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Breaks in monsoon and related precursors

U. S. DE and R. K. MUKHOPADHYAY

Meteorological Office, Pune, 411 005, India

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सार – इस शोध-पत्र में 1987 से 1997 की अवधि के दौरान उत्पन्न हुई मानसून की ग्यारह विरल स्थितियों का विस्तृत रूप से विश्लेषण करने का प्रयास किया गया है। इस शोध-पत्र में मानसून की विरल स्थितियों से संबंद्ध पहले की परिस्थितियों का पता लगाने के लिए विरल मानसून के प्रारम्भ होने/ मानसून के समाप्त होने से संबंद्ध दैनिक वर्षा के सामान्य से कम अथवा अधिक मात्रा पवन विसंगतियाँ तथा उपग्रह व्युत्पन्न निर्गमी दीर्घ तरंग विकिरण (ओ.एल.आर.) जैसे विभिन्न अभिलक्षणों का अध्ययन किया गया है। अध्ययन से प्राप्त हुए परिणामों से यह पता चला है कि 20^{O} उ. की दक्षिणी अक्षांशीय पटटी पर वास्तविक विरल मानसून दिवस से 5 दिन पहले सामान्य से कम अथवा अधिक मात्रा में हुई वर्षा में उत्तरोत्तर कमी (स्थिर अवस्था में) आई है। मानसून के पुनः आरंभ होने पर सामान्य से कम अथवा अधिक मात्रा में हुई दैनिक वर्षा के वर्गीकृत समय से यह पता चला है कि अक्षांशीय पटटी 5°उ. से 10°उ. के दक्षिणी छोर पर सामान्य से कम अथवा अधिक मात्रा में हुई वर्षा सबसे पहले विरल मानसून के समाप्त होने के पश्चात् दूसरे दिन से लेकर आगे तक के दिनों में सामान्य से अधिक रही। इस प्रकार निम्न तथा मध्य क्षोभमंडलों में भी विरल मानसून के प्रारम्भ होने के पाँच दिन पहले क्षेत्रीय पवन की पूर्वी क्षेत्र की विसंगतियाँ सबसे पहले दक्षिणी अक्षांश में देखी गई। इस दौरान निम्न तथा मध्य क्षोभमंडलों की अधिकतम पूर्वी विसंगतियाँ उत्तर की ओर 20° उ. तक आगे बढ़ीं। ओ.एल.आर.विसंगति के संयुक्त अक्षांशीय उपक्षेत्र के दृष्टिकोण से 20° द. से लेकर 10° उ. तक का विस्तृत क्षेत्र नाममात्र की ओ.एल.आर.विसंगति वाला क्षेत्र पाया गया है। इस क्षेत्र को दक्षिणी गोलार्द्ध-संवहनी क्षेत्र (एस.एच.सी.जेड.) नाम दिया गया है। ओ.एल.आर.की नाममात्र की विसंगति (10 Wm^{-2}) 5° द.से 0° उ. के आस पास के क्षेत्र में पाई गई है। विरल मानसून के दूसरे दिन उसी अक्षांशीय पटटी पर इस विसंगति में 20 Wm^{-2} तक की बढ़ोतरी हुई है। ओ. एल.आर. की दैनिक विसंगति के पैटर्न से यह पता चलता है कि विरल मानसून के आरम्भ होने पर भूमध्यवर्ती क्षेत्र के आस-पास ओ.एल.आर. की विसंगति में नाममात्र की बढ़ोतरी हुई है। इस शोध-पत्र में मानसून के प्रारम्भ होने/मानसून के समाप्त होने के पूर्वानुमान संबंधी पहलुओं पर भी विचार-विमर्श किया गया है।

ABSTRACT. A comprehensive analysis of eleven break monsoon situations that occurred during the period 1987 to 1997 have been attempted in the study. The various features like daily rainfall departures, wind anomalies and the satellite derived Outgoing Long wave Radiation (OLR) associated with the commencement/cessation of the break monsoon condition are studied with a view to identifying the precursors associate the break situation. The results reveal that there is progressive decrease of below normal rainfall departures 5 days prior to the actual break day in the latitude belts south of 20° N. During the period of the revival of the monsoon, the time section of the daily rainfall departures shows that the daily rainfall departure first starts becoming above normal in the southern most latitudinal belt 5° N to 10°N from the second day onwards after the cessation of the break. Similarly, the easterly anomalies in the zonal wind are first noticed in the southern latitude even 5 days prior to the starting of the break in the lower and middle troposphere. The maximum easterly anomalies in the lower and the middle troposphere move northwards upto 20° N. The composite latitudinal time section of OLR anomaly show a large area of negative OLR anomaly extending from 20°S to 10°N. The area is defined as the Southern. Hemispheric Convective Zone (SHCZ). The negative OLR anomaly (10 Wm^{-2} is noticed around 5° S to 0° N. It increases to 20 Wm^{-2} on the second day of the break on the same latitudinal belt. The daily OLR anomaly pattern shows that the area of the negative OLR anomaly around the equatorial region increases with the approach of a break epoch. The forecasting aspects of the commencement / cessation of the break have been also discussed.

Key words – Break monsoon situation, Outgoing long wave radiation (OLR), Southern hemispheric convective zone (SHCZ), Zonal and meridional wind anomalies, Daily rainfall departures.

1. Introduction

Exhaustive summaries on breaks in the monsoon were presented by Ramamurthy (1969) and De *et al.* (1998). Sadler *et al.* (1968) identified the meridional propagation of an equatorial buffer zone during the occurrence of breaks. They identified the presence of a clockwise gyre circulation around 5°N during the active monsoon spell prior to the occurrence of a break. They further demonstrated with the help of stream line analysis at 850 hPa, that this gyre during the break, propagates northward and acquires, anticyclonic characteristics. The arrival of this anticyclone over the latitude of the Monsoon Trough (MT) weakens and the MT initiates the break in the monsoon.

Koteswaram (1950) on the other hand, associated 'Breaks' with mid-tropospheric lows moving slowly westward across 10-15° N and causing the increase in rainfall over southern India and Sri Lanka.

