MAUSAM, **61**, 4 (October 2010), 553-564

551.553.21 : 551.461.2

The onset and advance of Indian summer monsoon in relation with the sea level pressure field

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(*Received 26 August 2009, Modified 23 March 2010*)

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सार – केरल में मानूसन के आगमन और मानसून के आगे बढ़ने की तारीख में व्यापक रूप से अन्तर्वार्षिक और अन्तरा मौसमी भिन्नताएँ पाई गई। भारतीय ग्रीष्मकालीन मानसून की उत्पत्ति दक्षिणी गोलार्ध में मेस्केरेन द्वीप पर मानी जाती है। मानसून आने का मूलभूत भौतिक कारण है – मेस्केरेन द्वीप में उच्च दाब और भारत के उत्तरी पश्चिमी भाग में निम्न दाब के मध्य की दाब प्रवणता, जो मानसून की पवनों के लिए प्रेरक बल के रूप में कार्य करती है। इस प्रकार मानसून की उत्पत्ति और मानसून के आगे बढ़ने की स्थिति समुद्र तल दाब क्षेत्र से घनिष्ठ रूप से जुड़ी हुई है। इसके फलस्वरूप इस अध्ययन में समुद्र तल दाब क्षेत्र के संबंध में मानसून के आरम्भ होने और मानसून के आगे बढ़ने की भिन्नता की जाँच की गई है। पंचक समुद्र तल दाब क्षेत्र, केरल में मानसून के शीघ्र और देर से आने के वर्षों तथा मानसून के तेज़ी से आने और निष्क्रिय रूप से आगे बढ़ने के वर्षों की भी विषमता को दर्शाता है।

ABSTRACT. The dates of onset of monsoon over Kerala and the advance of monsoon exhibit large interannual and intra seasonal variability. The genesis of Indian summer monsoon is considered to be in the southern hemisphere, over the Mascarene Island. The pressure gradient between the high pressure over Mascarene Island and low pressure over North West India is the fundamental physical cause of the monsoon, which acts as a driving force for the monsoon winds. Thus, the genesis of monsoon and its further advance is closely related to the sea level pressure field. With this backdrop, the variability of the onset and advance of the monsoon in terms of sea level pressure field is examined in this study. The pentad sea level pressure field does show contrast for the years of early and late onset of monsoon over Kerala and also for the years of rapid and sluggish advance of monsoon.

Key words – Monsoon onset over Kerala, Advance of monsoon, Sea level pressure.

1. Introduction

The onset of the Indian Summer Monsoon (ISM) over the main land of India occurs over Kerala, the southernmost tip of India. Thereafter, the advance of monsoon occurs mainly in the northward direction (Arabian Sea Branch) up to about 20° N and in the westward direction (Bay of Bengal Branch) from 80° E to 60° E, to cover the whole country. The normal date of onset of Monsoon over Kerala (MOK) is 1 June and the normal date by which the monsoon covers the entire country is 15 July. Thus, the normal span of the advance of ISM to cover whole India is of 45 days. This constitutes the 'Onset Phase' of ISM, which is characterised by a significant interannual variability. The important research contributions on various aspects of onset of ISM include IMD (1943), Ananthakrishnan *et al*. (1968); Mooley and Shukla (1987); Ananthakrishnan and Soman (1988, 1989); Soman and Slingo (1997). Ananthakrishnan and Soman (1988) have derived the dates of Monsoon Onset over Kerala (MOK) for 80 years, 1901 to 1980, using an objective criterion based only on the daily spatially averaged rainfall of south Kerala and north Kerala. On analysing the interannual variability of MOK, Pant and Rupakumar (1997) have observed that there is no significant long-term trend in the time series of the dates of MOK. A study by Joseph *et al*. (1994) has shown that the dates of MOK are significantly delayed during those years of El-Nino in which the warming of central equatorial Pacific during March-April-May (MAM) season is higher in (0) years than that in (+1) year. Biswas *et al*. (1998) have identified the establishment of a strong mid-tropospheric Sub Tropical Ridge (STR) over north India and the adjoining Tibetean 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 equatorward

