MAUSAM, **58**, 2 (April 2007), 189-212

551.58 : 551.515.4 (540)

Thunderstorm climatology over Indian region

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(*Received 27 July 2006*)

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सार – गर्ज के साथ तूफान आने की घटना मौसम की एक प्रचंड परिघटना है जिसके प्रभाव को समाज के सभी वर्गों द्वारा उत्तरोत्तर रूप से महसूस किया जा रहा है। इस अध्ययन में जलवायु विज्ञान के अधतन प्रमुख आंकडों के आधार पर भारतीय क्षेत्र में गर्ज के साथ आने वाले तूफानों से संबंधित जलवायु विज्ञान को विकसित करने का प्रयास किया गया है। इसमें भारत मौसम विज्ञान विभाग की 390 वेधषालाओं, भारतीय वायु सेना की 50 वेधषालाओं, बंगलादेष की 06 वेधषालाओं, पाकिस्तान की 02 वेधषालाओं, और नेपाल तथा श्रीलंका की एक – एक वेधषाला सहित कुल 450 वेधषालाओं के आंकडों का विष्लेषण किया गया है। अध्ययन में भारतीय वायु सेना ओर बंगलादेष के जलवायु विज्ञान संबंधी आंकडों को समावेषन से भारतीय क्षेत्र में प्रतिनिधित्व पूर्ण जलवायु विज्ञान को विकसित करने में सहायता मिली है। इस अध्ययन में पहले किए गए अध्ययनों में बताई गई आवृत्ति (80–100 दिन) की तुलना में गर्ज के साथ तूफान की वार्षिक उच्चतर आवृत्ति (100 – 120 दिन) को प्रस्तुत किया गया है। इस अध्ययन में पूर्व में असम और पष्चिम बंगाल के उप हिमालय क्षेत्र तथा उत्तर में जम्मू क्षेत्र में वार्षिक उच्चतम आवृत्ति (100 – 120 दिन) का पता चला है लद्दाख क्षेत्र में न्यूनतम आवृत्ति (5 दिन से कम) का पता चला है। पष्चिम बंगाल के गांगेय मैदानी भागों और बंगलादेष में प्रतिवर्ष गर्ज के साथ तूफान आने की आवृत्ति 80 और 100 दिन के मध्य रिकार्ड की गई है। प्रायद्वीपीय क्षेत्र में गर्ज के साथ तूफान आने की अधिकतम आवृत्ति (80–100 दिन) केरल में रिकार्ड की गई। देष में गर्ज के साथ आए तूफानों की अधिकतम संख्या (132 दिन) रिकार्ड की गई है। इसके बाद दक्षिण असम के कुंभीग्राम (सिल्चर) वेधषाला में (129 दिन) और पष्चिम बंगाल के उप हिमालय क्षेत्र के हासीमारा में गर्ज के साथ आए तूफानों की संख्या (123 दिन) रिकार्ड की गई है। देष में गर्ज के साथ आए तूफानों की न्यूनतम संख्या (15 दिन से कम) सौराष्ट्र और कच्छ में रिकार्ड की गई है।

गर्ज के साथ आए तूफानों की घटनाएं मुख्यत मेसोस्केल पर अल्पावधि की मौसम परिघटना है। अंषकालीन वेधषालाओं के मौजूदा सिनॉप्टिक संजाल में वेधषाला और इसके निकटवर्ती क्षेत्रों में गर्ज के साथ आए तूफानों की सभी घटनाओं को रिकार्ड करने की अपनी सीमित क्षमताएँ हैं। ऐसी वेधषालाओं से प्राप्त हुए आंकडों के समावेषन से उस घटना की न्यूनतम आवृत्ति का ही पता चल पाया है जो जलवायु विज्ञान को दुष्प्रभावित करती है। इस अध्ययन में मौसम की अधतन जानकारी देने वाली पूर्णकालिक (हवाई अडडा) वेधषालाओं, श्रेणी I की और चुनी हुई श्रेणी II की भारत मौसम विज्ञान विभाग की वेधषालाओं के सही आंकडों का उपयोग करते हुए गर्ज के साथ आने वाले तूफानों से संबंधित जलवायु विज्ञान को विकसित करने का प्रयास किया गया है। चूंकि अधिकांष उपखंडों में पूर्णकालिक वेधषालाओं की संख्या कम है अतः इस अध्ययन में उपखंडों में गर्ज के साथ आए तूफानों की गतिविधियों के सूक्षम स्थानिक परिवर्तन को प्रस्तुत नहीं किया जा सका है। गर्ज के साथ तूफान आने की घटना उच्च प्रभाव वाली प्रचंड मौसम परिघटना है जो समाज के सभी वर्गों को प्रभावित करती है अतः प्रचालनात्मक और जलवायु विज्ञान दोनों दृष्टिकोणों से गर्ज के साथ तूफान आने की सभी घटनाओं की सही रिपोर्ट देने की सुनिष्चितता बरतने के लिए प्रत्येक जिले में मौसम की अधतन जानकारी देने हेतु कम से कम एक पूर्णकालिक वेधषाला स्थापित करने तथा देष में गर्ज के साथ आने वाले तूफानों से संबंधित जिला स्तर पर जलवायु विज्ञान के गठन की आवष्यकता है।

ABSTRACT. Thunderstorm is a severe weather phenomenon, the impact of which is being increasingly felt by all the sectors of society. In this study attempt has been made to develop thunderstorm climatology over Indian region based on latest representative climatological data. In all, data of 450 observatories comprising of 390 IMD observatories, 50 IAF observatories, six Bangladesh observatories, two Pakistan observatories, and one each in Nepal and Sri Lanka have been analysed. Inclusion of climatological data of Indian Air Force and Bangladesh has helped in developing representative climatology over Indian region. The study has brought out higher (100-120 days) annual frequency of thunderstorm as compared to those given by earlier studies (80-100 days). The highest annual frequency (100-120 days) is observed over Assam and Sub Himalayan West Bengal in the east and Jammu region in the north. The lowest frequency (less than 5 days) is observed over Ladakh region. In the plains Gangetic West Bengal and Bangladesh record between 80 and 100 days of thunderstorm annually. Kerala records highest (80-100 days) thunderstorm frequency of thunderstorm over peninsula. Udhampur observatory (132 days) in Jammu sub-division records highest number of thunderstorms in the country followed by Kumbhigram (Silchar) observatory (129 days) in south Assam and Hasimara (123 days) in Sub Himalayan West Bengal. In the plains Saurashtra and Kutch record lowest number (less than 15 days) of thunderstorm in the country.

Thunderstorms are primarily short lived mesoscale weather phenomena. Existing synoptic network of part time observatories have limitations in recording all the occurrences of thunderstorms at the observatory and adjoining areas. Inclusion of data from such observatories results in lower frequency of the event and vitiates climatology. Efforts have been made in this study to develop thunderstorm climatology by using quality data of full time current weather (Airport) observatories, class I and selected class II IMD observatories. Since number of full time observatories in most of the sub divisions is few, the study is not able to bring out finer spatial variation of thunderstorm activity with in sub-divisions. Thunderstorm is a high impact severe weather event, which affects all the sectors of the society. Therefore, both from operational and climatological point of view, there is urgent need to establish at least one full time current weather observatory in each district to ensure proper reporting of all thunderstorm occurrences and to build district level thunderstorm climatology in the country.

Key words – Thunderstorm, Mesoscale, Aviation hazard, Climatology, Frequency, High impact weather event.

1. Introduction

Thunderstorm is one of the most spectacular weather phenomenon offered by nature. Giant cumulus cloud developing into a towering dark cumulonimbus accompanied with lightning flashes and thunder is a sight to watch. During summer season common man looks at the majestic and towering thundery cumulonimbus with hope, because of the oncoming showers to provide relief from scorching heat. While farmers welcome thunderstorm for rains and consequent benefits, the aviator dreads it and tries to keep away from it, as thunderstorm is a well known hazard to aviation and a large percentage of aircraft weather related accidents have been due to thunderstorms. Most of the high impact weather phenomenon on mesoscale like hailstorm, heavy rain and squalls are caused by thunderstorms. These cause loss to life, damage to crops and property. A knowledge of the of thunderstorm climatology with respect to its frequency of occurrence, intensity, diurnal variation and duration is essential particularly in the interest of safe air navigation and taking necessary precautions to avoid the loss of life and minimize the loss to property.

2. Earlier studies

The earliest study of thunderstorm frequency in India was by Dallas (1900) who took only 10 stations data for India during the year 1897. The first series of published charts of monthly frequency of days of thunder in India and neighbourhood based on data for a short period were published in the Climatological Atlas for Airmen (IMD, 1943). The average monthly and annual frequency of days of thunder for all Indian and neighbouring stations are given in the Climatological Tables of Observatories in India (IMD, 1953). Simultaneously, the World Meteorological Organisation (WMO) published the average frequencies of thunder in the WMO publication World distribution of thunderstorm days (WMO, 1953). These averages are based on data for a uniform period of 15 years.

Rao and Raman (1961) used data of 20 years to present monthly and annual frequency of thunderstorm in India in the form of chart with brief description. Raman and Raghavan (1961) for the first time systematically studied the diurnal variation of thunderstorm occurrence over India. Mukherjee and Sen (1983) studied the diurnal variation of thunderstorm for some selected stations to understand the influence of different physical features *viz*., plain stations, hill stations, coastal stations, island stations etc.

In addition to above there have been several studies, but most of the climatologiocal studies were restricted to particular places or small areas and were based on limited period of data. Gupta and Chorghade (1961) studied thunderstorm occurrences at Agartala based on period of three years (1957-59), Viswanathan and Faria (1962) for Bombay, Krishnamurthy (1965) for Pune, Awadesh Kumar (1992) for Lucknow, Moid (1996) for Mohanbari, Indrani Kar and Bandopadhyay (1998) for three stations in Gangetic West Bengal and Santosh *et al*. (2001) for three aerodrome stations in Kerala.

In earlier studies of thunderstorm climatology, there was a tendency to under estimate the frequencies of occurrence of thunderstorm over India. These may be due to lack of sufficient data in the past. In WMO publication (WMO, 1953) on World distribution of Thunderstorm days (Fig. 1), highest annual frequency of thunder in India is given as 60 days over northeast India. Subsequent study by Rao and Raman (1961) showed higher frequency of 75 days over northeast India, Bangladesh, West Bengal and adjoining areas with more than 100 days over northeastern parts of Assam [Fig. 2(a)]. The higher frequency of thunderstorm brought out by Rao and Raman is because of the inclusion of thunderstorm data from the aerodrome meteorological stations, in addition to the data from the conventional meteorological observatories. The map of the mean number of thunderstorms prepared by the office of Deputy Director General of Observatories, Pune on the basis of 30 years data, 1931-60 (IMD 1969) is given as Fig. 2(b) shows 75 days of thunderstorms over northeast India, Bangladesh, West Bengal and adjoining Orissa, with maxima of 100 days over northeastern parts of Assam (Alvi and Punjabi 1966) and about 50 days over western Himalayas, southern parts of Kerala and adjoining

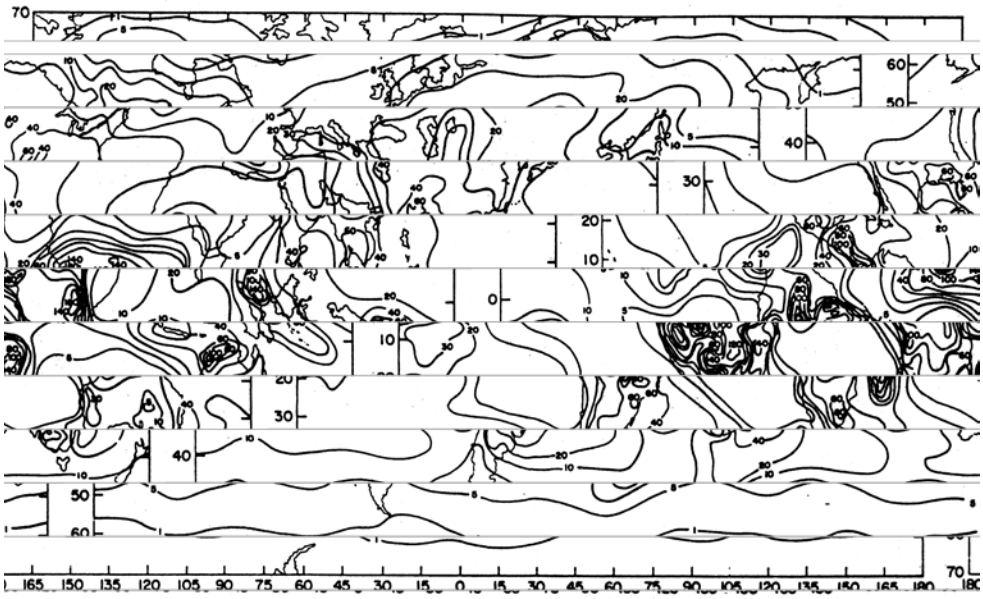


Fig. 1. World distribution of thunderstorm days (WMO Publication 1953)

Tamil Nadu. However later study by Rao (1981) gives maximum frequency of 60 to 80 days over West Bengal and adjoining Jharkhand and Orissa with relatively lower frequency of 40 to 60 days over Bangladesh and Assam [Fig. 2(c)], whereas annual mean number of thunderstorm given by Pant and Rupa Kumar (1997) shows thunderstorm activity of 60 days over northeast India, Bangladesh, West Bengal and adjoining areas with maximum number thunderstorm as 80 over northeast Assam [Fig. 2(d)].

