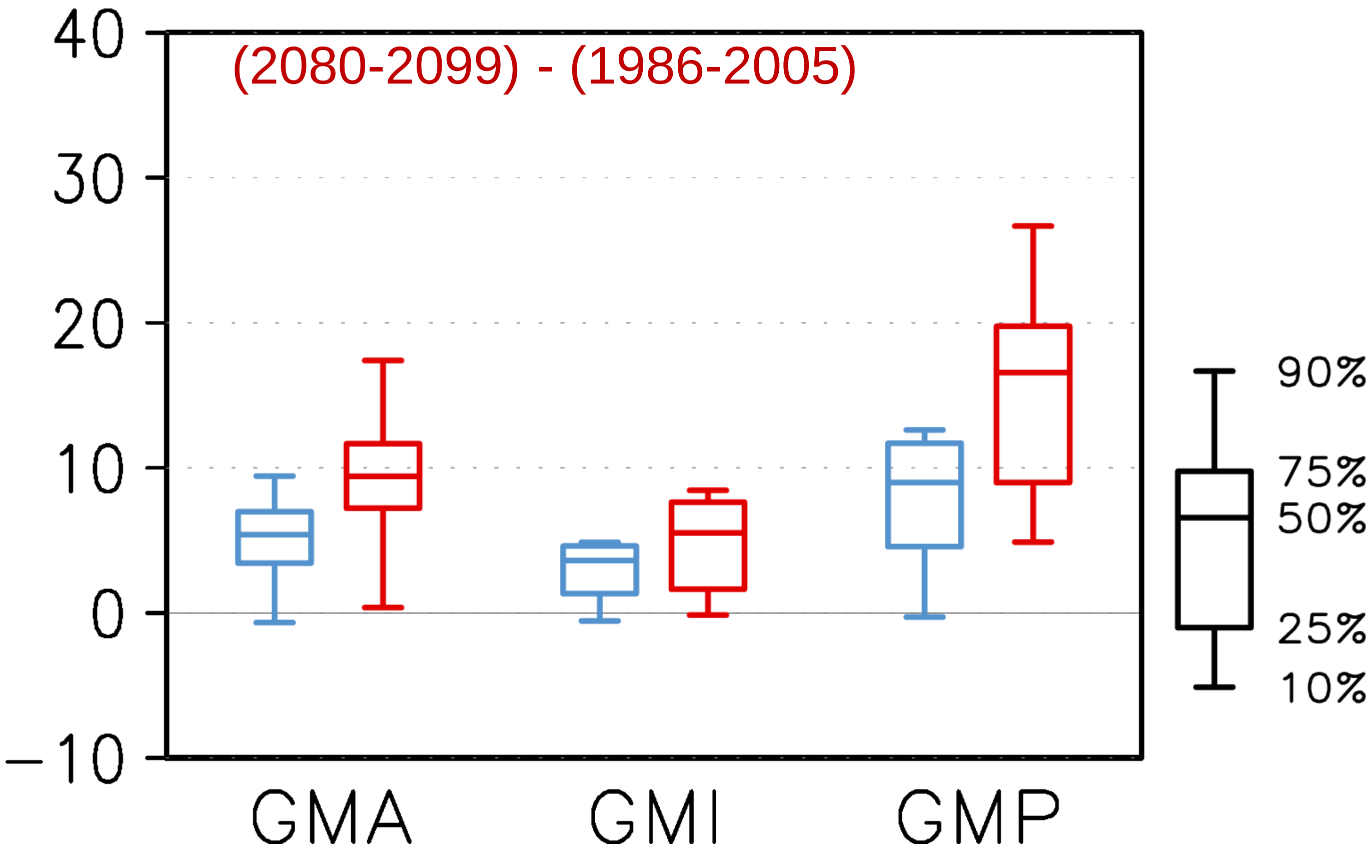
Yellow shading: only in present **Dark blue: only in future**



The global monsoon area will expand mainly over the central to eastern tropical Pacific, the southern Indian Ocean, and eastern Asia.

