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# Climatology of thunderstorm activity over the Indian region : II. Spatial distribution

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**सार** – पृथ्वी और वायुमंडल से संबंधित सूचना के अनेक क्षेत्रों में गर्ज भरे तूफान महत्वपूर्ण भूमिका निभाते हैं। तूफानों के इस महत्व से अवगत होने के बावजूद यह द्रष्टव्य है कि भारत में आए गर्ज भरे तूफानों के विषय में पहले बहुत कम ध्यान दिया गया है। भारत के ग्यारह भौगोलिक क्षेत्रों में आने वाले 276 भारतीय वेधशाला केन्द्रों में गर्ज भरे तूफानों (टी.एच.एन.) वर्षा के दिनों (टी.एन.आर.) और वर्षा की राशि (टी.आर.आर.) के दिनों की संख्या के नवीनतम (भारत मौसम विज्ञान विभाग, 1999) जलवायविक मासिक आँकड़ों का विश्लेषण इन प्राचलों के परस्पर संबंध की जाँच करने के लिए किया गया है। टी.एच.एन. और टी.एन.आर. के आँकड़ों के समूहों के विश्लेषण से यह पता चलता है कि मानसून से पूर्व की ऋतु में भारत का अधिकांश भाग लगातार और व्यापक रूप से आने वाले गर्ज भरे तूफानों किन्तु कभी कभी होने वाली वर्षा के दिनों के साथ, काफी प्रबल रूप से प्रभावित रहता है। तथापि मानसून ऋतु में गर्ज भरे तूफान के दिनों में वर्षा वाले दिनों की अत्यधिक वृद्धि होने से टी.एच.एन.–टी.एन.आर. का संबंध विपरीत हो जाता है। मानसून वर्षा ऋतु से पूर्व भारत की जलवायविक विशेषता, महाद्वीपी संवहन के कपासी वर्षा मेघ तंत्र की विशेषता के रूप में जानी जाती है तथा मानसून वर्षा ऋतु की विशेषताओं को मानसूनी संवहन के कपासी वर्षा मेघ प्रणाली के रूप में जाना जाता है। इसलिए मानसूनी संवहनी तंत्र की विशिष्टता भारत के दक्षिण पश्चिमी मानसून के निष्पादन को स्पष्ट करने के लिए अत्यंत महत्वपूर्ण है। भारत के ग्यारह भौगोलिक प्रदेशों में वार्षिक अवधि की चार ऋतुओं के दौरान टी.आर.आर. तथा टी.एच.एन. के बीच विश्लेषण किया गया। मानसून ऋतु से संबद्ध परिणामों से यह ज्ञात होता है कि वर्षा के समय गर्ज भरे तूफानों का योगदान अन्य तीन ऋतुओं में सबसे अधिक होता है यह पता चला है कि मानसूनी वर्षा के समय गर्ज भरे तुफानों की वर्षा का योगदान अत्यंत महत्वपूर्ण होता है।

**ABSTRACT.** Thunderstorms play important roles in many areas of information about earth-atmosphere relationship. Inspite of this awareness of importance of thunderstorms, it is noted that studies about thunderstorms over India received little attention in the past. Latest (IMD, 1999) climatological monthly data of number of thunderstorm days (Thn), rainy days (Tnr), and rainfall amount (Trr) for 276 Indian observatory stations are analyzed, over 11 geographic regions comprising India, to examine relationship between these parameters. Analysis of Thn and Tnr data sets showed that in the premonsoon season major part of India is strongly dominated by frequent and widespread thunderstorms but with occasional rainy days. However, in the monsoon season on account of very large increase in the rainy days over the thunderstorm days, the Thn-Tnr relationship is reversed. The climatological feature of India in the premonsoon season is noted as a characteristic of cumulonimbus regime of continental convection, and the one in the monsoon season is termed as cumulonimbus regime of monsoonsal convection. The prominence of monsoonal convective regime is therefore very important in deciding the performance of Indian southwest monsoon. The analysis between Trr and Thn was carried out over 11 geographic regions of India in the four seasons of the annual period. Results pertaining to monsoon season showed that the contribution of thunderstorms to rainfall is highest among the other three seasons. It is inferred that thunderstorm's rain contribution to monsoonal rainfall is significant.

**Key words** – Climatology, Thunderstorm activity, Spatial distribution.

## 1. Introduction

Thunderstorms are one of the wonders of the atmospheric phenomena for many reasons. They originate on account of contrasting features of surface heating, and moisture content over two regions of the earth adjacent to each other. Their development is involved in rapid vertical rearrangement of deep air layers. Large – scale processes promote and shape vertical and horizontal air motions, while small – scale processes distribute mass, momentum and energy within the convectively overturning layer of the atmosphere and produce rain, hail and strong local winds. Development of the strong electric field within and in the environment of a thunderstorm is also its very important property. Above statements about the qualifications of the action of

