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DECADAL TRENDS IN WESTWARD MOVEMENT OF MONSOON DEPRESSIONS OVER INDIA

1. The Monsoon Disturbances (MDs) are synoptic scale low pressure systems with two to three closed isobars with surface wind upto 33 knots while over the sea. These systems mostly form in the Bay of Bengal during south-west monsoon season (June to September) and move generally in a west northwesterly direction and cause considerable rainfall over India. If a MD travels large westward distance from the Bay of Bengal region, it covers more land area and produces rainfall over this large region. These MDs form initially as a low pressure areas and then intensify into depressions and occasionally become cyclonic storms. It has been observed that the origin of MDs can be associated with three categories : (*i*) the remnant of a typhoon from northwest Pacific enters as a low pressure system over north Bay of Bengal after moving through Burma, (*ii*) the remnant of a typhoon which is weakened even as a surface system enters over north Bay of Bengal as isallobaric low or cyclonic circulation in the troposphere and (*iii*) a vortex which develops in the middle troposphere and slowly descends to the surface through the lower troposphere and forms a low. Thus, the frequency of MDs over the Indian region depends on westward moving remnants of typhoons from west Pacific. Iyer (1935) first examined the tracks of typhoons over Pacific Ocean and south China Sea and found that July-November are the main months in which the residual lows from the typhoons over west Pacific travel westward and enter Indian area. Krishnamurti *et al*., (1977) examined the mean sea level pressure along

