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

Prospects of the CMIP6 GMMIP for climate change assessment: Background and Objectives

Tianjun ZHOU

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

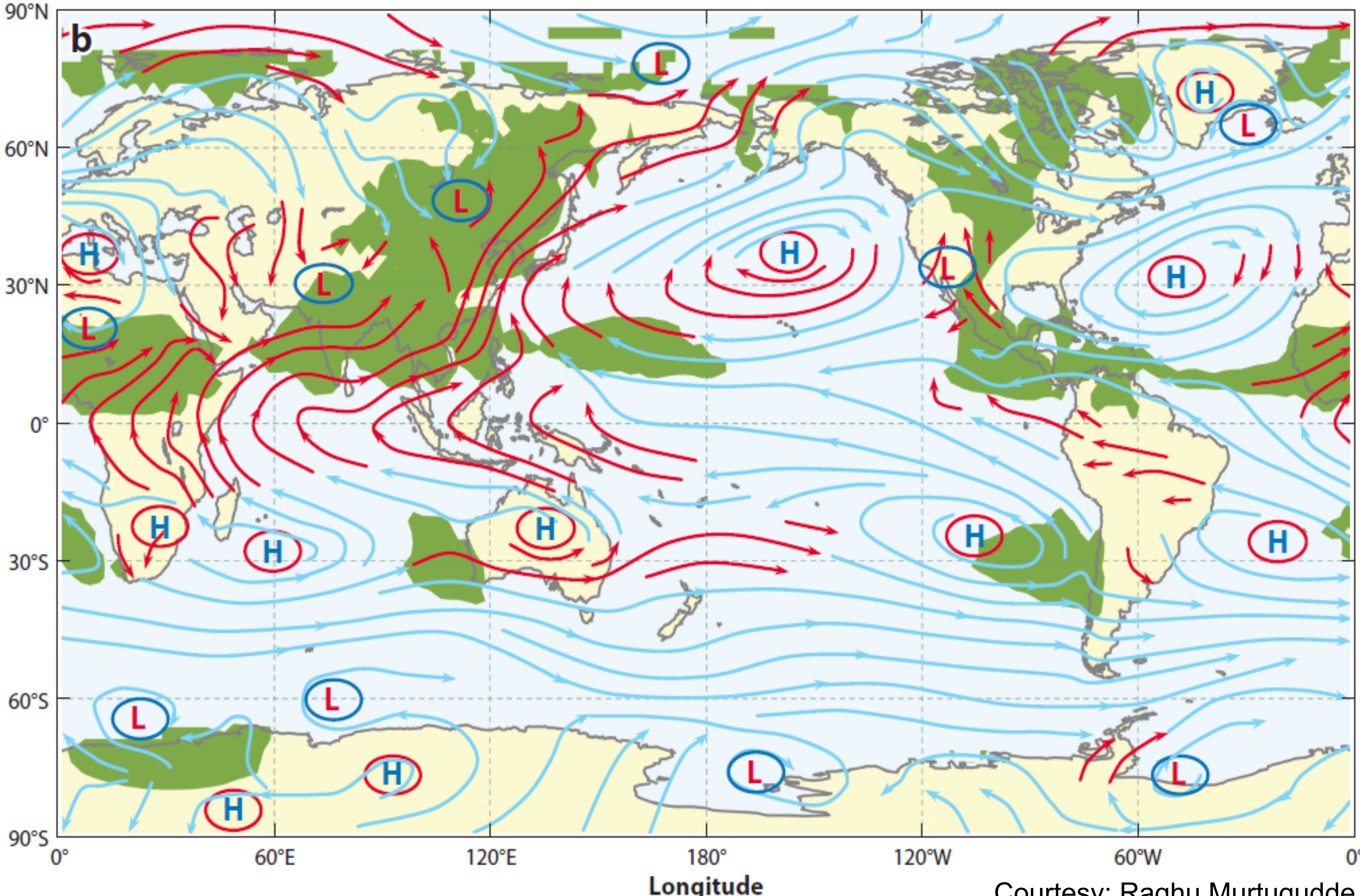
Targeted Training Activity (TTA) 2017: Monsoons in a Changing Climate

31 July - 4 August 2017, ICTP

Outline

1. Overview of GM
2. Mechanisms for long term GM changes
3. GMMIP for CMIP6
4. Concluding remarks

Boreal Summer monsoon



Courtesy: Raghu Murtugudde

Indian Flood

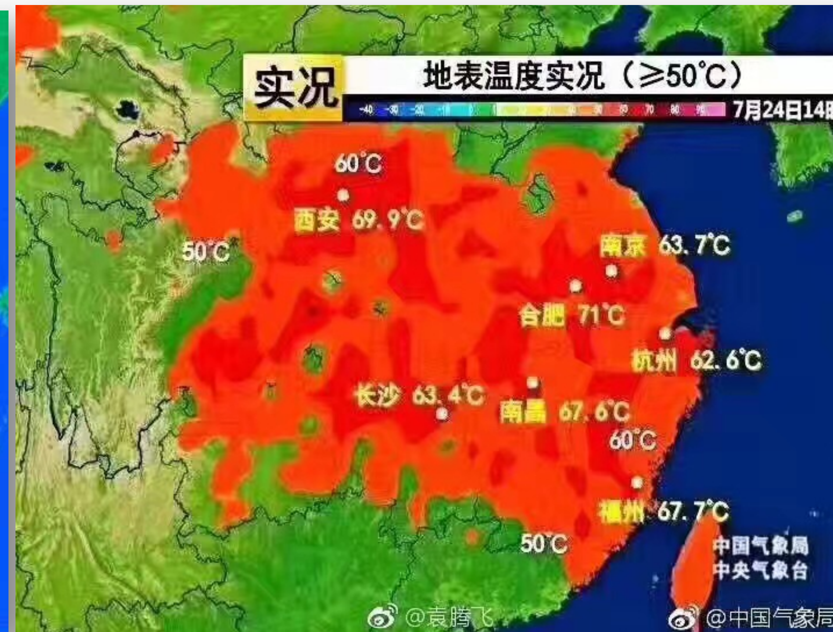
http://i.dailymail.co.uk/i/pix/2014/09/1

Indian Flood

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

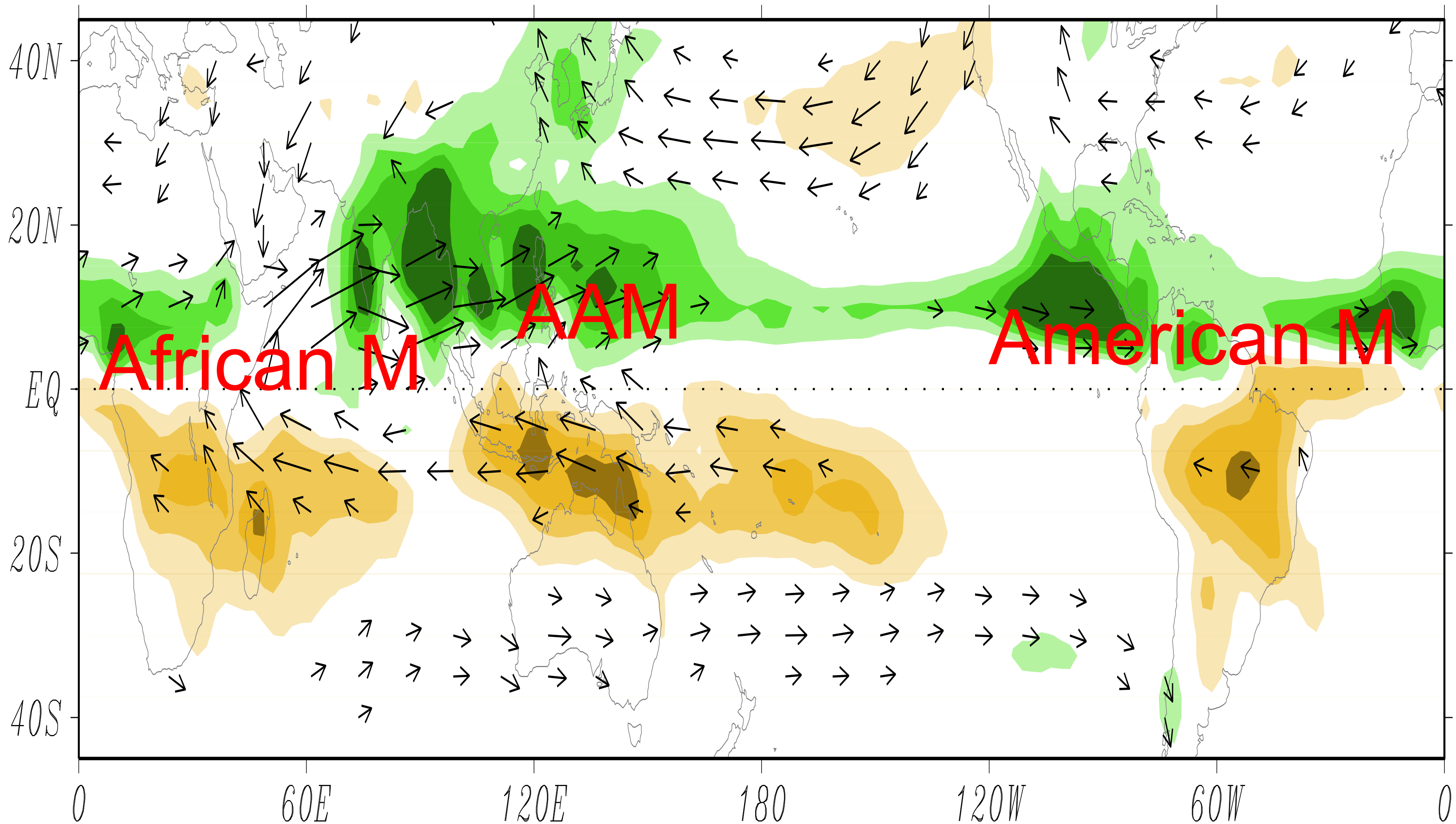

武汉站
Wuhan Railway Station
中新網
Chinanews.com
04 pm, 08 July, 2016

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



Heat Wave in China : 12 July - Today, 31 July 2017

Global Monsoons



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

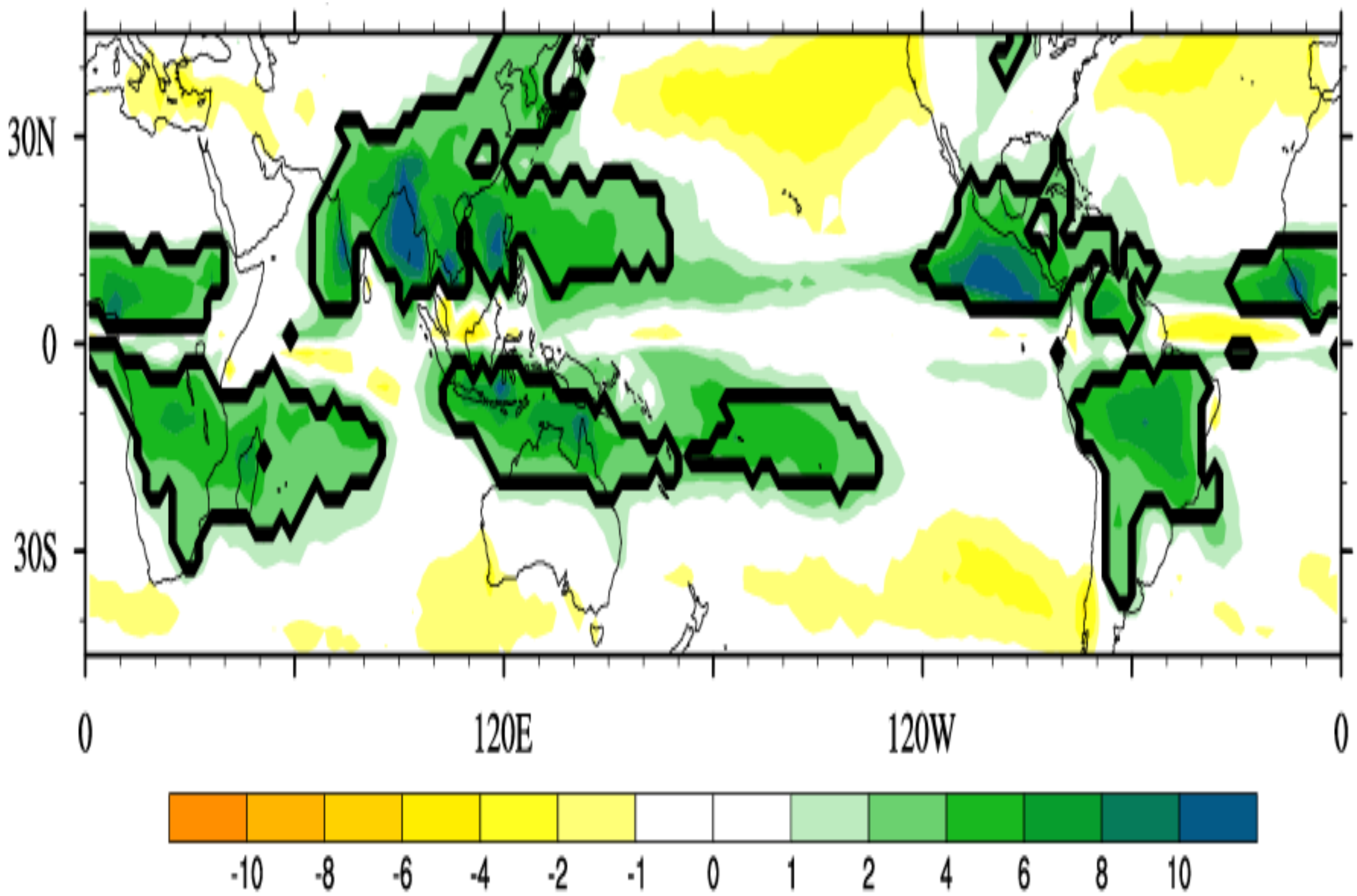
SHMI: SH-DJF “monsoon” precipitation

GMI: NHMI + SHMI

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

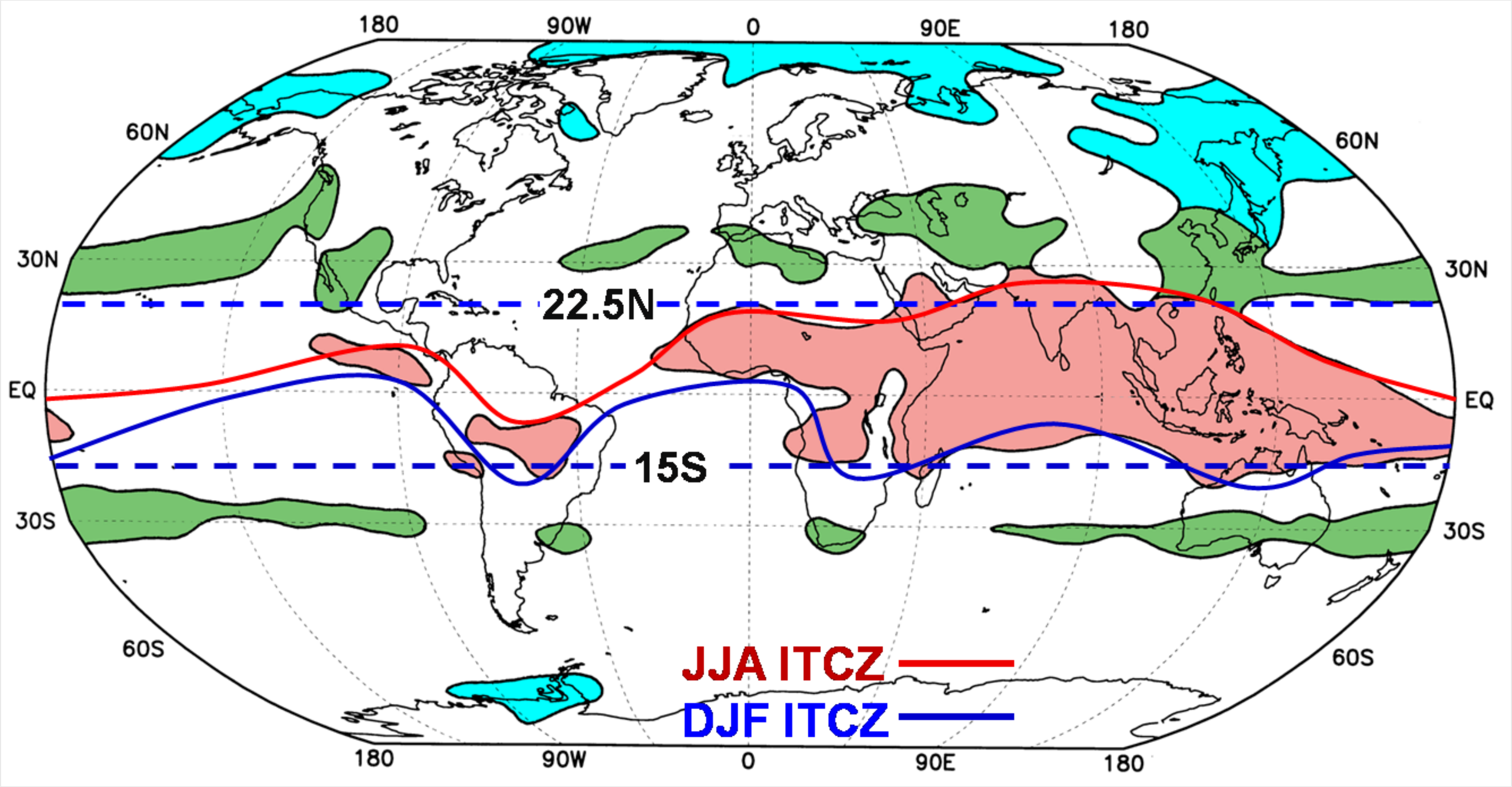
(Wang and Ding 2006 GRL)

Domain of Global monsoons



(Wang and Ding 2006 GRL)

Distribution of global monsoons



- tropical monsoon
- subtropical monsoon
- temperate-frigid monsoon

Defined based on wind

Li and Zeng (2003,2005)

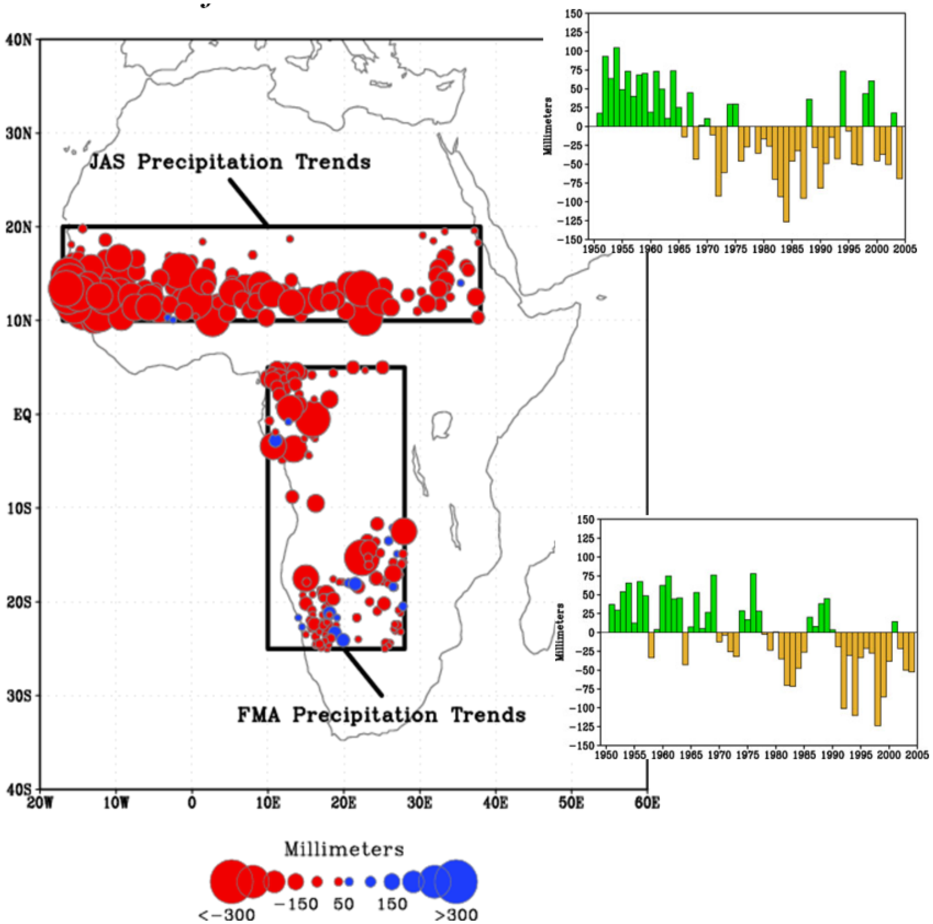
Photo by Fu Yunfei

Coordination among regional monsoons

- Each regional monsoon has its own characteristics due to its specific land-ocean configuration and orography, and due to differing feedback processes internal to the coupled climate system.
- There is coordination among regional monsoons: brought about by the annual cycle of the solar heating.
- There are connections in the global divergent circulation and thereby global monsoons: due to mass conservation.

