



## Changes in the means of temperatures and rainfall of the period 1981-2010 with respect to mean values of 1951-80 over the Indian stations

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**सार** – इस शोध पत्र में 1951-80 के औसत की तुलना के संबंध में 1981-2010 की अवधि के लिए भारत के 178 स्टेशनों पर अधिकतम तापमान, न्यूनतम तापमान और वर्षा के मासिक और वार्षिक औसतों में परिवर्तन का निर्धारण और विश्लेषण किया गया है। स्टेशन पर महत्वपूर्ण अंतर का परीक्षण करने के लिए स्टूडेंट के टी परीक्षण का प्रयोग किया गया है।

भारत के दक्षिणी और पश्चिमी क्षेत्रों के अधिकांश स्थानों पर अधिकतम तापमान के मासिक और वार्षिक औसत में वृद्धि की प्रवृत्ति पाई गई है। भारत के गांगेय मैदानी (IGP) क्षेत्रों में जनवरी से जून महीने में अधिकतम तापमान में कमी हुई है। अगस्त को छोड़कर सभी महीनों में भारत के दक्षिणी भाग (20°N के दक्षिण में) के अधिक स्थानों में उत्तरी भाग (20°N के उत्तर में) की तुलना में अधिकतम तापमान में उल्लेखनीय वृद्धि पर पाई गई है। देश के कुछ स्थानों पर तापमान में उल्लेखनीय गिरावट पाई गई है। वार्षिक अधिकतम तापमान में भी यही प्रवृत्ति देखने को मिली है। देश के अधिकांश स्थानों पर अप्रैल से जून को छोड़कर सभी महीनों में न्यूनतम तापमान में वृद्धि हुई है जबकि उत्तरी, मध्य और पूर्वी क्षेत्रों में गिरावट आई है। देश के उत्तरी भाग के अधिकांश स्थानों पर नवंबर से मार्च महीनों के दौरान, न्यूनतम तापमान में अधिक वृद्धि हुई है। उत्तराखंड को छोड़कर देश के अधिकांश स्थानों पर वार्षिक न्यूनतम तापमान में वृद्धि हुई है, देश के कुछ स्थानों पर न्यूनतम तापमान में उल्लेखनीय गिरावट देखी गई है।

पूरे देश में मासिक वर्षा में मामूली परिवर्तन हुआ है। मेघालय, पश्चिम बंगाल और केरल में वार्षिक वर्षा में वृद्धि और इन स्थानों को छोड़कर देश के अधिकांश स्थानों पर थोड़ी कमी हुई है। देश के कुछ स्थानों पर वार्षिक वर्षा में उल्लेखनीय कमी हुई है।

**ABSTRACT.** In this paper, the changes in monthly and annual means of maximum temperature, minimum temperature and rainfall at well distributed 178 stations of India for the period 1981-2010 as compared to the respective means of 1951-80, are determined and analysed. To test the significant differences at the station, Student's t test has been applied.

Increasing trend in monthly and annual mean maximum temperature is found at most places of southern and western regions of India. There is a decrease in maximum temperature in Indo-Gangetic Plains (IGP) region in January to June months. Significant rise in maximum temperature in all months except August is found at more places in southern part (south of 20° N) of India than northern part (north of 20° N). Significant fall in the temperature is found at a few places of the country. The same trend is found in annual maximum temperature. Minimum temperature has increased at most places of the country in all months except April to June where in it decreased over northern, central and eastern regions. During November to March months, minimum temperature increased more at most places of northern part of the country. Annual minimum temperature has increased at most places of the country except over UK, Significant fall in minimum temperature is observed at some places of the country.

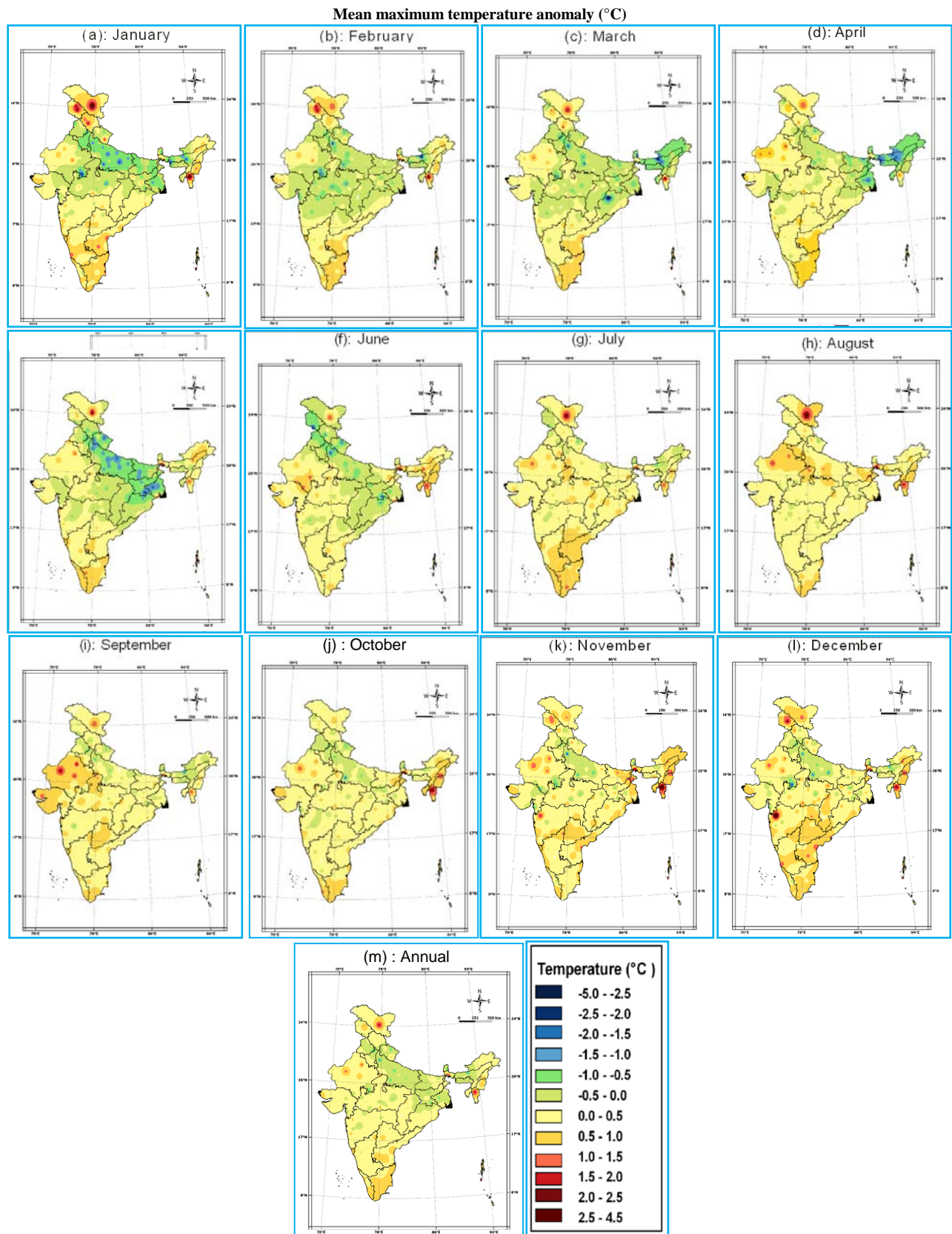
There is a less change in monthly rainfall all over the country. Annual rainfall slightly decreased at most places of the country except Meghalaya, WB and Kerala where it increased. There is a significant fall in annual rainfall at some places of the country.

