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Development of 1961-1990 monthly surface climatology of India and patterns of differences of some meteorological parameters with respect to the 1951-1980 climatology

A. K. JASWAL, S. R. BHAMBAK, M. K. GUJAR, S. H. MOHITE,

S. ANANTHARAMAN and S. BHAGYALAKSHMY

India Meteorological Department, Shivajinagar, Pune – 411 005, India

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e mail : akjaswal@imdpune.gov.in

सार – किसी स्थान विशेष की औसत जलवायविक स्थितियों को दर्शाने के लिए जलवायु नॉर्मल्स का उपयोग किया जाता है और सभी देशों की राष्ट्रीय मौसम विज्ञान सेवाओं के द्वारा इसकी गणना की जाती है। विश्व मौसम विज्ञान संगठन (डब्ल्यू. एम. ओ.) सभी देशों को 1930, 1960, 1990 और इससे आगे समाप्त तीस वर्षों की अवधि के जलवायु नॉर्मल्स को तैयार करके प्रस्तुत करने के लिए कहता है जिसके आधार पर विश्व जलवायु नॉर्मल्स का प्रकाशन किया जाता है। अभी हाल ही में भारत मौसम विज्ञान विभाग (आई. एम. डी.) ने 1961–1990 की अवधि के जलवायविक नॉर्मल्स तैयार किए है जो वर्ष 1951–1980 के मूलभूत आँकड़ों को परिवर्तित कर देगा। इस शोध पत्र में वर्ष 1961 से 1990 की अवधि में भारत की 30 वर्षों की जलवायु विज्ञान नॉर्मल्स को प्रस्तुत किया गया है और तापमान, सापेक्षिक आर्द्रता, बादल, वर्षा एवं पवन गति के स्थानीय पैटर्न के वार्षिक औसत के अंतरों को पूर्ववर्ती नॉर्मल्स (1951–1980) के आधार पर प्रलेखित किया गया है।

पूर्ववर्ती जलवायु विज्ञान नॉर्मल्स में आए परिवर्तन बताते है कि अधिकतम तापमान, सापेक्षिक आर्द्रता के वार्षिक औसत में वृद्धि हुई है और न्यूनतम तापमान, बादलों की मात्रा, वर्षा, वर्षा वाले दिनों तथा पवन गति के वार्षिक औसत में देश के अधिकाधिक भागों में 1961–1990 की अवधि के दौरान गिरावट आई है। देश के अधिकांश भागों में शुष्क बल्ब तापमानों एवं सापेक्षिक आर्द्रता में हुए स्थानिक पैटर्न में परिवर्तन अनुपूरक रही हैं। वर्ष 1951–1980 के जलवायु की तुलना में वर्ष 1961–1990 के दौरान देश के अधिकांश भागों में बड़े पैमाने पर गिरावट देखी गई है। शहरीकरण के कारण वेधशालाओं के खुलाव में हुए परिवर्तनों के कारण, पवन गति में आंशिक गिरावट मानी जा सकती है।

ABSTRACT. Climate normals are used to describe the average climatic conditions of a particular place and are computed by National Meteorological Services of all countries. The World Meteorological Organization (WMO) recommends that all countries prepare climate normals for the 30-year periods ending in 1930, 1960, 1990 and so on, for which the WMO World Climate Normals are published. Recently, Climatological Normals for the period 1961-1990 have been prepared by India Meteorological Department (IMD) which will change the baseline of comparison from 1951-1980. In this paper, preparation of the 30-year Climatological Normals of India for the period 1961 to 1990 and spatial patterns of differences of annual means of temperatures, relative humidity, clouds, rainfall and wind speed from the previous normals (1951-1980) are documented.

The changes from earlier climatological normals indicate increase in annual means of maximum temperature, relative humidity and decrease in annual means of minimum temperature, cloud amount, rainfall, rainy days and wind speed over large parts of the country during 1961-1990. The spatial patterns of changes in dry bulb temperatures and relative humidity are complementary over most parts of the country. Compared with 1951-1980 climatology, there are large scale decreases in annual mean rainfall, rainy days and wind speed over most parts of the country during 1961-1990. The decrease in wind speed may be partly due to changes in exposure conditions of observatories due to urbanization.

Key words – Climatology, Normals, Maximum temperature, Minimum temperature, Rainfall, Rainy days, Total cloud, Low cloud, Relative humidity, Pressure.

1. Introduction

Changes in climate occur as a result of internal variability within the climate systems as well as both natural and anthropogenic external factors. The influence of climate on our lives is endless as it is an important factor in agriculture, commerce, industry, transportation and many other fields. Accurate representation of the mean state and variability of the present climate is important for number of purposes in climate change research. Therefore, Climatological Normals are a useful way to describe the average weather of a location and they serve as a benchmark for comparing current climatic conditions. These normals find wide applications in climatological studies and are best used for generating anomaly based climate data sets. According to the World Meteorological Organization (WMO), the climatological normal of a meteorological element is defined as the average computed for a uniform and relatively long period comprising atleast three consecutive ten-year periods (WMO 1983 and 1989). Climatological Normals for the period 1961-1990 for India are prepared for 435 stations by India Meteorological Department (IMD), which will replace the previous normals for the period 1951-1980 brought out in the year 1999.

According to the estimates by IPCC (2007), average surface temperature has increased by 0.74° C during the period 1901-2005. Recent studies of climate change in India have also revealed that there are significant trends in some of the meteorological parameters which have been attributed to global warming, urbanization and changes in land use patterns. Studies by various investigators (Hingane *et al*. 1985; Srivastava *et al*., 1992; Rupa Kumar *et al*., 1994; Chhabra *et al*., 1997; De and Rajeevan, 1997; Sahai, 1998; Kothawale and Rupa Kumar, 2005; Dash *et al*., 2007) have in general reported increase in temperatures over India. Studying decadal trends in climate over India, Srivastava *et al*. (1992) found much larger increasing trends in maximum temperatures than the minimum temperatures over a major part of the country. A comparative study of 1931-1960 and 1961-1990 averages of temperatures and rainfall over India by Chhabra *et al*. (1997) has indicated significant fall in minimum temperature in north Indian stations and significant rise in maximum temperature in south Indian stations with no significant change in rainfall over the country. Even though rainfall trends for India as a whole are not significant (Mooley and Parthasarathy, 1984; Thapliyal and Kulshrestha, 1991), there are significant trends over some specific areas as reported by Parthasarathy (1984), Rupa Kumar *et al*. (1992) and Singh and Sontakke (2002). The spatial changes in rainfall activities are attributed to global warming and shift in atmospheric circulations. Changes in temperatures and rainfall have been studied extensively in India as compared to other meteorological parameters like pressure, humidity, sunshine duration, clouds, radiation and wind. Studying effects of urbanization on fifteen large cities of India, Rao *et al*. (2004) have found decreasing trends in radiation, sunshine duration, total cloud amount and wind speed and increasing trends in relative humidity and rainfall during last forty to fifty years. Recently, there are reports of decrease in total cloud cover (Jaswal, 2010b) and increase in relative humidity (Jaswal and Koppar, 2011) over India.

The objectives of this paper are to describe the methodology used for preparing the 1961-1990 Climatological Normals and to document the patterns of changes in some important meteorological parameters (temperatures, humidity, clouds, rainfall and wind speed) with respect to 1951-1980 surface climatology.

2. Data and methodology

According to WMO (1989), climate normal is optimally based on a 30 year period devoid of inconsistencies in observational practices (*e.g*., shifting of location of station, changes in instrumentation, time of observation etc.) as well as missing values. WMO requires the calculation of normals every 30 years and this limiting period is part of an internationally accepted agreement which is based upon the recommendations of the International Meteorological Conference held in Warsaw in 1933. The 30 year period is sufficiently long to filter out many of the short-term interannual fluctuations and anomalies in the climate. IMD is bringing out climatological normals for India and 1961-1990 climatological normals are sixth in the series of climate normals. The first climatological normals for 171 stations have been published in 1904 and the last publication of climatological normals of 391 stations for 1951-1980 has been in the year 1999.

