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Insights from a joint analysis of Indian and Chinese monsoon rainfall data

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Abstract

Monsoon rainfall is of great importance for the agricultural production in both China and India. Understanding its rule and possibility of long term prediction is a challenge for research. This paper gives a joint analysis of Indian monsoon and Chinese monsoon, finds their teleconnection to Sea Surface Temperature anomaly (SSTa) and other climate indices individually and relationship in common. The results show that northern China garners less rainfall when whole Indian rainfall is below normal. Also, with cold SSTa over the Indonesia region, more rainfall would be distributed over India and South China.

1 Introduction

Chinese monsoon and Indian monsoon are important for agricultural production and economy in China and India (Parthasarathy et al., 1988; Webster et al., 1998; Abrol and Gadgil, 1999). The two monsoons both belong to Asian monsoon and are primarily influenced by Indian Ocean and western Pacific Ocean. There are studies showing that they are somehow correlated. Kripalani and Singh (1993) argued that summer monsoon rainfall over northern part of China is highly correlated with that over India, and the subtropical ridge over the Indian region is an important predictor for both regions. Other studies suggest a spatial teleconnection between them as monsoon rainfall over north China is in phase with that over India (Chang et al., 2000; Kripalani and Kulkarni, 2001), and Zhang et al. (2007) shows that both East Asian monsoon and Indian summer monsoon have strong influences in China, especially in the Yangtze River basin. Also, it is widely believed that Indian monsoon and Chinese monsoon are both teleconnected to tropical Sea Surface Temperature (SST), which plays an important role in the large scale climate system. Considering both Indian monsoon and Chinese monsoon are related to El Nino-Southern Oscillation (ENSO), a previous study (Hu et al., 2005) showed that the ENSO-related phase of Indian monsoon is significantly positively correlated with the rainfall variations in northern China, while the ENSO-unrelated phase of Indian monsoon has a significant negative correlation with the rainfall variations in southwestern China. Yang and Lau (2004) also show that there is an upward trend in precipitation over southeastern China and downward trend in precipitation over northern China during their monsoon season, and the underlying reasons of these trends are linked to an ENSO-like mode of SSTs. Moreover, the precipitation in central eastern China is primarily linked to SST variations over the warm pool and the Indian Ocean.

It can be, therefore, concluded that Indian monsoon and Chinese monsoon are correlated in some way, and they are similarly influenced by some common climatic drivers (like ENSO, SST, Subtropical ridge, etc.) although the ways of influencing are different. Encouraged by these existing results, we consider Indian monsoon and Chinese monsoon belong to a larger monsoon structure. The primary goal of this study is to figure out the common climatic factors driving both monsoon structures, and the ways how these factors interplay in the mechanism of a larger monsoon structure. The principle component analysis (PCA) method is used to obtain the primary patterns of Chinese and Indian monsoon rainfall separately as well as jointly, and then the correlation analysis is performed between derived principle components and climate indices like Sea Surface Temperature Anomalies and moisture transport with the purpose to explore the driving factors.

The remainder of this paper is organized as follows. In Sect. 2 we describe the sources of data used in this study. Following this, in Sect. 3 we first perform a principle component analysis on monsoon rainfall data of China and India separately and study the correlation between the two regions, and then we perform another principle component analysis on the joint rainfall data of both India and China, and the correlation analysis is performed to investigate the climate factors influencing monsoon rainfalls in the two regions. Finally we discuss our results in Sect. 4 together with the conclusions.

2 Data

The gridded rainfall data of China and India comes from the WCRP GCOS Global Precipitation Climatology Centre (http://www.wcrp-climate.org/, http://www.wmo.int/pages/prog/gcos/index.php,http://gpcc.dwd.de/), and the recording period is from the year of 1951 to 2003. The spatial resolution of collected rainfall data for Indian part and Chinese part is different. For the Indian part, the grid resolution is 1.0 by 1.0 degree and we chose to include the entire India (totally 357 grids), while for the Chinese part the resolution is 0.5 by 0.5 degree and we choose the area within 90° E–125° E, 17° N–43° N (totally 3024 grids). To be noted, the latter area includes most part of China and also a small part of northern Southeast Asia (part of Myanmar, Thailand, Laos and Vietnam), which can represent the characteristics of Chinese monsoon and is, therefore, called Chinese part just for convenience. The Indian Monsoon season is from June to September. In China, the monsoon season varies from region to region, i.e., it begins earlier in southeastern China while later in northern China. On average, it lasts for four months from June to September. In this study, we choose the monsoon season of China and India included four months of June, July, August and September (shortly as JJAS).