3. Present study

It is seen that while there is similarity in general pattern of the distribution of annual number of thunderstorm in earlier studies, frequency and location of maxima thunderstorm shows wide variation. Therefore, in light of recent publication of latest Climatological Tables based on period 1951 to 1980 (IMD, 1995), the necessity to update climatology of thunderstorms for Indian region was felt. The document in three volumes consists climatological data of 390 surface observatories in India. It is one of the most exhaustive data set for Indian region. In addition to IMD observatories, climatological data of 50 Air Force observatories and 6 observatories of Bangladesh, 2 observatories of Pakistan, one observatory of Nepal and Sri Lanka has been used to develop thunderstorm climatology.

Annual frequency of thunderstorm for 450 observatories is given in Tables 1(a-c). The type of observatories included in climatological tables varies from Class I to Class V, the quality of climatological data of all observatories can not be taken for granted. Therefore, data from all observatories was put to quality check in respect of space and time consistency. The frequency of nearby observatories in same meteorological sub-division with similar topographic features was analysed to ascertain quality of data. It brings out marked difference in annual frequency of thunderstorms between airport and city observatories as shown in Fig. 3 for Jammu, Agra, Lucknow, Varanasi, Patna, Ranchi, Dhubari, Akola, Belgaum, Mangalore, Chennai and Madurai. This discrepancy is attributable to inherent limitation of synoptic observatories manned by part time observers as it is quite possible that thunderstorm occurrence between synoptic observations may often have escaped from observing. On the other hand, airport observatories take half hourly/hourly current weather observations and thus better equipped to record thunderstorm occurrences. Therefore, following criteria has been used to select observatories to develop thunderstorm climatology :

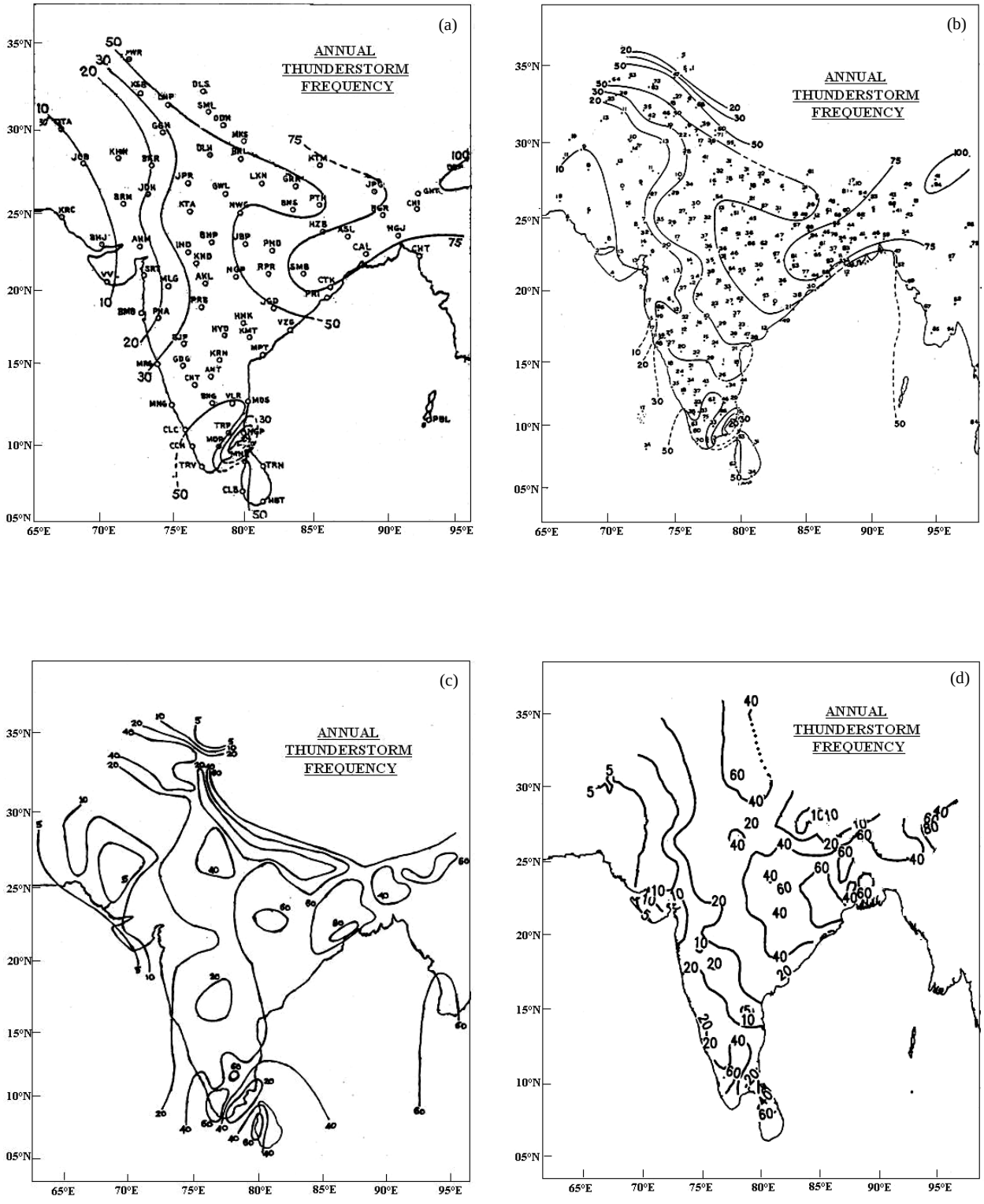
(*i*) Airport observatories manned by India Meteorological Department.

(*ii*) Indian Air Force (IAF) meteorological observatories.

(*iii*) Class I observatories manned by IMD staff.

(*iv*) Class II observatory whose annual frequency is within 20% of nearby airport or civil observatory in the same meteorological sub-division.

(*v*) Selected observatories of neighbouring countries.



Figs. 2(a-d). Annual thunderstorm frequency by (a) Rao and Raman (1961) (b) Alvi and Punjabi (1966) (c) Rao (1981) and (d) Pant and Rupa Kumar (1997)

TABLE 1(a)

Total number (annual) of thunderstorm days (India Meteorological Department observatories)

Station	No. of days	Station	No. of days	Station	No. of days	Station	No. of days
Abu (II b)	10.0	Beed (Bir) (II b)	12.3	Dahanu (I)	6.5	Halflong (II b)	34.0
Adiramapatinam (I)	19.7	Belgaum (II a)	5.9	Dalhausie (II b)	12.3	Hanamkonda (II b)	19.0
Agartala (A) (I)	85.3	Belgaum (Samra)(A)(I)	44.7	Daltonganj (I)	32.7	Hardoi (II b)	8.2
Agatti (A) (II b)	18.4	Bellary (II b)	9.3	Darbhanga (II b)	7.4	Harnai (II a)	7.1
Agra (II B)	1.3	Behrampore (II b)	17.9	Darjeeling (II b)	14.7	Hassan (II b)	18.5
Agumbe (I)	9.4	Betul (II b)	22.7	Daroi	0.0	Hazaribagh (II b)	55.8
Ahemdabad (I)	19.9	Bhagalpur (II a)	69.9	Deesa (II a)	7.9	Hirakud (II)	48.9
Ahmednagar (II b)	3.4	Bhatinda (II b)	9.4	Dehradun (I)	66.5	Hissar (I)	36.5
Aijal (II b)	10.2	Bhaunagar (A) (I)	10.8	Dehri (II b)	15.9	Honavar (I)	26.4
Ajmer (II b)	18.6	Bhawani Patna (II b)	3.6	Devgad (II b)	11.8	Hosangabad (I)	20.3
Akola (II b)	10.6	Bhilwara (II b)	11.1	Dhanbad (II b)	43.4	Hut Bay (II bo)	6.4
Akola (A) (I)	32.5	Bhira (II b)	3.5	Dharchula (II b)	41.0	Hyderabad (I)	37.9
Alapuzha (II a)	54.7	Bhopal (A)(I)	46.6	Dharamsala (I)	56.2	Idar (II b)	6.5
Alibag (II a)	10.5	Bhubneshwar (A) (I)	77.5	Dholpur (II bo)	23.8	Imphal (A) (I)	54.0
Aligarh (II b)	11.8	Bhuj (Rudramata) (A)(I)	13.6	Dhubri (II a)	25.0	Indore(A) (I)	34.8
Alirajpur (II b)	6.2	Bhuntar (A) (II a)	64.6	Dhubri/Rupsi (A) (II a)	83.5	Jabalpur (A) (I)	46.4
Allahabad (A) (I)	55.2	Bidar (II b)	6.5	Dibrugarh (A) (I)	91.8	Jagdalpur (I)	83.3
Alwar (II b)	22.4	Bijapur (II b)	8.6	Digboi (II b)	6.7	Jaipur (A) (I)	46.0
Ambala (II a)	12.4	Bikaner (II a)	30.5	Diu (II c)	2.0	Jaisalmer (I)	5.4
Ambikapur (II a)	39.0	Bokaro	29.1	Dohad (II b)	19.6	Jalgaon (II b)	17.8
Amini Divi (I)	16.3	Bolangir (II b)	15.8	Dumka (II b)	41.9	Jalore (II c)	9.2
Amraoti (II b)	21.3	Brahmapuri (II b)	15.0	Dungarpur (II c)	1.5	Jalpaiguri (II b)	52.8
Amritsar (A)	53.7	Broach (II b)	2.5	Durgapur	2.4	Jammu (I)	18.1
Anantpur (I)	29.9	Buldana (II b)	3.2	Dwarka (I)	0.8	Jamnagar	13.9
Angul (II b)	33.3	Burdwan (II b)	1.6	Erinpura (II bo)	10.0	Jamshedpur (II a)	43.1
Arogyavaram (II bo)	12.1	Car-Nicobar (II b)	16.4	Faizabad (II b)	32.5	Jamshedpur(A)(II a)	83.4
Ascote (II b)	32.9	Chibasa (II b)	32.3	Fatehpur (II b)	19.3	Jamui (II b)	9.3
Aurangabad (II b)	13.2	Chambal (II co)	32.1	Ferozpur (II b)	7.4	Jashpurnagar (II b)	1.8
AGD/Chikalathana (A)	27.7	Champa (II b)	57.0	Forbesganj (II b)	58.7	Jeur (II b)	10.5
Azamgarh (II b)	1.3	Chandbali (I)	8.6	Fort Cochin	65.3	Jhadol	0.0
Bagati (II b)	21.0	Chandigarh (II b)	2.6	Gadag (I)	29.6	Jhalwar (II bo)	15.4
Baghdogra (A)	97.0	Chandrapur (II b)	54.2	Gangtok (I)	57.0	Jhansi (II a)	4.1
Bagratwa (III)	11.8	Chaparmukh (II b)	33.3	Gannavaram (A) (I)	44.5	Jharsuguda (A) (I)	69.6
Bahraich (I)	29.0	Chapra (II b)	11.4	Gaya (I)	67.8	Joshimath (II b)	8.5
Balasore (I)	67.7	Chennai (Mbm) (A) (I)	49.0	Ginabahar	28.5	Kailashahar(A)(II a)	107.5
Balehonnur	4.6	Chennai(Nungambakkam)(I)	25.9	Goalpara (II b)	1.3	Kakinada (I)	19.7
Ballia (II b)	1.5	Cherrapunji (II a)	13.9	Gohpur (II b)	5.3	Kalimpong (II b)	0.1
Balurghat (II b)	28.6	Chhindwara (II b)	32.2	Golaghat (II b)	1.2	Kalingapattanam (I)	26.7
Banda (II b)	2.6	Chitradurga (I)	24.1	Gonda (II b)	6.1	Kallakkurichchi(IIb)	24.2
Bangalore (I)	40.3	Churu (I)	30.8	Gondia (II b)	32.0	Kandla (II bo)	11.1
Bangalore (A) (I)	40.5	Coimbatore (III a)	28.5	Gopalpur (I)	52.0	Kanker (II b)	28.6
Banihal (II a)	55.3	Coimbatore (A)(I)	49.1	Gorakhpur (I)	12.9	Kannod (II c)	4.9
Bankura (II b)	3.7	Contai (II b)	12.0	Gulbarga (II b)	16.1	Kanpur (II b)	15.1
Banswara (II bo)	2.7	Cooch Behar (A)(II a)	96.4	Gulmarg (I)	51.8	Kanyakumari (II a)	7.3
Baramati (II b)	12.2	Coonoor (VI bo)	7.0	Guna (I)	43.5	Karnal (II b)	7.0
Bareilly (I)	29.4	Cuddalore (I)	29.6	Gurgaon (II b)	2.1	Karwar (I)	4.3
Bariparda (II b)	84.4	Cuddapah (II b)	1.0	Guhawati (A) (I)	101.2	Keonjhargarh (II a)	9.4
Barmer (I)	15.8	Cuttack (II b)	28.6	Gwalior (I)	56.5	Keshod (A) (II a)	9.0