**Key words** – Maximum temperature, Minimum temperature, Rainfall, Monthly, Annual, Mean.

### 1. Introduction

The influence of climate on human life is much more effective as it is an important factor in agriculture, water

resources, power generation, industry transportation, tourism etc. Climate normal based on meteorological data of thirty year period are generally used to describe the climatic conditions of a particular place. The change in



**Figs. 1(a-m).** Mean maximum temperature anomaly (°C)

TABLE 1

## Stations having significant change in maximum temperature at 1% level

Month / Year	Stations having significant rise	Stations having significant fall
Jan	Srinagar, Bhuntar, Mukteshwar, Ajmer, Imphal, Aizwal, Okha, Porbandar, Betul, Bhubaneswar, Chandabali, Chandrapur, Ratnagiri, Bidar, Mahabaleshwar, Hyderabad, Sangli, Kakinada, Goa, Belgaum, Ongole, Honavar, Chitradurga, Anantapur, Kadapa, Agumbe, Chennai, Vellore, Long-Island, Kozhikode, Coonoor, Coimbatore, Salem, Cuddalore, Kodaikanal, Nagapattinam, Alleppey, Tondi, Hutbay, Car-Nicobar, Minicoy, Thiruvananthapuram	Ambala, Bareilly, Hardoi, Bahraich, Cooch Behar, Forbesganj, Dhubri, Allahabad, Patna, Jabalpur, Alipore, Surat
Feb	Srinagar, Quazikund, Jalpaiguri, Okha, Puri, Ratnagiri, Belgaum, Ongole, Honavar, Chitradurga, Anantapur, Kadapa, Chennai, Vellore, Long-Island, Kozhikode, Coimbatore, Salem, Cuddalore, Kodaikanal, Nagapattinam, Alleppey, Madurai, Tondi, Hutbay, Car Nicobar, Minicoy, Thiruvananthapuram	Jabalpur, Hosangabad, Jalgaon, Yeotmal, Surat
Mar	Dholpur, Aizwal, Okha, Chandabali, Gopalpur, Puri, Bidar, Hyderabad, Belgaum, Ongole, Anantapur, Kadapa, Nellore, Chennai, Vellore, Long-Island, Kozhikode, Coimbatore, Salem, Cuddalore, Kodaikanal, Tondi, Tiruchirappalli, Nagapattinam, Alleppey, Madurai, Hutbay, Car-Nicobar, Minicoy, Thiruvananthapuram	Ambala, Hardoi, Gangtok, Cooch Behar, Jabalpur, Agartala, Chaibasa, Kolahpur
Apr	Phalodi, Jaisalmer, Dholpur, Okha, Betul, Contai, Chandabali, Dahanu, Puri, Mahabaleshwar, Bidar, Gannavaram, Belgaum, Ongole, Anantapur, Chennai, Vellore, Long-Island, Aminidivi, Tondi, Coimbatore, Cuddalore, Kodaikanal, Nagapattinam, Hutbay, Car-Nicobar, Minicoy, Thiruvananthapuram	Ambala, Pasighat, Forbesganj, Mohanbari, Tezpur, Jabalpur, Agartala, Alipore, Surat, Jalgaon, Kolahpur
May	Phalodi, North Lakhimpur, Jalpaiguri, Aizwal, Okha, Shivpuri, Dwarka, Indore, Porbandar, Betul, Contai, Veraval, Dahanu, Gopalpur, Puri, Harnai, Belgaum, Honavar, Anantapur, Long-Island, Aminidivi, Kozhikode, Coimbatore, Kodaikanal, Alleppey, Punalur, Tondi, Minicoy, Thiruvananthapuram	Ambala, Dehradun, Roorkee, Najibabad, Bareilly, Hardoi, Bahraich, Allahabad, Varanasi, Patna, Gaya, Jabalpur, Chaibasa, Jamshedpur
Jun	Phalodi, Darjeeling, Coochbehar, Jalpaiguri, Purnea, Guwahati, Abu, Imphal, Agartala, Aizwal, Okha, Dwarka, Porbandar, Contai, Veraval, Dahanu, Harnai, Goa, Honavar, Anantapur, Long-Island, Kozhikode, Coimbatore, Port Blair, Madurai, Car-Nicobar, Minicoy, Thiruvananthapuram	Jammu, Ambala, Amritsar, Patiala, Dehradun, Karnal, Roorkee, Najibabad, Gangtok, Chaibasa
Jul	Mukhim, Phalodi, Jalpaiguri, Bhagalpur, Purnea, Ranchi, Imphal, Aizwal, Okha, Pendra, Porbandar, Balasore, Contai, Sagar Island, Veraval, Bhubaneswar, Chandabali, Dahanu, Jagdalpur, Gopalpur, Puri, Hanamkonda, Hyderabad, Harnai, Mahabaleshwar, Bidar, Sangli, Gannavaram, Goa, Belgaum, Gadag, Kurnool, Ongole, Honavar, Chitradurga, Anantapur, Hassan, Chennai, Long-Island, Kozhikode, Coonoor, Coimbatore, Salem, Port-Blair, Palakkad, Kodaikanal, Tiruchirappalli, Nagapattinam, Alleppey, Punalur, Madurai, Tondi, Car-Nicobar, Minicoy, Thiruvananthapuram	Gangtok
Aug	Mukhim, Dehradun, Hissar, Palam, Safdarjung, Phalodi, Aligarh, Bahraich, North-Lakhimpur, Ajmer, Dholpur, Lucknow, Coochbehar, Gwalior, Darbhanga, Jalpaiguri, Guwahati, Shivpuri, Satna, Jhansi, Fatehpur, Banda, Allahabad, Patna, Bhagalpur, Purnea, Satna, Gaya, Ranchi, Imphal, Shantiniketan, Agartala, Aizwal, Pendra, Contai, Sagar Island, Veraval, Bhubaneswar, Chandabali, Dahanu, Harnai, Gannavaram, Belgaum, Chennai, Long-Island, Kozhikode, Coimbatore, Port-Blair, Nagapattinam, Alleppey, Punalur, Madurai, Tondi, Car-Nicobar, Minicoy, Thiruvananthapuram	Daltonganj
Sep	Mukhim, Phalodi, Bikaner, Ajmer, Jaipur, Gwalior, Darbhanga, Jalpaiguri, Bhagalpur, Purnea, Deesa, Mount-Abu, Neemuch, Guna, Bhuj, Aizwal, Okha, Dwarka, Indore, Pendra, Porbandar, Betul, Balasore, Sagar Island, Veraval, Bhubaneswar, Chandabali, Dahanu, Chandrapur, Jagdalpur, Gopalpur, Puri, Ramagundam, Hanamkonda, Harnai, Bidar, Mahabaleshwar, Hyderabad, Gannavaram, Goa, Honavar, Belgaum, Chitradurga, Chennai, Long-Island, Kozhikode, Coimbatore, Salem, Port-Blair, Kodaikanal, Tiruchirappalli, Nagapattinam, Alleppey, Punalur, Madurai, Tondi, Minicoy, Thiruvananthapuram	Patiala, Gangtok
Oct	Mukhim, Phalodi, Agra, Darbhanga, Darjeeling, North-Lakhimpur, Mohanbari, Gwalior, Jalpaiguri, Purnea, Cherrapunji, Neemuch, Ranchi, Imphal, Aizwal, Okha, Dwarka, Indore, Pendra, Betul, Sambalpur, Contai, Sagar-Island, Bhubaneswar, Chandabali, Paradeep, Dahanu, Jagdalpur, Gopalpur, Puri, Mumbai, Harnai, Ratnagiri, Mahabaleshwar, Hyderabad, Chennai, Long-Island, Kozhikode, Coimbatore, Cuddalore, Kodaikanal, Tiruchirappalli, Nagapattinam, Alleppey, Madurai, Tondi, Car-Nicobar, Minicoy, Thiruvananthapuram	Ambala, Gangtok

