Causes of the Global Monsoon Precipitation Change over the Past Millennium

Jian Liu

Nanjing Institute of Geography and Limnology

Chinese Academy of Sciences

Acknowledge contributors:

Bin Wang, So-Young Yim, & June-Yi Lee

October 18th, UH, Honolulu

Background

- Global monsoon (GM) is an integral of all regional monsoon. It is a dominant mode of the annual cycle of the climate system (Wang and Ding 2008)
- Global Monsoon Precipitation (GMP) is a fundamental measure of the strength of the annual cycle of climate and hydrological cycle.
- GMP is a major water resource to more than two thirds of the world’s population and vegetation. Its spatio-temporal change in the future is one of the deepest concerns worldwide.

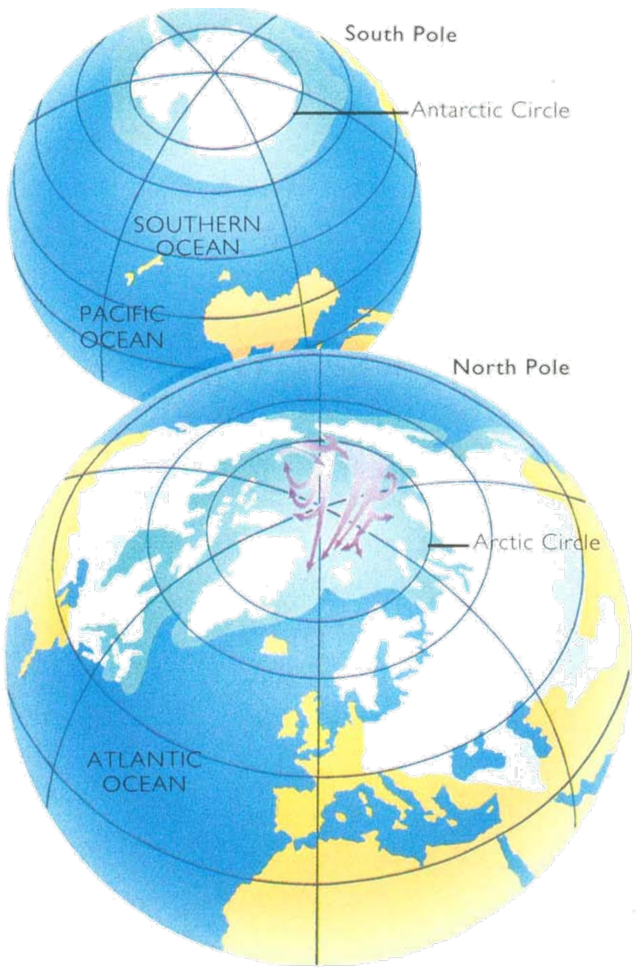
Motivation

- Quantifying and understanding of the past GMP changes is essential for projection and attribution of climate change.
- Previous studies have mostly focused on regional monsoon variations and modern change. The knowledge of GMP variability on multidecadal - centennial timescale is very limited.

Scientific Question

- What are the spatial-temporal structures of the GMP change on multidecadal - centennial timescale ?
- Can we distinguish the forced response and internal variability?
- What factors and physical processes determine the forced changes of the GMP?
- Are there any differences in the responses of NHMP and SHMP to external forcings?

Method: millennium simulation



ECHO-G Model:

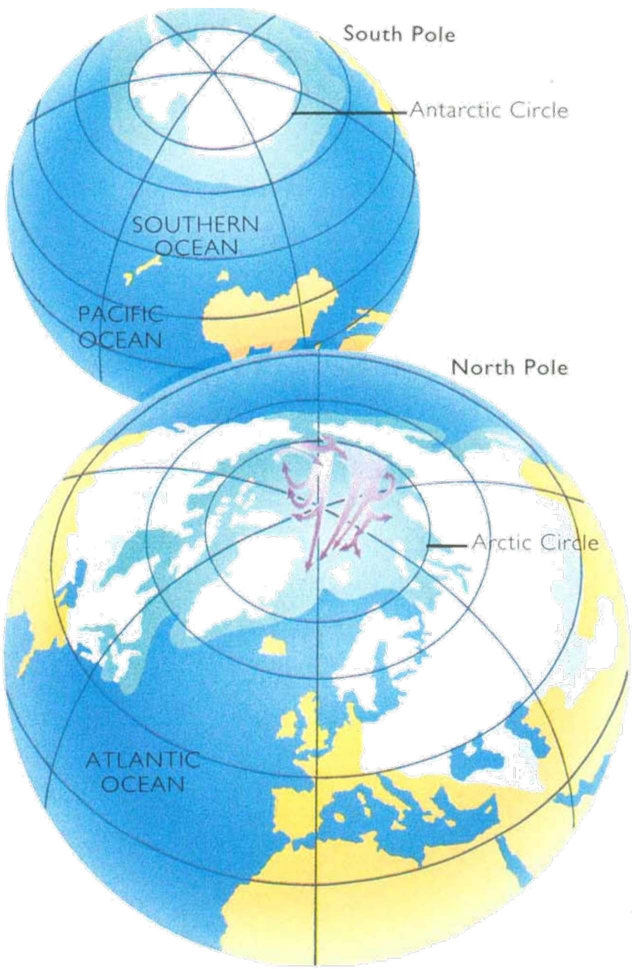
ECHAM4 & HOPE-G Model

ECHAM4 **spectral atmospheric model, resolution T30 (3.75˚ x 3.75 ˚), 19 levels**

HOPE G **primitive equation ocean model, equivalent resolution 2.8 ˚ x 2.8 ˚ with equatorial grid refinement, 20 levels**