Pisharoty and Desai (1956), Ramaswamy (1958, 1962, 1967) and Parthasarthy (1960) inferred that a break monsoon condition develops when the upper-tropospheric ridge, including the Tibetan high along 30° N weakens and a large amplitude trough or series of troughs in the polar westerlies or western disturbances protrude south of the Himalayas resulting in an increase in rainfall at the foothills of the Himalayas.

Krishnamurti and Bhalme (1976) have considered the low frequency modes to be responsible for the active break cycle over the Indian subcontinent.

De *et al*. (1995) observed that the major epochs of breaks in the Indian monsoon coincide with the active southern hemispheric equatorial trough (SHET) epochs. Vernekar and Ji (1999) have also supported the hypothesis that there exist an inverse relationship between the strength of ITCZ over the warm waters of the equatorial Indian Ocean and the continental ITCZ in the vicinity of the monsoon trough.

Recent studies on the break emphasize on the propagation of low frequency modes and middle latitude interactions. There are two relevant low frequency time scales that seem to modulate monsoon activity (a) around two weeks, *i.e*., 10 to 20 day oscillations (Krishnamurti and Bhalme, 1976; Murakami and Frydrych, 1974) and (b) the 30-50 day time scale (Sikka and Gadgil, 1980; Chowdhury *et al*., 1988a).

In the recent decades, the geo-stationary satellite INSAT, provided the data from the data sparse area of the Indian Ocean region, including satellite derived parameter *viz*., outgoing long wave radiation (OLR).

Every break has its own peculiar combination of antecedent factors which are unlikely be revealed by synoptic climatological studies. Thus an attempt has been made to investigate the such cases with a view to identifying the various features associated with the

TABLE 1

Break situation from 1987-1997

Year	Period
1987	28 July – 1 August
1988	5-8 July, 13-15 August
1989	10-12 July, 29-31 July
1990	8-10 July, 27-31 July
1991	3-9 September
1993	19-21 July
1995	12-15 August
1996	1-5 July

Total break situation – 11
Total number of break days - 45

commencement/cessation of the break monsoon condition. Important precursors arising out of the study are discussed *vis-a-vis* the role in foreshadowing the, commencement/ cessation of the break monsoon situations.

2. Data

11 break monsoon situations that occurred during the period 1987 to 1997 have been considered in the study. These break situations were identified by De *et al*. (1998) and are presented in Table 1. The breaks which lasted only for one or two days were not taken into account. The breaks which commenced, after the date of advance of the summer monsoon over the entire country and before the date when the withdrawal of the monsoon started, only were taken.

During these 11 years , the years 1992 and 1997 had no break monsoon situation, while the years 1988, 1989 and 1990 had two break situations in each of these years. These 11 break monsoon conditions cover, in all 45-break days, ranging from 3 to 7 days. For the calculation of the daily area weighted latitudinal percentage departure, first the stations having the daily rainfall data as well as daily normal values have been selected. The daily rainfall normal has been obtained from the long period average based on 1901-1970. The number of stations thus selected comes out to be 156. Daily actual and normal rainfall data of 156 well distributed observatory stations covering five latitudinal belts *viz*., (*i*) 5°-10° N; (*ii*) 10°-15° N, (*iii*) 15°-20° N, (*iv*) 20°-25° N and (*v*) 25°-30° N, for the period of nearly 15 days for each break monsoon condition are used. Out of these 15 days, 5 days, are prior to the starting of the actual break situation and 5 days are after the cessation of the break, while the remaining days are the actual duration of the break epoch. The areas of the meteorological sub-divisions, which fall roughly in the particular latitude belt, have been considered for the calculation of the daily area weighted latitudinal rainfall

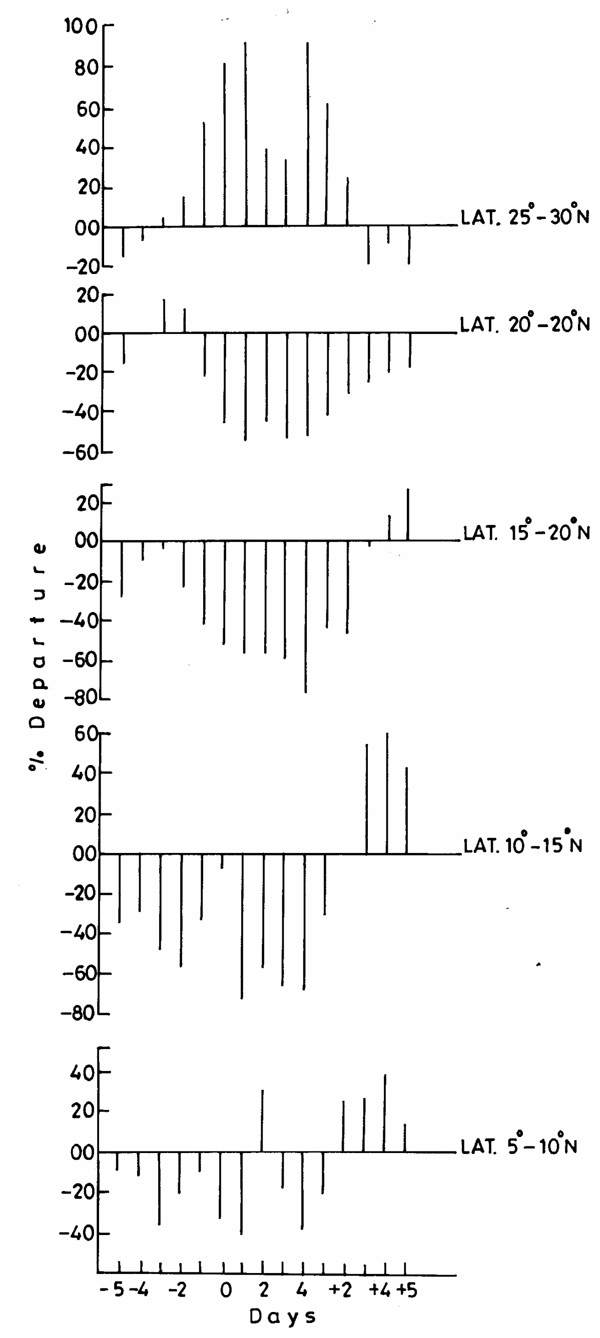


Fig. 1. Composite daily (%) departure of area weighted rainfall '0' date corresponds to starting of break, while '–5' indicates 5 days prior to break & '+5' indicates 5 days after the break

departure. It may be noted that the daily rainfall departure composite as been prepared from the daily rainfall departure which vitiates the temporal variation of the daily rainfall.

