

Meteorological conditions associated with very sluggish advance of Indian summer monsoon in 2002

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सार – वर्ष 2002 में सामान्य तारीख से एक माह बाद 15 अगस्त को मानसून समूचे भारत में फैल गया था। इस अध्ययन में एन. सी. ई. पी. – एन. सी. ए. आर. पुनः विश्लेषित ऑकड़ा सेट का उपयोग करके वर्ष 2002 में मानसून के असामान्य रूप से मंद गति से आगे बढ़ने की मूलभूत मौसम विज्ञानिक स्थितियों का विश्लेषण करने का प्रयास किया गया है। यह पाया गया कि वर्ष 2002 में भारतीय ग्रीष्मकालीन मानसून के आगे बढ़ने के चरण के दौरान पश्चिमाभिमुखी पवनों में प्रणालियों का असामान्य उच्च प्रभाव रहा है। यह कारक मानसून के आगे बढ़ने में प्रतिकूल सिद्ध हुआ। मानसून के विलंब से आगे बढ़ने के हाल के कुछ अन्य वर्षों जैसे वर्ष 2004 और वर्ष 2006 के इसी तरह के मानसून के आगे बढ़ने के अंतरालों के मामलों की भी इस शोध-पत्र में चर्चा की गई है।

ABSTRACT. In the year 2002, the monsoon covered entire India on 15th August, one month later than the normal date. An attempt has been done in this study to analyse the meteorological conditions underlying this abnormally sluggish advance of the monsoon in 2002, using the NCEP-NCAR Reanalysis data sets. It has been observed that, there had been an anomalously high influence of systems in the westerlies during the advance phase of Indian Summer Monsoon in 2002. This has proved to be a factor unfavourable for the advance of the monsoon. Similar cases of hiatuses in the advance of monsoon during other recent years of delayed advance, viz., 2004 and 2006, have also been discussed.

Key words – Monsoon advance, Hiatus, Blocking Ridge, Trough in westerlies

1. Introduction

The normal date of onset of Indian Summer Monsoon (ISM) over Kerala is 1st June and the normal date by which the monsoon covers the entire India is 15th July [Ananthakrishnan and Soman (1988), Soman and Krishna Kumar (1993)]. Thus, the normal duration of the phase of the advance of monsoon form Kerala to cover the entire country is of 45 days. The Indian Summer Monsoon of the year 2002 was peculiar in many respects. It was a first year of All-India Drought after 1987. The All-India seasonal (June to September) rainfall was 19% below normal. In 2002, the onset of Indian Summer Monsoon over Kerala occurred on 29 May, three days earlier to the normal date of onset. However, the further advance of monsoon to cover the entire India was characterized by three major epochs of hiatus. The monsoon covered the entire country only on 15th August (IMD, 2004), one month later than the normal date. The onset and advance of Indian Summer Monsoon is tele-connected with many a regional and global scale atmospheric and oceanic features. He *et al.* (1987) have listed the distinct changes

of large-scale circulation and rainfall distribution over large parts of southern and eastern Asia that accompany the onset of ISM, as: (i) northward displacement of Subtropical Westerly Jet (SWJ) from southern to northern periphery of the Tibetan plateau and (ii) the development of upper tropospheric south Asian (Tibetan) anticyclone and establishment of Tropical Easterly Jet (TEJ) along its southern periphery, and northward advance of polar front over the China plains and east China Sea and the commencement of rainy season of east Asia, Mei-yu in Yangzi river valley and Baiu in Japan. Biswas *et al.* (1998) have identified the establishment of a strong mid-tropospheric Sub Tropical Ridge (STR) over north India and the adjoining Tibetan plateau after mid-June, as being conducive for the progressive advance of monsoon. Their study revealed that in the absence of the development of such strong STR over north India, the mid-tropospheric westerly troughs propagate equator-ward across north India, causing delay in the advance of monsoon. Although the correlation between the dates of MOK and the total seasonal rainfall during ISM season is very weak [Joseph *et al.* (1994); Dhar *et al.* (1980)], the late MOK, if

TABLE 1
Duration of Phase of Advance (1945-2007)

Year	Duration of Advance Phase (No. of days)
1945	25
1946	31
1947	42
1948	41
1949	47
1950	43
1951	31
1952	38
1953	17
1954	46
1955	23
1956	36
1957	41
1958	22
1959	38
1960	46
1961	34
1962	39
1963	30
1964	29
1965	52
1966	36
1967	23
1968	31
1969	59
1970	38
1971	36
1972	21
1973	32
1974	47
1976	45
1977	32
1978	36
1979	34
1980	25
1981	41
1982	51
1983	35
1984	48
1985	47
1986	50
1987	55
1988	36
1989	29
1990	43
1991	47
1992	39
1993	38
1994	33
1995	35
1996	27
1997	40
1998	28
1999	48
2000	31
2001	41
2002	78
2003	27
2004	61
2005	25
2006	59
2007	27

combined with a sluggish advance of monsoon over the country, may create a severe water crisis over the northern parts of Indian mainland. With this backdrop, an attempt has been done in this study to assess various meteorological conditions associated with the very sluggish advance of summer monsoon in 2002.