Kitoh, A., H. Endo, K. Krishna Kumar, I. F. A. Cavalcanti, P. Goswami, and T. Zhou, 2013: Monsoons in a changing world: a regional perspective in a global context. ***J. Geophys. Res. Atmos.*,** 118, doi:10.1002/jgrd.50258

Future change (%): GMA, GMI & GMP



GMP: global monsoon total precipitation

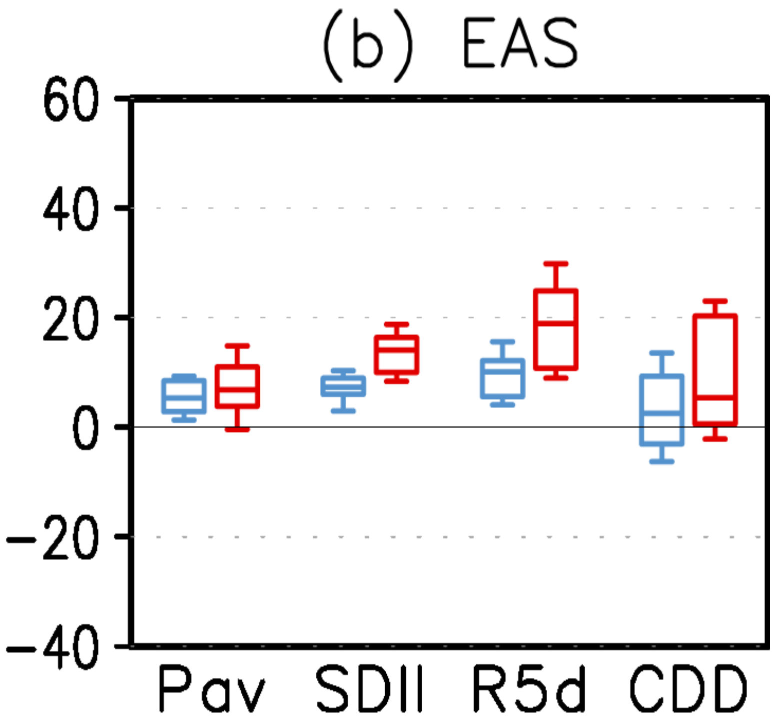
Blue: RCP4.5

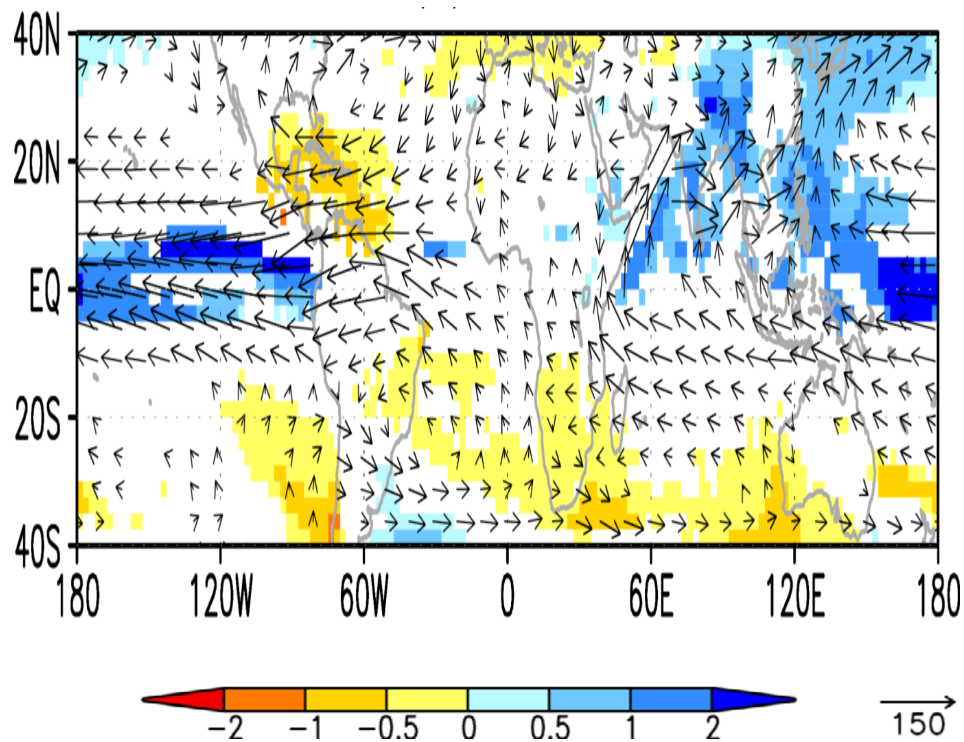
Red: RCP8.5

- GMP shows an increase in the RCP4.5 scenario and more so in the RCP8.5 scenario
- monsoon-related precipitation will significantly increase in a warmer climate

Kitoh, A., H. Endo, K. Krishna Kumar, I. F. A. Cavalcanti, P. Goswami, and T. Zhou, 2013: Monsoons in a changing world: a regional perspective in a global context. ***J. Geophys. Res. Atmos.*****,** 118, doi:10.1002/jgrd.50258