The daily upper wind data of 850 hPa, 500 hPa and 200 hPa levels of the available radiosonde stations for the same period of each break case were used. The daily zonal and meridional wind anomalies were calculated using "10-days averages of upper wind" (IMD, 1998).

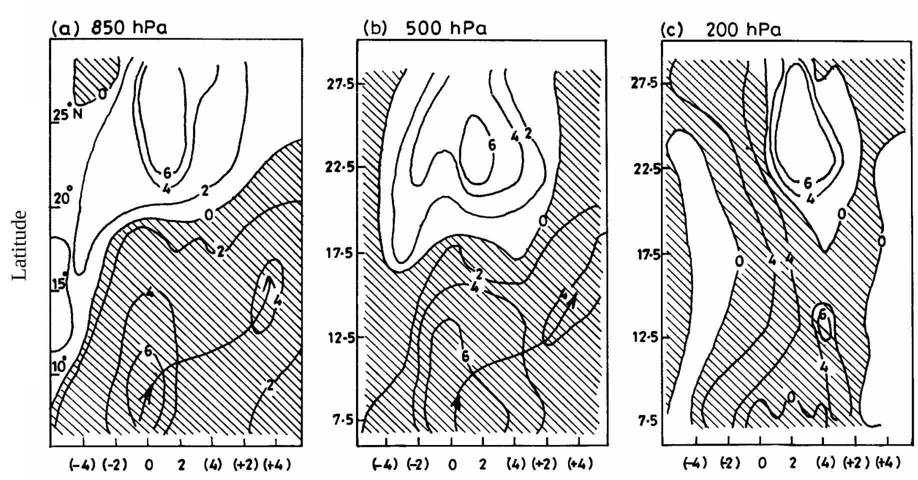
The daily satellite derived OLR values in 2.5° × 2.5° Lat./Long. box in the area of 40° E to 100° E and 35° N to 25° S for the same period for each break case have been used. The daily OLR values are then converted into daily OLR anomaly by subtracting 5 years mean value from the daily OLR values of each square grid. The 5 years mean OLR values were based on the period 1987 to 1991. These OLR anomalies were then analyzed in order to locate the area of maximum convection. The latitudinal time-section of the composite OLR anomaly was then prepared.

3. Results and discussion

3.1. *Daily rainfall pattern*

To examine the effect of the breaks on the daily rainfall departures at various latitudinal belts, the composite time section of five latitudinal belts were prepared and presented in Fig. 1. '0' on the time scale represents the starting of the break, while '-4' indicates four days prior to the commencement of the break and '+4 ' indicates four days after the cessation of the break. Only '4' means the fifth day of the break. The time section of the area weighted daily rainfall departures shows that out of 15 days period, the daily rainfall departures are above normal on most of the days in the northern latitudinal belt 25° to 30° N, while they are below normal in other four latitudinal belts. The maximum positive daily rainfall departure (92%) is seen on the second and fifth day of the break in the latitudinal belt 25° to 30° N, while the maximum negative departure (–78%) is noticed on the fourth day of the break in the latitude belt 15° to 20° N. Thus the time section of the various latitudinal belts confirms that, during the break, the rainfall almost ceases over most parts of the country. Heavy falls only occur in and near the Himalayas. In the south, Tamil Nadu and Rayalaseema also get more rains during break. This is also supported by the time section of the latitudinal belt 5° to 10°N. The positive daily rainfall departure (32%) is seen on the second day of the break for this latitude belt.

The time section of the daily rainfall departures also reveals that there is a progressive persistence of negative rainfall departures starting from 5 days before, the break, in the latitude belts between the equator and 20° N. The daily rate of decrease of rainfall is seen is to be most pronounced in the latitude 10° to 20° N. These negative departures lie between –30% and –50% on the second and third day prior to break. A reverse pattern is seen in the latitude belt 25° to 30° N. In this belt, instead of negative rainfall departure, the positive rainfall departures are,



Figs. 2(a-c). Composite latitudinal time section of zonal wind anomaly. Shaded portion indicates easterly. '0' date corresponds to starting of break, while '– 5' indicates 5 days prior to break & '+5' indicates 5 days after the break

observed to increase even from third day before the break. Just one day prior to break, the daily rainfall departure is noticed to increase from 15% on (–2) day to 55% on (–1) day.

