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Climatology of thunderstorm activity over the Indian region : III. Latitudinal and seasonal variation

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सार – भारतीय दक्षिण–पश्चिम मानसून को समझने के लिए भारतीय क्षेत्र में गर्ज वाले तूफानों के आने के अंतरालों की जानकारी का होना अत्यंत आवश्यक है। इस उद्देश्य की पूर्ति के लिए हमने 276 भारतीय वेधशाला केंन्द्रों में गर्ज वाले तूफान के गुजरने के दिनों की संख्या के मासिक औसत (Thn) तथा धरातलीय वायु के अधिकतम तापमानों (*T*max) के जलवायविक आँकड़ों का इसमें अध्ययन किया गया है और इससे प्राप्त हुए परिणामों को इस शोध–पत्र में प्रस्तुत किया गया है। भारत में Thn आँकड़ों के मासिक अक्षांशीय (7° उत्तर – 33° उत्तर) घट–बढ़ का विवेचन करने के लिए इनका विश्लेषण किया गया है और इससे प्राप्त हुए परिणामों पर विस्तार से विचार किया गया है। Thn और *T*max की मौसमी घट–बढ़, भारत के 11 भौगोलिक क्षेत्रों की 11 अक्षांशीय दूरियों के औसत, की भी इसमें विवेचना की गई है। इस विश्लेषण में, ऊष्णकटिबंध के अंदर तथा बाहर *T*max तथा Thn घट–बढ़ के परिणामों पर विचार किया गया है। पूरे वर्ष के दौरान भारतीय क्षेत्र के अक्षांशों में इन दो प्राचलों की अवस्था में परिवर्तन तथा दोहरे/एकल दोलन के व्यवहार में व्यवस्थित क्रम का पता चला है। सबसे अधिक महत्वपूर्ण बात यह है कि चारों मौसमों और पूरे वर्ष के लिए भारत के 11 भौगोलिक क्षेत्रों के प्रत्येक केन्द्र के औसत आँकड़े प्राप्त करने के लिए 11 भौगोलिक क्षेत्रों के Thn आँकड़ों का भी उपयोग किया गया है। यह माना गया है कि यह सूचना भारत के विभिन्न भागों में उच्च Thn गतिविधि के प्रमुख क्षेत्रों की पहचान करने के लिए उपयोगी हो सकती है। बिजली गिरने तथा इसी प्रकार की अन्य विपदाओं से निपटने के लिए यह सूचना काफी महत्वपूर्ण हो सकती है।

ABSTRACT. Knowledge of frequencies of occurrence of thunderstorms over Indian region is an issue of prime importance in the context of understanding of Indian southwest monsoon. To meet with this important need, we have examined climatological data of monthly mean number of thunderstorm days (Thn) as well as those of surface maximum air temperatures (*T*max) for 276 Indian observatory stations in this study and the results alt presented. Thn data have been analyzed to describe their monthly latitudinal (7° N - 33° N) variation over India and the results are discussed in details. Seasonal variation of Thn and *T*max, averaged over 11 latitude ranges of 11 geographic regions of India, is also described. In this analysis, results of variation of *T*max and Thn within and outside the tropics are discussed. These two parameters showed systematic sequence in their phase shift as well as in their behavior of double/single oscillation across the Indian range of latitudes over the course of annual period. More importantly, Thn data over 11 geographic regions have also been used to obtain their average score per station per each of the 11 geographic regions of India for the four seasons and for annual period. It is considered that this information may be useful for the identification of prime zones of high Thn activity in different parts of India. In meeting with the problems of lightning strikes and related issues this information could be of much value.

Key words – Thunderstorm activity, Seasonal variation, Latitudinal variation.

1. Introduction

It is well known that a total of about 1500 - 2000 thunderstorms regularly invade the surface of the Earth at any instant of time (Roble and Tzur, 1986). This large number of occurrence of thunderstorms indicates that their frequency of occurrence is the highest amongst the frequencies of occurrences of other natural phenomena witnessed by mankind. This ubiquitous nature of thunderstorms has made them so friendly with mankind that their concern with the society goes almost unattended. There are two important end products of thunderstorms: the charging of the Earth's electrical atmosphere and production of precipitation on the Earth. The charging of the Earth's atmosphere is primarily responsible for the maintenance of the steady state of the Earth Ionosphere electrical condenser system, and precipitation retains the balance of the, hydrological cycle on the Earth. These two qualifications of thunderstorms are, accomplished because thunderstorms are the nature's gigantic electric machines