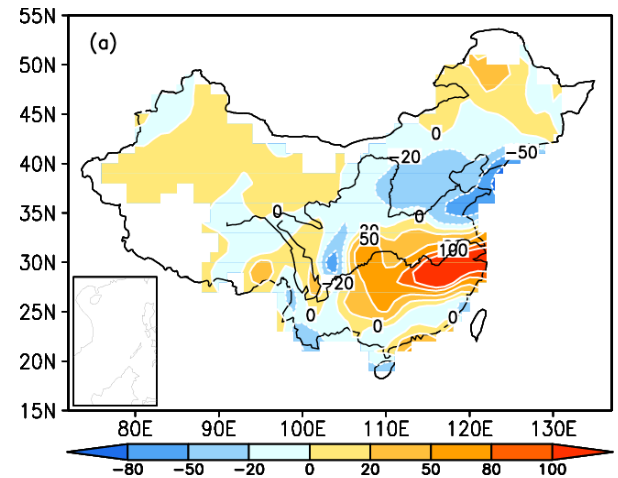
Coherent long term changes across different monsoons

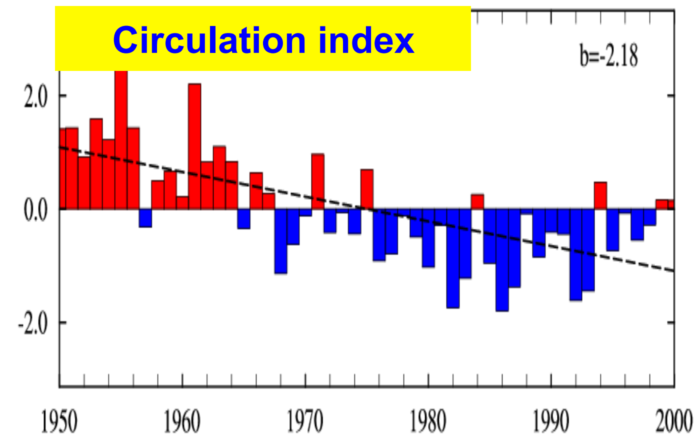
African rainfall



Hoerling et al. (2006) J. Climate

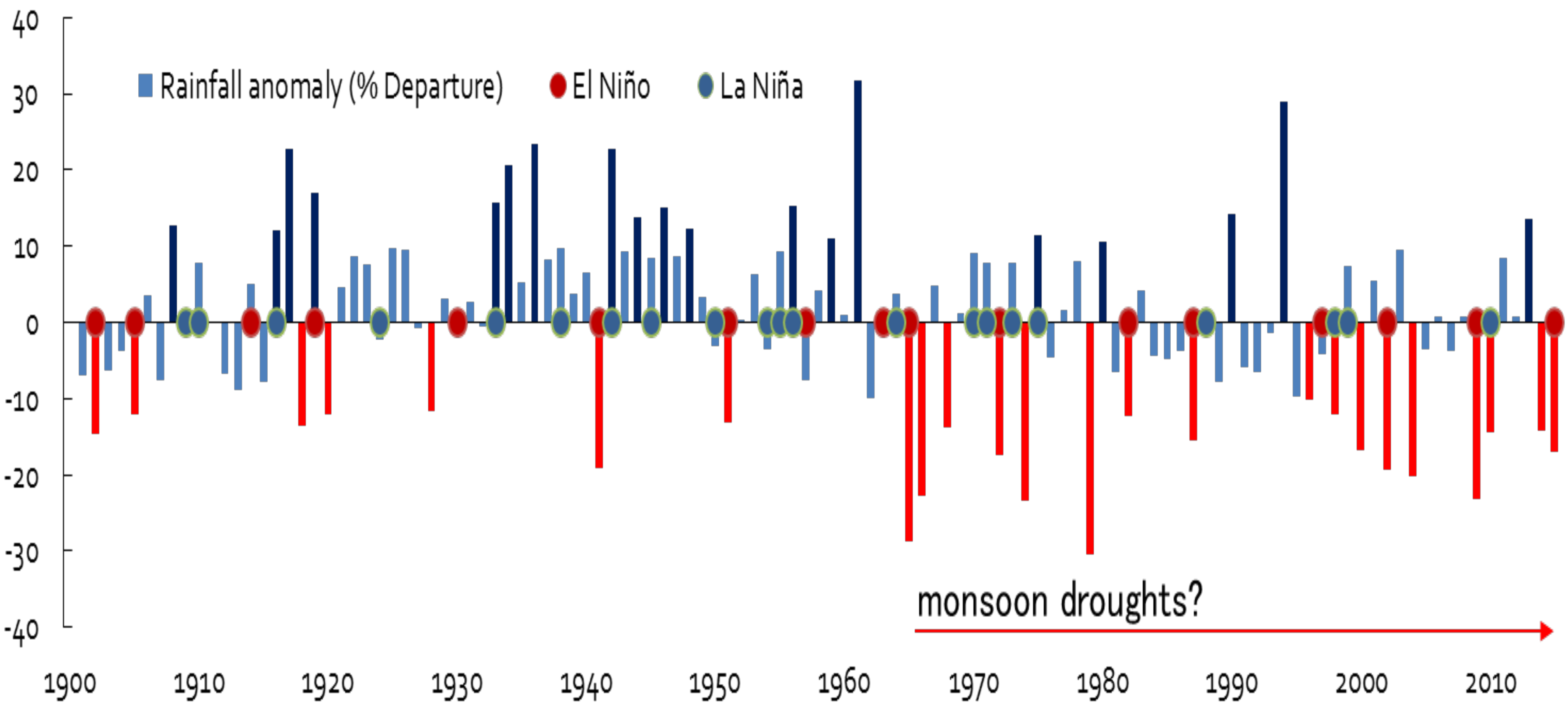
E Asian rainfall





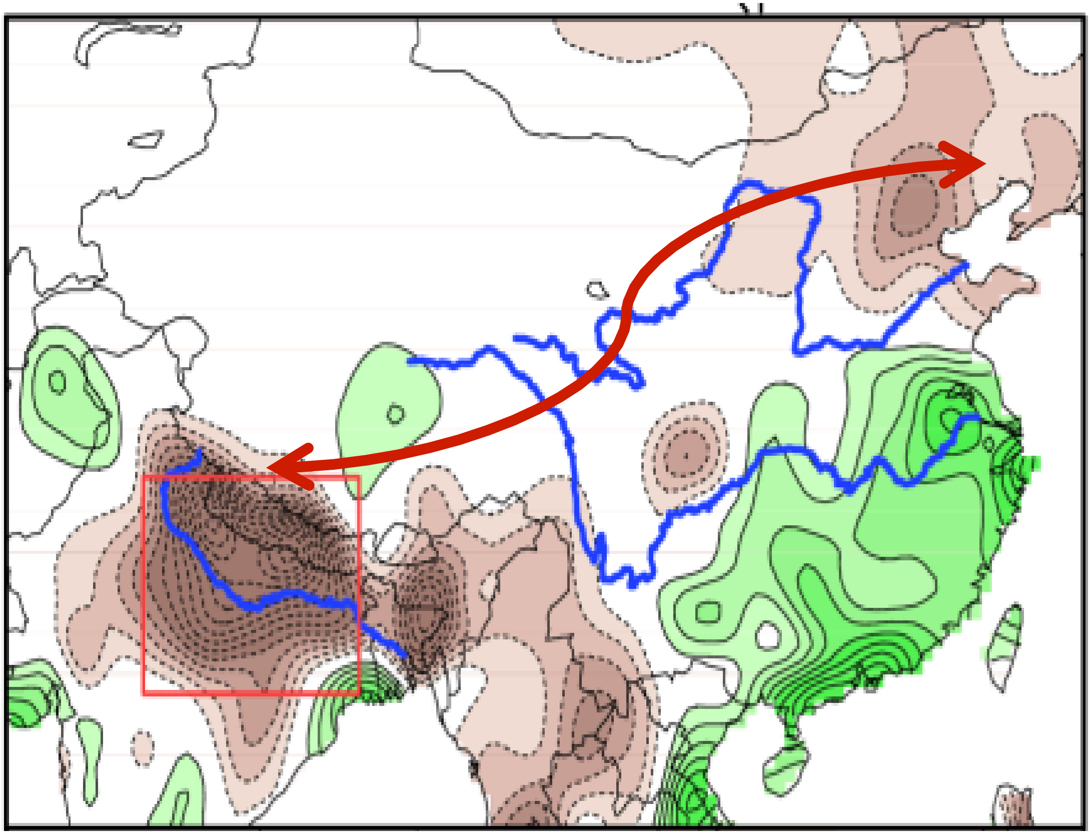
Zhou et al. (2009) Meteorologische Zeitschrift

The downward trend in the ISMR



Courtesy: Roxy Mathew Koll

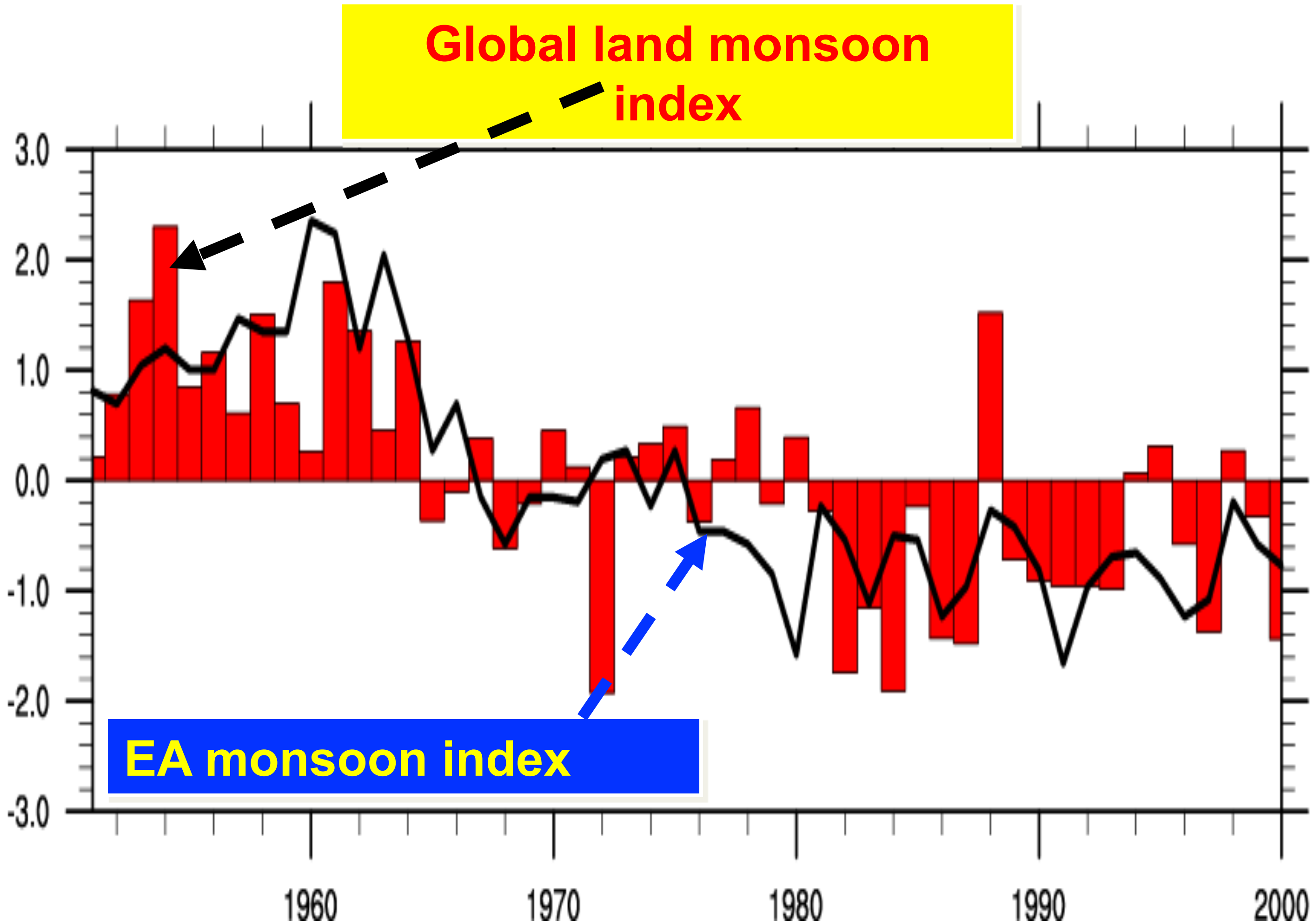
Changes of S. Asia and E. Asia summer rainfall



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.

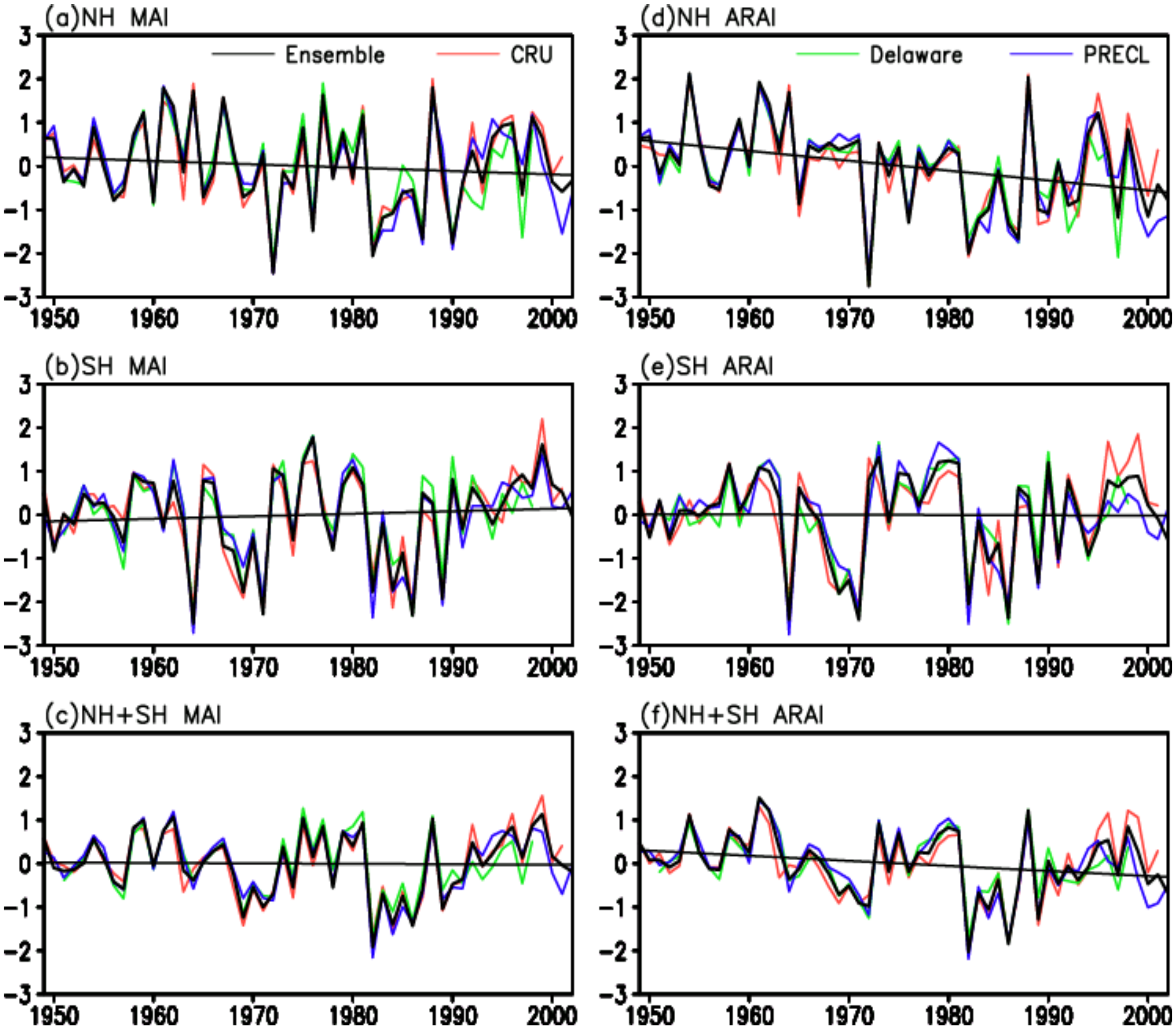
Nigam Sumant, Yongjian Zhao, Alfredo Ruiz-Barradas, **Tianjun Zhou**, 2015: The South-Flood North-Drought Pattern over Eastern China and the Drying of the Gangetic Plain, 437-359pp (Chapter 22) in: ***Climate Change: Multidecadal and Beyond***, edited by Chih-Pei Chang, Michael Ghil, Mojib Latif, John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

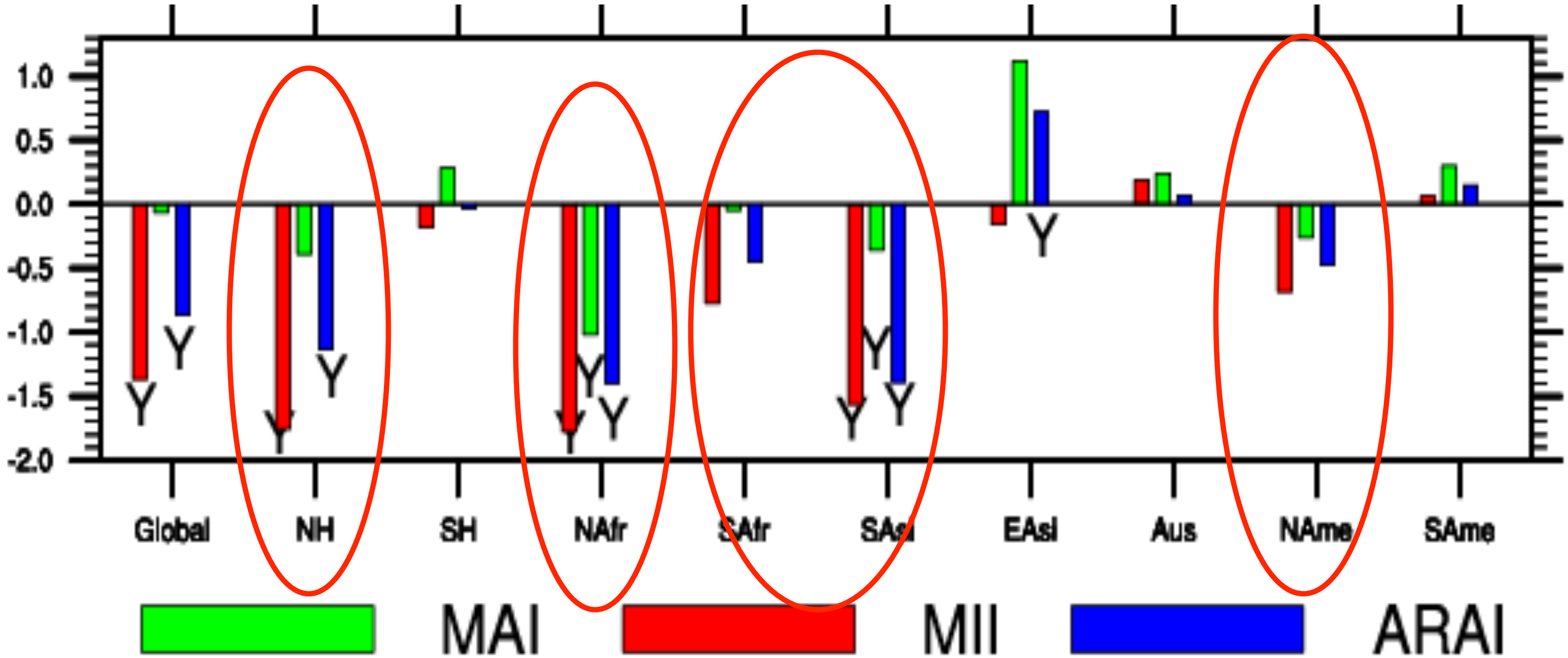
Changes of land monsoon area and total rainfall (1948-2003)



Zhou T, L. Zhang, and H. 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

Regional monsoon rainfall changes

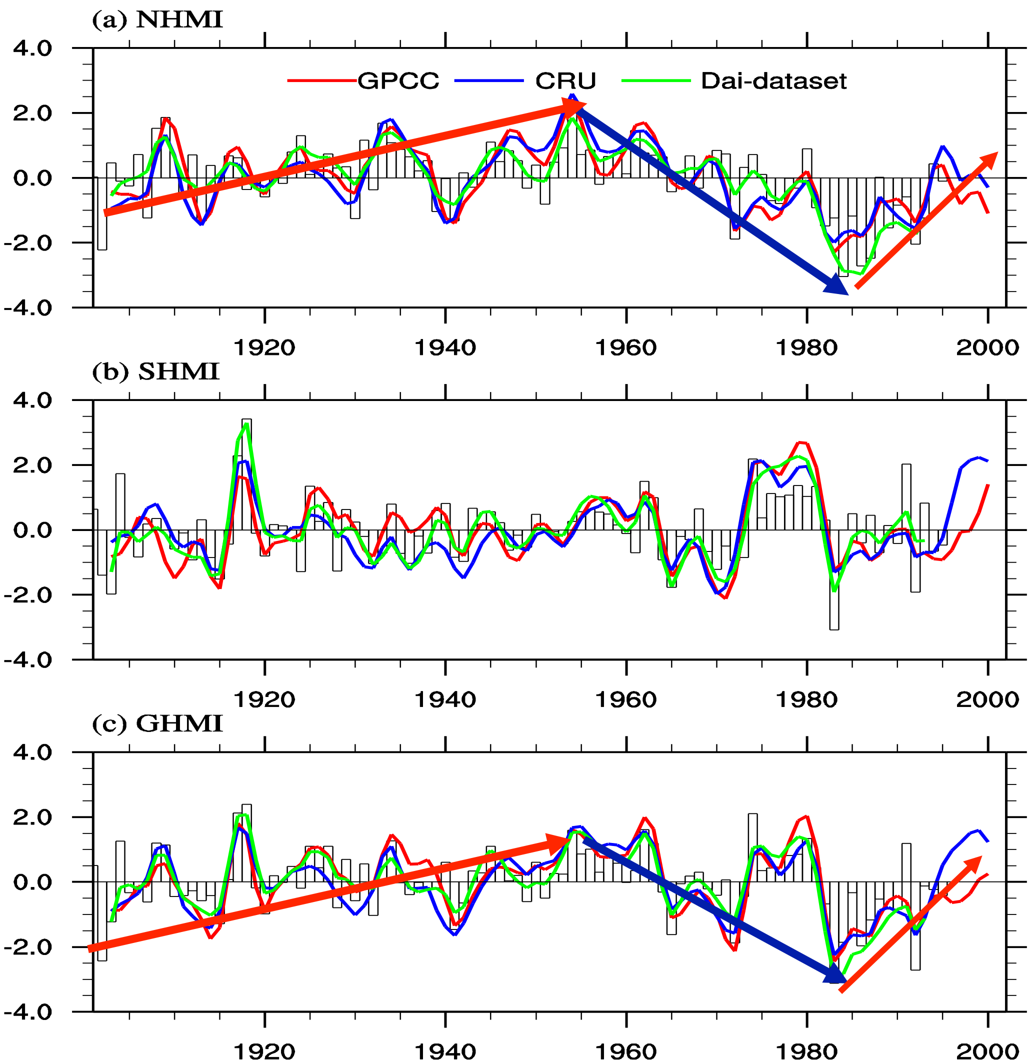
Trends of monsoon rainfall Area, intensity, and amount (1948-2003)



Monsoon Area **Intensity** **Amount**

(Zhou et al. 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 global land monsoon precipitation

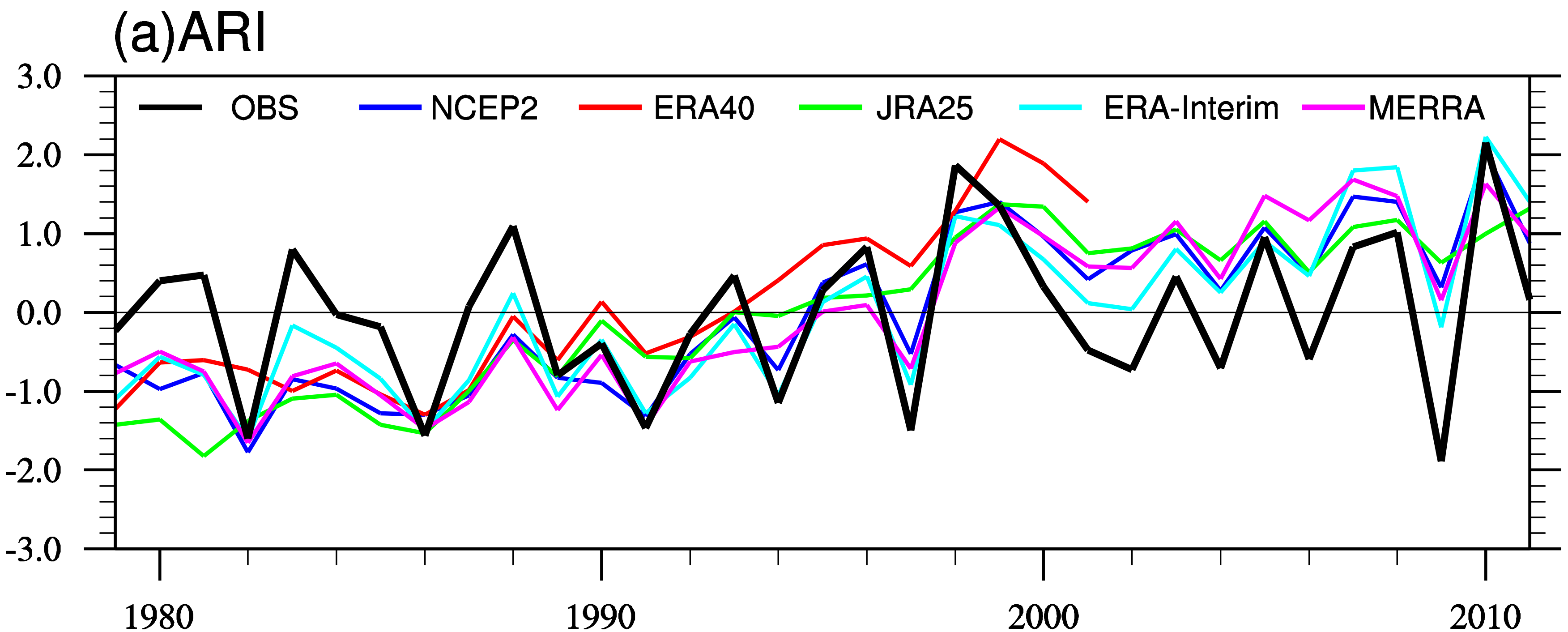


Global and NH land monsoon:

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.)