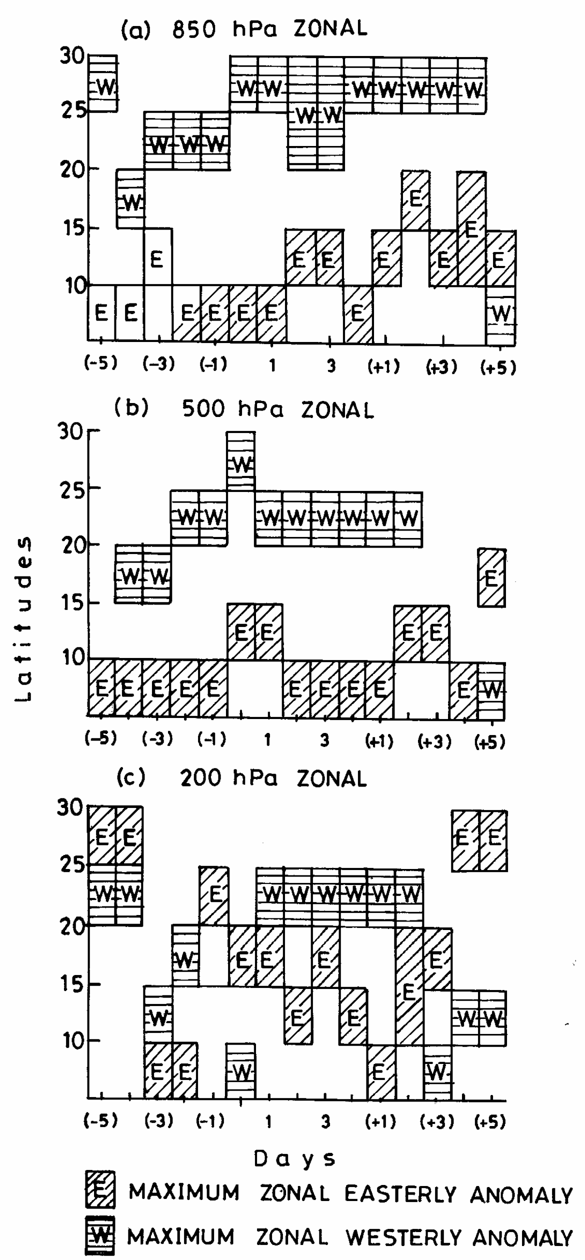
Further, the time section shows that during the revival period of the monsoon or after the cessation of the break, the daily rainfall departures start returning to normal/above normal in the southern most latitudinal belt 5° to 10° N. This starts from the second day after the cessation of the break. The northward propagation of the above normal rainfall departure with a speed of 5° latitude 1 day is noticed up to 20° N. This northward propagation may be attributed to low frequency mode 30-60 day in monsoon rainfall observed by authors, Sikka and Gadgil (1980), Alexander *et al*. (1978) and Chowdhury *et al*. (1988b).

The effect of the break persists even after five days of the cessation of the break in the latitudinal belt 20° to 25° N, which lies in the central part of the country, while in the northern latitudinal belt *i.e*., 25° to 30° N, instead of above normal rainfall departures, below normal rainfall departures are noticed from the third day onwards after the cessation of the break. This shows that in the central part of the country negative rainfall departures continue for longer time than in any other latitude belts; or in other words, the revival of the monsoon takes longer time than that of the starting of the break condition in the central India.

3.2. *Wind anomaly: zonal and meridional*

The composite latitudinal time section of the zonal wind anomalies for the levels 850 hPa, 500 hPa and 200 hPa, are presented in Figs. 2(a-c) respectively, while, the composite latitudinal time section of maximum easterly and westerly anomalies for the same levels are depicted in Figs. 3(a-c). Like rainfall pattern, zonal wind anomalies in the lower troposphere also show contrasting wind anomalies between the southern and the northern latitudinal belt. Easterly anomalies prevail south of 20° N, while westerly anomalies are seen ;north of 20° N. As the monsoon flow is mainly zonal, with weak meridional component, the above pattern confirms that an anomalous anticyclone exists around 20°N in the lower troposphere during the break [Fig. 2 (a)]. According to Alexander *et al.* (1978), the break monsoon is characterized by an anomalous anticyclonic low level circulation centered slightly south of 20° N. This anomalous anticyclone shifts southwards in the middle troposphere and is found to be more intense at 500 hPa level [Fig.2 (b)].

The presence of the easterly anomalies in the lower troposphere is seen first in the lower latitudes even five days prior to the starting of the break. Easterly anomalies move towards the north with a time lag of two to three days up to 20° N [Fig. 2 (a)]. Similarly, the maximum easterly anomaly which normally lies between 5° to 10° N moves to the northern latitude and lies between 10° and 15° N on the third day of the break [Fig. 3 (a)]. On the fifth day after the cessation of the break, the maximum westerly anomaly is noticed in the latitudinal belt 5° to 10° N both in the lower and the middle troposphere. The maximum westerly anomaly is observed in the latitudinal belt 15° to 20° N on the four day prior to the actual break day, while it is confined mostly in the latitudinal belt 20° to 25° N one to three days prior to the actual break in the lower troposphere. It then moves to the northern latitude till the 4 day after the cessation of the break. While in the



Figs. 3(a-c). Composite latitudinal time section of maximum zonal westerly and easterly anomaly. '0' date corresponds to starting of break, while '–5' indicates 5 days prior to break and '+5' indicates 5 days after the break

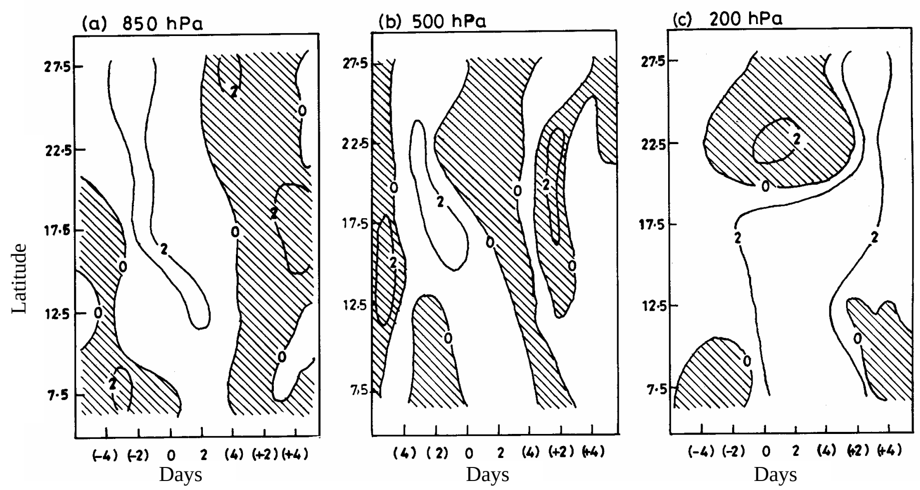
middle troposphere this maximum westerly is found to be at a latitude as south as 15° to 20° N during 3 to 4 days prior to the break and then moves to the north [Fig.3 (b)].