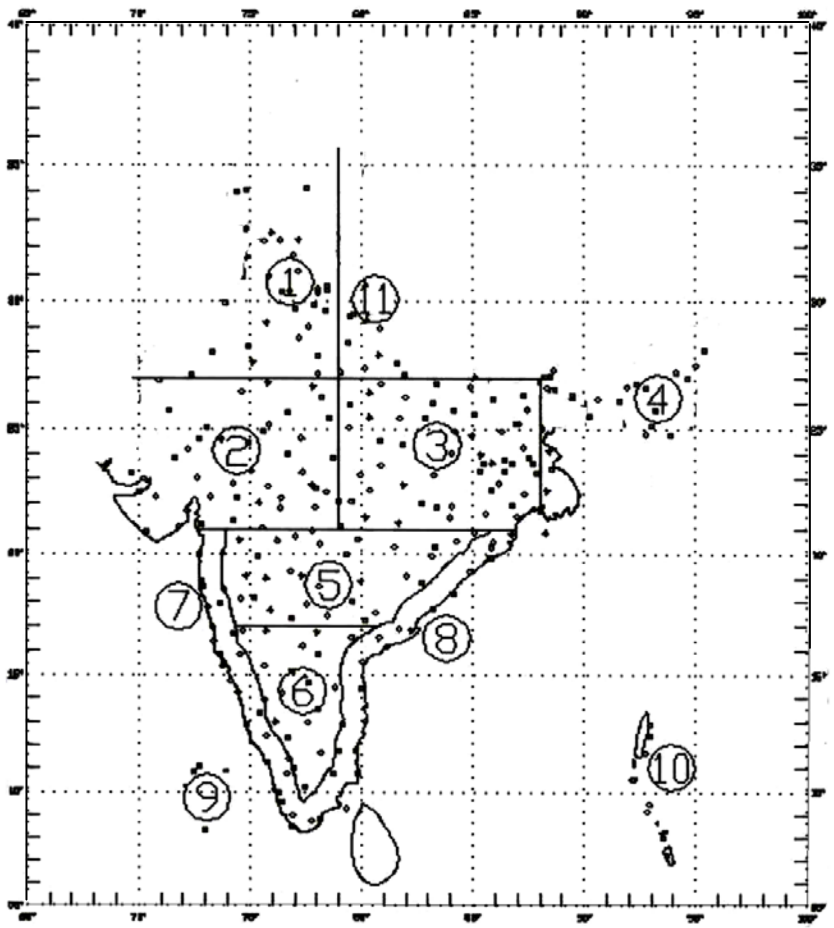


Fig. 1. Map of India showing the network of 276 observatory stations and the demarcation of India in 11 geographic regions used in this study

as well as potential stores of water in the form of precipitation. A survey of the literature in the past, representing regular and comprehensive works on thunderstorms over India, pointed out that thunderstorm studies over, India have received little attention (Raman and Rao, 1961; Rao *et al*. 1971; Manohar *et al.* 1999, Manohar and Kesarkar 2003, 2004). Significant results of above studies pointed out that although thunderstorms are producers of rainfall, their yield of rain per thunderstorm varies dramatically both in space and time. Corroborative results of this known fact are also available from some recent studies (Rutledge *et al*., 1992; Williams *et al*., 1992; Watson *et al*. 1994 a, b; Zipser 1994) performed elsewhere. Manohar *et al.* (1999) and Manohar and Kesarkar (2003) have further shown that a substantial fraction (~56%) of the annual thunderstorms over most parts of India takes place during the four month period of the monsoon season (June - September). This statistics suggest that thunderstorms are important ingredients of the monsoon systems and are fundamental to the monsoon phenomena as rain givers. Manohar *et al.* 1999, also pointed out that during the two episodes of lower seasonal frequencies of the thunderstorms (1972 and 1979) over India associated rainfall was also below normal by 23 % and 17 % respectively. Results of sensitivity study of occurrence of thunderstorms to surface air maximum temperature variation were very interesting and emphasizing (Manohar and Kesarkar 2003). Their results showed that surface (land) heating is a primary requirement for promoting the development of thunderstorms. The same study also pointed out that for subtle increment in the surface air temperature, thunderstorms tend to respond in an exponentially increasing manner. For planning and management of profitable agricultural activity, power transmission, safe air navigation and safety against forest fires from lightning and lightning strike events, etc. the knowledge of frequencies of occurrence of thunderstorms, in

TABLE 1 (a)

Regional statistics of number of thunderstorm days

Region	Number of stations	Pre-monsoon	Monsoon	Post monsoon	Winter	Annual
1	33	289.10 (8.76)	556.6 (16.87)	53.4 (1.62)	76.1 (2.31)	975.20 (29.5)
2	42	124.20 (2.96)	520.2 (12.39)	47.5 (1.13)	38.7 (0.92)	730.60 (17.4)
3	58	456.30 (7.86)	1444 (24.89)	113.3 (1.95)	107.5 (1.85)	2121.10 (36.5)
4	27	469.00 (17.36)	675 (25)	79.2 (2.93)	48.1 (1.78)	1271.30 (47)
5	33	225.20 (6.82)	325.4 (9.86)	58 (1.75)	19.8 (0.6)	628.40 (19)
6	25	254.80 (10.19)	197.5 (7.9)	99.5 (3.98)	7.7 (0.3)	559.50 (22)
7	20	228.90 (11.45)	158.4 (7.92)	167.5 (8.38)	29.3 (1.47)	584.10 (29)
8	20	136.00 (6.80)	328.9 (16.4)	113.8 (5.69)	15.9 (0.79)	594.60 (30)
9	3	26.60 (8.87)	21.5 (7.17)	15.1 (5.03)	6.9 (2.3)	70.10 (23)
10	7	89.80 (12.83)	84.2 (12.03)	26.4 (3.77)	15.7 (2.24)	216.10 (31)
11	8	48.30 (6.04)	113.6 (14.2)	10.8 (1.35)	14.7 (1.84)	187.40 (23)

(Figures at the top indicate the seasonal total Thn and figures in the parenthesis indicate the Thn normalized to stations contained in each region)