3 Analysis and results

3.1 Principle component analysis of Indian monsoon and Chinese monsoon separately

In this subsection we study the correlations between monsoon rainfall patterns in India and China. First we perform the principle component analysis (PCA) on Indian and Chinese yearly monsoon rainfall data individually. The results show that the first principle component (PC1) of India takes 20% of all and the second principle component (PC2) takes 10%. For Chinese part, the PC1 takes 11% of all and PC2 takes 8%.

India PC1 and China PC1 have a negative correlation −0.5, and India PC2 and China PC1 also have a negative correlation −0.4. China PC2 has low correlation with India PCs. These suggest that Indian monsoon and Chinese monsoon have some patterns in common.

The spatial correlation pattern of India PCs and China PCs is further investigated, which is shown in Fig. 1. As indicated by Fig. 1c, India PC1 presents a high positive correlation with the rainfall in middle India and the area around 40° N 110° E of China. This result confirms the existing conclusion that summer monsoon rainfall over India is in phase with the monsoon rainfall in the area around 40° N, 110° E of China (Kripalani and Singh, 1993; Kripalani and Kulkarni, 2001). Also, India PC1 has a high negative correlation with rainfall in southwestern China. On the contrary, China PC1 has an approximately opposite pattern compared to India PC1. The China PC1 has a high positive correlation with middle East China (downstream of Yangtze River) while a high negative correlation with northern parts of India and northern part of China around 40° N 110° E. It should be highlighted that both maps have similar dipole patterns in middle India and Middle East China (Yangtze River basin). We also list the corresponding results in Fig. 1b and d for China PC2 and India PC2 respectively. The similar phenomena could be found in PC2 figures compared to PC1 figures, which shows that India PCs have some common patterns with China PCs except their own patterns.

Additionally, the correlation coefficients between China/India PCs and Monsoon Indices (Wang, et al., 2001), i.e., Indian Monsoon Index (IMI) and western North Pacific Monsoon Index (WNPMI), are calculated and shown in Table 1. As we can see from Table 1, India PC1 is highly correlated to IMI and India PC2 is highly correlated to WNPMI, which agrees with the previous study (Wang et al., 2001). Both China PC1 and PC2 are correlated to IMI, and the correlation coefficient of China PC1 is slightly higher than that of China PC2. China PC2 is also correlated to WNPMI, while China PC1 is not well correlated to WNPMI.

3.2 Joint principle component analysis of Indian monsoon and Chinese monsoon

To get common characteristics from both Indian monsoon and Chinese monsoon, we perform the joint principle component analysis on the first two leading principle components (PC1 and PC2) of India and China separately, from which four leading principle components emerge. Among them, the first and the second principle component (joint PC1 and PC2) occupies 42% and 38% of the total weight respectively. The Table 2 lists the correlation coefficients between four individual PCs and four joint PCs, and the numbers show that joint PC1 is highly related to China PC1 and India PC1, and joint PC2 is highly related to China PC2 and India PC2. We study the special patterns of joint PC1 and PC2 by looking at the correlation map between joint PCs and monsoon rainfall in the study area (Fig. 2). It is clear that the joint PC1 has high positive correlation with middle China (mostly Yangtze River basin) and southern India, and has high negative correlation with northeastern China, part of southern China, northern India and middle India (Fig. 2a). This is almost the opposite for joint PC2 (Fig. 2b), which has high positive correlation with southern China and middle India, and negative correlation with middle China (mostly Yangtze River Basin) and southern India.

Again, we compare these joint PCs with Monsoon Indices (see also Table 1). Joint PC1 is highly correlated to IMI, while joint PC2 is highly correlated to WNPMI. From the previous analyses, joint PC1 mostly comes from middle China (mainly in Yangtze River Basin) and South India, it keeps the feature of India PC1, i.e., the high correlation with IMI. Joint PC2 partly comes from China PC2, and is highly correlated to WNPMI, while China PC2 is not well correlated to WNPMI. This is because the second PCA derived a common character from China PCs and India PCs, which may or may not be present in the first PCA on Chinese monsoon and Indian monsoon alone.