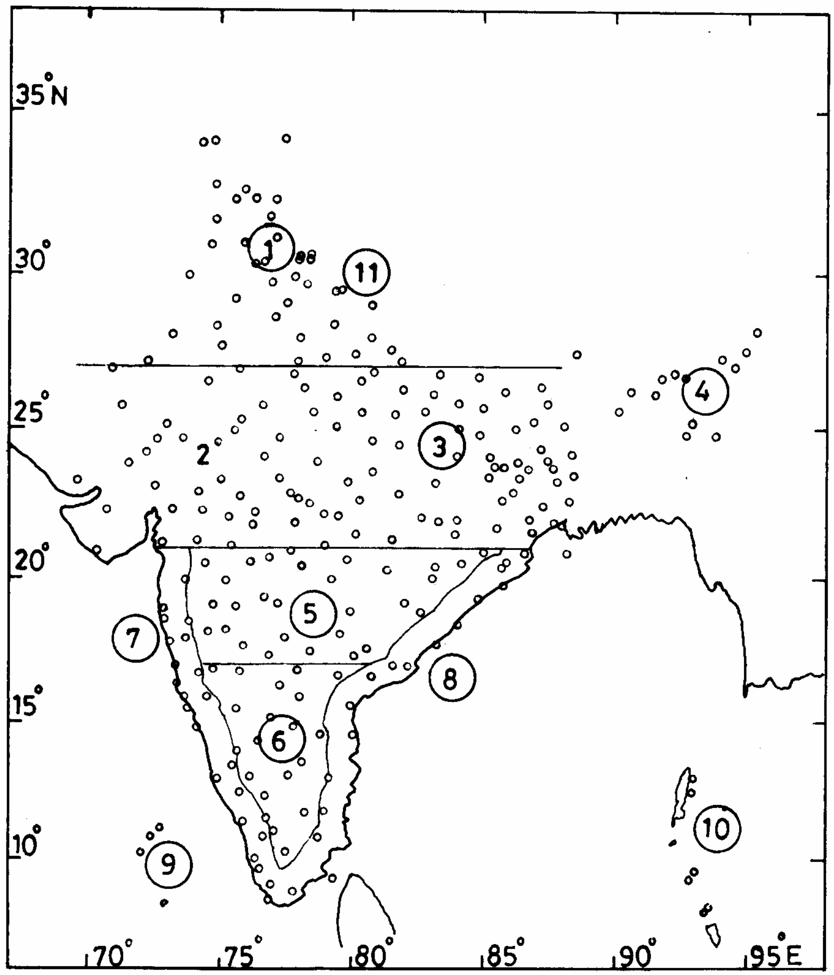



**Fig. 1 (a).** Map of India showing 11 geographic regions used in this study

thunderstorms may become clearer from some of the exemplary results of studies devoted to atmospheric research.

Rajamani (1989) studied the thermal and dynamical characteristics over monsoon depressions associated with large – scale thunderstorm activity. His results pointed out the presence of warm cores of air with positive temperature anomaly in the range 2 - 3° C in the altitude range 700 – 300 hPa level over the depression area. Thunderstorm studies are also important in the area of their assessment of precipitation yield. Earlier studies corroborating the seasonal rainfall with frequencies of thunderstorms were by Landsberg (1971) and Frier (1978). Their results showed that, in general the low – precipitation regimes matched with lower frequencies of thunderstorms or were due to lack of thunderstorms – producing conditions. Krehbiel (1986) has pointed out that a significant fraction of the earth's rainfall in temperate climates comes from electrified clouds. A possible link between electrical processes and precipitation development is also spelled out. Another important study in this regards was by Zipser (1994). He studied the correlation between rainfall and number of thunderstorm days for the tropical stations along the west – coast of Africa. His analysis showed variable results in rainfall along the north – south strip of West Africa. To our understanding the only available recent study on thunderstorms and rainfall over India was by Manohar *et al.* (1999). Although their study has presented very useful results concerning thunderstorm days and the Indian S-W monsoon rainfall, we also note limitedness in the data and the period of their study. A need for a comprehensive study employing latest data of large number of stations is strongly felt.

Flow of electric currents from the aggregate number of world's thunderstorms to the earth and ionosphere does