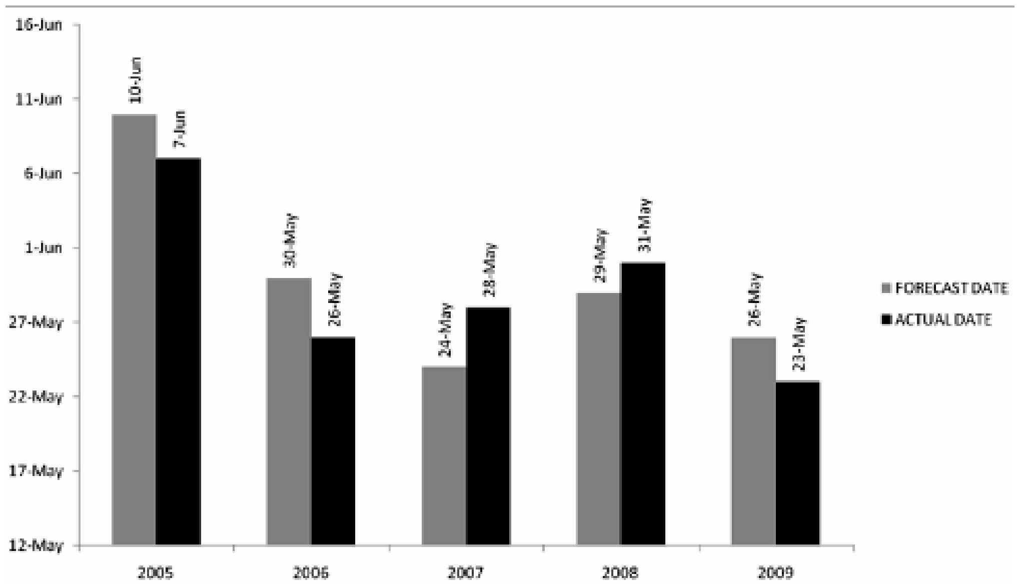

Fig. 1. The dates of Monsoon Onset over Kerala-Actual and Forecast

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 combined with a sluggish advance of monsoon over the country, may create a severe water crisis over the northern parts of Indian mainland. If the date of MOK is delayed considerably, it may affect the crucial agricultural operations like sowing of kharif crops.

In the recent times, there have some attempts to use the Numerical Weather Prediction (NWP) models to simulate and forecast the Monsoon Onset over Kerala [Ratnam, *et al.* (2007), Ratnam *et al*. (2008)]. Ratnam *et al.* (2007) have shown that the T170L42 Atmospheric Global Coupled Model could well simulate the onset of the monsoon during 2005 through the build-up of cross-equatorial flow.

Since 2006, India Meteorological Department (IMD) has been using an objective criterion for declaration of Monsoon Onset over Kerala (MOK) on operational basis. This criterion is as under:

Rainfall : If after 10th May, 60% of the available 14 stations along the Kerala coast report rainfall of 2.5 mm or more for two consecutive days, the onset over Kerala be declared on the 2nd day, provided the following criteria are also in concurrence.

Wind Field : Depth of westerlies should be maintained up to 600 hPa, in the box equator to Lat. 10° N and Long. 55° E to 80° E. The zonal wind speed over the area bounded by Lat. 5-10° N, Long. 70-80° E should be of the order of 15 – 20 kts at 925 hPa. The source of data can be RSMC wind analysis/satellite derived winds.

OLR : INSAT derived OLR value should be below 200 Wm^{-2} in the box confined by Lat. 5-10° N and Long. 70-75° E.

Also, IMD has started to issue the Long Range Forecast of the date of Monsoon Onset over Kerala since 2006, based on a statistical model. The performance of the model is summarized in Fig. 1.

The genesis of monsoon and its further advance is closely related to the sea level pressure field. Hence, it would be intriguing to examine the variability of the onset and advance of the monsoon in terms of sea level pressure field. With this backdrop, the characteristics of the onset and advance of the ISM are analysed in this study.

2. Data and methodology

The dates of the onset of monsoon over various Indian stations have been collected from the 'Monsoon Rainfall Summary' published by India Meteorological Department (IMD), for the period 1941-80 and from other IMD publications (like Mausam, Indian Daily Weather Report (IDWR), etc.) thereafter, up to 2006. The dates of

TABLE 1

Dates of Monsoon Onset over Kerala (MOK) during 1901-2006. (Dates are counted in days from May 1 as follows, May 1=1, June 1=32, etc.)

Year	Date of MOK	Year	Date of MOK	Year	Date of MOK	Year	Date of MOK
1901	38	1929	29	1957	32	1985	28
1902	37	1930	39	1958	45	1986	35
1903	43	1931	35	1959	31	1987	33
1904	38	1932	33	1960	14	1988	26
1905	41	1933	22	1961	18	1989	34
1906	45	1934	39	1962	17	1990	19
1907	39	1935	43	1963	31	1991	33
1908	42	1936	19	1964	37	1992	36
1909	33	1937	35	1965	26	1993	28
1910	33	1938	26	1966	31	1994	28
1911	37	1939	36	1967	40	1995	39
1912	39	1940	45	1968	39	1996	34
1913	33	1941	23	1969	17	1997	40
1914	35	1942	41	1970	26	1998	33
1915	46	1943	29	1971	27	1999	25
1916	33	1944	34	1972	49	2000	32
1917	31	1945	36	1973	35	2001	23
1918	11	1946	29	1974	26	2002	29
1919	34	1947	34	1975	31	2003	39
1920	34	1948	42	1976	31	2004	18
1921	33	1949	23	1977	30	2005	36
1922	31	1950	27	1978	28	2006	26
1923	42	1951	31	1979	42		
1924	33	1952	20	1980	32		
1925	27	1953	38	1981	30		
1926	37	1954	31	1982	32		
1927	27	1955	29	1983	44		
1928	34	1956	21	1984	31		

MOK for the period 1901-2006, are collected from similar IMD publications. Table 1 shows the dates of MOK during 1901-2006. The years of early MOK are defined as those in which the date of MOK is earlier than the normal date (1 June) by one Standard Deviation (SD) of 8 days or more *i.e.*, the years in which the date of MOK is prior to 24 May. The years of delayed MOK are defined as those in which the date of MOK is later than the normal date by one standard deviation or more *i.e.*, later than 9 June. The years in which the date of MOK falls within the period 24 May to 9 June (Normal date ± one standard deviation) are defined as the years of normal MOK. Table 2 depicts the years of early and delayed MOK, so defined, for the period 1951-2006.

