CLIMATOLOGY OF THUNDERSTORM ACTIVITY OVER THE INDIAN REGION: A STUDY OF EAST-WEST CONTRAST

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ABSTRACT: Based on the latest data (I. M. D., 1999) of monthly number of station thunderstorm days (Thn) and mean maximum surface air temperatures (Tmax) of 276 Indian stations, an important and a long pending issue of East-West contrast in the frequencies of occurrence of thunderstorms over India is resolved in substantial details in this study. On the premise of nearly equal land areas, and density of the station network, and location of ITCZ; India is divided in two regions: Eastern Region (ER) and Western Region (WR) across the 79° E longitude line over India. Results pertaining to the contrasting features of Thn over ER and WR are presented. Our analysis showed that the annual total Thn over the ER and WR are 4763 and 3194 respectively, and out of this nearly 50 % annual aggregate excess thunderstorm activity over the ER, nearly 80% excess activity is associated with each month of the monsoon season (June – September) alone. The temperature sensitivity of occurrence of Thn showed that thunderstorms respond in exponentially increasing manner to modest increment in Tmax on the semi-annual and annual time-scales in both the regions but with clear contrast in their sensitivity over ER. Our analysis suggests that the hot and humid extensive land area of the ITCZ occupied ER is more conducive and responsible for the development of monsoonal thunderstorms. Further, analysis employing $T_{\theta w}$ and CAPE data over the two regions showed that these thermodynamic parameters have significantly higher values over the ER which explains the E-W pronounced contrast in the thunderstorm activity.

INTRODUCTION

The tropical land region of the Earth is well understood as a central player in the convective overturn of the atmosphere (Riehl and Malkus, 1958) and as a result is acknowledged also for the preponderance of the world's majority of the thunderstorm activity (Williams, 2001). Thunderstorms being one of the main agencies of energy exchange in the atmosphere, and also being the potential source of precipitation on the surface of the earth, an understanding of their frequencies of occurrence over a region is useful in many studies like Global Electric Circuit (GEC), global energetics etc. The juxtaposition of the land and seas to the south of India and the expanse of the hot and humid land surface to the north, are well suited for the large-scale development of thunderstorms over India. These circumstances produce a valuable data base to scientific community to carryout studies of frequencies of thunderstorms at regular intervals over India. However, a review of the literature (Kendrew, 1949; Rao et al., 1971; and Manohar et al., 1999) on the thunderstorm studies over India indicates that scientific community have shown infrequent concern with long periods of waiting involved. The important summary of the foresaid studies suggests that thunderstorm activity, precipitation and many other issues related with thunderstorms over a region are strongly linked with each other. A climatological study of thunderstorm activity over India is therefore most essential. In the present work attention is focused on conducting a comprehensive study of frequencies of occurrences of thunderstorms over India with a special reference to quantify their East - West contrast in substantial details.

DATA AND METHOD OF ANALYSIS

The India Meteorological Department (IMD) has recently (1999) brought out a voluminous but very useful publication entitled "Climatological Normals 1951-1980". For the present study we have selected monthly data of number of thunderstorm days (Thn) and monthly mean of daily maximum surface air temperatures (Tmax) for 276 stations having standing for a minimum of 25 years. Figure 1 shows the network of the stations used in this study. It is noted from this figure that the stations are well spread and also are uniformly distributed over the extent of the country. The distance between the nearest two stations is 20 Km. or more. This would therefore effectively reduce the chance of a single storm being reported simultaneously by the two stations.

From figure 1 we see that the 79° E longitude line demarcates the trough line into two regions: eastern region and western region, each of which lies distinctly within and outside of the tropics. Thus it is felt that the two sections of the trough line, eastern and western, on the premise of tropics and subtropics provide a logistic support in the examination of the East – West contrast in thunderstorm activity over India. Therefore, for an examination of the East – West contrast, we have divided India in two regions: Eastern Region (ER) and Western Region (WR), on either side of the 79° E longitude line across the country (Fig 1). The number of stations contained in the ER and WR are 132 and 144 respectively which shows nearly equal and uniform distribution of stations over the two regions. It is noted that both the regions appear to be balanced with respect to each other. Monthly data of Thn and Tmax for the stations contained in the ER and WR are used to obtain the seasonal (monthly) means of Thn and Tmax over the two regions.