3.3 Correlation with Sea Surface Temperature anomaly (SSTa)

The Fig. 4 shows the correlation maps between SSTa in the monsoon summer season (JJAS) and China PCs, India PCs as well as joint PCs. The correlation maps in Fig. 3a–d show that China PCs have positive correlations while India PCs have negative correlations. The figures also indicate the significant influences of the ENSO on all PCs. Moreover, the Fig. 3d shows that India PC2 is influenced by Indian Ocean Dipole, which is in a different case for China PCs. The Fig. 3e and f shows the correlations between SSTa and the leading modes of joint PCs (i.e., joint PC1 and PC2). The results show that the joint PCs gives clearer correlation pattern with SSTa after combining China and India PCs together. The correlation coefficient between joint PC1 and SSTa within ENSO area is around 0.4–0.5, which is higher than the correlation coefficients (around 0.3–0.4) between China PCs or India PCs alone. The correlation coefficients between joint PC2 and SSTa are similar to those between India PC2 and SSTa, but higher than those between China PC2 and SSTa. Joint PC1 shows a significant positive correlation with SSTa in the months of JJAS with Pacific Ocean around 90° W–135° W, 10° N–10° S, which is mainly Nino3 area. Joint PC2 shows a significant positive correlation with Pacific Ocean around 135° E–180° E, 10° N–10° S, which is mainly Nino4 area. Joint PC2 shows a significant negative correlation with Indonesian sea.

Also presented here are the correlation maps (Fig. 4) between SSTa in the previous winter months (December, January and February, DJF) and PCs (India PCs, China PCs and joint PCs). Contrary to the correlation pattern between PCs and summer SSTa, joint PC1 shows a negative correlation with SSTa (DJF) around Nino 4 area, and joint PC2 shows a negative correlation with SSTa (DJF) around Nino 3 area.

3.4 Analysis of extreme years

To gain further insight into the mechanism, we analyze the statistical data during the years when these leading modes strike extreme values. For each of the 4 joint PCs, we identify 10% (5 out of 53) of the years in which the joint PC have the highest and the lowest values (Table 3). Then we make rainfall anomaly maps, moisture transport maps and SSTa maps for the average of 5 lowest value years and 5 highest value years. Looking at the average rainfall of highest value years from joint PC1, the Fig. 5a is consistent with the result from the Fig. 2a. The average rainfall of the five lowest value years from joint PC1 shows that middle China and south India are dry, and the locations with negative correlation with PC1 are wet. The pattern is almost the opposite in the highest value years.

The sea surface temperature patterns in the previous winter months (DJF) during the extreme years of joint PC1 show a weak relationship between joint PC1 and ENSO, as shown in Fig. 6a and b. During the lowest value years, the temperature in the ENSO region is slightly higher, but not high enough to present an El Nino phenomenon. The lowest value years from PC1 are wetter years for most regions in India. The sea surface temperature patterns in DJF in lowest value years and highest value years from joint PC2 show a much clearer relationship between joint PC2 and ENSO, as shown in Fig. 6c and d. During the lowest value years, the temperature in the ENSO region is obviously higher. The lowest value years from PC2 are wetter years for lower Yangtze River Basin in China and south India, and are dryer years for middle India.

Moreover, we studied five years average moisture transport during lowest value and highest value years determined from joint PC1 and PC2, which are shown in Fig. 7. As we can see from the figures, for the years of joint PC1, the average moisture transports during lowest value years in the west of India is stronger, as these moisture moves through the middle India, and brings more precipitation into middle India. On the other hand, the transport during highest value years is weaker, as these moisture bypass India through the south, bring more precipitation to the southeastern and northeastern India. For the years of joint PC2, the moisture from Indian Ocean is close during lowest value and highest value years, while the moisture from Pacific Ocean during the highest value years is a little stronger than the lowest value years. So that southeastern China is wetter during lowest value years.

These results from moisture transport coincide with the previous ones. Joint PC1 is correlated with IMI, so that the change of moisture fluxes from Indian Ocean plays an important role in monsoon precipitation during the peak years of joint PC1. Joint PC2 is correlated with WNPMI, so that the change of moisture fluxes from West Northern Pacific Ocean play an important role in monsoon precipitation during the peak years of joint PC2.