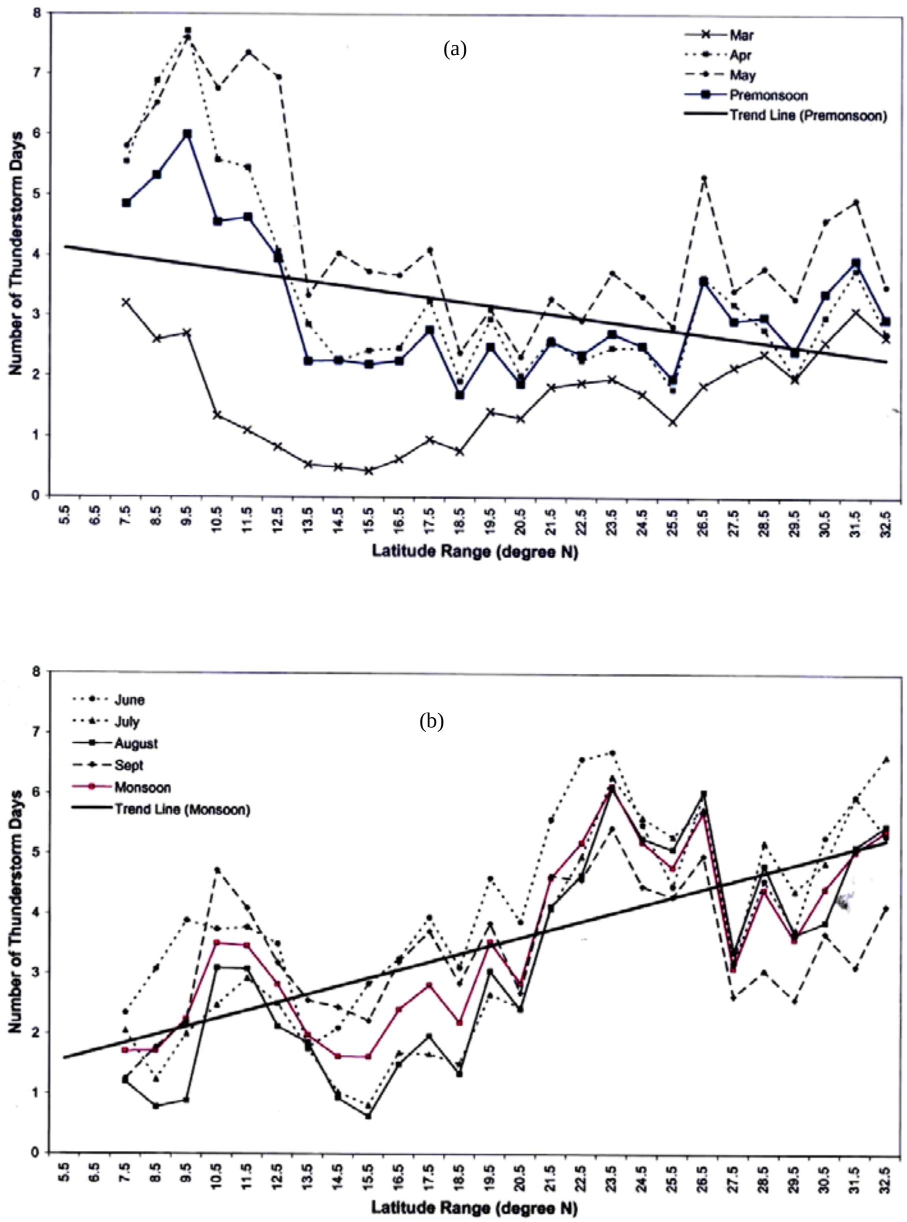
different parts of India, is all the more essential. These results therefore stress an urgent need of knowledge of seasonal and latitudinal thunderstorm activity over different geographic regions of India. Considering all these issues the present work has been taken up.

2. Data and method of analysis

In this study, again, we have selected climatological monthly mean data of number of thunderstorm days (Thn) and monthly mean of daily maximum surface air temperatures (*T*max) for 276 Indian observatories from the Climatological Normals "1951-1980" published by India Meteorological Department (IMD, 1999). Information about the station details, their network over Indian region and other particulars is available in our recent paper (Manohar and Kesarkar, 2003). For studying seasonal variation of thunderstorms over the expanse of India, we have carefully demarcated India in 11 different geographic regions which suit either of the climate regimes such as oceanic, coastal, inland, continental (deep inland), arid zone and hilly. Fig. 1 shows map of India and the 11 geographic regions of India into which it is demarcated. For some of these details one may refer to Manohar and Kesarkar (2004). Monthly data of Thn and *T*max are used to obtain their latitudinal and regional means.