TABLE 1(a) (*Contd.*)

Station	No. of days	Station	No. of days	Station	No. of days	Station	No. of days
Khammam (II b)	11.9	Minicoy (I)	35.4	Patna (I)	19.7	Sibsagar (II b)	72.9
Khandwa (II b)	10.1	Miraj	28.5	Patna (A)	54.7	Sidhi (II b)	6.0
Khargone (II c)	1.9	Motihari (II b)	4.3	Pendra (I)	84.0	Sikar (II b)	0.3
Kheri-Lakhimpur (II b)	41.6	Mukhim (IV a)	57.3	Phalodi (II b)	8.5	Silchar (I)	86.5
Khijrawan	27.4	Mukteswar (Kumaun)(I)	63.0	Phulbani (II b)	13.5	Silchar (Kumbhi) (I)	84.9
Kochi (Cochin) (II a)	96.9	Mumbai (I)	20.1	Pilani (II b)	6.3	Simla (II b)	22.3
Kodaikanal (I)	67.1	Mumbai (Santa Cruz)(I)	19.8	Pondichery (II b)	8.1	Sironcha (II b)	27.4
Kohima (II b)	11.2	Munsyari Milan (II b)	11.1	Porbandar (A) (I)	6.9	Solapur (I)	26.4
Kolhapur (II a)	25.8	Mussoorie (II b)	41.1	Port Blair (I)	66.3	Sonepur (III)	5.3
Kolkatta (I)	81.2	Muzaffarpur (II b)	16.2	Punalur (II b)	1.3	Shanti Niketan (I)	75.9
Kolkatta (Dumdum)(A)	77.7	Mysore (II b)	15.6	Punasa	4.1	Sri Ganganagar (II a)	25.2
Konar(III)	10.7	Nagapattinam (I)	25.9	Pune (I)	28.6	Srinagar (I)	36.3
Kondul (II b)	28.9	Nagaur (II b)	6.6	Puri (I)	16.6	Sultanpur (I)	21.7
Koraput (II b)	1.8	Nagpur(A)(I)	63.0	Purnea (II a)	18.2	Surat (II b)	6.3
Kota (II b)	18.8	Nainital (II b)	2.7	Purulia (II b)	52.3	Surendernagar (II b)	8.1
Kota (A) (II a)	35.8	Najibabad (II b)	31.2	Pusad (II b)	5.8	Suri (IV b)	23.3
Kothagudem(Bhadrachalam)	25.8	Naliya (I)	8.2	Quazigund (II a)	65.4	Tangla (II b)	6.8
Kozhikode (II a)	47.2	Nancowry (II b)	29.2	Radhanpur (II b)	1.0	Tehri (II a)	43.0
Krishnanagar (II b)	37.0	Nanded (II c)	4.6	Raichur (II b)	10.9	Thikri (III)	4.7
Kurnool (II a)	10.2	Nandurbar (II b)	1.0	Raigarh (II b)	8.5	Thiruvananthpuram (A)	84.5
Leh (VI c)	5.0	Nandyal (II b)	3.7	Raipur (I)	58.4	Thiruvananthpuram (II a)	59.8
Long Island (II b)	22.8	Narsinghpur (II b)	19.5	Raisen (II c)	14.6	Tikamgarh (II c)	21.3
Lucknow (II b)	13.2	Narnaul (II c)	2.5	Rajgarh (II b)	9.1	Tilaiya (III)	19.7
Lucknow (Amausi) (A) (I)	49.9	Nasik (IV b)	1.1	Rajkot (A) (I)	18.5	Tiruchchirapalli (A) (I)	51.4
Ludhiana (II b)	12.3	Nautanwa (II b)	0.7	Ramgarh (III)	26.0	Tirrupattur (II B)	5.5
Lumding (II b)	7.3	Nellore (I)	19.6	Ramagundam (I)	27.4	Titlagarh (II B)	27.2
Madurai (VI c)	16.6	New Delhi (Sdf)(A)(I)	42.3	Ranchi (A)(II a)	73.4	Tondi (I)	24.8
Madurai (A)(II a)	65.4	New Delhi (P) (I)	42.2	Rangia (II b)	5.4	Tonk (II b)	23.7
Mahableshwar (I)	15.1	New Kandla (II b)	9.3	Ratlam (II b)	14.3	Tura (II b)	2.7
Mahbubnagar (II b)	17.7	Nidadavolu	13.9	Ratangiri (I)	16.7	Tuticorin (II b)	6.1
Mahuva (II b)	0.9	Nimach (II b)	23.9	Raxaul (I)	79.3	Udaipur (II c)	27.8
Mainpuri (II b)	8.0	Nizamabad (I)	8.7	Rentachintala (II b)	11.1	Udaipur/Dabok (A) (II a)	34.6
Maithon (III)	34.7	North Lakhimpur (A)(I)	62.2	Rewa (II b)	20.5	Ujjain (II b)	11.4
Majbat (II b)	16.3	Okha (I)	6.4	Rohtak (II c)	29.6	Ulberria (II c)	17.4
Malda (II a)	58.2	Ongole (I)	14.4	Roorkie (II b)	35.3	Umaria (II b)	46.5
Malegaon (II b)	4.9	Orai (II b)	0.0	Sabaur (II b)	63.5	Uthagamandalam (II bo)	16.1
Manali (II c)	3.0	Ozar(A) (I)	22.0	Sagar (II a)	31.4	Vadodra (Io)	13.2
Mandi (II b)	33.6	Pachmarhi (II b)	41.0	Sagar Island (II b)	40.9	Vadodra(A) (II a)	17.3
Mandla (II b)	45.9	Palakkad (Palghat)	25.6	Salem (II a)	46.6	Vallabh Vidyanagar (II b)	3.8
Mandvi (II b)	1.8	Palayamkottai (II b)	11.0	Sambalpur (II a)	17.0	Varanasi (II b)	10.0
Mangalore (II b)	19.9	Pamban (I)	5.9	Sandheads (II b)	11.6	Varanasi (Babatpur) (I)	49.7
Mangalor (A) (I)	60.0	Panchet Hills (III)	27.3	Sangli (II a)	14.5	Vedaranniyam (II b)	5.9
Marumgao (I)	18.0	Panjim (I)	21.5	Satna (I)	46.9	Vellore (II a)	41.2
Masulipatanam	39.5	Paradip Port (II a)	6.8	Seoni (II b)	39.2	Vengurla (II c)	34.8
Mayabandar (II b)	40.9	Parangipettai(Port Nova)	19.6	Sheopur (II b)	21.3	Veraval (I)	5.1
Medikeri (Mercara) (II b)	19.6	Parbhani (II a)	20.7	Shillong (CSO) (I)	23.8	Vishakhapatanam (A)(I)	62.3
Merrut (III a)	0.7	Pasighat (A) (II a)	35.9	Shillong (I)	36.7	Wardha (II b)	4.2
Mettur Dam (II do)	3.7	Pathankot	87.5	Shimoga (II b)	13.8	Yeotmal (II b)	16.9
Midnapore (II b)	17.4	Patiala (I)	39.2	Shivpuri (II b)	1.7	Ziro (II b)	4.5

TABLE 1(b)

Total number (annual) of thunderstorm days (IAF observatories)

Station	Days	Station	Days	Station	Days
Adampur	77.5	Gwalior	68.0	Panagarh	80.8
AFA (Hyderabad)	64.9	Hakimpet	55.9	Pathankot	96.0
Agra	63.8	Hasimara	122.9	Pune	37.2
Allahabad	65.0	Halwara	58.7	Sarsawa	70.9
Ambala	64.0	Hindon	66.0	Shillong	106.7
Amritsar	40.5	Jaiselmer	31.0	Sirsa	47.9
Awantipur	46.5	Jammu	94.5	Srinagar	59.2
Bagdogra	108.3	Jamnagar	17.9	Suratgarh	45.0
Bareily	67.5	Jodhpur	31.9	Sulur	66.0
Bhatinda	52.7	Jorhat	116.1	Tambaram	78.3
Barrackpore	73.1	Kanpur	66.2	Tanjavur	45.4
Bhuj	16.5	Kalaikunda	110.2	Tezpur	100.8
Bidar	55.8	Kumbhigram	128.6	Thoise	3.0
Carnicobar	52.0	Leh	7.8	Udhampur	131.7
Chabua	94.0	Lucknow	65.1	Uttarlai (Bikaner)	20.6
Chandigarh	74.2	Nal (Bikaner)	45.7	Yelhanka	45.3
Gorakhpur	62.1	Naliya	6.8		

TABLE 1 (c)

Total number (annual) of thunderstorm days (Neighbouring countries' observatories)

Station	Days	Station	Days	Station	Days
Bogra	67.7	Dhaka	98.2	Mymensingh	4.1
Chittagong	79.3	Jessore	94.8	Peshawar	53.0
Colombo	80.0	Kathmandu	80.0	Quetta	19.0
Coxs Bazar	52.0				

The following are the observatories considered in this study:

3.1. *Airport observatories (India Meteorological Department)*

Dibrugarh, Guwahati, Kailashahar, Agartala, Kolkata, Bhubaneshwar, Jharsaguda, Jamshedpur, Ranchi, Gaya, Varanasi, New Delhi (Safdarjung), Amritsar, Bhuntar, Udaipur, Jaipur, Kota, Bhopal, Indore, Jabalpur, Ahmedabad, Vadodara, Mumbai, Ozar (Nasik), Aurangabad, Akola, Nagpur, Gannavaram, Vishakhapatnam, Hyderabad, Chennai, Thiruchirapalli, Madurai, Mangalore, Belgaum, Bangalore, Thiruvanathpuram (37).

3.2. *IAF observatories*

Tezpur, Jorhat, Kumbhigram (Silchar), Chabua, Shillong, Bagdogra, Hasimara, Kalaikunda (Khargpur), Gorakhpur, Bamrauli (Allahabad), Kanpur, Bareilly, Agra, Sarsawa (Sharanpur), Sirsa, Ambala, Chandigarh, Pathankot, Adampur, Halwara, Bathinda, Srinagar, Leh, Udhampur, Jammu, Jodhpur, Nal (Bikaner), Jaisalmer, Suratgarh, Gwalior, Bhuj, Jamnagar, Pune, Hakimpet (Hyderabad), Dindigul (Hyderabad), Sulur (Coimbatore), Bidar, Yelahanka (Bangalore) and Carnic (39).

3.3. *Class I observatories manned by IMD staff*

Port Blair, Sriniketan, Raxaul, Mukteshwar, Dehradun, Dharamsala, Gulmarg, Guna, Jagdalpur,

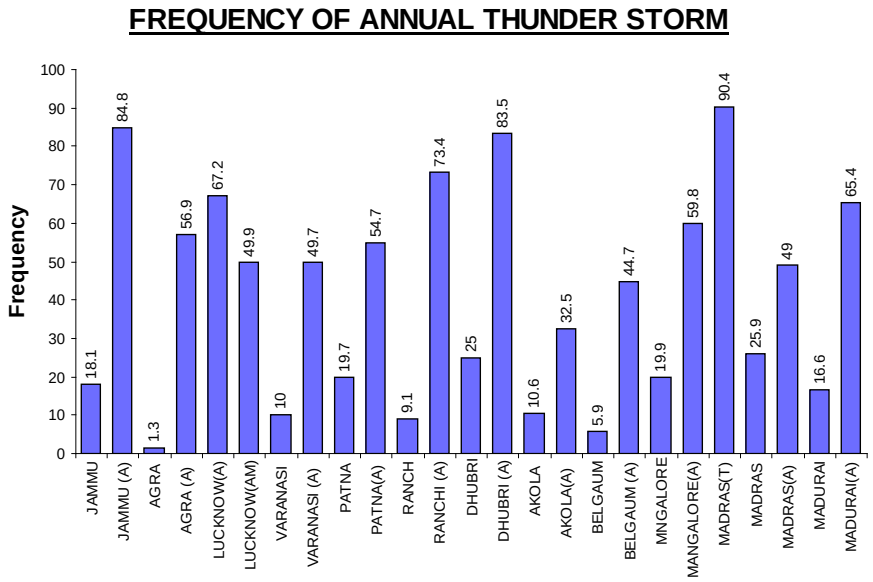


Fig. 3. Graph showing annual frequency of thunderstorm at selected IMD observatories

Raipur, Ananthpur, Kodaikanal, Gadag, Kochi, Minicoy (15).

3.4. *Class II observatory, whose annual frequency is within 20% of nearby airport or civil observatory in the same meteorological sub-division*

Sibsagar, Baripada, Bhagalpur, Dharchula, Mandi, Banihal, Quazigund, Panchmari, Umaria, Manda, Vengurla, Chandrpur, Champa, Vellore, Salem (15).

3.5. *Observatories of neighbouring countries*

Dhaka, Jessore, Chittagong, Coxs Bazar, Peshawar, Quetta, Kathmandu, Colombo (08).