Future change ratio of Pav, SDII, R5d and DD over E. Asia





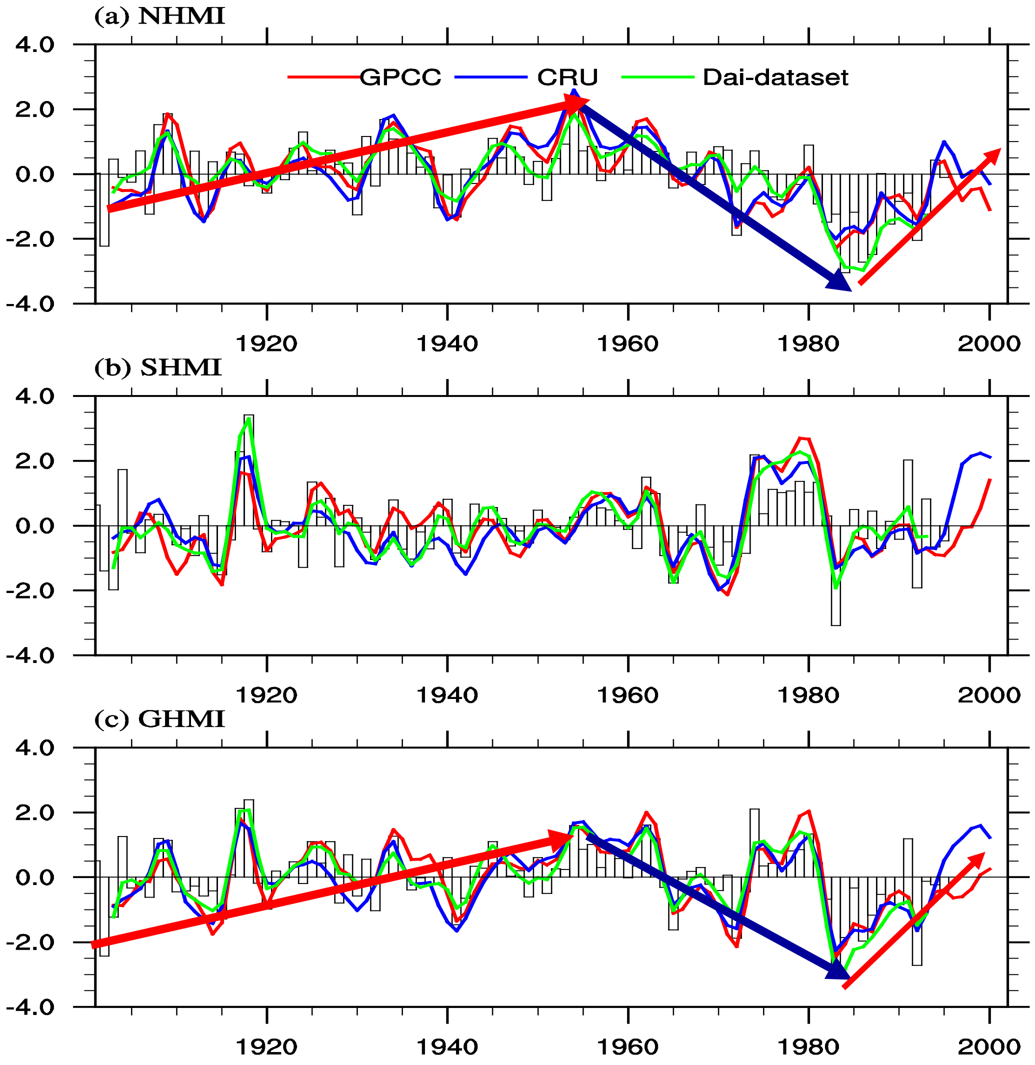
Blue: RCP4.5 **Red: RCP8.5**

shading: Precipitation

vector: vertically integrated water vapor flux

Kitoh, A., H. Endo, K. Krishna Kumar, I. F. A. Cavalcanti, P. Goswami, and **T. Zhou**, 2013: Monsoons in a changing world: a regional perspective in a global context. ***J. Geophys. Res. Atmos.***, 118, doi:10.1002/jgrd.50258