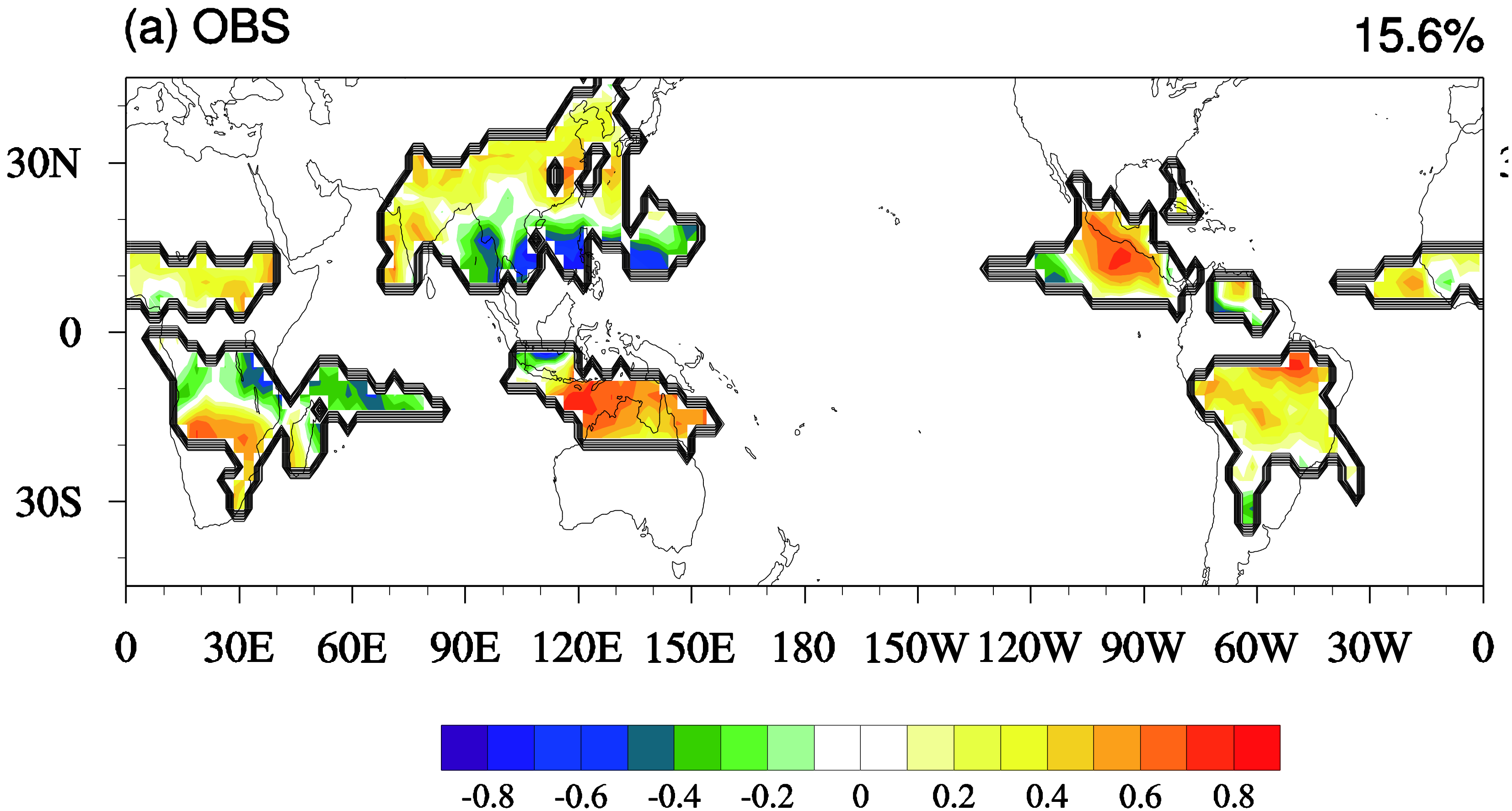
EOF PC1 of GM precipitation



- The corresponding observational ARI shows increasing tendency **for 1979-2011.**
- All five reanalysis datasets show similar but stronger increasing trends than the observation.

Lin R., T. Zhou, Y. Qian, 2014: Evaluation of Global Monsoon Precipitation Changes based on Five Reanalysis Datasets, ***Journal of Climate***, *27(3)*,1271-1289

Pattern of GM precipitation trends



- All five reanalysis can reproduce the observed positive anomalies in Australian monsoon region and northern part of Asian region.

Lin R., T. Zhou, Y. Qian, 2014: Evaluation of Global Monsoon Precipitation Changes based on Five Reanalysis Datasets, ***Journal of Climate***, *27(3)*,1271-1289

Point # 1

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

Outline

1. Overview of GM
2. Mechanisms for long term GM changes
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4. Concluding remarks

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

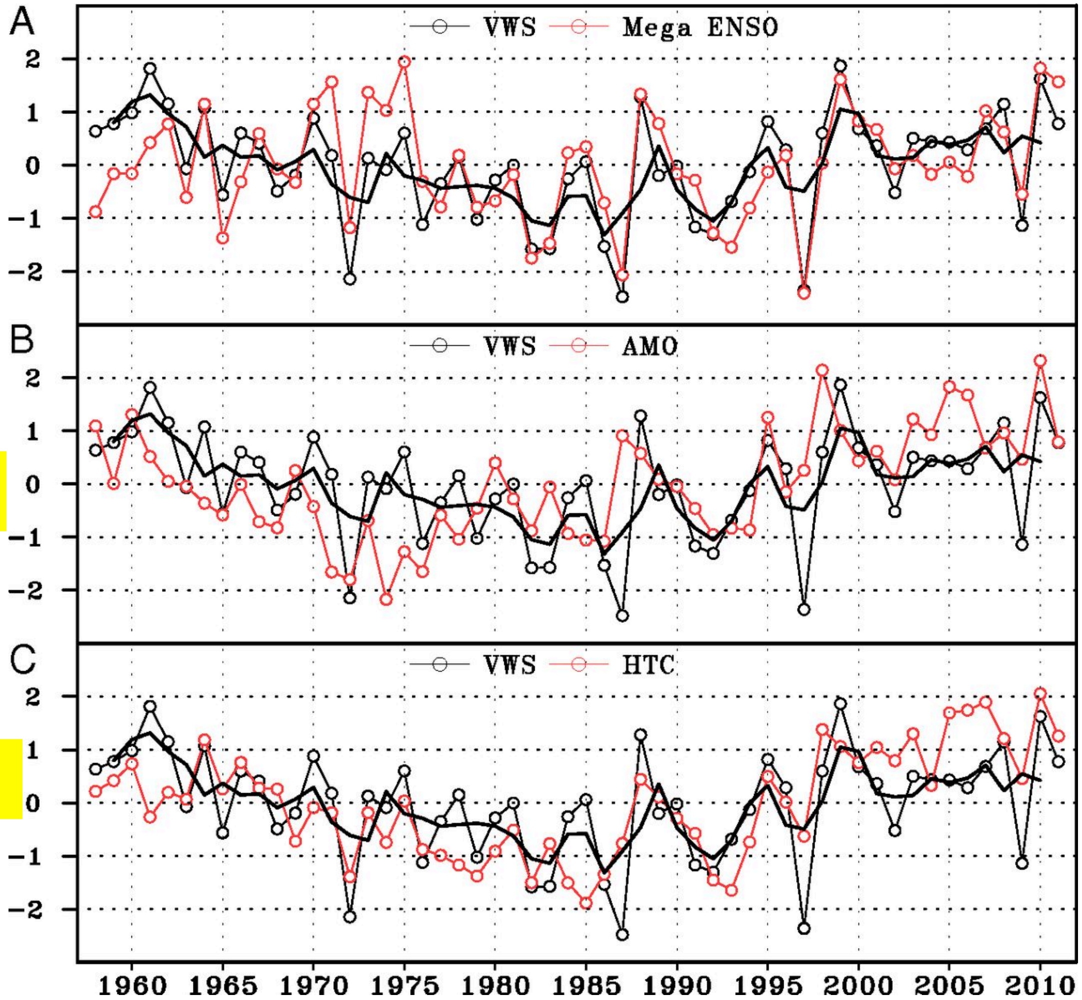
Contribution of IPO and AMO

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

IPO

AMO

HTC



Cor=0.77

Cor=0.44

Cor=0.63

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

Model & Experiments

◆NCAR CAM2: T42L26

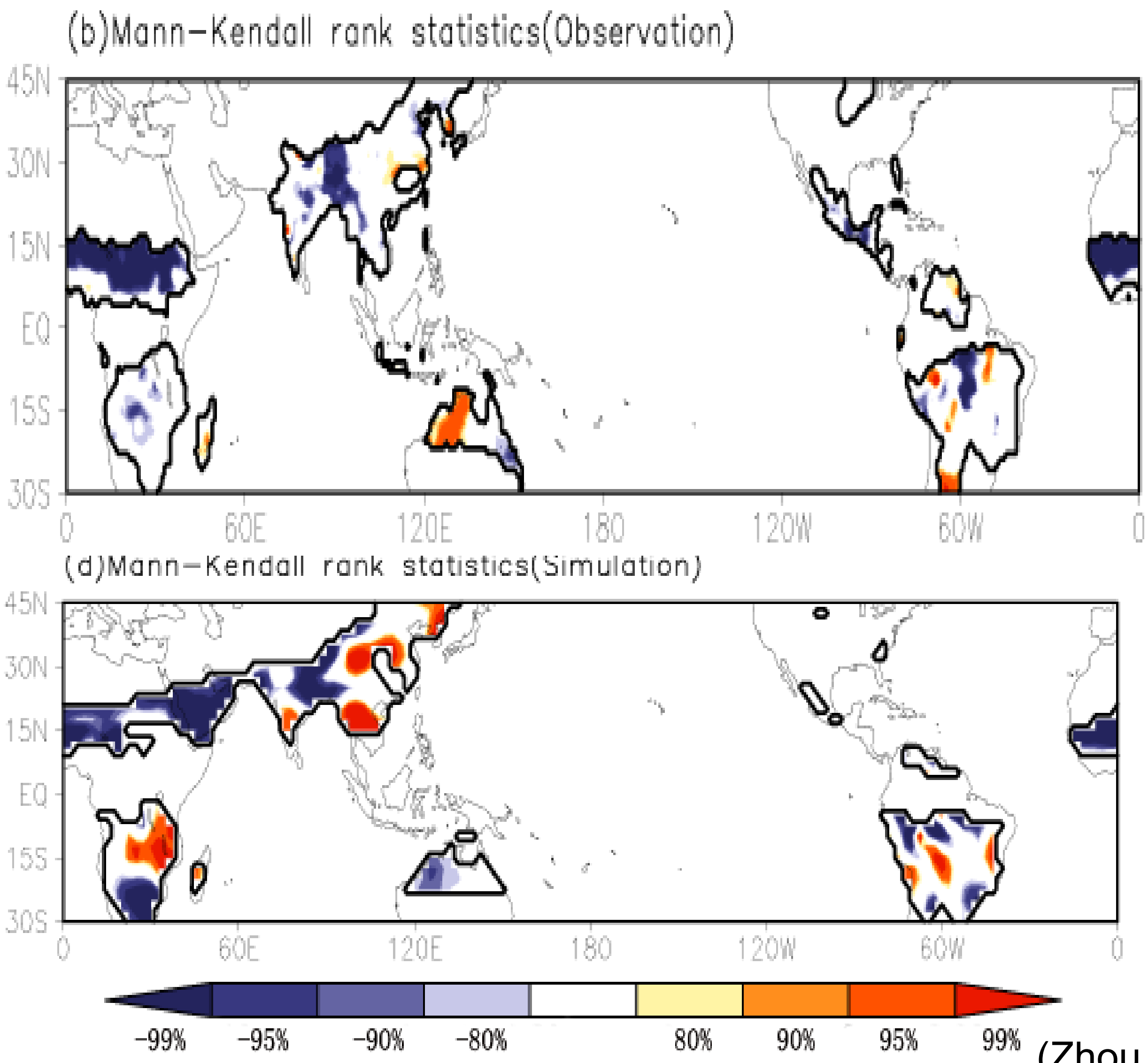
◆Global SST-forced 15-member ensemble simulation.

◆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

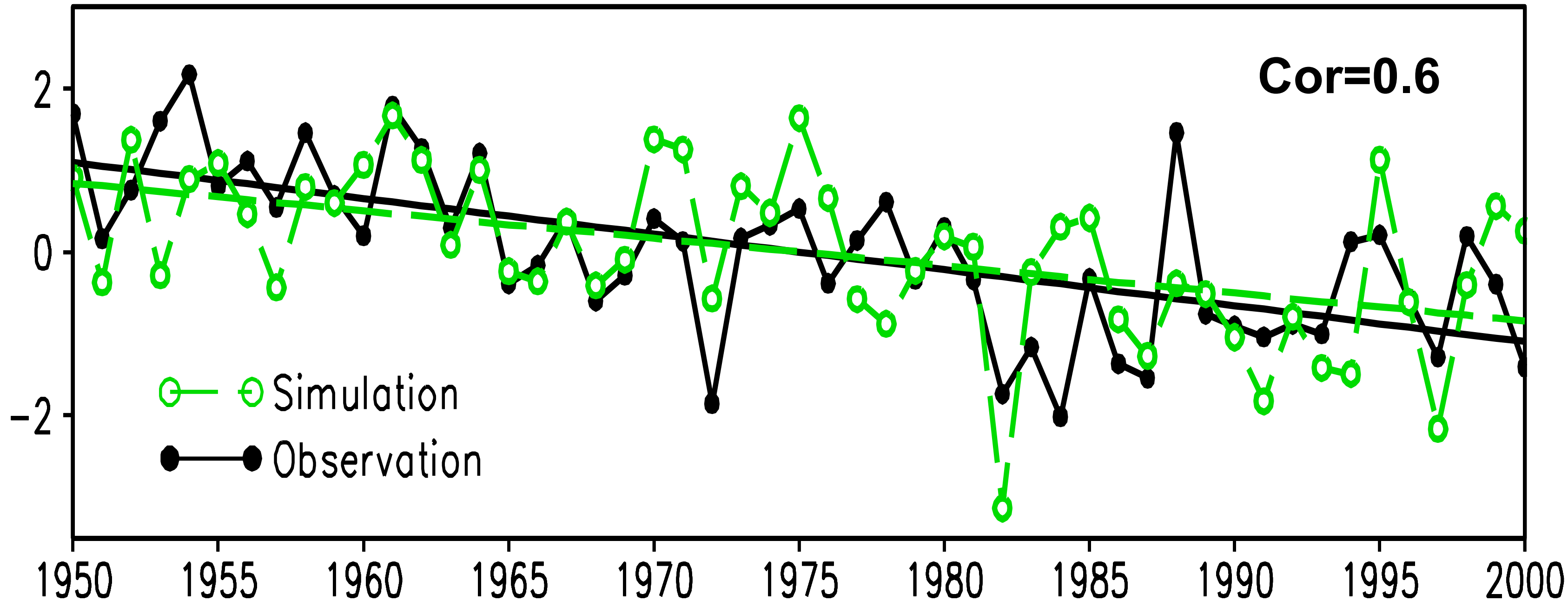


Observation

Simulation

(Zhou et al. 2008 J. Climate)

The observed and simulated Global Land monsoon index



SST-driven AGCM ensemble simulation, with 12 realizations

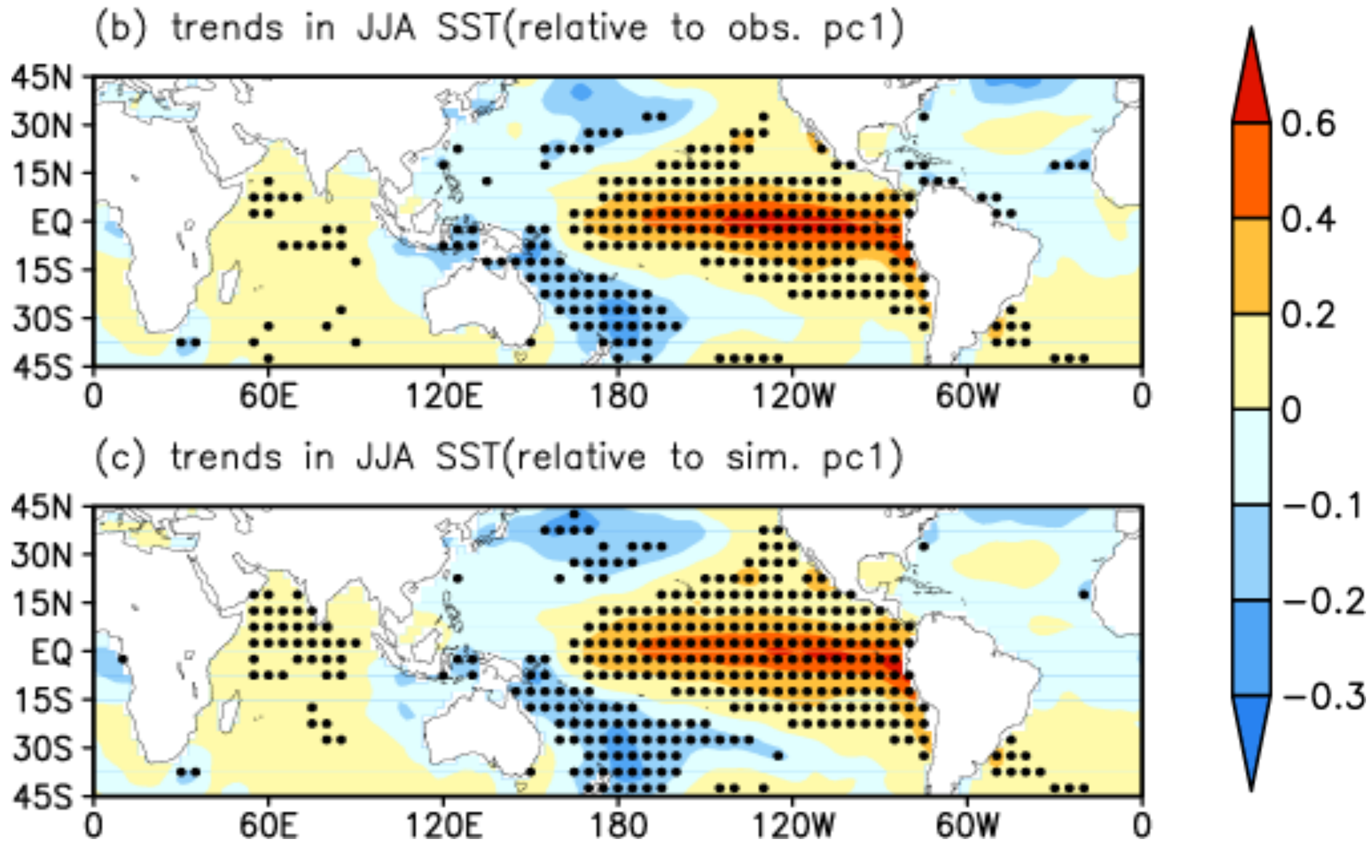
Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