TABLE 2

Years of Early and Delayed MOK (1951-2006)

Early MOK	Delayed MOK
1952	1958
1956	1972
1960	1979
1961	
1962	
1969	
1990	
2001	
2004	

TABLE 3

Advance of monsoon from Kerala to cover the entire country (1945-2006)

Year	Date of monsoon onset over Kerala (Normal : 1 June)	Date on which the monsoon covered the entire country (Normal : 15 July)	Span (No. of days) (Normal : 45 days)
1945	5 June (+4)	30 June (-15)	25 (-20)
1946	29 May (-3)	29 June (-16)	31 (-14)
1947	3 June (+2)	15 July (0)	42 (-3)
1948	11 June (+10)	22 July (+7)	41 (-4)
1949	23 May (-9)	9 July (-6)	47 (+2)
1950	27 May (-5)	9 July (-6)	43 (-2)
1951	31 May (-1)	1 July (-14)	31 (-14)
1952	20 May (-12)	27 June (-18)	38 (-7)
1953	7 June (+6)	24 June (-21)	17 (-28)
1954	31 May (-1)	16 July (+1)	46 (+1)
1955	29 May (-3)	21 June (-24)	23 (-22)
1956	21 May (-11)	26 June (-19)	36 (-9)
1957	1 June (0)	11 July (-4)	41 (-4)
1958	14 June (+13)	6 July (-9)	22 (-23)
1959	31 May (-1)	8 July (-7)	38 (-7)
1960	14 May (-18)	29 June (-16)	46 (+1)
1961	18 May (-14)	21 June (-24)	34 (-11)
1962	17 May (-15)	25 June (-20)	39 (-6)
1963	31 May (-1)	30 June (-15)	30 (-15)
1964	6 June (+5)	5 July (-10)	29 (-16)
1965	26 May (-6)	17 July (+2)	52 (+7)
1966	31 May (-1)	6 July (-9)	36 (-9)
1967	9 June (+8)	2 July (-13)	23 (-22)
1968	8 June (+7)	9 July (-6)	31 (-14)
1969	17 May (-15)	15 July (0)	59 (+14)
1970	26 May (-6)	3 July (-12)	38 (-7)
1971	27 May (-5)	2 July (-13)	36 (-9)
1972	18 June (+17)	9 July (-6)	21 (-24)
1973	4 June (+3)	6 July (-9)	32 (-13)
1974	26 May (-6)	12 July (-3)	47 (+2)
1975	31 May (-1)	30 June (-15)	30 (-15)
1976	31 May (-1)	15 July (0)	45 (0)
1977	30 May (-2)	1 July (-14)	32 (-13)
1978	28 May (-4)	3 July (-12)	36 (-9)
1979	11 June (+10)	15 July (0)	34 (-11)
1980	1 June (0)	26 June (-19)	25 (-20)
1981	30 May (-2)	10 July (-5)	41 (-4)
1982	1 June (0)	22 July (+7)	52 (+7)
1983	13 June (+12)	18 July (+3)	35 (-10)
1984	31 May (-1)	18 July (+3)	48 (+3)
1985	28 May (-4)	14 July (-1)	47 (+2)
1986	4 June (+3)	24 July (+9)	50 (+5)
1987	2 June (+1)	27 July (+12)	55 (+10)
1988	26 May (-6)	1 July (-14)	35 (-10)
1989	3 June (+2)	2 July (-13)	29 (-16)
1990	19 May (-13)	1 July (-14)	42 (-3)
1991	2 June (+1)	19 July (+4)	47 (+2)
1992	5 June (+4)	14 July (-1)	39 (-6)
1993	28 May (-4)	5 July (-10)	38 (-7)
1994	28 May (-4)	30 June (-15)	33 (-12)
1995	8 June (+7)	13 July (-2)	35 (-10)
1996	3 June (+2)	30 June (-15)	27 (-18)
1997	9 June (+8)	19 July (+4)	40 (-5)
1998	2 June (+1)	30 June (-15)	28 (-17)
1999	25 May (-6)	12 July (-3)	48 (+3)
2000	1 June (0)	2 July (-13)	31 (-14)
2001	23 May (-8)	3 July (-12)	41 (-4)
2002	29 May (-2)	15 August (+30)	78 (+33)
2003	8 June (+7)	5 July (-10)	27 (-18)
2004	18 May (-13)	18 July (+3)	61 (+16)
2005	5 June (+4)	30 June (-15)	25 (-20)
2006	26 May (-5)	24 July (+9)	59 (+14)

TABLE 4

Statistical Characteristics of Advance of Monsoon (1945-2006)

Parameter	Span (No. of days) of monsoon from Kerala to cover entire country (1945-2006)
Mean	38
Standard deviation	11
Coefficient of variation (%)	29%
Lowest value	17
Year of occurrence	1953
Highest value	78
Years of occurrence	2002