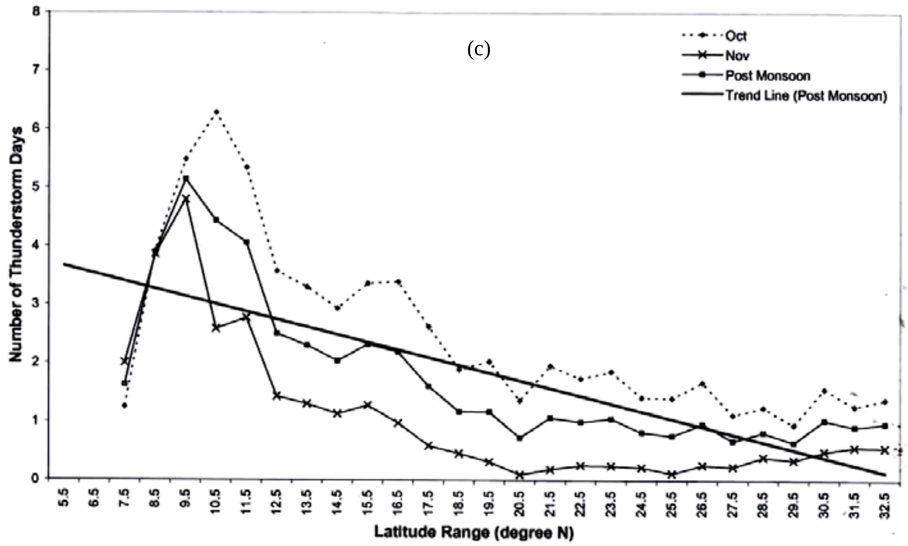
3. Results and discussion

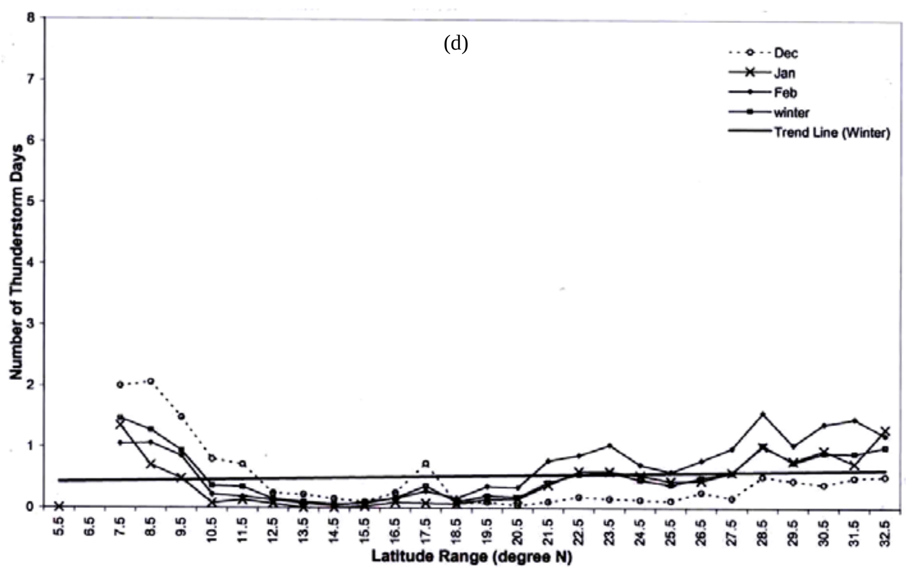
In sections 3.1 and 3.2 of this paper we have presented monthly — latitudinal and seasonal variation of Thn over India by using monthly climatological data of Thn for 276 Indian observatory stations. To understand the phenomenon of thunderstorms it is desirable to also discuss the presence of synoptic situations and the influence of orographic features which are associated with their occurrence. For this purpose we have furnished regional statistics of thunderstorm activity during four seasons of the annual period over 11 geographic regions of India in Table 1(a). From this table it is seen that some regions of India are having significant amounts of



Figs. 2(a&b). Latitudinal variation of monthly mean number of thunderstorm days during (a) pre-monsoon season and (b) monsoon season

thunderstorm activity in different seasons. The synoptic reasons for this thunderstorm activity are briefly given below. The synoptic - scale features are indirectly associated with tropical easterly jet and low level jet which makes its appearance over south peninsula before and during the monsoon seasons (Rao, 1976; WMO, 1979; Chowdhury and Banerjee, 1983; Asnani, 1993). It is noted that under the influence of jet stream mesoscale vortex and associated convergence often have predominant influence on development of convective clouds. From the table it is noted that in the pre-monsoon season Region 4 (Hilly region of NE India) gets considerable amount of thunderstorm activity due to convective instability and even due to norwesters. Regions 6 and 7; south parts of Regions 8, 9 and 10 are influenced by the thunderstorm activity in association with the convective instability due to summer heating, availability of moisture in preparation of the onset of the southwest monsoon. During the monsoon season there is a large dense thunderstorm activity in Regions 3 and 4 because the monsoon trough passes through Region 3 and also another trough passes through region 4. Easterly





Figs. 2(c&d). Latitudinal variation of monthly mean number of thunderstorm days during (a) post monsoon season and (b) winter season

waves of northeast monsoon give some thunderstorm activity over southern parts of Regions 8 and 7 and also in Region 9.

The mean altitude of the hilly land area of northeast India (Region 4) which is occupied by ranges of Garo, Patkai and Arakan mountains, is quite high. The orographic structure of this region on account of these hills has become complex. The mean wind flow over this region, nearness to the head Bay of Bengal, complex terrain and high mean altitude, all these factors put together have made significant influence on the development of thunderstorm activity over this region. This is evident from the statistics of thunderstorm activity presented in Table 1 (a). Over irregular and complex terrain the largest clouds develop into towers quite often and easily amongst clustered small clouds (Gamier, 1967; Rao 1976; Kessler, 1982). Over such terrain the ascent of air is concentrated and intensified particularly when the area is moist and warm by virtue of its composition, low albedo and high elevation.

3.1. *Monthly latitudinal variation of thunderstorm days*

3.1.1. *Pre-monsoon season*

Latitudinal variation of monthly lightning activity and frequencies of occurrence of thunderstorm days has been an important topic of study in the past by several investigators (Brooks, 1925; Prentice and Mackerras, 1977; Kowalezyk and Bauer, 1981; Turman and Edgar, 1982; Williams, 1992; Mackerras *et al*., 1998; Manohar *et al*., 1999). The basic idea involved in studying latitudinal seasonal variation of thunderstorms aims at proper understanding of the notion that the moist and humid Sun heated tropical land surfaces favor development of thunderstorms because heating is systematically stronger close to the tropics than at higher latitudes. This behavior is the result of the pole to equator temperature increase and the Clausius - Clapeyron relation (Williams, 1992). With this brief information we now, present the results of monthly latitudinal variation of Thn days over Indian region.

The monthly latitudinal variation of Thn across the latitude range 7° N - 33° N over the Indian region during different seasons is shown in Figs. 2 (a-d). The monthly mean number of thunderstorm days across the individual latitude range, starting from 7° N - 33° N, is plotted against mean latitude 7.5, 8.5 ..., 32.5° N. The months in these diagrams (a-d) have been grouped by season: that is March - April - May (Pre-monsoon), June - July - August - September (Monsoon), October - November (Post monsoon) and December - January - February (Winter), which constitutes the total annual period. A trend line of best fit and seasonal mean curve is also indicated in each diagram (a-d). A careful inspection of these seasonal curves depicts a systematic latitudinal behavior. Significant results of their seasonal variation are described below.

Fig. 2 (a) shows results for the pre-monsoon season months. A careful observation of the three curves in this diagram shows a distinct separation between them althroughout the range of latitude (7° N - 33° N) over the Indian region, such that March values are lower than those of April, and April values are lower than those of the month of May. This observation of inter-curve spacing clearly shows that as the season progresses, there is a clear increase in thunderstorm activity. Increase in the frequencies of occurrences of thunderstorms with the advance of season, therefore, appears to be an important characteristic feature of the Indian region. In the lower latitude range, (8° N - 12° N), thunderstorm frequencies in the months of April and May are noted to have dramatically increased by a factor of about 2 to 9 in comparison with that in the month of March. The meteorological sub-divisions which show this sharp hike in thunderstorm frequencies are Kerala, Tamil Nadu and South Karnataka. Another important result of this analysis is the systematic drop in each month in thunderstorm frequencies in the latitude range 14° N - 18.5° N. In each of these three months thunderstorm frequencies in this latitude range are the lowest across the whole of the Indian region. The meteorological sub-divisions corresponding to this latitude range are north interior Karnataka, Rayalaseema, coastal Andhra Pradesh and Telangana. As we move north of 18.5° N, we note that thunderstorm activity shows a monotonous behaviour with regular rise and fall. The result presented above appears to be consistent with the general view that thunderstorms are most frequent over moist and humid equatorial land regions. In the analysis we note that the seasonal - latitudinal distribution of thunderstorms is not so smooth. A trend line of best fit drawn through the monthly values of thunderstorm frequencies suggests that their frequencies decrease with increase in latitude. However, from the observations of Fig. 2 (a) it is important to infer that thunderstorm frequencies show a fall upto about 18.5° N, after their initial high values in the latitude range 8° - 10.5° N. Then onwards thunderstorm frequencies show a clear tendency to rise.