Coupled **through OASIS, flux correction**

Method: millennium simulation

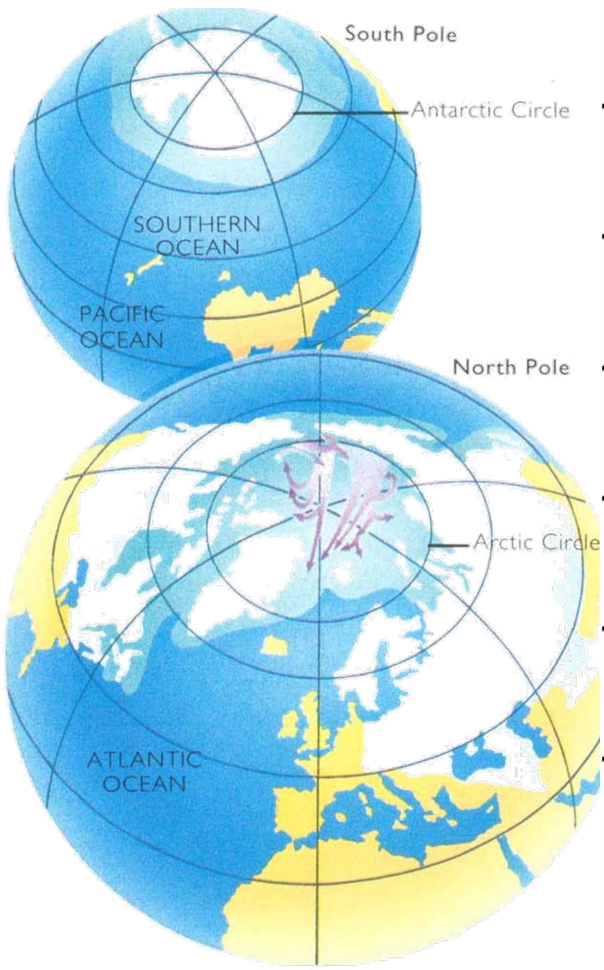


Experiments

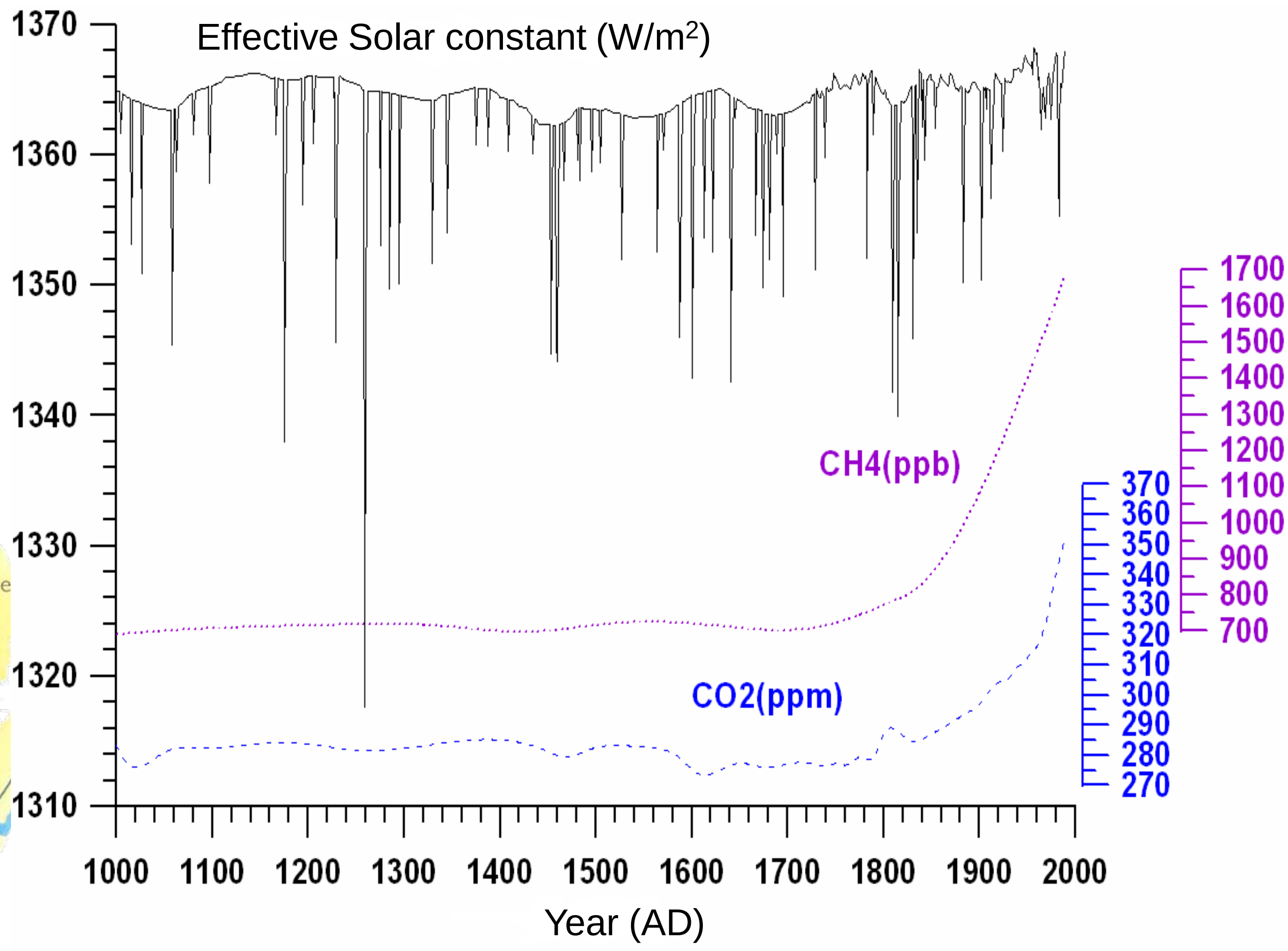
Free (Control) run (CTL) **driven by constant forcing of 1990 AD and integrated for 1000 years**

Forced run (ERIK) **started in the year 900 AD with the initial conditions from the CTL. Spin up for 100 years and attain an equilibrated state around the model year 1000 AD. Then it was driven by three external forcing factors: solar variability, volcanic aerosols and GHG concentrations (CO_2 and CH_4) from 1000 to 1990 AD**