In all 114 observatories out of 450 satisfy above criteria and the distribution of these observatories in various meteorological sub-divisions is shown in Table 2. It is seen that except Arunachal Pradesh all other meteorological sub-divisions are adequately represented. The location of observatories is shown in Fig. 4. Annual number of days of thunderstorm of representative observatories selected for developing climatology is given in Tables 3(a-c).

4. Annual frequency

The spatial distribution of the mean annual number of thunderstorm days over India and neighbourhood is shown in Fig. 5. The areas of highest activity of thunderstorms exceeding 120 days in the year are seen over Assam, Sub Himalayan West Bengal and windward side of Pir Panjal range in Jammu and Kashmir. The occurrence of thunderstorms is predominantly controlled by the local orography resulting in a complex spatial pattern. Although all meteorological sub divisions have been adequately represented, isopleths of number of days in the figure can be viewed only as a generalization, limited to reports from existing observational network, as a large number of isolated thunderstorm occurring outside the purview of the observatories might not have been recorded at all. The figure shows that the region of high thunderstorm activity (more than 100 days) are Jammu sub-division in the north-Assam, Meghalaya and adjoining parts of Bangladesh and West Bengal in the east followed by Kerala (80-100 days). Least number of thunderstorms (5 days) in the country occur in Ladakh.

In the plains, lowest occurrence is seen over Saurashtra and Kutch (15 days). Thunderstorm activity increases as one moves north eastwards from Saurashtra and Kutch across Rajasthan (20 to 40 days), Haryana (40 to 50 days), Punjab and Uttar Pradesh (50 to 70 days) to Himalayan foothills (80 days). Highest frequency over north India is recorded by Udhampur (132 days) in Jammu Sub-division. The station is on the windward side of Pir Panjal range. The frequency decreases to 60 days on lee-ward side over Srinagar valley and decreases sharply over Ladakh region on the leeward side of Zanskar range.

The frequency of thunderstorm over central parts of country is between 30 and 50 days. The frequency increases eastwards and is between 50 and 80 days over Bihar, east Madhya Pradesh, Chhatishgarh, Telangana and coastal Andhra Pradesh and Orissa. The frequency increases to 80 to 100 days over Gangetic West Bengal and Bangladesh and between 100 and 120 days over Sub-Himlayan West Bengal, Assam and adjoining northeastern

TABLE 2

Distribution of stations in meteorological sub-division

Sub-division	Civil observatories	Air force observatories
Andaman & Nicobar Islands	(*i*) Port Blair	(*i*) Carnic
Arunachal Pradesh	No full time observatory	
Assam	(*i*) Dibrugarh (A) (*ii*) Guwahati (A) (*iii*) Sibsagar (*iv*) Kailashahar (A)	(*i*) Tezpur (*ii*) Jorhat (*iii*) Kumbhigram (Silchar) (*iv*) Chabua
Meghalaya		(*i*) Shillong
Nagaland, Manipur, Mizoram & Tripura	(*i*) Agartala (A)	
Sub-Himalayan West Bengal & Sikkim		(*i*) Bagdogra (Siliguri) (*ii*) Hasimara
Gangetic West Bengal	(*i*) Kolkata (A) (*ii*) Sri Niketan	(*i*) Kalaikunda (Kharagpur)
Orissa	(*i*) Baripada (*ii*) Bhubaneshwar (A) (*iii*) Jharsuguda (A)	
Jharkhand	(*i*) Jamshedpur (A) (*ii*) Ranchi (A)	
Bihar	(*i*) Bhagalpur (*ii*) Gaya (A)	
East Uttar Pradesh	(*i*) Raxaul (*ii*) Varanasi (A)	(*i*) Gorakhpur (*ii*) Bamrauli (Allahabad)
West Uttar Pradesh		(*i*) Kanpur (*ii*) Bareilly (*iii*) Agra (*iv*) Sarsawa (Saharanpur)
Uttaranchal	(*i*) Mukteshwar (*ii*) Dehradun (*iii*) Dharchula	
Delhi & Haryana	(*i*) New Delhi (Safdarjung) (A)	(*i*) Sirsa (*ii*) Ambala
Punjab	(*i*) Amritsar (A)	(*i*) Chandigarh (*ii*) Pathankot (*iii*) Adampur (*iv*) Halwara (*v*) Bathinda
Himachal Pradesh	(*i*) Bhuntar (A) (*ii*) Dharamshala (*iii*) Mandi	
Jammu & Kashmir	(*i*) Banihal (*ii*) Gulmarg (*iii*) Quazigund	(*i*) Srinagar (*ii*) Leh (*iii*) Udhampur (*iv*) Jammu
West Rajasthan		(*i*) Jodhpur (*ii*) Bikaner (Nal) (*iii*) Jaishalmer (*iv*) Suratgarh

TABLE 2 (*contd*.)

Sub-division	Civil observatories	Air force observatories
East Rajasthan	(*i*) Udaipur (A) (*ii*) Jaipur (A) (*iii*) Kota (A)	
West Madhya Pradesh	(*i*) Bhopal (A) (*ii*) Guna (*iii*) Indore (A)	(*i*) Gwalior
East Madhya Pradesh	(*i*) Pachmari (*ii*) Umaria (*iii*) Jabalpur (A) (*iv*) Mandla	
Gujarat Region	(*i*) Ahmedabad (A) (*ii*) Vadodara (A)	
Saurashtra & Kutch		(*i*) Bhuj (*ii*) Jamnagar
Konkan & Goa	(*i*) Vengurla (*ii*) Mumbai (A)	
Madhaya Maharashtra	(*i*) Ozar (Nasik – A)	(*i*) Pune
Marathawada	(*i*) Aurangabad (A)	
Vidharbha	(*i*) Akola (A) (*ii*) Chandarpur (*iii*) Nagpur (A)	
Chattisgarh	(*i*) Jagdalpur (*ii*) Champa (*iii*) Raipur	
Coastal Andhra Pradesh	(*i*) Gannavaram (A) (*ii*) Vishakhapatnam (A)	
Telengana	(*i*) Hyderabad (A)	(*i*) Hakimpet (Hyderabad) (*ii*) Dindigul (Hyderabad)
Rayalseema	(*i*) Ananthpur	
Tamil Nadu	(*i*) Chennai (A) (*ii*) Kodaikanal (*iii*) Thiruchirapalli (A) (*iv*) Vellore (*v*) Madurai (A) (*vi*) Salem	(*i*) Coimbatore (Sulur)
Coastal Karnakata	(*i*) Mangalore (A)	
North Interior Karnataka	(*i*) Belgaum (A) (*ii*) Gadag	(*i*) Bidar
South Interior Karnataka	(*i*) Bangalore (A)	(*i*) Yelahanka (Bangalore)
Kerala	(*i*) Thiruvananthpuram (A) (*ii*) Kochi (N)	
Lakshadweep	(*i*) Minicoy	

states. Thunderstorm frequency is between 20 and 40 days over Madhya Maharashtra, Rayalseema and adjoining north Karnataka and shows increase southwards. The frequency is between 40 and 60 days over Karnataka and northern parts of Tamil Nadu and between 60 and 80 days over Kerala and adjoining south Tamil Nadu. Bay islands record between 50 and 70 days of thunderstorm activity.

5. Seasonal distribution of thunderstorms

Although annual mean thunderstorm days data set provides a convenient overall generalization of Indian thunderstorms, it does not reflect seasonal and monthly variability of thunderstorms. While physiographic characteristics of different regions within the country

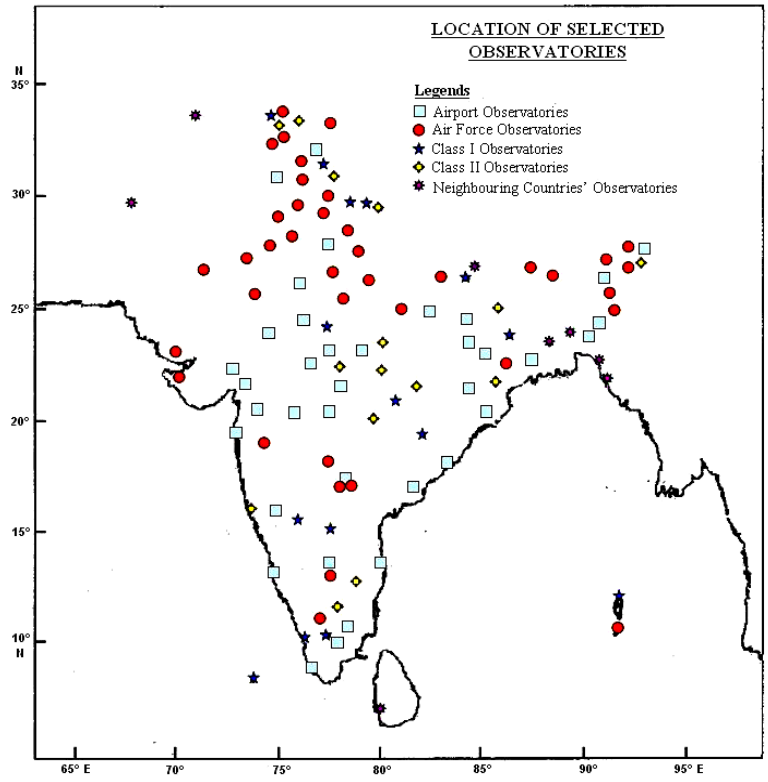


Fig. 4. Observatories selected for developing the thunderstorm climatology

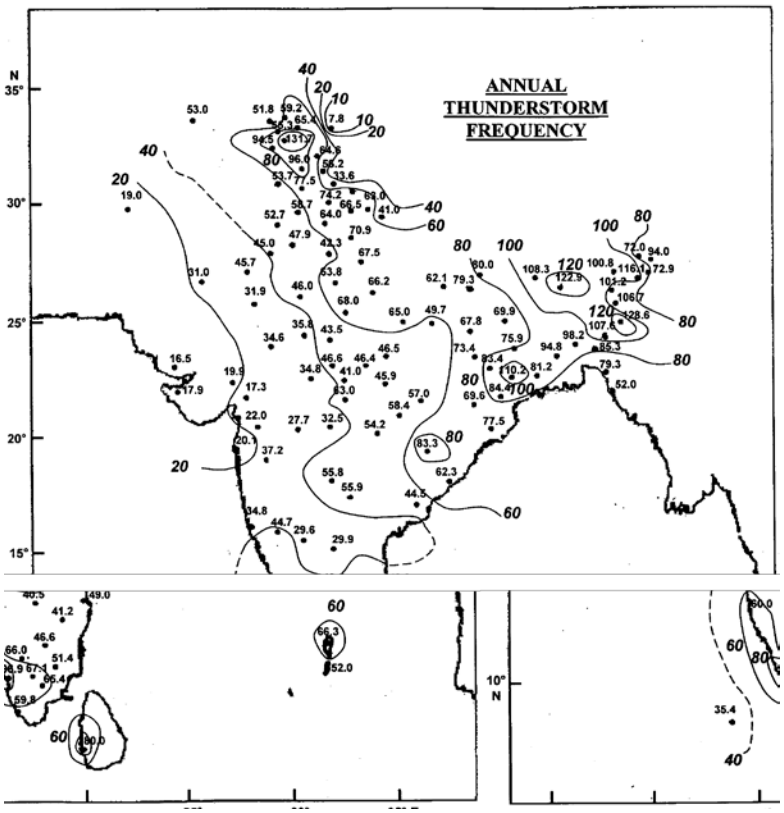


Fig. 5. Annual frequency of thunderstorm

TABLE 3 (a)

Representative observatories selected for developing climatology (IMD observatories)

Station	No. of days	Station	No. of days	Station	No. of days
Agartala (A)	85.3	Gaya (A)	67.8	Mumbai (A)	20.1
Ahemdabad (A)	19.9	Guhawati (A)	101.2	Nagpur (A)	63.0
Akola(A)	32.5	Gulmarg	51.8	New Delhi(Sdf) (A)	42.3
Amritsar (A)	53.7	Guna	43.5	Ozar (A)	22.0
Anantpur	29.9	Hyderabad (A)	37.9	Pachmarhi	41.0
Aurangabad (A)	27.7	Indore (A)	34.8	Port Blair	66.3
Bangalore(A)	40.5	Jabalpur (A)	46.4	Quazigund	65.4
Banihal	55.3	Jagdalpur	83.3	Raipur	58.4
Baripada	84.4	Jaipur (A)	46.0	Ranchi (A)	73.4
Belgaum (Samra) (A)	44.7	Jamshedpur (A)	83.4	Raxaul	79.3
Bhagalpur	69.9	Jharsuguda (A)	69.6	Salem	46.6
Bhopal (A) (Bairagarh)	46.6	Kailashahar (A)	107.5	Sibsagar	72.9
Bhubneshwar(A)	77.5	Kochi (Cochin) (N)	96.9	Sri Niketan	75.9
Bhuntar (A)	64.6	Kodaikanal	67.1	Thiruvananthpuram (A)	59.8
Champa	57.0	Kolkata (A)	81.2	Tiruchchirapalli (A)	51.4
Chandrapur	54.2	Kota (A)	35.8	Udaipur/Dabok (A)	34.6
Chennai (A)	49.0	Madurai (A)	65.4	Umaria	46.5
Dehradun	66.5	Mandla	45.9	Vadodra (A)	17.3
Dharamsala	56.2	Mandi	33.6	Varanasi (A)	49.7
Dharchula	41.0	Mangalore (A)	60.0	Vellore	41.2
Dibrugarh (A)	91.8	Minicoy	35.4	Vengurla	34.8
Gadag	29.6	Mukteswar	63.0	Vishakhapatanam (A)	62.3
Gannavaram (A)	44.5				