2. Data and methodology

The monsoon of 2002 was atypical in many respects (Sikka, 2003; Bhat 2006). The year 2002 was a major All India Drought year, with a seasonal rainfall deficiency of 19%. This seasonal rainfall was chiefly contributed by the large rainfall deficiency of 51% in July. As brought out by the studies by Rao and Sikka (2005) and Bhat (2006), strong atmospheric inversions around 800 hPa prevented the growth of convective clouds during the first fortnight and up to end of July. In 2002, the onset of monsoon over Kerala occurred on 29th May (IMD, 2004). The year 2002 has been the first year in the recorded history, in which the monsoon has covered the entire country, at such a delayed date of 15th August. Earlier to this, the year of the most delayed coverage of the entire country by monsoon has been 1987 (27 July). During 2002, after the onset, the advance of monsoon over peninsular India occurred steadily up to 12 June to cover an area of peninsular India, south of about 18° N. Thereafter, there was a hiatus in the advance, till 20 June, primarily due to absence of favourable synoptic scale system, like onset vortex, low pressure area or depression. In association with a well marked Low Pressure Area, which formed over North Bay of Bengal on 20 June and subsequently moved following a west-northwesterly track, across the central parts of India up to southeast Rajasthan, the advance of monsoon occurred into some parts of central India and Gangetic plains. This Low Pressure system weakened on 29 June and thereafter, the monsoon trough moved northwards, close to the foothills of Himalayas, resulting in a break-like situation that led to significant weakening of the strength of the monsoon current. Thus after an active phase during mid-June, break-like conditions prevailed even before the monsoon covered the entire country [Bhat (2006)]. With this and also in the absence of formation of any low pressure system, there was another prolonged hiatus in the further advance of monsoon. In association with a feeble low pressure area that formed over North West (NW) Bay on 17 July, which moved inland and weakened over east Madhya Pradesh on 19 July, the monsoon further advanced up to Delhi and neighbouring areas, as a weak current on 19 July. Followed by this, there was another prolonged hiatus in the advance of monsoon till 14 August. Finally, the monsoon covered the entire country only on 15 August, one month later than the normal date of 15 July. Thus, there have been following

three major epochs of prolonged hiatus in the advance of monsoon in the year 2002:

- (i) 13-19 Jun : Over Central India
- (ii) 5-18 Jul : Over west Uttar Pradesh and east Rajasthan
- (iii) 20 Jul-14 Aug : Over NW India

Out of the above three periods of hiatus in the advance of the monsoon, the first two are significant, whereas, the third period is not considered for the present study, as till this time, the monsoon had covered most parts of India, except for some regions of west Rajasthan.

Table 1 depicts the duration of phase of advance of monsoon from Kerala to cover the entire country, during the period 1945 to 2007. The Standard Deviation of this series is 11 days. It is observed from Table 1 that, during 1945-2007, there are two years (2004 and 2006), during which the duration of the onset phase has been more than the normal (45 days) with more than one standard deviation ($45 + 11 = 56$ days). The advance phase lasted for 59 days in 2004 and for 67 days in 2006. The duration of onset phase in 2002 is 78 days, more than normal by a period of two standard deviations ($45 + 22 = 67$ days). Table 2 shows the details of hiatus during 2002, 2004 and 2006.

For the two major epochs of hiatus in 2002, *viz.*, 13-19 June and 5-18 July, various meteorological parameters *viz.*, (Vector Wind Anomaly at 200 hPa, Geopotential Height Anomaly at 500 hPa and 200 hPa) and Air Temperature Anomaly at 500 hPa and 200 hPa, are examined in this study. The data region is selected as 50° S to 50° N and 20° E to 160° E. The features during 2002 are also compared with the similar parameters during the major epochs of hiatus during 2004 and 2006, as listed in Table 2.

The data sets used in this study are obtained from NOAA/Earth System Research Laboratory (ESRL) Physical Sciences Division, Boulder, Colorado, through their web site at '<http://www.cdc.noaa.gov/>'.

3. Discussion

3.1. Hiatus during 2002

Case I: 13-19 June 2002

(a) Daily vector wind anomaly at 200 hPa

The evolution of daily wind anomaly during 13-19 June 2002 shows the following: on 13th June, in northern sub tropics, the Sub Tropical Anticyclone at 40° N, to the

TABLE 2

Details of hiatus in the Advance of Monsoon

Year	Hiatus	
	Duration	Location
2002	13 – 19 Jun	Central India
	5 – 18 Jul	West Uttar Pradesh and East Rajasthan
	20 Jul – 14 Aug	West Rajasthan
2004	24 – 31 May	South Karnataka
	19 Jun – 4 Jul	West Uttar Pradesh and Rajasthan
	9 – 17 Jul	West Rajasthan, Punjab and Haryana
2006	7 – 22 Jun	Madhya Maharashtra, Marathwada, Telangana and South Chattisgarh
	1 – 8 Jul	West Uttar Pradesh
	12 – 19 Jul	West Rajasthan

far east of India ($150-155^{\circ}$ E) is observed. On 15th June, a well defined anomalous trough in mid-latitude westerlies is observed along 70° E, to the north of 25° N, which is observed to persist till 17th June. It moved eastwards and is located along 75° E on 18th. It further continued its eastward movement till 22nd and moved further eastwards, away from the Indian region. Thus, till that time during which this anomalous trough in upper tropospheric westerlies was observed over the Indian region, there was a hiatus in the advance of summer monsoon. This is as per the suggestions contained in Biswas *et al.* (1998). To the east of this trough, a blocking ridge is observed between $35-45^{\circ}$ N and $80-100^{\circ}$ E, which may be responsible for the stagnation of the anomalous trough in the upper level westerlies. The hiatus was terminated after the eastward movement of the trough began, away from the Indian region. It is also observed that the upper tropospheric easterlies over the peninsular India were weaker than normal.