2.1. *Selection of stations and data source*

There are more than 500 surface observatories in the network of IMD but some of the observatories have closed down during the 1961-1990 period and some have large data gaps. For preparing 1961-1990 surface Climatological Normals, only those stations which have continuous data for 10 years or more are selected. The numbers of such stations are 435 and their locations are shown in Fig. 1. Out of these 435 stations, 377 stations are from the list of stations which have 1951-1980 Climatological Normals. 14 stations which have 1951-1980 normals but do not have continuous data for more than 10 years are not included for preparing 1961-1990 normals. Out of 435 stations selected for 1961-1990

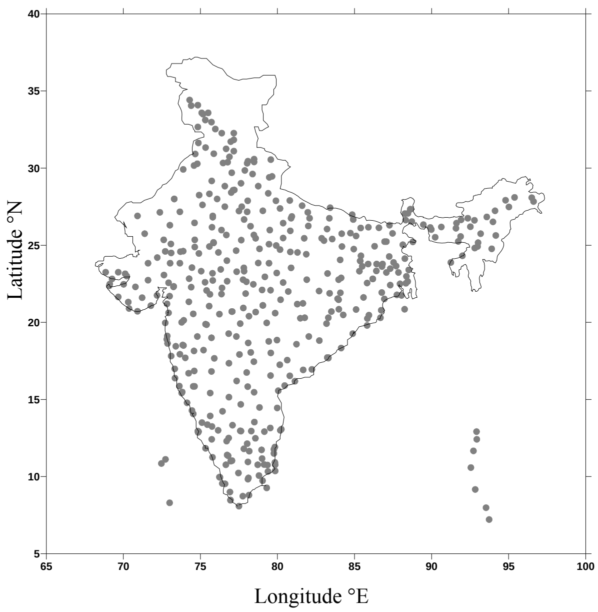


Fig. 1. Location of 435 stations selected for the preparation of Climatological Normals for 1961-1990

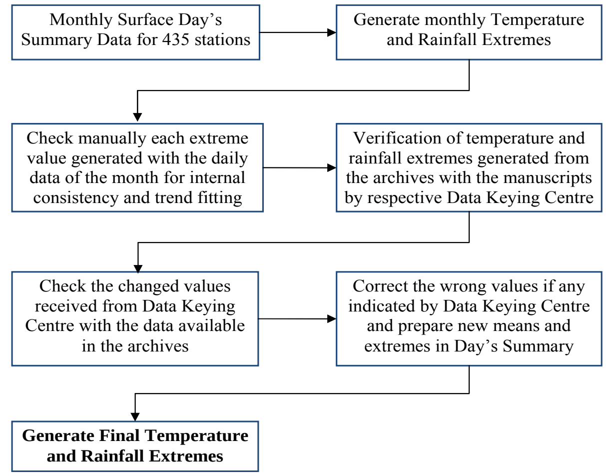


Fig. 2. Steps involved in the validation of monthly extremes of temperature and rainfall during preparation of 1961-1990 Climatological Normals

normals, numbers of stations having 25 years or more data are 308. Only 26 stations are having 10 to 15 years surface data available. Surface meteorological data used for the development of 1961-1990 surface climatology of India are taken from the archives of National Data Centre (NDC) of IMD located at Pune. Daily and monthly surface meteorological data recorded at 0300 and 1200 UTC are used in preparing the Climatological Tables. Rainfall data which are archived separately in NDC are used in preparing means and extremes of rainfall parameter.

2.2. *Quality control of data*

The daily and monthly surface data are subjected to a fairly comprehensive series of Quality Control (QC) checks before archival at NDC. Nonetheless, all data used for preparing 1961-1990 surface climatology of India are subjected to further QC procedures. In the first stage, the mean (μ) and standard deviation (σ) technique is employed for identifying doubtful monthly values of temperature, pressure and humidity parameters. For data series having numbers of years (N) ≤ 15, $\mu \pm 3\sigma$ is used to identify outliers while for data series having $N > 15$ the relation $\mu \pm (1.76 + 0.08\ N)\sigma$ is used. All doubtful values flagged in this way are manually verified with the corresponding daily values and as a rule the erroneous daily values are removed from the dataset and new monthly means are generated again. In the second stage, the climatological means for 1961-1990 are computed and its differences with previous available normals (1951-1980) are found. Stations showing abnormally high differences in means of various parameters are once again checked with available daily values and errors removed. All the monthly extremes of temperature (maximum and minimum) and rainfall (wettest month, driest month and 24 hours heaviest) are sent to respective data keying centres located at Regional Meteorological Centre (RMC)/Meteorological Centre (MC) for verification with the manuscripts as shown in Fig. 2. The extremes received from these data keying centres are further subjected to manual comparison and trend fitting with daily data available in NDC archives. No explicit corrections or adjustments are made to normals values to account for any variations in station locations, instruments or observing procedures.

2.3. *Preparation of climatological tables for 1961-1990*

Standard period for calculation of Climatological normals is thirty years which is long enough to eliminate year-to-year variations. WMO (1989) has established that normals should be arithmetic means calculated for each month of the year from daily data with a limited number of allowable missing values. The Climatological Tables include monthly and annual means of station level pressure, maximum temperature, minimum temperature, highest maximum temperature, lowest minimum temperature, relative humidity, vapour pressure, low cloud amount, total cloud amount, wind speed, rainfall and rainy days based upon 1961-1990 data. Besides the monthly and annual means, the Climatological Tables include extremes of maximum temperature, minimum temperature and rainfall with dates of occurrence based upon all available data up to 1990 and frequencies of weather phenomena, cloud amounts, wind speed, wind direction and visibility.

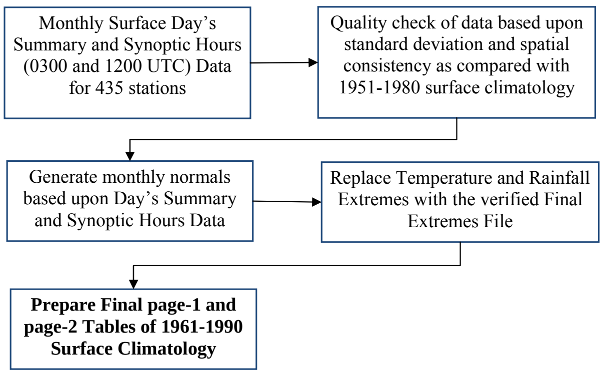


Fig. 3. Preparation of tables of 1961-1990 Climatological Normals

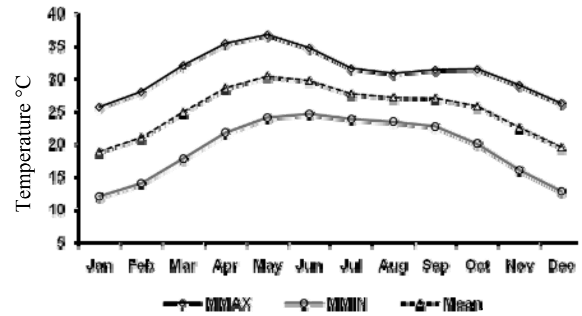


Fig. 4. All India monthly March of mean maximum temperature (MMAX), mean minimum temperature (MMIN) and mean temperature (MEAN) based upon 1961-1990 climatology of India