SSTA congruent with the weakening trend of global land monsoon precipitation

Inter-decadal Pacific Oscillation: IPO/PDO

OBS

Model



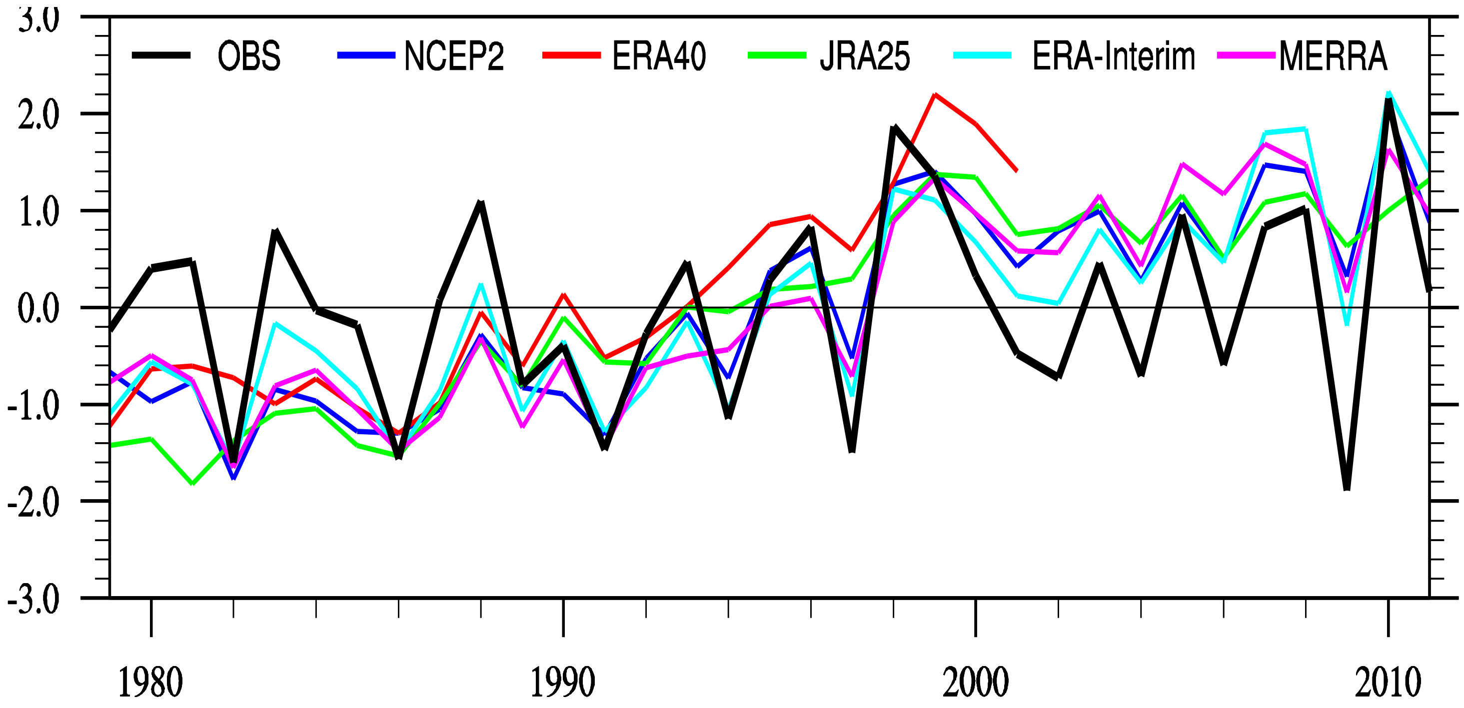
Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

Point # 2

- When forced by historical sea surface temperatures covering 1949-2001, the ensemble simulation with CAM2 model 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.

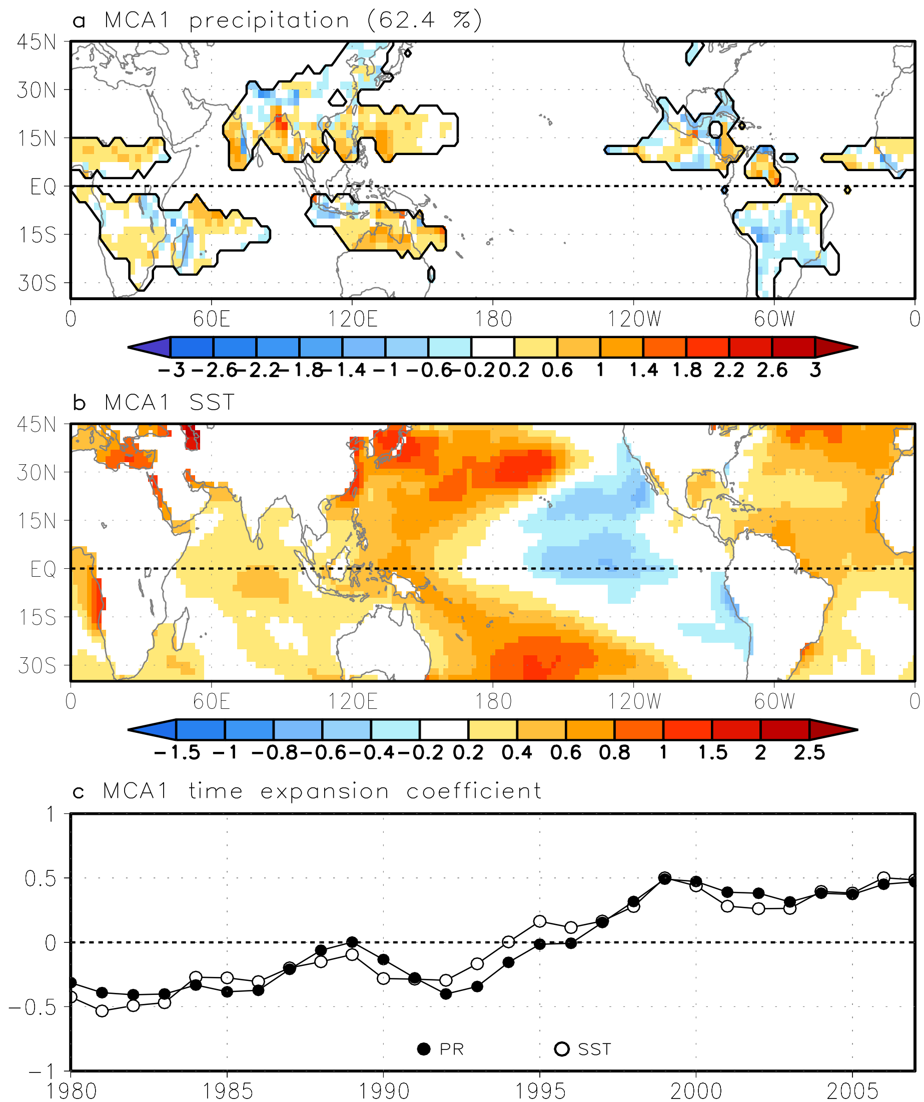
Zhou T., R. Yu., **Hongmei LI** et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852

Doses similar mechanism apply to the recent recovery of GM?



Lin R., T. Zhou, Y. Qian, 2014: Evaluation of Global Monsoon Precipitation Changes based on Five Reanalysis datasets, ***Journal of Climate**, 27(3)*,1271-1289

Recovery of Global Monsoon since early 1980s



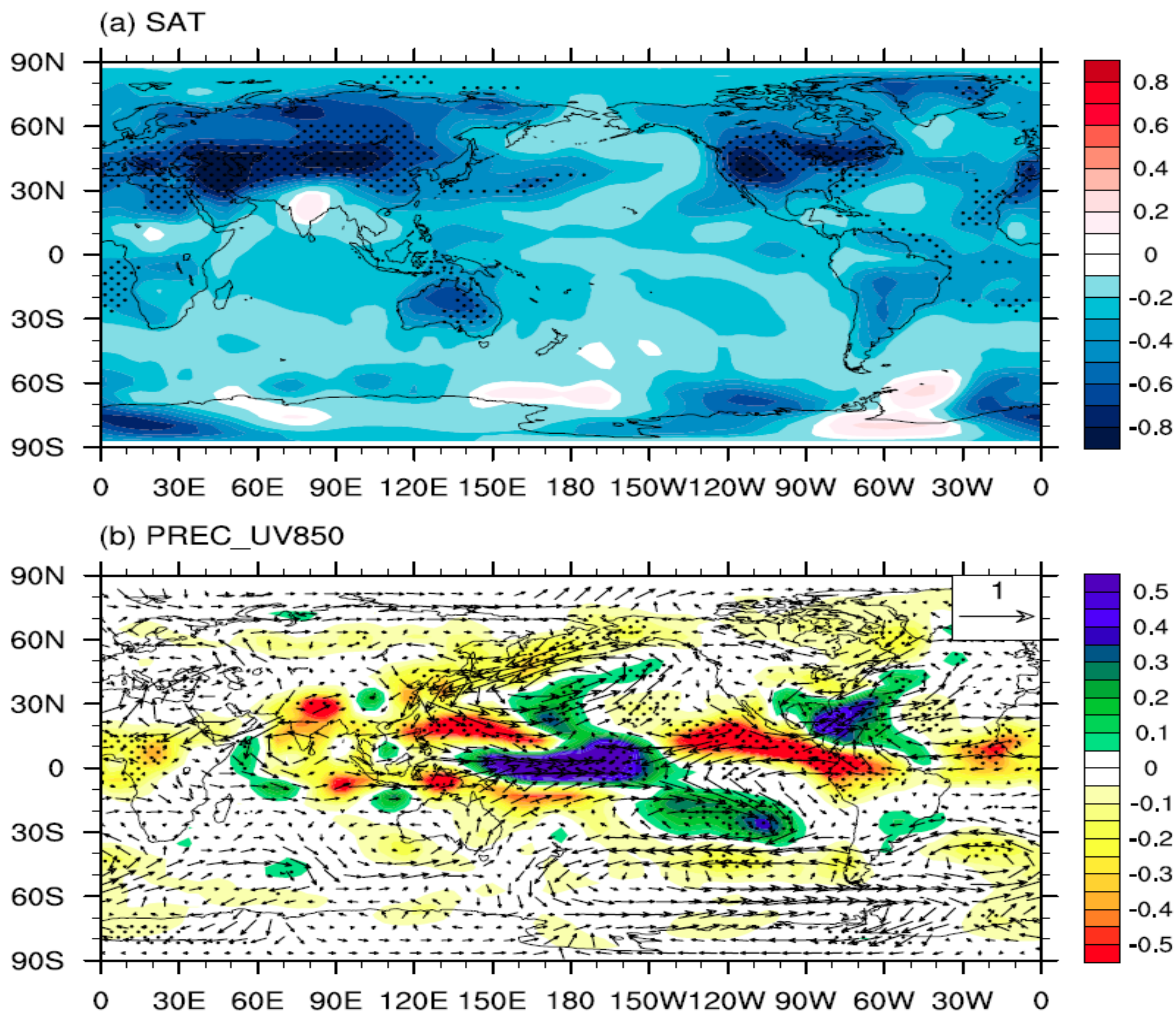
Maximum Covariance Analysis (MCA) of Monsoon precipitation and SST

3-year running mean datasets of GPCP and ERSST.

Wang et al. 2012 CD; 2013, PNAS


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

Point # 3

- The enhanced trend of Global land monsoon since the 1980s is mainly driven by the phase transition of IPO.
- Other external forcing such as volcanic aerosols may also drive the GM changes.
- An increase of moisture convergence due to increased surface evaporation and water vapor in the air column would lead to more monsoon rainfall in a warming world.


GHG & Aerosols

SO2 and Black Carbon emission from the preindustrial to present

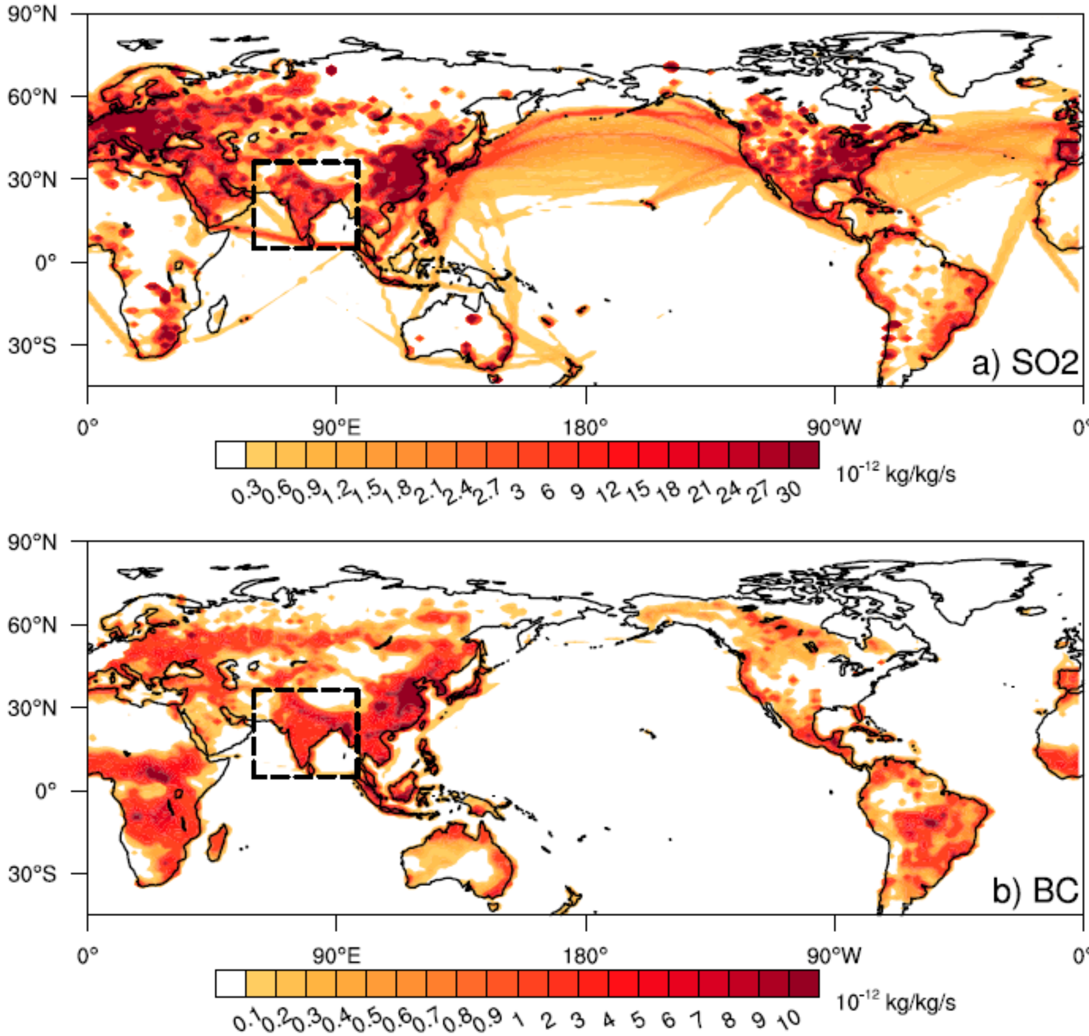
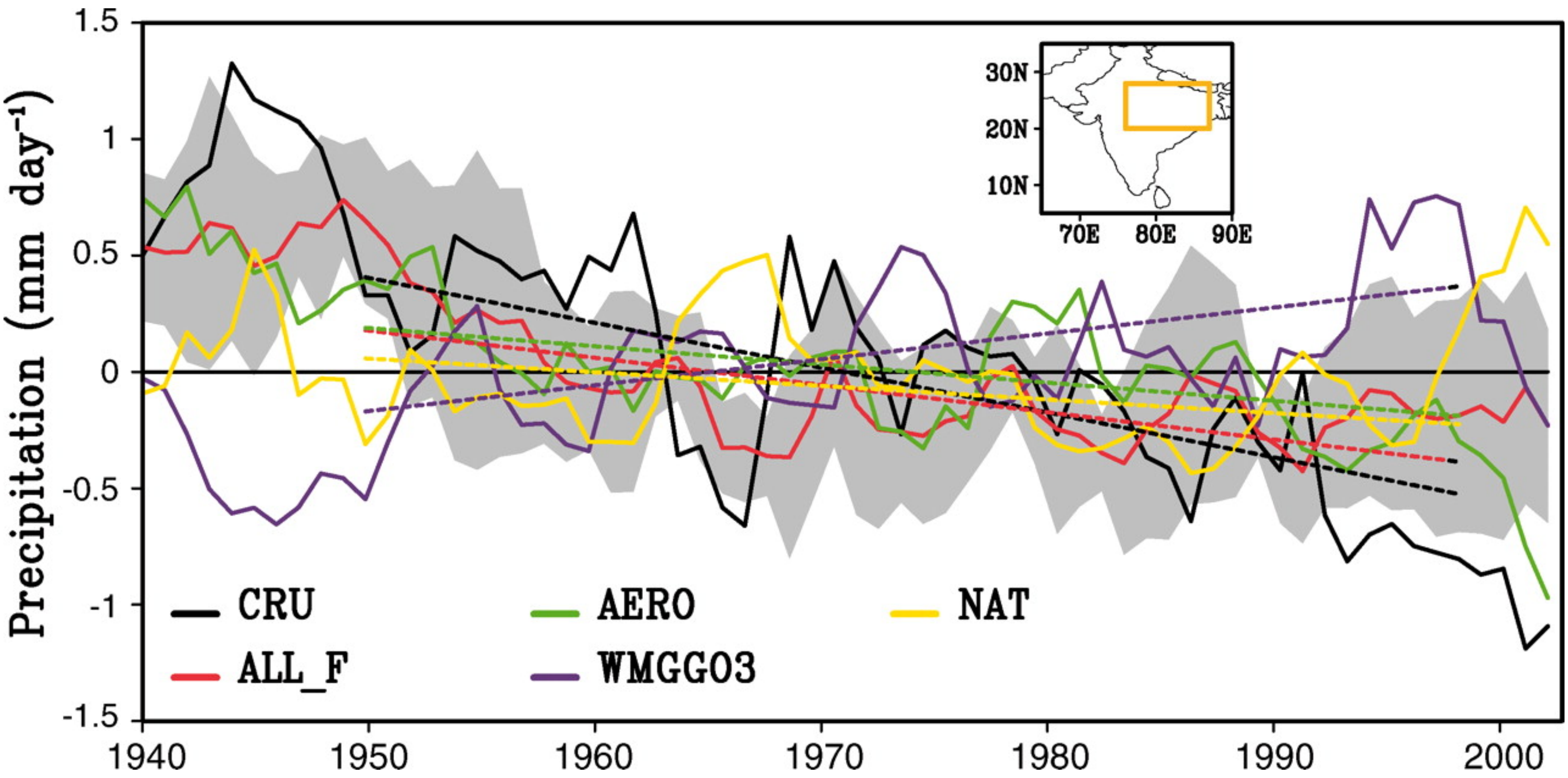


FIG. 1. Change of emissions (10^{-12} kg kg^{-1} s^{-1}) from the preindustrial (1860) to present-day (1976–2005) periods: (a) SO_2 and (b) BC. Data are from the RCPs database (Smith et al. 2001; Bond et al. 2007).

Guo et al. 2016 JC

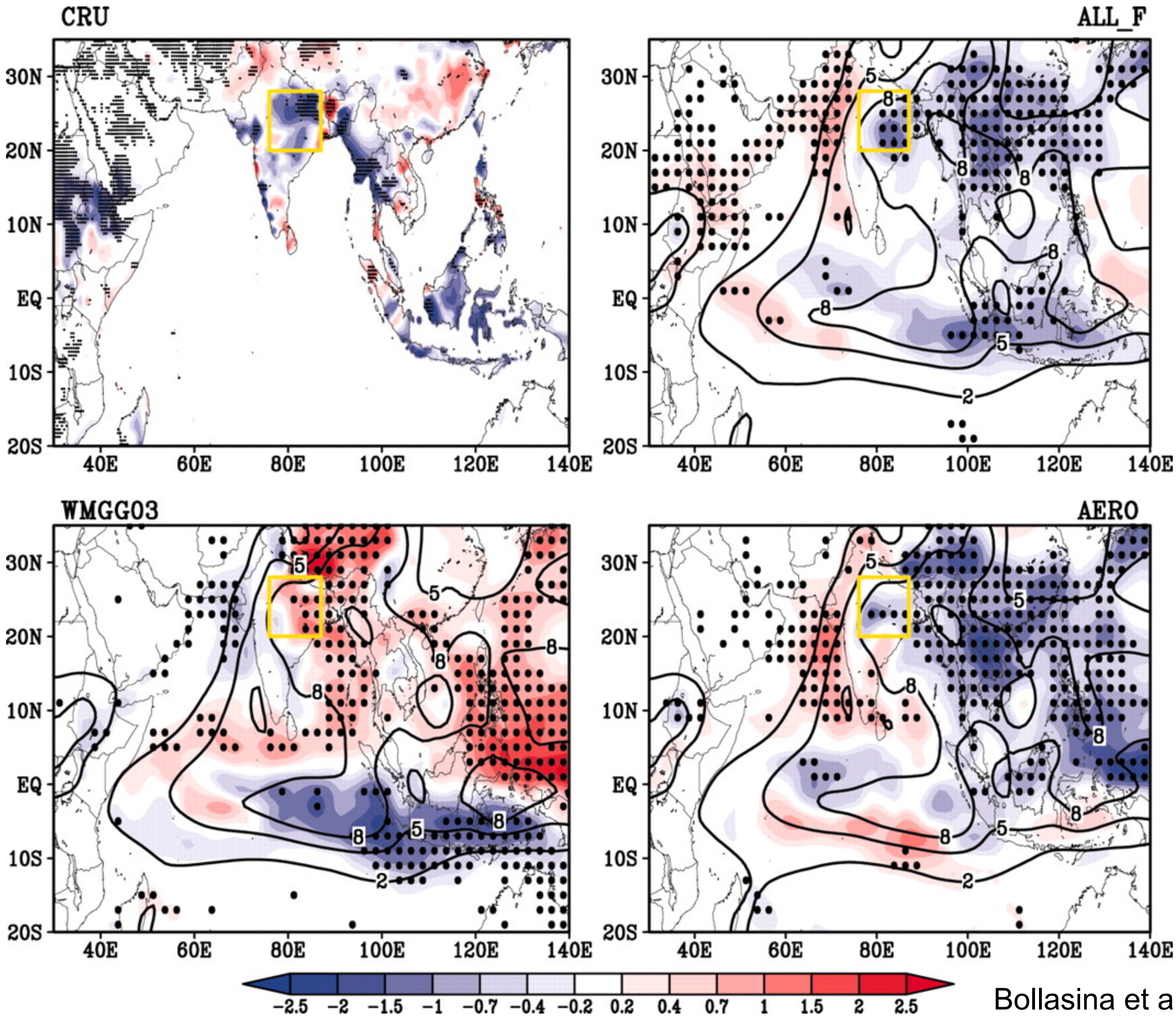
Five-year running mean June-September average precipitation anomalies over central-northern India



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

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

Point # 4

- Observations show that South Asia underwent a widespread summertime drying during the second half of the 20th century, but it is unclear whether this trend was due to natural variations or human activities.
- A series of climate model experiments is used to investigate the South Asian monsoon response to natural and anthropogenic forcings. The observed precipitation decrease can be attributed mainly to human-influenced aerosol emissions.
- The drying is a robust outcome of a slowdown of the tropical meridional overturning circulation, which compensates for the aerosol-induced energy imbalance between the Northern and Southern Hemispheres.
- These results provide compelling evidence of the prominent role of aerosols in shaping regional climate change over South Asia.

