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INCREASE IN SST OF BAY OF BENGAL AND ITS CONSEQUENCES ON THE FORMATION OF LOW PRESSURE SYSTEMS OVER THE INDIAN REGION DURING SUMMER MONSOON SEASON

1. Low Pressure Systems (LPS - lows, depressions or cyclonic storms) play an important role in the distribution of rainfall during the southwest monsoon season. Lows or depressions give widespread rainfall as compared to cyclonic or severe cyclonic storms which produce intense rainfall over a smaller area. Distribution of monsoon rainfall depends on the movement and duration of LPS. Most of the LPS formed over the Bay of Bengal travel in northwest direction strengthening the rainfall activities over large parts of the country. LPS tries to maintain normal position of the monsoon trough and enhances the monsoon activities.

Koteswaram and George (1958), Rao and Jayaraman (1958), Sikka (1977), Joseph (1981) and Saha *et al*. (1981) and others have extensively studied the storms/depressions in monsoon season. Mandal (1991) studied year to year fluctuations in the frequency of cyclonic disturbances and concluded that there is no trend or periodicity in the series. Decadal frequency however showed decreasing trend since 1950s. Patwardhan and Bhalme (2001) observed a significant decreasing trend in the frequency of cyclonic disturbances during the recent years. Mooley and Shukla (1987) have examined some characteristic features of LPS in terms of formation, location, movement and duration of LPS. Xavier and Joseph (2000) showed that frequency of depressions/storms depends on the vertical wind shear. Muzumdar *et al.* (2000) observed a rising trend in monthly, seasonal and annual SST of almost all sectors of Indian Ocean. Rajeevan *et al.* (2000) noticed a statistically decreasing trend in the activity of the depressions/storms during Indian monsoon season for the period 1951-98 in spite of above normal SST of Bay of Bengal. Singh (2001) investigated long term trends in the frequency of cyclonic disturbances over the Bay of Bengal and the Arabian Sea using the 100-year (1890-1999) data and found significant decreasing trends. Jadhav (2002) studied the performance of monthly monsoon rainfall of the meteorological sub-divisions with respect to the location and duration of LPS. Dash *et al*. (2003) found that the number of low pressure areas has been increasing during last two decades and the dynamic conditions are not favourable for their intensification into depressions and cyclones. Jadhav and Munot (2004) made statistical analysis of all the low pressure systems during monsoon months and monsoon season as a whole. They found that number of LPS Days have significantly increased during the period 1971-90.

TABLE 1

Decadal mean frequency and duration of LOW, DDS and LPS over the Indian region during monsoon season

	Frequency			Duration in days		
Decade	LOW	DDS	LPS	LOW	DDS	LPS
1891-1900	5.3	8.0	13.3	33.3	28.8	62.1
1901-1910	7.4	6.5	13.9	36.5	19.9	56.4
1911-1920	5.3	6.1	11.4	31.7	17.7	49.4
1921-1930	5.4	8.0	13.4	31.3	26.3	57.6
1931-1940	5.0	6.7	11.7	28.9	20.5	49.4
1941-1950	6.2	7.7	13.9	29.7	25.6	55.3
1951-1960	5.1	7.1	12.2	55.3	21.0	50.5
1961-1970	5.3	7.2	12.5	30.2	22.3	52.5
1971-1980	6.2	8.0	14.2	35.9	33.0	68.9*
1981-1990	8.5*	5.1#	13.6	55.7*	15.3#	71.0*
1991-2000	9.6*	2.9#	12.5	50.9*	10.4#	61.3
1891-2000	6.3	6.7	13.0	35.8	21.9	57.7

***** Significantly increasing **#** Significantly decreasing

TABLE 2

Decadal mean sea surface temperature of north and south Bay of Bengal for MAM and JJAS seasons

	North Bay of Bengal		South Bay of Bengal	
Decade	MAM	JJAS	MAM	JJAS
1891-1900	28.31#	28.30#	28.88#	27.84#
1901-1910	28.37#	28.44#	28.88#	27.82#
1911-1920	28.49	28.62	29.02	28.03
1921-1930	28.65	28.57	29.04	28.04
1931-1940	28.81	28.69	29.25	28.21
1941-1950	28.43#	28.57	28.97	28.17
1951-1960	28.67	28.73	29.11	28.10
1961-1970	28.77	28.69	29.21	28.26
1971-1980	28.60	28.78	29.20	28.29
1981-1990	28.89*	28.95*	29.36*	28.43*
1991-2000	29.09*	29.03*	29.59*	28.71*
1891-2000	28.65	28.67	29.14	28.17