(b) Daily geopotential height anomaly at 500 hPa and 200 hPa

During the entire hiatus period, the Geopotential Height anomaly values, at 500 hPa and at 200 hPa, over Tibet and adjoining region are negative indicating lower than normal geopotential height over these regions. Thus, during the hiatus period, the strength of Tibetan Anticyclone has been lower than the normal. Also, over North West India, negative height anomaly values are observed. These negative anomaly values over the above regions indicate weaker sub tropical high pressure over the regions. At 200 hPa, an area of positive geopotential height anomaly is observed to the north east of the normal location of Tibetan Anticyclone.

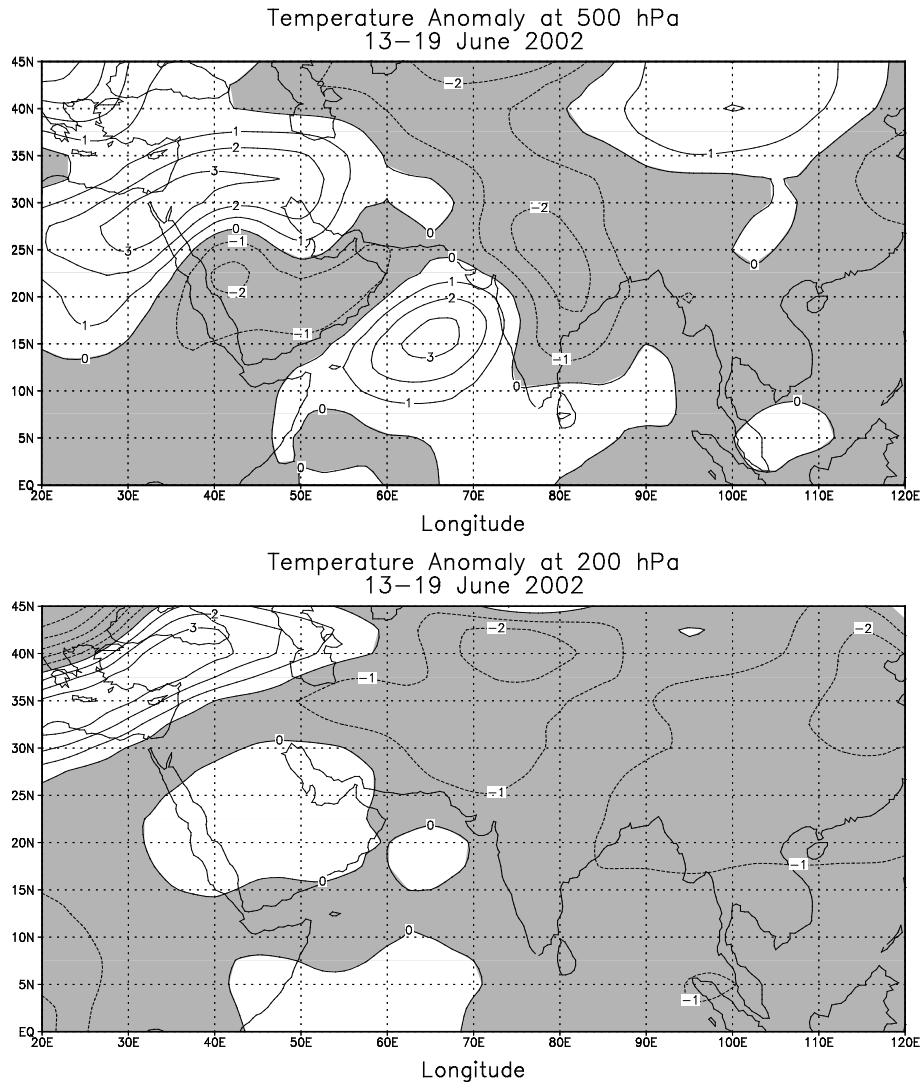


Fig. 1. Composite air temperature anomaly at 500 hPa and 200 hPa during 13–19 June 2002 (The shaded area indicates the area of negative temperature anomaly)

(c) *Air temperature anomaly at 500 hPa and 200 hPa*

During the period of hiatus, the values of composite air temperature anomalies at 500 hPa and 200 hPa, over Tibet and surrounding areas, are negative (Fig. 1). These colder than normal temperatures indicate that, the warming of Tibetan Plateau has not taken place. The warming of Tibetan Plateau is essential and conducive for establishment of Tibetan Anticyclone and also for the advance of monsoon [Biswas, *et al.*, (1998)].