TABLE 1 (Contd.)

Month / Year	Stations having significant rise	Stations having significant fall
Nov	Srinagar, Mukhim, Mukteshwar, Bikaner, Phalodi, Agra, Pasighat, Darjeeling, North-Lakhimpur, Mohanbari, Ajmer, Cooch Behar, Gwalior, Darbhanga, Jalpaiguri, Guwahati, Purnea, Malda, Cherrapunji, Neemuch, Ranchi, Imphal, Bhuj, Agartala, Aizwal, Okha, Dwarka, Indore, Pendra, Betul, Sagar-Island, Veraval, Bhubaneswar, Chandabali, Chandrapur, Jagdalpur, Gopalpur, Puri, Mumbai, Nizamabad, Hanamkonda, Harnai, Ratnagiri, Mahabaleshwar, Solapur, Bidar, Hyderabad, Sangli, Gannavaram, Kakinada, Belgaum, Ongole, Honavar, Anantapur, Kadapa, Chennai, Long-Island, Kozhikode, Cuddalore, Kodaikanal, Nagapattinam, Alleppey, Hutbay, Car- Nicobar, Minicoy, Thiruvananthapuram	Manali, Ambala, Dhubri, Jabalpur, Surat
Dec	Srinagar, Mukhim, Phalodi, North-Lakhimpur, Mohanbari, Ajmer, Jalpaiguri, Shivpuri, Darjeeling, Sidhi, Ranchi, Imphal, Aizwal, Bhuj, Okha, Dwarka, Indore, Seoni, Mandla, Pendra, Porbandar, Betul, Sagar-Island, Veraval, Bhubaneswar, Chandabali, Chandrapur, Jagdalpur, Gopalpur, Puri, Mumbai, Nizamabad, Hanamkonda, Harnai, Ratnagiri, Mahabaleshwar, Solapur, Bidar, Hyderabad, Sangli, Gannavaram, Kakinada, Belgaum, Ongole, Honavar, Chitradurga, Anantapur, Kadapa, Agumbe, Chennai, Long Island, Kozhikode, Coimbatore, Cuddalore, Kodaikanal, Tiruchirappalli, Nagapattinam, Alleppey, Tondi, Hutbay, Car-Nicobar, Minicoy, Thiruvananthapuram	Ambala, Jabalpur, Surat
Annual	Mukhim, Srinagar, Bhuntar, Mukteshwar, Bikaner, Phalodi, Darjeeling, North-Lakhimpur, Ajmer, Dholpur, Jalpaiguri, Imphal, Shivpuri, Purnea, Bhuj, Aizwal, Okha, Dwarka, Indore, Pendra, Porbandar, Betul, Sagar-Island, Veraval, Bhubaneswar, Chandabali, Dahanu, Chandrapur, Jagdalpur, Gopalpur, Puri, Mumbai, Nizamabad, Harnai, Ratnagiri, Mahabaleshwar, Solapur, Bidar, Hyderabad, Goa, Kurnool, Ongole, Honavar, Chitradurga, Anantapur, Kadapa, Chennai, Vellore, Long-Island, Coonoor, Coimbatore, Cuddalore, Kodaikanal, Tiruchirappalli, Nagapattinam, Alleppey, Punalur, Madurai, Tondi, Hutbay, Minicoy, Thiruvananthapuram	Jammu, Patiala, Ambala, Karnal, Najibabad, Hardoi, Jabalpur, Gangtok, Tezpur, Jhalawar, Surat, Ahmednagar

means of weather elements from their earlier respective means indicates the climate change over the location. Studies on climate change have been done by various researchers - Thapliyal *et al.* (1991); Srivastava *et al.* (1992); De and Rajeevan (1997); Sahai (1998); Kothawale and Rupa Kumar (2005) and Jaswal *et al.* (2012). The temperature and rainfall are considered as prime key elements of climate that are commonly used as indicators of climate change. The temperature has increased in the last four decades due to excessive emission of anthropogenic gases and rapid growth in population, concrete areas, infrastructure and deforestation. Singh *et al.* (2006); Jenamani (2007); Sawaisarji *et al.* (2014) and Hingmire *et al.* (2018) have studied the occurrence and persistence of fog and its effect on the temperature. The number of fog occurrence over the IGP region has been increasing continuously during the period from 1979 to 2004 (*source* : [http://www.imdpune.gov.in/ndc\\_new/ndc\\_index](http://www.imdpune.gov.in/ndc_new/ndc_index)). The increase in frequency and long-time persistence of fog is one of main reasons for the fall of maximum temperature and increase of minimum temperature. Kothawale *et al.* (2010) found that Indian annual mean (average of maximum and minimum), maximum and minimum temperatures have warming trends of 0.51, 0.72 and 0.27 °C per 100 year respectively

during the period 1901-2007. Moreover, the temperatures (average of maximum and minimum temperature) sharply increased by about 0.2 °C per decade for the period 1971-2007. A comparative study of average of temperatures and rainfall over India by Chhabra *et al.* (1997) has shown significant fall in minimum temperature in north Indian stations and significant rise in maximum temperature in south Indian stations and no significant variation in rainfall recorded at all stations except some of hill stations and major cities where rainfall has a decreasing and increasing trends respectively.

In this paper the authors have made an attempt to find out the change in monthly and annual means of maximum and minimum temperatures and rainfall at 178 Indian stations located in plains, hilly and coastal regions for the 30 year period; 1981- 2010 as compared to their respective means of the period 1951-80.

## 2. Data and methodology

For present study, 178 stations well distributed over India whose surface data are available in National Data Centre (NDC) of the India Meteorological Department at Pune, have been selected. Mean of daily maximum and

mean of daily minimum temperatures and monthly rainfall data pertaining to the Indian stations for each month are archived by NDC after applying a series of quality control checks. Mean of daily maximum temperature and monthly mean of daily minimum temperature and rainfall in respect of the selected stations for each month for two spans of period 1951-80 and 1981-2010 have been taken from NDC. The series for mean maximum temperature and mean minimum temperature and rainfall separately for each month and annual are prepared to determine monthly and annual means for each span of 30 year period. The change in monthly and annual means of maximum and minimum temperature separately and rainfall at 178 stations during the period 1981-2010 as compared to the respective means of 1951 to 1980 is shown in figures.