TABLE 3 (b)

Representative observatories selected for developing climatology (IAF observatories)

Station	Days	Station	Days
Adampur	77.5	Jamnagar	17.9
Afa	64.9	Jodhpur	31.9
Agra	63.8	Jorhat	116.1
Allahabad	65.0	Kalaikunda	110.2
Ambala	64.0	Kanpur	66.2
Bagdogra	108.3	Kumbhigram	128.6
Bareily	67.5	Leh	7.8
Bhatinda	52.7	Nal (Bikaner)	45.7
Bhuj	16.5	Pathankot	96.0
Bidar	55.8	Pune	37.2
Carnic	52.0	Sarsawa	70.9
Chabua	69.0	Shillong	106.7
Chandigarh	74.2	Sirsa	47.9
Gorakhpur	62.1	Srinagar	59.2
Gwalior	68.0	Sulur	66.0
Hakimpet	55.9	Suratgarh	45.0
Halwara	58.7	Tezpur	100.8
Hasimara	122.9	Udhampur	131.7
Jaiselmer	31.0	Yelhanka	45.3
Jammu	94.5		

TABLE 3 (c)

Representative observatories selected for developing climatology (neighbouring countries' observatories)

Station	Days	Station	Days
Chittagong	79.3	Jessore	94.8
Colombo	80.0	Kathmandu	80.0
Coxs Bazar	52.0	Peshawar	53.0
Dhaka	98.2	Quetta	19.0

determine the control on regional scale thunderstorm activity, leading to distinctly different thunderstorm maxima and minima, impact of different seasons on their spatial variations also needs to be analysed. Seasonal mean number of days of thunderstorm for observatories is given in Tables 4(a-c). It is interesting to note that outside Kerala, Tamil Nadu and adjoining parts of Karnataka, the highest number of thunderstorm in the country occur during monsoon season. Apparently instead of insolation, low level wind and moisture regimes play dominant role over these areas. Least amount of thunderstorm activity is observed during winter season. Spatial variation of thunderstorm in different seasons is discussed with the help of Figs. 6 (a-d).

TABLE 4 (a)

Seasonal mean number of thunderstorm days (IMD observatories)

Station	Winter	Pre-monsoon	Monsoon	Post Monsoon	Station	Winter	Pre-monsoon	Monsoon	Post Monsoon
Agartala (A)	2.3	30.0	46.0	7.0	Kailashahar (A)	2.3	36.8	60.3	8.1
Ahmedabad (A)	0.6	2.4	15.5	1.4	Kochi (N)	6.6	41.5	23.3	25.5
Akola (A)	2.5	6.1	21.5	2.4	Kodaikanal	1.3	8.9	21.6	12.4
Amritsar (A)	4.4	13.9	32.9	2.5	Kolkata (A)	2.4	19.6	51.0	8.2
Anantpur	0.2	12.2	12.9	4.6	Kota (A)	1.3	6.6	26.4	1.5
Aurangabad (A)	1.2	7.7	15.9	2.9	Madurai (A)	1.7	20.2	28.5	15.0
Bangalore (A)	0.6	18.6	14.9	6.4	Mandla	3.6	11.4	28.8	2.1
Banihal	4.1	24.2	22.6	4.4	Mandi	2.4	11.7	17.8	1.7
Baripada	2.6	26.4	49.5	5.9	Mangalore (A)	1.9	19.9	19.5	18.7
Belgaum (A)	1.2	24.9	10.9	7.7	Minicoy	4.4	16.2	9.3	5.5
Bhagalpur	1.9	12.3	50.8	4.9	Mukteswar	4.5	21.8	32.4	4.3
Bhopal (A)	3.4	7.1	33.6	2.5	Mumbai (A)	0.4	2.7	12.8	4.2
Bhubaneshwar (A)	2.4	17.7	49.8	7.6	Nagpur (A)	3.0	15.8	41.0	3.2
Bhuntar (A)	4.7	26.9	28.6	4.4	New Delhi (A)	4.1	10.5	25.8	1.9
Champa	2.8	12.5	39.1	2.6	Ozar (A)	0.9	5.2	11.9	4.0
Chandrapur	2.2	14.3	33.7	4.0	Pachmarhi	3.4	8.7	26.5	2.4
Chennai (A)	0.9	5.2	28.2	14.7	Port Blair	3.4	27.0	26.5	9.4
Dehradun	5.0	15.2	42.9	3.4	Quazigund	2.3	27.1	31.6	4.4
Dharchula	1.5	11.0	25.7	2.8	Raipur	2.3	13.8	39.2	3.1
Dharamsala	4.2	15.7	32.9	3.4	Ranchi (A)	4.4	19.0	46.7	3.3
Dibrugarh (A)	8.5	32.5	45.3	5.5	Raxaul	2.0	17.4	55.3	4.6
Gadag	0.5	15.1	10.0	4.0	Salem	0.6	15.7	21.6	8.7
Gannavaram (A)	0.4	10.0	24.9	9.2	Sibsagar	4.2	22.4	42.6	3.7
Gaya (A)	3.6	15.7	52.7	2.6	Sriniketan	2.2	18.4	50.8	4.5
Gulmarg	0.6	19.9	28.3	3.0	Thiruvanathpuram (A)	6.2	30.1	7.2	16.3
Guna	2.9	7.7	30.7	2.2	Tiruchchirapalli (A)	1.1	14.2	23.8	12.3
Guwahati (A)	3.1	36.1	56.5	5.5	Udaipur (A)	1.0	31.8	25.8	2.1
Hyderabad (A)	1.0	14.5	18.4	4.0	Umaria	4.4	8.8	31.0	2.3
Indore (A)	2.1	5.9	24.2	2.6	Vadodra (A)	0.4	1.7	13.3	1.9
Jabalpur (A)	3.3	8.5	32.5	2.1	Varanasi (A)	3.5	7.3	36.6	2.3
Jagdalpur	1.4	29.8	45.2	6.9	Vellore	0.4	11.4	21.6	7.8
Jaipur (A)	3.0	8.9	31.9	2.2	Vengurla	0.4	10.0	12.9	11.5
Jamshedpur (A)	3.0	19.9	55.8	4.7	Vishakhapatanam (A)	0.7	15.4	36.5	9.7
Jharsuguda (A)	3.0	14.9	47.9	3.8					

TABLE 4 (b)

Seasonal mean number of thunderstorm days (IAF observatories)

Station	Winter	Pre-monsoon	Monsoon	Post Monsoon	Station	Winter	Pre-monsoon	Monsoon	Post Monsoon
Adampur	7.1	17.5	48.3	4.6	Jamnagar	0.6	0.3	14.3	2.7
Afa	2.2	18.8	35.4	8.5	Jodhpur	1.0	6.5	22.3	2.1
Agra	4.1	12.9	44.9	1.9	Jorhat	5.6	39.2	64.7	6.6
Allahabad	4.8	10.2	47.5	2.5	Kalikunda	4.3	30.6	67.9	7.4
Ambala	5.4	15.3	40.6	2.7	Kanpur	3.7	12.0	48.0	2.5
Bagdogra	3.4	28.9	69.3	6.7	Kumbhigram	6.4	49.1	64.8	8.3
Bareilly	4.4	12.6	48.3	2.2	Leh	0.0	1.6	6.2	0.0
Bhatinda	4.9	14.8	30.6	2.4	Nal (Bikaner)	2.1	11.7	29.1	2.8
Bhuj	0.3	4.2	8.7	3.3	Pathankot	8.8	22.6	60.8	3.8
Bidar	0.6	20.5	30.6	4.1	Pune	0.4	10.4	16.3	10.1
Carnic	6.6	17.0	18.2	10.2	Sarsawa	5.5	17.3	46.3	1.8
Chabua	2.9	28.6	35.4	2.1	Shilong	2.9	43.9	51.1	8.8
Chandigarh	5.6	17.4	48.4	2.8	Sirsa	3.7	14.4	27.4	2.4
Gorakhpur	3.6	12.1	43.4	3.0	Srinagar	1.6	26.7	27.0	3.9
Gwalior	4.0	13.6	48.4	2.0	Sulur	1.5	24.4	20.6	19.5
Hakimpet	1.0	17.8	29.7	7.4	Surartgarh	2.7	12.7	27.6	2.0
Halwara	4.6	17.2	34.6	2.3	Tezpur	5.1	36.3	54.5	4.9
Hasimara	4.5	39.6	71.1	7.7	Udhampur	12.2	34.4	78.4	6.7
Jaisalmer	1.3	7.3	20.6	1.8	Yelhanka	0.0	10.2	23.8	11.3
Jammu	7.5	24.6	58.2	4.2					

TABLE 4 (c)

Seasonal mean number of thunderstorm days neighbouring countries' observatories

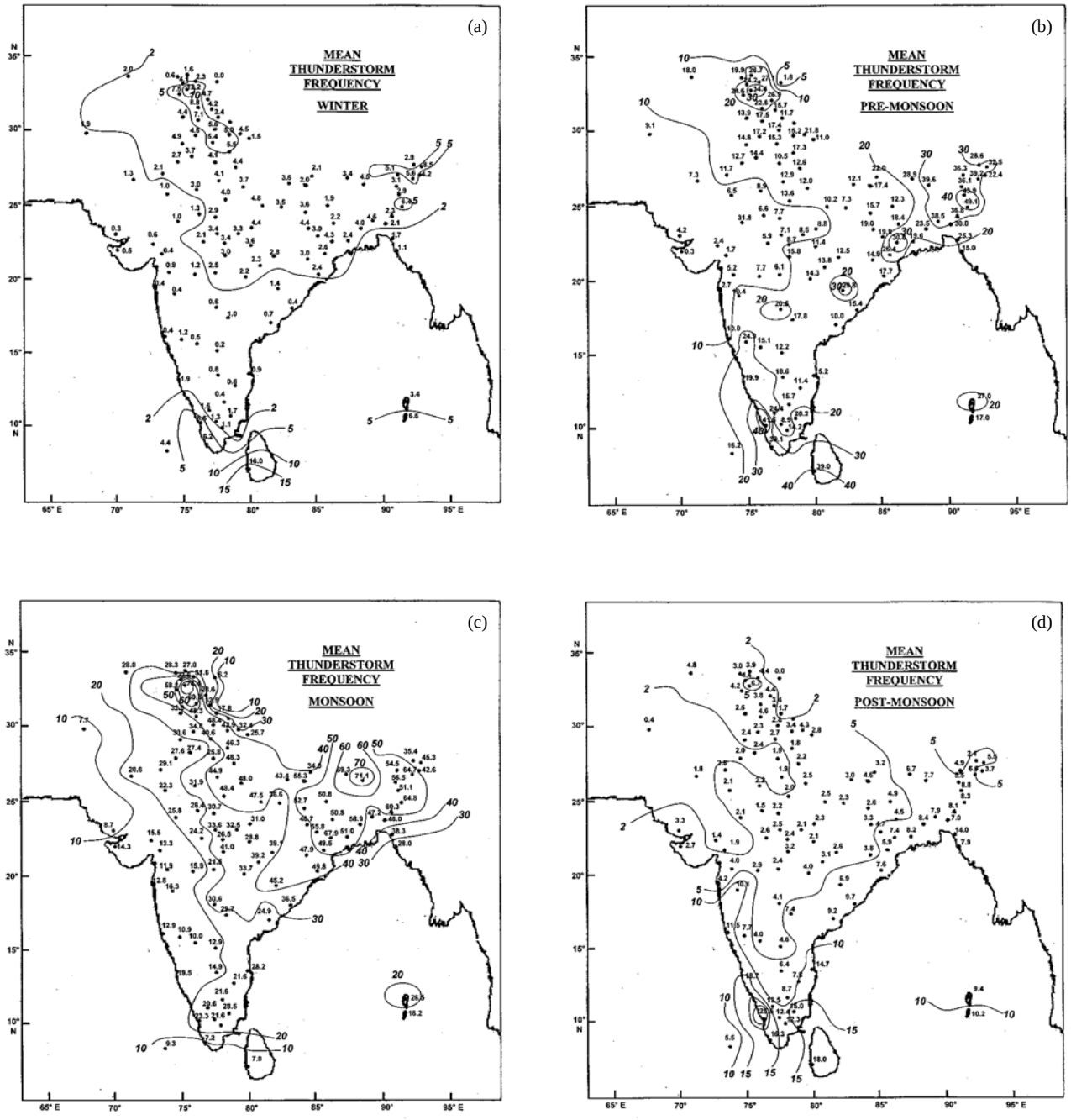
Station	Winter	Pre-monsoon	Monsoon	Post Monsoon
Chittagong	1.7	25.3	38.3	14.0
Colombo	16.0	39.0	7.0	18.0
Coxs Bazar	1.1	15.0	28.0	7.9
Dhaka	4.6	38.5	47.2	7.9
Jessore	4.0	23.5	58.9	8.4
Kathmandu	2.1	22.0	34.0	3.2
Peshawar	2.0	18.0	28.0	4.8
Quetta	1.9	9.1	7.7	0.4

5.1. *Winter*

Country as a whole records the lowest number of thunderstorms during winter season. It is primarily due to stable and dry atmospheric conditions prevailing over most parts of the subcontinent with the exception of Srilanka and southern Kerala. Highest frequency during this season is over Sri Lanka (16 days) associated with northeast monsoon activity [Fig. 6(a)]. Second maxima (13 days) is seen over windward side of Pir Panjal range over Jammu and adjoining region. This maxima is associated with western disturbances. Thunderstorm activity shows sharp decline on the lee ward side over Kashmir and Ladakh region. Punjab, Harayana and adjoining west Uttar Pradesh, northern parts of Assam and southern parts of Kerala record more than 5 days of thunderstorm. Thunderstorms occur between 2 and 4 days over the plains of north and central India. Saurashtra, Kutch, Gujarat, Konkan and Madhya Maharashtra sub-divisions in the west and coastal Andhra, Rayalseema and adjoining Tamil Nadu and Karnataka in peninsula record less than one thunderstorm occurrence during winter.

