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Link between break/active phases of summer monsoon over India and China

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An attempt has been made to examine the relationship between break/active phases of the Indian summer monsoon and rainfall activity over China. Twelve cases of active and fifteen cases of break phases during the Indian summer monsoon have been examined. Rainfall data over China from 'Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation of the Water Resources' have been used for this study. The amount and areal coverage of rainfall over China were examined during break/active phases of the Indian summer monsoon. It was found that during initiation of break phase in the Indian summer monsoon, rainfall amount and its areal coverage increased over China. The onset of its decrease marked the beginning of the end of the break phase. Exactly opposite trend was observed during the active monsoon phases. This study provides some clue about the end of the break or active phase, although it does not give any signal of initiation of break or active phase in monsoon.

Keywords: Break/active phase, interseasonal/interannual variability, lows and depressions, summer monsoon rainfall.

INDIA receives approximately 80% of annual rainfall during the southwest monsoon and it is the key factor which affects the economy of the country. It is well known that the SW monsoon sets in over Kerala, the southern tip of the Indian land mass, by about 1 June and covers the entire country by about 15 July. In September, the monsoon starts retreating from the country. The SW monsoon shows large intraseasonal variations; there are spells of heavy rainfall and weak/break monsoon conditions. The Indian summer monsoon, which last for four months (June–September), is characterized by periods of active and weak in monsoon conditions. It is the duration of these active (periods of high rainfall over the Indian subcontinent) and weak/break (periods of deficient or no rainfall over the Indian subcontinent) monsoon phases which decides the fate of agriculture production of the Indian subcontinent. In addition to the above phases, a special feature known as 'break in monsoon conditions' occurs[1]. According to the traditional break in monsoon conditions, the following synoptic conditions occur over the Indian subcontinent: (1) The migration of monsoon trough to the foothills of the Himalaya. (2) Absence of low-level easterly wind over North India. (3) Increased rainfall activity over the foothills of the Himalaya and decrease in rainfall over the rest of the country.

Several studies have been made on the intraseasonal/interannual variability of the summer monsoon[2–4]. These authors have studied the influence of intraseasonal oscillations on the seasonal mean/interannual variability of the Indian summer monsoon.

The Indian summer monsoon is an important component of the global climate system and has vigorous intraseasonal oscillations (ISO) that manifest the subseasonal active and break spells of monsoon rainfall. The Indian summer monsoon is characterized by convectively coupled monsoon ISOs that manifest in the form of active and break phases[5], and the overall mean monsoon precipitation distribution significantly depends on the manifestation of ISOs in a season[6]. Monsoon synoptic systems, namely lows and depressions account for most of monsoon rainfall during June–September monsoon[7]. A review of the literature shows that tropical intraseasonal variability is an important part of the character and evolution of the Asian summer monsoon. Whereas its most pronounced influence is associated with its direct connection to the monsoon active and break periods, other effects include its modulation of higher frequency variability, and of the role it may play to help determine interannual and longer-term variability[6].

Break/active phases are influencing components of intraseasonal variability. The duration of active and break days during the peak monsoon months of July and August decides the fate of monsoon rainfall over the Indian subcontinent. The timing and duration of the active and break events are particularly important for an agricultural country like India, where 60–80% of the mean annual rainfall is received during the SW monsoon season. Further, prolonged breaks can adversely affect crop development, growth and yield.

Aijuan *et al.*[8] have observed climatological features and variations of wet spells, especially their trends over China using a dataset of 595 meteorological stations across China from 1951 to 2003. The results show that lower the latitude longer is the annual duration of wet spells. The mean annual precipitation from wet spells is higher in south eastern coastal areas and much lower in

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Table 1. Duration and weather conditions for 11 cases of break/active phases of the Indian monsoon