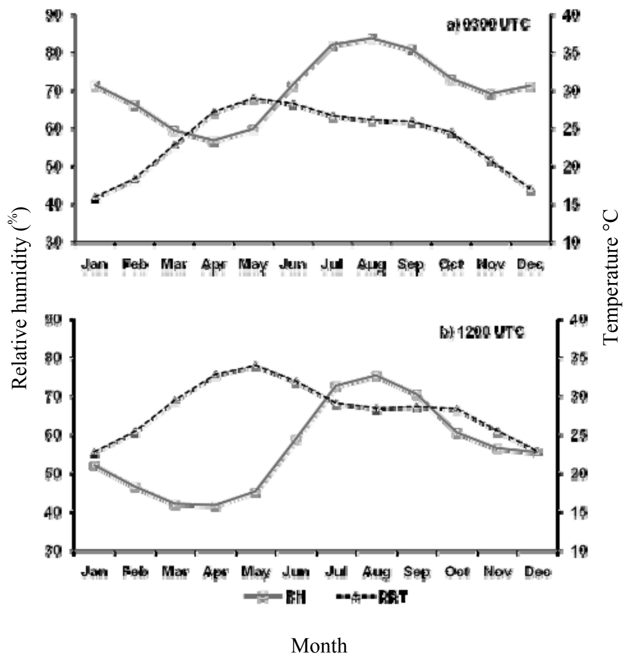
The rainy days are defined as days with rainfall amount more than 2.4 mm. Station level pressure (hPa) is the atmospheric pressure at the station elevation which is recorded at every synoptic hour. Vapour pressure (hPa) is the pressure exerted by the water present in an air parcel which increases as the amount of water vapour increases. Relative humidity (%) is the ratio of the actual amount of water vapour present in a given parcel of air to the maximum amount that the parcel is capable of holding at a given temperature. It is derived from dry bulb and wet bulb temperatures. Cloud amounts are estimated by observers and reported in okta. The average numbers of days of occurrence of specified weather parameters (thunder, hail, fog, dust storm and squall) are calculated based upon the visual observations. In the case of rainfall, mean number of days with 0.3 mm or more are calculated from rainfall data and included in the Climatological Tables. Extremes are compiled from the entire period of record of each location up to 1990, the last year of the normal period 1961-1990. Extreme values which occur more than once are identified with an '&' in the Climatological Tables.

Daily and monthly data of 435 stations in IMD network as depicted in Fig. 1 are used to prepare 1961-1990 surface climatology of India. Normals values are calculated from monthly average or total as appropriate for the element, as the mean for each month from all the individual months in the period 1961-1990 which atleast have 10 monthly values. The annual normal value was calculated as the mean or total of monthly normals values. The steps involved in the processing of data and preparing Climatological Tables for 1961-1990 are shown in Fig. 3. The monthly normals for pressure, temperature, clouds, humidity, wind speed and precipitation are computed simply by averaging the appropriate 30 values from the 1961-1990 dataset. The annual normals are calculated by taking the average of the 12 monthly normals except for precipitation where monthly normals are added.

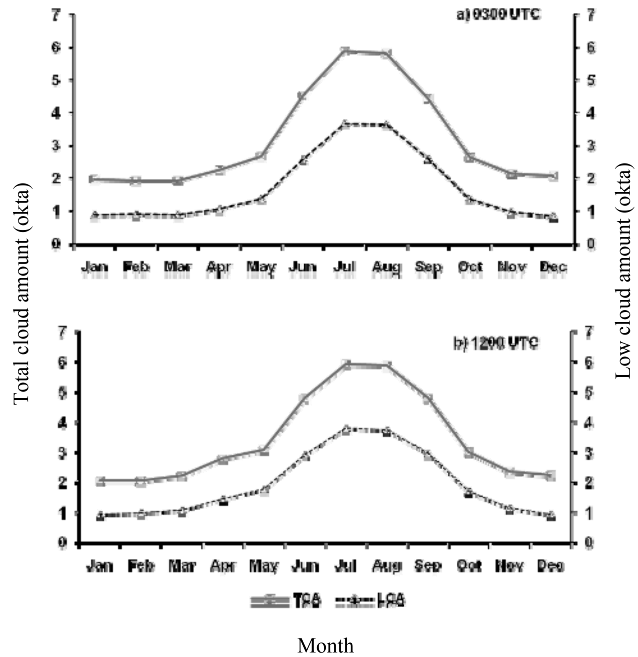
The annual March of mean temperature, mean maximum temperature and mean minimum temperature based upon 1961-1990 climatology of India are shown in Fig. 4. Similarly, all India variations of air temperature and humidity; total cloud and low cloud amount; rainfall and rainy days in a year are shown in Figs. 5 to 7. Out of 435 stations selected for 1961-1990 surface climatology of India, 377 stations are common with the previous published climatology (1951-1980). The difference in climatological annual means of meteorological parameters temperature, humidity, clouds, precipitation and wind speed for these two periods are computed for these 377 stations. The spatial patterns of 1961-1990 means and differences of means from 1951-1980 climatological averages are prepared by gridding the station values and plotting the maps using GIS software Surfer 8.0. The spatial patterns of these means and differences for meteorological parameters maximum temperature, minimum temperature, relative humidity, total cloud amount, low cloud amount, rainfall, rainy days and wind speed are shown in Figs. 8 to 15.

3. Results and discussion

Climate is the average state of the atmosphere and the underlying land or water in a particular region over a particular time-scale. It is typically described by the atmospheric and surface variables such as temperature, precipitation, wind, humidity, cloudiness, soil moisture, sea surface temperature and many other parameters. Climate variability is the variation of these variables around the mean state of climate. Based upon 435 stations, all India monthly averages of maximum temperature, minimum temperature, relative humidity, total cloud amount, low cloud amount, rainfall and rainy days are calculated and their annual March over the country is shown in Figs. 4 to 7.



Figs. 5(a&b). All India monthly March of mean relative humidity (RH) and dry bulb temperature (DBT) at 0300 UTC and 1200 UTC. Data series are based upon monthly means for 1961-1990



Figs. 6(a&b). All India monthly March of mean total cloud amount (TCA) and low cloud amount (LCA) at 0300 UTC and 1200 UTC. Data series are based upon monthly means for 1961-1990

3.1. *1961-1990 surface climatology of India*

Fig. 4 shows yearly variations in mean maximum temperature, mean minimum temperature and mean temperature over the country. Temperatures rise steadily over the country from the lowest values in January to highest in May (mean maximum temperature and mean temperature) and June (mean minimum temperature). With onset of southwest monsoon over India, temperatures start falling from June till August. While mean maximum temperature rises slightly in September (31.3° C) and October (31.4° C) from August value (30.7° C) before steadily falling from November onwards, mean minimum temperature continuously falls after reaching the highest value (24.6° C) in June. All India lowest mean maximum temperature, mean minimum temperature and mean temperature are lowest in January (25.6° C, 12.0° C and 18.8° C respectively) while the highest values are reached in May for mean maximum temperature (36.7° C) and mean temperature (30.4° C) and in June for mean minimum temperature (24.6° C). All India mean temperature behaves more similar to mean maximum temperature than the mean minimum temperature. Air temperature and relative humidity variations at 0300 UTC and 1200 UTC are shown in Figs. 5. Mean air temperatures at 0300 and 1200 UTC are lowest in January (15.9 and 22.8° C respectively) and attain highest values in May (29.0 and 34.0° C respectively) which then starts falling. But annual March of relative humidity recorded at 0300 and 1200 UTC show two maxima (January and August) and minima (April and November-December) for both hours. All India mean relative humidity values at 0300 UTC and 1200 UTC are highest (83.8 and 75. 3%) and lowest (56.6 and 41. 6%) respectively.

Annual March of total cloud and low cloud amount at 0300 UTC and 1200 UTC show lowest values in December-January and highest in July (Fig. 6). There is not much diurnal variability in all India mean cloud cover and the highest total cloud and low cloud amounts are 5.9 and 3.8 okta respectively which are attained in the peak monsoon month July. Based upon 435 surface stations, the highest monthly mean total rainfall and rainy days for the country as a whole are 322.1 mm and 13.0 days respectively which occur in the month of July. It is clear from Fig. 7 that all India mean rainfall and rainy days follow the patterns of cloud amount.