5.2. *Pre-monsoon*

Pre monsoon season is characterized by increase in thunderstorm activity over all parts of the country with significant increase over northeast India Bangladesh, West Bengal, south peninsula and Jammu region [Fig. 6b)].



Figs. 6(a-d). Thunderstorm frequency over Indian region in each season (a) winter, (b) pre-monsoon, (c) monsoon and (d) post-monsoon

Highest frequency of more than 40 days is observed over Meghalaya and adjoining Assam, Sub-Himalayan West Bengal and Kerala and more than 30 days over rest of northeast India and parts of Bangladesh and West Bengal. In the north, Jammu sub-division records highest frequency (25-30 days) of thunderstorm in the pre monsoon season. Topography, insolation and advection of moisture under favourable wind regime contribute to thunderstorm maxima over these areas. Synoptically, Western Disturbances and induced lows in the north and easterly waves in south provide favourable conditions for the occurrence of thunderstorm over these

TABLE 5 (a)

Monthly frequency of thunderstorm (IMD observatories)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agartala (A)	0.4	1.8	5.7	11.1	13.2	12.2	8.7	11.3	13.8	6.0	1.0	0.1
Ahmedabad (A)	0.2	0.2	0.5	0.7	1.2	4.5	4.8	3.0	3.2	1.1	0.3	0.2
Akola (A)	0.7	1.5	2.0	1.6	2.5	8.2	5.5	3.1	4.7	1.9	0.5	0.3
Amritsar (A)	1.3	2.2	3.8	4.3	5.8	7.1	10.6	10.5	4.7	1.7	0.8	0.9
Anantpur	0.0	0.1	0.8	4.3	7.1	3.3	1.3	2.0	6.3	4.0	0.6	0.1
Aurangabad (A)	0.4	0.5	1.7	2.3	3.7	6.9	2.3	2.4	4.3	2.0	0.9	0.3
Bangalore (A)	0.0	0.3	0.9	6.2	11.5	4.1	2.3	2.6	5.9	5.3	1.1	0.3
Banihal	0.8	2.6	4.8	7.7	11.7	8.4	6.3	3.3	4.6	3.2	1.2	0.7
Baripada	0.2	2.4	4.3	9.4	12.7	13.8	11.1	12.1	12.5	5.7	0.2	0.0
Belgaum (A)	0.2	0.7	3.2	11.1	10.6	3.4	0.8	0.9	5.8	6.0	1.7	0.3
Bhagalpur	0.7	1.0	2.1	3.2	7.0	10.9	13.1	14.3	12.5	4.7	0.2	0.2
Bhopal (A)	1.6	1.3	2.3	1.9	2.9	9.9	8.5	8.8	6.4	2.0	0.5	0.5
Bhubaneshwar (A)	0.3	2.0	3.5	5.7	8.5	12.2	11.6	12.9	13.1	7.3	0.3	0.1
Bhuntar (A)	1.4	2.8	6.9	8.9	11.1	11.2	7.8	3.8	5.8	3.0	1.4	0.5
Champa	0.8	1.7	3.9	3.8	4.8	10.7	9.6	10.5	8.3	2.4	0.2	0.3
Chandrapur	0.6	1.3	3.5	5.9	4.9	10.4	7.6	7.8	7.9	3.6	0.4	0.3
Chennai (A)	0.0	0.0	0.4	1.8	3.0	5.4	7.1	7.7	8.0	10.0	4.7	0.9
Dehradun	2.1	2.3	4.1	4.3	6.8	10.2	12.3	10.8	9.6	2.6	0.8	0.6
Dharchula	0.6	0.8	2.6	3.6	4.8	8.0	4.9	5.6	7.2	2.4	0.4	0.1
Dharamsala	2.1	1.6	3.9	5.0	6.8	9.2	9.0	8.0	6.7	2.5	0.9	0.5
Dibrugarh (A)	2.7	5.2	9.0	12.5	11.0	11.0	11.1	13.2	10.0	4.5	1.0	0.6
Gadag	0.1	0.3	1.0	6.6	7.5	3.6	0.8	1.0	4.6	3.2	0.8	0.1
Gannavaram (A)	0.0	0.4	0.9	2.9	6.2	7.1	4.7	4.9	8.2	7.6	1.6	0.0
Gaya (A)	1.4	1.9	2.9	2.2	3.8	10.9	14.6	15.3	11.9	2.5	0.1	0.3
Guhawati (A)	0.7	2.1	5.8	13.8	16.5	14.4	12.7	16.1	13.3	4.5	1.0	0.3
Gulmarg	0.3	0.3	3.1	7.1	9.7	10.6	7.4	5.6	4.7	2.7	0.3	0.0
Guna	1.5	1.1	2.2	2.0	3.5	9.0	9.0	7.6	5.1	1.8	0.4	0.3
Hyderabad (A)	0.3	0.7	2.0	6.2	6.3	6.3	2.7	2.9	6.5	3.6	0.4	0.0
Indore (A)	1.1	0.6	1.2	1.5	3.2	8.4	6.2	4.5	5.1	2.1	0.5	0.4
Jabalpur (A)	1.3	1.5	3.3	2.3	2.9	10.0	8.5	8.1	5.9	1.9	0.2	0.5
Jagdalpur	0.3	0.9	4.2	12.5	13.1	14.4	8.0	10.0	12.8	5.8	1.1	0.2
Jaipur (A)	0.8	1.5	2.4	2.3	4.2	7.5	10.2	9.3	4.9	1.8	0.4	0.7
Jamshedpur (A)	1.1	1.8	4.5	5.9	9.5	14.3	14.4	13.8	13.3	4.6	0.1	0.1
Jharsuguda (A)	0.9	1.8	3.7	4.5	6.7	12.6	10.4	12.9	12.0	3.7	0.1	0.3
Kailashahar (A)	0.5	1.8	7.0	13.4	16.4	16.8	13.1	14.7	15.7	7.3	0.8	0.0
Kochi (N)	1.1	2.0	6.6	17.8	17.1	9.6	5.3	2.7	5.7	13.6	11.9	3.5

TABLE 5 (a) (*Contd*.)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kodaikanal	0.2	0.8	3.7	13.4	14.7	5.2	3.1	4.7	8.6	9.6	2.8	0.3
Kolkata (A)	0.4	1.9	3.8	6.4	9.4	12.2	11.0	12.8	15.0	7.9	0.3	0.1
Kota (A)	0.3	0.6	1.1	1.9	3.6	6.3	7.6	7.5	5.0	1.1	0.4	0.4
Madurai (A)	0.0	0.7	2.0	7.4	10.8	5.5	5.0	7.5	10.5	10.4	4.6	1.0
Mandla	1.4	1.8	3.8	4.4	3.2	9.4	7.5	6.4	5.5	1.7	0.4	0.4
Mandi	0.7	1.4	3.2	3.8	4.7	5.9	5.2	3.6	3.1	1.2	0.5	0.3
Mangalore (A)	0.2	0.1	1.1	7.9	10.9	8.6	5.9	1.4	3.6	11.9	6.8	1.6
Minicoy	1.0	1.0	2.0	6.3	7.9	5.1	2.1	1.0	1.1	2.5	3.0	2.4
Mukteswar	1.6	2.4	5.3	6.7	9.8	11.3	7.8	5.8	7.5	3.7	0.6	0.5
Mumbai (A)	0.1	0.1	0.1	0.4	2.2	4.8	2.2	1.6	4.2	3.1	1.1	0.2
Nagpur (A)	1.0	1.4	4.4	5.9	5.5	13.4	10.3	8.1	9.2	2.7	0.5	0.6
New Delhi (A)	1.4	1.9	3.1	2.6	4.8	6.0	8.0	7.8	4.0	1.6	0.3	0.8
Ozar (Nasik-A)	0.3	0.3	0.9	1.9	2.4	5.3	1.1	1.2	4.3	3.1	0.9	0.3
Pachmarhi	1.4	1.6	3.2	2.9	2.6	9.0	6.0	5.9	5.6	1.9	0.5	0.4
Port Blair	0.7	0.5	2.5	10.1	14.4	8.4	8.1	5.4	4.6	5.1	4.3	2.2
Quazigund	0.6	1.4	5.1	8.2	13.8	9.2	9.5	6.7	6.2	3.1	1.3	0.3
Raipur	0.7	1.4	3.6	4.7	5.5	11.8	9.6	8.8	9.0	3.0	0.1	0.2
Ranchi (A)	1.1	3.1	4.2	5.6	9.2	13.0	11.9	12.1	9.7	3.1	0.2	0.2
Raxaul	0.8	1.0	1.9	3.8	11.7	14.3	15.4	14.9	10.7	3.9	0.7	0.2
Salem	0.0	0.2	1.2	6.1	8.4	5.1	3.8	6.0	6.7	6.8	1.9	0.4
Sibsagar	0.8	2.6	5.4	8.1	8.9	9.3	11.2	10.0	12.1	3.3	0.4	0.8
Sriniketan	0.4	1.8	3.2	5.9	9.3	12.1	14.7	13.1	10.9	4.2	0.3	0.0
Thiruvananthpuram (A)	1.0	2.2	5.4	14.6	10.1	3.0	0.6	0.9	2.7	9.2	7.1	3.0
Tiruchchirapalli (A)	0.0	0.1	1.1	5.0	8.1	4.6	4.2	5.9	9.1	9.6	2.7	1.0
Udaipur/Dabok (A)	0.1	0.8	0.9	0.9	3.9	7.3	7.7	6.1	4.7	1.8	0.3	0.1
Umaria	1.6	2.3	3.6	2.3	2.9	8.5	8.9	7.3	6.3	1.8	0.5	0.5
Vadodra (A)	0.1	0.1	0.3	0.5	0.9	4.1	3.5	2.7	3.0	1.6	0.3	0.2
Varanasi (A)	1.4	1.5	2.6	1.9	2.8	6.3	11.1	10.5	8.7	2.2	0.1	0.6
Vellore	0.0	0.1	0.7	2.6	8.1	5.6	4.6	5.3	6.1	6.1	1.7	0.3
Vengurla	0.0	0.0	0.4	3.6	6.0	7.1	1.9	1.0	2.9	8.1	3.4	0.4
Vishakhapatanam (A)	0.2	0.5	1.8	5.0	8.6	10.2	6.9	8.0	11.4	8.2	1.5	0.0

TABLE 5 (b)