Duration	Phase	Weather conditions
7–15 July 1972	Active	South west (SW) monsoon set over the entire country on 9 July. The monsoon was generally active over many parts of the country during the first two weeks. The entire monsoon trough lay close to the foothills of Himalaya during the second half of July till 4 August. Subsequently, there was good monsoon activity over many parts of Central and North India up to 25 August. Break monsoon condition prevailed over the country during the first six days of September.
17 July–3 August 1972	Break	
4–19 August 1972	Active	
1–6 September 1972	Break	
23 July–1 August 1973	Break	SW monsoon set over the entire country on 6 July. During the last week of July monsoon trough was close to the foothills of the Himalaya and monsoon was generally weak. Active monsoon conditions prevailed over the country leading to normal/excess rainfall in most parts in August.
2–19 August 1973	Active	
24–28 July 1975	Break	There was a short break in monsoon activity over large parts of the country from 24 to 28 July. The monsoon was active/vigorous in the first fortnight and again on 27 and 28 August.
11–28 August 1975	Active	
1–15 July 1978	Active	SW monsoon set over the entire country on 3 July. Monsoon was active over many parts of the country in the first fortnight. There was a break in the monsoon during 16–21 July.
16–21 July 1978	Break	Monsoon revived over the central parts of the country on 21 July.
17–23 July 1979	Break	SW monsoon set over the entire country on 15 July. There was a break in the monsoon from 17 to 23 July. Active monsoon conditions prevailed generally over the country in the first fortnight of August. The western half of the trough shifted to the foothills of the Himalaya on 15 August. The eastern half also moved close to the foothills of East Himalaya on 18 August. From 18 August, the entire monsoon trough shifted to the foothills of the Himalaya leading to break, which continued till the end of the month.
4–12 August 1979	Active	
15 August–3 September 1979	Break	
26–30 July 1981	Break	SW monsoon set over the entire country on 10 July. The axis of the monsoon trough shifted to the foothills of the Himalaya by 26 and remained there till the end of the month. Monsoon trough shifted towards the foothills of the Himalaya in the last week of August. Under the influence of lows and depressions, monsoon was active/vigorous during the first three weeks of August.
2–19 August 1981	Active	
23–27 August 1981	Break	
10–19 July 1984	Active	Monsoon was active/vigorous over many parts of the country during 10–19 July. During break period, there was rainfall activity over the foothills of the Himalaya region and Northeast India.
20–24 July 1984	Break	
18–26 July 1990	Active	Monsoon was active/vigorous over many parts of the country during 18–26 July. During break period there was rainfall activity along the foothills of the Himalaya region and Northeast India.
27–31 July 1990	Break	
1–5 July 1996	Break	Monsoon trough at sea level running close to the foothills of the Himalaya during 1–5 July. Thereafter the monsoon was active/vigorous over many parts of country till 18 July.
10–15 July 1996	Active	
23–28 July 2002	Break	Irrespective of early onset, monsoon took two months to cover the entire country (15 August). The July rainfall was lowest (–51%) during the past 100 years. Monsoon trough at sea level running close to the foothills of the Himalaya during 23–28 July. Rainfall in the remaining three months was near normal.
19–30 August 2002	Active/normal	
19–21 July 2004 and 26 August–9 September 2004	Break	Rainfall was not distributed in time domain, owing to the prolonged weak/break conditions during late June, most of July, late August and early September. Monsoon was active/vigorous over many parts of country during 12–23 August
12–23 August 2004	Active	

Table 2. Maximum rainfall (cm) and date of the end of the break phase as reported and from the present study for break phases

Break phase duration	Maximum rainfall (cm)/date	Break phase ended on (as reported)	Break phase ended on (from the present study)
17 July–3 August 1972	200/20 July, 120/28 July	3 August	1 August
1–6 September 1972	150/2 September	6 September	7 September
23 July–1 August 1973	130/25, 29, 31 July	1 August	3 August
24–28 July 1975	160/30 July	28 July	2 August
16–21 July 1978	90/20 July	21 July	22 July
17–23 July 1979	140/19 July	23 July	23 July
15 August–3 September 1979	140/22 August, 1 September	3 September	3 September
26–30 July 1981	120/26 July	30 July	1 August
23–27 August 1981	130/24 August	27 August	27 August
20–24 July 1984	110/25 July	24 July	29 July
27–31 July 1990	120/31 July	31 July	5 August
1–5 July 1996	150/3 July	5 July	7 July
23–28 July 2002	190/23 July	28 July	27 July
15–21 July 2004	180/18 July	21 July	22 July
16 August–9 September 2004	120/27 August, 90/5 September	9 September	11 September

western and northern China. The lowest wet spells are found in southwest China and the eastern Tibetan Plateau. The maximum daily precipitation of wet spells decreases from the southeast to the northwest, with the highest in southeastern coastal areas and lowest in western China. The trends of wet spells exhibit striking regional differences.