RESULTS AND DISCUSSION

OBSERVATIONS OF EAST – WEST CONTRAST:

Fig. 2 a, b shows the seasonal variation of Thn and Tmax respectively for the two regions under study. In the ER, the first maximum is seen to occur in the month of June while in the WR the first maximum is seen to spread over in the months of May and June. A careful examination of the two curves of Thn in fig. 2a indicates that in 10 out of the 12 months the curve for the ER lays well over the curve for the WR. The prominence in the difference in their monthly amplitude is alarmingly high in the five months period from May-September which covers the last month of the pre-monsoon season and whole of the monsoon season. During these five months, Thn over the ER are in excess in the range 36 % to 139 % of the WR. The seasonal percentage distribution of the annual thunderstorm activity revealed that 60 % (49 %), 28 % (32 %), 7 % (13 %) and 5 % (6 %) thunderstorms occur during the monsoon, pre-monsoon, post-monsoon (O-N) and winter season (D-J-F) months respectively over the ER (WR). Annual total number of thunderstorm days over the ER and WR are 4763 / 3194 and monthly mean Thn per station are 3.0 / 1.8 respectively. Comparison between the seasonal variations of Thn and Tmax over the two regions enables us to obtain quantitative estimates of sensitivity to temperature changes of thunderstorm occurrence. Correlation coefficients over the annual period of 12 months between Tmax and Thn over the ER and WR work out to be 0.74 and 0.84, while these correlations for the monsoon season months work out to be 0.95 and 0.98 respectively. These correlation coefficients are significant at 0.01, 0.001, 0.05 and 0.02 % level of significance respectively. One month shift between the first maximum in Thn and Tmax in both the regions is witnessed. Our results clearly corroborate the nearly one month time lag in heating of the land surface following the maximum in insolation. For the results presented so far we refer to studies of Williams (1994, 1997) where relationship between the tropical surface air temperature for the globe and many other parameters of GEC, including thunderstorm days, has been examined. These studies revealed a good phase agreement between surface air temperature and GEC parameters.

TOPOGRAPHICAL INFLUENCE

The results presented in the previous section require some explanations and results supported by other parameters. To our understanding, explanation for these results can be sought on the basis of the contrasts in the properties of surface meteorological parameters and some situations prevalent over these regions. The elevation of land surface above the mean sea level is an important property in deciding the surface heating of a region. This situation is some what similar and hence comparable to one where surface heating is dominated by the relative prevalence of land and water (Williams, 2002). In either case the lower land areas are known to be systematically hotter than the far elevated ones and the ones dominated by the surrounding extensive presence of waters. The average altitude above mean sea level of the ER works out to be 3 meter, while that of the WR works out to be 580 meters. This more than two order of lower elevation of the ER is an important factor in maintaining a Tmax contrast in influencing the development of strong convection and development of thunderstorms.

Fig. 2 b shows a plot of Tmax over the two regions. It is noted that during the pre-monsoon and monsoon season months the Tmax over the ER are hotter in the range 0.15 to 1.3 ° C than over the WR. We note that this period of seven months is larger than the remaining five months period when western region temperatures are just marginally in excess of the eastern region. Evidences for a primary role of dry-bulb temperature in influencing deep convection, development of thunderstorms, and lightning on regional and global scales can be found in some of the recent studies (Williams, 1994, 1997, 1999; Price, 1993). The important conclusion is that the extensive hot land regions of the tropics are more suitable and responsible for the development of deep convection and occurrences of thunderstorms. The present study therefore stresses the importance of subtle higher values of Tmax in their effect on parcel buoyancy in the dry phase that substantially impacts the moist stage.

SENSITIVITY AND PREDICTION EQUATION BETWEEN THN AND TMAX

We propose to obtain suitable prediction equations of the Thn in relation to Tmax over the ER and WR. These equations are used for studying the difference in the sensitivity of occurrences of Thn with changes in Tmax over the two regions. Fig 3 a, b shows the scatter diagram of x – y plot of Tmax Versus Thn. Exponentially growing best fit curves have been fitted to the scatter points in each figure.

We note that, the sensitivity of occurrences of Thn with subtle changes in Tmax is higher over the ER than that over the WR. For example, at 34° C of Tmax, Thn over the ER is 4.0 and over the WR it is 2.6. At 36° C of Tmax the Thn over ER and WR are 5.1 and 3.3 respectively. From the analysis it is inferred that for Tmax in the range 34 – 36 ° C, the amplitudes of occurrences of Thn over the ER are nearly 54 % larger than that over WR. This result is in agreement with the findings that the aggregate number of Thn over the ER (~ 4800) is found to be nearly 50% larger than that of the aggregate number (~ 3600) over the WR.