TABLE 5

Years of rapid and sluggish advance of monsoon

Years of Rapid Advance of Monsoon	Years of Sluggish Advance of Monsoon
1945	1969
1946	2002
1951	2004
1953	2006
1955	-
1958	-
1963	-
1964	-
1967	-
1968	-
1972	-
1975	-
1977	-
1980	-
1989	-
1994	-
1996	-
1998	-
2000	-
2003	-
2005	-

The variability of the advance of monsoon is analysed by computing the span of the advance and comparing it with the normal span. Table 3 summarizes the details of the monsoon advance from Kerala to entire country for the period 1945 to 2006. The normal dates used in this table are obtained from the map of mean onset dates of SW monsoon over India, (IMD, 1943). Table 4 summarises the statistical properties of the dates of advance of monsoon over India. From Table 4, it is evident that, the Standard Deviation of the span of the monsoon advance from Kerala to entire country for the period 1945-2006 is 11 days. The years of rapid advance of monsoon are defined as those in which the span of coverage is earlier than the normal value of the span (45 days) by one Standard Deviation (SD) of 11 days *i.e.*, the years in which the span is less than 34 days. The years of sluggish advance are defined as those in which the span of coverage is later than the normal value of the span (45 days) by one Standard Deviation (SD) of 11 days or more *i.e.*, the years in which the span is more than 56 days. The years in which the span of advance falls within the period of 34 to 56 days (Mean value ± one standard deviation) are defined as the years of normal MOK. Table 5 depicts the years of early and delayed MOK, so defined, for the period 1945-2006. For the years of early and delayed MOK (Table 2) and also for the years of rapid and sluggish advance of monsoon (Table 5), the composite pentad Sea level Pressure anomaly values over the region 60° S to 40° N and 10° E to 180° E, have been computed from the corresponding data for the individual years, from the Climate Diagnostic Centre (CDC). These values of the sea level pressure anomaly are then analysed. The pentad (0) is considered as the one centered on the date of MOK.

3. Discussion

3.1. *Monson Onset over Kerala and Sea level Pressure Field*

Figs. 2 (a&b) depicts the composite Sea Level Pressure anomaly for the years of early and late onset of monsoon over Kerala, for the pentads P (-8) to P (0), respectively.

The pentad-wise evolution of convection and contrasts therein for the years of early and late MOK are as follows:

3.1.1. *Evolution of Sea Level Pressure for early onset years*

During pentad (-8), the SLP anomaly over Mascerene High (MH) region is positive (But SLP

