MAUSAM, **61**, 3 (July 2010), 369-382

551.506.9 (546.1)

Recent trends in meteorological parameters over Jammu and Kashmir

A. K. JASWAL and G. S. PRAKASA RAO*

India Meteorological Department, Pune – 411 005, India

**India Meteorological Department, New Delhi – 110003, India*

(*Received 3 February 2009*)

e mail : akjaswal@imdpune.gov.in

सार – इस शोध पत्र में जम्मू और कश्मीर के दस स्टेशनों के 1976 से 2007 तक की अवधि के मौसम वैज्ञानिक प्राचलों जैसे तापमान, वर्षा, सापेक्षिक आर्द्रता और बादलों की वार्षिक प्रवत्ति का अध्ययन किया गया है। प्रवत्ति के विश्लेषण से यह पता चलता है कि राज्य के तापमान में वृद्धि हो रही है जिसमें कश्मीर क्षेत्र के अधिकतम तापमान (+0.04 से +0.05° से./वर्ष) और जम्मू क्षेत्र के न्यूनतम तापमान में (+0.03 से +0.08° से./वर्ष) विशेष बढ़ोतरी हुई। अधिकतम तापमान में अधिक बढ़ोतरी होने के कारण कश्मीर क्षेत्र में द्विवार्षिक तापमान रेंज बढ़ रही है जबकि न्यूनतम तापमान में बढ़ोतरी की प्रबल प्रवत्तियों से जम्मू क्षेत्र के डी. टी. आर. में कमी आ रही है। वार्षिक वर्षा और वर्षा वाले दिनों की प्रवत्तियाँ जम्मू को छोड़कर, जहाँ वार्षिक प्रवत्ति में विशेष बढ़ोतरी (+12.05 मि. मि./वर्ष) है, दोनों राज्यों के क्षेत्रों में कम हो रही है। दिन के समय की सापेक्षिक आर्द्रता की प्रवत्तियाँ मिली जुली है जबकि कुल मेघ राशि की प्रवत्तियाँ कश्मीर क्षेत्र में कम हो रही है और जम्मू क्षेत्र में बढ़ रही है। पिछले दो दशकों में जम्मू क्षेत्र शहरीकरण से अधिक प्रभावित हुआ है ओर इस क्षेत्र का न्यूनतम तापमान प्रभावित हुआ है। इस अध्ययन की अवधि के दौरान उत्तर भारत में वायुमंडल परिसंचरण में परिवर्तनशीला के परिप्रेक्षय में जम्मू और कश्मीर में उष्णता की प्रवत्तियों के अन्वेषण की और अधिक आवश्यकता है।

ABSTRACT. Annual trends of meteorological parameters temperature, rainfall, relative humidity and clouds for ten stations in Jammu and Kashmir during the period 1976-2007 were studied. Trend analysis shows that temperatures are increasing over the state with significant increase in maximum temperature in the Kashmir region (+0.04 to + 0.05° C/year) and minimum temperature in the Jammu region (+0.03 to + 0.08° C/year). The diurnal temperature range (DTR) is increasing over Kashmir region due to higher increasing trends in the maximum temperature while the strong increasing trends in the minimum temperature are contributing more towards the decrease in DTR over the Jammu region. Annual rainfall and rainy days trends are decreasing in both the regions of the state except at Jammu where rainfall trend is significantly increasing (+12.05 mm/year). Day-time relative humidity trends are mixed while total cloud amount trends are decreasing over Kashmir region and increasing over Jammu region. The effects of urbanization in the last two decades are more pronounced in Jammu region and this is strongly expressed in minimum temperature over the region. The warming trends observed over Jammu and Kashmir state during the period of study need further investigation in relation to variability of atmospheric circulation over North India.

Key words – Maximum temperature, Minimum temperature, Mean temperature, Rainfall, Relative humidity, Total cloud, Diurnal temperature range, Rainy days, Trend.