Figure 3 c, shows a scatter diagram of x – y plots of the monthly differences in Tmax between the ER and WR versus the similar monthly differences in Thn. An exponentially growing best fit curve, statistics of best fit and the month corresponding to each scatter point is presented in this figure. We note that, the best fit curve not only corroborates the results discussed in the previous paragraph but also reveals seasonal features of the thunderstorm activity associated with changes in Tmax over the two regions. It is noted from the labels of the months that the cluster of the months exhibits a systematic pattern of seasonality evolving during the course of the annual period. The results showing the higher values of wet-bulb potential temperatures, and CAPE, over the eastern region during the monsoon season are briefly presented below.

To complement our results of contrasting number of thunderstorm days described above, we present in brief the surface temperature conditions in terms of $T_{\theta w}$°C; (monthly mean maximum surface wet-bulb potential temperature), and the values of CAPE (J/kg) in the monsoon environment over the two regions. Table 1 presents regional average picture of $T_{\theta w}$ and that of the CAPE representing the two regions. CAPE values are retrieved from the relation between $T_{\theta w}$ and CAPE from the studies of Williams et al., 1992.

We note that the $T_{\theta w}$ values and the CAPE over the ER are consistently higher than those over the WR. The $T_{\theta w}$ values are larger in the range 1.2° C – 2.1° C over the ER and the CAPE values are as much higher as the CAPE values over the WR. This result therefore shows that the eastern tropical land region is more conditionally unstable and the larger CAPE values favor the deep and frequent convection that produces thunderstorms.

INFLUENCE OF TCZ

From fig. 2 (a) and 3 (c) it is seen that in the monsoon season the mean Thn over the ER and WR are 5.3 and 2.7 respectively while in the pre-monsoon season these means are 3.3 and 2.3 respectively. These figures indicate that thunderstorm activity during the monsoon season over the ER is enhanced by 60% with respect to the pre-monsoon season, while the similar enhancement over the WR is only 17%. The important point of information of this analysis is that the seasonal enhancement in the thunderstorm activity is a common feature of both the regions. But activity-wise the ER is clearly seen to dominate over the WR. Similar enhancement in the thunderstorm activity over the Indian region was also pointed out in a recent study by Manohar et al. 1999. Therefore, the E-W disparity in their activity needs some explanation. The E–W disparity in the enhancement in the Thn, witnessed above may be attributed to a large extent to the seasonal expanse of the mean location of tropical convergence zone (TCZ) across the 79° E longitude over the Indian region. TCZ is a dominant upwelling zone which favors the monsoonal convection and the development of thunderstorm (Rutledge et al. 1992, Williams et al 1992, and Manohar et al. 1999). The character of the TCZ is that it produces monsoonal convection mainly as a result of synoptic-scale convergent air motion. These air motions are themselves driven by horizontal pressure gradients that are set up by latitudinal gradients in surface temperatures. Although these monsoonal thunderstorms are in excess in number than the pre-monsoon seasons ones, the above mentioned studies have clearly shown that these thunderstorms are weakly electrified and their per-thunderstorm contribution to rainfall is much larger than those of the pre-monsoon season.

CONCLUSIONS

The results of the present study showed that over both the regions Thn showed clear signals of the semi-annual oscillations of the seasonal variation. But the first maximum of this signal over the ER occurred in the month of May, while over the WR it occurred in the months of May and June. It was noted that the amplitude of the first maximum over the ER was higher by about 72 % than over WR. The monthly mean amplitudes of the seasonal variation of Thn over the ER exceeded those over the WR during most parts of the annual period. This feature was witnessed particularly in the five months period from May to September. The annual total number of thunderstorm days over ER was noted to be 4763 and over the WR was 3194. This analysis showed that thunderstorm activity over ER is nearly twice higher than that over WR. The computation of correlation coefficients between monthly values of Thn and Tmax showed that Thn and Tmax were highly correlated. This result indicates that there exists a good phase agreement between Tmax and the occurrence of thunderstorms over the two regions. The analysis pertaining to temperature sensitivity of occurrence of Thn for 1° C increment in Tmax showed that thunderstorms respond exponentially to modest increase in Tmax on the semi-annual and annual time-scales in both the regions. But the response over ER was nearly twice higher than that over WR. Our analysis suggested that the more hot and humid extensive plain land region of the TCZ occupied ER is more suitable and responsible for the higher development of thunderstorms. Results showing higher values of CAPE and surface wet-bulb potential temperature over ER explain the East-West contrast in thunderstorm activity over India.