3.2. *Comparison between climatological normals for 1951-1980 and 1961-1990*

The spatial patterns of comparison of the 1961-1990 climatology with the earlier published surface climatology of India based upon 1951-1980 data is shown along with

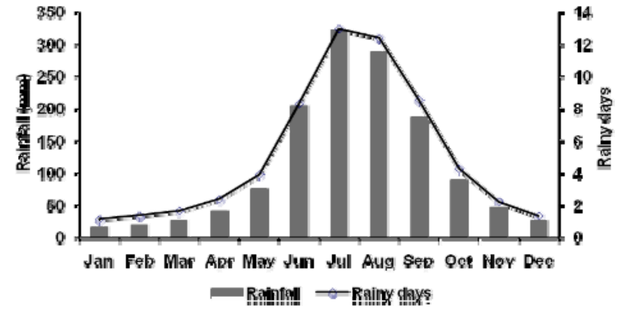
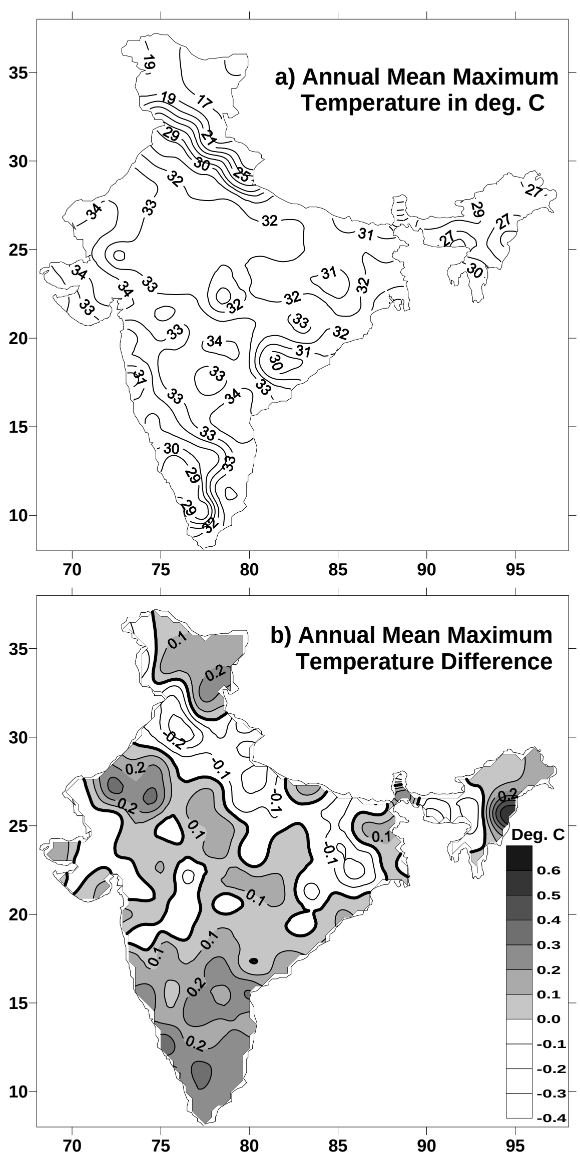
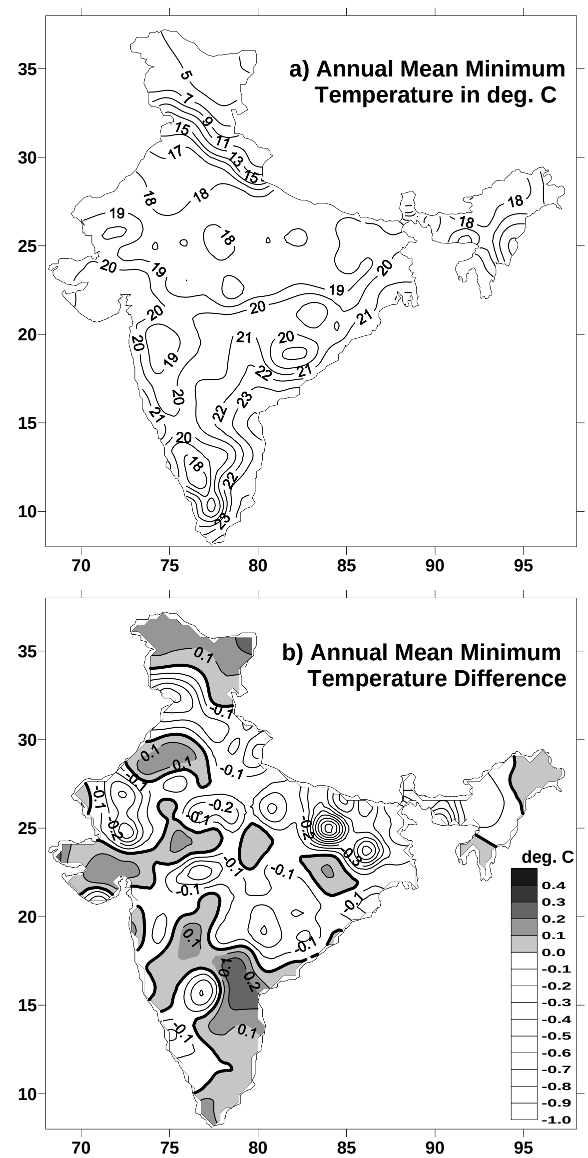


Fig. 7. All India monthly March of mean annual rainfall and annual rainy days based upon 1961-1990 climatological normals



Figs. 8(a&b). Spatial patterns of 1961-1990 climatological annual mean maximum temperature and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Fig. (b)

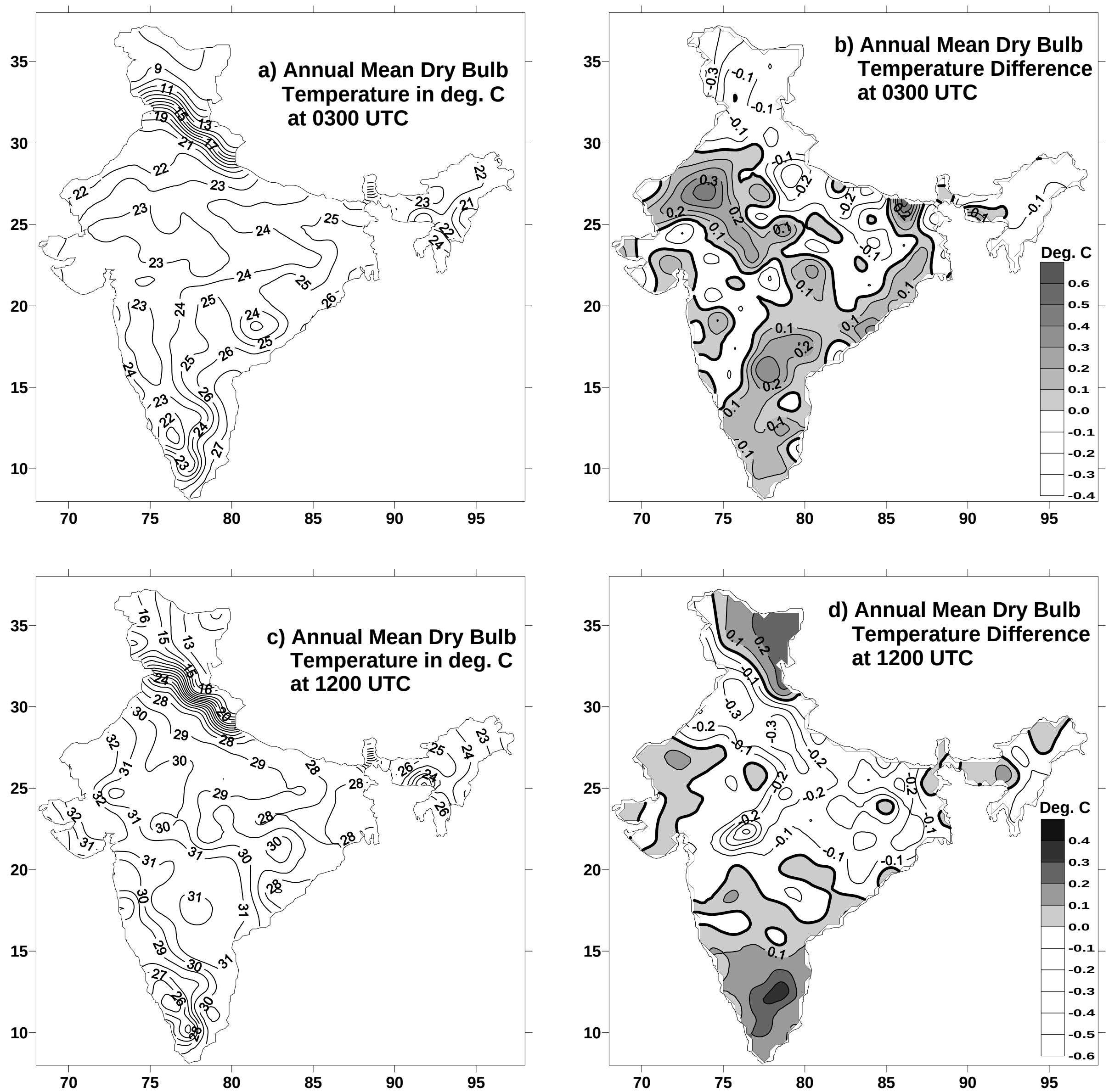


Figs. 9(a&b). Spatial patterns of 1961-1990 climatological annual mean minimum temperature and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Fig. (b)