1. Introduction

The state of Jammu and Kashmir comprises of mountainous areas in the north-west Himalayas that shares international boundaries with Pakistan in the west, China in the north and Tibet in the north-east. According to the 2001 census, the size of the Jammu & Kashmir population is 10,069,917, which is 0.98 per cent of the country's total population. The total forest area in the state is 20,230 square km, which is roughly 20% of the total geographical area of the state. The three regions of the state (Jammu, Kashmir and Ladakh) experience different climatic patterns *i.e.*, the Ladakh Region (cold arid zone of high altitude in the inner Himalayas with severe cold, dry winter and moderate summer), the Kashmir valley (temperate zone of wet and cold winter, dry moderate

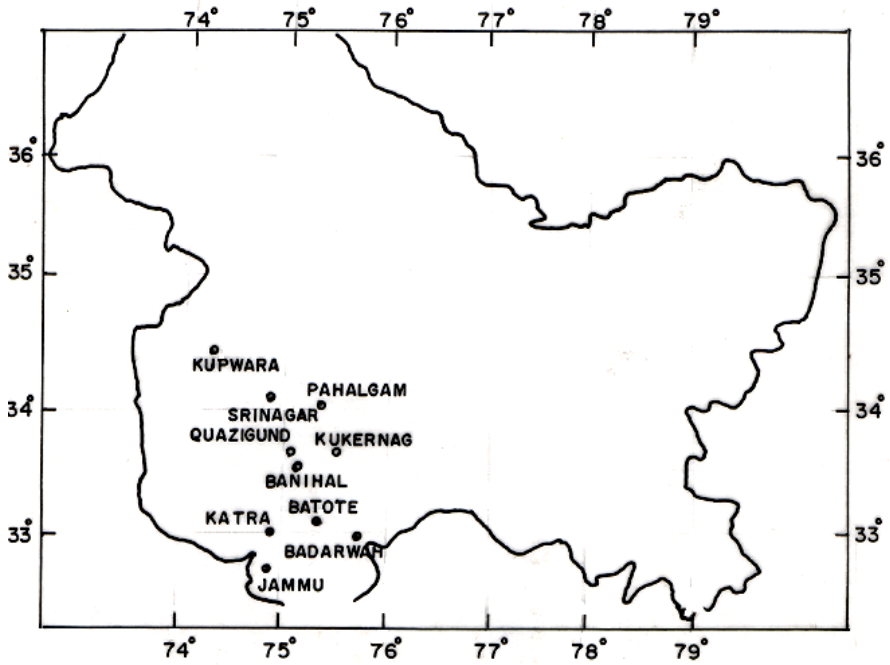

Fig. 1. Location of meteorological stations selected for study

summer) and the Jammu region (sub tropical zone consisting of foothills (of Shivalik), plains and hills with hot summer and dry winter.

The global average surface temperature has increased by about 0.6° C since the beginning of the twentieth century and most of this warming has occurred during two main periods 1910-1945 and 1976 to present (IPCC, 2001). However this increase has not been uniformly distributed over time and temperatures have risen sharply since 1976. During the present episode of rapid warming, global temperatures have increased at a rate of 0.15° C/decade (Jones *et al*., 2001). Differential changes in daily maximum and minimum temperatures are resulting in a narrowing of the diurnal temperature range (DTR) all over the globe (Easterling *et al*., 1997). But the amount of rainfall over land has changed insignificantly from 0.5 to 1.0% per decade while the number of extreme precipitation events in some areas of the globe has increased (IPCC, 2001).