The maximum easterly anomaly (6 m/s) is noticed in the latitudinal belt 5° to 10° N a day prior to the break day at 850 hPa level, while at 500 hPa level, this maximum easterly anomaly (6 m/s) is also observed a day prior to the break but it continues till the fourth day of the break. Similarly the maximum westerly anomaly (6m/s) is seen in the latitudinal belt 20° to 25° N at both these levels. The maximum easterly and westerly anomaly occur simultaneously in the lower troposphere, but there is a time lag of 2 days in the middle troposphere, easterly being ahead of westerly. It is of interest to note that, unlike rainfall, during the revival phase of the monsoon, the westerly anomalies in the northern latitudes are first replaced in the middle troposphere by easterly anomaly from third day of the cessation of the break [Fig.2 (b)].

In upper troposphere, it is well known that the zonal normal wind is easterly and it gains a jet speed called easterly jet with a core around 150 hPa level along the 13°N. The latitudinal time section of the zonal anomalies at 200 hPa level [Fig. 2 (c)] shows that the speed of this easterly wind decreases prior to the starting of the break. The decrease in speed of the easterly at 200 hPa level occurs simultaneously upto the latitude 25° N, 5 to 3 days prior to the break. This may be seen by the presence of westerly anomalies in the latitude 5° to 25° N, during this period [Fig.2 (c)]. It can be seen [Fig. 3 (c)] that the maximum westerly anomaly lies between 10° and 25° N during 5 to 2 day prior to the commencement of the break, which supports the observed weakening of easterlies at 200 hPa.

The most striking feature during the break is the presence of 4 to 6 m/sec westerly anomalies in the latitude belt 20° to 25° N [Figs. 2(c) & 3(c)]. One of the reasons for this is the extension of the mid latitude westerlies over Indian region causing the break monsoon situation (Pisharoty and Desai, 1956; Ramaswamy, 1962 and Parthasarthy, 1960). This is further supported by the composite latitudinal time section of the meridional anomalies at 200 hPa level. The northerly anomalies are observed to the north of 20°N even 3 days prior to the break day in the upper troposphere [Fig. 4 (c)]. The presence of these northerly anomalies are also noticed at 500 hPa level during the break period [Fig. 4 (b)]. In the lower troposphere, the southerly anomalies are observed in the latitude belt 10° to 15° N, 3 days prior to the break [Fig. 4 (a)]. These southerly anomalies persist through out the break period. The strong northerly anomalies can also been seen in the lower troposphere in the latitude 5° to 20° N during 5 to 3 days prior to the break.

Prior to break situation, in the lower latitude *i.e.*, up to 20° N, easterly anomalies are found to increase at a rate of 1.5 m/sec/day and 2.5m/sec/day in the lower and the middle troposphere respectively. Similarly, in the northern latitude *i.e.*, north of 20° N, the increase in the westerly is found to be at a rate 1.7m/sec/day and 2.7 m/sec/day in the lower and middle troposphere respectively. In the upper



Figs. 4(a-c). Composite latitudinal time section of meridional wind anomaly shaded portion indicate normally. '0' date corresponds to starting of break, while '-5' indicates 5 days prior to break and '+5' indicates 5 days after the break

troposphere, the easterly anomaly is becoming westerly in the latitude belt 5° to 10° N, at a faster rate 3.7m/sec/day, while, the increase in westerly in the upper troposphere at 25° to 30° N latitude belt the rate is 3.6 m/sec/day.

The composite vertical time section is shown in Fig. 5. It can be seen, that in the southern most belt (5° to 10° N), there is a clear cut descent of easterly anomaly from 200 hPa to 850 hPa level prior to the starting of the actual break situation. This descent can also been seen in the next latitudinal belt (10° to 15° N) but less marked. The most striking feature is that the descent starts even 3 days prior to the actual break day. Thus, this descent of the easterly anomaly strengthens the oceanic ITCZ (Sikka and Gadgil, 1980) or strengthen the SHET (De *et al.*, 1995). To the north of 20° N, instead of descent, there is an ascent in the easterly from the middle troposphere to upper troposphere during 5 to 1 day prior to the actual break day. Similarly, westerly anomaly is found to ascend from lower troposphere to the upper troposphere during the break period. In the latitude belt 15° to 20° N, also there is an ascent in the easterly anomaly.

3.3. *OLR anomaly*

The composite latitudinal-time section of OLR anomaly pattern is depicted in Fig. 6(a). The latitudinal OLR anomaly value is averaged one between 59° E and 99° E. A large area of negative OLR anomaly, which corresponds to the area of convective activity, is noticed around the equatorial region [Fig. 6 (a)]. The area extends from 20° S to nearly 10°N and may be termed as the southern hemispheric convective zone (SHCZ). It supports the earlier findings of De *et al.* (1995). They have shown that there is an inverse relationship between the southern hemispheric equatorial trough (SHET) clouding and