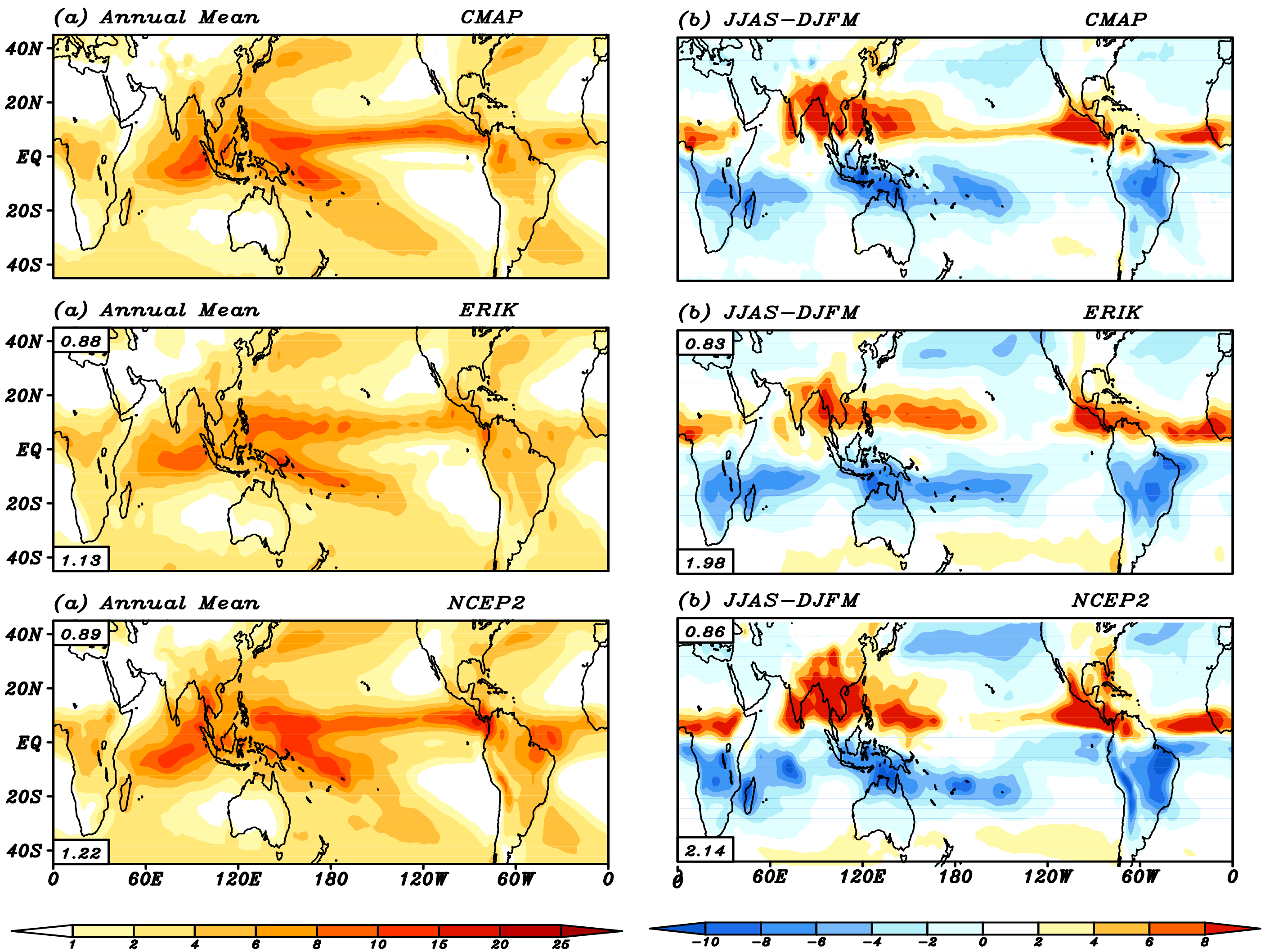
Method: millennium simulation



Forcing in ERIK run



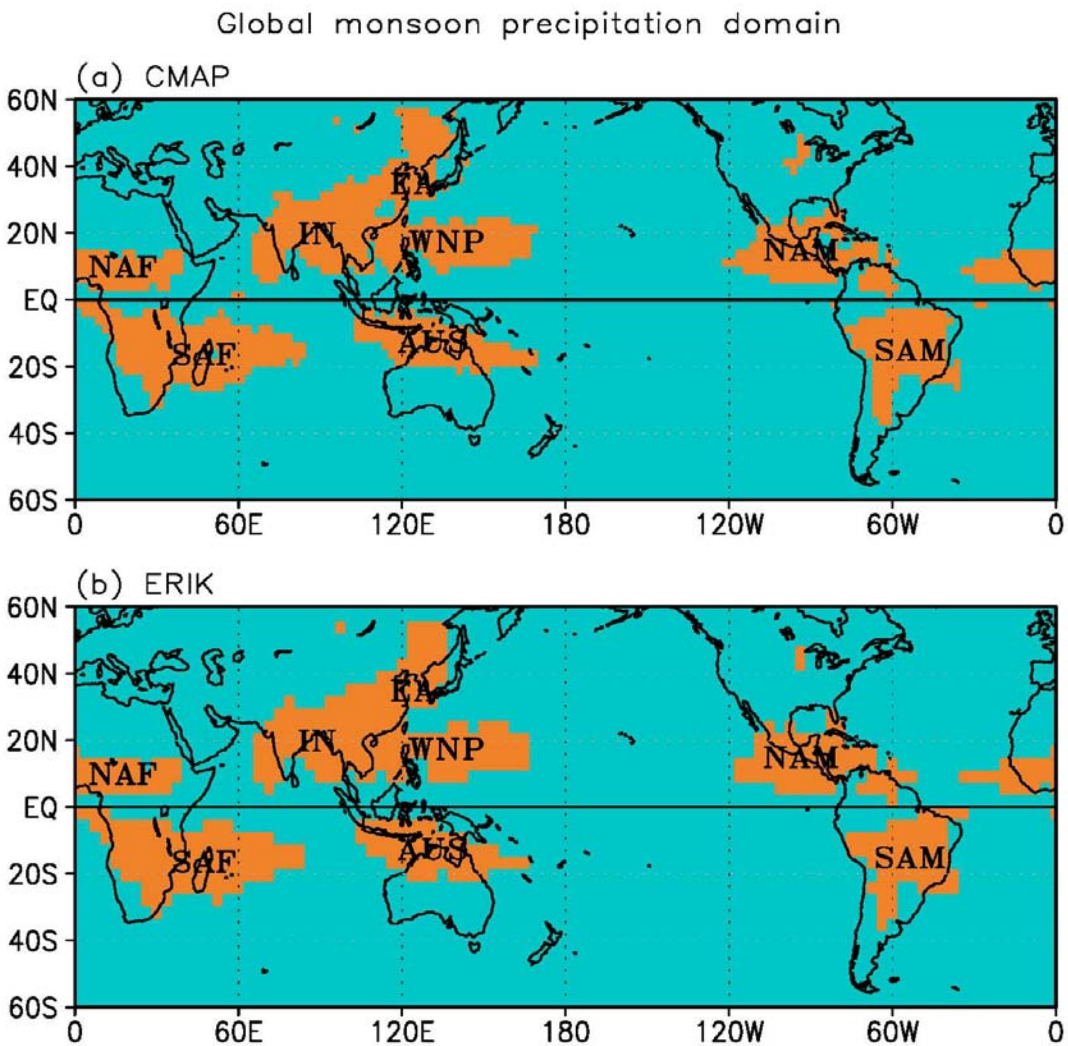
Validation



CMAP and NCEP-2 reanalysis data were derived for the period 1979-2004. ERIK was derived for the period 1965-1990 AD. The numbers shown in the upper-left corners and the lower-left corners indicate pattern correlation coefficients and root mean square errors with the CMAP data, respectively.

ERIK simulated the annual mean and annual range comparable to those captured by reanalysis.

Validation



Comparison of the GMP domains between
(a) CMAP (1979-2008) and (b) ERIK simulation

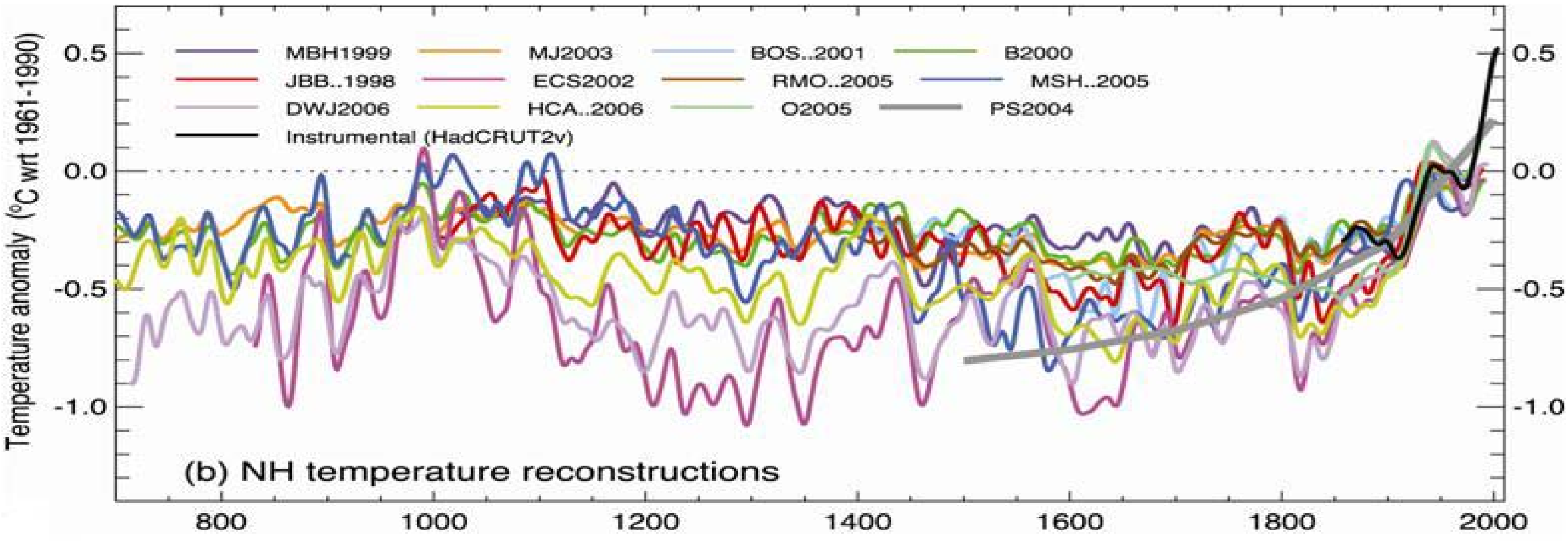
GMP Domain:

1. AR > 2.0 mm/day
2. Local summer precipitation > 55% of annual rainfall

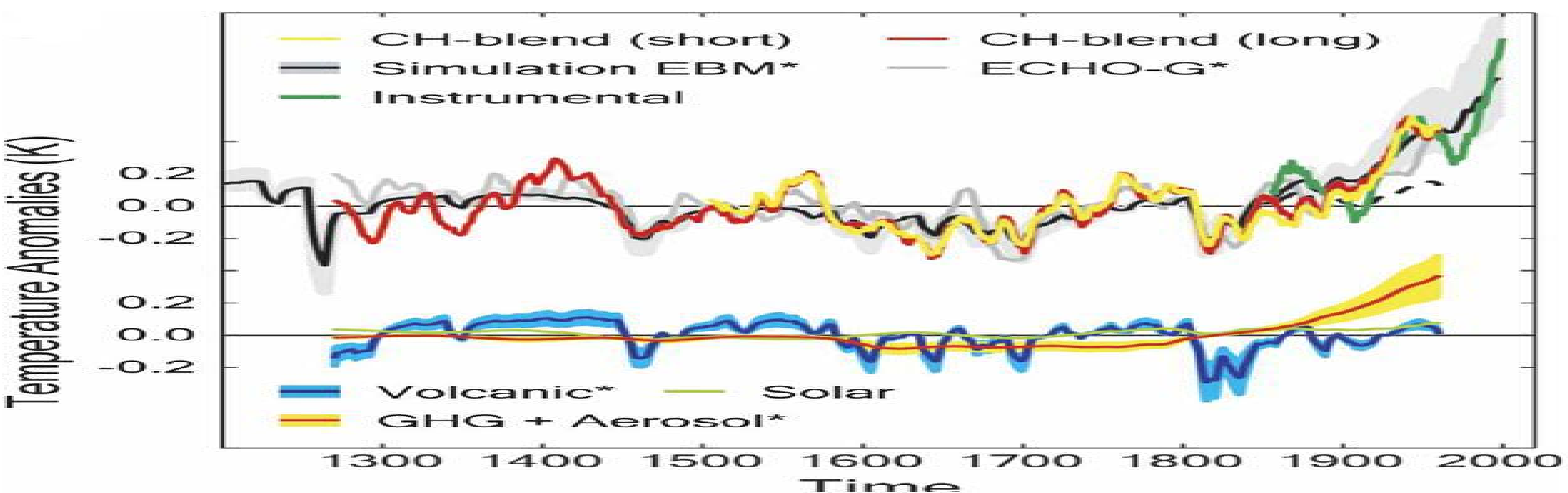
AR: MJJAS precipitation minus NDJFM precipitation in the Northern Hemisphere (NH) and NDJFM minus MJJAS precipitation in the Southern Hemisphere (SH).