In the present study an attempt has been made to examine the relationship between break/active phases of the Indian summer monsoon and rainfall activity over China. The purpose of the study was also to see whether we could get some clue for the prediction of the beginning and end of the break/active phases during monsoon, which is vital for agriculture, water management, etc. For this study we selected 15 cases of break and 12 cases of active phases of the Indian summer monsoon during 1972–2004.

Data and methodology

Break/active periods in the monsoon for the present study were selected following De *et al*.[9] and Indian Daily Weather Reports (IDWR). Rainfall data which are rain gauge-based 0.5° daily grid precipitation products developed by the Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of water resources (APHRODITE's water resources project; http://www.chikyu.ac.jp/precip/) have been used for the study. Duration and weather conditions for the break/active cases are given in Table 1. The total rainfall and its areal coverage over China were examined during the break/active phases of the Indian monsoon. The total rainfall (cm) is the arithmetic addition of rainfall for all grid points over China. To see whether the rainfall over China is isolated or widespread, the rainy area was computed. For this purpose, the 0.5 cm rainfall contours were drawn. Grid mesh was drawn at 5° lat. and 5° long. over China. Then the number of meshes which have been occupied by half or more contours of 0.5 cm was counted manually, this was taken as rainy area in units of $5° \times 5°$.

Results and discussion

Most of the cases were selected in July and August, when majority of the rainfall occurs, with a duration of more than five days.

Figure 1 shows total rainfall (cm) over China during 15 breaks of the Indian summer monsoon. It can be seen from Figure 1 that with the onset of break, the total rainfall over China increases, reaches a peak value and then decreases. When rainfall reaches a peak value and starts decreasing, this marks the beginning of the end of the break phase. Also, after decreasing, the day when rainfall again starts increasing more or less matches with the end of break reported. However, during long breaks more than one peak is observed. In this case, it is observed that when rainfall is less than 60 cm the break ends. The duration of break, maximum rainfall values reached along with date, and the date of the end of the break phases are given in Table 2. Figure 2 *a* shows peak rainfall value reached during the break phases; it is found to be more than 90 cm. Out of 15 break phases, it is observed that in 12 cases departure in days of the end of the break phase in this study from that reported is in the range –2 to +2 days (Figure 2 *b*). The range –2(+2) days indicates that the end of break from this study is two days earlier (later) than that reported. For the remaining three breaks, the end of the break phase from the study is delayed by 5 days.

To study whether the rainfall over China is well distributed or isolated, we computed rainy area (Figure 3). It is found that as rainfall increases, areal coverage also increases for all break phases. Thus it is concluded that rainfall is widespread.

Similarly, we examined active phases during the Indian summer monsoon. Exactly the opposite trend of China rainfall as that of break is found during active monsoon phases. Figure 4 shows total rainfall (cm) over China during 12 active phases of Indian summer monsoon. It can be seen from Figure 4 that as the active phase begins the total rainfall over China decreases, reaches a lowest peak and then increases. When the rainfall reaches a minimum value and starts increasing, this is the beginning of the end of the active phase. When it starts decreasing again, this day more or less matches with the end of the active phase as reported. The duration of the active phase, minimum rainfall values reached along with date and the date of the end of the active phases as reported and from this study are shown in Table 3. Figure 2 *c* shows the lowest rainfall value reached during active periods; it is found to be less than 70 cm. For 11 out of 12 active phases, it is observed that the departure in days of the end of the active phase in this study from that reported is in the range 0 to –3 days (Figure 2 *d*).

Similar to break phases, we studied the areal coverage of rainfall of active phases also (Figure 5). It can be seen from Figure 5 that as rainfall decreases, its areal coverage also decreases.

The physics and dynamics of the relationship between the break/active phases of the Indian summer monsoon and rainfall activity over China will be the topic of a future study.