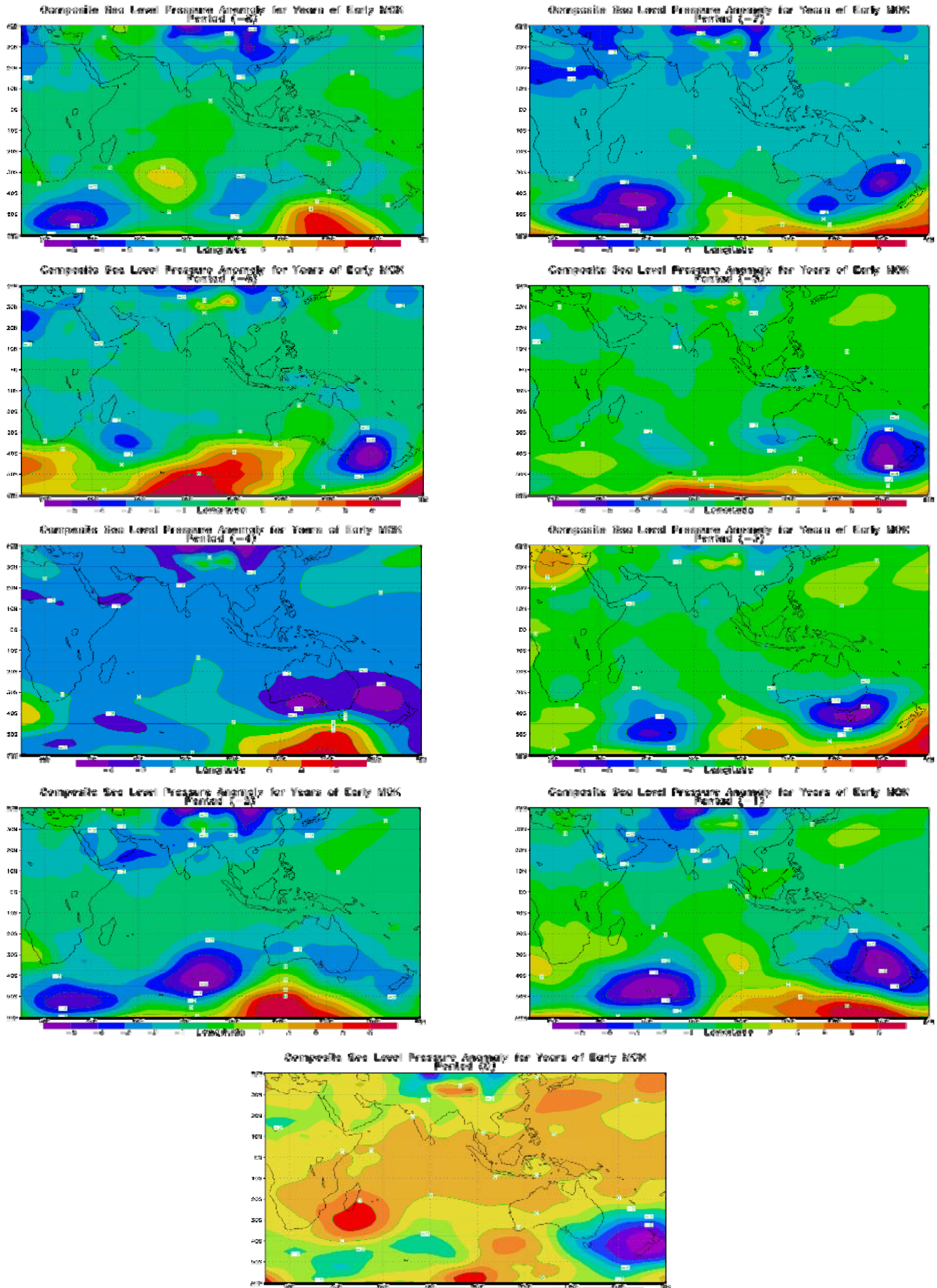

Fig. 2 (a). Pentad Composite Sea Level Pressure Anomaly for the years of early Monsoon Onset over Kerala (MOK)

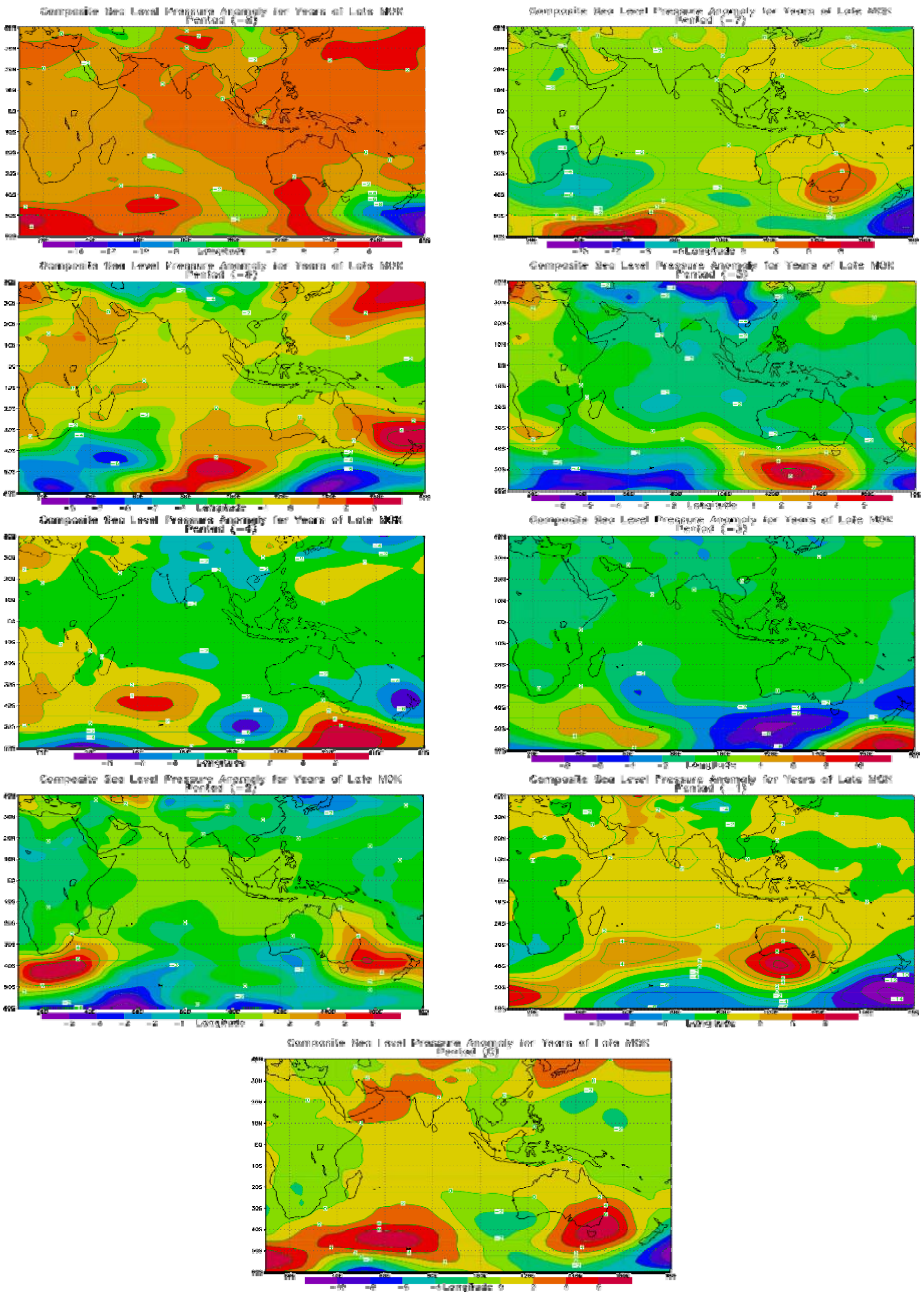

Fig. 2 (b). Pentad Composite Sea Level Pressure Anomaly for the years of late Monsoon Onset over Kerala (MOK)