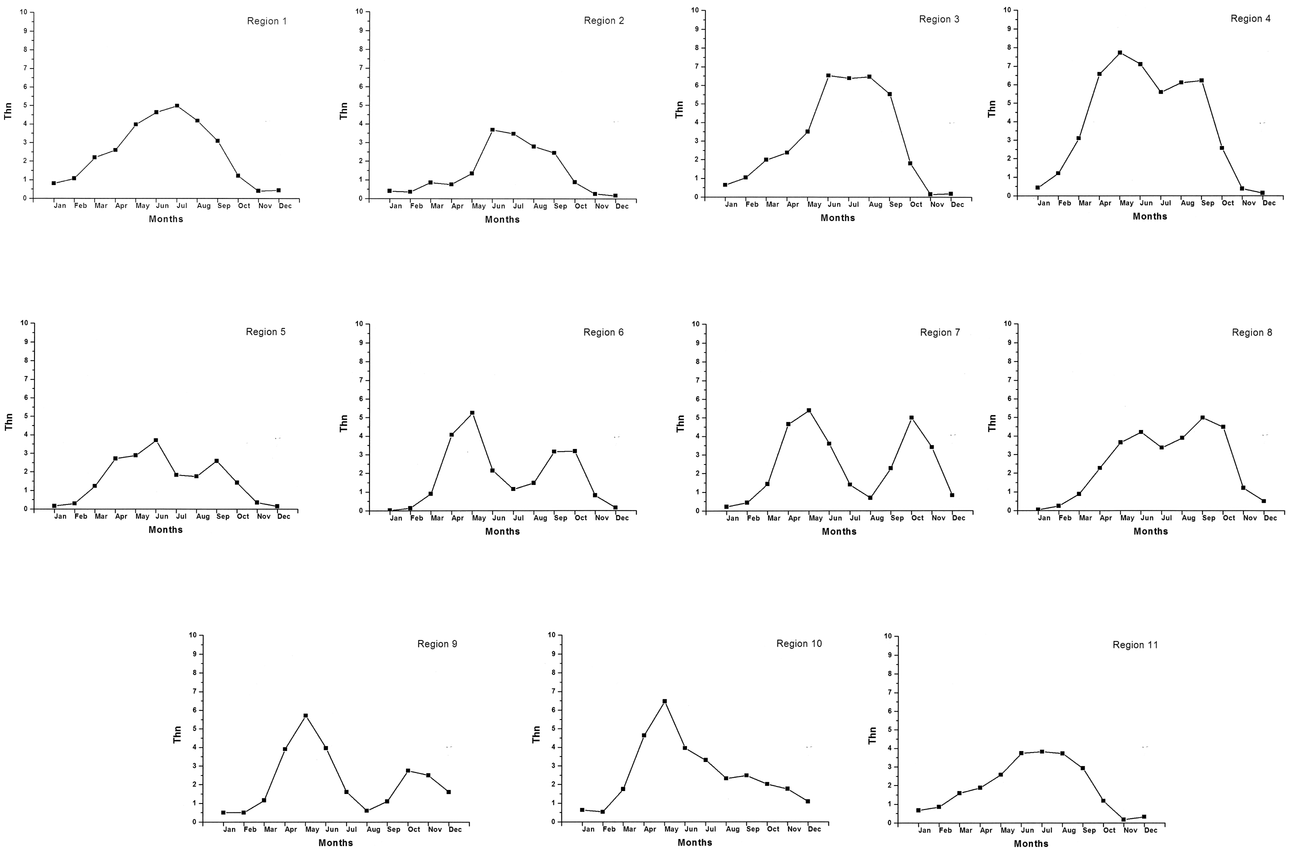



**Fig. 1 (b).** Seasonal variation of mean number of thunderstorm days over 11 geographic regions of India

the charging of the earth – Ionosphere condenser system. Thunderstorms thus play a key role as generators of atmospheric electricity (Wilson, 1920; Chalmers, 1967; Robel and Tzur, 1986). The first quantitative evidence to show that the tropical land regions have 5 – 10 fold higher thunder days than that over the oceans came from the world's station thunder days analysis by Brooks (1925). Many further studies have also emphasized that a significant majority of the world's thunderstorms are reported to occur over the tropical (± 30°) hot and humid land areas (Kessler, 1986; Williams 2001). Thunderstorms being so important phenomena, we note that their studies of spatial distribution over India are not in pace with the requirement. The only available record of studies of frequencies of thunderstorms over India was by Rao *et al*. (1971). Such studies are reported to be conducted regularly and frequently in other parts of the world (Court and Griffiths, 1982).

In this paper we have focused our attention on studying spatial distribution of thunderstorms and the aspect of variability in relationship between thunderstorm days, rainy days and rainfall amount in different geographic regions of India. Monthly and seasonal isoceraunic contours for India are prepared and results are compared with early studies of Rao *et al.* (1971). In the intervening period of three decades (1971 – 2003), since the last study (Rao *et al*., 1971), greatly expanded network of Indian observatories must have added sufficient data of the above three parameters. This new outlook of the latest and increased data (IMD, 1999) forms an important component of our present study. It is believed that results of this study may be welcome by the scientific community.

## 2. Data and method of analysis

The India Meteorological Department (IMD) has recently (1999) brought out a voluminous but very useful publication entitled "Climatological Normals 1951-80". Normals provided in the publication are in the form of tables of mean monthly values of surface data of