Case II : 5-18 July 2002

(a) *Daily vector wind anomaly at 200 hPa*

The evolution of daily wind anomaly during 13–19 July 2002 shows the following: an anomalous trough was

in developing stage along about 65° E. On 8th July, the trough is observed along 60° E, during 9th to 14th July, along 65° E and on 15th the trough has weakened. Thus, an anomalous trough was anchored along about 65° E during the entire hiatus period. To the east of this trough, a blocking ridge is observed between 35–45° N and 80–120° E. As in the previous case of the hiatus, the presence of this blocking ridge may be responsible for the stagnation of the anomalous trough in the upper level westerlies. The hiatus was terminated only when this trough became less marked.

(b) *Daily geopotential height anomaly at 500 hPa*

During the period 6th to 14th July, the geopotential height anomaly values were negative over Tibet and

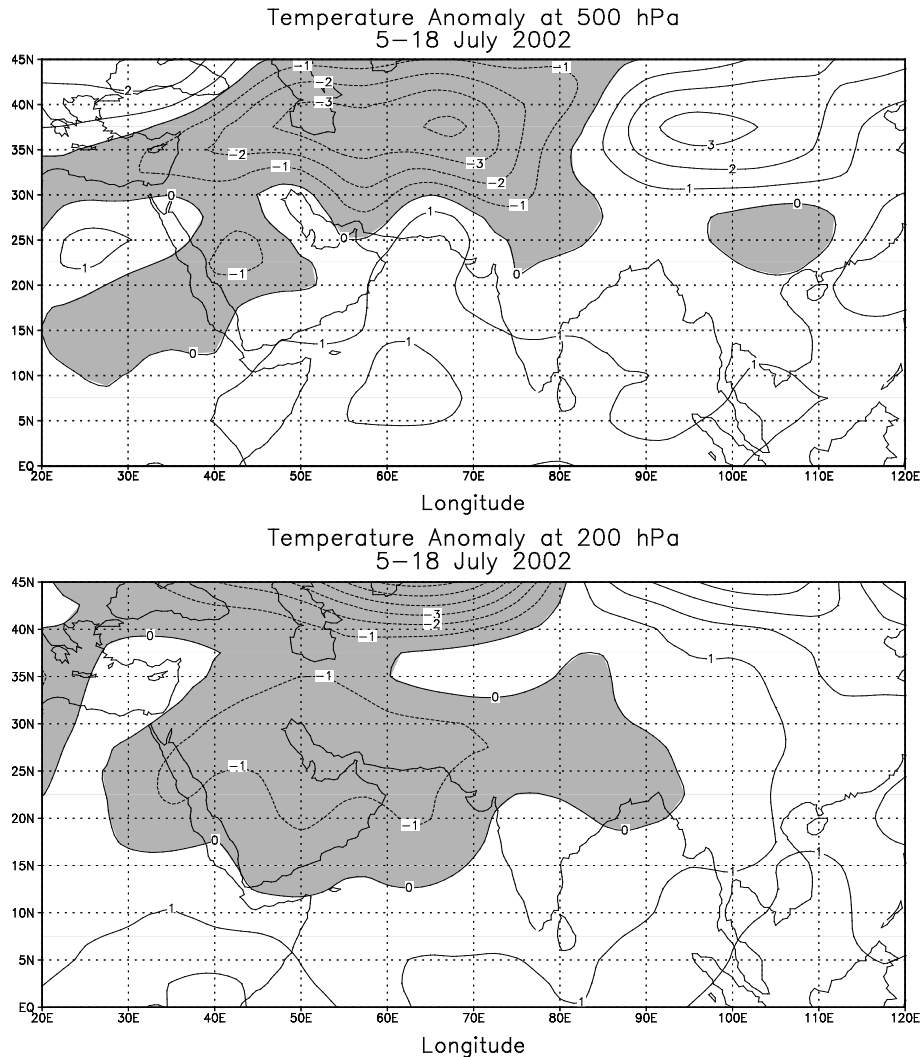


Fig. 2. Composite air temperature anomaly at 500 hPa and 200 hPa during 5-18 July 2002 (The shaded area indicates the area of negative temperature anomaly)

adjoining areas, indicating weaker than normal strength of sub tropical high pressure over the region. The negative anomaly values over India changed to positive from 15th July. Thus, as long as the geopotential height anomaly values over Tibet and adjoining areas were negative, the advance of monsoon did not occur. Also, over North West India, negative height anomaly values were observed, which indicated weaker sub tropical high pressure over the regions.

(c) *Daily geopotential height anomaly at 200 hPa*

It is observed that, from 6th to 18th July, the geopotential height anomaly values were positive over Tibet and adjoining areas. Thus, during the hiatus period, the Tibetan Anticyclone had been stronger than the normal. However, during this period, to the west of Indian

region, an area of strong negative geopotential height anomaly values is observed. On 18th July, these negative geopotential values were decreased in magnitude, subsequent to which only, the hiatus was terminated and further advance of monsoon occurred. Thus, impact of these negative geopotential anomaly values to the west of India seems to have an overriding influence over the impact of Tibetan Anticyclone being stronger than normal. Also, over North West India, negative height anomaly values are observed, indicating weaker sub tropical high pressure over the region.