4 Discussion and conclusion

From the joint analysis of the Indian and Chinese monsoon rainfall data, the teleconnection between SSTa and monsoon rainfall has been identified and explained. The joint PC1 rainfall pattern (Fig. 2) is roughly uniform over India. Over China, on the other hand, the pattern is uniform along east-west direction but varies from the North to the South, and can be divided into three regions along that direction. This variability may be caused by an early or late shift of subtropical jet (Kuang and Zhang, 2005) going from the south to the north of Tibet Plateau. The correlation of SSTa with the joint PC1 (Fig. 3) shows warm anomaly over the whole tropical belt except western Pacific Ocean, especially over Indian Ocean. This suggests weaker than normal surface wind speed over the Indian Ocean. Indeed this SSTa pattern corresponds to the PC1 pattern of negative loading rainfall over India. According to Fig. 2a, when the whole Indian rainfall anomalies is negative, northern China garners less rainfall (consistent with Kripalani and Singh, 1993), while Mei-Yu over the Yangtze River Valley along about 30° N gets more rainfall. This phenomena is because of the weaker than normal monsoon. Warmer tropical SST makes smaller land-sea temperature difference, and smaller land-sea temperature difference leads to weaker than normal monsoon. So that Mei-yu advances northward too slow and stays over Yangtze River valley too long, and produces more rainfall there, but less rainfall over north China.

Joint PC2 (Fig. 2b) is closely related to mid-east subtropical jet veered towards India, Indochina Peninsula and Western Pacific Ocean. Joint PC2 loading of rainfall variability over India is more or less a dipole of rainfall over Ganges River basin: north cyclone route from Bay of Bangal (BoB) to northern India and the relatively south route of the cyclones from BoB. The variability of northern India is coherent with that over Indochina Peninsula and Southern China, probably with a common cause favoring cyclone activities. The winter SSTa pattern associated with joint PC2 (Fig. 4f) show that with cold SST over the Indonesia region, more rainfall would be distributed over India and South China.

In this paper we studied the teleconnection between SSTa and monsoon rainfall in India and China. We observed that SSTa in the previous season can influence Indian and Chinese monsoon rainfall. Hence there is predictability for Indian and Chinese monsoon rainfall pattern through joint PC1 and joint PC2.

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Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀ ▶
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

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Table 1. Correlation coefficients between China/India rainfall PCs and Monsoon Indices (IMI & WNPMI).

Correlation	India PC1	India PC2	China PC1	China PC2	Joint PC1	Joint PC2
IMI	0.83	0.04	−0.35	−0.42	−0.73	−0.19
WNPMI	0.21	−0.65	−0.14	0.28	0.08	0.58

HESSD

8, 3167–3187, 2011

Insights from a joint analysis of Indian and Chinese monsoon rainfall data

M. Zhou et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀◀ | ▶▶
◀ | ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Table 2. Correlation coefficients between individual PCs and joint PCs.

Coefficient	Joint PC1	Joint PC2	Joint PC3	Joint PC4
India PC1	0.60	−0.37	0.37	0.6
India PC2	0.37	0.60	−0.60	0.37
China PC1	−0.70	−0.11	−0.11	0.69
China PC2	0.11	−0.70	0.70	−0.11

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀ ▶
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Table 3. Five lowest value years and five highest value years from Joint PC1 and Joint PC2.

	Lowest					Highest				
Joint PC1	1959	1961	1994	1956	1978	1965	1987	1974	1991	1999
Joint PC2	1983	1998	1988	1989	1964	1994	2001	1997	1952	1961