Temperature trends over India have been studied by a number of researchers (Sen Roy and Prasad, 1991; Srivastava *et al*., 1992; Rupa Kumar *et al*., 1994; De and Rajeevan, 1997; Sinha Ray *et al*., 1997; Sahai, 1998; Kothawale and Rupa Kumar 2005) and the trends in maximum and minimum temperatures are similar to what have been reported world over (Karl *et al*. 1993; Easterling *et al*., 1997; Jones *et al*., 1999; New *et al*., 2000; IPCC, 2001; New *et al*., 2001; Giorgi, 2002, Jones and Moberg 2003 and many more). According to Kothawale and Rupa Kumar (2005), all India mean annual temperature has significantly increased by 0.05° C/10 yr during the period 1901-2003 and they have found an accelerated warming at the rate of 0.22° C/10 yr during 1971-2003. Roy and Balling (2005) have found significant increase in maximum and minimum temperature over the Deccan plateau and in general decrease in DTR over northwest Kashmir in summer. Based upon three stations (Shimla, Srinagar and Leh), Bhutiyani *et al*. (2007) have found significant rise in air temperature by 1.6° C during the last century in the northwest Himalayan region with winters warming at a faster rate. Also, significant increasing trend in DTR in the northwest Himalayan region have been reported by Bhutiyani *et al.* (2007) attributing this increase to rise in both maximum and minimum temperatures with maximum increasing more rapidly. Recent studies on effect of urbanization on climate by Kalnay and Cai, (2003), Zhou *et al*. (2004) and Zhang *et al.* (2005) have attributed surface temperature warming to land-use change. Kalnay and Cai (2003) have estimated that land-cover changes have caused surface warming of ~0.27° C per century. De *et al.* (2001) have noted increase in atmospheric aerosols over many Indian cities leading to sharp decline in atmospheric visibility

TABLE 1

Details of observatory stations selected for the study

Station name	Position	Population (2001 census)	Altitude (m)	Year of start	Classification
Kupwara	34° 25'N, 74° 18'E	10,624	1609	1977	Ordinary Climatological Station opened under TMO Scheme
Srinagar	34° 05'N, 74° 50'E	8,94,940	1587	1891	Principal Climatological Station
Kukernag	33° 35'N, 75° 30'E	4,858	1011	1977	Ordinary Climatological Station opened under TMO Scheme
Pahalgam	34° 02'N, 75° 20'E	5,922	2310	1978	Do
Quazigund	33° 35'N, 75° 05'E	4,307	1739	1956	Ordinary Climatological Station
Banihal	33° 30'N, 75° 10'E	2,729	1630	1955	Ordinary Climatological Station
Batote	33° 07'N, 75° 19'E	3,733	1585	1977	Ordinary Climatological Station opened under TMO Scheme
Baderwah	32° 59'N, 75° 43'E	10,849	1689	1977	Do
Katra	33° 00'N, 74° 54'E	7,569	1170	1980	Do
Jammu	32° 40'N, 74° 50'E	3,78,431	367	1910	Principal Climatological Station

TMO – Tourist Meteorological Office

during winter season. All these studies highlight the role of urbanization, deforestation and land-use change on climate change.

In this paper, an analysis of variation of meteorological parameters (temperatures, relative humidity, cloud cover and precipitation) for ten stations in Jammu and Kashmir over the period 1976-2007 is presented.

2. Data and methodology

2.1. *Station network*

Out of 16 stations in the surface observatories network of India Meteorological Department (IMD) in Jammu and Kashmir, ten stations were chosen on the basis of period of data and completeness of data records for the study period 1976-2007. These stations are Jammu, Katra, Batote, Banihal and Baderwah in the Jammu region and Srinagar, Pahalgam, Kukernag, Quazigund and Kupwara in the Kashmir region as outlined in Fig. 1. The selected stations fall in 'subtropical' (Katra and Jammu), 'intermediate' (Baderwah, Banihal and Batote) and 'temperate' (Srinagar, Kupwara, Kukernag, Quazigund and Pahalgam) agro-climatic zones of the country. No station from Ladakh region of the state could be taken up for study as the two surface observatories (*viz*., Leh and Dras) in the region have large data gaps during the years 1976-2007. Table 1 gives details of stations selected for study *viz*., latitude, longitude, population (as per the 2001 census), starting year, elevation and classification of observatory. Four out of these ten stations namely Srinagar, Quazigund, Banihal and Jammu have data prior to 1976.