Conclusion

This study shows that there exists a definite link between break/active phases of the Indian summer monsoon and rainfall over China. The study shows that after initiation of break (active) phase, total rainfall and its areal coverage over China increases (decreases). The period when it starts decreasing (increasing), after attaining the highest (lowest) values, marks the beginning of the

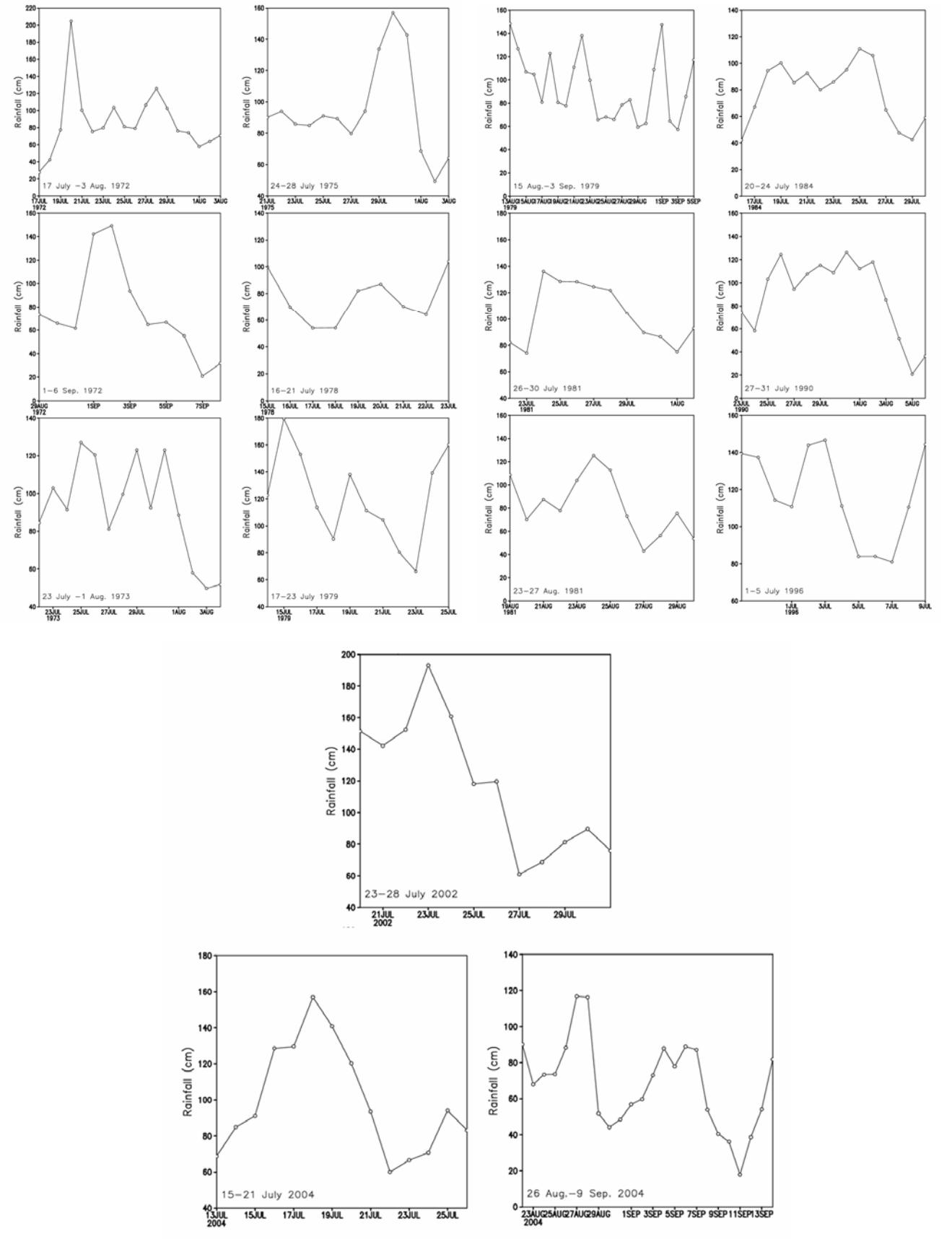

Figure 1. Total rainfall (cm) over China during break phases of Indian summer monsoon.