The simulated GMP domains are quite realistic. Minor differences are due to different model and CMAP resolutions

Validation



MBH1999
MJ2003
BOS..2001
B2000
JBB..1998
ECS2002
RMO..2005
MSH..2005
DWJ2006
HCA..2006
O2005
PS2004
Instrumental (HadCRUT2v)
Temperature anomaly (°C wrt 1961-1990)
0.5
0.0
-0.5
-1.0
(b) NH temperature reconstructions
800
1000
1200
1400
1600
1800
2000



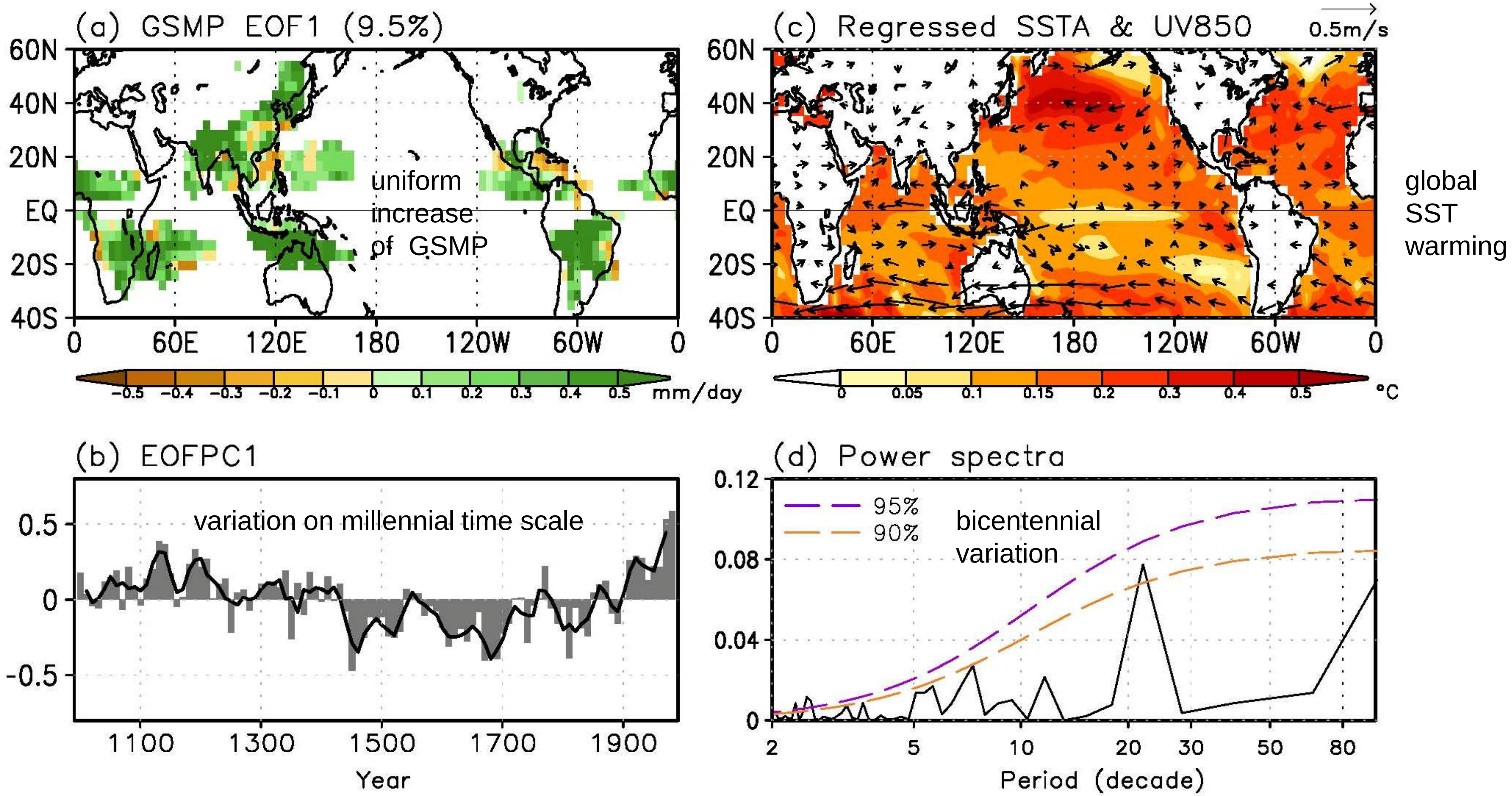
CH-blend (short)
CH-blend (long)
Simulation EBM*
ECHO-G*
Instrumental
Temperature Anomalies (K)
0.2
0.0
-0.2
0.2
0.0
-0.2
Volcanic*
Solar
GHG + Aerosol*
1300
1400
1500
1600
1700
1800
1900
2000
Time

Validation

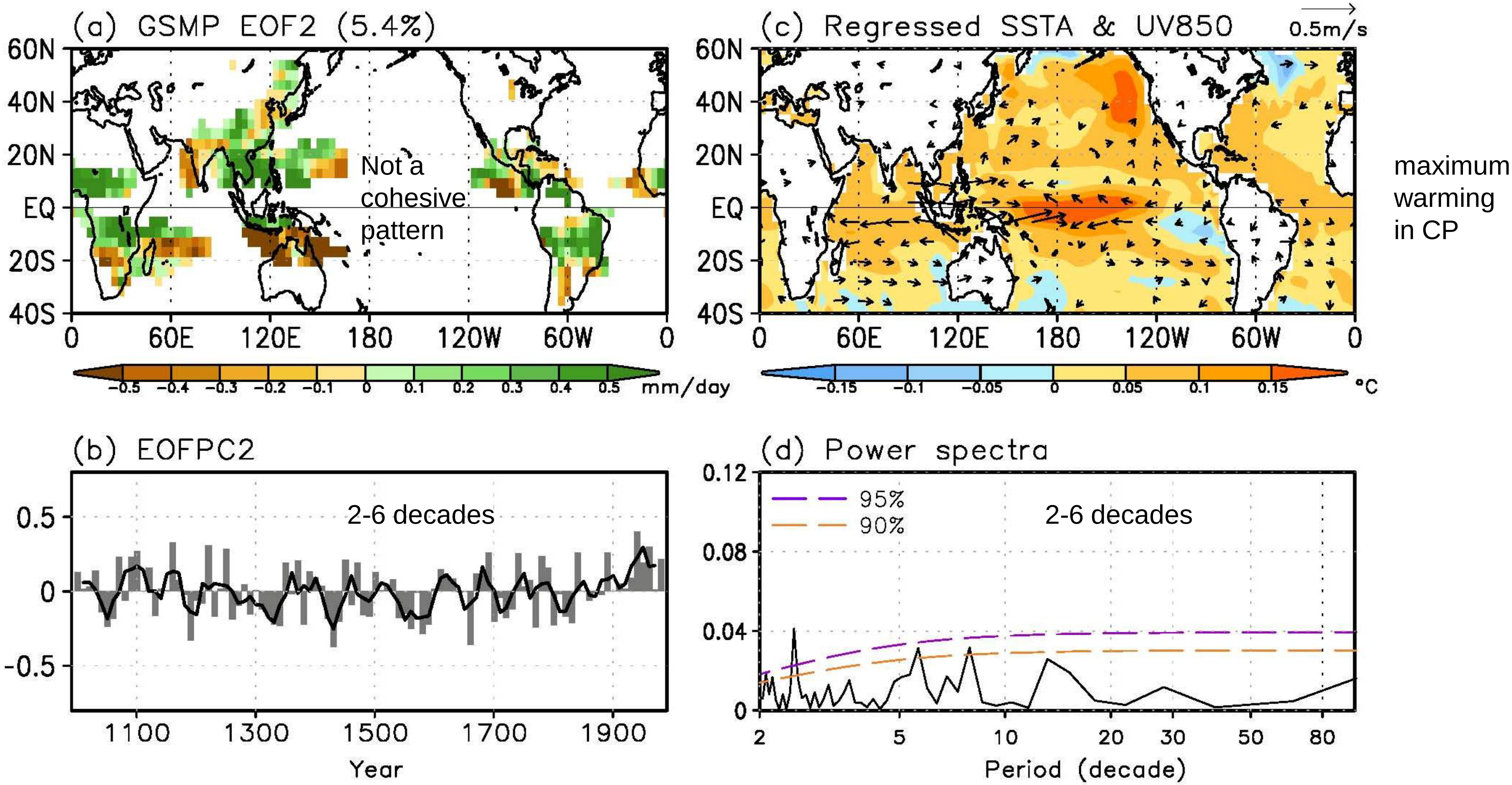
In a word, the overall model simulations on global scale are realistic and adequate for our study of the long-term modulations of the global monsoon system under imposed natural and anthropogenic forcing.