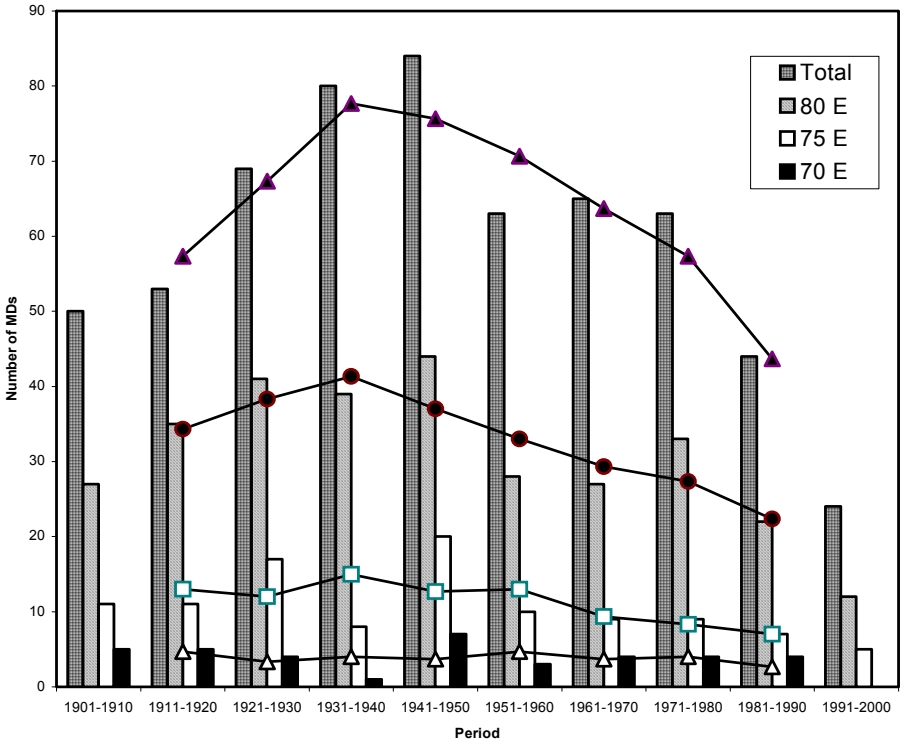


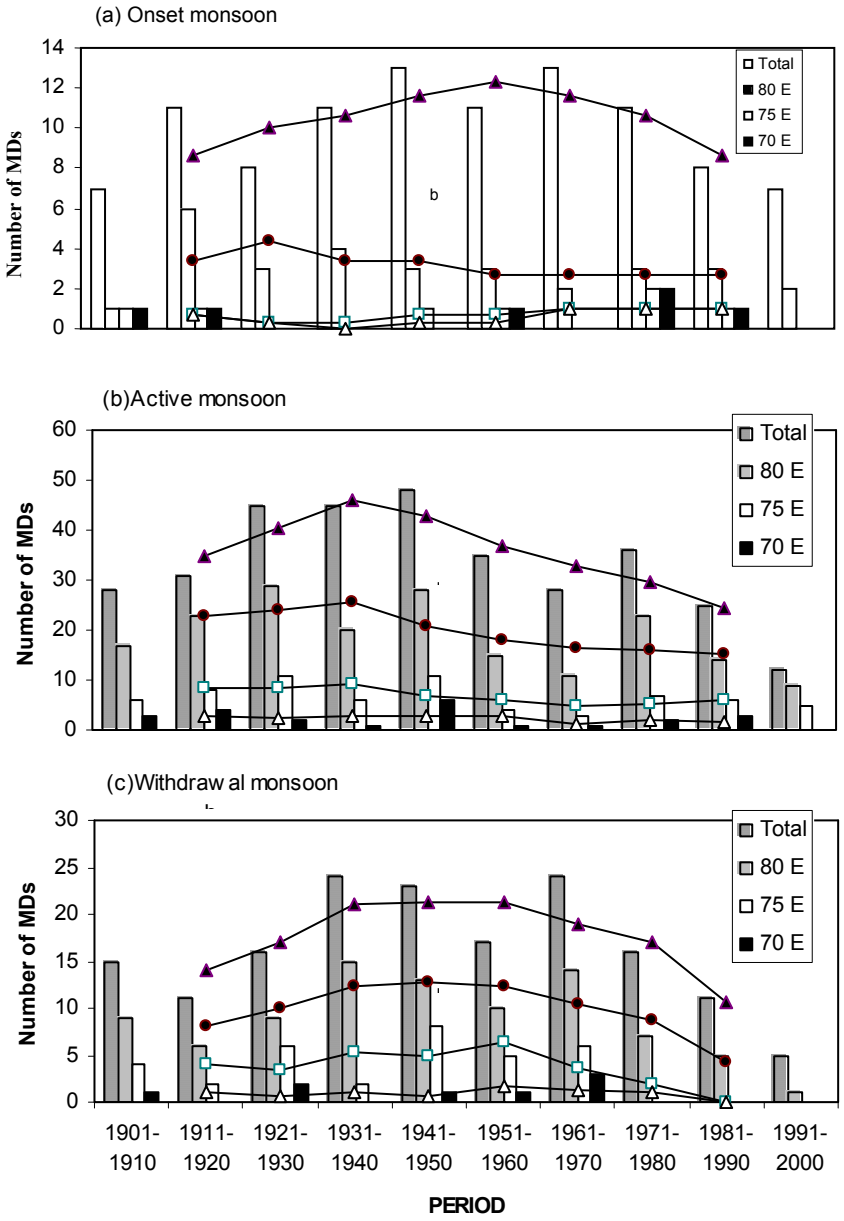
Fig. 1. Decadal frequency of total number of monsoon depressions formed east of 80° E during June to September along with their westward movement crossing longitudes of 80° E, 75° E and 70° E. The corresponding running mean values of three decades are also shown here with top line showing for total MD formed and next lower line for MDs crossing 75° E

latitude 20° N for 43 years (1933 to 1976 excluding 1945) during the monsoon season and found very slow westward propagating wave group, initiated by a typhoon from the western Pacific. Further movement of MDs from Bay of Bengal in a west northwesterly direction over Indian region towards the central part of country gives rise to widespread rainfall over the region. Sometimes, these systems after crossing the main land enter the Arabian Sea. As many MDs over the Bay of Bengal develop from the regenesis of westward-propagating residual lows from the east, Chen and Weng (1999) while studying the interannual and intraseasonal variation in the frequency of occurrence of MDs found that any mechanism causing a variation in the frequency of occurrence of weather disturbances in the western tropical Pacific-south China Sea region may result in a corresponding change in the formation frequency of MDs over the Bay of Bengal. Recent studies (Rajeevan *et al*., 2001; Pattanaik and Thapliyal, 2002) reported a decreasing trend in this frequency. The question now arises whether like the reported decrease in the number of MDs in recent times is there any change in the extent of their westerly movement? Does any relation exist between the extent of this westward movement of MD's and their frequency? The present study aims to answer these questions by analysing data of past 100 years (1901 to 2000).

2. The detailed data of MDs formed in the Bay of Bengal along with their tracks during the period 1901 to 1990 were collected from the storm atlas and its addendum published by India Meteorological Department (IMD 1979, 1996). The data for recent period (1991 to 2000) have been obtained from the office of Deputy Director General of Meteorology (Weather Forecasting), India Meteorological Department, Pune.

3. During the period 1901 to 2000, a total of 595 MDs formed over the Bay of Bengal and adjoining land area during the monsoon season (June to September). Out of them 100, 147, 186 and 162 respectively formed during the month of June, July, August and September.