the 1961-1990 annual means of maximum temperature, minimum temperature, relative humidity, total cloud, low cloud, rainfall, rainy days and surface wind speed in Figs. 8 to 15.

3.2.1. *Maximum temperature*

Annual mean maximum temperatures are lowest in extreme north India where Gulmarg has the lowest mean value 11.5° C. The highest mean maximum temperature is 35.5° C at Ariyalur in the south peninsula. The spatial

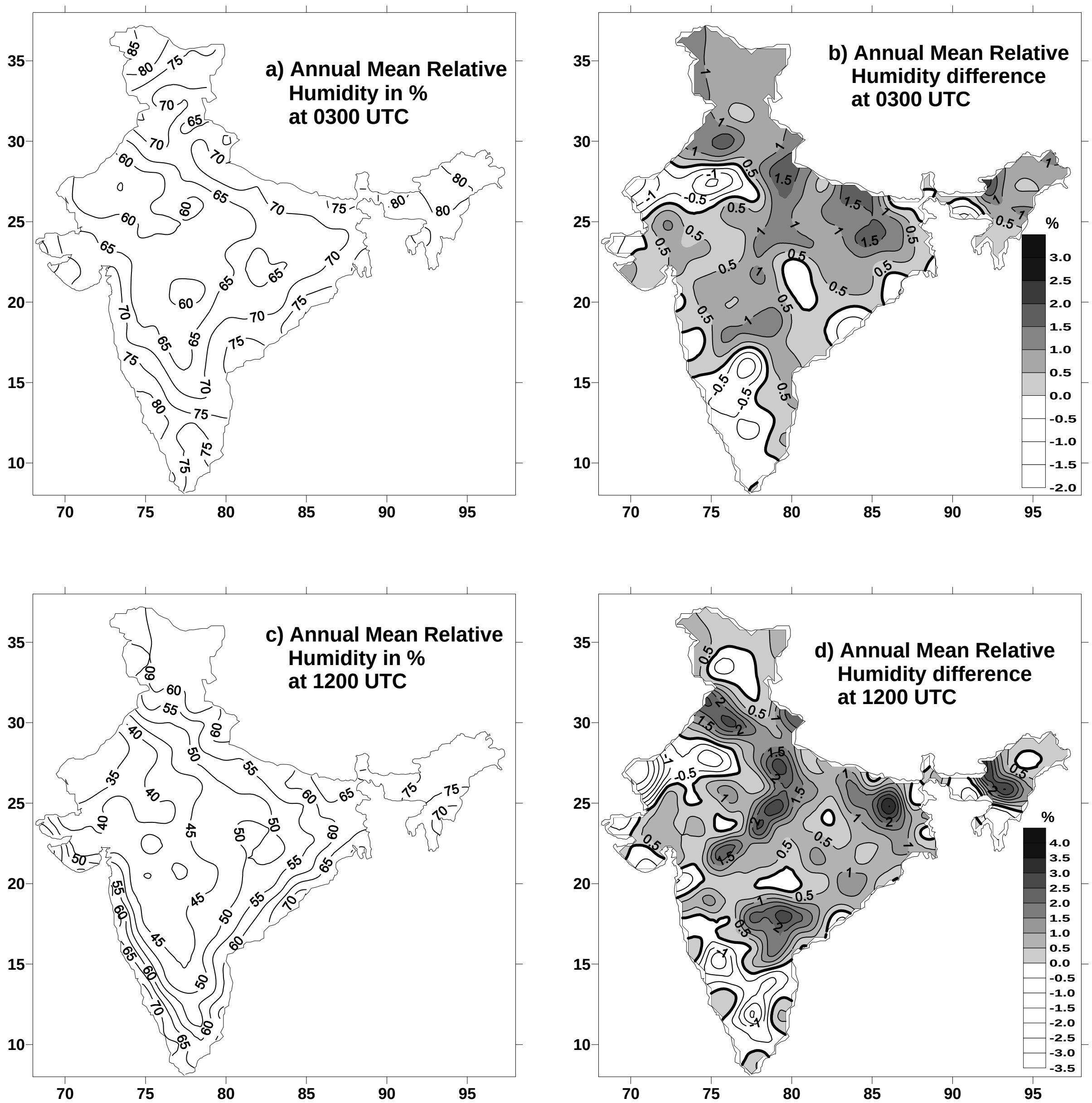


Figs. 10(a-d). Spatial patterns of 1961-1990 climatological annual mean dry bulb temperature at 0300 UTC & 1200 UTC and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Figs. (b&d)

distribution of annual mean maximum temperature indicates pockets of highest temperatures over western, and southern parts of India [Fig. 8(a)]. Spatial distribution of annual mean maximum temperature difference for 1951-80 and 1961-90 periods are shown in Fig. 8(b). Except over Indo-Gangetic plains and some parts of south Rajasthan, there is in general increase in annual mean maximum temperature over all parts of the country which is similar to the changes reported by Chhabra *et al.* (1997). The change in maximum temperature is between -0.8° C and +1.0° C.

3.2.2. *Minimum temperature*

Annual mean minimum temperatures are lowest in north India 1.5° C (Gulmarg) and highest in south India 25.6° C (Pamban). The spatial patterns of annual mean minimum temperatures [Fig. 9(a)] are almost similar to annual mean maximum temperature. The change in annual mean minimum temperature as compared to 1951-1980 averages is in the range -2.1° C to +0.5° C. The spatial distribution of difference between annual mean minimum temperature for the two periods indicate increase over