**TABLE 1**

**Region wise details of stations, climate suitability and Thn statistics**

| Region No. | Suitability to climate regime | No. of stations | Annual total | Statistics of Thn | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pre-monsoon season | | | | Monsoon season | | | | Post Monsoon season | | | | Winter season | | | |
| | | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1. | Hilly region of NW India | 33 | 975.2 | 2.99 | 2.2 | 0.7 | 30 | 4.24 | 3.3 | 0.8 | 57 | 0.83 | 0.6 | 0.7 | 5 | 0.79 | 0.7 | 0.8 | 8 |
| 2. | Arid zones | 42 | 730.6 | 0.99 | 0.9 | 0.9 | 17 | 3.10 | 2.4 | 0.8 | 71 | 0.57 | 0.4 | 0.7 | 7 | 0.31 | 0.3 | 1.1 | 5 |
| 3. | Central deep inland / continental | 58 | 2120.7 | 2.62 | 2.0 | 0.7 | 21 | 6.22 | 4.0 | 0.6 | 68 | 1.0 | 0.8 | 0.8 | 6 | 0.62 | 0.4 | 0.7 | 5 |
| 4. | Hilly region of NE India | 27 | 1271.3 | 5.79 | 3.7 | 0.6 | 37 | 6.25 | 4.9 | 0.8 | 53 | 1.7 | 1.2 | 0.8 | 6 | 0.59 | 0.6 | 1.1 | 4 |
| 5. | Inland | 33 | 628.4 | 2.27 | 2.0 | 0.9 | 36 | 2.47 | 2.3 | 0.9 | 52 | 0.88 | 0.9 | 1.0 | 9 | 0.20 | 0.3 | 1.4 | 3 |
| 6. | Inland | 25 | 559.5 | 3.40 | 2.2 | 0.6 | 45 | 1.98 | 1.8 | 1.0 | 35 | 2.0 | 1.7 | 0.9 | 19 | 0.10 | 0.1 | 1.1 | 1 |
| 7. | Coastal | 20 | 584.1 | 3.82 | 4.4 | 1.1 | 39 | 1.98 | 1.4 | 0.7 | 27 | 4.19 | 3.5 | 0.8 | 29 | 0.49 | 0.9 | 1.8 | 5 |
| 8. | Coastal | 20 | 594.6 | 2.27 | 1.5 | 0.7 | 23 | 4.11 | 3.1 | 0.7 | 55 | 2.85 | 1.8 | 0.6 | 19 | 0.27 | 0.5 | 1.8 | 3 |
| 9. | Oceanic | 3 | 70.1 | 2.96 | 2.1 | 0.6 | 38 | 1.79 | 0.5 | 0.3 | 31 | 2.52 | 0.2 | 0.1 | 21 | 0.77 | 0.6 | 0.7 | 10 |
| 10. | Oceanic | 7 | 216.1 | 4.28 | 2.5 | 0.6 | 41 | 3.01 | 2.1 | 0.7 | 39 | 1.89 | 1.4 | 0.7 | 12 | 0.75 | 0.6 | 0.8 | 8 |
| 11. | Foothills of Himalayas | 8 | 187.4 | 2.27 | 2.1 | 1.1 | 26 | 4.0 | 3.2 | 0.9 | 61 | 0.76 | 0.6 | 0.8 | 6 | 0.68 | 0.4 | 0.7 | 7 |

Where,
1. Average number of thunderstorm days over the specified region
2. Standard deviation
3. Coefficient of variation
4. Percentage Thn of annual total in specified season

meteorological parameters for a large number of Indian observatories. For the present study we have selected monthly mean data of number of thunderstorm days (Thn), number of rainy days (Tnr), and rainfall amount (mm, Trr) for 276 stations having standing for minimum 25 years except for station Agatti having data for 15 years. Information about the station details, their network over the Indian region and other important particulars is available in our earlier paper (Manohar and Kesarkar, 2003).

Following the works of Rao (1976) and Manohar *et al*. (1999), for the purpose of studying spatial characteristics of seasonal thunderstorm activity and the associated features of rainfall, we have carefully demarcated India in 11 different geographic regions which suit either of the different climate regimes such as: oceanic, coastal, inland, continental (deep inland), arid zone and hilly [Fig. 1 (a)]. Table 1 provides details of the stations and statistics of Thn with regard to 11 geographic regions. Fig. 1 (b) shows graphs of seasonal variation of Thn over 11 geographic regions of India. A careful observation of these graphs brings out several important aspects of their phase shift and amplitude variation as we move northwards away from the tropics. Basically, the semiannual variation of Thn frequency is linked with heating of the land (or water) mass during north – south oscillations of the sun and the land – ocean contrast of the region of the earth surface. All these discussions need a separate platform. At present it is interesting to observe the vast variety in these oscillations across and within the latitude belts over India. Monthly data of the three parameters *viz*. Thn, Tnr and Trr contained in the 11 geographic regions are used to obtain their seasonal means etc.

## 3. Results and discussion

### 3.1. *An examination of prevalence of "monsoonal"/ "continental" convective regimes over the Indian region*

The significant feature of the monsoon season over India is the presence of a highly moist air-mass in great depth over most part of the country (Rao, 1976). During this season the country as a whole receives about 80% of its annual rainfall (Parthasarathy *et al*., 1990 and Ananthakrishnan and Pathan, 1991). Precipitation thus received could be in the form of light continuous rain for a couple of days from stratiform-cumulonimbus thick cloud

**TABLE 2(a)**

**Region wise seasonal means of number of thunderstorm days (Thn) and rainy days (Tnr)**

| Regions | Pre-monsoon | | | Monsoon | | | Post-monsoon | | | Winter | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thn | Tnr | $R = \frac{Thn}{Tnr}$ | Thn | Tnr | $R = \frac{Thn}{Tnr}$ | Thn | Tnr | $R = \frac{Thn}{Tnr}$ | Thn | Tnr | $R = \frac{Thn}{Tnr}$ |
| 1. | 2.99 | 2.76 | 1.08 | 4.24 | 8.57 | 0.49 | 0.83 | 1.32 | 0.62 | 0.79 | 2.52 | 0.31 |
| 2. | 0.99 | .44 | 2.3 | 3.10 | 8.56 | 0.36 | 0.57 | 1.11 | 0.52 | 0.31 | 0.43 | 0.71 |
| 3. | 2.62 | 1.79 | 1.4 | 6.22 | 12.25 | 0.51 | 1.0 | 2.16 | 0.45 | 0.62 | 1.06 | 0.59 |
| 4. | 5.79 | 8.26 | 0.70 | 6.25 | 16.30 | 0.38 | 1.7 | 5.40 | 0.27 | 0.59 | 1.36 | 0.43 |
| 5. | 2.27 | 1.73 | 1.31 | 2.47 | 10.83 | 0.23 | 0.88 | 2.88 | 0.31 | 0.20 | 0.48 | 0.42 |
| 6. | 3.40 | 3.08 | 1.10 | 1.98 | 9.94 | 0.20 | 2.0 | 6.28 | 0.32 | 0.10 | 0.79 | 0.13 |
| 7. | 3.82 | 3.46 | 1.10 | 1.98 | 18.89 | 0.10 | 4.19 | 6.45 | 0.65 | 0.49 | 0.81 | 0.60 |
| 8. | 2.27 | 1.64 | 1.38 | 4.11 | 9.39 | 0.44 | 2.85 | 6.95 | 0.41 | 0.27 | 1.50 | 0.18 |
| 9. | 2.96 | 2.96 | 1.00 | 1.79 | 12.84 | 0.14 | 2.52 | 8.03 | 0.31 | 0.77 | 1.99 | 0.39 |
| 10. | 4.28 | 6.63 | 0.64 | 3.01 | 16.46 | 0.18 | 1.89 | 12.59 | 0.15 | 0.75 | 4.39 | 0.17 |
| 11. | 2.27 | 2.48 | 0.91 | 4.0 | 10.67 | 0.37 | 0.76 | 1.53 | 0.50 | 0.68 | 1.53 | 0.44 |
| Mean | | | 1.17 | | | 0.30 | | | 0.41 | | | 0.40 |
| SD | | | 0.42 | | | 0.14 | | | 0.15 | | | 0.18 |
| Median | | | 1.1 | | | 0.40 | | | 0.41 | | | 0.40 |