As mentioned earlier if a MD travels large westward distance from the Bay of Bengal region it covers more land area and produces rainfall over this large region of Indian subcontinent. In order to see the decadal trends in westerly movement of MDs over India during past 100 years (1901-2000), the decade-wise westward movement



Figs. 2(a-c). Decadal frequency of total number of monsoon depressions formed east of 80^0E during different phases of monsoon *viz*., (a) onset (June), (b) active (July-August) and (c) withdrawal (September) along with their westward movement crossing longitudes of 80° E, 75° E and 70° E

of MDs during the monsoon season in last ten decades is shown in Fig. 1. The different bars in Fig. 1 indicate total number of MDs formed over the Bay of Bengal and adjoining land region east of 80° E and their westward movement frequency crossing longitudes of 80° E, 75° E and 70° E during different decades. The corresponding moving average values for 3 consecutive decades are superposed in Fig. 1. It is seen that the decadal frequency of MDs formed east of 80° E is showing increasing tendency from the first decade (1901-10) to the fifth decade (1941-50) when the peak value is noted. After the fifth decade (1941-50) a sudden decrease in the frequency of MDs is noted which remains for 3 subsequent decades (1951-60, 1961-70, 1971-80) and reduced drastically

TABLE 1

The total number of MDs during June to September and different phases of monsoon *viz*., onset(June), active (July-Aug), and withdrawal phase (September) and its westward movement crossing longitude of 80° E, 75° E and 70° E during period '1' (1900 -50) and period '2' (1951-2000). JJAS stands for June to September. In case of westward movement, the percentage of total MDs is also given in the brackets

Systems	Period from 1900 to 1950				Period from 1951 to 2000			
	JJAS	Jun	Jul-Aug	Sep	JJAS	Jun	Jul-Aug	Sep
Total MDs	336	50	197	89	259	50	136	73
Crossed 80° E	186 (55.4%)	17 (34%)	117 (59.4%)	52 (58.4%)	122 (47.1%)	13 (26.0%)	72 (52.9%)	37 (50.7%)
Crossed 75° E	67 (19.9%)	3 (6%)	42 (21.3%)	22 (24.7%)	40 (15.4%)	4 (8.0%)	25 (18.4%)	11 (15.1%)
Crossed 70° E	22 (6.5%)	2 (4%)	16 (8.1%)	4 (4.5%)	15 (5.8%)	4 (8.0%)	16 (11.8%)	4 (5.5%)

during the last decade (1991-2000). With respect to the westward movement of MDs during last 10 decades it is seen from Fig. 1 that there is not much variation in westward movement frequency of MDs with respect to crossing the longitude of 70° E (as shown by almost horizontal line of moving average) except in the decade of 1991 to 2000 in which there is not a single MD which crossed the longitude of 70° E while moving westward. The highest frequency of MDs crossing the longitude of 70° E is reported during the decade of 1941-50 when the frequency of MDs formed was also maximum. During the same decade, frequency of MDs crossing the longitude of 80° E and 75° E is also highest. The total number of MDs formed east of 80° E during the monsoon season and its corresponding westward movement frequency during 1st half (1901-50) and 2nd half (1951-2000) is given in Table 1. It is seen from Table 1 that there exist contrasting behaviour of westerly movement of MDs during first half (1901-50) and second half (1951-2000) with slightly less westerly movement of MDs during last five decades compared to first five decades.

The values indicated in Table 1 show that out of 336 MDs which formed during the first five decades (1901 - 50), 186(56.4%) MDs crossed the longitude of 80° E, 67(19.9%) MDs crossed the longitude of 75° E and 22(6.5%) crossed the longitude of 70° E. On the other hand, during last five decades (1951 - 2000) out of 259 MDs formed east of 80° E during June to September, 122 (47.1%) MDs crossed the longitude of 80° E, 40(15.4%) MDs crossed the longitude of 75° E and 15(5.7%) MDs crossed the longitude of 70° E. Thus, it is not only a decreasing trend of frequency of MDs during latter half period but also corresponding decreasing tendency in westerly movement frequency of the MDs observed during the latter half of the period (1951 - 2000) as compared to the first half (1901 - 1950).