Bollasina et al. 2011 Science


How about the East Asian summer monsoon ?

The details of 17 CMIP5 models

No.	Model	Institute	Atmospheric resolution (lat*lon)	Member (35)
1	bcc-csm1-1	BCC/China	64*128	1
2	BNU-ESM	BNU/China	64*128	1
3	CanESM2	CCCma/Canada	64*128	5
4	CCSM4	NCAR/USA	192*288	3
5	CNRM-CM5	CNRM-CERFACS/France	128*256	6
6	CSIRO-Mk3-6-0	CSIRO-QCCCE/Australia	96*192	1
7	FGOALS-g2	IAP-THU/China	60*128	1
8	GFDL-CM3	NOAA GFDL/USA	90*144	1
9	GFDL-ESM2M	NOAA GFDL/USA	90*144	1
10	GISS-E2-H	NASA-GISS/USA	90*144	1
11	GISS-E2-R	NASA-GISS/USA	90*144	1
12	HadGEM2-ES	MOHC/UK	144*192	4
13	IPSL-CM5A-LR	IPSL/France	96*96	3
14	MIROC-ESM	MIROC/Japan	64*128	3
15	MIROC-ESM-CHEM	MIROC/Japan	64*128	1
16	MRI-CGCM3	MRI/Japan	160*320	1
17	NorESM1-M	NCC/Norway	96*144	1

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*

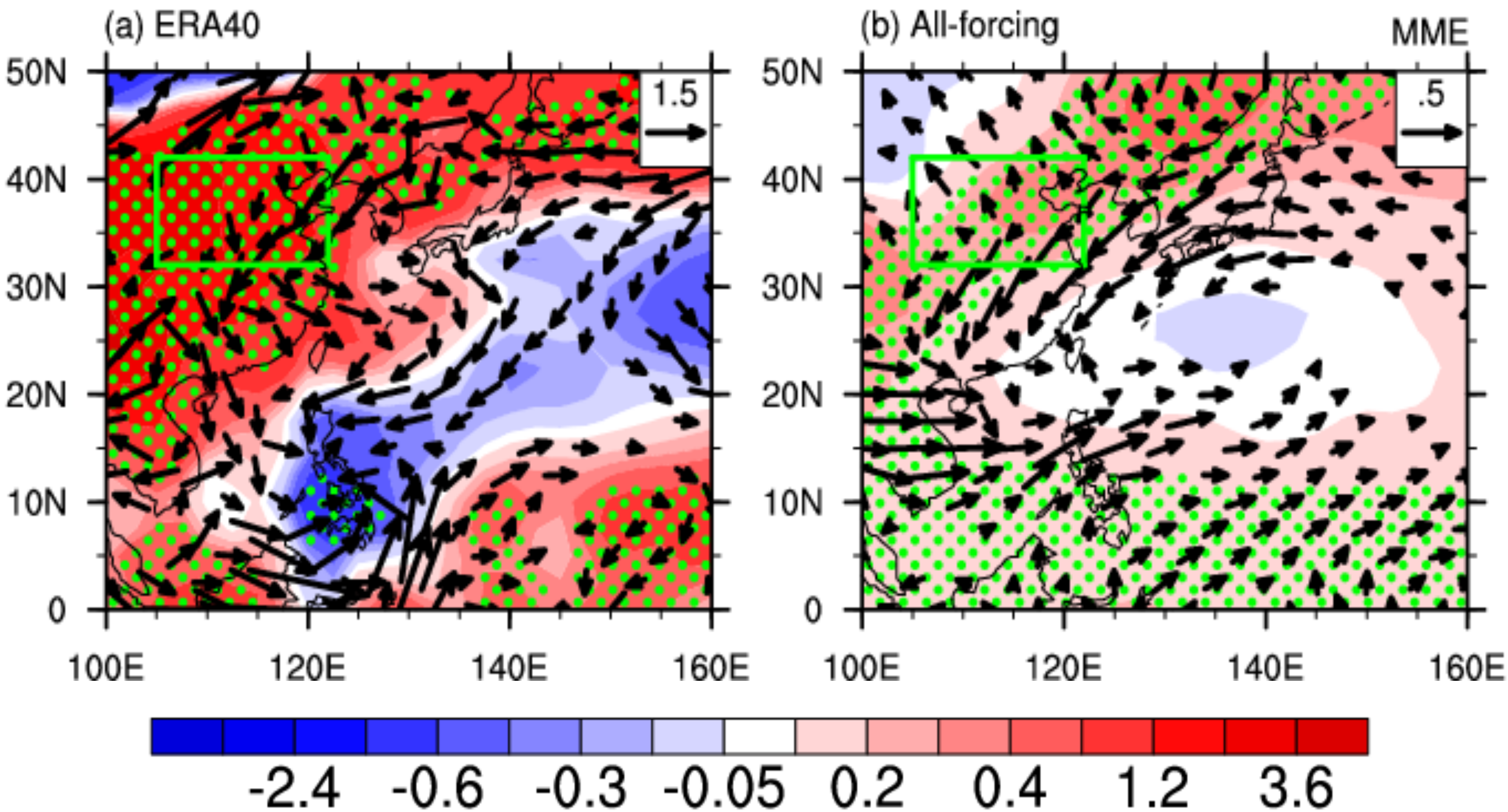
Details of three sets of CMIP5 experiments

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*

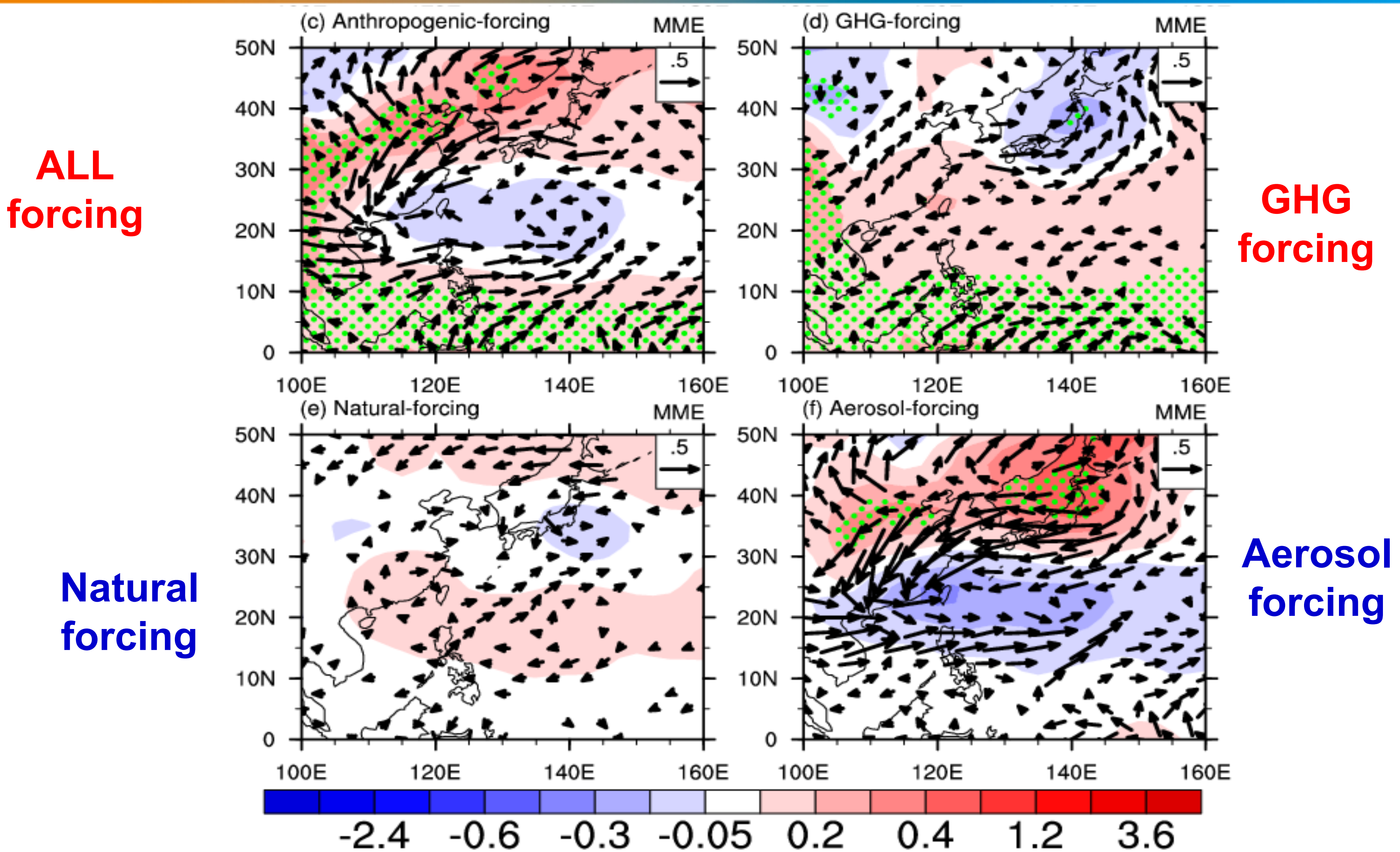
Linear trends of SLP and 850 hPa winds (1958-2001)



ERA40 **MME of CMIP5**

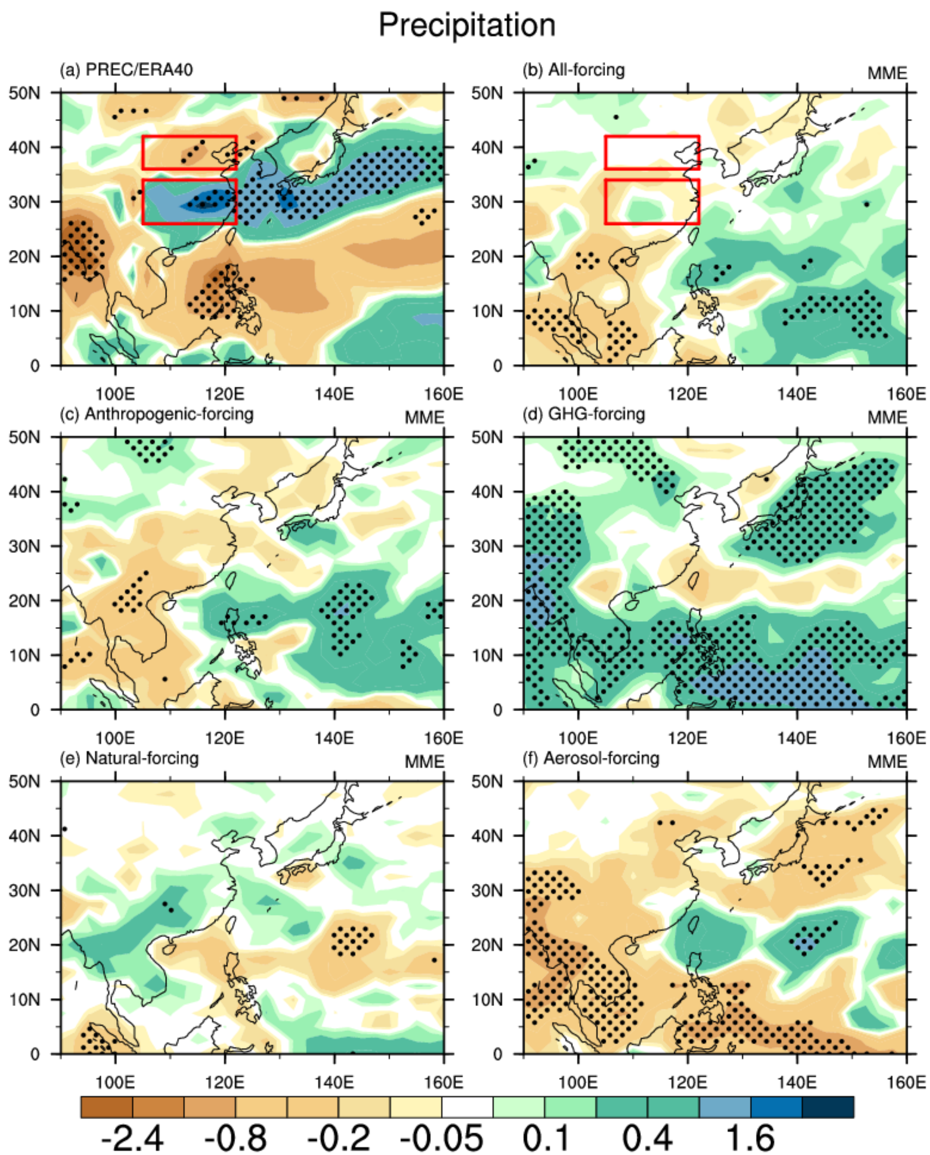
Song F., **T. Zhou**, and Y. Qian, 2013: Responses of East Asian summer monsoon to natural and anthropogenic forcings in the 17 latest CMIP5 models. *Geophysical Research Letters, 10.1002/2013GL058705*

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*

Linear trends of JJA precipitation (1958-2001)



ALL forcing

Anthropogenic

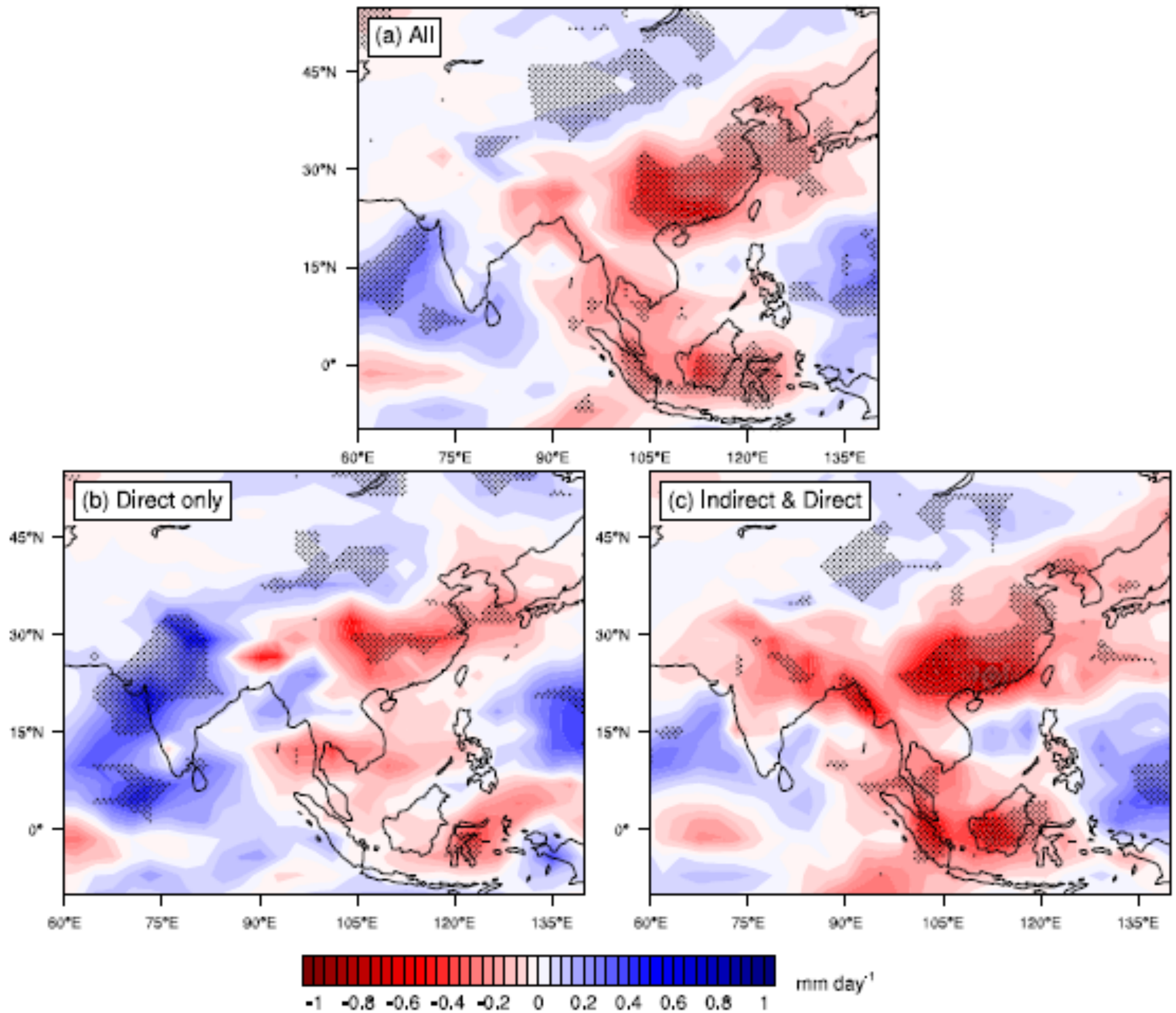
GHG forcing

Natural forcing

Aerosol forcing

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

Point # 5

- The observed weakening trend of low-level EASM circulation during 1958–2001 is partly and weakly reproduced under all-forcing runs. A comparison of separate forcing experiments reveals that the aerosol forcing plays a primary role in driving the weakened low-level monsoon circulation.
- The preferential cooling over continental East Asia caused by aerosol affects the monsoon circulation through reducing the land-sea thermal contrast and results in higher sea level pressure over northern China.
- The increasing GHG forcing is favorable for an enhanced monsoon circulation.
- The models still failed in the simulation of monsoon rainband changes.

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*

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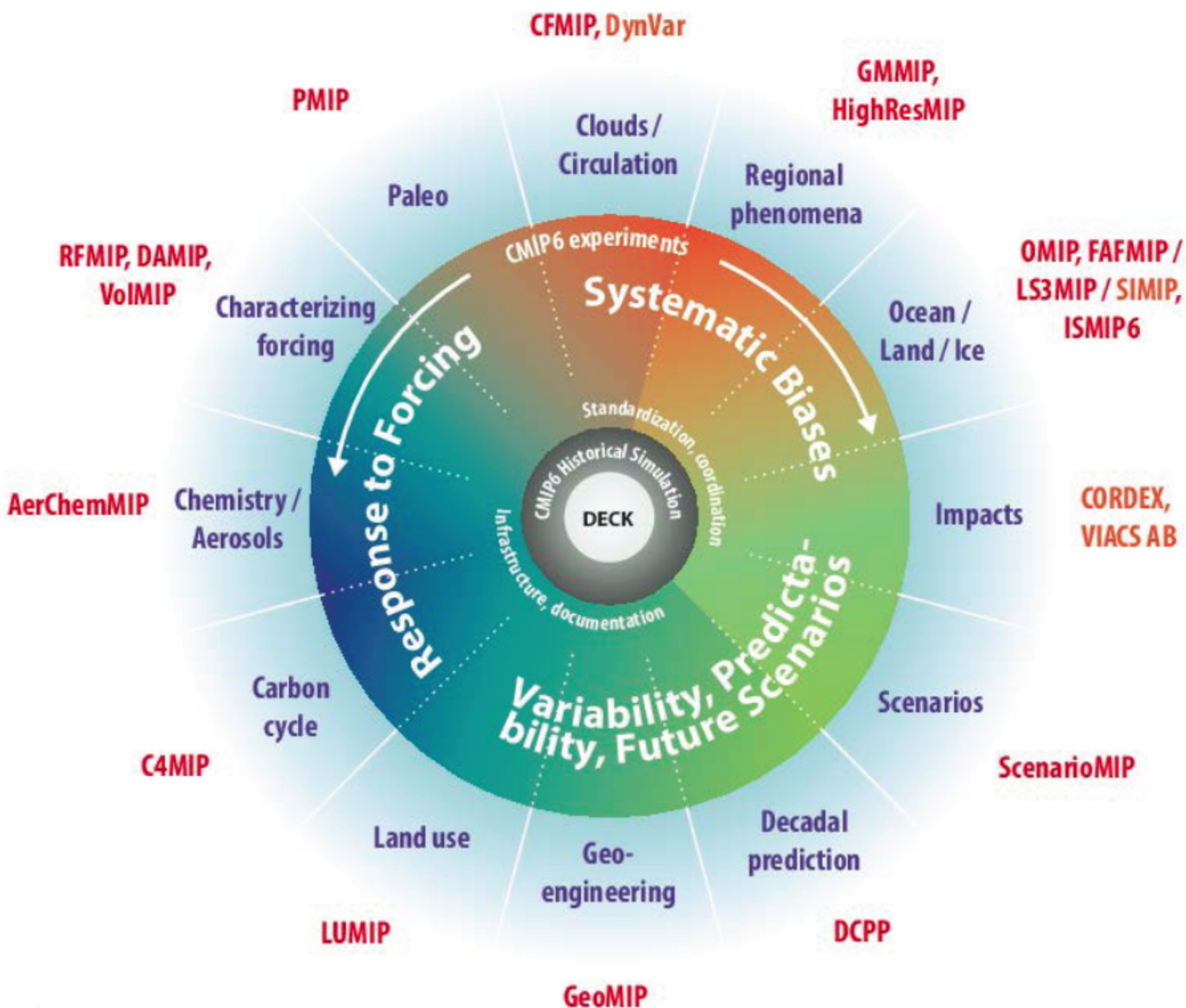
21 CMIP6-Endorsed MIPs