Changes of global land monsoon precipitation

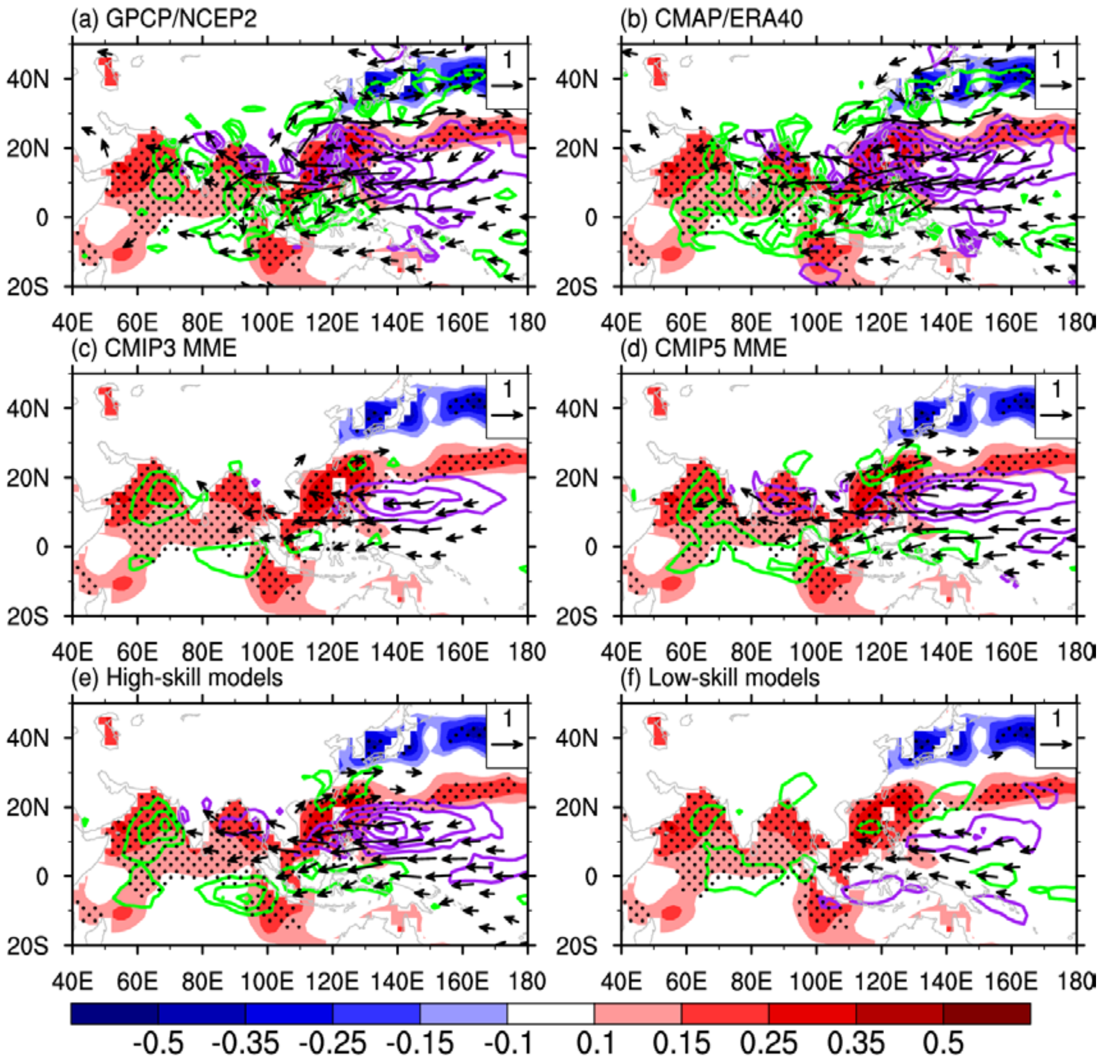


Global and NH land monsoon:

1) upward trend during 1901-1950s (95% confidence)
2) downward trend from 1950s to 1980s(95% confidence)
3) Recovering since the 1980s

(Zhang and Zhou, 2011, Clim Dyn.)