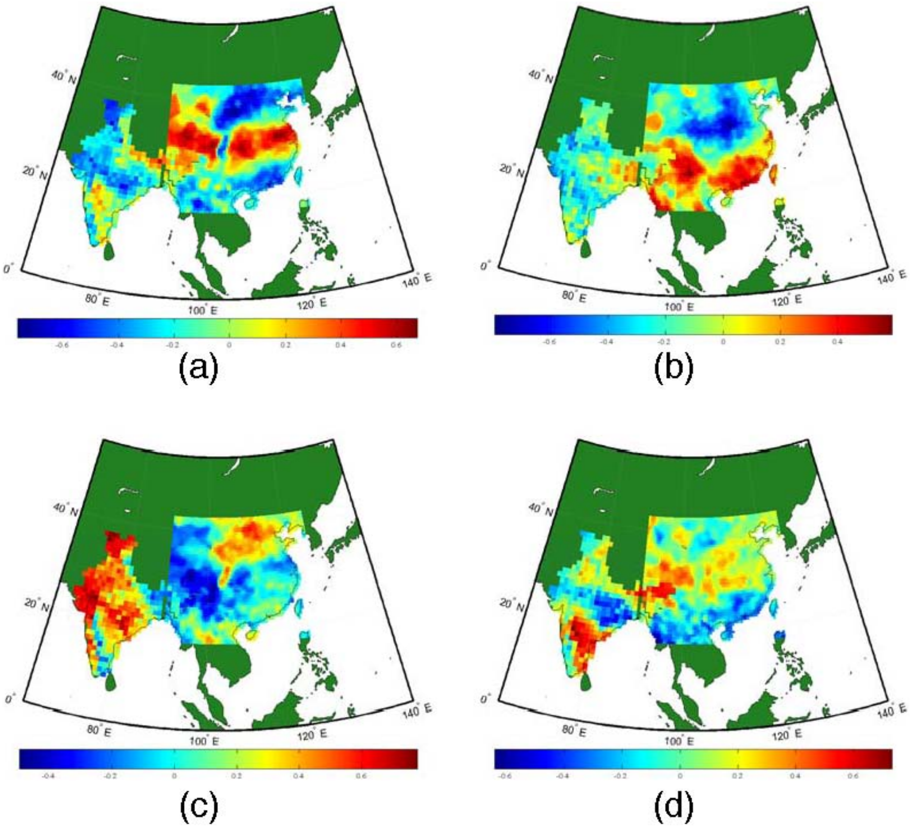
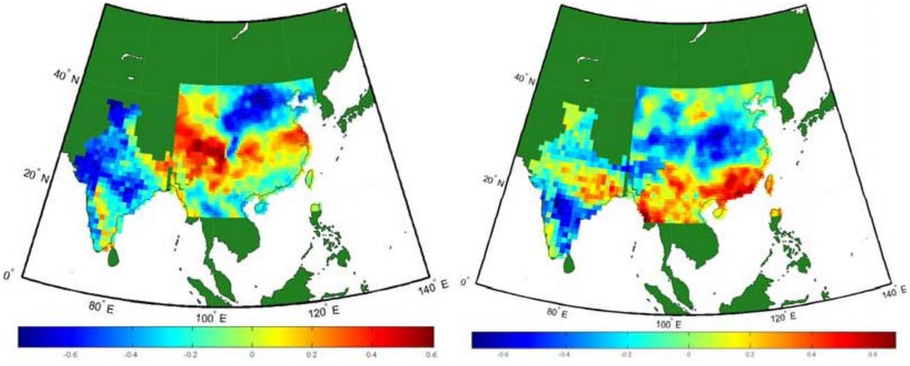