Moreover, the series of monthly and annual values for each span of 30 years are used to examine the significant change in maximum and minimum temperature separately and rainfall during the period 1981-2010 in comparison of 1951-80. To test the significances of differences in two series, Student's 't' test has been applied and stations which have differences significant at 1% level are presented. This has been done to present only the noticeable differences at stations indicated in tables.

### 3. Results and discussion

#### 3.1. Temperature

The spatial changes in monthly and annual means of maximum and minimum temperatures of the period 1981-2010 from the respective means of the period 1951-80 are shown in Figs. 1(a-m) and Figs. 2(a-m) respectively. Significant changes in maximum temperature and minimum temperature at stations are determined by applying Student's 't' test at 1% level in mean values of two series and stations are given in Table 1 and Table 2 respectively.

##### 3.1.1. Mean maximum temperature

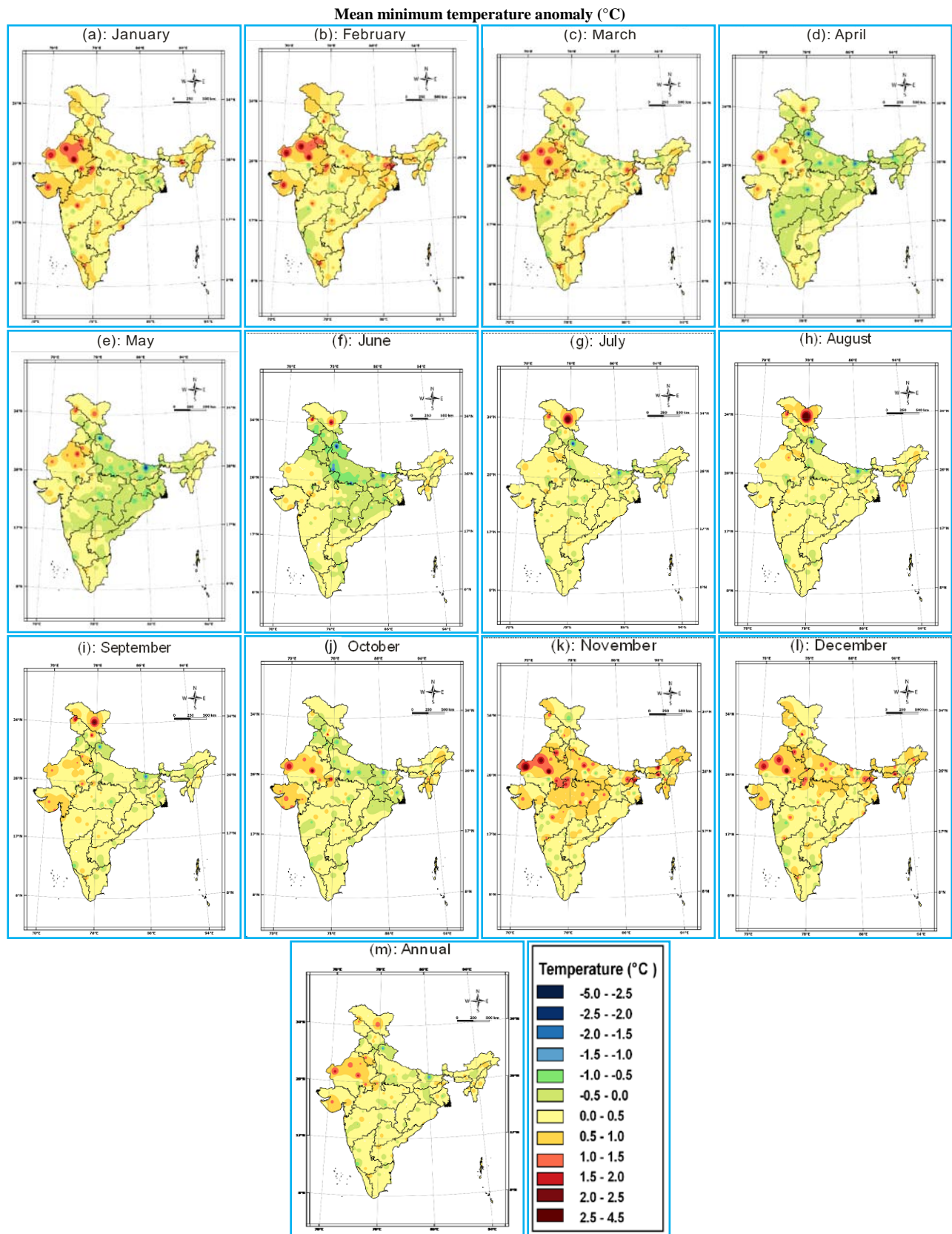
Fig. 1(a) shows mean maximum temperature in January during the period 1981-2010 has increased by 1 °C-2 °C at most places of Jammu & Kashmir (J&K), Himachal Pradesh (HP) & Mizoram and < 1 °C at most places of Uttarakhand (UK) Rajasthan, Gujarat, Chhattisgarh, Assam, Nagaland, Manipur, Arunachal Pradesh, Odisha and southern states of India. However, it decreased by 1 °C or more over Indo-Gangetic Plains (IGP) region and by 0.5 °C at most places of East Rajasthan, Madhya Pradesh (MP), Jharkhand and Meghalaya. Significant rise in the temperature is found at most places of southern states and some places of Odisha,

Gujarat and hilly terrain as shown in Table 1. However, significant fall is observed at some places of IGP. Trend of temperature variation in February is almost the same as in January. Moreover, the temperature decreased by 0.5 °C at more places of Gujarat, Chhattisgarh, Odisha and Maharashtra as shown in Fig. 1(b). Significant change in the temperature is found at less places in February than January. There is a significant fall at a few places of central region of India.

Spatial pattern of mean maximum temperature variation in March is almost the same as in February. Moreover, the temperature decreased by 1 °C at more places of northeastern states and increased at more places of western and southern regions as shown in Fig. 1(c). Significant rise in the temperature is observed at most places of Odisha coast and southern states. However, a significant fall is found at a few places of northern part of India. In April the temperature has decreased by 1 °C or more over Assam, Meghalaya and Arunachal Pradesh and by 0.5 °C over IGP, Jharkhand, Nagaland, Manipur & Tripura and some places of Gujarat, MP, Maharashtra and Odisha. The temperature increased by 1 °C at most places of Tamil Nadu (TN) & Andhra Pradesh (AP) and some places of Mizoram, J&K and Rajasthan and slightly increased in the remaining parts of the country as shown in Fig. 1(d). The significant change in the temperature is found almost the same as in March. In May the temperature has increased at most places of Rajasthan, Gujarat, West MP, Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram and southern states. However, it decreased at most places of Meghalaya, Tripura, East MP, Chhattisgarh, northern and eastern regions and some places of Gujarat and Maharashtra as shown in Fig. 1(e). Significant rise in the temperature is found at most places of coastal areas, whereas significant fall is observed at most places of IGP.