***** Significantly increasing **#** Significantly decreasing

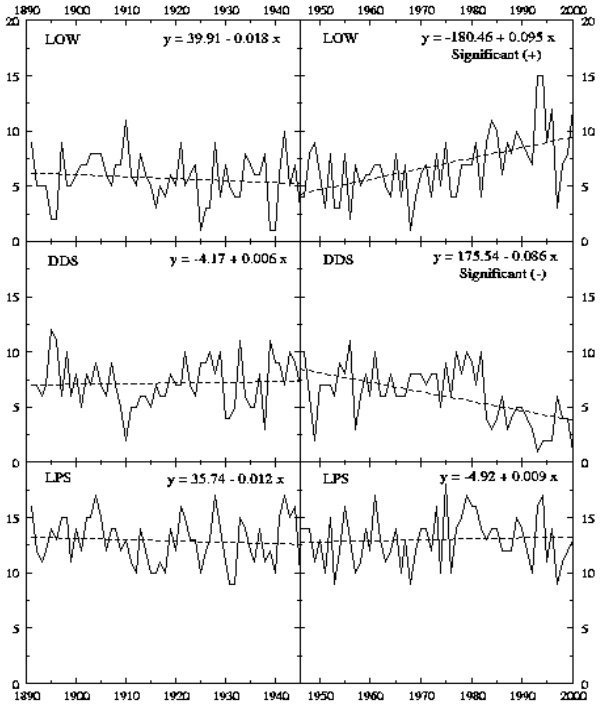

Fig. 1. Trend analysis of frequency LOW/DDS/LPS during monsoon season (1891 - 1945 & 1946 - 2000)

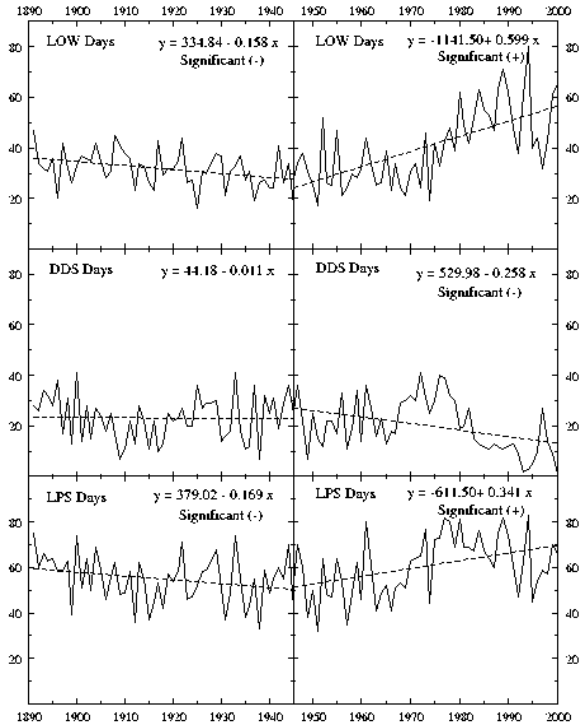

Fig. 2. Trend analysis of frequency LOW/DDS/LPS during monsoon season (1891 - 1945 & 1946 - 2000)

In this paper the monthly SST of Bay of Bengal is studied in relation to the frequency and duration of all the LPS (*i.e.*, lows/depressions/storms) formed during the monsoon season, June to September for the period 1891-2000 over the Indian region.

2. *Data analysis* - Daily locations of LPS formed over the Indian region for the period 1891-1983 are obtained from the research report by Mooley and Shukla (1987) and daily locations of LPS for the period 1984-2000, are collected from 0300 UTC charts of Indian Daily Weather Reports (IDWR), India Meteorological Department (IMD), Pune.

The total number of LPS are obtained from the daily locations of LPS and duration of LPS is counted in terms of LPS Days during the monsoon season for the period 1891-2000. Intensity of the LPS is categorized into two; *viz.*, lows (LOW) and depressions/storms (DDS). The duration of lows is termed as LOW Days and that of depressions/storms is as DDS Days.

Monthly SST data used for this study for the period 1891-2000 were derived from the Global Sea Ice Sea Surface Temperature (GISST) dataset (version 2.3 b) (Raynor *et al*. 1996). The GISST data, on a 1 × 1 grid, are quality controlled, smoothed in space, and missing grid boxes are filled in using an EOF - based technique.