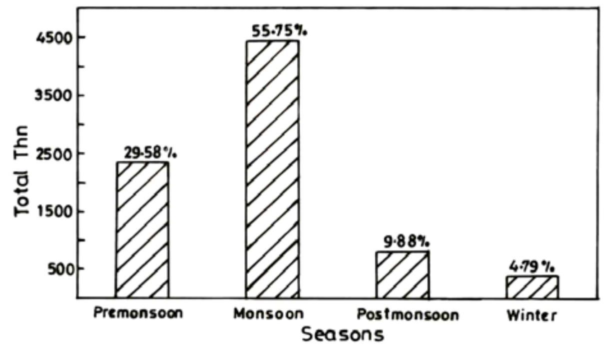


Fig. 3. Seasonal distribution of aggregate number of Thn over India

3.1.2. *Monsoon season*

Fig. 2 (b) shows the curves for the four months of the monsoon season. An inspection of each curve in this figure shows that thunderstorm activity, by and large, increases with increase in latitude. We note that there are three clear maxima in the latitudinal thunderstorms in each month, interspersed with two minima. The first maximum is located in the latitudinal range 11° N - 13° N, the second and third maximum is located in the latitude ranges 23° N - 28° N and 31° N - 33° N respectively. The slope of the line of best fit through the data points also brings out the observation that thunderstorm activity in the monsoon season increases with increase in latitude. This latitudinal behaviour of the thunderstorms across the latitude range 7° N - 33° N, over the Indian region is in contrast with that in the pre-monsoon season. This observation therefore suggests the preponderence of thunderstorms in the monsoon season. In order to highlight this result we present in Fig. 3 the distribution of seasonal total number of thunderstorm days taken over the whole Indian region. In Fig. 3 we clearly note that about 56% of the annual total thunderstorms occur in the monsoon season. This observation is consistent with the results of previous studies (Rao *et al*., 1971, Manohar *et al*. 1999). This result clearly emphasizes the significant role of thunderstorms in monsoon studies.

We also note that amongst these three maxima, the second and third maximum is highly pronounced than the first one. The meteorological sub-divisions corresponding o the first, second and third maximum in thunderstorm activity are: Northern parts of Tamil Nadu, Pondicherry, and south interior Karnataka; the Indian region occupied by the normal position of Inter Tropical Convergence Zone (ITCZ); and Punjab, Himachal Pradesh and Jammu and Kashmir respectively.

The seasonal lowest profile in thunderstorm activity is seen as a dip centering around latitude range 15° N - 18° N. The meteorological sub-divisions corresponding to this dip are Marathwada, Telangana and adjoining regions. The dip region in Fig 2 (b) was matched with the data of the India Meteorological Department (IMD, 1981). It was noted that this is also the same arid zone / less rainfall region of Marathwada, Telangana and its adjoining parts in south central India where seasonal thunderstorm days as well as rainfall are less.

Since thunderstorm frequencies significantly differ in the pre-monsoon and monsoon seasons, it is necessary to have some discussion on the electrical and meteorological conditions prevalent during these seasons.

In the pre-monsoon season, intense afternoon heating, associated with low level moisture, usually favours generation of deep isolated thunderstorms associated by synoptic conditions over the continents. Elevated topography is a preferred region for convective triggering and convection thus initiated can spread in adjoining areas. Development of isolated deep convective thunderstorms is a characteristic feature of tropical land areas in the pre-monsoon season. For most of these thunderstorms there is a pronounced specific diurnal cycle. The Convective Available Potential Energy (CAPE) associated with these storms is often reported to be very high (>1000 J Kg^{-1}) in this season (Rutledge *et al*. 1992, Williams *et al*., 1992).

Atmospheric conditions during the monsoon season are different from those in the pre-monsoon season. In the monsoon season, highly moist airmass in great depth over most part of the country, with suppressed surface temperature is present. CAPE values in the monsoon environment are noted to be typically below (<1000 J Kg^{-1}). In, the upwelling zone of the monsoon environment the air is moist neutral and the vertical air motions in this season are not the result of CAPE but rather are the result of synoptic scale air motions driven by horizontal pressure gradient that in turn are set up by latitudinal gradients in the surface temperature. In the monsoon season there is no specific diurnal cycle for the initiation of thunderstorms. It has been generally noted that the electrical vigor of monsoonal thunderstorms is considerably lower than those of the pre-monsoon season ones (Manohar *et al*. 1999).

3.1.3. *Post monsoon season*

In Fig. 2 (c) we have shown seasonal frequencies of occurrence of thunderstorms for the post monsoon season months (October - November). In these months we note that thunderstorms show a systematic latitudinal diminution. The November frequencies are seen to be far less than those in the month of October. In the narrow latitude belt 9° N - 12° N their frequencies are initially high in the range of 5 - 7 thunderstorms. The higher frequency of ~6 thunderstorms in the lower latitudes is associated with the presence of the convective nature of distributed weather during the northeast monsoon season over most parts of the east coast of south India. As we move north of this latitude belt, we note that althroughout the higher latitude range, thunderstorms decrease with increase in latitude.