(d) *Air temperature anomaly at 500 hPa and 200 hPa*

During the period of hiatus, the values of composite air temperature anomalies at 500 hPa and 200 hPa, over

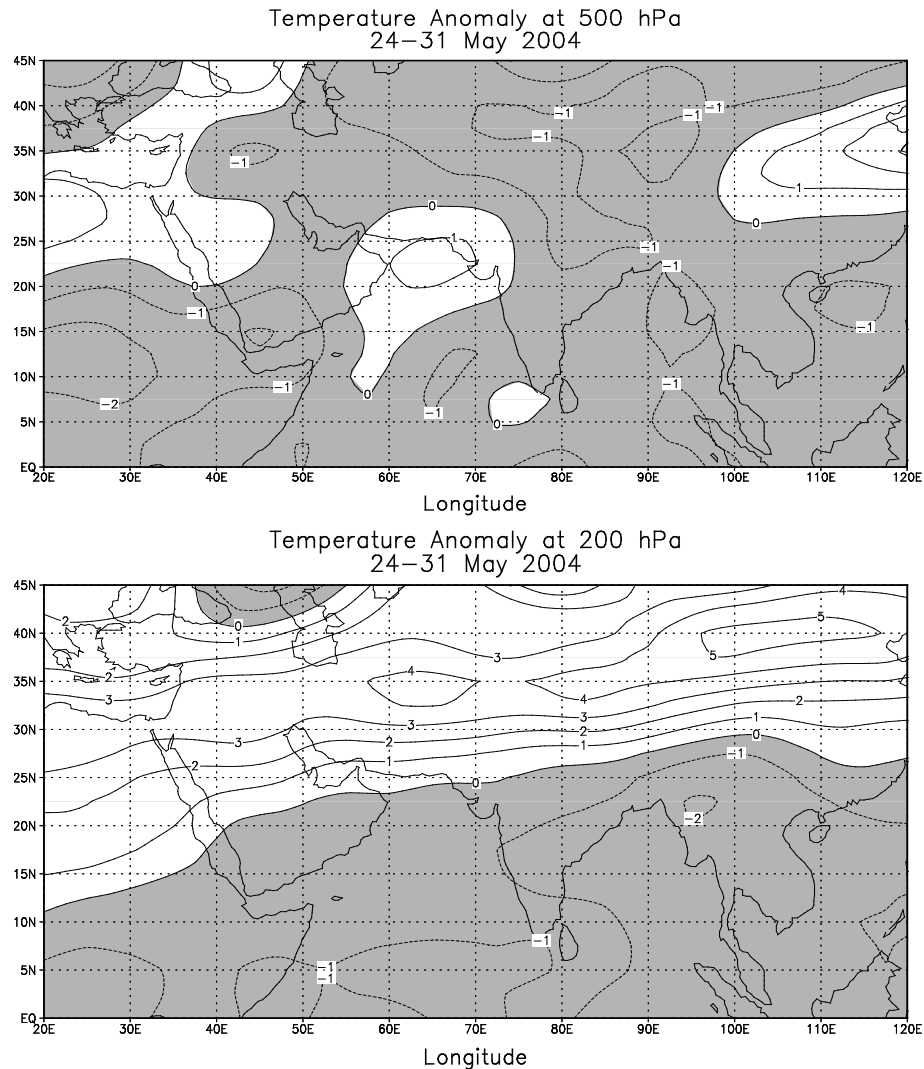


Fig. 3. Composite air temperature anomaly at 500 hPa and 200 hPa during 24-31 May 2004 (The shaded area indicates the area of negative temperature anomaly)

Tibet and surrounding areas (particularly, over the region west of 85° E longitude), are negative (Fig. 2). However, unlike in the earlier case of hiatus, the temperature anomalies over the region east of 85° E longitude are positive. This observation is, thus, not in conformity of the result of the study by Biswas, *et al.*, (1998).

3.2. Hiatus during 2004

Case I: 24-31 May 2004

The evolution of daily vector wind anomaly at 200 hPa and geopotential height anomaly at 500 hPa and 200 hPa shows the following: As the hiatus in the advance of monsoon was over peninsular India (south Karnataka), no well delineated signature, in terms of movement of trough in upper tropospheric westerlies across northern

India or enhanced intrusion of systems in mid-latitude westerlies, is observed. The upper tropospheric easterlies over peninsular India were weaker than the normal. The field of geopotential at 500 hPa and 200 hPa during 24-31 May shows the presence of negative geopotential height anomalies over central and peninsular India and positive anomalies over Tibetan region. The Tibetan Anticyclone was thus stronger than normal. However, the effect of enhanced strength of Tibetan Anticyclone was offset by negative geopotential height anomalies over central and peninsular India, thereby not allowing the monsoon current to propagate northwards, resulting in to hiatus.