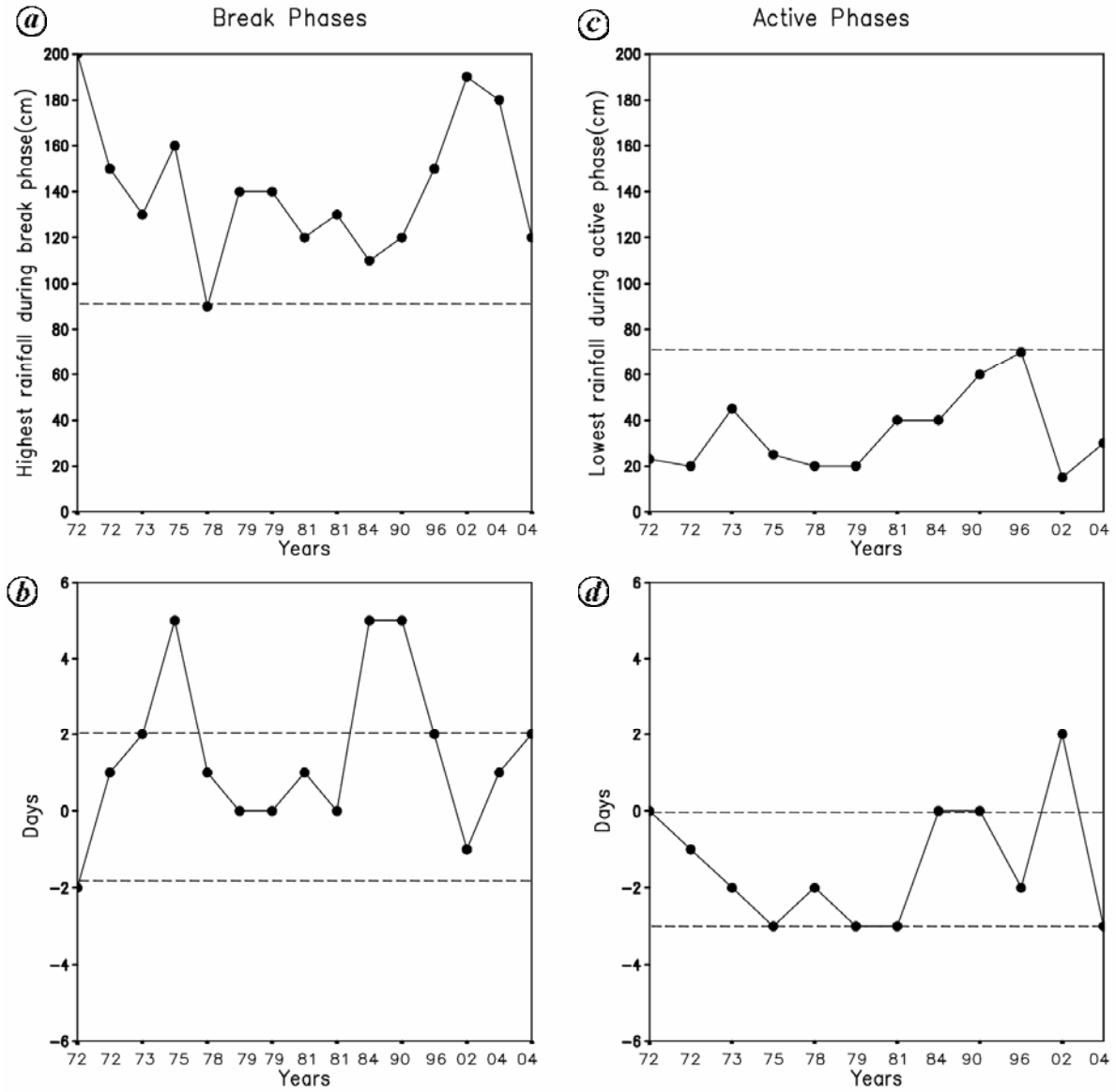

Figure 2. Peak total rainfall (***a***) and departure in days of the end of the break phase in the present study from that as reported (***b***). Lowest peak total rainfall (***c***) and departure in days of the end of the active phase in the present study from that reported (***d***).