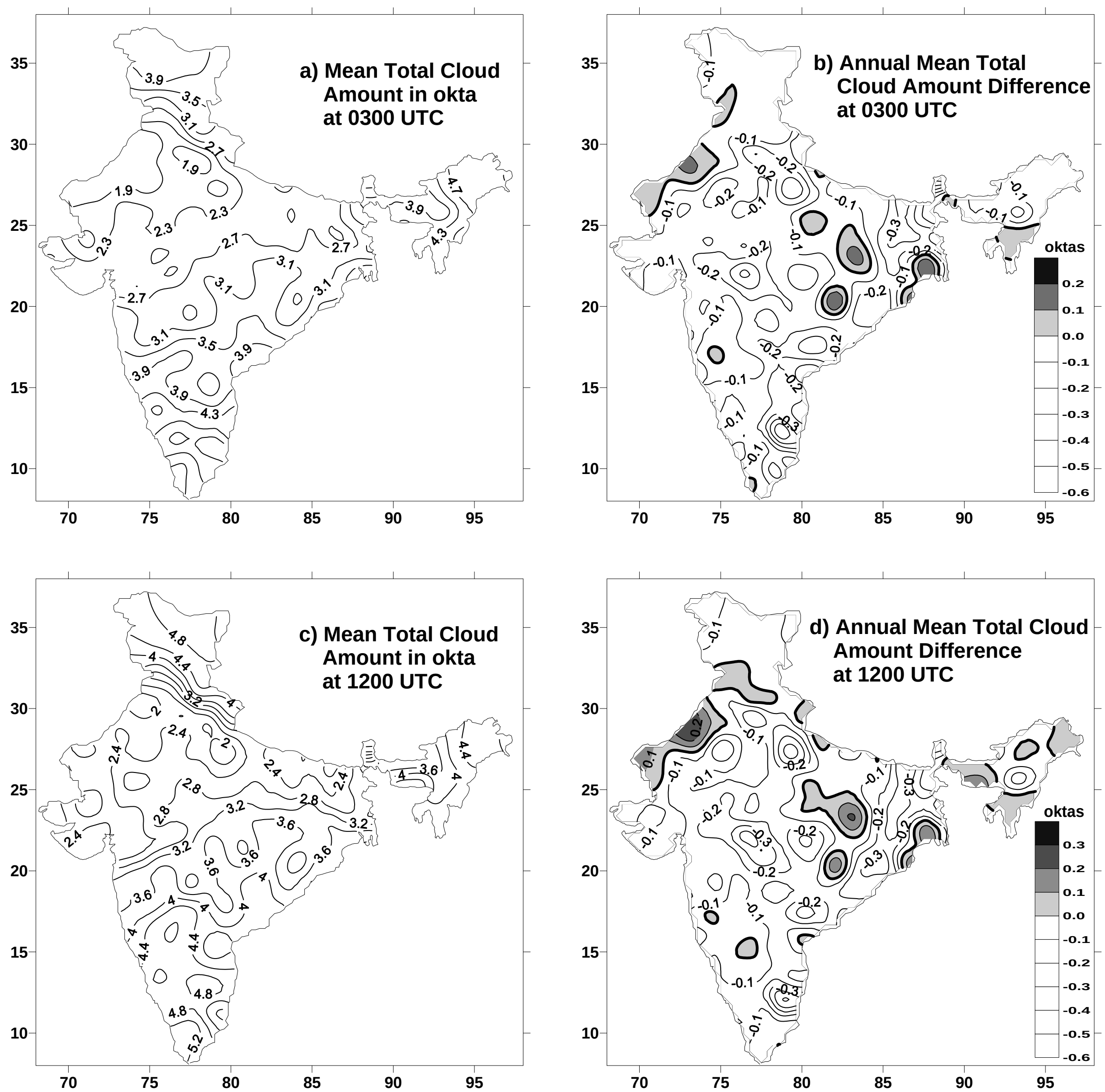


Figs. 11(a-d). Spatial patterns of 1961-1990 climatological annual mean relative humidity at 0300 UTC & 1200 UTC and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Figs. b & d

Jammu and Kashmir, south peninsula and some pockets over western India [Fig. 9(b)]. However, large parts of the country over Indo-Gangetic plains, central India and northeast India show decrease in annual mean minimum temperatures. The differences in annual minimum temperature obtained for the two periods do not agree with the changes reported in similar study by Chhabra *et al*. (1997). This may be due to different averaging periods (1931-1960 and 1961-1990).

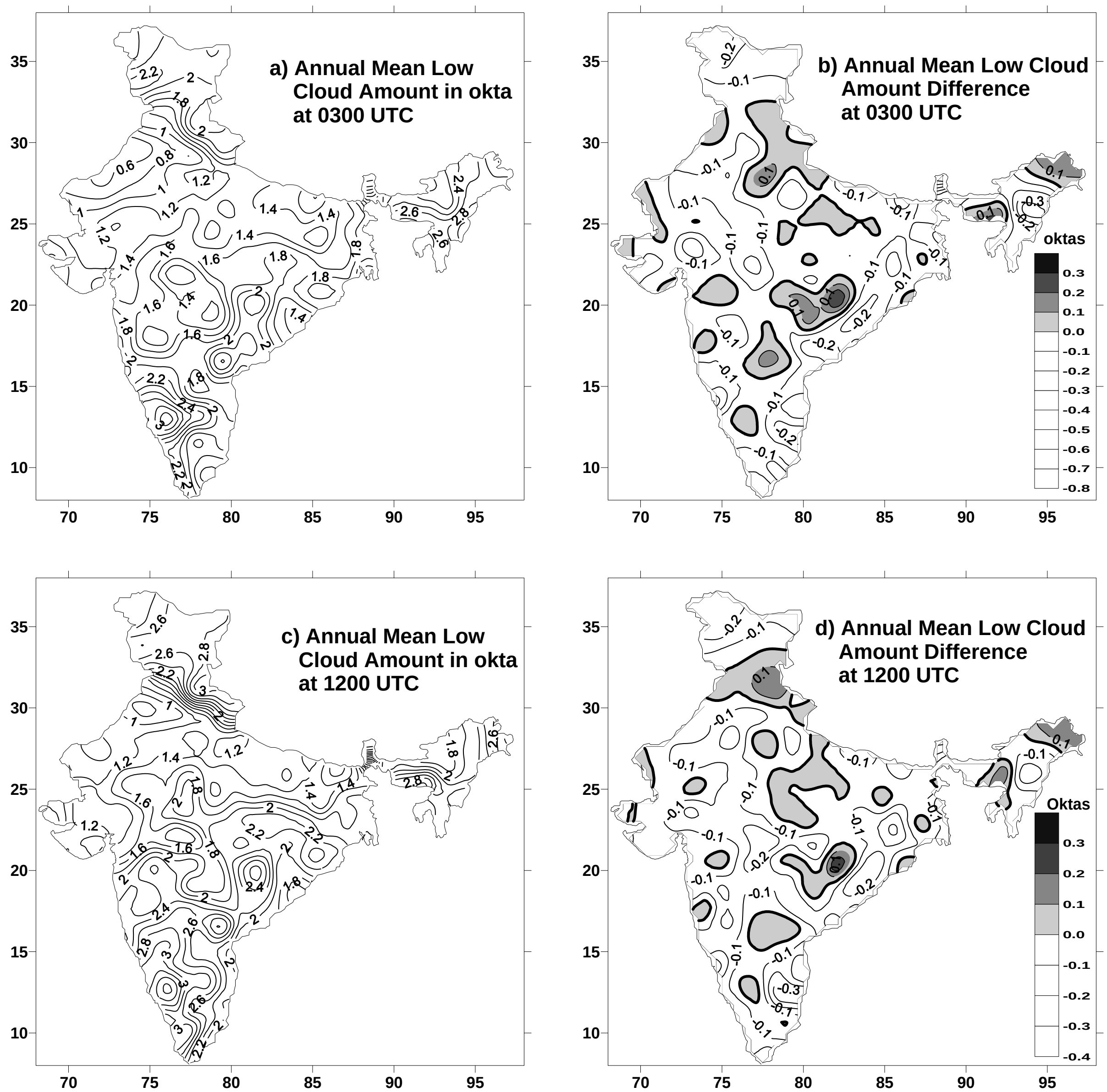
3.2.3. *Dry bulb temperature*

Annual mean dry bulb temperatures at 0300 UTC are lowest in extreme north India and highest in south India. The lowest mean value is 5.8° C at Gulmarg and the highest is 28.3° C at Ariyalur. The spatial patterns of annual mean dry bulb temperature show lowest temperature values over Jammu and Kashmir and highest values over western, central and southern parts of the



Figs. 12(a-d). Spatial patterns of 1961-1990 climatological annual mean total cloud amount at 0300 UTC & 1200 UTC and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Figs. b & d