3.1.4. *Winter season*

In Fig. 2(d) we have shown thunderstorm frequencies for the winter season months (D-J-F). We note that in the latitude belts 8° N - 10° N, and 22° N - 33° N, thunderstorm frequencies are low in the range 1 - 2 thunderstorms. In the remaining span of latitude, thunderstorm frequencies are quite close to zero. Among these three months, the lowest frequencies of thunderstorms are witnessed in the months of December and January.

Monthly latitudinal variation of thunderstorm days over Indian region was presented in a recent study by Manohar *et al*., 1999. Their analysis was based on station data, taken from Monthly Weather Reports of India Weather Review (I. M. D., 1970 - 1980), limited to just 78 Indian observatories. Moreover the latitude resolution in their analysis was confined to 5° interval across the

TABLE 1 (b)

Significant observations of seasonal variation of Thn over 11 geographic regions of India

Geographic Region No.	Location of mean Latitude of Region (°N)	Month of Latitudinal Ist maximum in		Nature of seasonal oscillation of Thn single/double	Mean annual amplitude of Thn $\frac{\text{Max} - \text{Min}}{\text{Mean}}$
		*T*max	Thn		
9	10	April	May	Pronounced double	2.3
10	10	April	May	Double with annual maximum very weak	2.4
6	13.5	April	May	Pronounced double	2.6
7	15.5	April	May	Highly pronounced double	1.9
8	15.5	May	June	Double with annual maximum stronger	2.0
5	19	May	June	Highly pronounced double	2.8
2	24	May	June	Single	2.0
3	24	May	June	Broad single	2.1
4	2.5	April	May	Double	1.8
11	28.5	May	July	Broad single	1.3
1	30.5	June	July	Single	1.6

Indian region from 8° N - 30° N. In this study the nature of data is, different and the station network is ~4 times dense and the latitude resolution is still closer. Inspite of these differences it is gratifying to note that almost all the results in the two studies are in very good agreement. The results presented here therefore may be taken as characteristics of thunderstorms over India.

3.2. *Seasonal variation of number of thunderstorm days (Thn) and surface air maximum temperatures (Tmax) over 11 geographic regions of India*

In the tropics and adjoining regions the seasonal variation of thunderstorms (Thn) is linked with heating of surface of the Earth during the north-south oscillation of the Sun across the equator over the course of annual period of the year. It is also controlled by the surface conditions of the region dictated by proximity to the seas / oceans, topographical features, aridity etc. India is endowed with the above mentioned climate varieties. Since surface heating is a central agency in all these considerations it is interesting to study how surface air maximum temperatures correlate with thunderstorms over these regions. Fig. 4 shows variation of Thn and *T*max over 11 geographic regions. Positions of diagrams in this figure are consistent with the respective locations of 11 regions (Fig. 1). For example, pairs of regions 9, 10; 7, 8; and 2, 3 are placed along the same mean latitude of these respective pairs of regions [Table 1 (b)]. This arrangement of diagrams was essential to understand how monthly values of these two parameters (Thn, *T*max) undergo change with their latitudinal locations and proximity to sea etc.

Some significant observations of phase shift, double/ single oscillation (Fig. 4) and mean annual amplitude of Thn in these belts are summarized in Table 1 (b). The correlation between months of latitudinal Pt maximum in *T*max and Thn is evident from columns (3) and (4) of Table 1 (b), and this result is discussed separately in Section 3.4 of this paper. From column (5) of Table 1 (b) we note that latitudinal belts within the tropics exhibit a pronounced double maximum in Thn, while latitude belts outside the tropics exhibit a clear single maximum in Thn. We thus notice pronounced difference in the signals (double/single oscillation) of Thn activity across the latitude belts over the Indian region as we move northwards away from the equator. We compare our result with the results of previous studies and note that our results of seasonal variation of thunderstorm day activity are in good agreement with the studies of Williams (1994) and Manohar *et al*. (1999).

Regions 9 and 10 are small islands and are oceanic in their character and lie on the same latitude of 10° N. These regions are therefore expected to show similar seasonal variation in Thn. However, we note some differences in their seasonal behaviour. They are as follows. At region 9 the August minimum is very strong which is unlike in the region 10. The second maximum at region 9, which is in the Arabian Sea occurs in the month of October but at region 10 it occurs in the month of September. Thus, there is difference of about one month