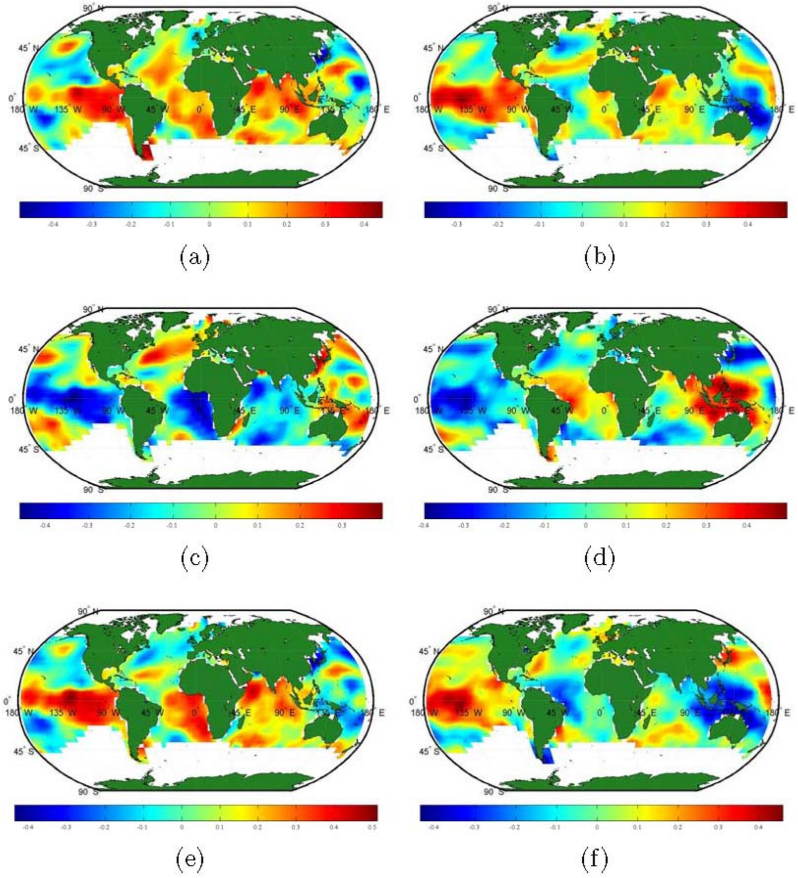
Fig. 1. Correlation maps between rainfall PCs and rainfall field of China and India. **(a)** China PC1 vs. rainfall field of China and India; **(b)** China PC2 vs. rainfall field of China and India; **(c)** India PC1 vs. rainfall field of China and India; **(d)** India PC2 vs. rainfall field of China and India.



(a)

(b)

Fig. 2. Correlation maps between Joint PCs and rainfall field of China and India. **(a)** Joint PC1 vs. rainfall field of China and India; **(b)** Joint PC2 vs. rainfall field of China and India.



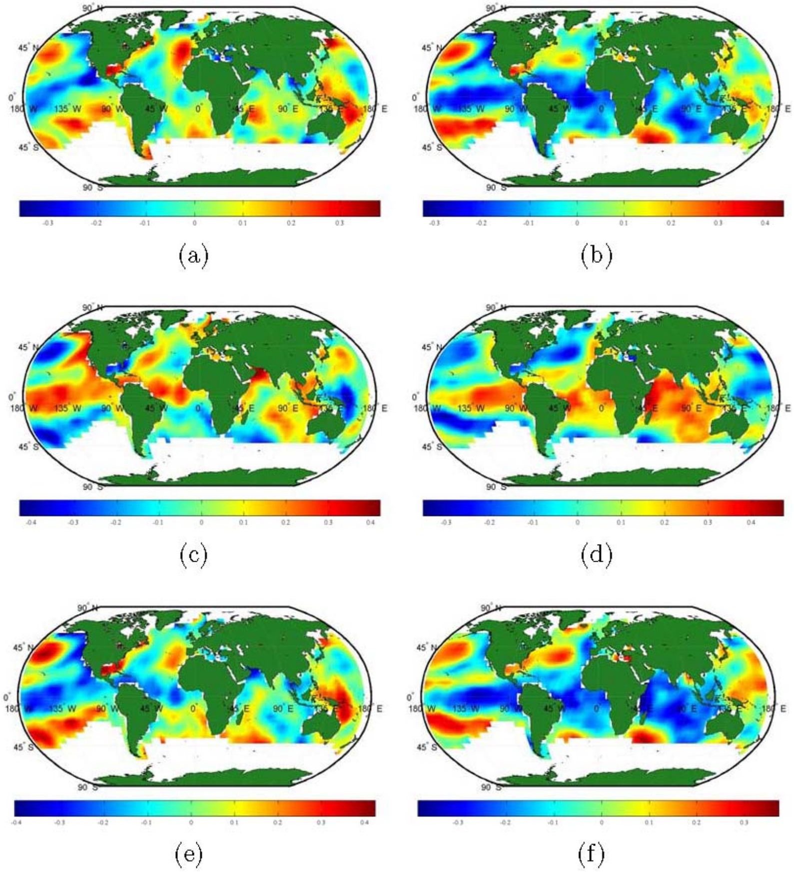
(a) (b)

(c) (d)

(e) (f)

Fig. 3. Correlation maps between SSTa in the monsoon summer season (JJAS) and PCs. **(a)** China PC1 vs. SSTa; **(b)** China PC2 vs. SSTa; **(c)** India PC1 vs. SSTa; **(d)** India PC2 vs. SSTa; **(e)** Joint PC1 vs. SSTa; **(f)** Joint PC2 vs. SSTa.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
I◀ ▶I
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion



(a) (b)

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Fig. 4. Correlation maps between SSTa in the previous winter season (DJF) and PCs. **(a)** China PC1 vs. SSTa; **(b)** China PC2 vs. SSTa; **(c)** India PC1 vs. SSTa; **(d)** India PC2 vs. SSTa; **(e)** Joint PC1 vs. SSTa; **(f)** Joint PC2 vs. SSTa.