**TABLE 2 (b)**

**Region wise seasonal means of number of thunderstorms days (Thn) and rainfall (Trr)**

| Regions | Pre-monsoon | | | Monsoon | | | Post-monsoon | | | Winter | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Thn | Trr | $\frac{Trr}{Thn}$ | Thn | Trr | $\frac{Trr}{Thn}$ | Thn | Trr | $\frac{Trr}{Thn}$ | Thn | Trr | $\frac{Trr}{Thn}$ |
| 1. | 2.99 | 30.4 | 10.17 | 4.24 | 204.85 | 48.31 | 0.83 | 23.41 | 28.2 | 0.79 | 38.21 | 48.37 |
| 2. | 0.99 | 5.0 | 5.05 | 3.10 | 196.82 | 63.49 | 0.57 | 19.19 | 33.67 | 0.31 | 4.71 | 15.19 |
| 3. | 2.62 | 24.13 | 9.21 | 6.22 | 264.07 | 42.45 | 1.0 | 44.07 | 44.07 | 0.62 | 12.84 | 20.71 |
| 4. | 5.79 | 180.4 | 31.16 | 6.25 | 469.99 | 75.2 | 1.7 | 110.81 | 65.18 | 0.59 | 18.04 | 30.58 |
| 5. | 2.27 | 19.94 | 8.78 | 2.47 | 236.07 | 95.57 | 0.88 | 49.61 | 56.38 | 0.20 | 6.59 | 32.95 |
| 6. | 3.40 | 49.26 | 14.49 | 1.98 | 161.90 | 81.77 | 2.0 | 107.57 | 53.79 | 0.10 | 11.53 | 115.3 |
| 7. | 3.82 | 78.25 | 20.48 | 1.98 | 521.00 | 263.13 | 4.19 | 137.36 | 32.78 | 0.49 | 16.40 | 33.47 |
| 8. | 2.27 | 28.81 | 12.69 | 4.11 | 152.24 | 37.04 | 2.85 | 181.15 | 63.56 | 0.27 | 30.25 | 112.04 |
| 9. | 2.96 | 70.99 | 23.98 | 1.79 | 238.85 | 133.44 | 2.52 | 129.90 | 51.55 | 0.77 | 27.96 | 36.31 |
| 10. | 4.28 | 152.2 | 35.56 | 3.01 | 373.42 | 124.06 | 1.89 | 259.06 | 137.07 | 0.75 | 95.23 | 126.97 |
| 11. | 2.27 | 43.91 | 19.34 | 4.0 | 54.64 | 13.66 | 0.76 | 46.16 | 60.74 | 0.68 | 16.85 | 24.78 |
| Mean | | | 17.36 | | | 88.92 | | | 57 | | | 54.24 |
| SD | | | 9.76 | | | 68.31 | | | 29.5 | | | 42.04 |
| Median | | | 14.49 | | | 75.2 | | | 53.79 | | | 33.47 |

decks, or in the form of heavy thundershowers of brisk durations from the more vigorous and more sparsely distributed thunderstorms. These two distinct categories of the cloud systems were identified by Rutledge *et al.* (1992) and Williams *et al.* (1992) in their Australian monsoon research programme: "DUNDEE". In this section we proposed to examine the prevalence of above mentioned two cloud systems over the course of four seasons in different part of India by employing an index introduced by Rao *et al*. (1971). We have adopted the same index in the present analysis. The index "R" is defined as the ratio of number of thunderstorm days (Thn) to the number of rainy days (Tnr), (R=Thn/Tnr) over a region for the same period or season. Table 2 (a) presents seasonal averages of Thn and Tnr for the 11 geographic regions of India. By using these averages, indices of "R" are worked out and they are also given in Table 2(a). Some useful statistics of "R" values over the 11 geographic regions are presented in Table 2(a). The seasonal indices of "R" over 11 geographic regions are used to prepare a diagram showing their variation [Fig. 2 (a)].