Diagnostic MIPs

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**

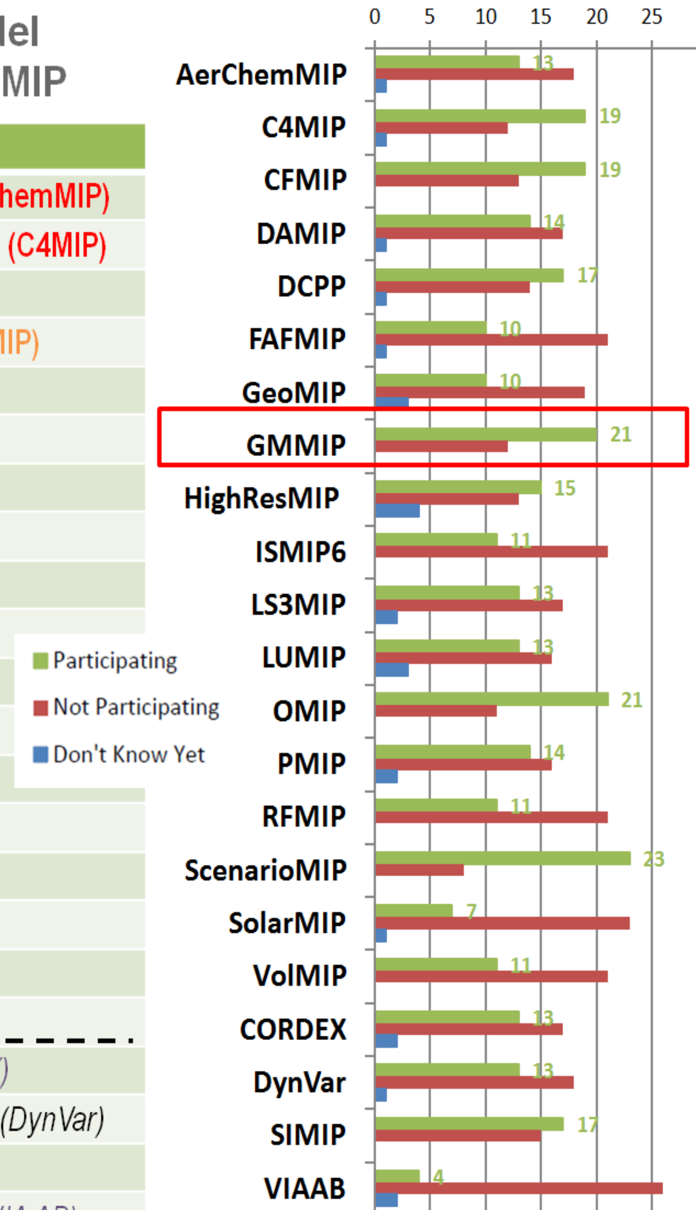
WCRP World Climate Research Programme

cmip Coupled Model Intercomparison Project

Model Groups' Commitments to participate in each MIP

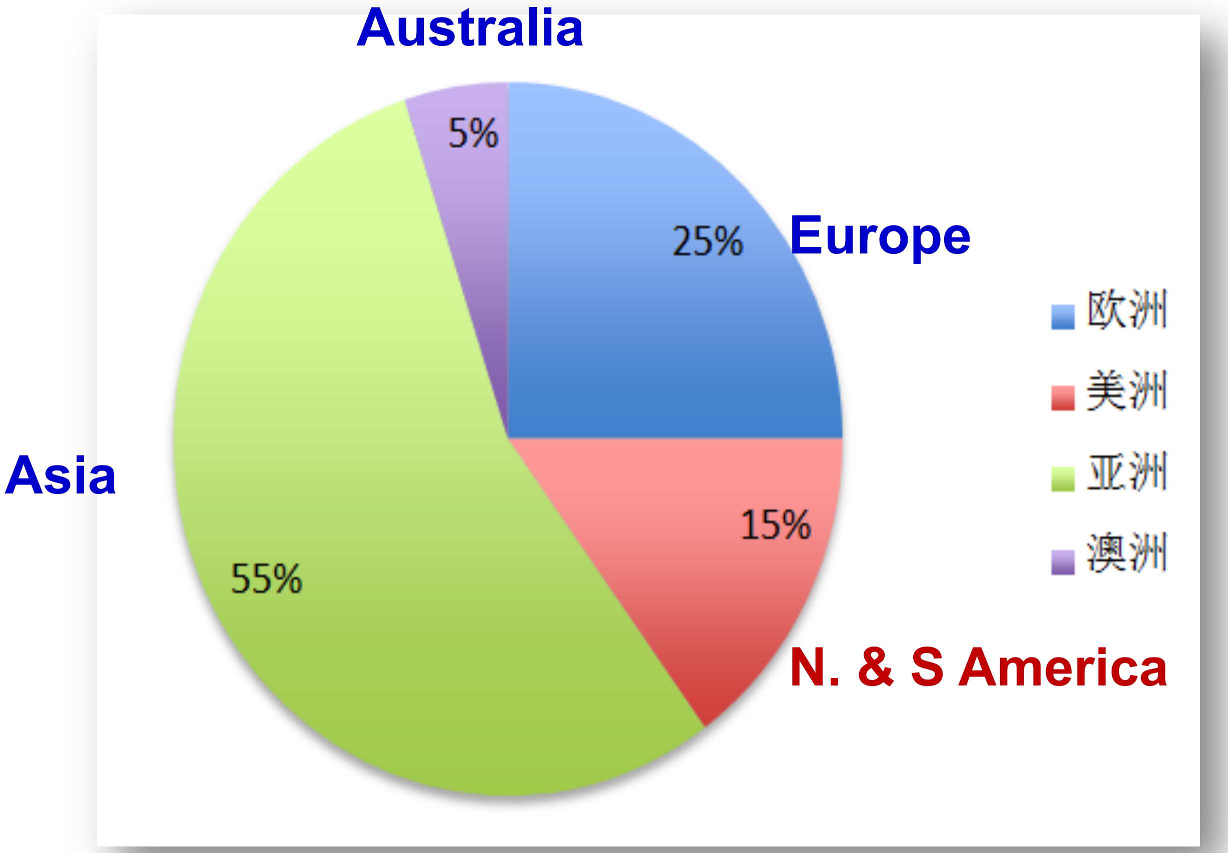
Proposals from CMIP6-Endorsed MIPs & Model Groups' Commitments to Participate in each MIP

	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

Model groups' commitment to participate in GMMIP



21 model groups from 14 countries

The World Climate Research Programme's Coupled Model Intercomparison Project

GMMIP Partner Institutes

Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-69, 2016
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Geoscientific Model Development Discussions
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Table 1. Description of models participating GMMIP

Model	Institute/Country
ACCESS	CSIRO-BOM/Australia
BCC-CSM2-MR	BCC/China
BNU-ESM	BNU/China
CAMS-CSM	CAMS/China
CanESM	CCCma/Canada
CAS-ESM	CAS-IAP/China
CESM	NCAR-COLA/USA
CESS-THU	THU/China
CMCC	CMCC/Italy
CNRM-CM	CNRM-CERFACS/France
FGOALS	IAP-LASG/China
FIO	FIO/China
GFDL	NOAA-GFDL/USA
GISS	NASA-GISS/USA
HadGEM3	MOHC-NCAS/UK
IITM	IITM/India
IPSL-CM6	IPSL/France
MIROC6-CGCM	AORI-UT-JAMSTEC-NIES/Japan
MPI-ESM	MPI-M/Germany
MRI-ESM1.x	MRI/Japan
NUIST-CSM	NUIST/China

WCRP World Climate Research Programme

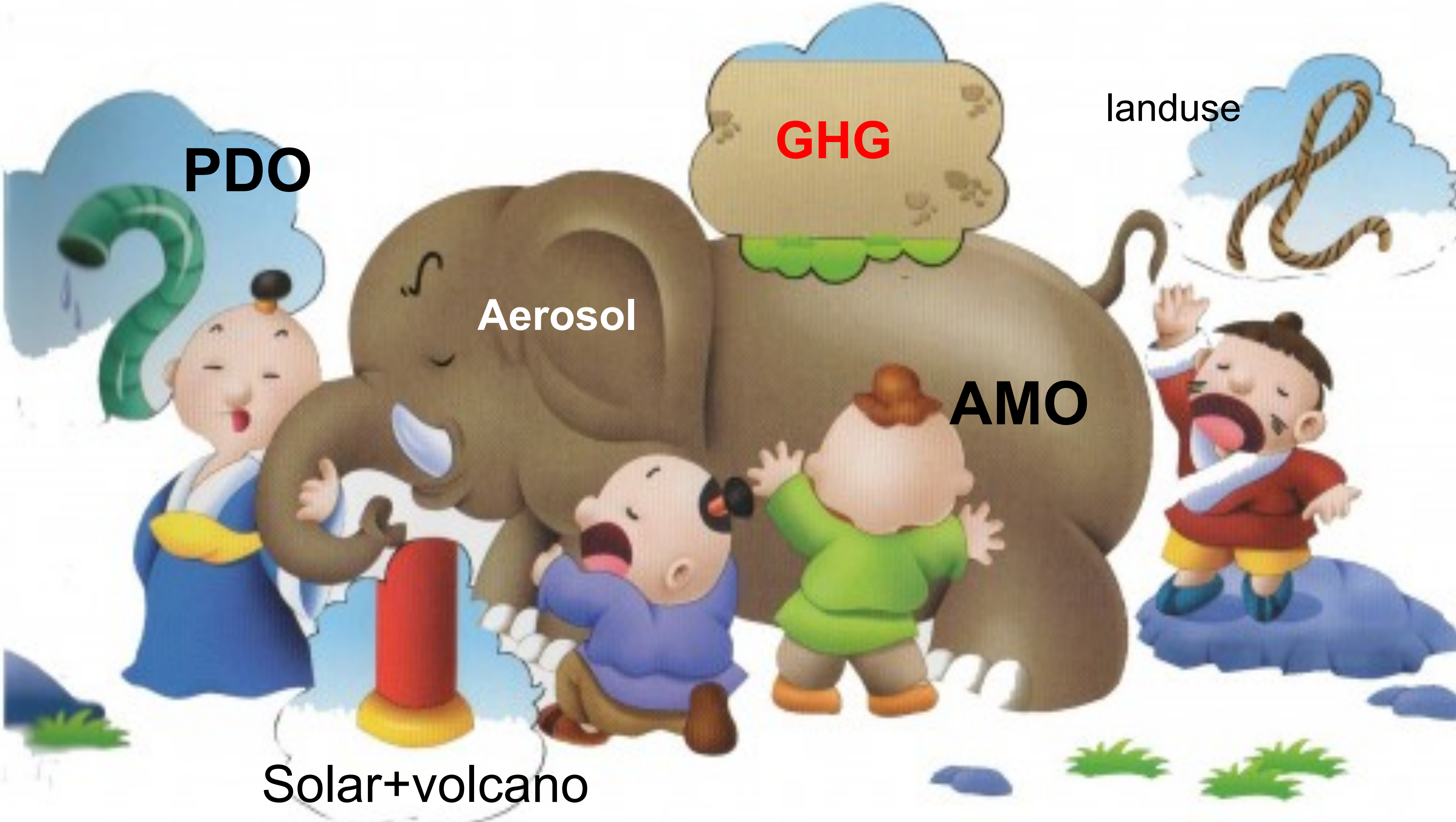
cmip Coupled Model Intercomparison Project

Zhou T., A. Turner, J. Kinter, B. Wang Y. Qian et al. 2016, **Geosci. Model Dev.**, 9, 1-16

Coupled
Model
Intercomparison
Project

Why do we propose GMMIP ?

Forcings to GM changes



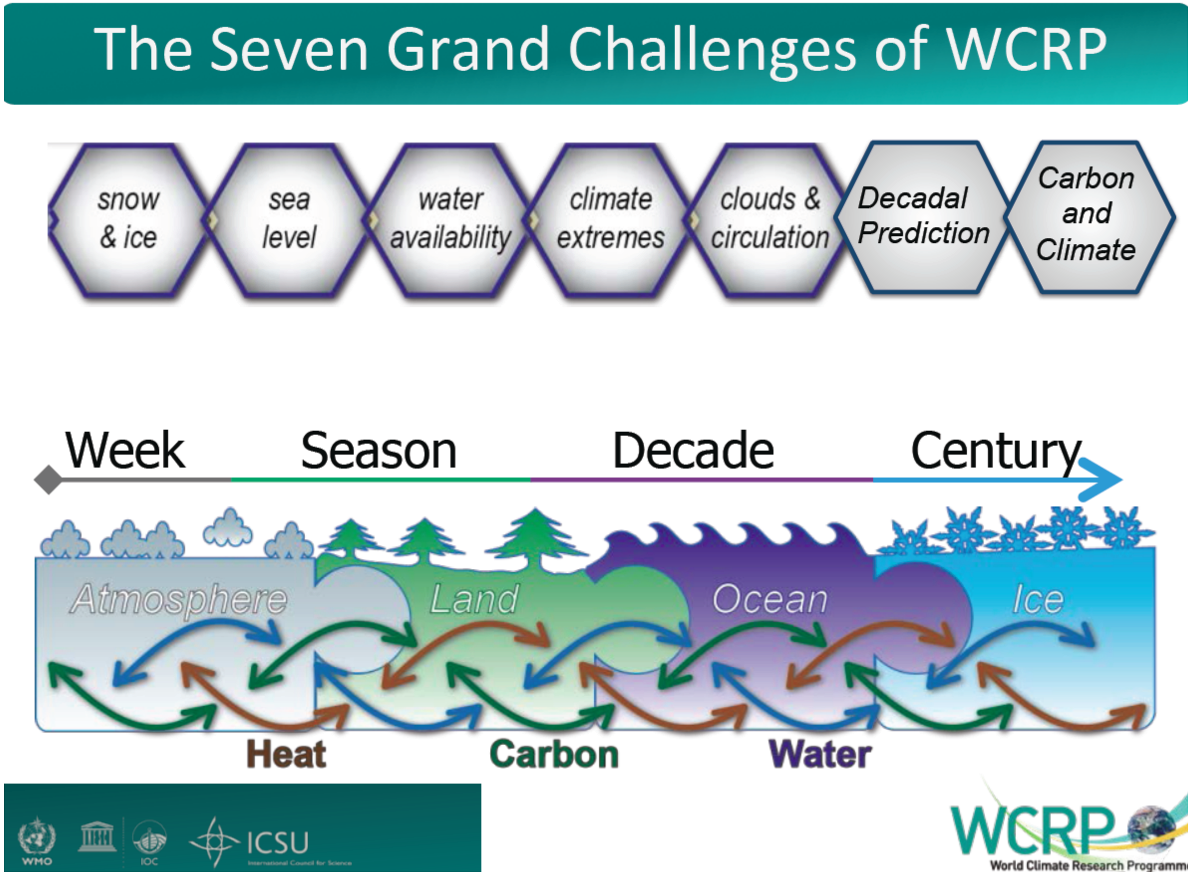
Forcings to Monsoon changes

- Increasing evidences indicate that the observed monsoon changes are driven by both internal (IPO & AMO) and external forcing agents.
- But the understanding of the underlying mechanisms are model-dependent, in particular for precipitation.
- A multi-model inter-comparison is crucial.
- CMIP6 provides an excellent opportunity for the community.

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?

WCRP Grand Challenges



GMMIP will address the WCRP Grand Challenges in the following ways:

1.Water availability *(Rank-1)*,

2.Clouds, circulation and climate sensitivity *(Rank-2)*,

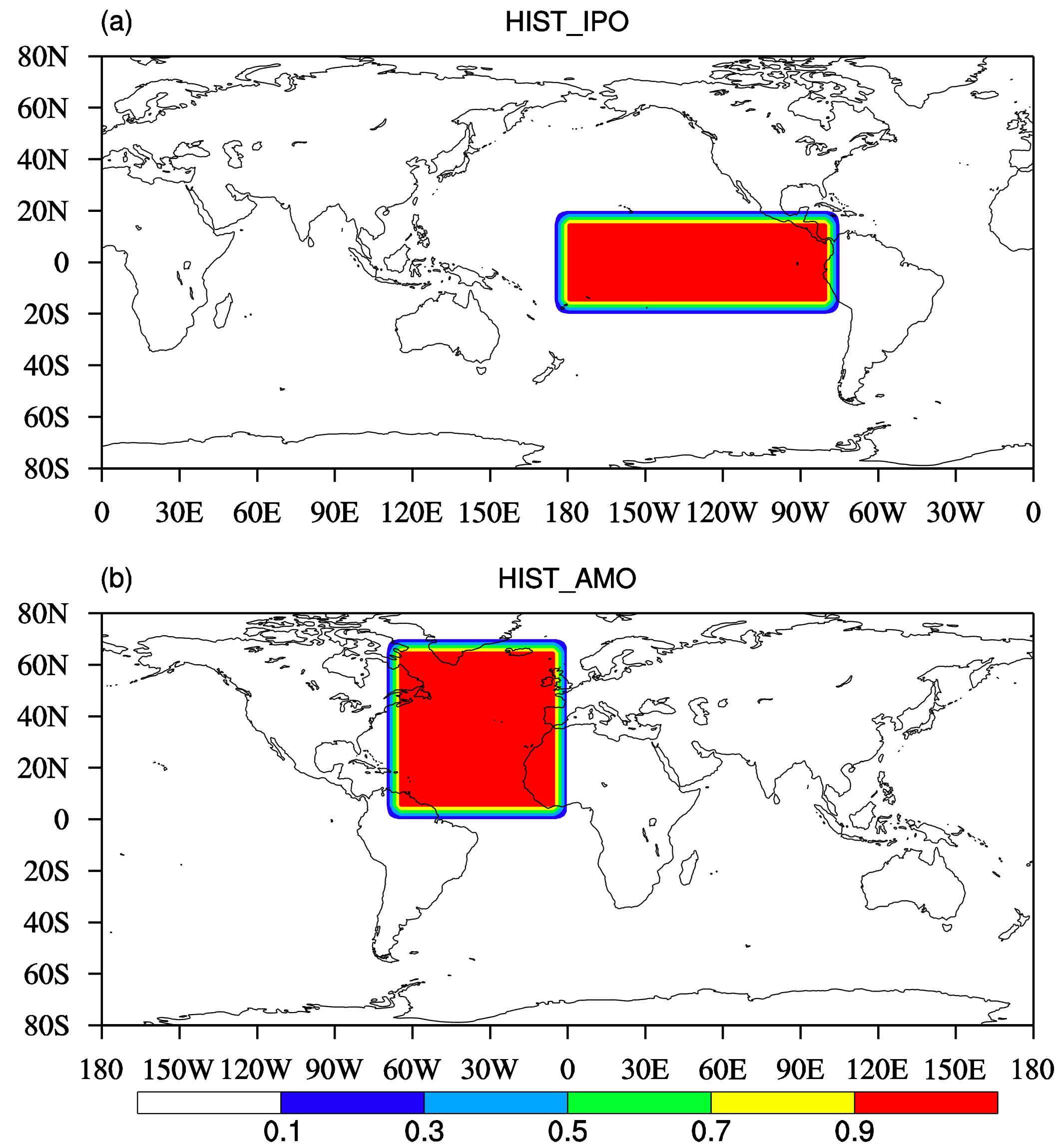
3.Climate extremes *(Rank-2)*

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

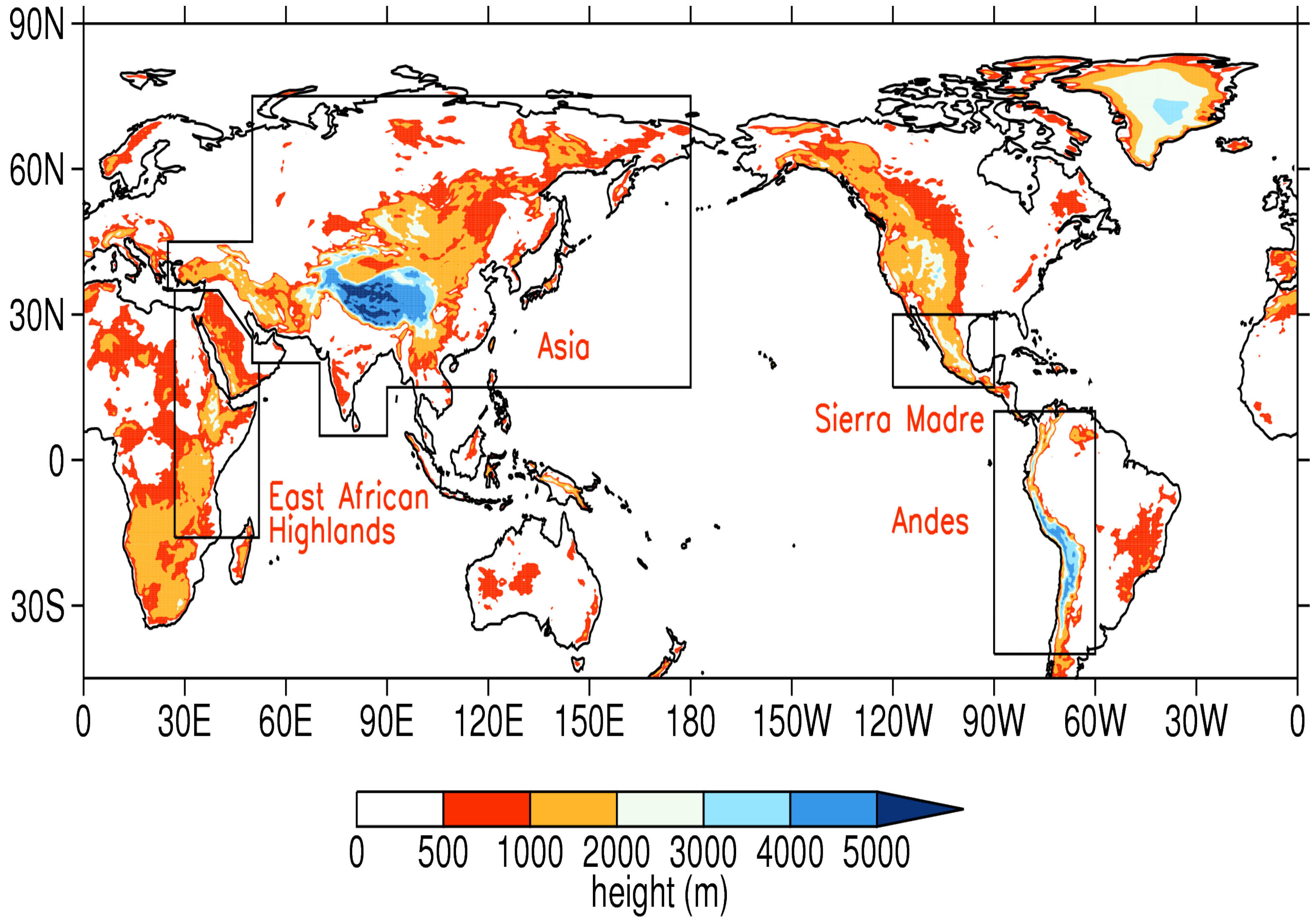
IPO、AMO Pacemaker Exps



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.