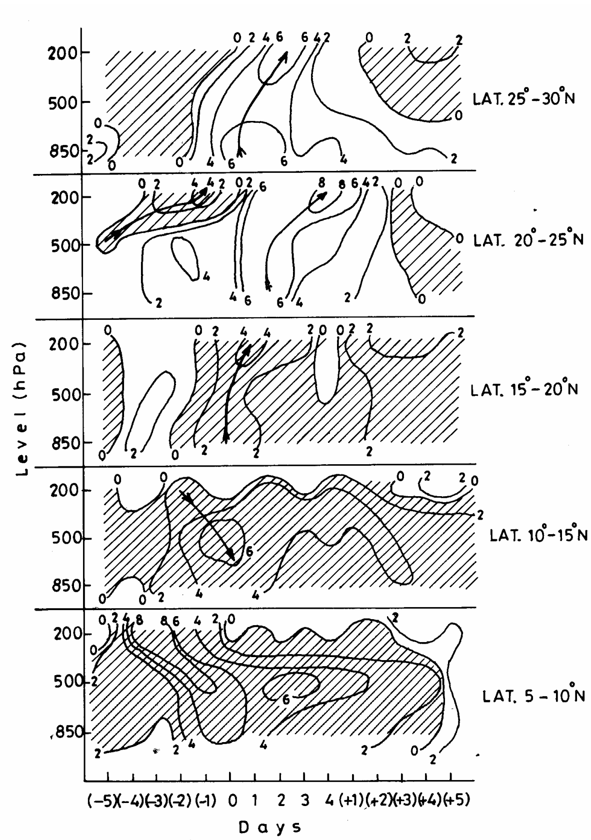
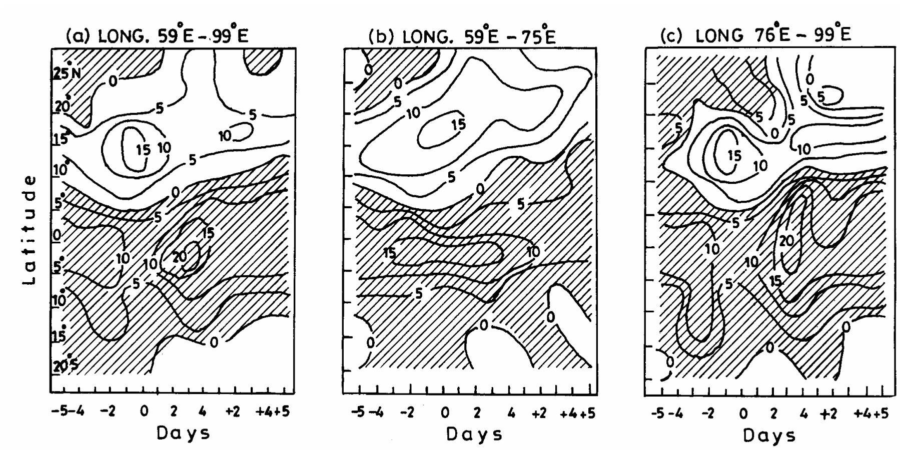


Fig. 5. Composite level wise zonal wind anomaly (m/s). shaded area indicates easterly anomaly '0' date corresponds to starting of break, while '–5' indicates 5 days prior to break and '+5' indicates 5 days after the break

rainfall in the central parts of the country .If we take the period of active SHET from De *et al*. (1995) and examine its relationship with the actual break epochs that occurred during the period 1987-91, it can be noticed that on 63%



Figs. 6(a-c). Composite latitudinal time section of OLR anomaly (W/m^2). Shaded portion indicate –ve OLR anomaly. '0' date corresponds to starting of break, while '–5' indicates 5 days prior to break and '+5' indicates 5 days after the break

of the occasions break occurs during the period of active SHET. This further supports the view that there is a relationship between the break and SHCZ.

The maximum negative OLR anomaly (20 W/m^2) is observed on the second day of the break situation and is located at 2.5° S. The northern hemisphere is seen to be an area of positive OLR anomaly indicating no/less convective activity. The maximum positive OLR anomaly (15 W/m^2) is observed just one day before the actual date of the starting of the break condition. It lies around the latitude 15°N. This positive OLR anomaly over Indian region can be explained with the help of observed rainfall distribution during the break condition. It is well known that break occurs when the monsoon trough shifts to the foothills of the Himalayas. This means that thermally forced meridional circulation has an ascending branch near the foothills of the Himalayas while most parts of India are under the descending branch of this thermally forced meridional circulations and hence no cloud and no convective activity over central India.

Figs. 6 (b&c) show the latitudinal time section of the composite OLR anomaly pattern for (a) the western half (59° E to 75° E) and (b) the eastern half (76° E to 99° E) respectively. Though two OLR anomaly patterns are similar in respect of negative OLR anomaly extending from 20° S to 10° N *i.e.*, in respect of SHCZ, there are differences between the two. They are (*i*) eastern half shows the higher negative OLR anomaly values than those of the western half during all the days prior to the break and also later on. The maximum negative OLR anomaly (20 W/m^2) is seen on the third day of the break in the eastern half, while the maximum negative OLR anomaly (10 W/m^2) is noticed in the western half. This indicates that SHCZ is more intense in the eastern half than that in the western half. (*ii*) In the western half, the positive OLR anomaly is noticed between latitude 10° N to 30° N during the period '0' date to '+4' date indicating the cessation of rain in this half of the country. While, in the case of the eastern half, the positive OLR anomaly only lies between latitude 10° N and 20°N. The negative OLR anomaly (5 W/m^2) is observed between 20°N and 30° N during the period '–2' day to third day of the break, indicating convective activity in the area. This indicates an increasing rainfall activity at the foothills of the eastern half of the Himalayas and supports the view of Rao (1979). According to him, the Himalayas to the east of 85° E are susceptible to much heavier falls than to the west.

After the cessation of the "Break" the negative OLR anomalies are observed between the latitude 10° S to 10° N in both eastern and western halves. The revival seems to start first from the eastern half [Fig. 6(c)]. Pant (1980) and Sikka and Gadgil (1980) have also noticed northward propagation of MCZ after a break. The northward propagation of SHCZ can also be seen during the revival period both over western and eastern halves, but the propagation is more pronounced in the eastern half [Fig. 6(c)].