The air temperature anomalies at 500 hPa and 200 hPa reveal that warming of Tibetan plateau has occurred at 200 hPa, but, the temperature anomalies over central and peninsular India are negative, indicating

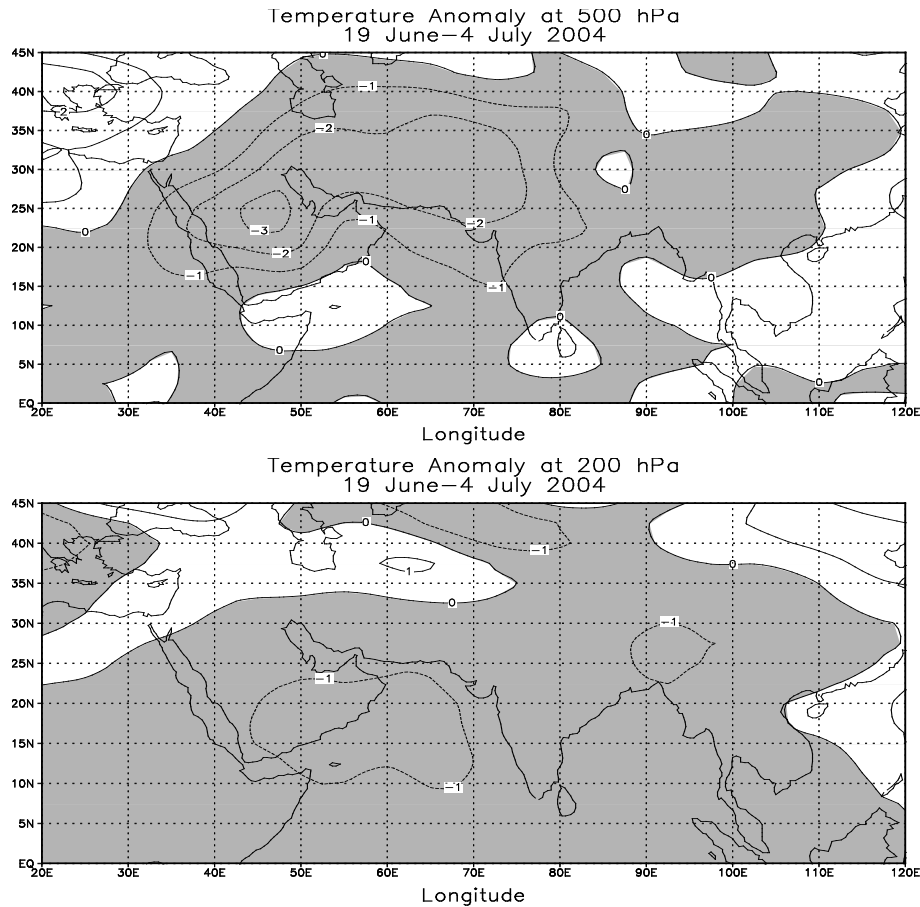


Fig. 4. Composite air temperature anomaly at 500 hPa and 200 hPa during 19 June-4 July 2004 (The shaded area indicates the area of negative temperature anomaly)

conditions unfavorable for northward propagation of monsoon current (Fig. 3).

Case II : 19 June - 4 July 2004

(a) *Daily vector wind anomaly at 200 hPa*

During 19 to 24 June, a cyclonic circulation was observed over Tibetan area, indicating that the Tibetan Anticyclone was weaker than normal. This cyclonic circulation showed eastward movement and it moved away on 24th June. Thereafter, since 25th June onwards, a trough in westerlies appeared over the region north of 30° N, along 75° E on 25th and 26th, 80° E on 27th and 28th, 85° E on 29th, which became less marked on 30th. Tibetan Anticyclone appeared on 26th June and gradually became stronger, but due to the movement of the trough in westerlies, the monsoon advance did not occur. Only when the trough became less marked and Tibetan Anticyclone continued to stronger than normal, the hiatus in the advance of the monsoon was terminated.

(b) *Daily geopotential height anomaly at 500 hPa*

The geopotential height anomalies were negative over Tibet and adjoining areas during 19-29th June, indicating weaker than normal Tibetan Anticyclone. The Tibetan Anticyclone gained strength and was observed to be stronger than normal from 30th June onwards.

(c) *Daily geopotential height anomaly at 200 hPa*

The geopotential height anomalies were negative over Tibet and adjoining areas during 19-27th June, indicating weaker than normal Tibetan Anticyclone. The anomalies became positive over the Tibetan region from 28th June onwards, but then, the anomalies over NW India and adjoining areas were negative, inhibiting the advance of monsoon over NW India.

(d) *Air temperature anomaly at 500 hPa and 200 hPa*

The anomalies over Tibetan Plateau region as well as over most parts of India were negative during the period 19 June to 4 July (Fig. 4).