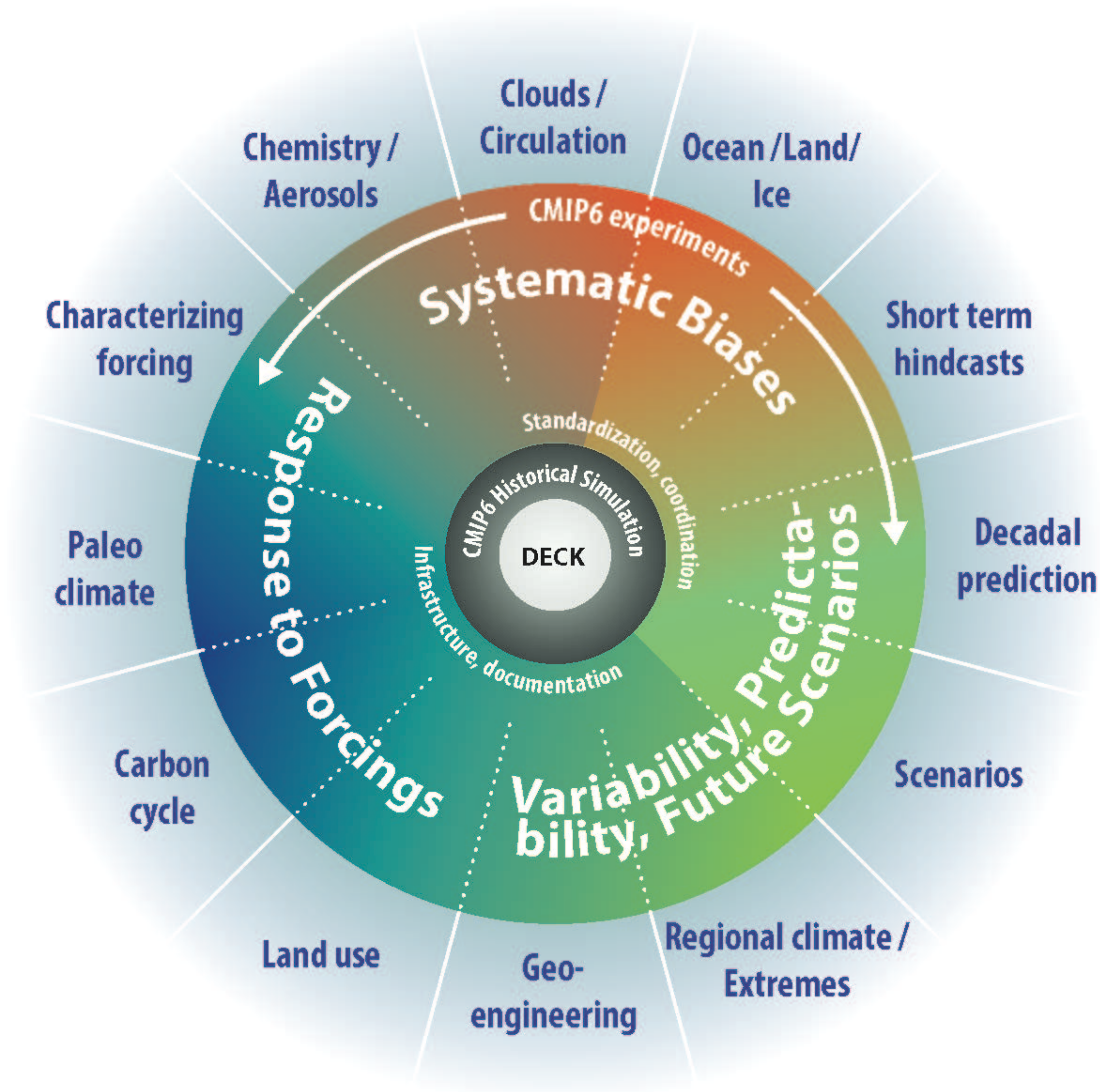
Orography regions specified for the Tier-3 experiments



Connection with other MIPs

- DAMIP (understand the contributions from anthropogenic factors and natural forcing)
- HighResMIP (understanding the impact of high-resolution in reproducing global monsoon)
- VolMIP (understanding the effects of volcanism on global monsoon)
- DCPP (skills of global monsoons in decadal climate prediction)

Connection with DECK and CMIP6 Historical Simulation



Diagnosis, Evaluation, and Characterization of Klima (DECK) Experiments

DECK (entry card for CMIP)

i.AMIP simulation (~1979-2014)

ii.Pre-industrial control simulation

iii.1%/yr CO_2 increase

iv.Abrupt 4xCO_2 run

CMIP6 Historical Simulation

(entry card for CMIP6)

v.Historical simulation using CMIP6 forcings (1850-2014)

(Courtesy of Veronika Eyring)

GMMIP Exps and related other MIPs

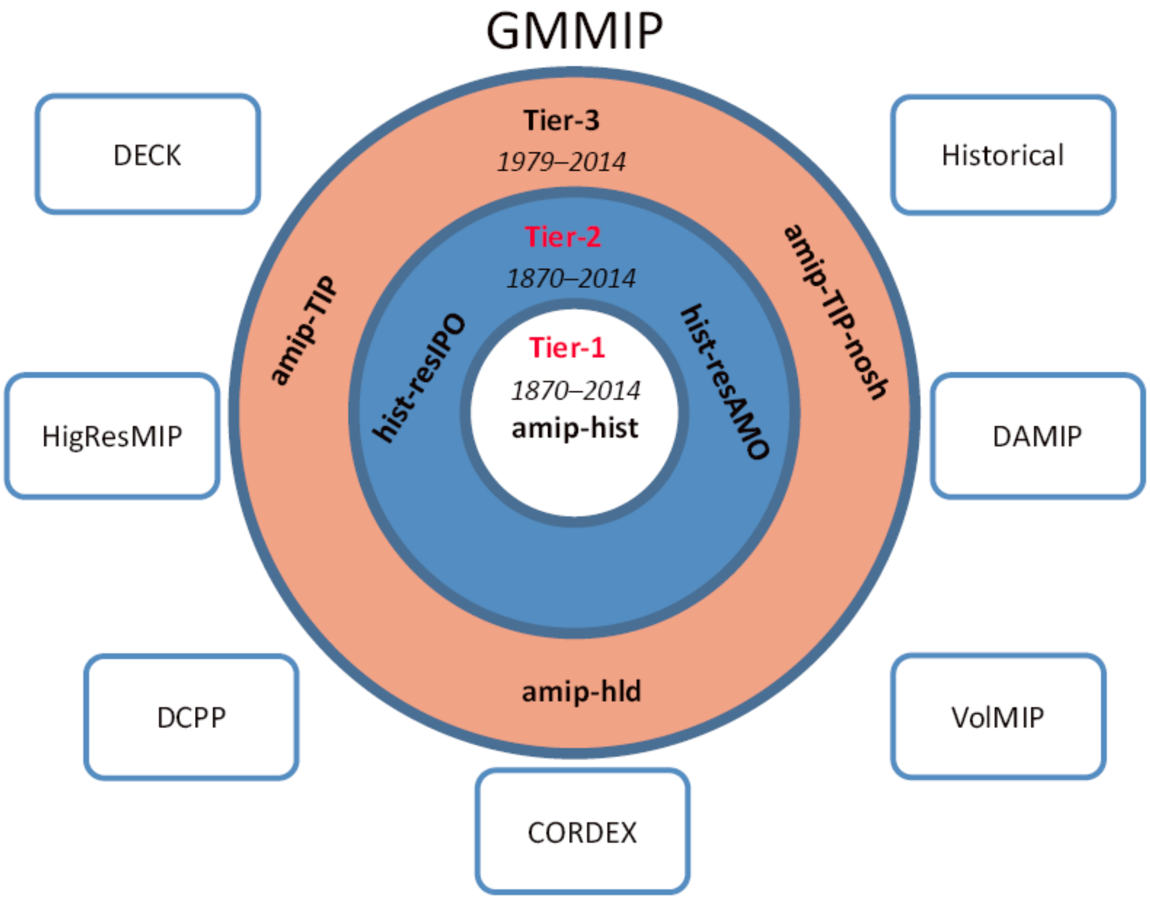
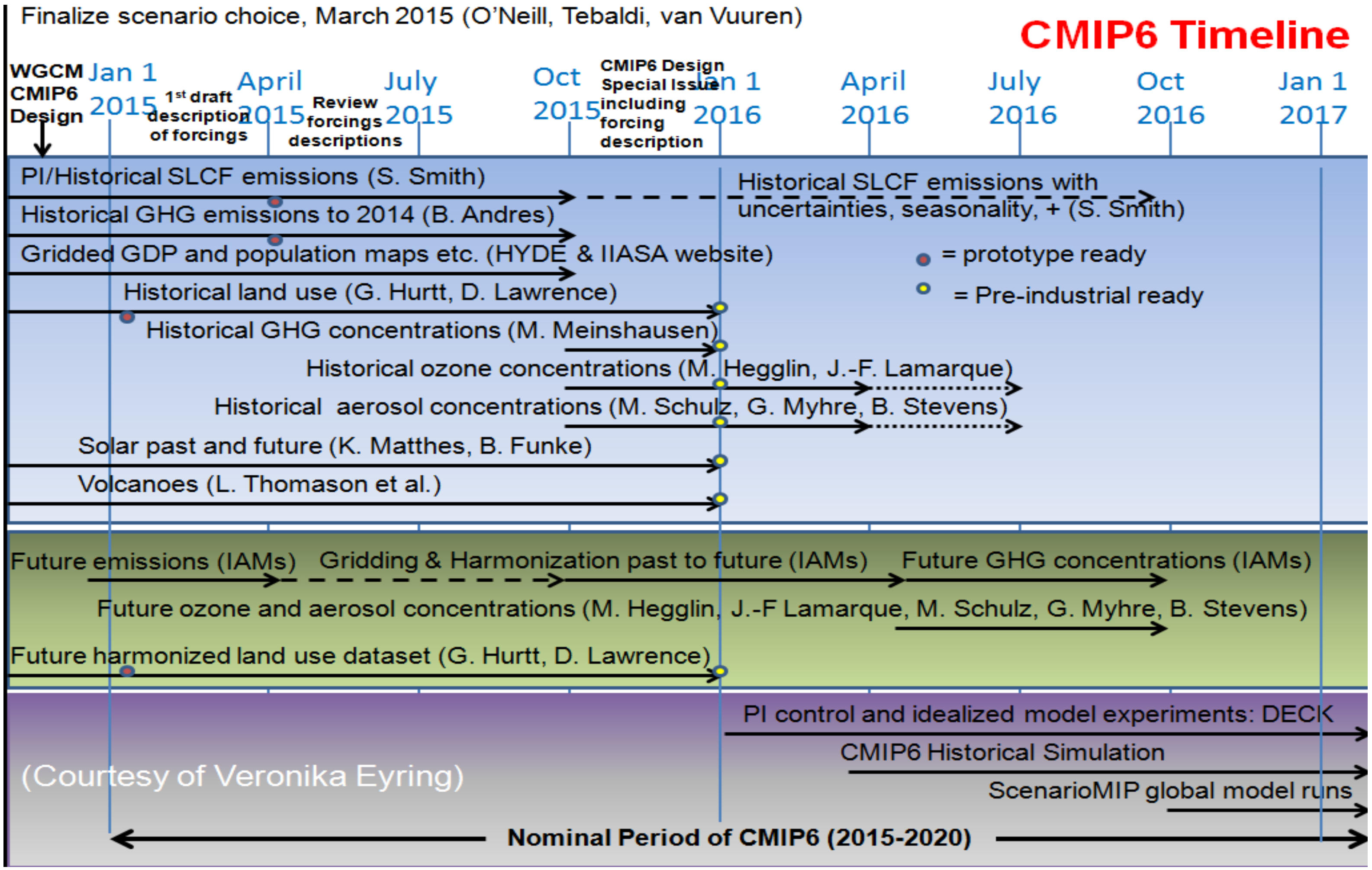


Figure 3. Three-tier experiments of GMMIP and its connections with DECK, historical simulation and endorsed MIPs.

Data to be available in late 2017



CMIP6 Timeline

Outline

1. What is GMMIP?
2. Why do we propose GMMIP ?
3. What will GMMIP do?
4. Concluding remarks

Concluding Remarks

- Global monsoons have undergone significant long term changes in the past century.
- Both the internal (IPO and AMO) and the external forcing (GHG, aerosol) contributes to the changes, but their relative contributions are still 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.

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doi:10.5194/gmd-9-1-2016

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

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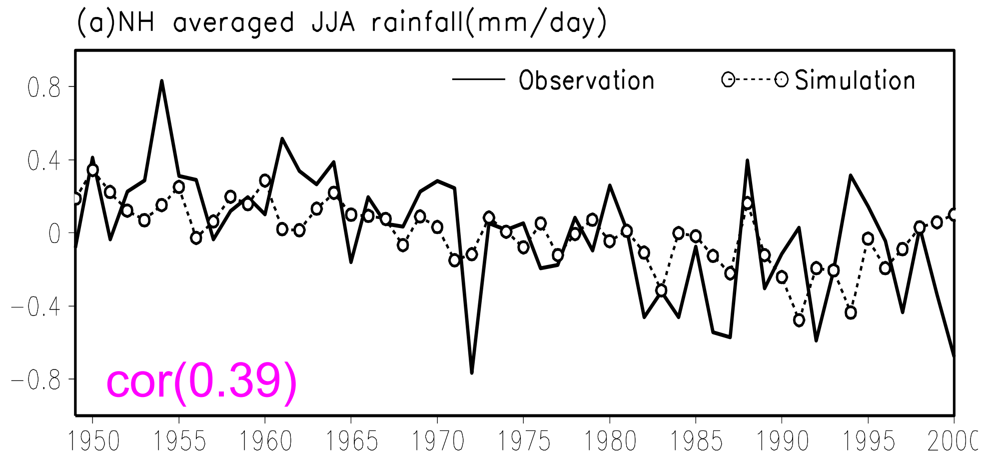
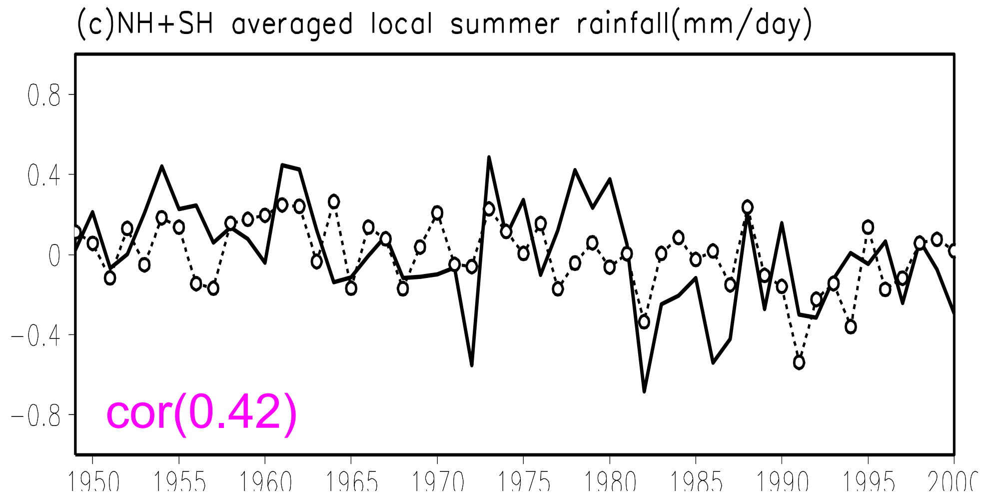
THANKS

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

The time evolution of land monsoon precipitation in the observation and the simulation





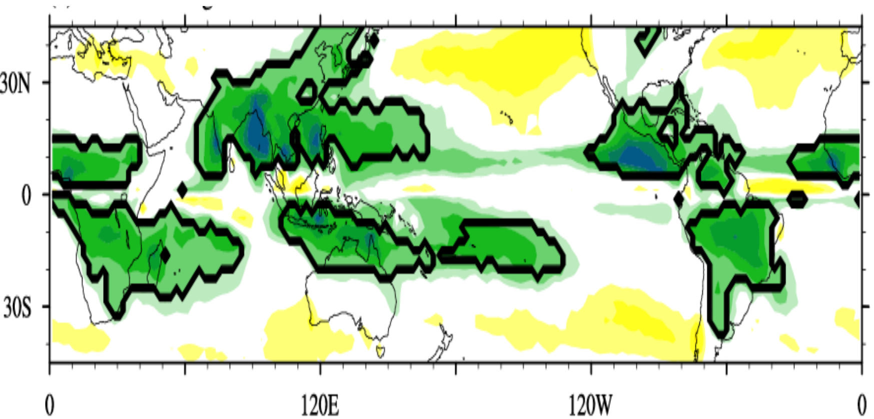
- The observed monsoon index show a decreasing trend across the entire 50 years, and particularly before 1980s.
- The observed decreasing trend is found in the simulation, although slightly weaker than the observation.

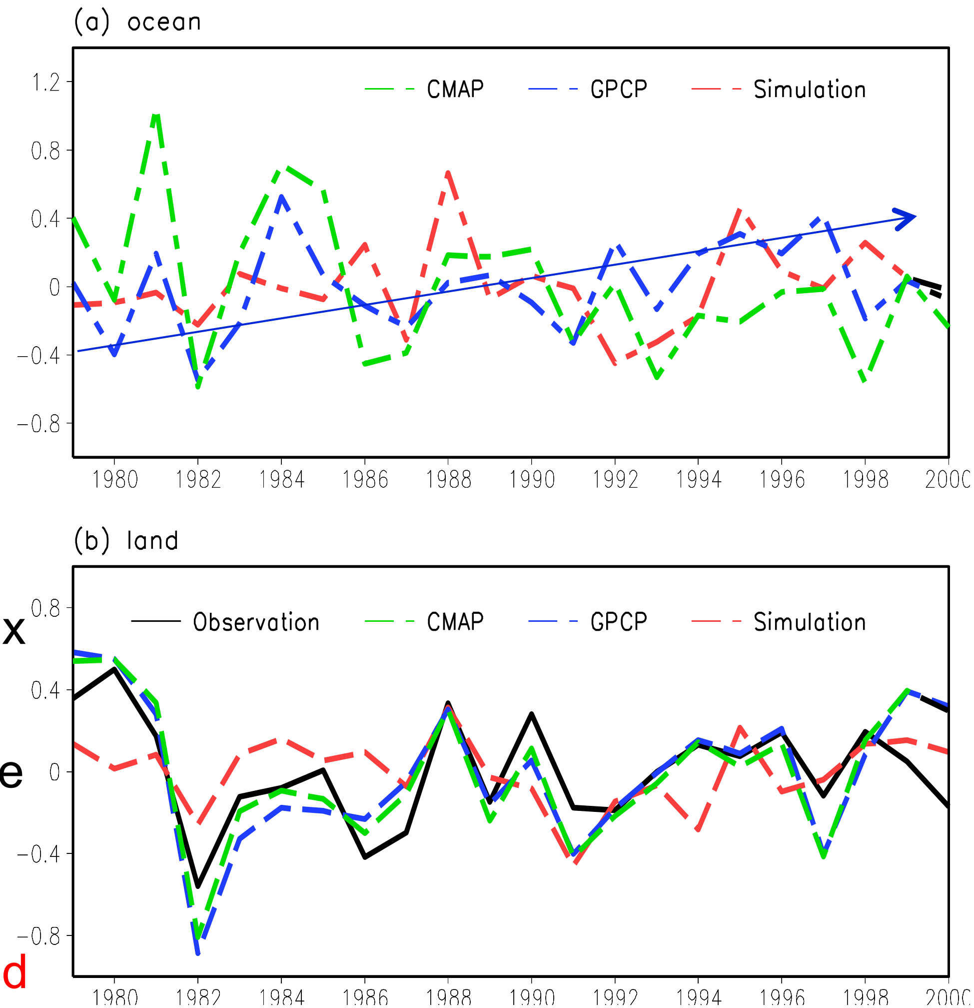
-0.36mm/day/50year in simulation

-0.59mm/day/50year in observation

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

Monsoon precipitation changes in global land and ocean areas





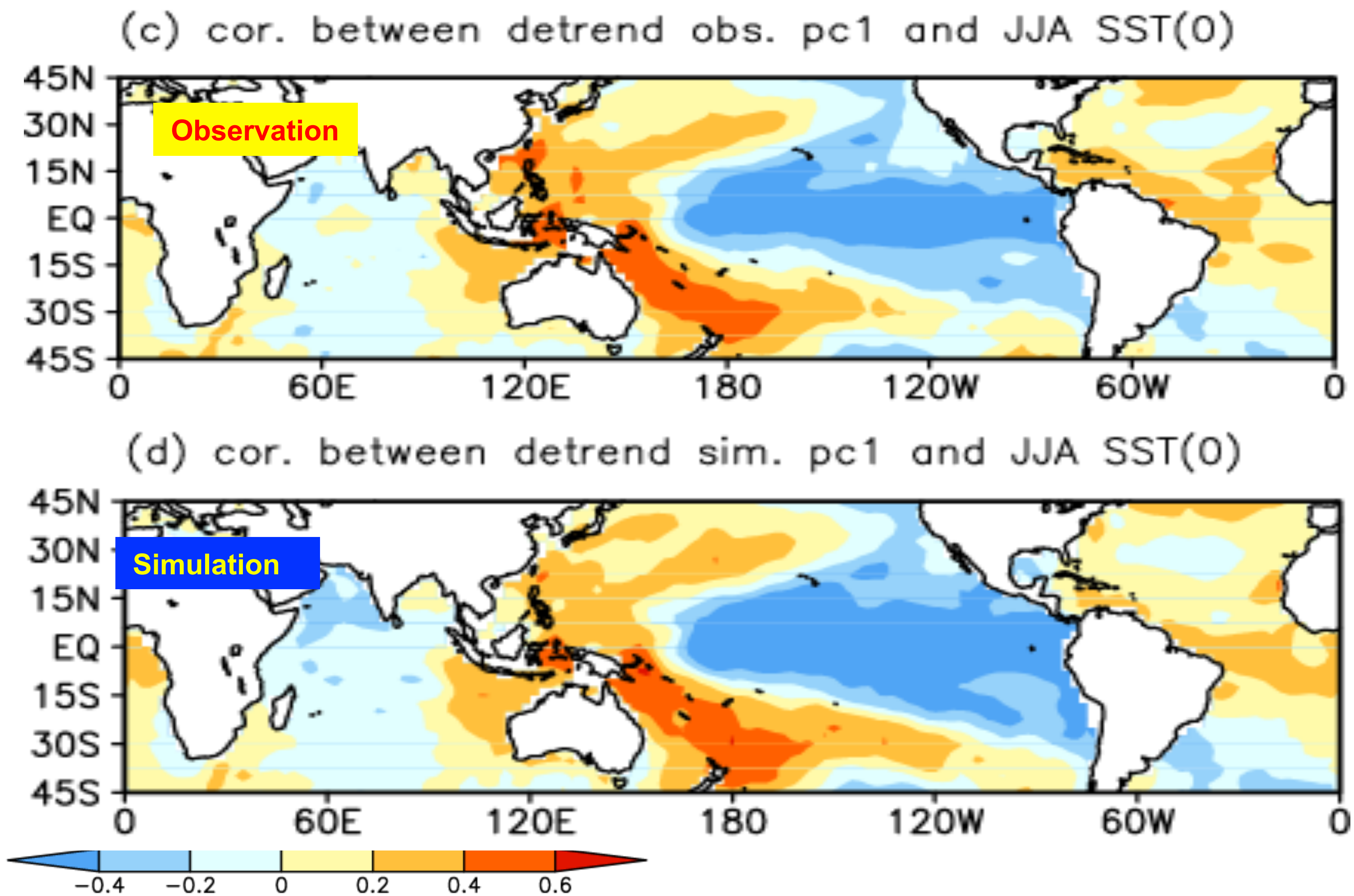
◆ There is barely any correspondence between the simulation and the observation in the global monsoon index over the ocean area.