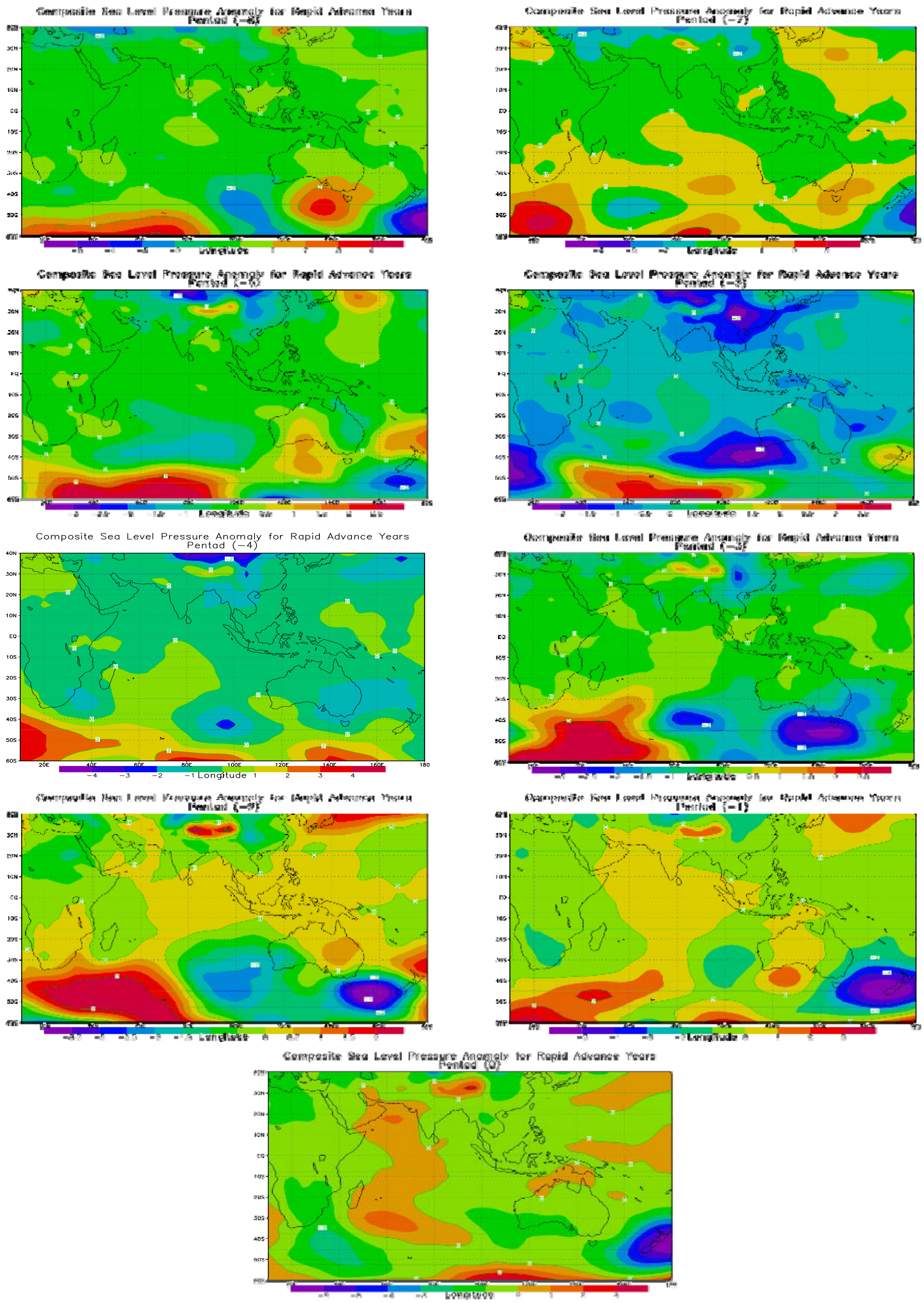

Fig. 3 (a). Pentad Composite Sea Level Pressure Anomaly for the years of rapid advance of monsoon