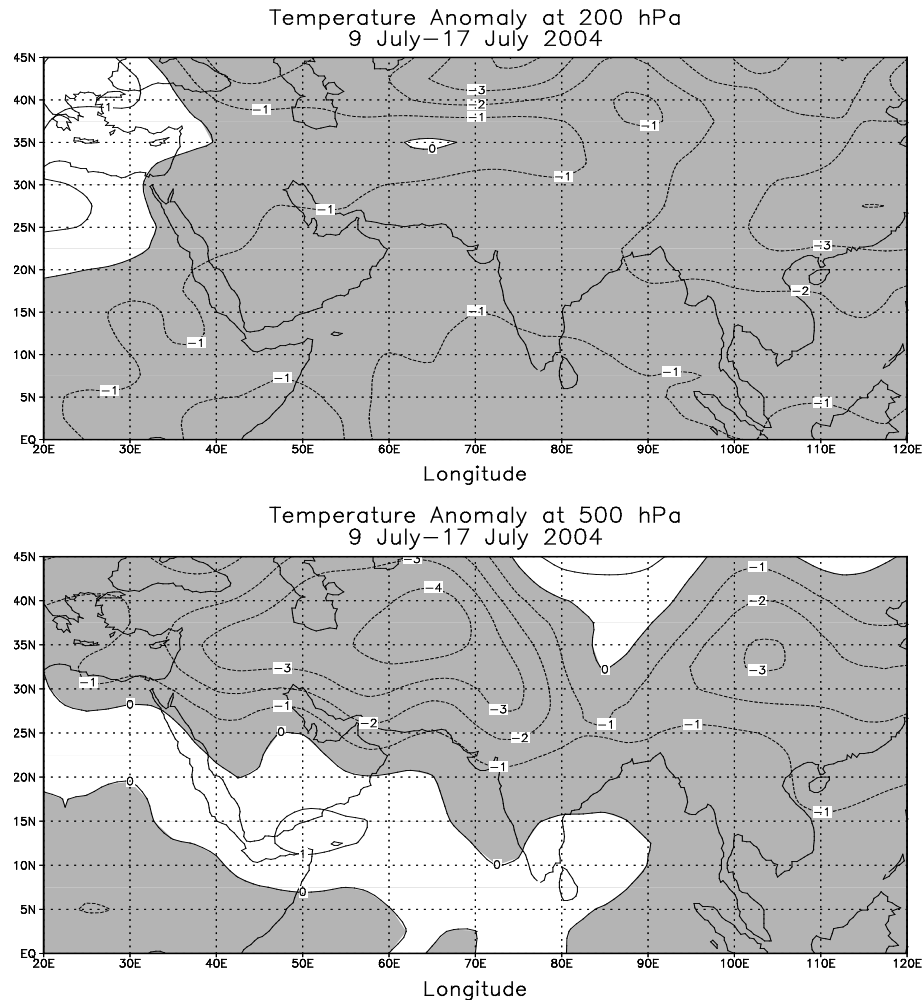


Fig. 5. Composite air temperature anomaly at 500 hPa and 200 hPa during 9 -17 July 2004 (The shaded area indicates the area of negative temperature anomaly)

Case III : 9-17 July 2004

(a) *Daily vector wind anomaly at 200 hPa*

During 9-17 July, a strong wave in mid-latitude westerlies passed over the Indian region, with two troughs, to the west and to the east of India and a ridge in between these two troughs anchored over northern India. From 10-14 July, a trough in westerlies is observed along 110° E, north of 25° N. Also, to the west of India, a trough is observed along 50° E on 10th, along 55° E on 11th and 12th, along 60° E on 13th, along 65° E on 14th and 15th, along 70° E on 16th and 17th. With the eastward passage of troughs in westerlies to the west of India and with the continued anchorage of another trough to the east of India (along 110° E), the wave amplitude got amplified giving rise to a well marked blocking ridge over Northern and North Western parts of India, causing the hiatus in the advance of the monsoon.

(b) *Daily geopotential height anomaly at 500 hPa and 200 hPa*

The geopotential height anomalies at 500 hPa were negative over Tibet and adjoining areas during 9-17th June, indicating weaker than normal Tibetan Anticyclone. At 200 hPa level as well, high negative geopotential height anomaly values were observed over Tibetan region and to the region west of India (over the regions where anomalous troughs in westerlies were observed).

(c) *Air temperature anomaly at 500 hPa and 200 hPa*

The anomalies over Tibetan Plateau region as well as over most parts of India were negative during the period 19 June to 4 July (Fig. 5).

3.3. Hiatus during 2006

Case I : 7-22 June 2006

(a) Daily vector wind anomaly at 200 hPa

During 7-22 June, the Sub Tropical Ridge is very strong with embedded anticyclonic circulations to the west and east of India. Also, a trough in mid-latitude westerlies (with an embedded cyclonic circulation) is observed over the region north of 20° N, along 60° E during 7-9 June, along 70° E on 11th June, along 75° E during 12-13th and 16-19th June. This flow pattern of wave in westerlies with very high amplitude was observed up to 20th, which weakened with reduction in the wave amplitude, subsequently, facilitating the termination of the hiatus.

(b) Daily geopotential height anomaly at 200 hPa

The pattern of geopotential height anomaly values at 200 hPa is in conformity with the wind flow pattern as discussed above. The positive values of geopotential height anomaly values during 7-12th June indicate stronger than normal Tibetan Anticyclone. However, during this period, the geopotential height anomaly values over central and peninsular India were negative, which moved north east wards over Tibet and adjoining areas from 13th June. Thus Tibetan Anticyclone was weaker than normal during 13-22nd June.

(c) Daily geopotential height anomaly at 500 hPa

The negative values of geopotential anomaly over Tibet and adjoining areas during 7-18th June indicate weaker than normal Tibetan Anticyclone. Thereafter, values of geopotential height anomaly over Tibet and adjoining areas became positive, however, during this period, values of geopotential height anomaly over central and peninsular India were negative.