2.2. *Computational methods*

The daily meteorological data for this study were obtained from the archives of National Data Centre of India Meteorological Department (IMD), Pune. The daily values of temperature, clouds, rainfall and humidity were further subjected to quality control checks and outliers were removed. Annual (Jan-Dec) means of maximum temperature, minimum temperature, mean temperature (average of maximum and minimum temperatures), diurnal temperature range (DTR = difference of maximum and minimum temperatures), day-time (average of 0300, 0600, 0900 and 1200 UTC) relative humidity and total cloud amount, total rainfall and number of rainy days (days having rainfall more than 2.4 mm) were computed for all the stations based on their daily values for 1976-2007. Table 2 shows comparison of 1976-2007 means of maximum temperature, minimum temperature, relative humidity, total cloud amount, rainfall and rainy days for four stations (Srinagar, Quazigund, Banihal and Jammu) with their 1951-1980 published Climatological Normal values. The time series of all these meteorological parameters were subjected to linear trend analysis by the method of least square. The calculated trends were tested at 95% level of confidence using Student's *t*-test and trend values are summarized in Table 3. Temporal variations of meteorological parameters having significant trends for 1976-2007 are shown in Figs. 2-9.

3. Results and discussion

3.1. *Comparison of climatological mean*s

Srinagar, Quazigund, Banihal and Jammu stations have started prior to 1976 (Table 1) and Climatological

TABLE 2

Comparison of 1976 onwards annual means of maximum temperature, minimum temperature, relative humidity, total cloud amount, total rainfall and total rainy days for stations having 1951-80* Climatological Normal

	Data Period	Srinagar	Quazigund	Banihal	Jammu
Maximum Temperature (°C)	1951-1980	19.2	18.3	20.6	30.1
	1976-2007	**20.0**	**19.2**	**21.4**	**29.6**
Minimum Temperature (°C)	1951-1980	7.3	6.5	8.2	17.7
	1976-2007	**7.5**	**6.5**	**8.2**	**17.8**
Relative Humidity (%)	1951-1980	70.0	69.0	63.0	54.0
	1976-2007	**68.5**	**69.1**	**62.0**	**63.3**
Total Cloud Amount (okta)	1951-1980	4.3	4.3	3.7	3.1
	1976-2007	**4.3**	**4.2**	**3.7**	**3.3**
Rainfall (mm)	1951-1980	674.9	1292.3	1305.0	1087.7
	1976-2007	**674.7**	**1169.7**	**1263.6**	**1258.5**
Rainy Days	1951-1980	55.1	71.5	72.2	48.9
	1976-2007	**52.9**	**69.4**	**67.8**	**56.6**

* - Climatological Tables 1951-1980, Director General of Meteorology, New Delhi.

TABLE 3

Increasing (+)/decreasing (-) trends of annual means of maximum temperature (MAX), minimum temperature (MIN), mean temperature (MEAN), diurnal temperature range (DTR), relative humidity (RH) total cloud amount (TC) and total rainfall (RF) and rainy days (RD). Trend values significant at 95% level of significance are shown in bold