From the mean monthly SST grid data, mean SST during March-April-May (MAM) and June to September (JJAS) seasons are computed for north Bay of Bengal (14.5° - 22.5° N, 79.5° - 95.5° E) and south Bay of Bengal (2.5° - 10.5° N, 79.5° - 95.5° E) for the period 1891-2000.

3. *Statistical analysis* - The statistical analysis is carried out for monthly LOW, DDS, LPS and their respective duration, LOW Days, DDS Days, LPS Days for the monsoon season and also for monthly SST of north Bay of Bengal, south Bay of Bengal. Some significant results are as follows.

3.1. *Decadal variation* - Decadal analysis is carried out for the frequency of LOW/DDS/LPS and their duration during the monsoon season and for the SST of the north and south Bay of Bengal during the pre-monsoon and monsoon seasons. Results are tested by student's *t*-test to see if any decadal mean is significantly different from its long term mean. (Tables 1 and 2).

Decadal means of LOW are significantly higher and decadal means of DDS are significantly lower than their

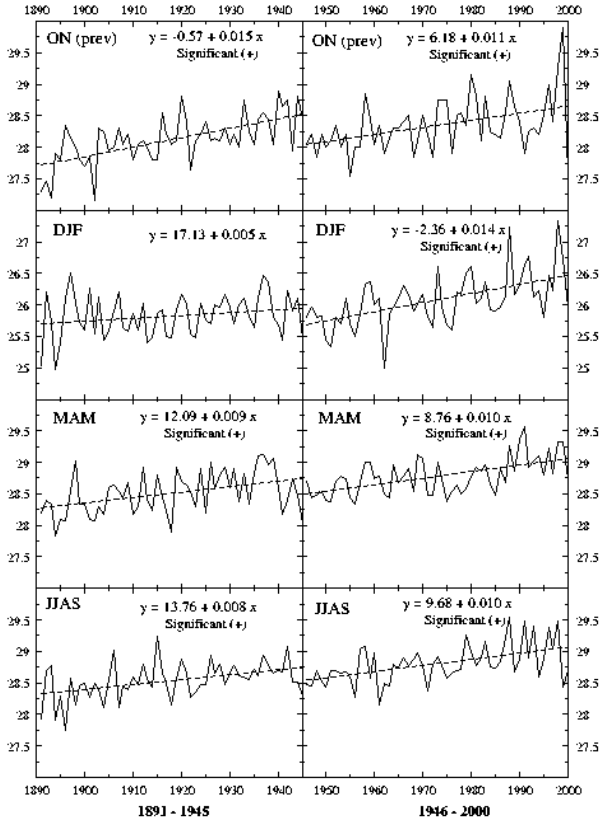

Fig. 3. Trend analysis of north Bay of Bengal sea surface temperature (°C) (1891 - 1945 & 1946 - 2000)

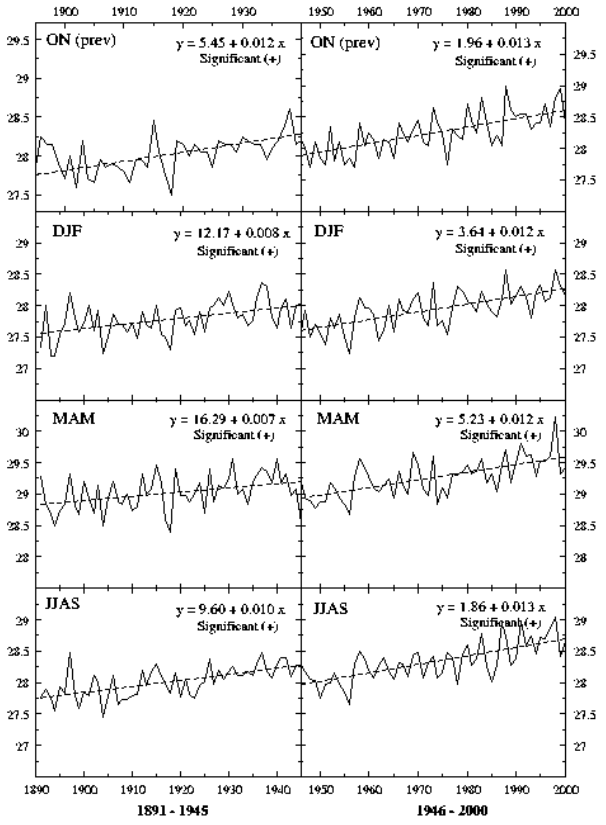

Fig. 4. Trend analysis of south Bay of Bengal sea surface temperature (°C) (1891 - 1945 & 1946 - 2000)

respective long term means for the decades 1981-90 and 1991-2000 during the monsoon season. This shows that there is significant increase in the frequency of lows while significant decrease in the frequency of depressions/storms during the monsoon season for the decades, 1981-90 and 1991-2000. However the frequency of LPS has not significantly increased or decreased during these decades.