Monthly frequency of thunderstorm (IAF observatories)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adampur	1.7	4.5	4.7	6.1	6.7	8.8	15.3	14.3	9.9	1.9	2.7	0.9
Afa	0.2	2.0	2.3	7.3	9.2	10.2	9.6	6.9	8.7	7.5	1.0	0.0
Agra	1.3	2.3	2.8	3.9	6.2	8.6	15.6	13.4	7.3	1.6	0.3	0.5
Allahabad	1.3	2.6	1.9	3.6	4.7	8.5	14.5	14.6	9.9	2.4	0.1	0.9
Ambala	1.7	3.3	4.5	4.1	6.7	8.3	12.7	12.0	7.6	1.6	1.1	0.4
Bagdogra	0.8	2.0	3.3	7.3	18.3	18.3	18.5	16.6	15.9	6.3	0.4	0.6
Bareilly	1.7	2.2	3.1	2.8	6.7	8.8	15.3	15.5	8.7	1.4	0.8	0.5
Bhatinda	0.9	1.9	2.9	4.9	7.0	8.0	10.2	7.4	5.0	2.0	0.4	2.1
Bhuj	0.3	0.0	0.0	1.0	0.7	2.5	4.5	1.9	2.3	3.3	0.0	0.0
Bidar	0.4	0.2	2.2	9.0	9.3	10.3	7.1	6.2	7.0	3.0	1.1	0.0
Chabua	1.7	0.9	9.1	10.6	8.9	9.6	8.6	8.8	8.4	1.8	0.3	0.3
Carnic	1.0	0.6	1.6	6.8	8.6	6.6	3.0	5.8	2.8	2.4	7.8	5.0
Chandigarh	1.4	3.6	4.2	5.8	7.4	10.6	15.0	14.0	8.8	1.9	0.9	0.6
Gorakhpur	1.2	2.2	2.0	3.7	6.4	9.2	12.7	12.4	9.1	2.4	0.6	0.2
Gwalior	1.2	2.0	2.2	4.6	6.8	9.6	15.8	14.5	8.5	1.6	0.4	0.8
Hakimpet	0.6	0.4	1.7	7.2	8.9	7.3	7.3	6.1	9.0	6.7	0.7	0.0
Halwara	1.5	2.6	4.0	5.5	7.7	7.4	10.5	10.1	6.6	1.7	0.6	0.5
Hasimara	1.1	3.0	4.0	14.0	21.6	20.1	17.2	17.2	16.6	6.7	1.0	0.4
Jaisalmer	0.2	0.5	1.2	2.7	3.4	4.8	7.6	4.9	3.3	1.6	0.2	0.6
Jammu	1.8	4.8	6.8	7.7	10.1	11.5	16.8	18.7	11.2	2.9	1.3	0.9
Jamnagar	0.4	0.2	0.0	0.2	0.1	4.3	6.0	1.4	2.6	2.7	0.0	0.0
Jodhpur	0.4	0.6	0.9	2.4	3.2	5.4	7.4	5.6	3.9	2.0	0.1	0.0
Jorhat	1.5	4.0	9.1	16.1	14.0	16.5	17.2	15.5	15.5	5.2	1.4	0.1
Kalikunda	0.8	3.2	4.2	11.9	14.5	17.2	17.4	18.4	14.9	7.3	0.1	0.3
Kanpur	1.4	1.9	2.6	3.0	6.4	8.9	14.0	14.5	10.6	1.7	0.8	0.4
Kumbhigram	0.9	5.0	11.6	17.0	20.5	18.8	14.3	14.9	16.8	7.1	1.2	0.5
Leh	0.0	0.0	0.0	0.1	1.5	0.9	2.3	2.8	0.2	0.0	0.0	0.0
Nal	1.0	0.9	1.8	3.7	6.2	7.0	10.6	6.7	4.8	2.5	0.3	0.2
Pathankot	2.5	5.6	5.8	7.1	9.7	12.3	19.3	17.4	11.8	1.9	1.9	0.7
Pune	0.0	0.2	1.1	3.7	5.6	7.6	1.3	0.6	6.8	8.3	1.8	0.2
Sarsawa	1.6	3.5	4.6	4.3	8.4	9.5	14.4	14.6	7.8	1.3	0.5	0.4
Shillong	0.7	1.7	7.3	17.7	18.9	13.9	9.7	14.9	12.6	7.5	1.3	0.5
Sirsa	0.9	2.1	2.2	5.0	7.2	7.3	9.2	6.3	4.6	2.1	0.3	0.7
Srinagar	0.0	1.3	4.3	8.0	14.4	9.5	2.3	9.6	5.6	3.0	0.9	0.3
Sulur	0.1	0.6	2.0	11.0	11.4	3.6	2.1	5.4	9.5	13.1	6.4	0.8
Surartgarh	0.7	1.7	2.5	4.2	6.0	7.0	9.8	6.5	4.3	1.6	0.4	0.3
Tezpur	1.4	3.4	6.2	14.9	15.2	14.2	11.3	14.8	14.2	4.1	0.8	0.3
Udhampur	3.8	7.3	10.4	10.8	13.2	15.6	23.2	23.9	15.7	4.2	2.5	1.1
Yelhanka	0.0	0.0	1.3	8.9	0.0	5.8	3.5	5.8	8.7	10.7	0.6	0.0

TABLE 5 (c)

Monthly frequency of thunderstorm (neighbouring countries' observatories)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chittagong	0.7	1.0	6.3	9.0	10.0	9.3	9.7	8.0	11.3	12.0	2.0	0.0
Colombo	3.0	5.0	11.0	19.0	9.0	2.0	1.0	2.0	2.0	8.0	10.0	8.0
Coxs Bazar	0.2	0.7	2.0	4.0	9.0	10.0	4.0	5.0	9.0	7.0	0.9	0.2
Dhaka	0.3	4.0	6.9	12.7	18.9	12.1	11.3	9.2	14.6	7.2	0.7	0.3
Jessore	0.5	3.3	3.9	6.5	13.1	13.5	14.5	14.2	16.7	8.0	0.4	0.2
Kathmandu	1.0	1.0	4.0	7.0	11.0	9.0	8.0	8.0	9.0	3.0	0.2	0.1
Peshawar	0.2	1.5	5.0	6.0	7.0	6.0	9.0	8.0	5.0	4.0	0.8	0.3
Quetta	0.6	0.7	4.0	4.0	1.1	1.7	5.0	0.9	0.1	0.1	0.3	0.6

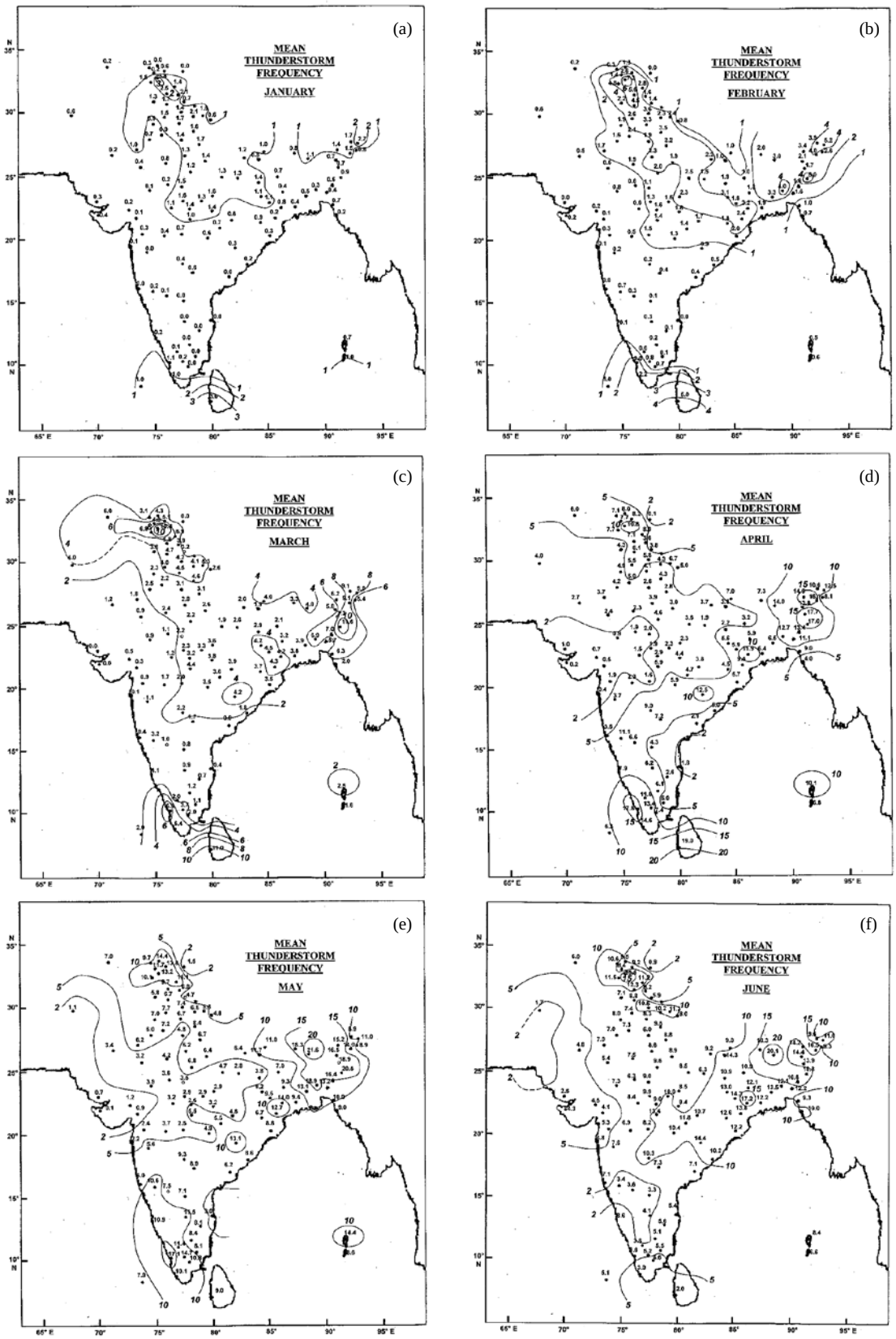
regions. Ladakh records practically no thunderstorm activity during this season. In the plains, the lowest frequency of 2 to 3 days is observed over Gujarat and between 5 and 10 days over Rajasthan, West Madhya Pradesh and north Maharashtra and between 10 and 15 days over Indo Gangetic plains and rest of peninsula. Thunderstorm frequency increases to 15-20 days over East MP, Chhatishgarh, Orissa and adjoining parts of Andhra. Thunderstorms occur between 20 and 30 days over West Bengal and adjoining Jharkhand and Orissa, South Tamil Nadu and Karnataka.

5.3. *Monsoon*

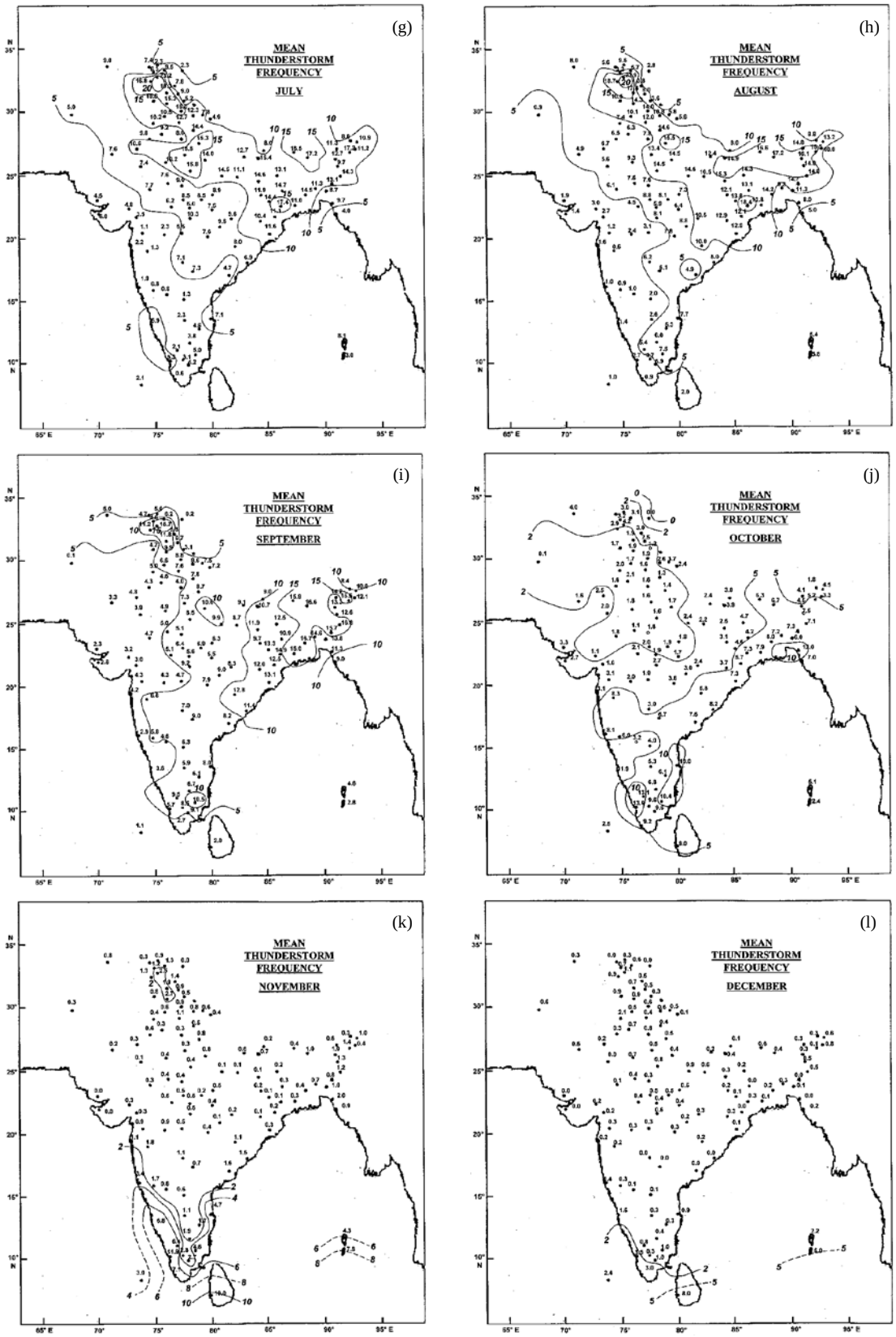
Country as a whole outside Kerala records the highest frequency of thunderstorms during monsoon season. Availability of moisture and favourable synoptic features contribute to general increase of thunderstorm activity over all parts of the country outside Kerala. The highest thunderstorm activity in the country continues to be over northeastern states, Bangladesh, West Bengal and adjoining states, which record more than 50 days of thunderstorm during the season with maxima of 70 days over Sub-Himalayan West Bengal [Fig. 6(c)]. Another maxima of 70 days is seen over wind ward side of Pir Panjal range in Jammu region. Topography in conjunction with favourable wind regime during break monsoon conditions contributes to thunderstorm maxima over these two regions. Indo Gangetic plains record fairly high thunderstorm activity of more than 40 days during this season, most of which is caused by monsoon trough. Although western parts of the country continues to the area of the lowest thunderstorm activity in the country, increase from 2 to 3 days of thunderstorm in the Pre monsoon season to over Gujarat to 10 to 15 days in the monsoon season is quite substantial. West Rajasthan, MP and western parts of Maharashtra and Karnataka also record between 10 and 15 days of thunderstorm. Against general trend of the increase in thunderstorm activity all over the country in the monsoon season, Kerala witnesses significant decrease in thunderstorm occurrence with less than 15 days of thunderstorm taking place over south Kerala. Thunderstorm activity increases eastwards from western parts of the country. North-south oriented belt from Haryana and East Rajasthan to Andhra Pradesh and Tamil Nadu across West MP and Marathwada experience thunderstorm between 20 and 30 days. Most of thunderstorm activity over Rajasthan, Gujarat, Madhya Pradesh and northern parts of Maharashtra is caused by westward moving monsoon lows and depressions whereas over Tamil Nadu, Andhra Pradesh and adjoining areas thunderstorm occur during weak/break monsoon conditions.