Spatial pattern of change in the temperature in June [Fig. 1(f)] is almost the same as in May. Consequent upon, the temperature increased at most places of northeastern states, Bihar and West Bengal (WB). The significant change is also almost the same. In July the temperature has increased all over the country except some places of IGP, Jharkhand, Arunachal Pradesh, Meghalaya and Maharashtra where it decreased by 0.5 °C. Moreover, the temperature increased more by 1 °C over Telangana, AP, TN, Kerala, Karnataka and Mizoram as shown in Fig. 1(g). Significant rise in the temperature is observed at most places of Odisha, Gujarat and southern states and a few places of northern part. In August, the temperature increased all over the country as shown in Fig. 1(h). The temperature has significantly increased at most places of IGP, MP, northeastern and southern states and some places of Rajasthan, Gujarat and





**Figs. 2(a-m).** Mean minimum temperature anomaly (°C)

TABLE 2

## Stations having significant change in minimum temperature at 1% level

Month / Annual	Stations having significant rise	Stations having significant fall
Jan	Banihal, Hisar, Najibabad, Bikaner, Pilani, Palam, Pasighat, Hardoi, Gangtok, Mohanbari, Jaisalmer, Ajmer, Lucknow, Guwahati, Kota, Shivpuri, Bhagalpur, Malda, Shillong, Guna, Kailashahar, Dwarka, Rajkot, Baroda, Seoni, Surat, Veraval, Akola, Dahanu, Aurangabad, Gopalpur, Hyderabad, Kolahpur, Kakinada, Goa, Kurnool, Nellore, Hassan, Chennai, Kozhikode, Coimbatore, Kodaikanal, Madurai, Minicoy, Kanyakumari	Mukhim, Darjeeling, Mount-Abu, Hazaribag, Agumbe
Feb	Manali, Hisar, Najibabad, Bikaner, Pilani, Palam, Hardoi, Bahraich, Gangtok, North-Lahimpur, Mohanbari, Jaisalmer, Ajmer, Dholpur, Lucknow, Dhubri, Guwahati, Kota, Shivpuri, Bhagalpur, Malda, Shillong, Guna, Kailashahar, Imphal, Jabalpur, Bankura, Agartala, Dwarka, Rajkot, Seoni, Alipore, Jharsuguda, Balasore, Veraval, Paradeep, Aurangabad, Gopalpur, Hyderabad, Kakinada, Kurnool, Nellore, Hassan, Chennai, Kozhikode, Coimbatore, Kodaikanal, Tiruchirapalli, Madurai, Minicoy, Kanyakumari	Mukhim, Darjeeling, Mount-Abu, Bolangir, Belgaum, Gadag, Nagapattinam, Hut Bay
Mar	Hisar, Bikaner, Palam, Hardoi, Gangtok, North-Lahimpur, Mohanbari, Jaisalmer, Ajmer, Jaipur, Lucknow, Dhubri, Guwahati, Kota, Shivpuri, Bhagalpur, Malda, Guna, Daltonganj, Kailashahar, Imphal, Jabalpur, Bankura, Okha, Dwarka, Rajkot, Baroda, Seoni, Alipore, Porbandar, Nagpur, Jharsuguda, Veraval, Puri, Paradeep, Aurangabad, Gopalpur, Kalingpatnam, Hyderabad, Kakinada, Kurnool, Ongole, Nellore, Chennai, Bengaluru, Kozhikode, Coonoor, Coimbatore, Cuddalore, Kodaikanal, Tiruchirapalli, Madurai, Minicoy	Mukhim, Dharamshala, Darjeeling, Cherrapunji, Mount- Abu, Chhindwara, Bolangir, Ahmednagar, Nagapattinam
Apr	Manali, Hisar, Palam, Gangtok, Mohanbari, Daltonganj, Bhagalpur, Jaisalmer, Ajmer, Jaipur, Kota, Shivpuri, Guna, Jabalpur, Bankura, Okha, Dwarka, Rajkot, Baroda, Seoni, Veraval, Paradeep, Gopalpur, Kakinada, Kurnool, Nellore, Chennai, Kozhikode, Coonoor, Coimbatore, Kodaikanal, Madurai, Minicoy	Mukhim, Phalodi, Darjeeling, Gwalior, Gorakhpur, Varanasi, Mount- Abu, Gaya, Chaibasa, Bolangir, Ahmednagar, Pune, Harnai, Ramagundam, Ratnagiri, Nagapattinam
May	Bhuntar, Hisar, Palam, Pasighat, Gangtok, North-Lahimpur, Mohanbari, Jaisalmer, Ajmer, Jaipur, Shivpuri, Ahmedabad, Bhopal, Okha, Dwarka, Rajkot, Baroda, Porbandar, Paradeep, Aurangabad, Gopalpur, Kurnool, Nellore, Benglauru, Kozhikode, Coimbatore, Minicoy, Thiruvananthapuram	Mukhim, Mukteshwar, Phalodi, Agra, Darjeeling, Gorakhpur, Mount- Abu, Gaya, Hazaribag, Chaibasa, Jamshedpur, Sambalpur, Yeotmal, Bolangir, Ramagundam, Vellore
Jun	Pasighat, Gangtok, Mohanbari, Jaisalmer, Guwahati, Bhagalpur, Kailashahar, Imphal, Ahmedabad, Bankura, Agartala, Okha, Dwarka, Rajkot, Baroda, Paradeep, Dahanu, Aurangabad, Gopalpur, Mumbai, Mahabaleswar, Goa, Kurnool, Honavar, Chennai, Bengaluru, Kozhikode, Coimbatore, Minicoy, Thiruvananthapuram	Mukhim, Mukteshwar, Jammu, Dharmshala, Amritsar, Ambala, Karnal, Phalodi, Aligarh, Darjeeling, Gwalior, Lucknow, Fatehpur, Mount-Abu, Gaya, Chhindwara, Chaibasa, Jamshedpur, Bolangir, Vellore, Salem
Jul	Hisar, Safarjung, Bahraich, Gangtok, Mohanbari, Jaisalmer, Ajmer, Jaipur, Dhubri, Guwahati, Barmer, Kota, Bhagalpur, Guna, Satna, Sidhi, Daltonganj, Kailashar, Bhopal, Sagar, Jabalpur, Bankura, Shantiniketan, Agartala, Dwarka, Rajkot, Baroda, Indore, Alipore, Raigarh, Nagpur, Akola, Bhubaneshwar, Paradeep, Dahanu, Aurangabad, Parbhani, Gopalpur, Puri, Pune, Ramagundam, Hanamkonda, Kalingpatnam, Mahabaleswar, Bidar, Kakinada, Goa, Kurnool, Honavar, Nellore, Chennai, Bengaluru, Kozhikode, Coimbatore, Kodaikanal, Madurai, Minicoy, Thiruvananthapuram	Mukhim, Dharmshala, Phalodi, Darjeeling, Jhansi, Mount-Abu, Gaya, Bolangir, Agumbe
Aug	Patiala, Ganganagar, Hisar, Palam, Safdarjung, Bareilly, Pasighat, Hardoi, Bahraich, Gangtok, North Lahimpur, Mohanbari, Jaisalmer, Jaipur, Dhubri, Kota, Allahabad, Bhagalpur, Satna, Sidhi, Daltonganj, Kailashar, Bhopal, Sagar, Jabalpur, Bankura, Shantiniketan, Agartala, Aizwal, Rajkot, Baroda,endra, Alipore, Surat, Raigarh, Paradeep, Aurangabad, Parbhani, Gopalpur, Puri, Pune, Ramagundam, Mahabaleswar, Bidar, Kakinada, Kurnool, Honavar, Hassan, Chennai, Bengaluru, Kozhikode, Coimbatore, Cuddalore, Kodaikanal, Tiruchirapalli, Madurai, Minicoy, Thiruvananthapuram	Mukhim, Phalodi, Darjeeling, Mount-Abu, Hazaribag, Bolangir, Agumbe, Vellore, Salem
Sep	Manali, Hisar, Bikaner, Palam, Safdarjung, Gangtok, Mohanbari, Jaisalmer, Jaipur, Kota, Shivpuri, Bhagalpur, Satna, Sidhi, Daltonganj, Kailashar, Ahmedabad, Bhopal, Sagar, Agartala, Aizwal, Dwarka, Rajkot, Baroda, Seoni, Porbandar, Surat, Paradeep, Dahanu, Aurangabad, Parbhani, Gopalpur, Puri, Mumbai, Pune, Hanamkonda, Bidar, Hyderabad, Kakinada, Kurnool, Honavar, Nellore, Hassan, Chennai, Bengaluru, Kozhikode, Coimbatore, Kodaikanal, Tiruchirapalli, Madurai, Minicoy, Thiruvananthapuram	Mukhim, Dharmshala, Amritsar, Aligarh, Darjeeling, Mount-Abu, Gaya, Bolangir, Agumbe, Vellore, Salem