Indian Ocean-western Pacific anticyclone tele-connection



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

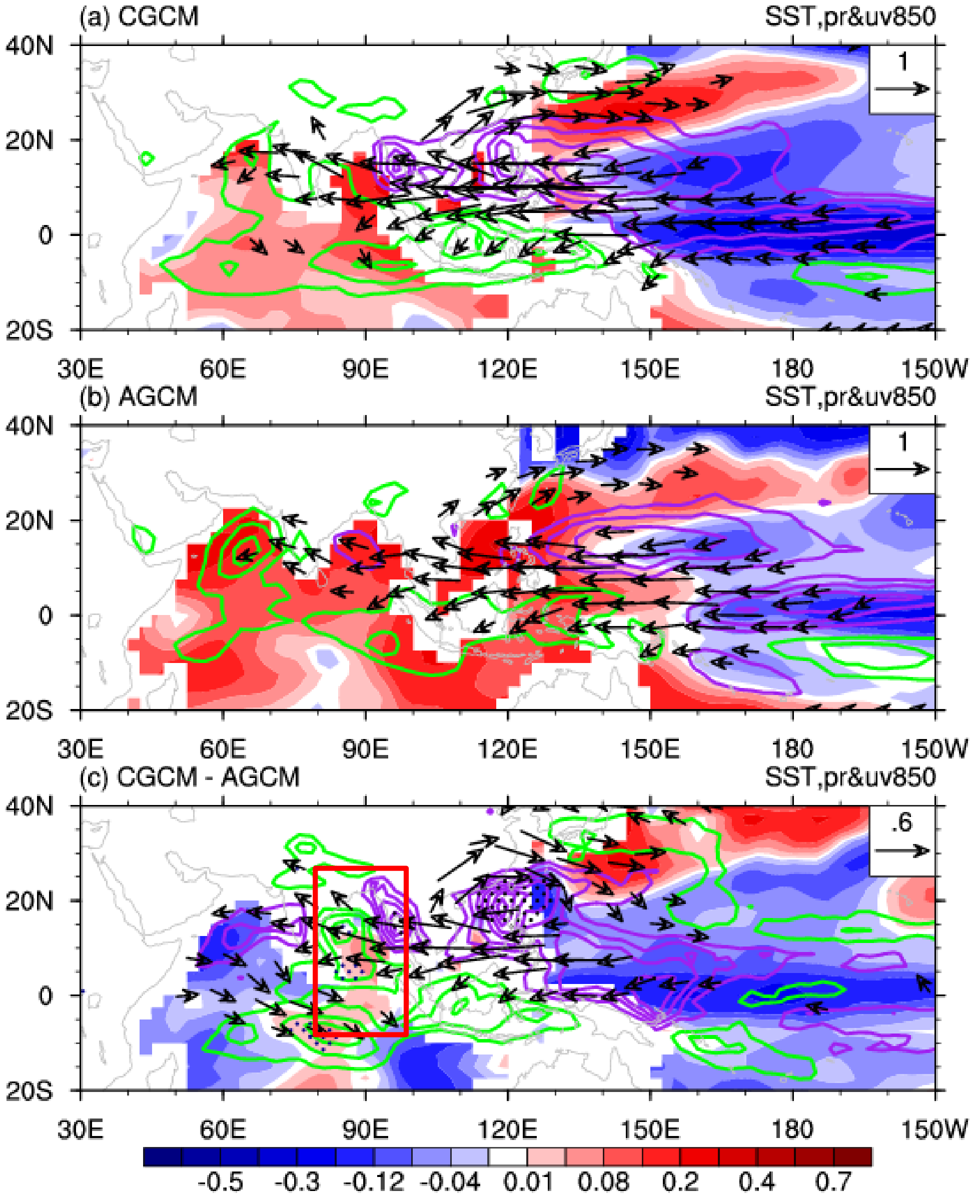
Song Fengfei, **Tianjun Zhou**, 2014: Interannual Variability of East Asian Summer Monsoon Simulated by CMIP3 and CMIP5 AGCMs: Skill Dependence on Indian Ocean–Western Pacific Anticyclone Teleconnection. ***J. Climate***, 27, 1679–1697

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***

Main Experiments

All the GMMIP partners are encouraged to conduct both the Tier-1 and Tier-2 experiments.

	EXP name	Integration time	Description	Model type	Motivation
Tier-1	AMIP 20C	1870-2014	Extended AMIP run that covers 1870-2014.	AGCM run, min realization 3	understand the roles of SST forcing and external forcings
Tier-2	HIST-IPO	1870-2014	Pacemaker 20th century historical run that includes all forcing as used in CMIP6 Historical Simulation, and the observational historical SST is restored in the tropical lobe of the IPO domain (20° S-20° N, 175° E-75° W)	CGCM min realization 3	understand the forcing of IPO-related tropical SST to global monsoon changes.
	HIST-AMO	1870-2014	Same as HIST-IPO, but the observational historical SST is restored in the AMO domain (0° -70° N, 70° W-0°)	CGCM min realization 3	understand the forcing of AMO-related SST to global monsoon changes

Tiered Experiments

	EXP name	Integration time	Description	Model type	Motivation
Tier-3	**DTIP**	1979-2014	The topography of the TIP is modified by setting surface elevations to 500m	AGCM run, min realization 1	Understanding the combined thermal and mechanical forcing of the TIP.
	DTIP-DSH	1979-2014	Surface sensible heat released at the elevation above 500m over the TIP is not allowed to heat the atmosphere	AGCM run, min realization 1	Understanding the thermal forcing of the TIP
	DHLD	1979-2014	The topography of the highlands in Africa, N. America and S. America TP is modified by setting surface elevations to a certain height (500m),	AGCM run min realization 1	Understanding the combined thermal and mechanical forcing of other plateaus except the TIP.