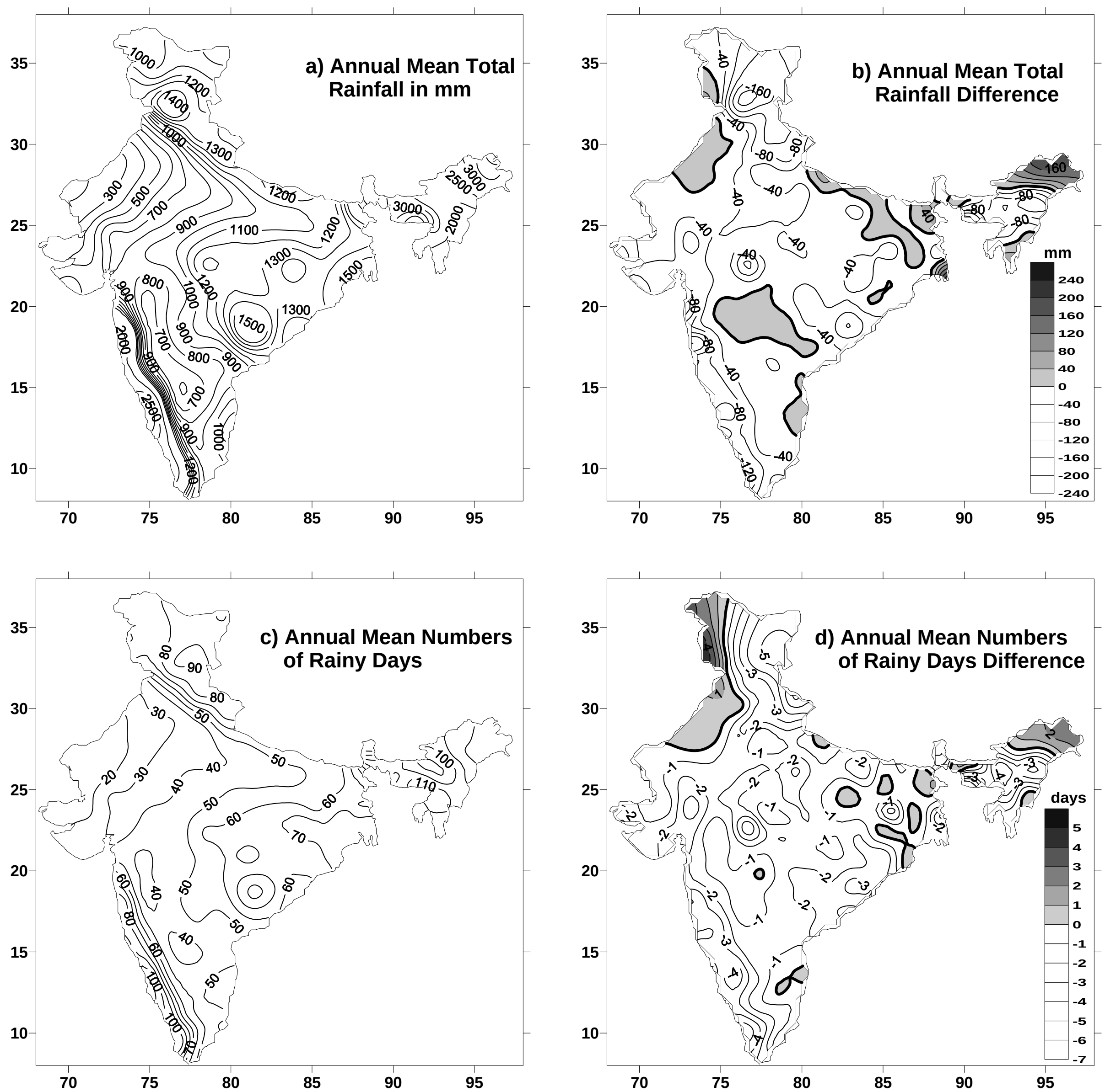
country where temperatures are more than 28°C [Fig. 10(a)]. The spatial patterns of difference between climatological periods 1951-1980 and 1961-1990 indicates increase in 0300 UTC mean annual dry bulb temperatures over most parts of the country except over Jammu and Kashmir and Indo-Gangetic plains as shown in Fig. 10(b). The change in annual mean dry bulb temperature at 0300 UTC as compared to 1951-1980 averages is in the range -0.7° C to +1.1° C. The spatial patterns of 1200 UTC mean annual dry bulb temperatures are similar to 0300 UTC patterns except that the regions of highest mean dry bulb temperature are spatially more coherent [Fig. 10(c)]. The changes in 1200 UTC annual mean dry bulb temperatures between 1951-1980 and 1961-1990 periods indicates decrease over Indo-Gangetic plains and central India while temperatures have increased over extreme north, west and south India [Fig. 10(d)]. The change in annual mean dry bulb temperature at 1200 UTC as compared to 1951-1980 averages is in the range -1.5° C to +0.7° C.



Figs. 13(a-d). Spatial patterns of 1961-1990 climatological annual mean low cloud amount at 0300 UTC & 1200 UTC and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Figs. b & d

3.2.4. *Relative humidity*

Fig. 11(a) shows spatial patterns of annual mean relative humidity at 0300 UTC indicating regions of higher humidity over north, northeast and along the coastal regions of India. Large parts in western and central India have the lowest annual mean relative humidity. The highest mean annual relative humidity at this hour is at Agumbe (89%) while the lowest (51%) is at Kota. The spatial distribution of changes in 0300 UTC mean annual relative humidity during the two periods 1951-1980 from 1961-1990 indicate general increase in major parts of the country as shown in Fig. 11(b). The change in humidity at 0300 UTC is between -4% and +10%. It is clear from Fig. 11(c) that the spatial patterns of 1200 UTC mean annual relative humidity are nearly similar to 0300 UTC patterns. The highest recorded mean annual relative humidity (85%) at this hour is at Kondul while the lowest is recorded at Bikaner (30%). Large parts of the country over north, central and northeast India are having increase



Figs. 14(a-d). Spatial patterns of 1961-1990 climatological annual mean rainfall, rainy days and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Figs. b & d

in mean annual relative humidity at 1200 UTC as shown in Fig. 11(d). The change in humidity at 1200 UTC hour is between -5% and +8%.

3.2.5. *Total cloud amount*

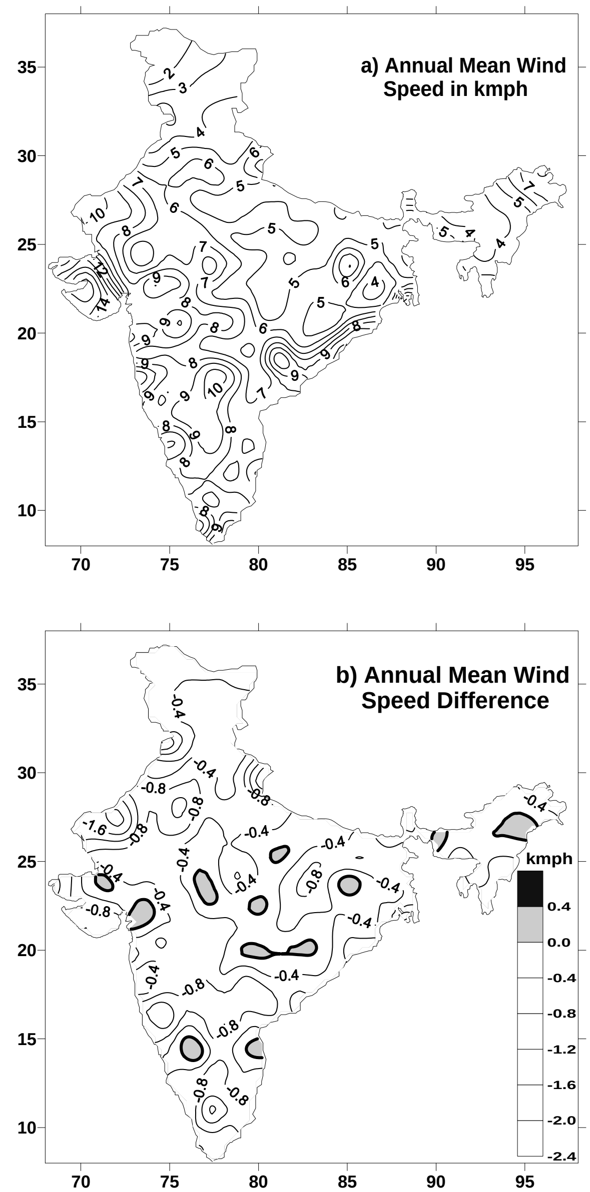
Spatial patterns of annual mean total cloud amount at 0300 UTC indicate regions of higher cloud cover over Jammu & Kashmir, northeast and along Western Ghats as shown in Fig. 12(a). Regions over western and central parts of the country have the least amount of cloud cover at this hour. While Hut Bay (5.7 okta), Port Blair (5.5 okta) and Shimoga (5.3 okta) have higher mean annual total cloud amount in the country, stations like Meerut (0.4 okta), Sikar (1.1 okta), Bhatinda and Karnal (1.2 okta each) have recorded lower mean annual total cloud amount during 1961-1990. The highest mean annual total clod amount is Meerut has recorded the lowest mean annual total cloud cover. It is clear from Fig. 12(b) that mean annual total cloud amount for 1961-1990 has in general decreased over India in comparison with 1951-1980 climatological normals. However, some pockets over northwest India show increase during this period. The magnitude of difference in annual mean total cloud cover during these two periods lies between -1.1 okta and +0.8 okta. Spatial patterns of 1200 UTC mean annual total cloud amount are shown in Fig. 12(c). The patterns are similar to 0300 UTC but the magnitude of mean total cloud amount has increased over north and south peninsula and has decreased over west and central India. It is clear from Fig. 12(d) that the mean annual total cloud cover for 1961-1990 has considerably decreased over the country as compared to 1951-1980 climatology. The change in annual mean total cloud amount at 1200 UTC is between -1.0 okta and +0.7 okta.