Table 3. Minimum rainfall (cm) and date of the end of the active phase as reported and from the present study for active phases

Active phase duration	Minimum rainfall (cm)/date	Active phase ended on (as reported)	Break phase ended on (from the present study)
7–20 July 1972	23/17 July	20 July	20 July
4–19 August 1972	20/11 August	19 August	18 August
1–23 August 1973	45/5 August	23 August	21 August
11–28 August 1975	25/21 August	28 August	25 August
1–15 July 1978	20/6 July	15 July	13 July
1–16 August 1979	20/6 August	16 August	13 August
2–19 August 1981	40/7 August	19 August	16 August
10–19 July 1984	40/16 July	19 July	19 July
18–26 July 1990	60/22 July	26 July	26 July
10–18 July 1996	70/12 July	18 July	16 July
19 August–12 September 2002	15/31 August	12 September	14 September
12–23 August 2004	30/17 August	23 August	20 August

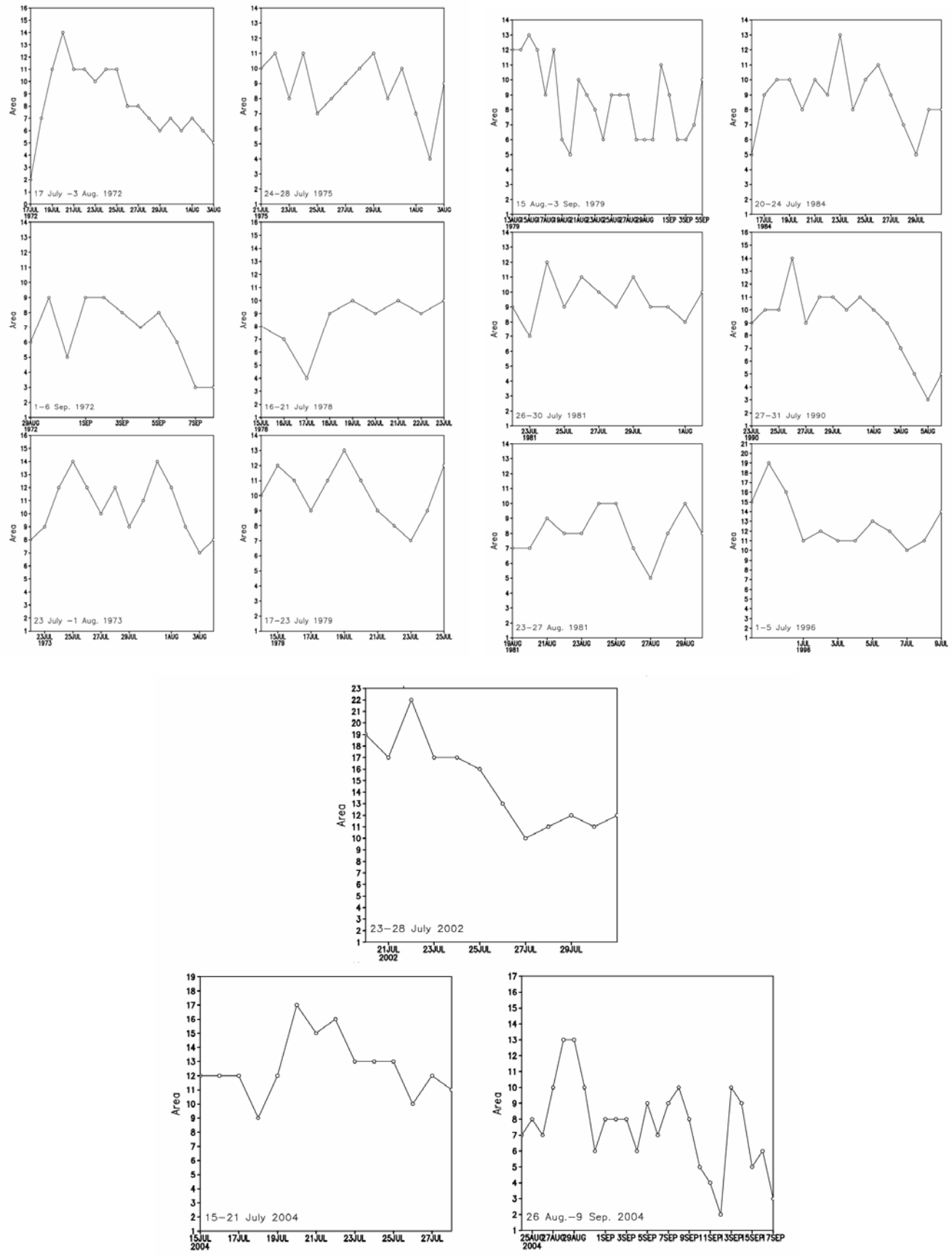

Figure 3. Rainy area of rainfall (in units of 5° × 5°) over China during break phases of Indian summer monsoon.