5.4. *Post monsoon*

After the withdrawal of monsoon, country outside Tamil Nadu coastal AP and Kerala witnesses marked decrease in thunderstorm activity. Thunderstorm occur on less than 2 days over Gujarat, Rajasthan, Haryana and west UP and between 2 and 4 days over rest of north and central parts of country [Fig. 6(d)]. Northeastern states, Bangladesh and West Bengal also experience sharp decline in thunderstorm activity with only 6 to 7 days of thunderstorm during the season. Thunderstorm activity increases as one moves southwards along west coast and east coast. Highest number of thunderstorms during this season occur over Kerala (20 to 25 days) whereas neighbouring state Tamil Nadu has frequency of 10 to 15



Figs. 7(a-f). Thunderstorm frequency over Indian region in each month (a) January (b) February (c) March (d) April (e) May and (f) June



Figs. 7(g-l). Thunderstorm frequency over Indian region in each month (g) July (h) August (i) September (j) October (k) November (l) December

days. Higher activity over south peninsula is associated with retreating monsoon and easterly waves.

6. Monthly frequency of thunderstorm

6.1. *January*

For the country as whole January is the month of least thunderstorm activity. On an average thunderstorm frequency is less than one day over most parts of the country [Fig. 7(a)]. Thunderstorm frequency is between one and two days over Punjab, Uttar Pradesh, Madhya Pradesh, Kerala and Assam. Maximum thunderstorm activity (2 to 4 days) in the month occurs over Pir Panjal range and its foothills associated with western disturbances.

6.2. *February*

Thunderstorm activity shows slight increase in most of the sub-divisions in the month of February. Significant increase in the thunderstorm frequency is seen over northeast states, Bangladesh and West Bengal [Fig. 7(b)]. Over Punjab and adjoining regions of Jammu, Himachal and west UP thunderstorm occur on an average on 2 to 4 days with highest frequency of 7 days at Udhampur in the Jammu region. Western parts of the country and peninsular region out side Kerala continue to have monthly frequency of less than one day.

6.3. *March*

There is general increase in thunderstorm activity all over the country with significant increase over Kerala [Fig. 7(c)]. It is interesting to note that areas of maximum thunderstorm activity are located at three corners of the country *i.e.*, Assam, Kerala and western Himalayas. Kumbhigram (Silchar) in Assam records the highest (11.6) number of thunderstorm days in the country. In the west Gujarat, west Rajasthan and Konkan record on an average less than one thunderstorm day in April. Thunderstorm activity increases to about 2 to 3 days over central India and to about 3 to 5 days over eastern India.

6.4. *April*

With the onset of summer conditions over most parts of the country during the month, thunderstorm activity records significant increase in April [Fig. 7(d)]. The chief areas of most frequent (more than 15 days) thunderstorms are Assam, Meghalaya and adjoining Bangladesh and Sub Himalayan West Bengal in the northeast and Kerala and adjoining Tamil Nadu in the south. Shilong (18 days) and Cochin (18 days) record highest number of thunderstorm in the month. Thunderstorm frequency is between 5 and 7 days over Karnataka, Tamil Nadu, Andhra Pradesh, Vidarbha, Chhatishgarh, Orissa, Jharkhand and Gangetic West Bengal. However with in these areas, pockets of high thunderstorm activity are observed in Gangetic West Bengal (Kalaikunda/Kharagpur), Chattishgarh (Jagadalpur) and North Karnataka (Belgaum). Gujarat continues to record less than one day of thunderstorm. Thunderstorm occurs between 2 to 4 days over Madhya Pradesh, Uttar Pradesh, East Rajasthan and Haryana. Thunderstorm frequency increases to 8 days over Jammu and Kashmir with Udhampur recording 11 days of thunderstorm.

6.5. *May*

Frequency of thunderstorm activity in different parts of the country in the month of May is similar to that of April, Assam and adjoining Bangladesh and Sub-Himalayan West Bengal in the northeast and Kerala and adjoining Tamil Nadu continue to record maximum thunderstorm activity in the country in this month and Gujarat the lowest [Fig. 7(e)].

6.6. *June*

Distribution of thunderstorm activity undergoes significant change in this month. While there is marked increase in thunderstorm activity over central and western parts and northern plains associated with the advance of monsoon, in the south Kerala, Tamil Nadu and Karantaka record decline in number of thunderstorms in the month of June as compared to May [Fig. 7(f)]. The areas of most frequent thunderstorm (12 to 15 days) are Northeastern states, Bangladesh, West Bengal, Jharkhand, Orissa and Chattishgarh. Thunderstorm frequency over Madhya Pradesh and Uttar Pradesh, Punjab, Himachal and Jammu and Kashmir is between 7 and 9 days. In the west Gujarat records significant increase in the thunderstorm activity as compared to May.

6.7. *July*

Monsoon trough over Indo Gangetic plains being the prominent feature of the month, there is marked increase in thunderstorm activity over Bihar, Uttar Pradesh and Punjab and Jammu and Kashmir in the month of July [Fig. 7(g)]. On an average 12 to 14 days thunderstorm occur over northern plains and northeastern states. Highest frequency (18 to 20 days) in the country is on the wind ward side of Pir Panjal range, with second maxima over Sub Himalayan West Bengal and north Assam (15 to 17 days). Udhampur records highest number (23 days) of thunderstorms in the country in the month of July. In the plains Gangetic West Bengal and adjoining Jharkhand record high frequency (14 to 16 days) of thunderstorm. Madhya Pradesh, east Rajasthan and Haryana record

between 8 and 10 days of thunderstorm. Thunderstorm frequency decreases southwards and westwards. Thunderstorm frequency is between 5 and 7 days over west Rajasthan and Andhra Pradesh and between 3 and 5 days over Gujarat and southern parts of peninsula. Konakan and Madhya Maharashtra record the lowest number (1 to 3 days) of thunderstorms in the country in the month of July.

6.8. *August*

Distribution pattern and frequency of thunderstorm occurrence over different parts of the country in the month of August remains similar to that of July [Fig. 7(h)]. Thunderstorm activity continues to be high along foothills of Himalayas, over Indo Gangetic plains and northeast states. Konkan and adjoining areas record the lowest thunderstorm activity. With monsoon current extending up to higher ranges of Himalayas, Ladakh records highest monthly frequency of 2.8 thunderstorm days in the month of August. In the south slight increase in the thunderstorm activity is observed over Tamil Nadu.

6.9. *September*

With withdrawal of monsoon taking place from northwest India during the month, decline in thunderstorm activity is observed over Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Rajasthan and Uttar Pradesh [Fig. 7(i)]. Thunderstorm activity continues to be high (13 to 15 days) over West Bengal, Orissa, Jharkhand and northeastern states. Highest number of thunderstorms (15 to 17 days) occurs over West Bengal and adjoining parts of Bangladesh. There is general increase in thunderstorm activity over peninsula (7 to 9 days) and west coast (3 to 5 days).

6.10. *October*

After the withdrawal of monsoon, sharp decline in thunderstorm activity is seen over the most parts of the country outside south peninsula and west coast [Fig. 7(j)]. Thunderstorm frequency reduces to 1 to 2 days in the month over north and west India. Thunderstorms occur on an average between 2 to 4 days over central India and between 4 to 6 days over Gangetic West Bengal, Bangladesh and northeastern states in the month of October. Thunderstorm frequency increases southwards along east and west coast. Highest thunderstorm frequency is recorded over Kerala (11 to 13 days) and Tamil Nadu (8 to 10 days).

6.11. *November*

Central and western parts of the country are practically free from thunderstorm activity in the month of November. One thunderstorm may occur in theses areas over a period of two to three years [Fig. 7(k)]. Thunderstorm frequency over Assam and adjoining states is just one day and over western Himalaya and adjoining plains it is between 1 and 2 days. Only area where significant amount of thunderstorm activity takes place in this month is Kerala and adjoining Tamil Nadu. Southern part of Kerala records the highest frequency (10 to 12 days) in the country.

6.12. *December*

Country as whole records the lowest monthly frequency of thunderstorm in this month. Thunderstorm occurrence is rare over Andhra Pradesh, Orissa, Gangetic West Bengal, Saurashtra and west Rajasthan [Fig. 7(l)]. Thunderstorm may occur once in two three years in Uttar Pradesh, Madhya Pradesh, Harayana, East Rajasthan, Mahrashtra and Assam. Although significant decrease in thunderstorm activity takes over Kerala, still south Kerala continues to be the area of the highest frequency (3 to 5 days) of thunderstorms in the country. Western Himalayas and adjoining areas of foothills record 1 to 2 days of thunderstorm in the month of December.

7. Conclusion

In this study attempt has been made to develop thunderstorm climatology over Indian region based on latest representative climatological data. In all data of 450 observatories comprising of 390 IMD observatories, 50 IAF observatories, 6 Bangladesh observatories, 2 Pakistan observatories and one each in Nepal and Sri Lanka. Analysis of the data brought out wide difference in thunderstorm frequency between neighbouring full time and part time observatories. Therefore data of full time observatories has been primarily used in developing thunderstorm climatology over India.

Inclusion of climatological data of Indian Air Force and Bangladesh has helped in developing representative climatology over Indian region. It has brought out higher (100-120 days) thunderstorm frequency as compared to those given by earlier studies (80-100 days).

The spatial distribution of thunderstorms is primarily controlled by topography region. The highest annual frequency (more than 100 days) is observed over Assam and Sub Himalayan West Bengal in the east and Jammu region in the north. The lowest frequency (less than 5 days) is observed over Ladakh region. In the plains Gangetic West Bengal and Bangladesh record between 80 and 100 days of thunderstorm annually. Kerala records highest (80-100 days) thunderstorm frequency of thunderstorm over peninsula.

Udhampur observatory (132 days) in Jammu sub division, Kumbhigram (Silchar) observatory (129 days) in south Assam, and Hasimara observatory (123 days) in Sub Himalayan West Bengal record highest number of thunderstorms in the country.

In the plains, minimum number (less than 15 days) of thunderstorms occurs over Saurashtra and Kutch. Thunderstorm frequency increases from Saurashtra across neighbouring states northwards to Himalayas, eastwards to Assam and southwards to Kerala.

The lowest number of thunderstorm over Indian region occurs during winter season. Thunderstorm frequency shows sharp increase over entire region during pre monsoon season. The highest number of thunderstorm in the country outside Kerala occur during monsoon season. Thunderstorm activity is mainly confined to peninsula during post monsoon season.

8. Limitations of study and recommendations

Thunderstorm is primarily short lived mesoscale weather phenomena. Existing synoptic network of observatories have limitations in recording all the occurrences of thunderstorms at the observatory and adjoining areas. Efforts have been made in this study to develop thunderstorm climatology by using quality data of available full time current weather (Airport) observatories, Class I and selected Class II IMD observatories. As there are just a few full time observatories in most of the sub divisions, the study is not able to bring out fine spatial variation of thunderstorm activity with in sub divisions. Thunderstorm is a severe weather event, the impact of which is being increasingly felt by all the sectors of the society. Proliferation of 24 Hour TV and Radio News Channels and increasing awareness about weather among masses would demand precise information about the occurrence of thunderstorms. With economic and infrastructure development, taking place in rural areas and increase in out door activities, weather information will be required by users not only in metro and major cities but also in smaller towns and remote areas. Therefore, both from operational and climatological point of view, there is urgent need to establish at least one full time current weather observatory in each district to ensure authentic and accurate observation of thunderstorm occurrences at the district level in the country.

Acknowledgements

The author acknowledges dedication of Met observers of Airport observatories who have painstakingly recorded thunderstorm occurrences round the clock. Author is thankful to Junior Warrant Officer Tapas Bhowmick and Corporal Sandeep Ahlawat for collating voluminous data and carrying out meticulous secretarial work.

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