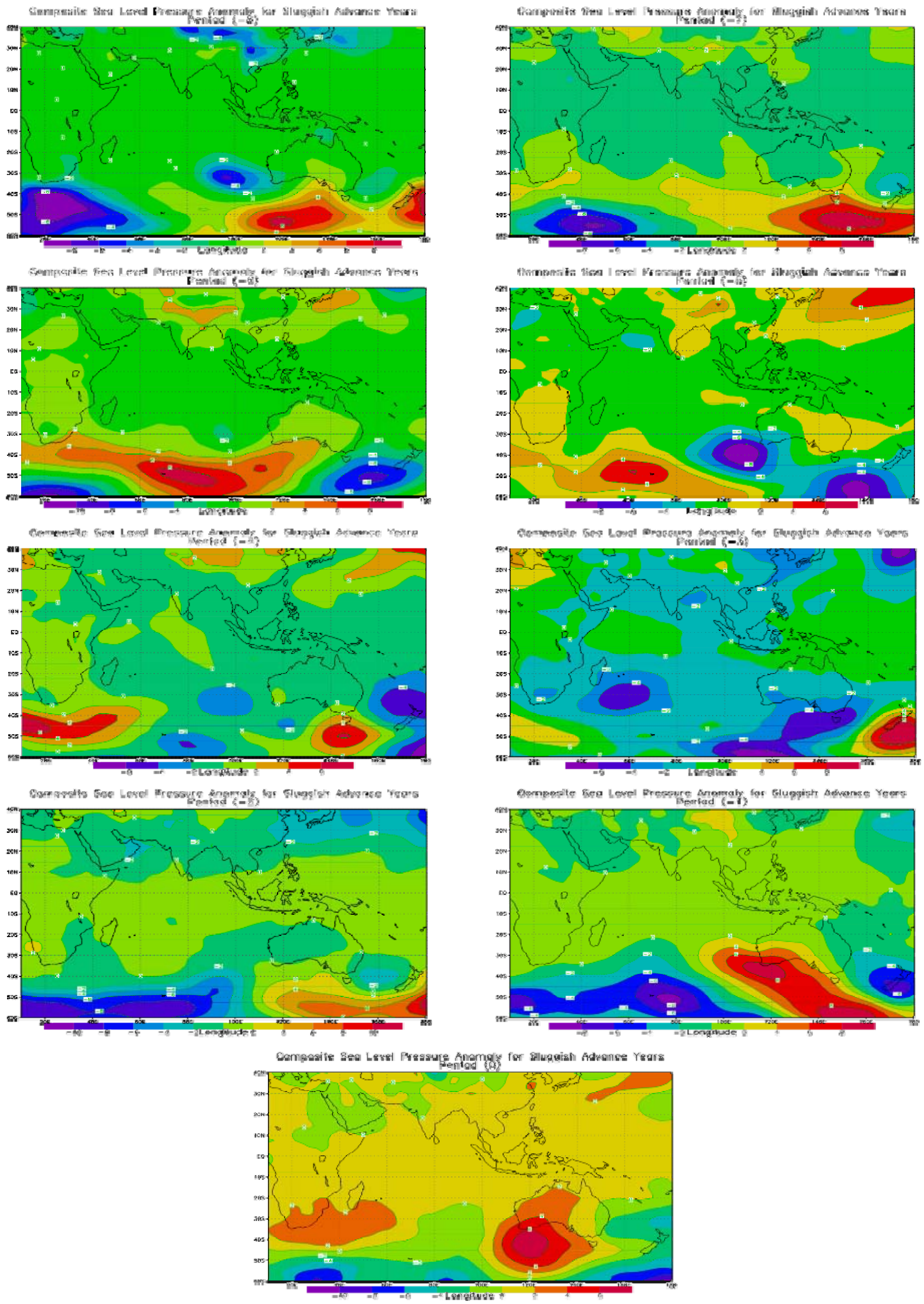

Fig. 3 (b). Pentad Composite Sea Level Pressure Anomaly for the years of sluggish advance of monsoon anomaly values are weak ~ +2 to 3 hPa). Also, this region of positive SLP anomaly is observed to the east of the normal position of MH. The Australian High (AH) is observed to the south of its normal position. However, during pentad (-7), large negative SLP anomaly values are observed over MH region indicating that MH is weaker than normal. The AH shifts westwards compared to its position in earlier pentad and continues to be to the south of its normal position. During pentad (-6), the positive SLP anomaly over AH region shifts further westwards and northwards towards MH region. During all these 3 pentads, the SLP anomaly over northwest India is observed to be negative, thus, the pressure gradient from Southern Hemisphere to Northern Hemisphere remains quite weak during this period. During pentad (-5), the area of the positive SLP anomaly shifts further westwards and to the south compared to previous pentad. The intensities of MH and AH and pressure gradient from Southern Hemisphere to Northern Hemisphere are weaker than normal. During pentad (-4), the intensity of MH and AH weaken further and also the pressure gradient weakens further compared to previous pentad. During pentad (-3), an area of positive SLP anomaly appears over the region south of Australia, which shows systematic westward and northward spreading from pentad (-3) to pentad (-1). During pentad (0), the MH is stronger than normal by ~ 3 to 4 hPa, thereby resulting into strengthening of the outflow from the MH. The SLP anomaly over northwest India is negative. Thus, the pressure gradient from MH to northwest India is enhanced, facilitating strengthening of cross-equatorial flow, thereby heralding the MOK.