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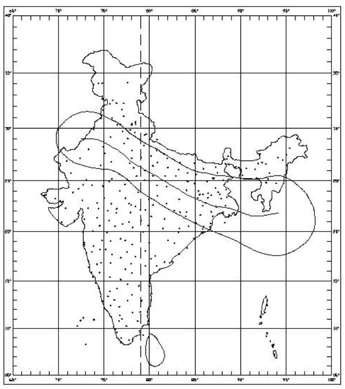

Figure 1: Map of India showing station network of 276 stations used in this study. Map also shows mean position of monsoon trough and envelop around is showing one standard deviation of variation in monsoon trough.

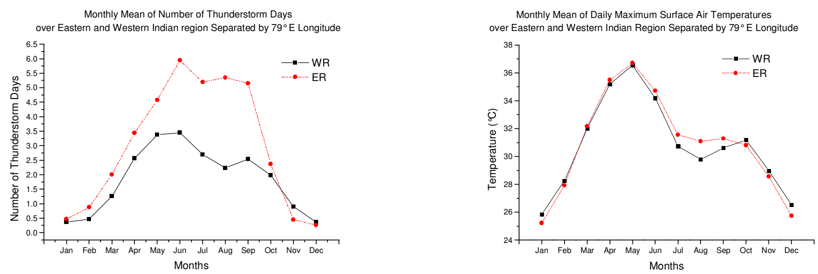

Fig 2 (a): Monthly mean number of thunderstorm days over the ER and WR of India separated by 79° E longitudes. (b) Monthly mean maximum surface air temperatures over the ER and WR of India separated by 79° E longitudes

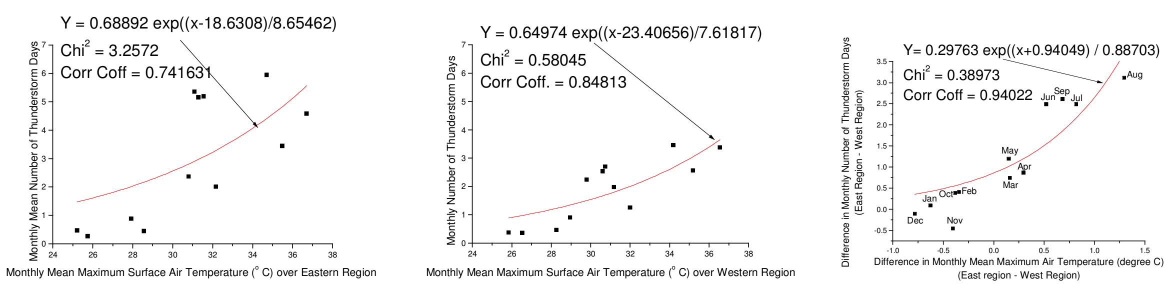

Fig 3 (a): Scatter plot of Tmax Vs. Thn over ER (b): Scatter plot of Tmax Vs. Thn over WR (c): Scatter plot of difference in Tmax (ER-WR) Vs. Thn (ER-WR)

Table 1: Monthly Mean Maximum Wet-Bulb Potential Temperature ($T_{\theta w}$, ° C) during the Monsoon Season months of the years 1972 and 1975 over the ER and WR

Months	1972				1975			
	WR (results based on data of 40 stations)		ER (results based on data of 38 stations)		WR (results based on data of 40 stations)		ER (results based on data of 38 stations)	
	$T_{\theta w}$ ° C	CAPE (J/Kg)	$T_{\theta w}$ ° C	CAPE (J/Kg)	$T_{\theta w}$ ° C	CAPE (J/Kg)	$T_{\theta w}$ ° C	CAPE (J/Kg)
June	24.9	1950	26.2	3300	24.6	1750	26.1	3200
July	24.8	1800	26.3	3500	24.8	1800	26.0	3150
August	24.2	1150	25.9	3000	24.9	1950	26.3	3500
September	23.5	500	25.6	2800	24.5	1600	25.9	3000