TABLE 2 (Contd.)

Month / Annual	Stations having significant rise	Stations having significant fall
Oct	Manali, Hisar, Bikaner, Palam, Hardoi, Gangtok, Mohanbari, Jaisalmer, Ajmer, Jaipur, Guwahati, Kota, Shivpuri, Bhagalpur, Shillong, Guna, Daltonganj, Kailashahar, Bhopal, Jabalpur, Aizwal, Okha, Dwarka, Rajkot, Baroda, Seoni, Veraval, Akola, Dahanu, Aurangabad, Hanamkonda, Bidar, Hyderabad, Kakinada, Kurnool, Nellore, Chennai, Bengaluru, Kozhikode, Coimbatore, Cuddalore, Kodaikanal, Tiruchirapalli, Madurai, Minicoy, Thiruvananthapuram, Kanyakumari	Mukhim, Quazikund, Dharmshala, Ambala, Mount-Abu, Gaya, Bolangir, Agumbe, Salem
Nov	Manali, Hisar, Najibabad, Bikaner, Palam, Bareilly, Hardoi, Bahraich, Gangtok, Mohanbari, Jaisalmer, Ajmer, Gwalior, Lucknow, Jalpaiguri, Guwahati, Kota, Shivpuri, Allahabad, Bhagalpur, Purnea, Malda, Shillong, Guna, Satna, Daltonganj, Kailashahar, Silchar, Bhopal, Jabalpur, Agartala, Aizwal, Dwarka, Rajkot, Seoni, Alipore, Khandwa, Veraval, Akola, Dahanu, Aurangabad, Gopalpur, Hanamkonda, Hyderabad, Sangli, Kakinada, Nellore, Chennai, Long Island, Kozhikode, Kodaikanal, Madurai, Minicoy	Mukhim, Mount-Abu
Dec	Banihal, Hisar, Bikaner, Pilani, Palam, Bareilly, Hardoi, Bahraich, Gangtok, Mohanbari, Jaisalmer, Ajmer, Dholpur, Lucknow, Dhubri, Guwahati, Kota, Shivpuri, Allahabad, Patna, Bhagalpur, Malda, Shillong, Guna, Kailashahar, Jabalpur, Imphal, Seoni, Agartala, Dwarka, Rajkot, Alipore, Nagpur, Veraval, Paradeep, Dahanu, Aurangabad, Gopalpur, Hyderabad, Kakinada, Kurnool, Nellore, Kodaikanal, Minicoy	Mukhim, Banaswara, Mount-Abu, Ahmednagar, Vellore
Annual	Ganganagar, Hisar, Bikaner, Palam, Bahraich, Gangtok, Mohanbari, Jaisalmer, Ajmer, Lucknow, Guwahati, Kota, Allahabad, Bhagalpur, Shillong, Guna, Satna, Sidhi, Kailashahar, Ahmedabad, Bhopal, Jabalpur, Agartala, Aizwal, Okha, Rajkot, Baroda, Indore, Alipore, Porbandar, Nagpur, Paradeep, Dahanu, Aurangabad, Gopalpur, Puri, Kalingapatnam, Hyderabad, Kolahpur, Kakinada, Kurnool, Honavar, Nellore, Chennai, Bengaluru, Kozhikode, Coimbatore, Kodaikanal, Madurai, Minicoy, Thiruvananthapuram, Kanyakumari	Mukhim, Dharmshala, Amritsar, Darjeeling, Mount-Abu, Chhindwara, Bolangir, Ahmednagar, Vellore

Odisha. Fig. 1(i) shows that trend of spatial variation in the temperature in September is almost the same as in July. Moreover, the temperature increased by about 1 °C over Rajasthan, Gujarat, West MP and Telangana. The trend of significant change in the temperature is also almost same as in July.

The temperature in October to December months has increased at most places of the country except IGP where it decreased as shown in Figs. 1(j-i). In October the temperature significantly increased over MP, Odisha and southern states and some places of Gujarat, Chhattisgarh, eastern & northeastern states and hilly terrain. In November, the temperature significantly increased at most places of Gujarat, MP, Odisha and southern states and some places of J&K, UK, Rajasthan, Jharkhand, WB and northeastern states. However, significant fall is found at only four places. The trend of significant change in the temperature in December is found almost the same as in November.

Annual maximum temperature has risen all over the country except over IGP, Jharkhand and Meghalaya and some places of Odisha, Chhattisgarh, MP and Maharashtra as shown in Fig. 1(m). The temperature has significantly increased at most places of Rajasthan, Gujarat, Odisha,

southern states and hilly terrain and some places of MP, Chhattisgarh and WB. However, a significant fall is found at some places of IGP as given in Table 1.

During December to February months, the increasing of fog frequency during the period 1979-2004 and long time persistence of fog during the period 1971-2010 ([http://www.imdpune.gov.in/ndc\\_new/ndc\\_index](http://www.imdpune.gov.in/ndc_new/ndc_index). and Sawaisarje *et al.*, 2014 respectively) is one of the reasons for decreasing the maximum temperature over IGP region. Maximum temperature also decreased over IGP, Odisha, Assam and Meghalaya during March to May months. As a number of thunderstorms days in April and May have been increased over northeast and adjoining eastern region of India during the period 1981-2008 as compared to the period 1951-1980 according to study of Singh *et al.*, 2011. The increasing of thundershowers activity is main cause for decreasing the temperature over the regions. In August, significant rise in the temperature is found at more places in northern part (north of 20° N) of the country than southern part (south of 20° N). As Kumar *et al.*, 2009 studied that frequency and duration of break monsoon spells in July and August have increased over India during the period 1981-2007. Increasing the number and duration of break monsoon spells is one of the reasons for rising the temperature over northern part of the country in August.