Analysis

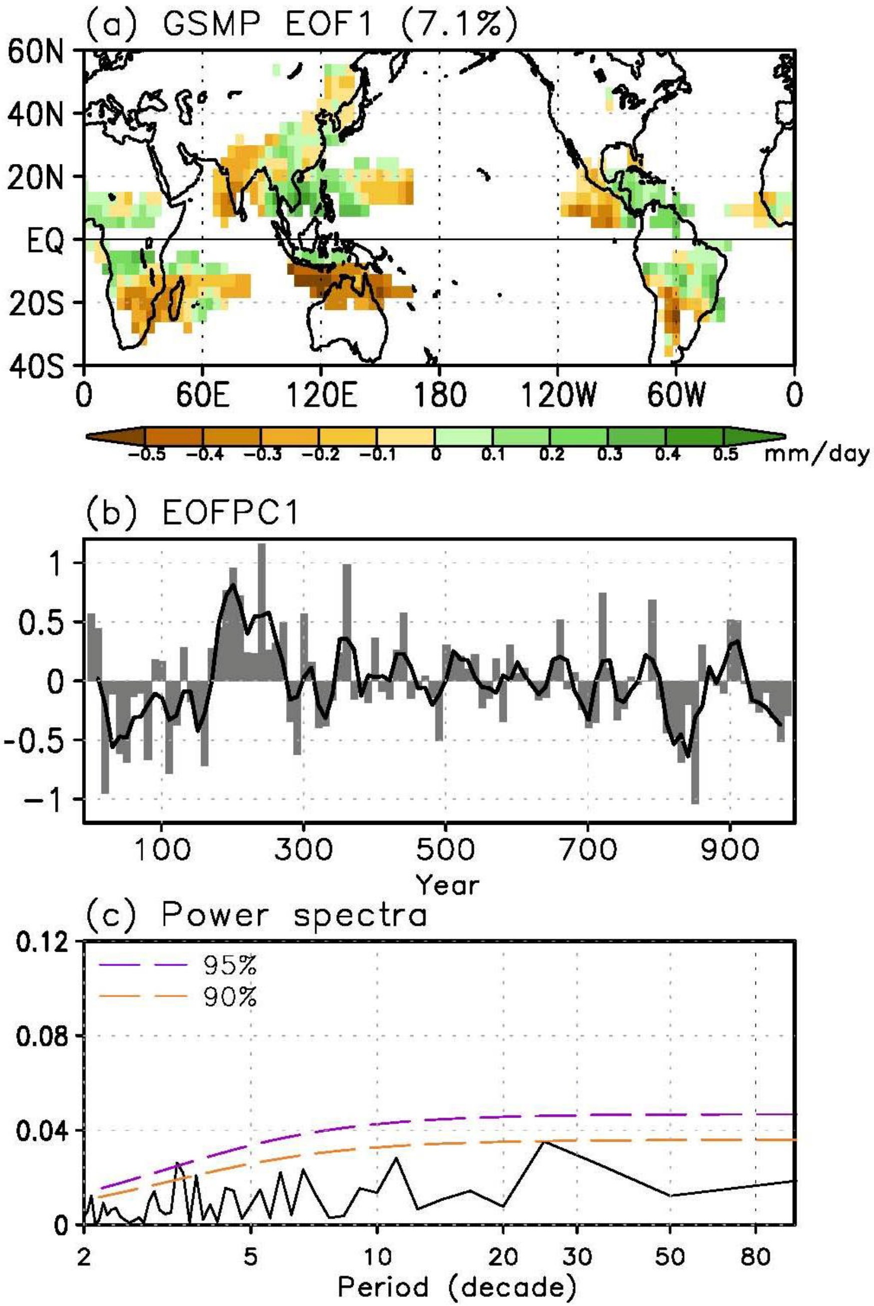
- GSMP: NHSMP +SHSMP
- NHSMP: MJJAS rainfall falling in NH monsoon domains
- SHSMP: NDJFM rainfall falling in SH monsoon domains



Forced mode: The leading EOF mode of the GSMP variation over the past millennium: (a) spatial structure, (b) regressed SST and 850 hPa wind anomalies for local summer season, (c) the corresponding principal component (PC); the smoothed curve is 3-decade running mean, and (d) the corresponding PC spectra. The fraction on the top of panel (a) denotes the fractional variance. Shown are wind vectors that are significant above 90% confidence level. The data were decadal mean time series derived from ECHO-G forced (ERIK) simulation. The correlation matrix was used for EOF analysis.

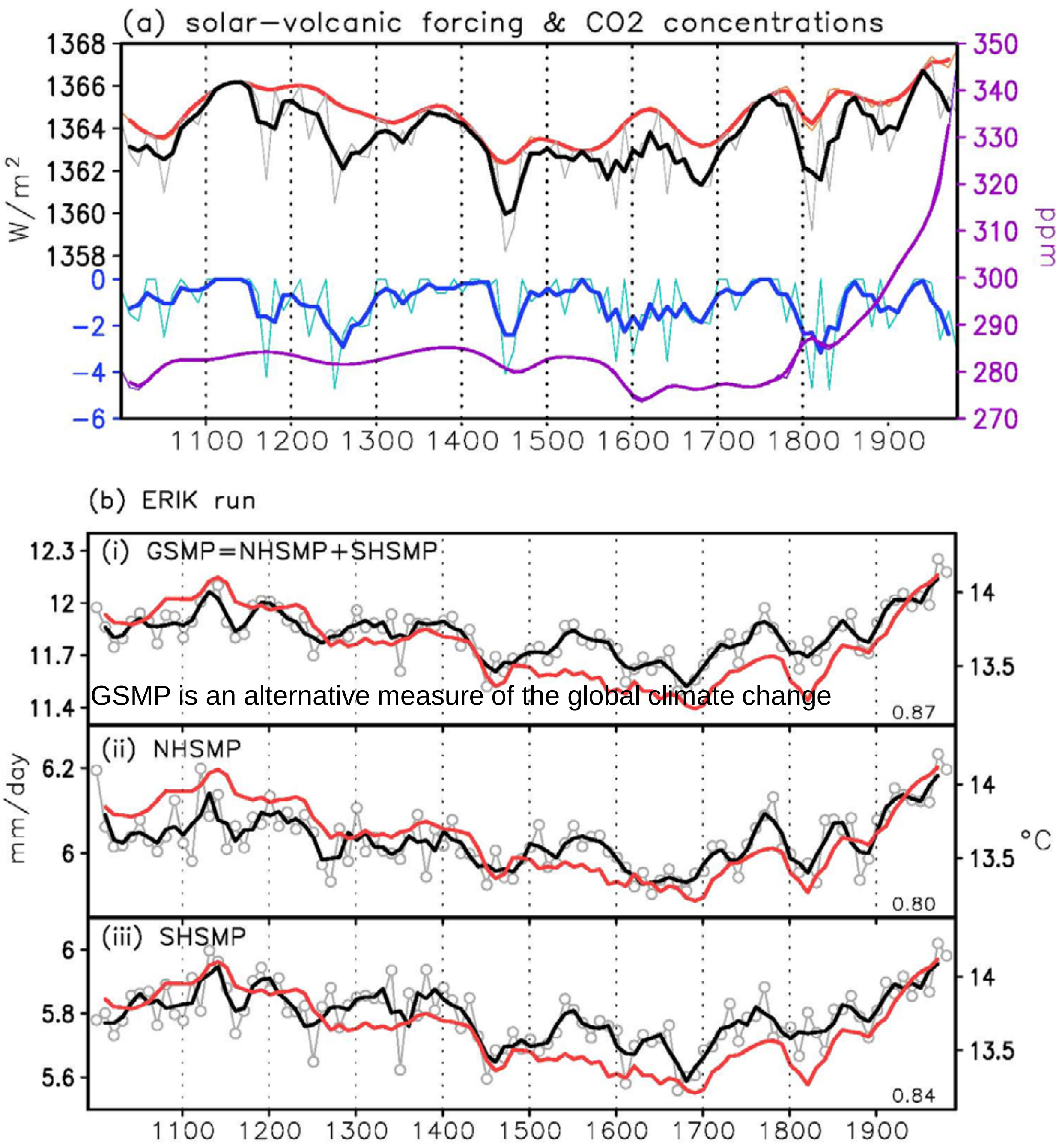


Modulated internal mode: The second EOF mode of the GSMP variation over the past millennium: (a) spatial structure, (b) regressed SST and 850 hPa wind anomalies for local summer season, (c) the corresponding principal component (PC); the smoothed curve is 3-decade running mean, and (d) the corresponding PC spectra.