Station	Data period	Trend values per year							
		Max (°C)	Min (°C)	Mean (°C)	DTR (°C)	RH (%)	TC (okta)	RF (mm)	RD (days)
Kupwara	1977-2007	**+ 0.05**	+ 0.01	**+ 0.03**	**+ 0.04**	+ 0.05	**- 0.02**	**- 9.77**	**- 0.50**
Srinagar	1976-2007	**+ 0.04**	+ 0.01	**+ 0.03**	+ 0.02	**- 0.18**	no trend	- 1.72	- 0.20
Kukernag	1978-2007	**+ 0.05**	+ 0.01	**+ 0.03**	**+ 0.04**	**+ 0.14**	- 0.01	**- 16.19**	**- 0.62**
Pahalgam	1978-2007	**+ 0.05**	**+ 0.03**	**+ 0.04**	+ 0.02	- 0.04	no trend	**- 12.65**	**- 0.56**
Quazigund	1976-2007	+ 0.01	no trend	+ 0.01	+ 0.01	**- 0.26**	**- 0.02**	- 4.72	- 0.34
Banihal	1976-2007	**+ 0.05**	**+ 0.04**	**+ 0.05**	**+ 0.02**	**- 0.38**	no trend	- 0.94	**- 0.59**
Batote	1977-2007	**+ 0.02**	**+ 0.03**	**+ 0.03**	- 0.01	**- 0.10**	- 0.01	- 8.47	**- 0.64**
Baderwah	1977-2007	+ 0.03	**+ 0.08**	**+ 0.05**	**- 0.05**	- 0.07	+ 0.01	- 7.24	- 0.25
Katra	1980-2007	+ 0.02	**+ 0.06**	**+ 0.04**	**- 0.04**	+ 0.07	**+ 0.02**	- 5.45	- 0.04
Jammu	1978-2007	+ 0.01	**+ 0.05**	**+ 0.03**	**- 0.04**	**+ 0.13**	+ 0.01	**+ 12.05**	- 0.25