Decadal means of LOW Days are significantly higher and decadal means of DDS Days are significantly lower than their respective long term means for the decades 1981-90 and 1991-2000 during the monsoon season. The LPS Days are also significantly higher during the decades 1971-80 and 1981-90. This shows that LOW Days have significantly increased while DDS Days have significantly decreased during the monsoon season for the last two decades, 1981-2000.

Decadal means of SST of north Bay of Bengal, south Bay of Bengal during pre-monsoon (MAM) and monsoon season (JJAS) are significantly higher than their respective long term means for the decades 1981-90 and 1991-2000. This shows that surface temperature of Bay of Bengal has significantly increased during pre-monsoon and monsoon seasons for the period 1981-2000.

3.2. *Trend Analysis* - In the context of global warming it is very much likely that there may be significant changes in the frequency and duration of LPS as well as SST's over Indian Ocean. In view of this, to bring out the significant changes if any during recent period, the LPS and SST data sets are sub-divided into two sub-periods 1891-1945 and 1946-2000 and subjected to trend analysis by applying Mann-Kendall rank statistics as suggested by WMO (1966). The time series with fitted trend lines are shown for frequency of LOW, DDS and LPS for the periods 1891-1945 and 1946-2000 in Fig. 1. It shows that LOWs are significantly increasing by 0.95 days/10 years whereas DDS are significantly decreasing by 0.86 days/10 years after 1946. In view of these opposite trends in the frequency of LOWs and DDS, there is no any significant trend in the frequency of LPS.

In Fig. 2, the time series with fitted trend lines are shown for LOW Days, DDS Days and LPS Days for the

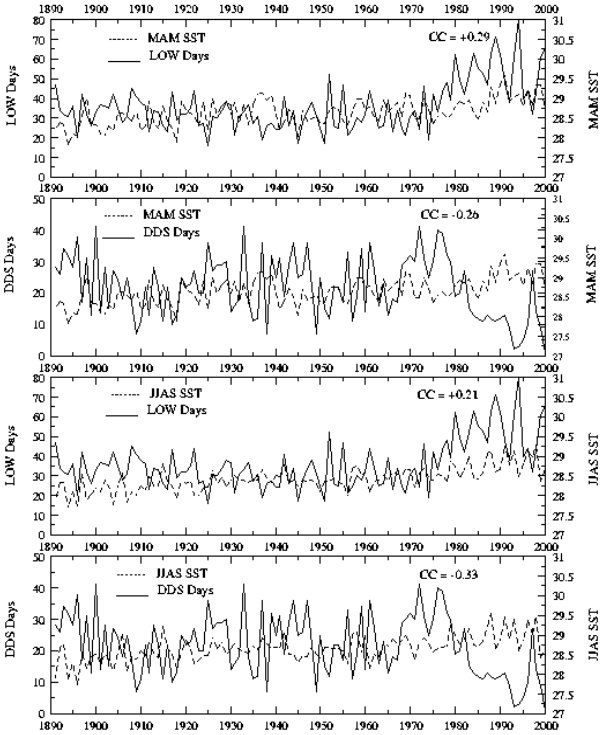

Fig. 5. Mean MAM/JJAS SST of north Bay of Bengal and LOW/DDS Days during monsoon season over the Indian region for the period 1891- 2000