To analyse the sub-seasonal behaviour of change in westerly movement of MDs, the season is divided into three phases *viz*., the onset (June), active (July-August) and withdrawal (September) phases. Like Fig. 1 for the season as a whole, the decade-wise total MDs formed east of 80° E, corresponding westward movement frequency of MDs and corresponding three decades running mean during different phases of monsoon for past 100 year-period (1901 - 2000) is shown in Fig. 2. For the main monsoon phase [Fig. 2(b)], the decadal variation of total MDs formed is almost identical with that of seasonal pattern as shown in Fig. 1 with peak during the decade of 1941-50. With respect to the westward movement during the active monsoon phase of July-August, in all ten decades, there were many MDs, which crossed 75° E longitude while moving westward. However, just like the seasonal pattern as shown in Fig. 1 in case of active phase also there is not a single MD, which crossed the longitude of 70° E during the last decade of 1991 to 2000. The total number of MDs formed east of 80° E during the different phases of monsoon and its corresponding westward movement frequency during 1st half (1901-50) and 2nd half (1951-2000) is also given in Table 1. It is observed from Table 1 that out of 197 MDs which formed east of 80° E in July and August during first five decades from 1901 to 1950, 117(59.4%) MDs crossed the longitude of 80° E, 42(21.3%) MDs crossed the longitude of 75° E and 16 (11.8%) MDs crossed the longitude of 70° E. On the other hand, during last five decades (1951 - 2000), out of 136 MDs formed east of 80° E during July and August, 72 (52.9%) MDs crossed the longitude of 80° E, 25(18.4%) MDs crossed the longitude of 75° E and 16(11.8%)

crossed the longitude of 70° E. Thus, like the seasonal pattern from June to September (JJAS) as indicated in Table 1, there exist decreasing number of MDs associated with decreasing tendency in westward movement frequency of the MDs with respect to crossing the longitudes of 80° E and 75° E during the latter half period compared to the former half period. However, with respect to crossing the longitude of 70° E, it is same in both periods (Table 1) although the corresponding percentage of total MDs formed is more in latter half period.

During the onset phase [Fig. 2(a)], it is seen that the total number of MDs formed east of 80° E is almost identical in all decades with only a little variation. It is also seen that the number of MDs formed during first five decades (1901-50) and during latter five decades (1951-2000) is same (50). With respect to the westerly movement of MDs during the onset phase of June, it is observed that not a single MD crossed even 75° E longitude during the decades of 1921-30, 1931-40, 1961-70 and 1991-2000 and no significant variation in westerly movement was observed during other decades. As seen from Table 1 there exist no significant difference of MDs with respect to its westward movement. However, one contrasting feature regarding the westerly movement of MDs during first five decades and second five decades of onset phase is that there is restricted westerly movement with respect to crossing the longitudes of 75° E and 70° E during the former period compared to the latter period. Out of 50 MDs formed during first five decades of onset phase, 3 MDs crossed 75° E and 2 crossed 70° E. On the other hand, out of 50 MDs formed during second five decades, 4 MDs crossed 75° E as well as 70° E.

In case of withdrawal monsoon phase it is seen from Table 1 that the total MDs formed east of 80° E during first five decades (89) is higher than the number of MDs formed during last five decades (73). With respect to westerly movement of MDs during withdrawal phase, it is observed from Table 1 that out of 89 MDs which formed in first five decades from 1901 to 1950, 52(58.4%) MDs crossed the longitude of 80° E and 22(24.7%) MDs crossed the longitude of 75° E, which are higher than corresponding numbers in 2nd half. Thus, similar to the behaviour during entire monsoon season the westward movement probability of MDs is also decreased during withdrawal monsoon phase in latter period (1951-2000) compared to the former period (1901-50) with respect to crossing the longitude of 80° E and 75° E. However, with respect to crossing the longitude of 70° E the number of MDs is same (4) in former five decades (1901-50) and latter five decades (1951-2000) and it is basically due to more westerly movement during the decade from 1961-70 [Fig. 2(c)]. But after the decade of 1961-70 another significant variation in westerly movement of MD is noticed during the withdrawal phase [Fig. 2(c)] with not a single MD having crossed the longitude of even 75° E for a relatively longer period of 3 decades from 1971-2000. This indicates that there is a shift in the behaviour of westward movement of MDs particularly during the withdrawal phase of monsoon after 1970.

4. Following conclusions can be drawn from the present study : -

The decadal analysis of movement of MDs indicate restriction in the westward movement of MDs with respect to crossing the longitudes of 80° E, 75° E, and 70° E in monsoon season during the period from 1951 to 2000 compared to the period from 1901 to 1950. The sub-seasonal analysis of the same also indicate identical behaviour during main monsoon phase with that of seasonal pattern with respect to crossing the longitudes of 80° E and 75° E. During the onset phase, although there is not much decadal variation in number of MDs and its westward movement probability, one contrasting feature of restricted westerly movement with respect to crossing the longitudes of 75° E and 70° E is noticed during former five decades (1901-50) compared to latter five decades (1951-2000). On the other hand the withdrawal phase of monsoon is also observed restricted westerly movement during last five decades compared to first five decades with respect to crossing the longitudes of 80° E and 75° E. Again it is seen that during the withdrawal phase of monsoon, restriction of westerly movement is very high in recent times for last three decades from 1971 to 2000 with not a single MD crossing the longitude 75° E.

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