4. Forecasting aspects

The several meteorological conditions associated with break monsoon condition have been discussed in the earlier section. The authors are of the view that OLR data, being available for both land and sea provide a better tool, to be used as precursor of the commencement of the break monsoon condition. As an illustration, the OLR anomaly pattern of 5 consecutive days (22 to 26 July 1990) just prior to the break situation (27 to 31 July 1990) are presented in Fig. 7, while, the daily OLR anomaly during the actual break condition are presented in Fig. 8. The OLR anomaly pattern clearly shows that the area of

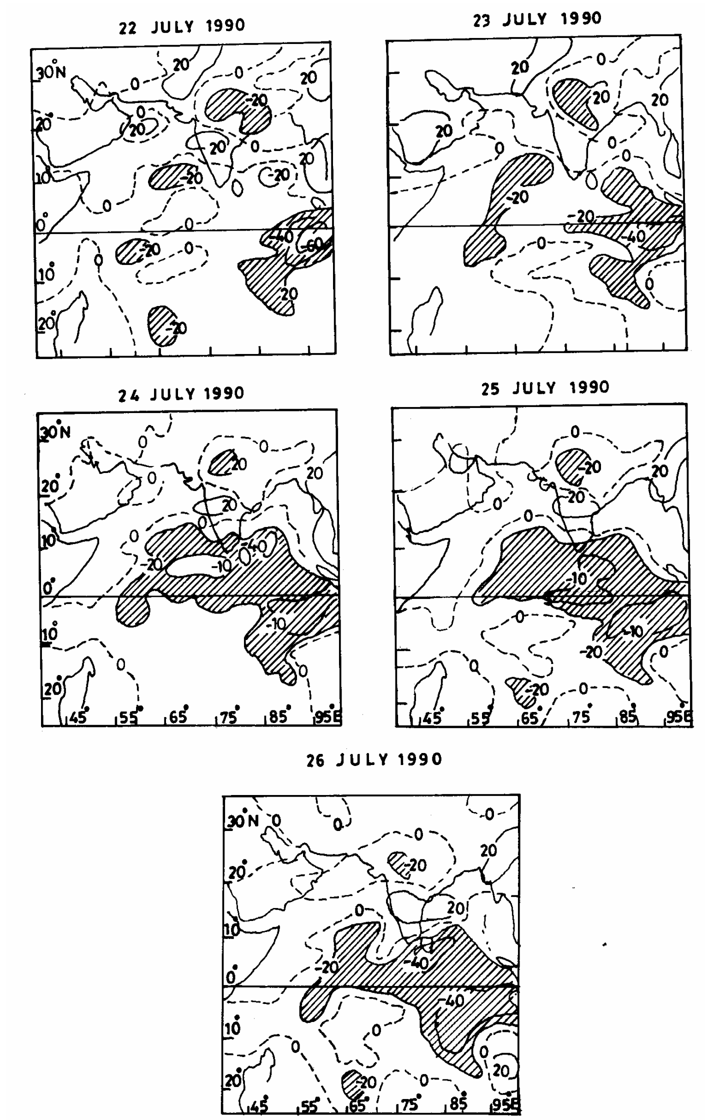


Fig. 7. The daily OLR anomaly (W/m^2) pattern prior to break situation (shaded portion indicates –ve OLR anomaly)

SHCZ increases with the approach of the actual break day. This increase in SHCZ area over the equatorial region can be used as a pre-cursor of the commencement of the break.

The time section of the area weighted rainfall departures in the latitude belts south of 20° N also give an indication of the starting of the break even 5 days prior to the actual break day. The zonal wind anomalies also show the presence of the easterlies in the lower and middle troposphere over the southern latitude 5 days prior to the break condition, while in the upper troposphere, the westerly anomalies are noticed in the latitude 5° to 25° N during this period. The meridional wind anomalies show the presence of the southerly around 17.5° N in the lower troposphere, while in the upper troposphere the northerly anomaly appears north of 20° N, 3 day prior to the break. At the time of forecasting the commencement of the actual break day, the simultaneous occurrences of all these features could be taken into account. Thus the present study is highly useful in forecasting the commencement of the break monsoon situation.

5. Conclusions

The following conclusions may be drawn from the study:

(*i*) The time section of the area weighted daily rainfall departures show below (above) normal rainfall south (north) of 25°N. The maximum positive daily rainfall

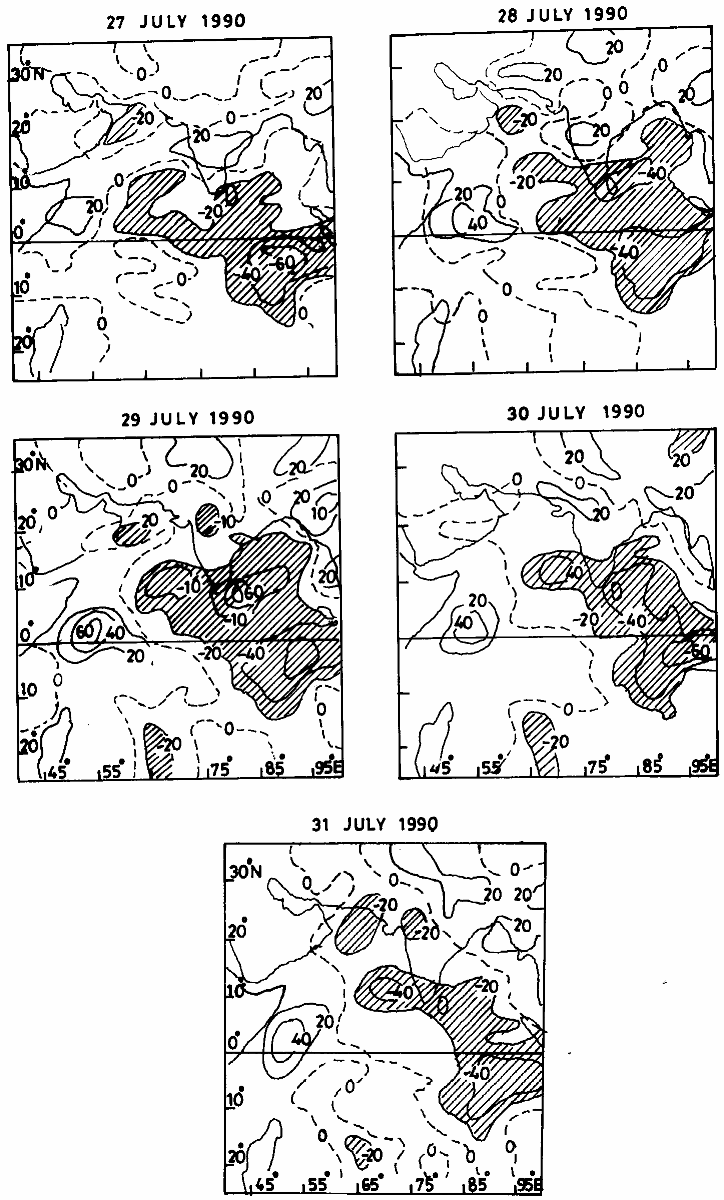


Fig. 8. The daily OLR anomaly (W/m^2) pattern during break situation (shaded portion indicates –ve OLR anomaly)

departure (92%) is observed on the second and fifth day of the break in the latitude belt 25° to 30° N, whereas, the maximum negative departure (–78%) is observed on the fourth day of the break in the latitude belt 15° to 20° N.