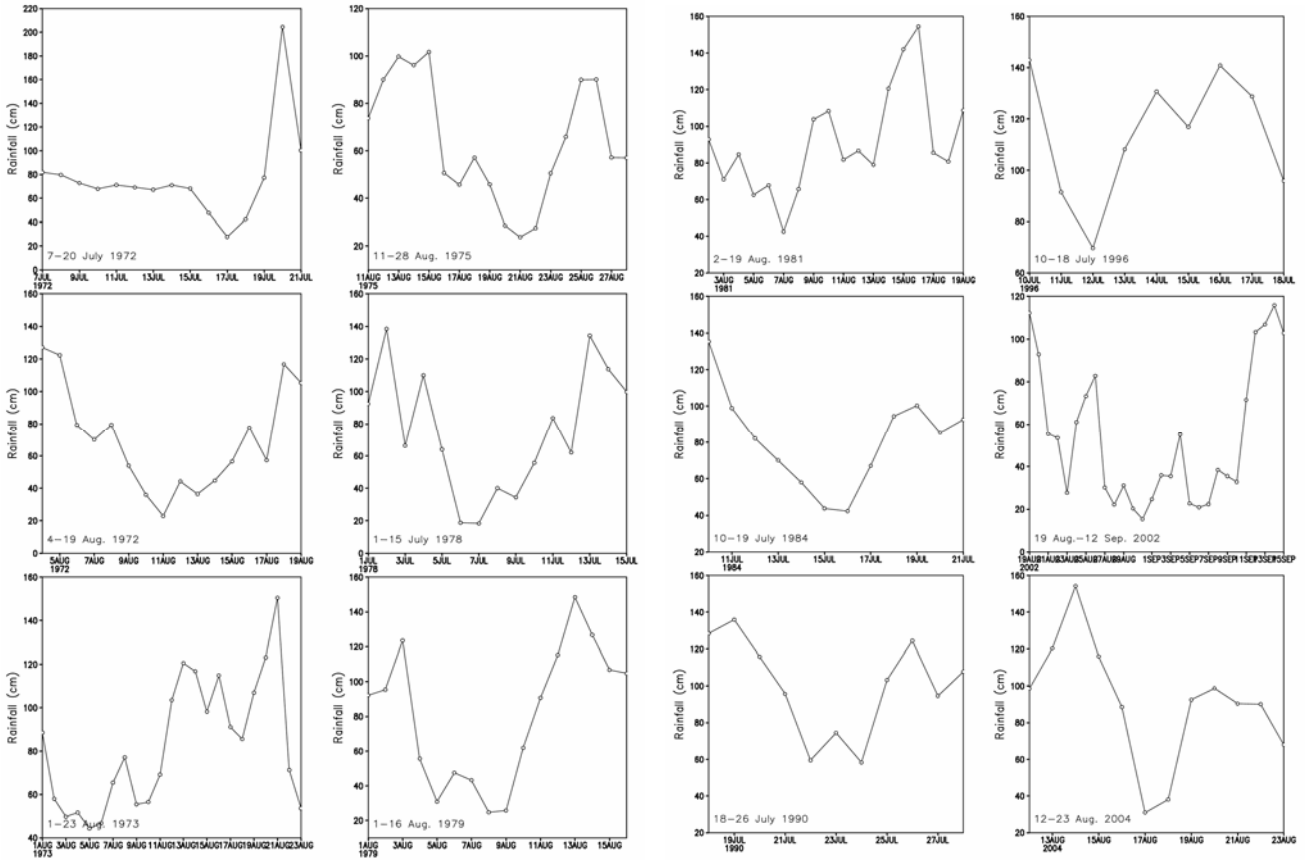

Figure 4. Same as Figure 1, but for active phases of Indian summer monsoon.