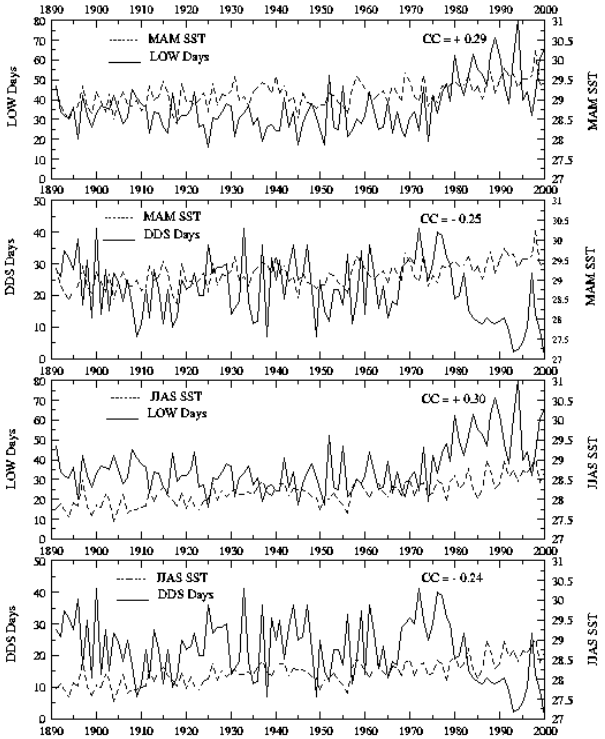

Fig. 6. Mean MAM/JJAS SST of south Bay of Bengal and LOW/DDS Days during monsoon season over the Indian region for the period 1891- 2000

periods 1891-1945 and 1946-2000. The Fig. 2 reveals that there is significantly increasing trend of 5.9 days/10 years in the duration of LOWs whereas duration of DDS is significantly decreasing by 2.6 days/10 years after 1946. The duration of LPS days is also significantly increasing by 3.4 days/10 years.

In Figs. 3 and 4 time series of sea surface temperatures with fitted trend lines are shown for ON(October-November), DJF(December-January-February), MAM and JJAS seasons for north Bay of Bengal as well as for south Bay of Bengal respectively. It is seen that SSTs for both north and south Bay of Bengal are significantly increasing for all the seasons as mentioned above for both the sub-periods 1891-1945 and 1946-2000 except for DJF season for 1891-1945 over north Bay of Bengal.

3.3. *Correlation* - LOW Days, DDS Days and LPS Days are correlated with SST of north and south Bay of Bengal for MAM and JJAS seasons. The correlation coefficients are tested for 99% CL and some significant relationships are brought out. (Figs. 5 and 6).

DDS Days are significantly negatively correlated and LOW Days are significantly positively correlated with the SST of north and south Bay of Bengal during pre-monsoon (MAM) and monsoon (JJAS) seasons. But the prominent relationship is observed during monsoon season *i.e.*, increase in SST of north Bay of Bengal decreases the cyclonic disturbances while increase in the SST of south Bay of Bengal increases the duration of lows during monsoon season.

The detrended series of SST of north and south Bay of Bengal for MAM and JJAS season do not show any significant relationship with the frequency and duration of LOW/DDS. This indicate that the increase in the frequency and duration of LOW and decrease in the frequency and duration of DDS is perhaps due to the increase in the SST of Bay of Bengal.

4. *Discussion* - The study reveals that the frequency and duration of lows have significantly increased while the frequency and duration of depressions/storms have significantly decreased during the the last two decades, 1981-2000. SST of north and south Bay of Bengal has significantly increased during the same period. It is also seen that SST of north Bay and south Bay of Bengal for MAM and JJAS seasons are significantly negatively correlated with the frequency of cyclonic disturbance and positively correlated with the frequency and duration of lows. This indicates that the warmer SST of north and south Bay of

Bengal may not be favourable for intensifying lows into depressions.

5. *Results and conclusions* - The frequency and duration of lows has significantly increased while the frequency and duration of depressions/storms has significantly decreased during the monsoon season for the last two decades, 1981-90 and 1991-2000.

(*i*) The frequency of LPS has neither decreased nor increased significantly. But the duration of LPS has significantly increased. This means, the average total formation of the systems are the same but the duration is increased. The lows stay for longer duration than the depressions/storms. So obviously the duration of LPS has significantly increased.

(*ii*) Sea surface temperature of Bay of Bengal has significantly increased for the last two decades, 1981-90 and 1991-2000.

(*iii*) SSTs of north and south Bay of Bengal during pre-monsoon season (MAM) are significantly negatively correlated with the DDS Days and positively correlated with LOW Days of monsoon season. This may suggest that warmer SST of north and south Bay of Bengal for MAM season causes the decrease in cyclonic disturbances and increase in lows during monsoon season.

(*iv*) SST of north Bay of Bengal is highly significantly negatively correlated with the DDS Days while SST of south Bay of Bengal is positively correlated with the LOW Days during monsoon season (JJAS) suggesting that increase in SST of north and South Bay of Bengal decreases cyclonic disturbances.

(*v*) Warmer SST of north and south Bay of Bengal during JJAS seasons may not be favourable for intensifying lows into depressions.

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