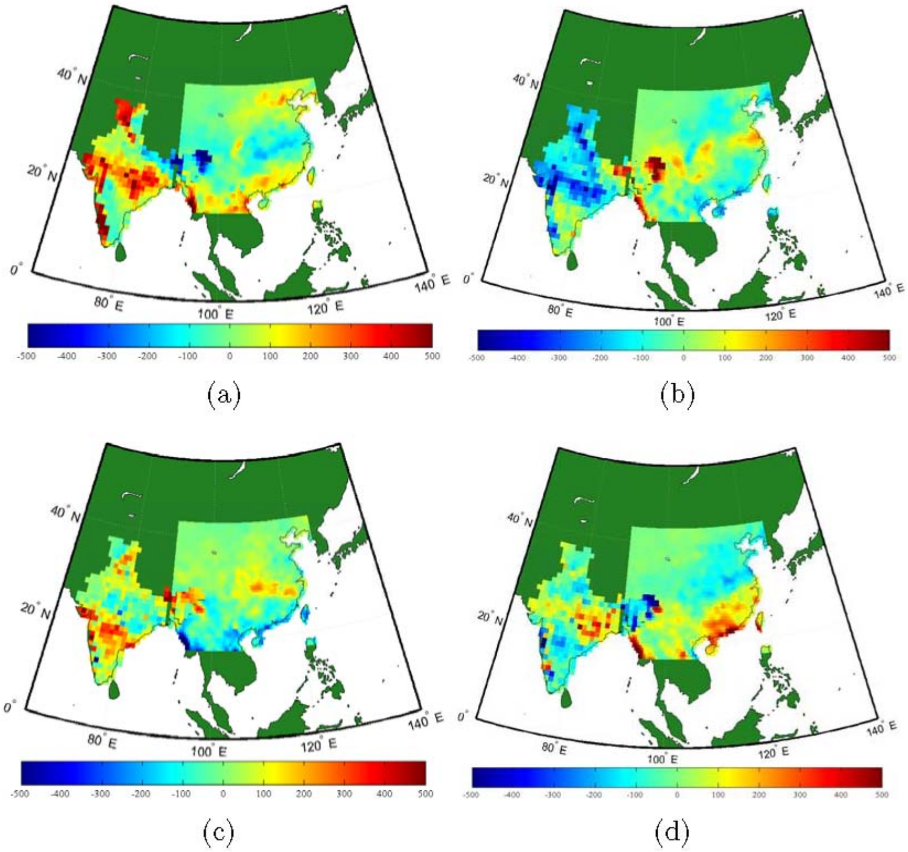


Fig. 5. Average rainfall anomaly in the monsoon months (JJAS) during five lowest or highest value years from Joint PCs. **(a)** Lowest value years from Joint PC1; **(b)** highest value years from Joint PC1; **(c)** lowest value years from Joint PC2; **(d)** highest value years from Joint PC2.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀I | ▶I
◀ | ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