3.2.6. *Low cloud amount*

1961-1990 climatological annual mean low cloud amount recorded at 0300 UTC is the lowest at Meerut (0.1 okta) and the highest at Darjeeling (4.5 okta). Similarly, Bhatinda (0.3 okta) and Darjeeling (5.4 okta) have the lowest and highest mean annual low cloud amount at 1200 UTC respectively. The spatial distributions of annual mean low cloud amount at 0300 UTC [Fig. 13(a)] and 1200 UTC [Fig. 13(c)] suggest highest low cloud amount over north, northeast and Western Ghats and lowest over Rajasthan and adjoining areas. Similar to changes in mean annual total cloud amount, there is in general decrease in mean annual low cloud amount also over India during 1961-1990 as compared with 1951-1980 climatology [Figs. 13(b&d)]. However some pockets over north, northeast and south India are having positive difference both at 0300 and 1200 UTC. The change in mean annual low cloud amount for these two periods is between -0.8 okta and +0.9 okta (0300 UTC) and between -1.1 okta and +0.9 okta (1200 UTC).

3.2.7. *Rainfall and rainy days*

Annual mean rainfall is highest in the country at Cherrapunji (11262.7 mm) while the lowest (183.6 mm) is at Jaisalmer. Other stations having higher annual mean rainfall are Agumbe (7510.5 mm) and Mahabaleshwar (5617.7 mm). Spatial patterns of annual mean rainfall [Fig. 14(a)] shows Western Ghats and northeast India as the wettest regions and western Rajasthan and adjoining Gujarat as the driest regions of country. Stations receiving lesser (< 300 mm) annual mean rainfall are Jaisalmer (183.6 mm), Phalodi (251.2 mm), Barmer (260.2), Bikaner (295.6 mm) and Okha (297.3 mm). Spatial patterns of difference of annual mean rainfall from 1951-1980 climatological values shows general decrease over the country [Fig. 14(b)]. However some pockets over northwest, central and northeast India are showing



Figs. 15(a&b). Spatial patterns of 1961-1990 climatological annual mean wind speed and their differences from 1951-1980 climatological means. Positive differences are shown by shaded areas in Fig. (b)

increase in annual mean rainfall. Stations showing large decrease in annual mean rainfall are Mahabaleshwar (-445.1 mm), Tura (-379.6 mm) and Dahanu (-358.4 mm) which are incidentally heavy precipitation stations. The largest increase in annual mean rainfall is obtained at Sandheads (825.2 mm) where there is strong increasing trend in annual rainfall during 1981-1990.

Fig. 14(c) shows spatial patterns of annual mean rainy days over India indicating lowest numbers of days over west Rajasthan and highest over Western Ghats and northeast India. The lowest numbers of days are observed at Jaisalmer (10.6 days) while the highest (160.5 days) is recorded at Gangtok. Interestingly Cherrapunji which has recorded the highest mean annual rainfall amount 11262.7 mm has the second highest annual mean rainy days (153.5 days). The difference of present annual mean rainy days climatology with previous (1951-1980) climatology [Fig. 14(d)] indicates overall decrease in rainy days over almost entire country except small pockets over western parts of northwest India and extreme eastern parts of northeast India. Stations having large decrease in annual mean rainy days are spread over all parts of the country but are more concentrated over northwest, central and northeast regions. Some of the stations showing higher increase in mean annual rainy days are Gulmarg (5.2 days), Jammu (4.1 days) and Patiala (3.1 days). The decrease in annual mean rainfall and rainy days between the two climatological periods is noteworthy.

3.2.8. *Wind speed*

It is clear from Fig. 15(a) that annual mean wind speed is highest in western half of the country where many stations are having mean wind speed > 16 kmph. The spatial patterns indicate parts of northwest, central and northeast India as region of lower wind speed. Stations having higher annual mean wind speed are more coherent in Gujarat. Annual mean wind speed is lowest (< 2 kmph) at Tadong, Kupwara, Silchar, Gangtok and Berhampore. The spatial patterns of differences of annual mean wind speed for the two periods indicate general decrease over the country as shown in Fig. 15(b). Nearly 80% stations have recorded decrease in annual mean wind speed which may be partially due to changes in exposure conditions of observatories due to urbanization. The magnitude of difference of annual mean wind speed varies between -3.8 kmph (at Coimbatore) and +2.1 kmph (at Hazaribagh).

From the above results, it can be concluded that appreciable changes in meteorological parameters have occurred over India during 1961-1990 period. Trends similar to observed changes in temperature, rainfall, humidity, clouds and wind speed have been reported by many researchers in India. Kothawale and Rupa Kumar (2005) have reported significant increasing trend in annual mean temperature over India. Dash *et al*. (2007) have found increase in winter maximum temperature while Jaswal (2010a) has reported higher significant increase in maximum temperature in February over North India as compared to South India. Even though long-term rainfall trends for India as a whole are not significant, there are significant trends over some specific areas as reported by Rupa Kumar *et al*. (1992) and Singh and Sontakke (2002). Rao *et al*. (2004) have found decreasing trends in radiation, sunshine duration, total cloud amount and wind speed and increasing trends in relative humidity and rainfall. The general decrease in cloud cover and increase in relative humidity during 1961-1990 as compared to 1951-1980 climatology is supported by the decreasing trends in total cloud cover reported by Jaswal (2010b) and increasing trends in relative humidity reported by Jaswal and Koppar (2011).

4. Conclusions

A climate normal is simply an average and therefore does not completely characterize a particular climate. However conclusions may vary when comparisons are made using different baselines. The WMO standard Climatological Normals for 1961-1990 are computed for station level pressure, maximum temperature, minimum temperature, highest maximum temperature, lowest minimum temperature, relative humidity, vapour pressure, low cloud amount, total cloud amount, wind speed, rainfall and rainy days (as mentioned in section 2.3). Comparisons of annual means of maximum and minimum temperature, relative humidity, total cloud, low cloud, total rainfall, rainy days and wind speed with 1951-1980 normals are studied. When compared with the 1951-1980 climatological normals, there are decreases in cloud amount, rainfall, rainy days and wind speed and increases in relative humidity nearly all over the country. The spatial patterns of differences in annual mean maximum temperature indicate large scale increase over the country except Indo-Gangetic plains and parts of Assam, Bihar, West Bengal, Orissa and Gujarat. Annual mean minimum temperature difference during the two periods show decreases over Indo-Gangetic plains and large parts of Assam, Bihar, West Bengal, Orissa, Andhra Pradesh and Rajasthan. All these changes are similar to long-term trends in meteorological parameters over India reported by various researchers in recent decades.

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