(d) Air temperature anomaly at 500 hPa and 200 hPa

The negative values of air temperature over Tibet and adjoining areas during 7-22 June indicated suppressed warming of the Tibetan Plateau (Figure not shown).

Case II : 1-8 July 2006

For this case of the hiatus, no well delineated signature is observed in the wind field at 200 hPa and geopotential height field at 500 hPa and 200 hPa. However, the air temperature anomaly values at 500 hPa and at 200 hPa over Tibet region were positive; indicating enhanced warming over the Tibetan plateau region (Figure not shown).

Case III : 12-19 July 2006

(a) Daily vector wind anomaly at 200 hPa

An anomalous trough in mid-latitude westerlies is observed over the region north of 25° N, along 65° E on 12th, 70° E on 13th and 14th, 75° E on 15th, which became less marked thereafter. Subsequently, the Tibetan Anticyclone was stronger. The movement of the trough in westerlies was quite slow.

(b) Daily geopotential height anomaly at 200 hPa and 500 hPa

The pattern of geopotential height anomaly values is in conformity with the wind flow pattern. The Tibetan Anticyclone was stronger than normal; however, the geopotential height anomaly values over northwestern India were negative.

(c) Air temperature anomaly at 500 hPa and 200 hPa

The positive values of air temperature anomalies over Tibet and adjoining areas indicated enhanced warming of the region (Figure not shown).

Thus, for the years of 2002 and 2004, during the periods of hiatus in monsoon advance in July, the temperature anomalies at 500 hPa and 200 hPa over northwest India and over Tibet were negative. However, in contrast, for the year of 2006, during both the cases of hiatus in the monsoon advance in July, the temperatures at 500 hPa and 200 hPa, over northwest India and Tibet were warmer than normal. These features indicate that the Tibetan Anticyclone was stronger than normal during July 2006. However, the movement of troughs in upper tropospheric westerlies across the Indian region was quite slow, which was responsible for two major hiatuses during the month.

4. Comparison with the onset of monsoon during 2002 with the study by Flatau, *et al.* (2003)

Flatau, *et al.* (2003) have shown that, the 2002 monsoon followed the pattern of 'double monsoon onset'. They have observed that, the two conditions which are important for the formation of 'double monsoon onset', *viz.*, (i) an early May propagation of the Intra Seasonal Oscillation (ISO) leading to intense convection and SST decreases in the Bay of Bengal and (ii) further propagation of ISO into the western Pacific, leading to an enhanced Walker circulation and suppressed convection in the Indian Ocean in the late May, were satisfied in the case of 2002 monsoon. Also, it is evident that, in 2002, the May ISO leading to the bogus onset could be attributed to

a convectively coupled Kelvin wave, rather than an MJO-like disturbance that has been typically associated with the real onset of the monsoon. In 2002, the ISO convection in the western Pacific triggered the westward propagating waves that led to subsequent ISO in the western Pacific Ocean. Based on their analysis regarding the development of large scale circulation, Flatau, *et al.* (2003) further argue that, the onset of monsoon during 2002 was delayed; the actual onset over Kerala occurred on June 13, rather than on May 29 as declared by India Meteorological Department. In the event of accepting this argument also, as the present study has brought out, there had been a major hiatus in the advance of the monsoon over central India (over the region, north of latitude 18° N) during the period 13-19 June 2002. This is mainly attributed to anchorage of trough in upper tropospheric westerlies over the Indian region.

5. Conclusions

(a) Following characteristic features are observed associated with one of the two cases of prolonged hiatus in the advance of the south west monsoon during 2002:

(i) There had been an anomalously higher influence of systems in the westerlies during the advance phase.

(ii) As a result of the presence of a blocking ridge over the region to the east of India, there was an anchorage of a trough in the mid-latitude westerlies, over northern and north western India, in the middle and upper levels of the troposphere. This has proved to be a factor unfavourable for the advance of the monsoon.

(iii) The colder temperature anomalies over Tibet and surrounding areas at 500 hPa and at 200 hPa, during the period of hiatus, suggest the absence of establishment of Tibetan Anticyclone, attributed to the absence of warming over that region.

(b) However, for the other case of prolonged hiatus in the advance of the monsoon, the impact of negative geopotential anomaly values at 200 hPa to the west of India seems to have an overriding influence over the impact of Tibetan Anticyclone being stronger than normal. But, as in the other case, anomalously higher influence of systems in the westerlies (particularly, the anchorage of trough in the mid-tropospheric westerlies over India owing to the presence of a blocking ridge to the east of India) is observed in this case as well.

(c) For other cases of prolonged hiatus in the advance of the monsoon during other years of most delayed advance of monsoon (2004 and 2006) also, prolonged and strong influence of systems in mid-latitude westerlies over

northern and north western regions of India is observed. This influence is observed in the form of passage of amplified waves in westerlies, presence of blocking HIGH or blocking ridge and/or a combined effect of both. The study further supports the work of Biswas, *et al.* (1998), indicating that, anchoring of troughs in mid-latitude westerlies along 65-70° E, retards the northward/westward advance of summer monsoon over south Asia.

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