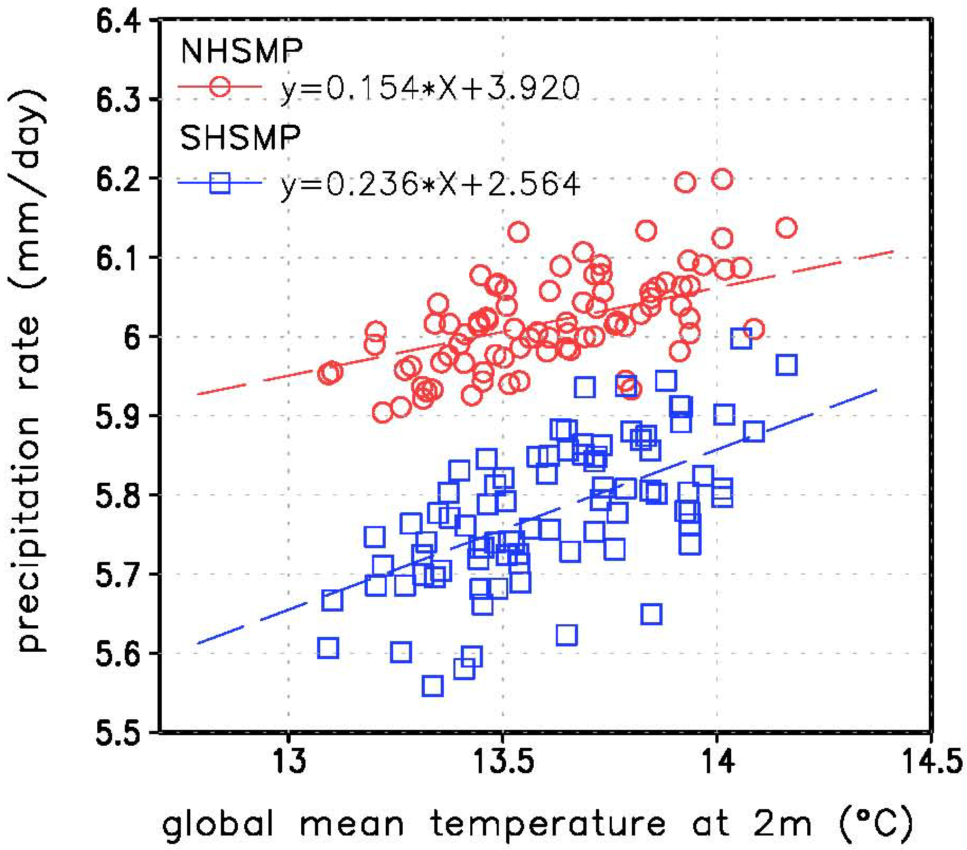
In this force-free run, the leading mode must arise from internal feedback processes within the coupled climate system.

Internal mode in CTL run: The leading EOF mode of the GSMP variation over the past millennium derived from the ECHO-G CTL (force-free) run: (a) spatial structure, (b) the corresponding principal component with 3-decade running means, and (c) the corresponding spectrum. The number on the top of panel (a) denotes the fractional variance.



(a) The four forcing (decadal mean) time series: solar (red),volcanic (blue), effective solar forcing (black), and CO_2 concentration (purple).

(b) The global mean 2m air temperature (GMT, red), global-average local summer monsoon precipitation (GSMP, over the monsoon domain), and the NHSMP, and SHSMP, respectively. The smoothed curves are 3-decade running means. The correlation coefficients with GMT are shown at the lower-right corner of each panel (the correlation coefficients are calculated using 3-decade running mean time series).

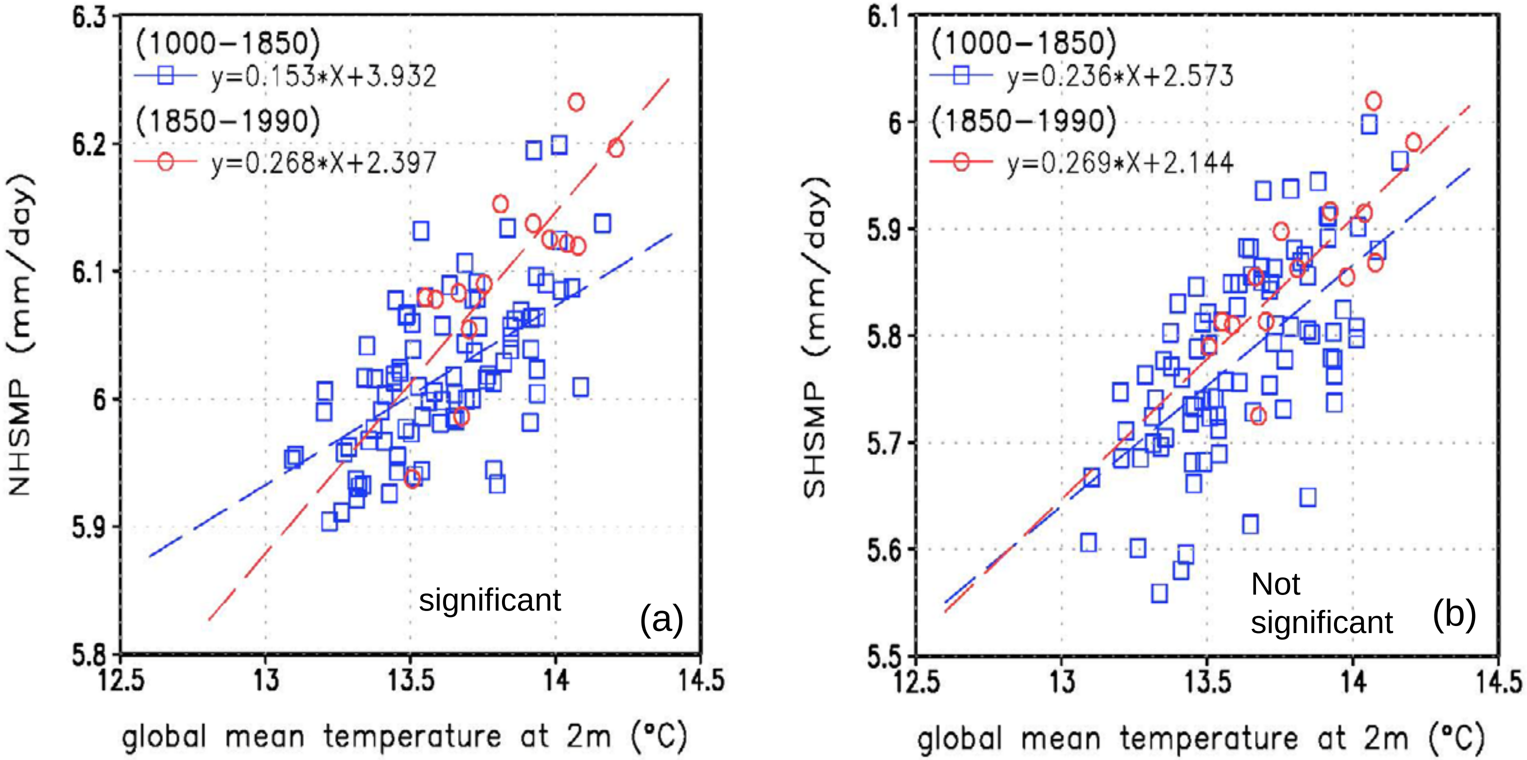


NHSMP/GMT = 2.5 % K^{-1}

SHSMP/GMT = 4.1 %K^{-1}

The SHSMP is more sensitive to the SV forcing than the NHSMP, in terms of per unit increases of the global mean temperature.