3.1.2. *Evolution of Sea Level Pressure for late onset years*

During pentad (-8), the AH as well as MH are observed to be stronger than normal. Also, the SLP anomaly over NW India is positive, so that, the pressure gradient from Southern Hemisphere to Northern Hemisphere is very weak. During pentad (-7), MH appears to have shifted to south of its position in the previous pentad. The SLP anomaly over MH region is now negative. The intensity of AH however continues to be stronger than normal. During pentad (-6), the intensity of MH further weakens while AH intensity continues to be stronger than normal. The direction of pressure gradient from Southern Hemisphere to Northern Hemisphere is observed to be reversed (negative SLP anomaly over MH region and positive SLP anomaly over northwest India) during this pentad. During pentad (-5) also, MH continues to be weaker than normal. The SLP anomaly over NH India changes from positive during previous pentad to negative, so that, the pressure gradient from Southern Hemisphere to Northern Hemisphere is very weak. The AH appears to have shifted to the south of its normal position. During the next pentad (-4), there is rapid westward shift of High Pressure area over Mascarene Islands Region, so that MH is now stronger than normal. Due to this, the pressure gradient from Southern Hemisphere to Northern Hemisphere is enhanced. The AH, however, continues to remain to the south of its normal position. During pentad (-3) also, the same pattern continues, however, the values of the SLP anomaly over MH region decrease in magnitude as compared to previous pentad. During pentad (-2), the intensity of MH is strengthened but MH is observed to gradually shift westwards. During pentad (-1), suddenly large positive SLP anomalies develop over Southern Hemisphere and over Indian region as well. As such, the pressure gradient from Southern Hemisphere to Northern Hemisphere becomes too weak to accelerate the cross-equatorial flow. During pentad (0), same features as those during the previous pentad (-1) prevail with further strengthening of MH and AH and increase in magnitude of positive SLP anomaly over North West India. Thus, the pressure gradient from Southern Hemisphere to Northern Hemisphere is further weakened, thereby adversely affecting the building up of cross-equatorial flow.

3.2. *Advance of Monsoon and Sea level Pressure Field*

Figs. 3 (a&b) depicts the composite Sea Level Pressure anomaly for the years of rapid and sluggish advance of monsoon over India, for the pentads P (-8) to P (0), respectively.

The pentad-wise evolution of convection and contrasts therein for the years of early and late MOK are as follows:

3.2.1. *Composite Sea Level Pressure Anomaly for Years of Rapid Advance*

During pentad (-8), the intensities of MH and AH are stronger than normal, however, the MH is shifted to south of its normal position. During pentads (-7) and (-6), the area of positive SLP anomaly over Mascarene Islands area and Australian region shift southwards and westwards.

During pentad (-5), the positive SLP anomaly over these regions is replaced by negative SLP anomaly. However from pentad (-4), the MH starts building up. During pentad (-3), MH is stronger than normal though AH is weaker than normal. During pentad (-2) to pentad (0), the strength of MH is stronger than normal so that the outflow from MH is stronger, leading to enhancement of cross-equatorial flow.

3.2.2. *Evolution of Sea Level Pressure for Years of Sluggish Advance*

During pentad (-8), the intensity of MH is weaker than normal. The AH is shifted to the south of its normal position. During pentad (-7), there is gradual westward shifting of negative SLP anomaly over MH region and positive SLP anomaly over AH region. During pentad (-6) to pentad (-4), the intensity of both MH and AH is stronger than normal. However during this pentad, the pressure over Indian region is also higher than normal, so that the pressure gradient from Southern Hemisphere to Northern Hemisphere is very weak. During pentad (-3), the positive SLP anomaly over southern hemisphere shifts westwards and is replaced by negative SLP anomaly over MH and AH regions. Also, the pressure gradient from Southern Hemisphere to Northern Hemisphere continues to be weak. During pentad (-2), over the region south of Australia, positive SLP anomalies appear which gradually shift westwards and northwards during pentad (-1). As a result, during pentad (0), the intensity of both, MH and AH, is stronger than normal. However, the pressure gradient from Southern Hemisphere to Northern Hemisphere continues to be weaker than normal.

4. Conclusions

(*i*) There is well discernible contrast in the evolution of Sea Level Pressure field for the years of early and late onset of monsoon over Kerala and for the years of rapid and sluggish advance of monsoon over India.

(*ii*) During the pentads (-8) to (-4), the intensity of Mascarene High and the pressure gradient from southern to northern hemisphere is weaker than normal for the years of both, early and late onset of monsoon. However, for the years of early monsoon onset, since pentad (-3) to pentad (0), there is systematic westward movement of High pressure area towards Mascarene islands, so that, the Mascarene High is stronger than normal by 3 to 4 hPa, facilitating building up of strong pressure gradient from southern to northern hemisphere and strengthening of cross-equatorial flow. In contrast, for the years of late monsoon onset, during this period, the pressure gradient from southern to northern hemisphere is weaker than normal.

(*iii*) For the years of rapid advance of monsoon, the Mascarene High starts building up since pentad (-4), which continues till pentad (0), thereby resulting into enhancement of cross equatorial flow. On the other hand, for the years of sluggish advance, even though the strength of Mascarene High is stronger than normal during pentads (-6) to (-4), the pressure gradient from southern to northern hemisphere is weaker than normal, which continues to be so till pentad (0), thereby adversely affecting the building up of cross equatorial flow and resulting into sluggish advance of monsoon.

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