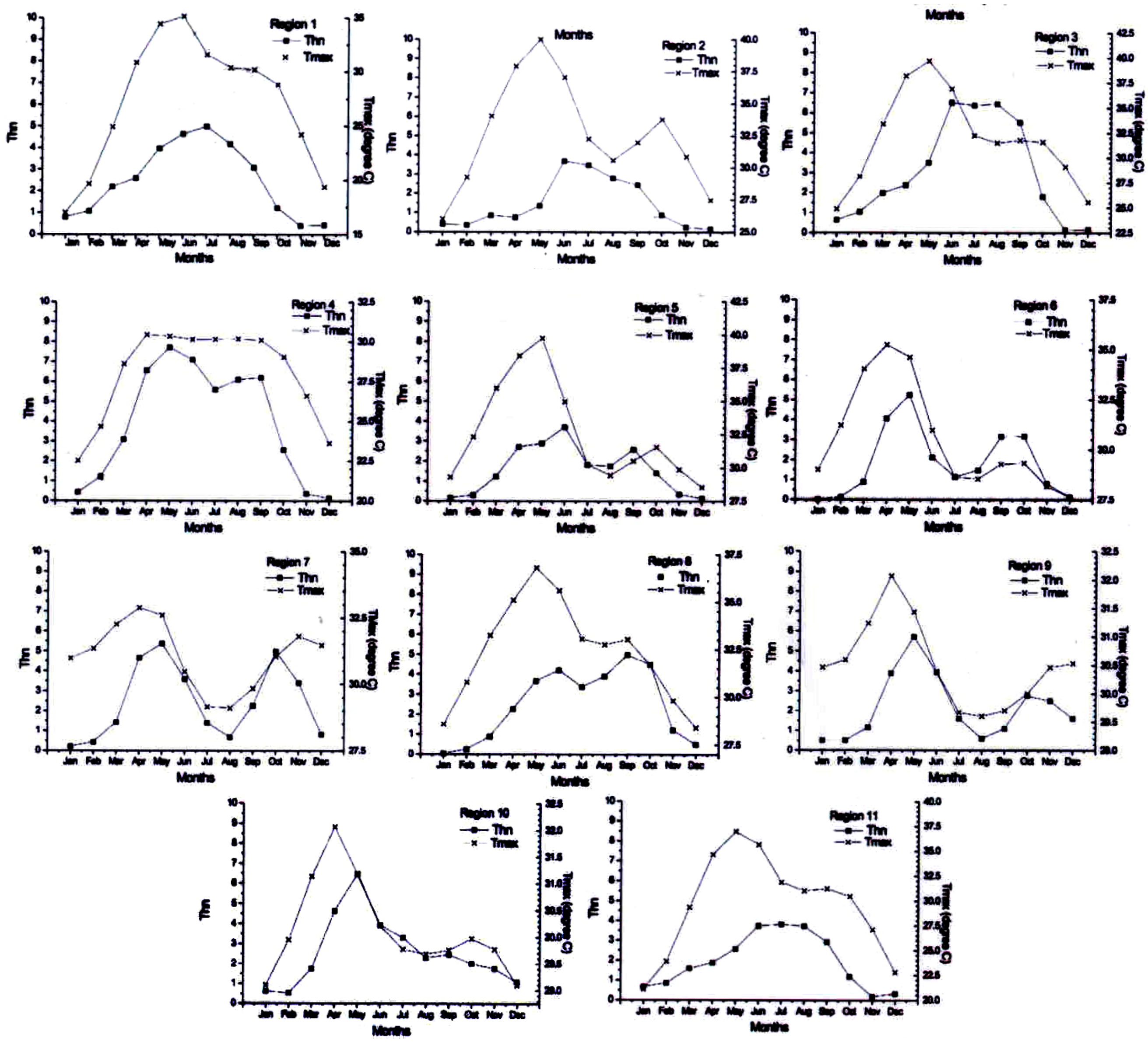
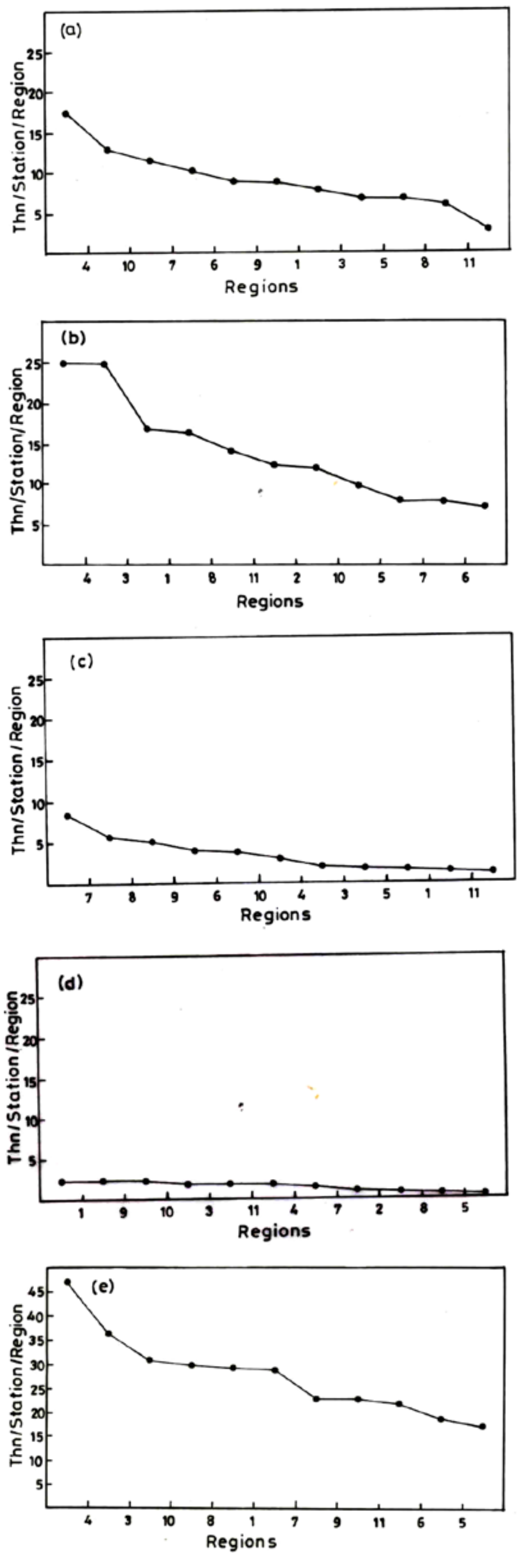


Fig. 4. Seasonal variation of Thn and *T*max over 11 geographic regions of India

in these maximum over regions 9 and 10. This difference in the months of second maximum is attributed to the early setting up of the northeast trade winds over region 10 and not over region 9 which is still dominated by the southwesterly air flow. It is considered that the prevalence of continental/maritime conditions over a region is an important factor in deciding convective activity. Regions 7 and 8 are coastal strips situated respectively along the west and east coasts of India. It is therefore expected that the features of seasonal variation in Thn over these regions should be comparable with each other. However we note that the 2^{nd} maximum in Thn over region 8 is more pronounced than the first one. This feature is unlike over region 7. The stronger 2^{nd} maximum in Thn over region 8 is due to the presence of convective nature of disturbed weather during the northeast monsoon season over most parts of the east coast of south India. Also we note that the west coast happens to be on the leeward side for the northeast trade winds. Region 3 is situated marginally within the tropics and comprises most parts dominated by the presence of ITCZ (Fig. 1). In this region Thn activity is highly enhanced during the three months of June, July and August (Fig. 4) and shows a broad single maximum. Broad single maximum over