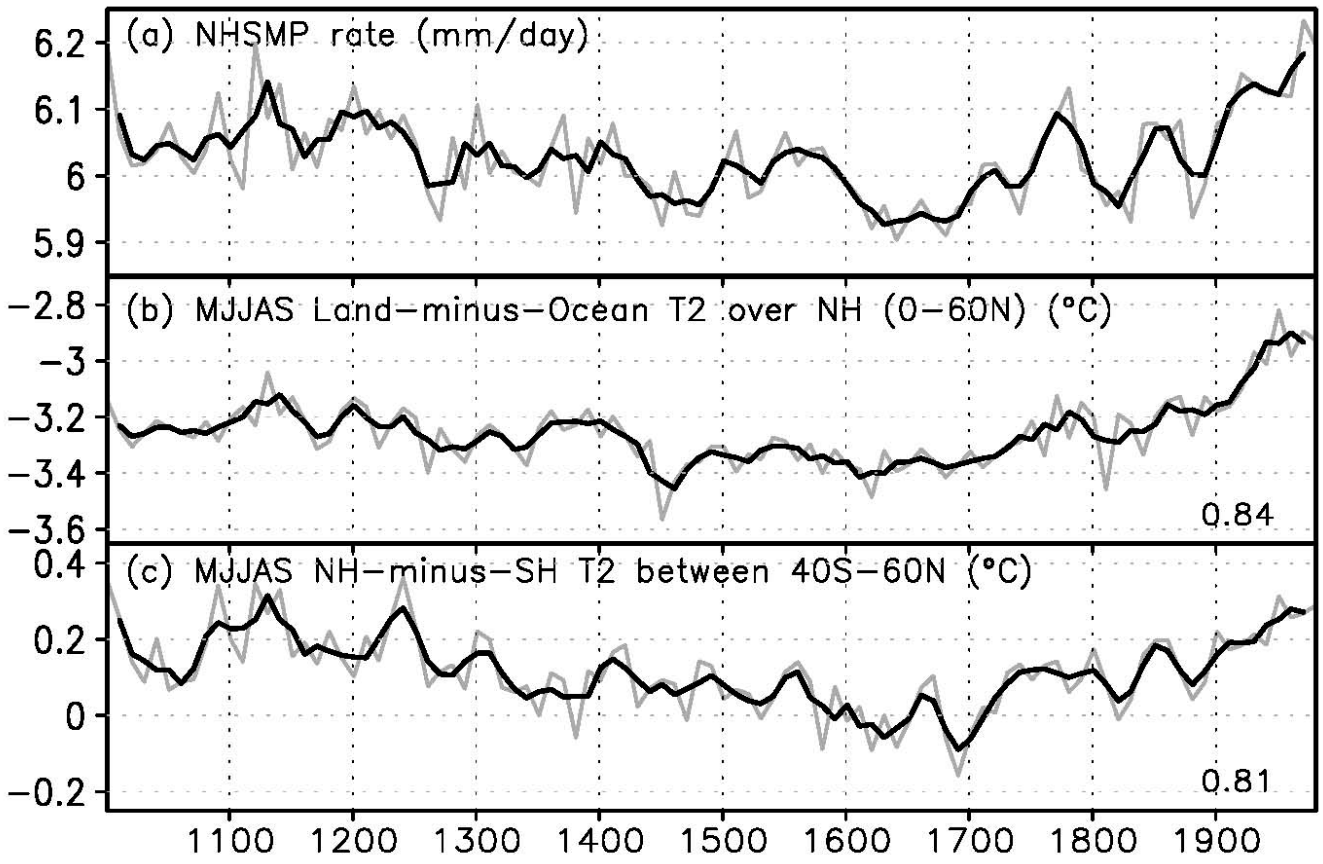
Scatter diagram showing the NHSMP and SHSMP rate as functions of global mean 2m air temperature for the preindustrial period 1000-1850 which is dominated by SV forcing. The difference between the two slopes is significant at 95% confidence level, suggesting that the SHSMP is more sensitive to the SV forcing than the NHSMP.



The NHSMP responds to the GHG forcing sensitively

The SHSMP responds to the GHG forcing not significantly

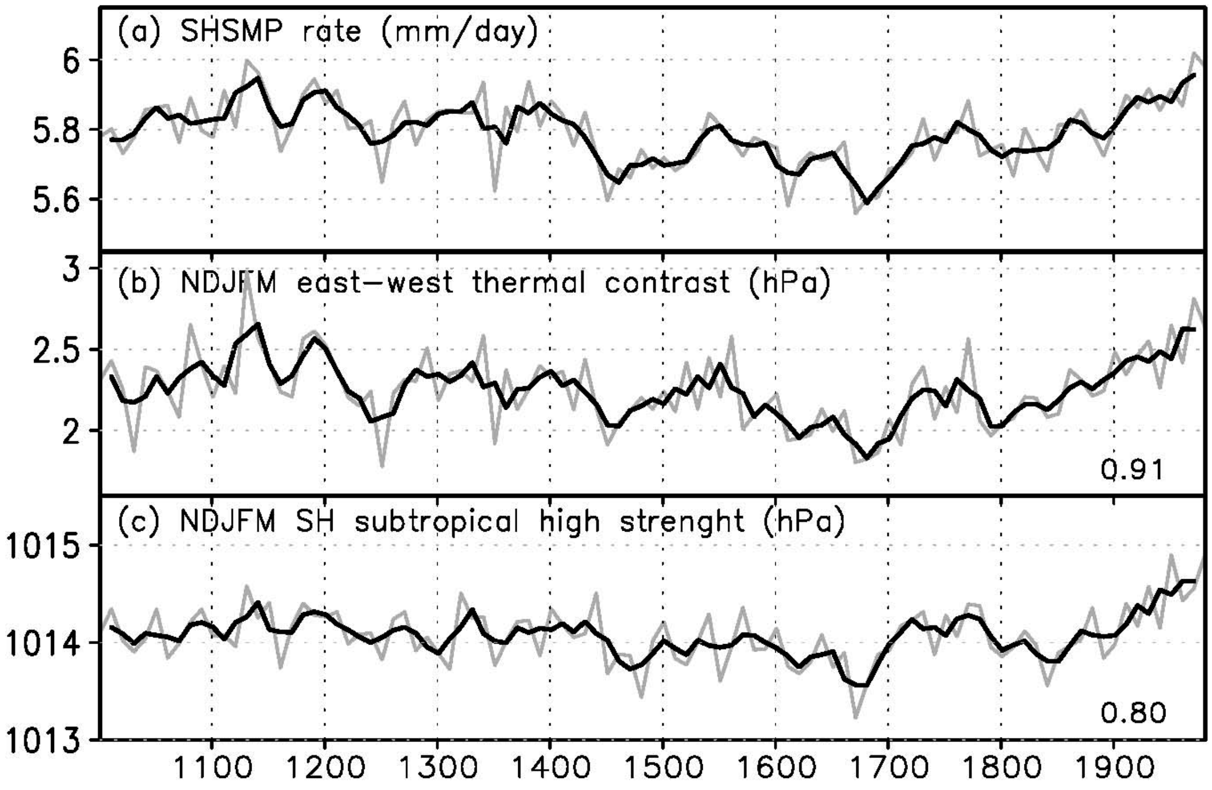
Scatter diagram showing the NHSMP (a) and SHSMP (b) rate as functions of global mean 2m air temperature for the preindustrial period 1000-1850 and the industrial period 1850-1990. The difference between the two slopes is significant at 95% confidence level for NHSMP in (a), but not significant for SHSMP in (b).



warm land-cold ocean:
Increased land-ocean thermal contrast enhances monsoon low and associated moisture convergence

warm NH-cold SH:
warmer NH generates cross-equatorial pressure gradients that drive low-level cross-equatorial flows from SH to NH, again strengthening the NH monsoon