### 3.1.2. Mean minimum temperature

In January minimum temperature during the period 1981-2010 has increased all over the country except some places of IGP, MP, Jharkhand, Maharashtra and Karnataka where it decreased by 0.5 °C as shown in Fig. 2(a). The temperature has significantly increased by 1 °C or more over Rajasthan, Gujarat and northeastern states and some places of the remaining parts of the country as given in Table 2. Significant change is observed at some places of hilly terrain. Spatial pattern of change in the temperature in February [Fig. 2(b)] is almost the same as in January. The trend of significant change in the temperature in February is also almost the same.

The change in the temperature in March [Fig. 2(c)] is almost the same as in February. In April the temperature decreased at most places of IGP, Jharkhand, Chhattisgarh, Odisha, Maharashtra, Karnataka and northeastern states and some places of Rajasthan, MP, Telangana and AP. However, it increased over the remaining parts of the country as shown in Fig. 2(d). Significant rise in the temperature is found at most places of Gujarat and some places of Rajasthan, MP, Odisha, AP, TN and northern states, whereas a significant fall is found at some places of the country. Spatial pattern of temperature variation in May [Fig. 2(e)] is almost the same as in April. The significant rise in the temperature is found at most places of Gujarat and some places of Rajasthan, Odisha, northern and southern states, whereas significant fall is found at some places of the country. Significant change in temperature is found at some hilly stations.

Spatial pattern of minimum temperature variation in June is almost the same as in May. Moreover, the temperature increased by 0.5 °C at more places of Maharashtra, WB and northeastern states as shown in Fig. 2(f). The trend of significant rise in the temperature is also almost the same as in May. There is a significant fall at most places of IGP region. In July, the temperature has risen by 0.5 °C or more all over the country except UK and some places of IGP, Rajasthan, MP, Jharkhand and southern states where it decreased by 0.5 °C as shown in Fig. 2(g). Significant rise in the temperature is observed at most places of Rajasthan, MP and Maharashtra and some places of the remaining parts of the country. Moreover, a significant change is also found at some places of hilly area. Spatial pattern of temperature change in August [Fig. 2(h)] and September [Fig. 2(i)] is almost the same as in July. The trend of significant change in the temperature in both months is also almost the same as in July.

In October, minimum temperature has increased all over the country except most places of Jharkhand and IGP and some places of Odisha, Rajasthan and southern states, where, it decreased by 0.5 °C as shown in Fig. 2(j).

Significant rise in the temperature is found at most places of Rajasthan, MP and Gujarat and some places of Assam, Meghalaya northern and southern states, whereas a significant fall is found at some places of hilly area. The temperature in November has increased more all over the country except a few places as shown in Fig. 2(k). It increased by 1 °C or more over northern part of the country. The significant rise in the temperature is found at most places of MP and IGP and some places of Rajasthan, Gujarat, southern and northeastern states. The significant change in the temperature is found at some hilly stations. In December the temperature has increased by 1 °C or more at most places of Rajasthan, IGP & northeastern states and some places of Gujarat & MP and by 0.5 °C over the remaining regions of the country, however, it decreased at some places as shown in Fig. 2(l). The trend of significant change in the temperature is also almost the same as in November.

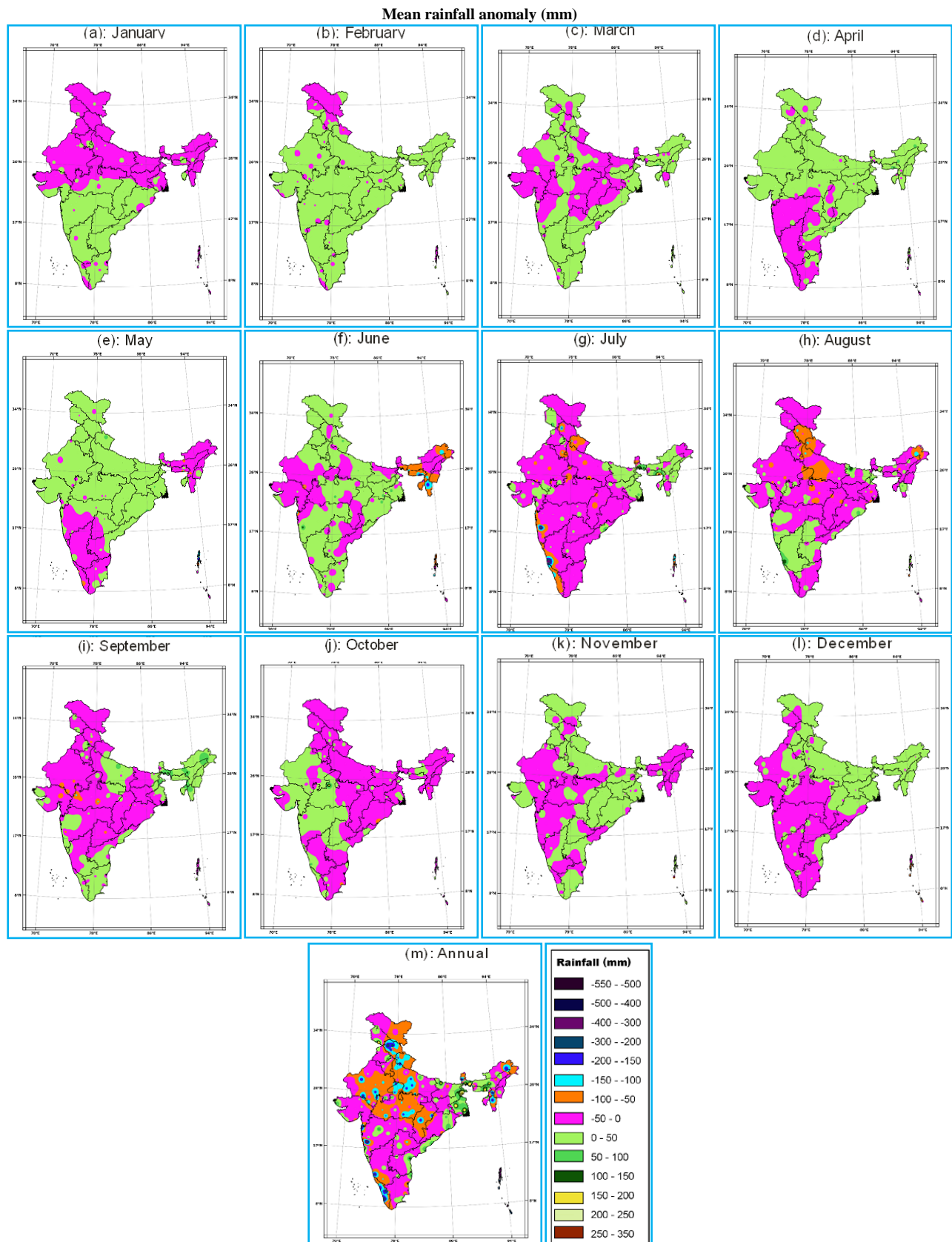
Annual minimum temperature has increased all over the country except most places of UK and some places of IGP, Jharkhand Odisha, MP, Rajasthan and southern states where it slightly decreased by 0.5 °C as shown in Fig. 2(m). The temperature significantly increased over MP, Gujarat and Rajasthan and some places of Odisha, IGP, northeastern and southern states as given in Table 2. Significant change is found at some places of hilly area.