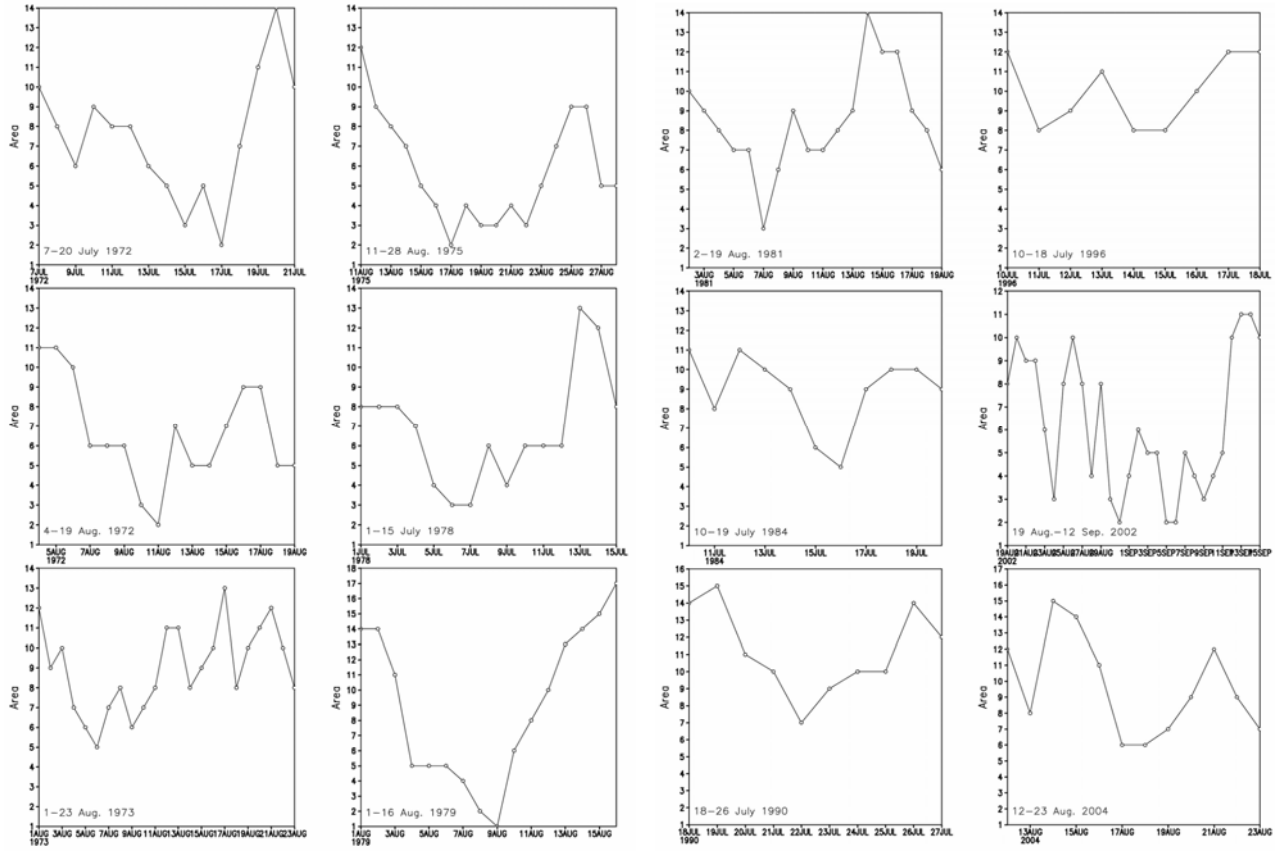

Figure 5. Same as Figure 3, but during active phases of Indian summer monsoon.

end of the break (active) phase. This study provides some clue about the end of the break/active phases, although it does not give any information about the initiation of the break/active phases. Departure in days of the end of the break/active phases in this study from that as reported is in the range –2 to +2 (except 3 cases out of 15) for break and 0 to –3 (except one case) for active phase respectively. The present study shows that the highest rainfall over China remains more than 90 cm during the break phase and the lowest rainfall remains less than 70 cm during the active phase.

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