Figs. 5(a-e). Thn per station per region during (a) Pre-monsoon season, (b) Monsoon season, (c) Post monsoon season, (d) Winter season and (e) Annual region

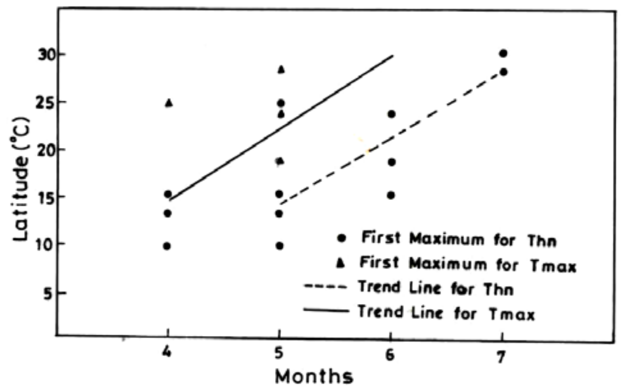


Fig. 6. Relation between month of occurrence of latitudinal first maximum in *T*max and Thn

region 3 is therefore quite expected since thunderstorm activity in these months (monsoon season) is far more than that during other season (Fig. 3).

3.3. *Identification of zones of high thunderstorm activity*

Figs. 5 (a-e) presents average score of Thn per station over 11 geographic regions for the four seasons (Pre-monsoon, Monsoon, Post monsoon and Winter), and also for the annual period. The scores of thunderstorms are arranged in descending order their number and the geographic regions, corresponding to the scores, are labeled in order of their sequence and are shown along the *X* - axis in Figs. 5 (a-e). It is important to note that in each diagram of Fig. 5 the sequence of names of geographic regions is not the same. The information presented in this analysis is keeping in mind the threat of lightning activity that evolves from the development of thunderstorms. The possibility of occurrence of lightning activity increases with higher score of number of occurrence of thunderstorms and hence it is believed that this information may be most welcome.

From Figs. 5 (a-e) it is noted that vulnerable zones in the pre-monsoon season are Regions 4, 10 and 7; in the monsoon season they are Regions 4, 3, and 1; in the post monsoon season they are Regions 7, 8 and 9; while in the winter season they are Regions 1, 9, and 10. On the annual scale these zones are Regions 4, 3 and 10. In particular, it is noted that the Region 4 (hilly areas of northeast India, comprising Arunachal Pradesh, Assam and Meghalaya, Nagaland, Manipur, Mizoram and Tripura) stands out and therefore Region 4 should receive highest priority in establishing lightning measuring equipments and protective measures against lightning hazards from thunderstorms.

3.4. *Relation between 1 maximum in Tmax and Thn on seasonal time scale*

Fig. 4 shows curves of seasonal variation of *T*max and Thn averaged over the latitude ranges occupied by 11 geographic regions. The months of the Ist maximum in *T*max and Thn and the mean latitudes of 11 regions are picked up from 11 diagrams of, Fig. 4 [Table 1 (b) for cross reference]. These two data sets are used to prepare Fig. 6 to study the correlation between months of occurrence of Ist maximum in *T*max and Thn across the latitudes of India. In Fig. 6 months of maxima in Thn (•) and *T*max (▲) are plotted along *X* - axis and respective latitudes are plotted along *Y* - axis. Some points in this figure overlap because the mean latitudes of Regions 9, 10; 7, 8; and 2, 3 are same [Table 1 (b)], and hence we do not see 11 symbols in this figure. Straight lines of best fit are drawn through the two sets of data points in this figure. Inspite of some scatter in these data, it is noteworthy that both lines run almost parallel to each other such that Thn line is shifted to the right side of the diagram by 1 month. This result clearly suggests that the months of seasonal maximum in Thn occur with a positive lag of about 1 month from that of the months of maximum in *T*max. The time relation between the North - South oscillation of the Sun and associated migration of ITCZ was studied by Riehl (1979). Similarly, the time relation between seasonal variation of area averaged insolation, in the latitude range ± 25° with air temperature for the global topics, was studied by Williams (1994). We note that our present result and the results of studies cited above are in good agreement with each other. It is gratifying to note that this old but very important result in meteorology is corroborated by using the large and latest climatological data from the Indian sub-continent.

4. Conclusions

Latitudinal inter-month comparison of Thn during the pre-monsoon season showed a significant increase in Thn within a small range (8° N - 12° N) of latitude in the months of April and May as compared to that in the month of March. However, from the observations of Fig. 2 (a) it is important to infer that thunderstorm frequencies show a fall upto about 18.5° N, after their initial high values in the latitude range 8° N - 10.5° N. Then onwards thunderstorm frequencies show a clear tendency to rise. The analysis for the four months of monsoon season showed that the latitudinal variation in Thn was in contrast with that in pre-monsoon season. This behaviour of latitudinal Thn activity in the monsoon season clearly pointed out a systematic increase in Thn with increase in latitude. An important result corroborating above observation showed that about 56%, of the annual total Thn occurs in the monsoon season alone. Since thunderstorm are recognized as the potential source of precipitation and about 56% of the annual thunderstorm activity over India occurs during the monsoon season it is realized that this study emphasizes the important role of thunderstorms in relation to monsoon studies. The other result of this analysis showed that most of the Indian region in the months of December and January is quite free from thunderstorms because of low moisture content and colder temperature conditions over most of the Indian region in the months of December and January. Seasonal variation of Thn and *T*max averaged over 11 latitude ranges of 11 geographic regions of India showed systematic sequence in their phase shift as well as in their behaviour of double/single oscillation within and outside the tropics over the course of annual period. Thn data over 11 geographic regions were used to obtain their averages per station per region for four seasons as well as for the annual period. Information from this analysis is very important in identification of vulnerable zones of high thunderstorm activity. It is believed that this result may be useful in the planning of lightning studies and in the management of effective measures against hazards of lightning strikes etc.

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