From the statistics of "R" values Table 2 (a) and from Fig 2 (a) it is clearly noted that the "R" in the premonsoon season alone is systematically significantly higher than those in the rest of the three seasons. A careful observation of Table 2 (a) and Fig. 2(a) also shows that "R" values in the monsoon season are the lowest of all the three seasons. As we move out of the monsoon season "R" values show some improvement. It is inferred that, behavior of "R" may be considered as an index of monsoonality. The reason which is of fundamental importance to explain the disparity in the "R" values between the monsoon season and other seasons is the huge contrast between the increase in Tnr in the monsoon season over the premonsoon season as against the similar increase in Thn. Our analysis showed that, Tnr in the monsoon season increase by 280 % over the premonsoon season, while Thn increase just by 14 %. This analysis therefore concludes that the prominence of monsoonal convective regime is very important in deciding the performance of Indian southwest monsoon.

### 3.2. *Seasonal rainfall and thunderstorm day relation*

To study the relation between rainfall and number of thunderstorm days, for the West African tropical region, an index was earlier introduced by Zipser (1994). The same index was also used by Manohar *et al*. (1999) in a recent study for the Indian region to examine a relationship between thunderstorm activity over India and the southwest monsoon rainfall. The index is defined as the ratio of monthly rainfall (Trr) to number of thunderstorm days (Thn) [$\frac{\text{Trr}}{\text{Thn}}$ is abbreviated as RTR]. For the purpose of present study, data of monthly rainfall (Trr), and number of thunderstorm days (Thn) for the number of stations contained in each of the 11 geographic regions (Table 1) are used to work out the regionwise seasonal means Table 2(b). By using these means the seasonal RTR indices are prepared for the 11 geographic regions. RTR indices are also shown in Table 2(b). The seasonal indices of RTR over 11 geographic regions are used to prepare a diagram showing their variation [Fig. 2(b)]. It is seen from the figure that the RTR data in the pre-monsoon season show clustering of values with minimum variance compared to those in the other three seasons. This behavior of RTR is remarkable. This observation suggests that thunderstorm activity is frequent and fairly wide-spread with occasional rain over most parts of the country in the pre-monsoon season.

The spectrum of RTR in the monsoon season shows maximum variation [Fig. 2(b)]. Region 7 shows highest value of RTR. This region corresponds to the stations along the west coast of India Fig. 1. Regions 9 and 10 stand second and third in order respectively. These two regions correspond to stations in the Arabian Sea and Bay of Bengal respectively. The lowest value of RTR is noted in the region 11 [Fig. 2(b) and Table 2(b)]. This region comprises stations north of the monsoon trough and along the foot hills of Himalayas. In order to understand the observed variations in RTR, we seek explanations form the works of Rao (1976). Rao studied the cloud and rainfall characteristics over India during the monsoon season. The most striking feature of the regions 7, 9 and 10 was described as abundant rainfall with minimum number of thunderstorm days. Rao's study further reports that precipitation recorded over region 11 is mainly received from thunderstorms which are more frequent over there. We thus note that the wide distribution of RTR in the monsoon season is consistent with the observations of rainfall and thunderstorm activity over the extent of the country.

In the post monsoon season, regions 10 and 8 show highest and second highest value of RTR [Fig. 2(b) and Table 2(b)]. Rest of the values of RTR in this season show a cluster of points with lower values. The regions 10 and 8 cover areas of Bay of Bengal and the east coast of south India. During post-monsoon season these areas get most rainfall under the influence of northeast monsoon season. This period is also well recognized for the presence of convective nature of the disturbed weather situations in the north-east monsoon season. In the winter season the regions 10, 6 and 8 again show larger values of RTR. These secular high values of RTR are attributed to very low frequencies of thunderstorms.