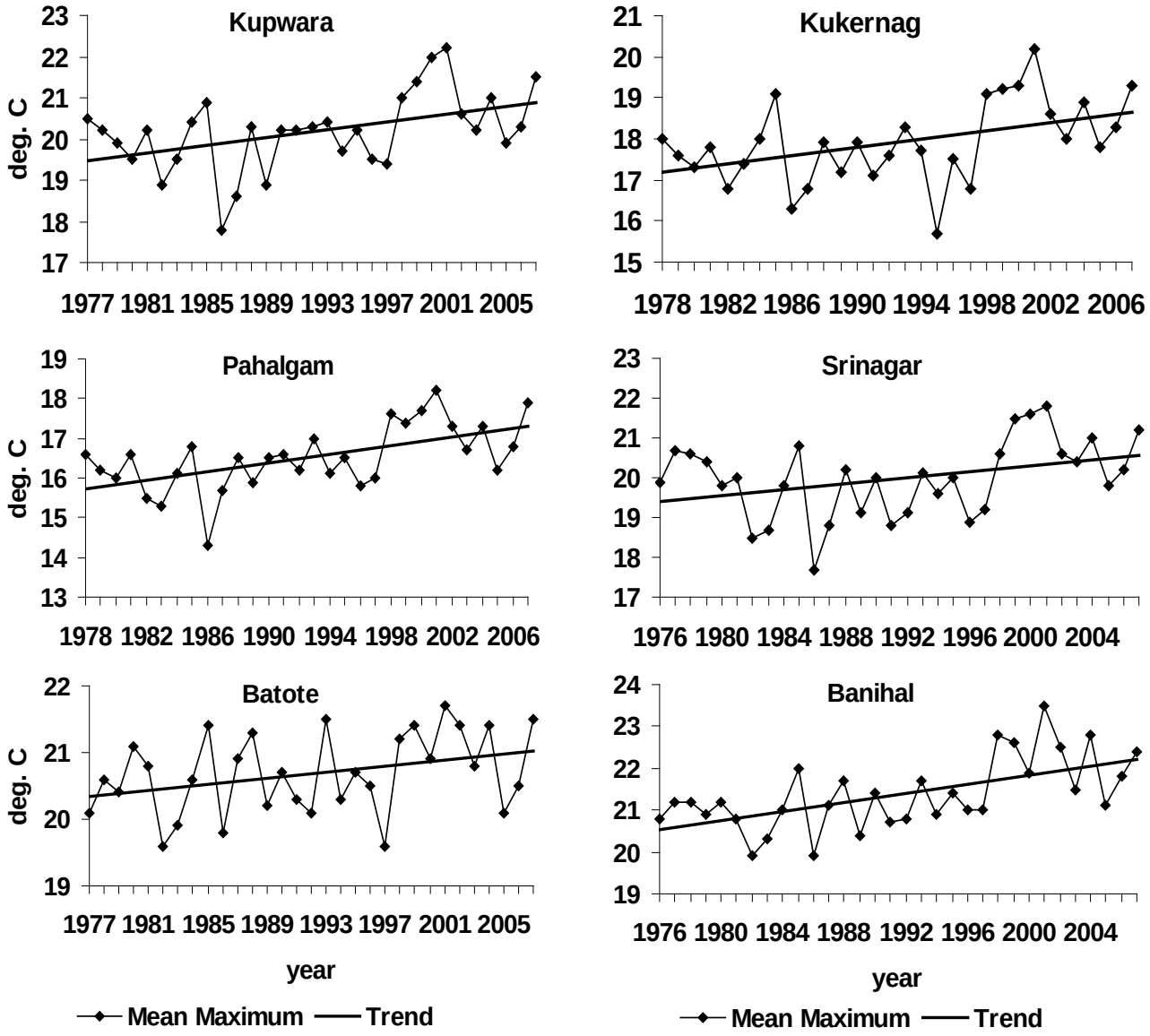

Fig. 2. Annual mean maximum temperature trends for 1976-2007 significant at 95% level

Tables for 1951-1980 for these stations have been published by IMD. Comparison of climatological normal values (1951-1980) with the mean values for the study period (Table 2) shows that annual mean maximum temperature has increased at Srinagar (+0.8° C), Quazigund (+0.9° C) and Banihal (+0.8° C) and decreased at Jammu (-0.5° C). The magnitude of change in annual mean minimum temperature is lesser (0.0 to +0.2° C). Annual mean relative humidity has decreased at Srinagar (-5%) and Banihal (-1%) and has increased at Quazigund (+1%) and Jammu (+9%). Mean annual total cloud amount has decreased at Quazigund (-0.1 okta) and has increased at Jammu (+0.2 okta) while Srinagar and Banihal are showing no change. Mean total annual rainfall and rainy days have decreased at Srinagar, Quazigund and Banihal. At Jammu, mean total annual rainfall and rainy days have increased (+170.8 mm and +7.7 days respectively). This indicates increase in mean temperature and decrease in mean rainfall over other three stations except at Jammu where mean maximum temperature has decreased and mean rainfall and rainy days have increased.