◆ This discrepancy might arise from the uncertainty of observational data.

◆ The CMAP and GPCP data show confusing results on the the increasing trend of oceanic monsoon index.

Zhou et al. J. Climate (2008)

Correlation at interannual time scale



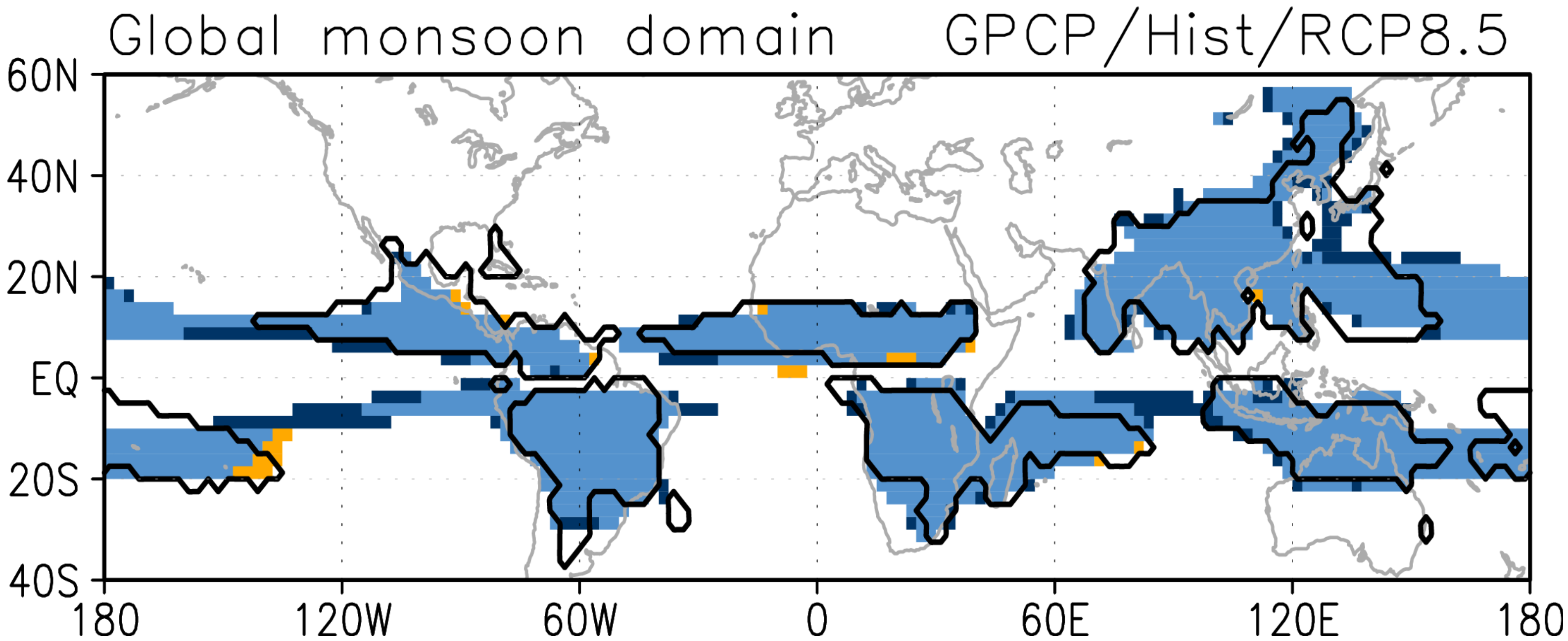
Zhou et al. 2008 Ocean forcing to changes in global monsoon precipitation over the recent half century, ***Journal of Climate***, **21** (15), 3833–3852


Changes under Global warming

Global Monsoon: Area (GMA)

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

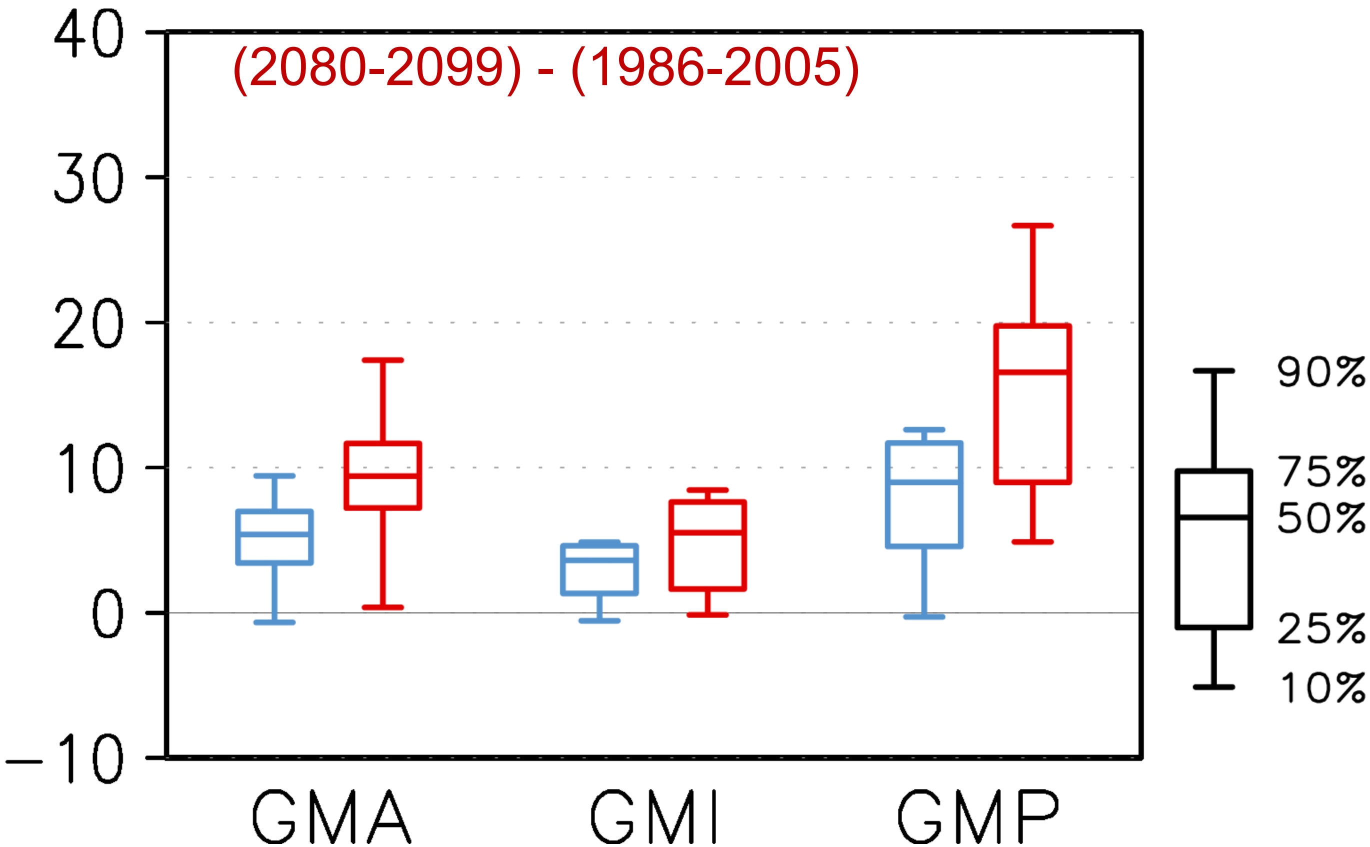
Yellow shading: only in present **Dark blue: only in future**



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

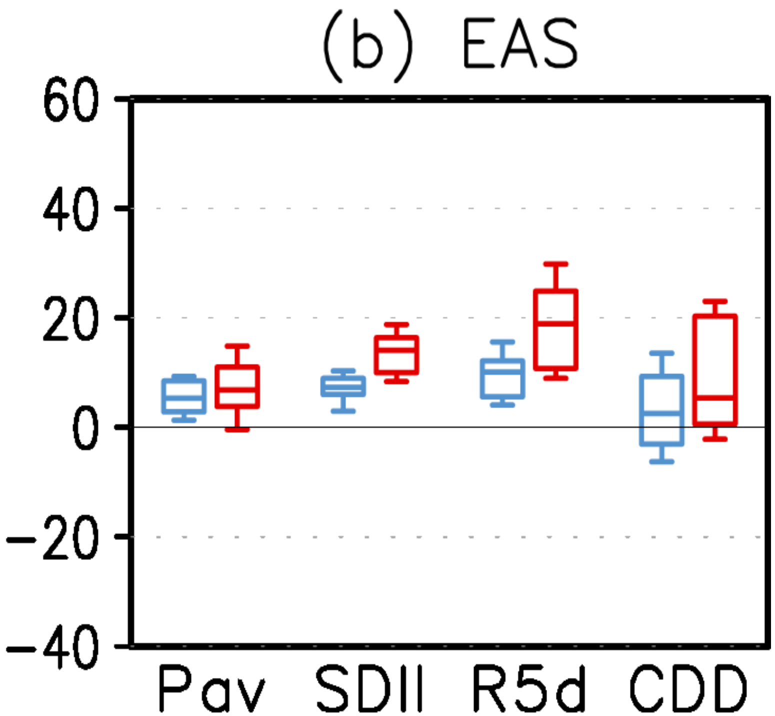
Blue: RCP4.5

Red: RCP8.5

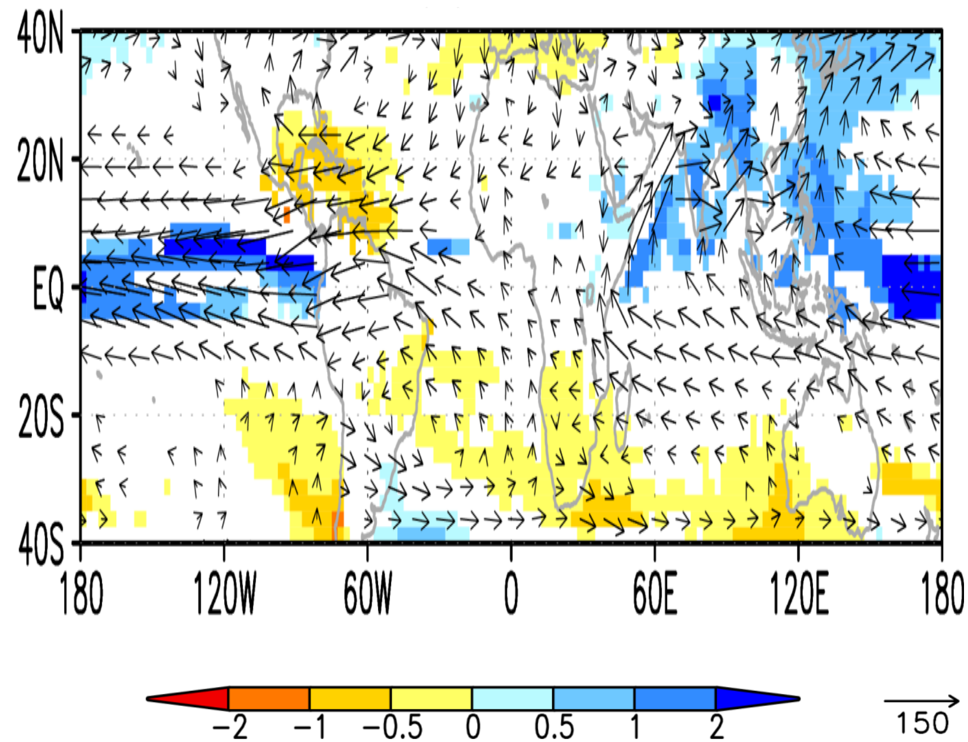
- GMP shows an increase in the RCP4.5 scenario and more so in the RCP8.5 scenario
- monsoon-related precipitation will significantly increase in a warmer climate

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**



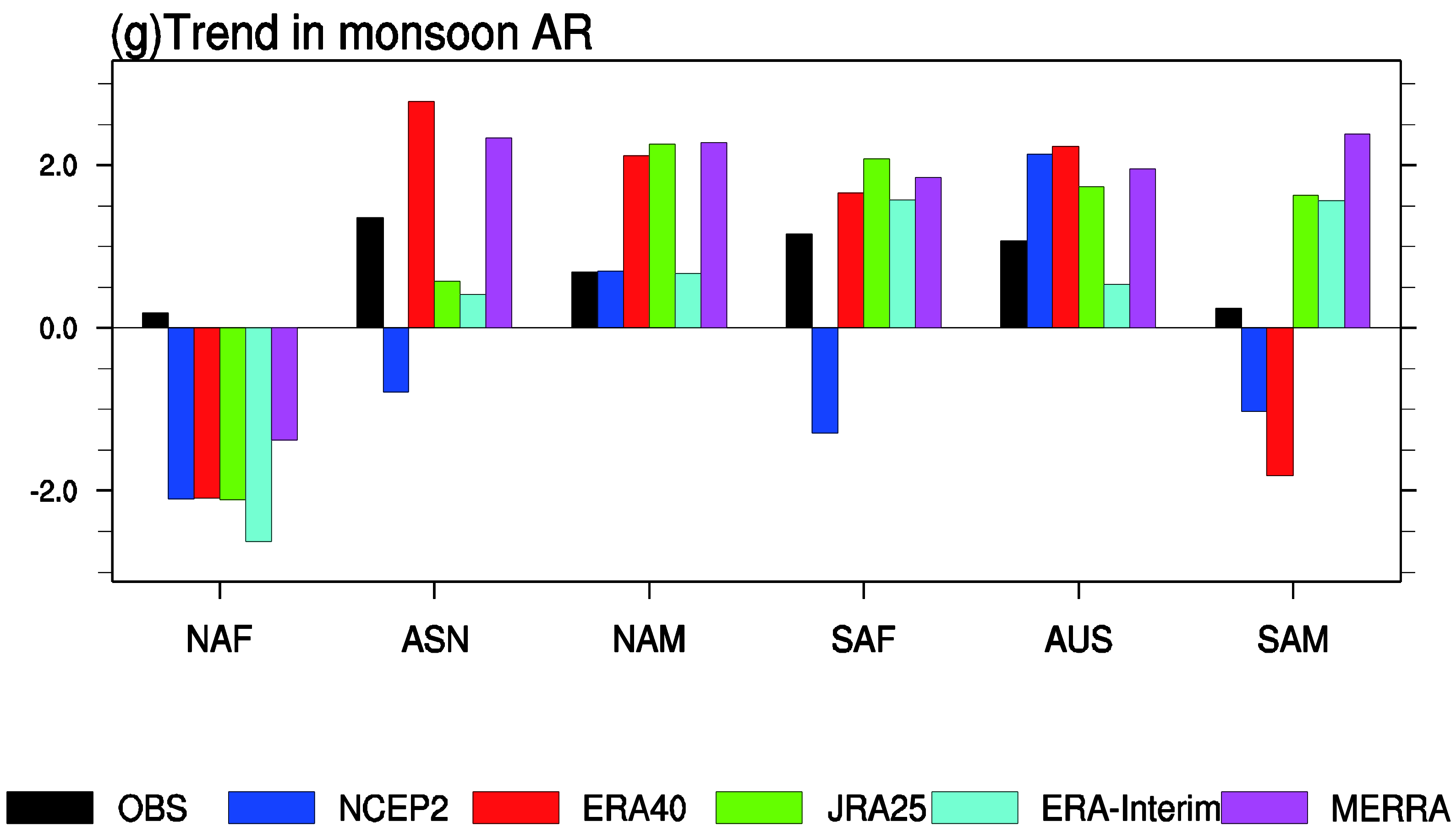
shading: Precipitation
vector: vertically integrated water vapor flux

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

Point # 5

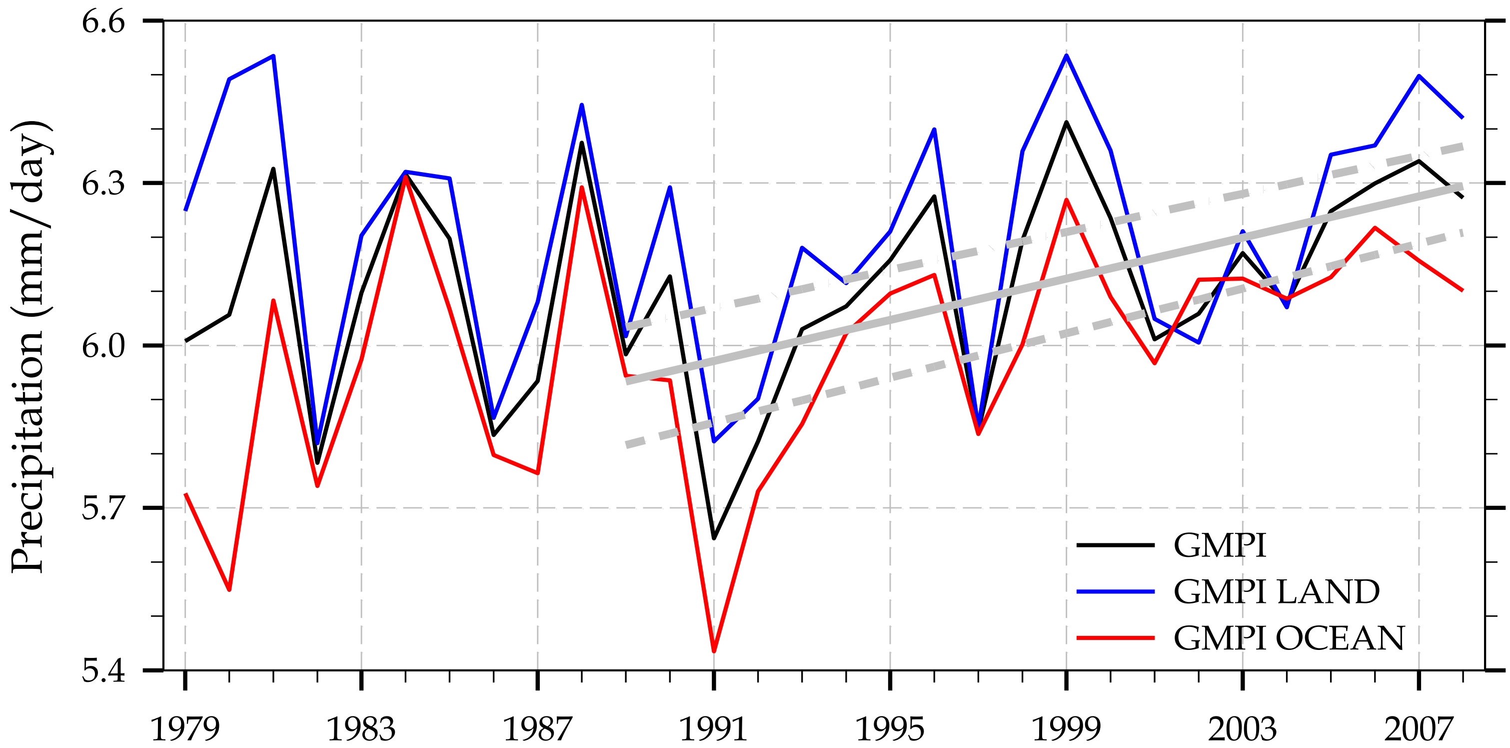
1. The global monsoon area defined by the annual range in precipitation *is projected to expand mainly* over the central to eastern tropical Pacific, the southern Indian Ocean, and eastern Asia.
2. The global monsoon precipitation *intensity* and the global monsoon *total precipitation* are also projected to increase. Indices of *heavy precipitation* are projected to *increase much more than those for mean precipitation*.
3. The projected increase of the global monsoon precipitation can be attributed to an *increase of moisture convergence due to increased surface evaporation and water vapor in the air column* although *offset to a certain extent by the weakening of the monsoon circulation*.

Long-term trends of precipitation in regional monsoon areas



Lin R., T. Zhou, Y. Qian, 2014: Evaluation of Global Monsoon Precipitation Changes based on Five Reanalysis datasets, ***Journal of Climate***, *27(3)*,1271-1289

Changes of global land monsoon precipitation



global land and ocean : upward trend for 1979-2009 (95% confidence level)

（Wang et al. 2012 Clim Dyn.)