Minimum temperature has increased at most places of the country in all months except April to June wherein it decreased at most places of J&K, IGP, central and eastern regions and some places of northeastern and southern region. In April and May, the increase in thunderstorm activities over northeast and adjoining east India is main reason of decreasing the temperature over the region and its adjacent areas. The significant rise in November and December is observed at more places in northern part than southern part. The increase in persistence of fog over some regions is one main reason to increase the minimum temperature during December to February. Significant rise in the temperature is found at more places than places experienced a significant fall. Significant change is found at some places in hilly terrain.

### 3.2. Rainfall

The changes in monthly and annual means of rainfall of the period 1981-2010 from the respective means of 1951-80 are found less all over the country as shown in Figs. 3(a-m).

In January rainfall has decreased slightly ( $\leq 5$  cm) over northern part of the country, however, it increased slightly ( $\leq 5$  cm) over southern part as shown in Fig. 3(a). Rainfall in February slightly increased all over the country



**Figs. 3(a-m).** Mean rainfall anomaly (mm)

TABLE 3

## Stations having significant change in Rainfall at 1% level

Month / Year	Stations having significant rise	Stations having significant fall
Jan	Kakinada, Ongole	Manali, Noncowry
Feb	Ganganagar, Tezpur	
Mar	-	Darjeeling
Apr	Dehradun, Gwalior, Kota	Yeotmal, Aminidivi
May	Banda, Sambalpur	Phalodi, Pune, Kolahpur, Hassan, Mayabundar, Long-Island, Alleppey
Jun	Pune, Sangli	Phalodi, Silchar
Jul		Roorkee, Phalodi, Jaipur, Dholpur, Fatehpur, Kolahpur, Mahabaleshwar, Palakkad, Coimbatore
Aug		Palam, Phalodi, Hardoi, Dholpur, Gwalior, Lucknow, Darbhanga, Cuddalore
Sep		Phalodi, Ratlam, Hanamkonda, Hyderabad
Oct	Guwahati, Agumbe	Hanamkonda
Nov		
Dec	Jalpaiguri	Bareilly
Annual	Jammu, Malda	Manali, Mandi, Najibabad, Phalodi, Hardoi, Jaipur, Dholpur, Darbhanga, Shivpuri, Seoni, Raigarh, Hanamkonda, Mayabundar, Long-Island, Alleppey, Noncowry

except J&K and some area of HP & UK where it decreased as shown in Fig. 3(b).

In March [Fig. 3(c)] rainfall has slightly increased over the country except western and central regions and some places of IGP and eastern region where it mostly decreased. In April rainfall increased over the country except southern states where it decreased as shown in Fig. 3(d). In May [Fig. 3(e)], rainfall decreased over northeastern and southern states, whereas it increased in the remaining parts of the country.

In June rainfall decreased at most places of Rajasthan, Gujarat, AP, Chhattisgarh and northeastern states, whereas it increased in the remaining parts of the country as shown in Fig. 3(f). In July the decreasing trend in rainfall is found all over the country except over Bihar, WB & northeastern states where rainfall increased as shown in Fig. 3(g). Rainfall in August [Fig. 3(h)] decreased all over the country except most places of Karnataka and Telangana where it increased. In September [Fig. 3(i)], rainfall decreased all over the country except most places of UP, AP, Kerala, TN and northeastern states where it increased.

In October the rainfall has slightly increased at most places of Rajasthan, Gujarat, West MP, Maharashtra & Telangana, however it slightly decreased in the remaining parts of the country as shown in Fig. 3(j). The rainfall in November [Fig. 3(k)] has slightly decreased at most places of Rajasthan, MP, Maharashtra, Karnataka, Kerala & northeastern states and some places of IGP, Gujarat,

Telangana, AP & TN, whereas it slightly increased in the remaining parts of the country. In December the rainfall has slightly increased at most places of IGP, Chhattisgarh, Jharkhand, Odisha, Sikkim and northeastern states and some places of Rajasthan, MP and AP, however it slightly decreased in the remaining parts of the country as shown in Fig. 3(l).

Less ( $\leq 5$  cm) variation in monthly rainfall is found all over the country. The rainfall decreased at more places of the country in July and August, it is because of increasing the number and duration of break monsoon spells in both months during the period 1981-2010. In February it slightly increased at more places.

There is a decrease in annual rainfall all over the country except most places of Meghalaya, WB & Kerala and some places of the remaining states where it increased as shown in Fig. 3(m). Moreover, it decreased by 10 cm at most places of Rajasthan, MP and Chhattisgarh.

The significance differences by applying Student's 't' test at 1% level in two series of rainfall values have been examined at stations as given in Table 3. There is no significant change in rainfall at any place of India in November. Significant change in monthly rainfall is found at a few places. Annual rainfall has significantly decreased at some places of the country.

#### 4. Conclusions

Increasing trend in maximum temperature during the period 1981-2010 is found over southern and western

regions of India in all months. During July to December months the temperature has increased at most places of the country. However, there is a decrease in maximum temperature over IGP region in January to June. Annual maximum temperature has increased all over the country except over IGP, Jharkhand and Meghalaya.

The significant rise in maximum temperature in all months except August is found at more places in southern part (south of 20° N) of India than northern part (north of 20° N). Significant rise in the temperature is found at most places of coastal areas and some places of hilly terrain. Annual maximum temperature significantly increased at most places of western & southern regions and hilly terrain. Significant fall in monthly and annual temperature is found at a few places of the country.

Minimum temperature has increased all over the country in all months except April to June wherein it decreased at most places of IGP, central and eastern regions and some places of the remaining region. During November to March months, minimum temperature has increased moreover northern part of the country. Annual minimum temperature has increased at most places of the country except over UK and some places of IGP, Jharkhand, Odisha, MP, Rajasthan and southern states where it decreased.

Significant rise in monthly and annual minimum temperature is found at more places in northern part of India than southern part. There is a significant change at some places of hilly terrain. Significant fall is found at some places of the country.

Both maximum and minimum temperature increased over Gujarat and Rajasthan.

Less ( $\leq 5$  cm) variation in monthly rainfall is found all over the country. The rainfall has slightly decreased at more places in July and August, whereas it slightly increased at more places in February. There is a decrease in annual rainfall all over the country except most places of Meghalaya, WB and Kerala where it increased. Moreover, it decreased by 10 cm or more at most places of Rajasthan, MP and Chhattisgarh. Significant fall in annual rainfall is observed at some places of the country.

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