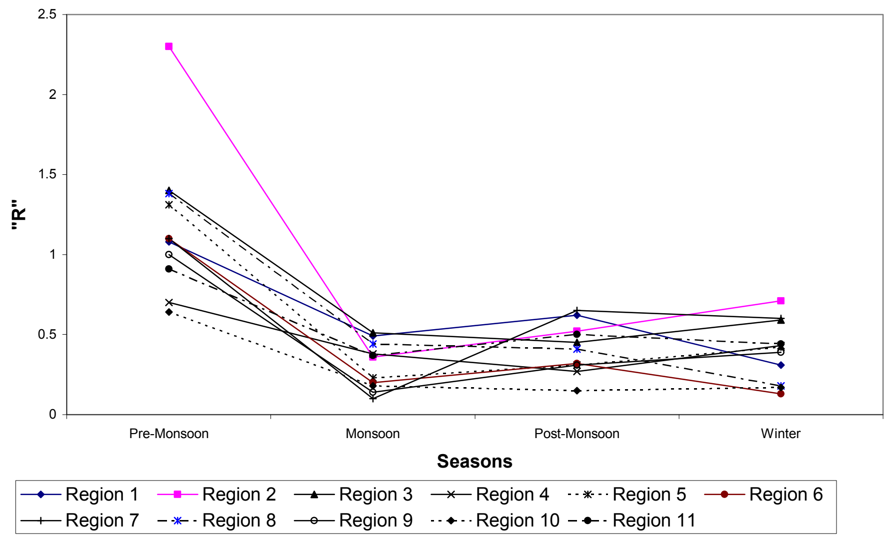



**Fig. 2(a).** Seasonal variation of "R" = (Thn/Tnr) in Geographic regions of India

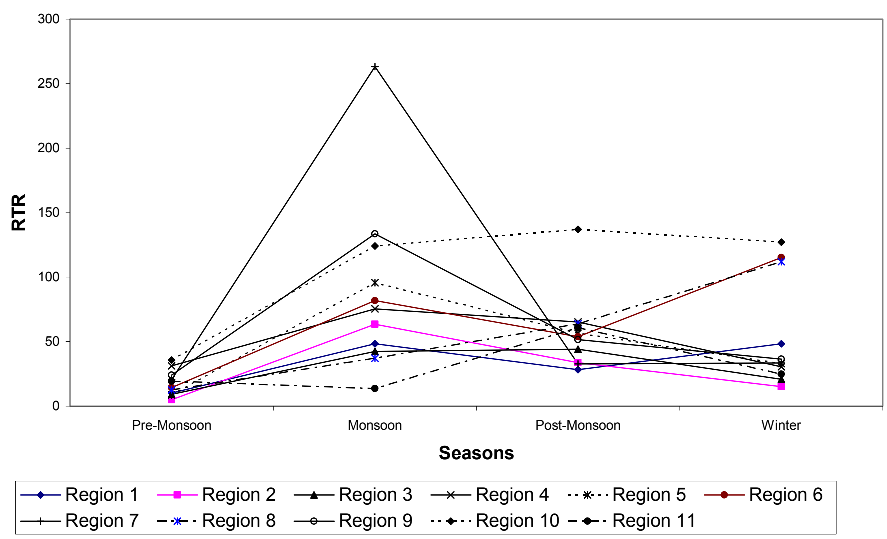
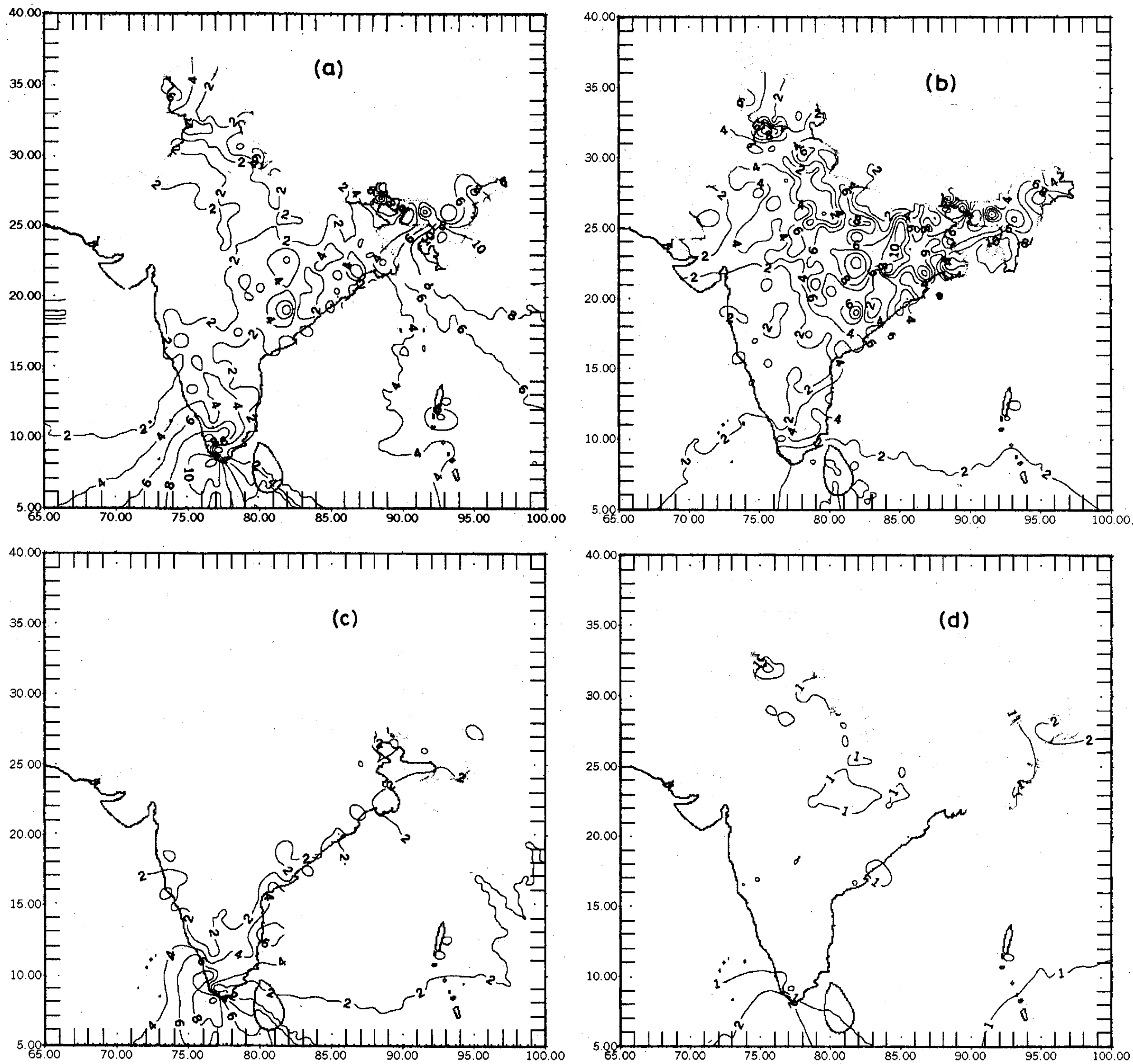