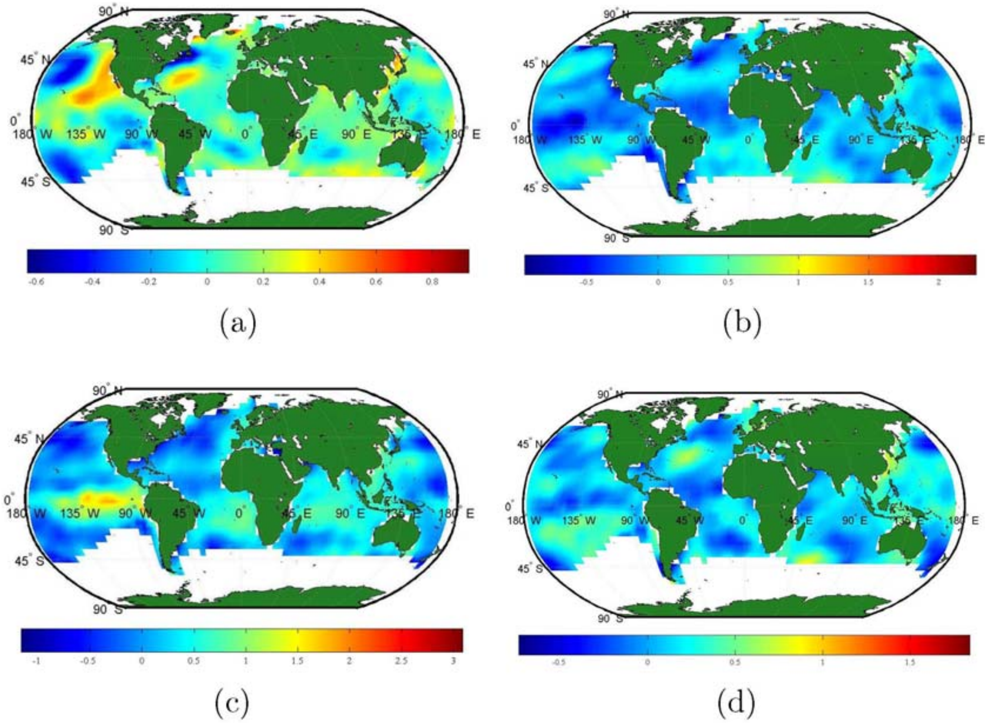
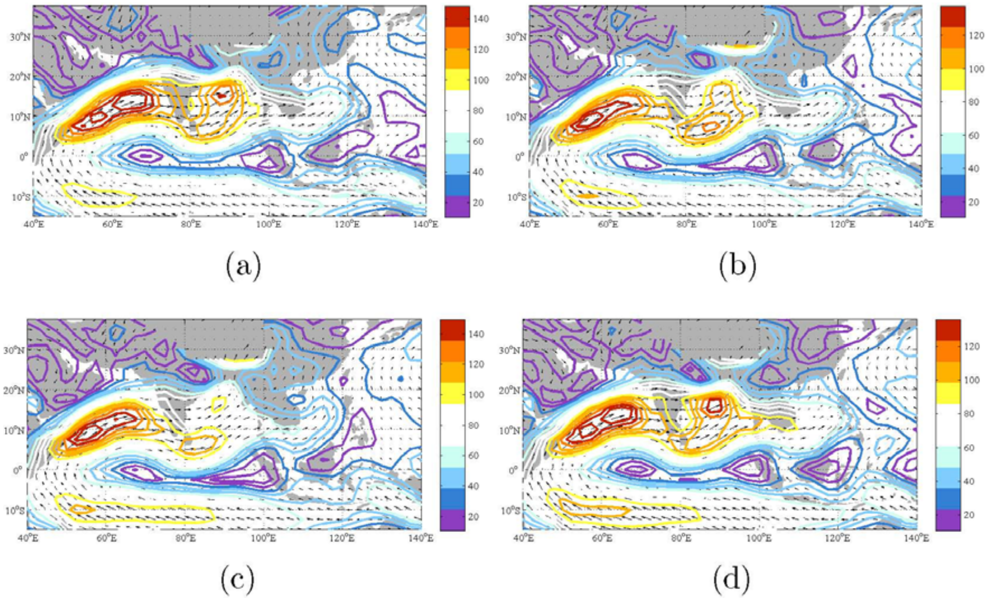


Fig. 6. Average SSTa in the previous winter months (DJF) during five lowest or highest value years from Joint PCs. **(a)** Lowest value years from Joint PC1; **(b)** highest value years from Joint PC1; **(c)** lowest value years from Joint PC2; **(d)** highest value years from Joint PC2.



(a) (b)

(c) (d)

Fig. 7. Average moisture transport at 700 mb–1000 mb in the monsoon months (JJAS) during five lowest or highest value years from Joint PCs. **(a)** Lowest value years from Joint PC1; **(b)** highest value years from Joint PC1; **(c)** lowest value years from Joint PC2; **(d)** highest value years from Joint PC2.