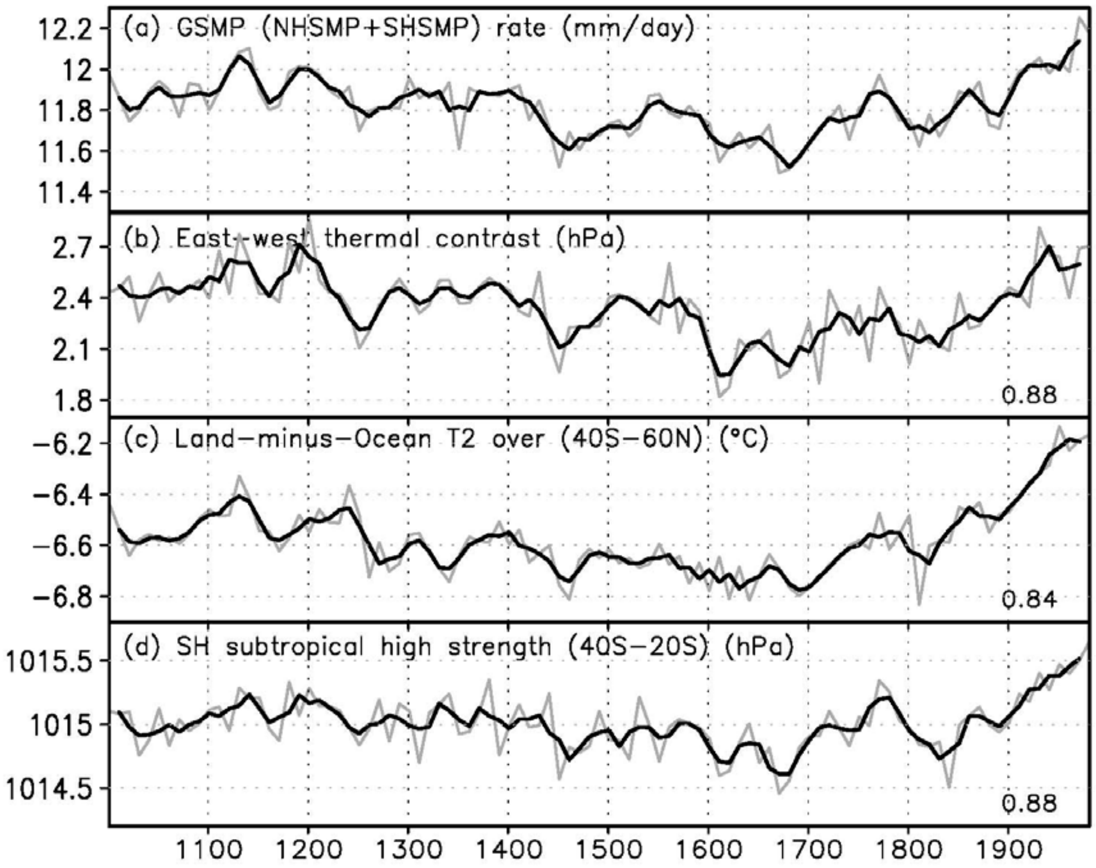
Factors controlling NHSMP. The decadal mean time series of (a) NHSMP (mm/day), (b) Land-ocean thermal contrast: T2m (land) minus T2m (ocean) between the equator to 60N in MJJAS (^{o}C), and (c) Hemispherical thermal contrast: T2m (NH, 0-60N) minus T2m (SH, 0-40S) in MJJAS (^{o}C). The thick lines denote 3-decade running means. The correlation coefficients with NHSMP using 3 decade running mean time series are shown at the lower-right corner of each panel.



Increased east-west SLP gradient causes a westward air mass and moisture transport, which enhances moisture convergence into the SH monsoon regions

The enhanced SH subtropical high increases the trade winds in SH oceans , also driving the convergence of air mass and moisture into the SH monsoon low pressure regions.

Factors controlling SHSMP. The decadal mean time series of (a) SHSMP (mm/day), (b) the east-west thermal contrast: SLP in SE Pacific (0-40S, 180-70W) minus SLP in Indian Ocean (20S-20N, 40E-120E) during NDJFM (hPa), and (c) the SH subtropical high strength: SLP averaged between 20S and 40S (hPa). The thick lines denote 3-decade running means. The correlation coefficients with SHSMP using 3 decade running mean time series are shown at the lower-right corner of each panel.



Enhanced east-west thermal contrast induces rising SLP in the eastern Pacific, which enhance the trade winds, transporting moisture into the monsoon regions

Increased land-ocean thermal contrast enhances monsoon low and associated moisture convergence.

Enhanced SH subtropical high increases the pressure gradient between the NH and SH, increasing both NHSMP and SHSMP.

Factors controlling GSMP. The decadal mean time series of (a) GSMP, i.e. NHSMP+SHSMP (mm/day), (b) East-west thermal contrast: annual mean SLP in SE Pacific (0-40S, 180-70W) minus SLP in Indian Ocean (20S-20N, 40E-120E) (hPa), (c) Land-ocean thermal contrast: annual mean T2m (Land) minus T2m (ocean) between 40S and 60N in ^{o}C, (d) the SH subtropical high strength: annual mean SLP (40S-20S). The thick lines denote 3-decade running means. The correlation coefficients with GSMP using 3 decade running mean time series are shown at the lower-right corner of each panel.

Conclusion

- GSMP has two distinct modes over the past millennium: The forced mode and the internal mode. The forced mode is characterized by a nearly uniform increase of monsoon precipitation across all regional monsoon regions and has dominant bicentennial-millennial variation; The internal mode has a multi-decadal oscillation with a maximum SST warming in the central Pacific.
- GSMP is highly related to GMT and provides an alternative measure of the global hydroclimate change, which is far more relevant for food production and water supply than the GMT.
- NHSMP and SHSMP have different responses to external forcing: NHSMP responds to GHG forcing is more sensitive than SHSMP, while SHSMP responds to the natural solar-volcanic (SV) forcing more sensitively than NHSMP.

Conclusion

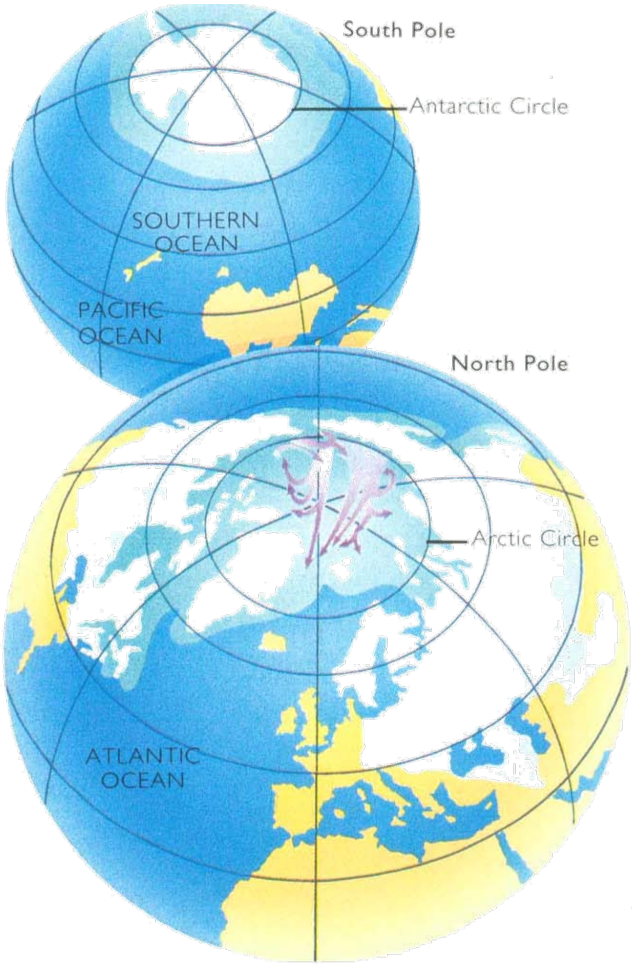
- The causes of NHSMP: An enhanced NHSMP is primarily caused by (a) warm land-cold ocean and (b) warm NH-cold SH.
- The causes of SHSMP: A strengthened SHSMP concurs with enhancement of (a) the thermal contrast between southeastern Pacific and tropical Indian oceans and (b) the SH subtropical high.
- The causes of GSMP: The increase of total amount of GSMP is determined by (a) the enhanced land-ocean thermal contrast in both hemisphere (40S-60N), (b) the enhanced east-west thermal contrast between the southeastern Pacific and Indian oceans, and (c) the enhanced SH subtropical high, which contributes to the hemispherical sea level pressure difference.

Limitation

This study carried out by using only

- One model
- One ensemble member runs

This results should be tested by using other models and on other time scales, such as PMIP-3 ensemble model outputs for past millennium, last glacial maximum and mid-Holocene periods.


South Pole
Antarctic Circle
SOUTHERN OCEAN
PACIFIC OCEAN
North Pole
Arctic Circle
ATLANTIC OCEAN

Thank you!