**Fig. 2(b).** Seasonal variation of RTR = (Trr/Thn) in 11 Geographic regions of India

We now compare our present results of RTR [Table 2(b)] with the results of Manohar *et al*. (1999) for the pre-monsoon and monsoon seasons. A comparison of the RTR statistics in the two studies indicates that the present sets of RTR values are nearly twice larger. Some possible reasons to explain this difference are as under. Firstly, their (Manohar *et al.* 1999) results were based on data for only 78 stations over a limited period of 11 years during 1970-80. Our results are based on the data from Climatological Normals 1951-80 for 276 stations. Secondly and more importantly, we note that during the limited period of 11 years, India witnessed two strong episodes of deficit monsoon rainfall: 1972 (-23%) and 1979 (-17%). It is felt that two seasons of severe deficit monsoon rainfall are sure to reduce the averages when summarized over just a limited period of 11 years. Since the present averages are based on Climatological Normals of large number of stations they represent most general stable picture.

The general conclusion of this analysis is that RTR values in the monsoon season are larger than those in the



**Figs. 3(a-d).** Average monthly number of thunderstorm days in (a) Pre-monsoon season, (b) Monsoon season, (c) Post monsoon season and (d) Winter season

other three seasons. This result is consistent with the result of our earlier study mentioned above and is also in agreement with the results of Zipser (1994). The larger values of RTR in the monsoon season suggest that the contribution of the thunderstorm rains to monsoon season is significant.

### 3.3. *Significant features of seasonal thunderstorm activity over India*

In this section spatial distribution of thunderstorms over India is studied. For this purpose seasonal isoceraunic maps of India are prepared [Figs. 3(a-d)].

#### (*i*) *Pre-monsoon season (M-A-M)*

This period is known as a hot weather season. In this season intense convective activity is witnessed over a large portion of the country. From Fig. 3(a) we note two prominent zones of core activity of about 10 – 12 storms per month which are located over southern tip of Kerala and hilly parts of northeast India (geographic region 4). Variable and reduced activity of 4 – 8 storms per month is quite well spread over continental parts of east Madhya Pradesh, through Orissa, Bihar and Gangetic plains (geographic region 3). The areas of lowest activity lie over zones comprising Saurashtra, Kutch and Gujarat (geographic region 2). Pockets of isolated higher activity are seen in some corners of geographic regions 1 and 11. We note that the east coast south of latitude 15° N and the west coast north of 18° N are the areas of minimum activity.

(*ii*) *Southwest monsoon season (J-J-A-S)*

There are several important features of thunderstorm activity with the monsoon season. From Fig. 3 (b) we note that almost all parts India, excepting region west of 80° E and south 20° N (western portions of geographic region 5 and some parts of geographic region 6) experience large scale thunderstorm activity with some variation in different zones. Many parts of Gangetic West Bengal, East Uttar Pradesh and hilly regions of northeast India report activity of about 10-15 storms per month in this season. This indicates that about every third day is a day of storm in high core zones of these areas. Areas of reduced activity are arid zones of Saurashtra, Kutch, Gujarat coast and western portion of Madhya Maharashtra (mostly geographic regions 2 and partly 5). Comparisons of regions of thunderstorm activity between the premonsoon and monsoon seasons is interesting. The distribution pattern in the two seasons clearly shows that thunderstorm activity in the lower latitudes in the premonsoon shifts northwards in the monsoon season and lies concentrated in the regions where tropical convergence zone (TCZ) is located. This result is of prime importance with the studies concerning monsoon activity over India. These observations and the results are in good agreement with the result of Manohar *et al.* (1999).

(*iii*) *Post monsoon season (O-N)*

Fig. 3(c) shows the map of thunderstorm activity in this season. We note that in this season a marked change occurs in the pattern of thunderstorm activity. Most part of India, excepting southern portion of east coast and extreme south India are free from thunderstorms. Maximum activity of approximately 10 – 12 storms is witnessed over tip of Kerala, and activity in the range of 2 – 4 storms is seen along some parts of east coast and regions of Bay of Bengal.

(*iv*) *Winter season (D-J-F)*

Fig. 3 (d) shows activity in the winter season. We note from the figure that in the winter season thunderstorm activity is markedly low. Thunderstorm activity of about 1 -2 storms per month of the season is identified in 3 -4 small pockets of few geographic regions. These regions are southern tip of Kerala, hilly regions of Punjab and Himachal Pradesh and northeast India. In general it is noted that most part of Indian region excepting few small pockets are free from the occurrence of the thunderstorms.

## 4. Conclusions

By employing the monthly climatological data of Thn, Tnr and Trr at 276 Indian observatory stations, relationships between Thn and Tnr and Thn and Trr were examined during four seasons of the annual period over the Indian region. Our analysis of Thn-Tnr data showed they behave differently in the pre-monsoon and monsoon season. Pre-monsoon season is strongly influenced by frequent and widespread thunderstorms with occasional rainy days over major parts of India, while the monsoon season is marked with very large increase in rainy days as against thunderstorm days. Convection in these seasons is termed as "Continental" and "monsoonal" respectively. The Trr – Thn relationship showed that rainfall amount per thunderstorm day in the monsoon season is highest among the other three seasons. Contribution of thunderstorm rains to monsoon rainfall is very important. Results from seasonal isoceraunic maps of India are as discussed in section 3.3.

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