(*ii*) The progressive development of negative rainfall departures start from the southern most latitude upto 20-25° N, even 5 days prior to the break. Similarly, during the revival phase of the monsoon, the daily rainfall departures became positive in the southernmost latitude and slowly move towards north upto 20° N. The effect of the break persists even five days after the cessation in latitudinal belt 20° to 25° N.

(*iii*) An anomalous anticyclone exists around 20° N in the lower troposphere while in the middle troposphere it found to be more intense and is shifted southward during the break. In the upper troposphere the strong westerly anomalies are observed around the latitude 22.5° N.

(*iv*) The easterly anomalies in the lower and middle troposphere are seen first in the lower latitudes even five days prior to the commencement of the break. They move northward with active lag of one or two days up to 20° N in the lower troposphere. Unlike rainfall departures, during the revival phase of the monsoon, the westerly anomalies in the northern latitudes are replaced by easterly anomaly from the third day after cessation of the break.

(*v*) The latitudinal OLR anomaly shows a large area of negative OLR anomaly, which corresponds to the area of convective activity around the equatorial region. The maximum negative OLR anomaly ($20 W/m^2$) is noticed on the second day of the break situation and is located at 2.5° S.

(*vi*) The latitudinal OLR anomaly in the eastern half (76° to 99° E) shows higher negative OLR anomaly than those of the western half during all the days prior to the break and later on. During the revival phase of the monsoon, the northward propagation of SHCZ are seen both over western and eastern halves, but the propagation is more pronounced in the eastern half.

(*vii*) Daily OLR anomaly pattern of 5 consecutive days prior to the break situation shows that the area of SHCZ increases with the approach of the actual break day. This increase in area of SHCZ along with time situation of the area weighted rainfall departures in the latitude belt south of 20° N and zonal wind anomalies in the lower and middle troposphere of the same region should be used as precursors for forecasting the commencement of the actual date of break.

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References

Alexander, G., Keshavamurthy, R.N., De, U. S., Chellapp, R. Das, S. K. and Pillai, P.V., 1978, "Fluctuations of monsoon activity", *Indian J. Met. Hydrol. & Geophys*., **29**, 76-87.

Chowdhury, A., Sinha Ray K. C. and Mukhopadhyay, R. K, 1988a, "Intra-seasonal cloud variations over India during summer monsoon season", *Mausam*, **39**, 4, 359-366.

Chowdhury, A., Mukhopadhyay R. K. and Sinha Ray, K. C., 1988b, "Low frequency oscillations in summer monsoon rainfall over India", *Mausam*, **39**, 4, 375-382.

De, U. S., Prasad, O. and Vaidya, D. V., 1995, "The influence of Southern Hemispheric Equatorial Trough on rainfall during southwest monsoon", *Theor. Appl. Climatol*., **52**,177-181.

De, U. S., Lele, R. R. and Natu, J. C., 1998, "Breaks in southwest monsoon", IMD, PPSR, 1998/3.

IMD, 1998, "Ten day averages of upper winds for Indian stations".

Koteswaram, P., 1950, "Upper level lows in low latitudes in the Indian area during southwest monsoon season and breaks in monsoon", *Indian J. Met. Geophs*., **1,** 162-164.

Krishnamurti, T. N. and Bhalme, H. N., 1976, "Oscillations of a monsoon system, Part –I Observational aspects", *J. Atmos. Sci*., **33**, 1937-1954.

Murakami, T. and Frydrych, M., 1974, "On the preferred period of upper wind fluctuations during the summer monsoon", *J. Atmos. Sci.,* **31**, 1549-1555.

Pant, P . S., 1980, "Phases of the summer monsoon and oscillations of the equatorial Trough", *Mausam*, **31**, 2, 215-221.

Parthasarathy, K., 1960, "Some aspects of the rainfall in India during the southwest monsoon", Monsoon of the world, *Hind. Union. Press*, New Delhi, 185-194.

Pisharoty, P. R. and Desai, B.N., 1956, "Western disturbances and Indian weather", *Indian J. Met. Geophys*., **7**, 333-338.

Ramamurthy, K., 1969, "Some aspects of the 'Break' in the Indian southwest monsoon during July and August", *IMD FMU Rep.* IV-18.3.

Ramaswamy, C., 1958, "A preliminary study of the behaviour of the Indian southwest monsoon in relation to the Westerly jetstream", *Geophysica*, **6**, 455-476.

Ramaswamy, C., 1962, "Breaks in the Indian summer monsoon as a phenomenon of interaction between the easterly and the sub-tropical westerly jet-streams", *Tellus*, **14,** 337-349.

Ramaswamy, C., 1967, "On synoptic methods of forecasting the vagaries of southwest monsoon over India and neighbouring countries", Proc. Symp. Meteorol. Results Int. Indian Ocean Expedition; IMD, 317-336.

Sadler, J. C., Brett, W. Harris, B. and Ho, F., 1968, "Forecasting minimum cloudiness during the summer monsoon", Scientific Report, 'No.1, Air Force Cambridge Research Laboratories.

Sikka, D. R. and Gadgil, S., 1980, "On the maximum cloud zone and the ITCZ over Indian longitudes during the southwest monsoon", *Mon. Wea. Rev*., **108**, 1840-1853.

Vernekar, A. D. and Ji, Y., 1999, "Simulation of the onset and intra-seasonal variability of two contrasting summer monsoons", *J. Climate*., **12,** 6, 1707-1725.