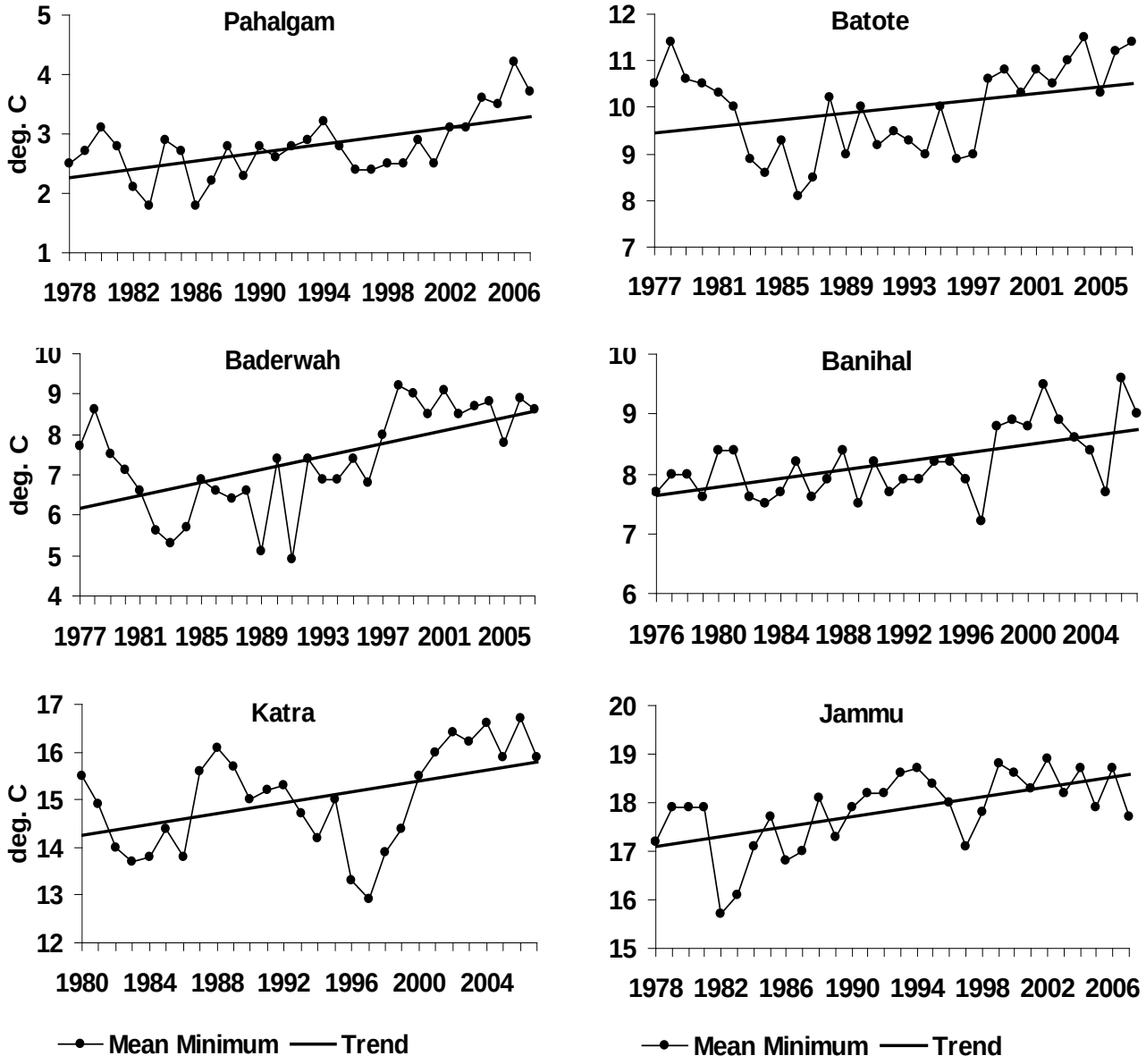

Fig. 3. Annual mean minimum temperature trends for 1976-2007 significant at 95% level

3.2. *Temperature trends*

Annual mean maximum, mean minimum and mean temperatures are increasing in both the regions of the state as shown in Table 3. Kupwara (+0.05° C/year), Kukernag (+0.05° C/year), Pahalgam (+0.05° C/year), Srinagar (+0.04° C/year) in Kashmir region and Batote (+0.02° C/year) and Banihal (+0.05° C/year) in Jammu region are showing significant increasing trend in maximum temperature (Fig. 2). The trends in annual mean minimum temperature are significantly increasing at all stations in the Jammu region and at Pahalgam in the Kashmir region. Stations showing significant increasing trend in minimum temperature are Jammu (+0.05° C/year), Katra (+0.06° C/year), Baderwah (+0.08° C/year), Batote (+0.03° C/year), Banihal (+0.04° C/year) and Pahalgam (+0.03° C/year) as shown in Fig. 3. Annual mean temperature is increasing in both the regions of the state and the increasing trends are significant at Jammu (+0.03° C/year), Katra (+0.04° C/year), Baderwah (+0.05° C/year), Batote (+0.03° C/year), Banihal (+0.05° C/year), Srinagar (+0.03° C/year), Kupwara (+0.03° C/year),

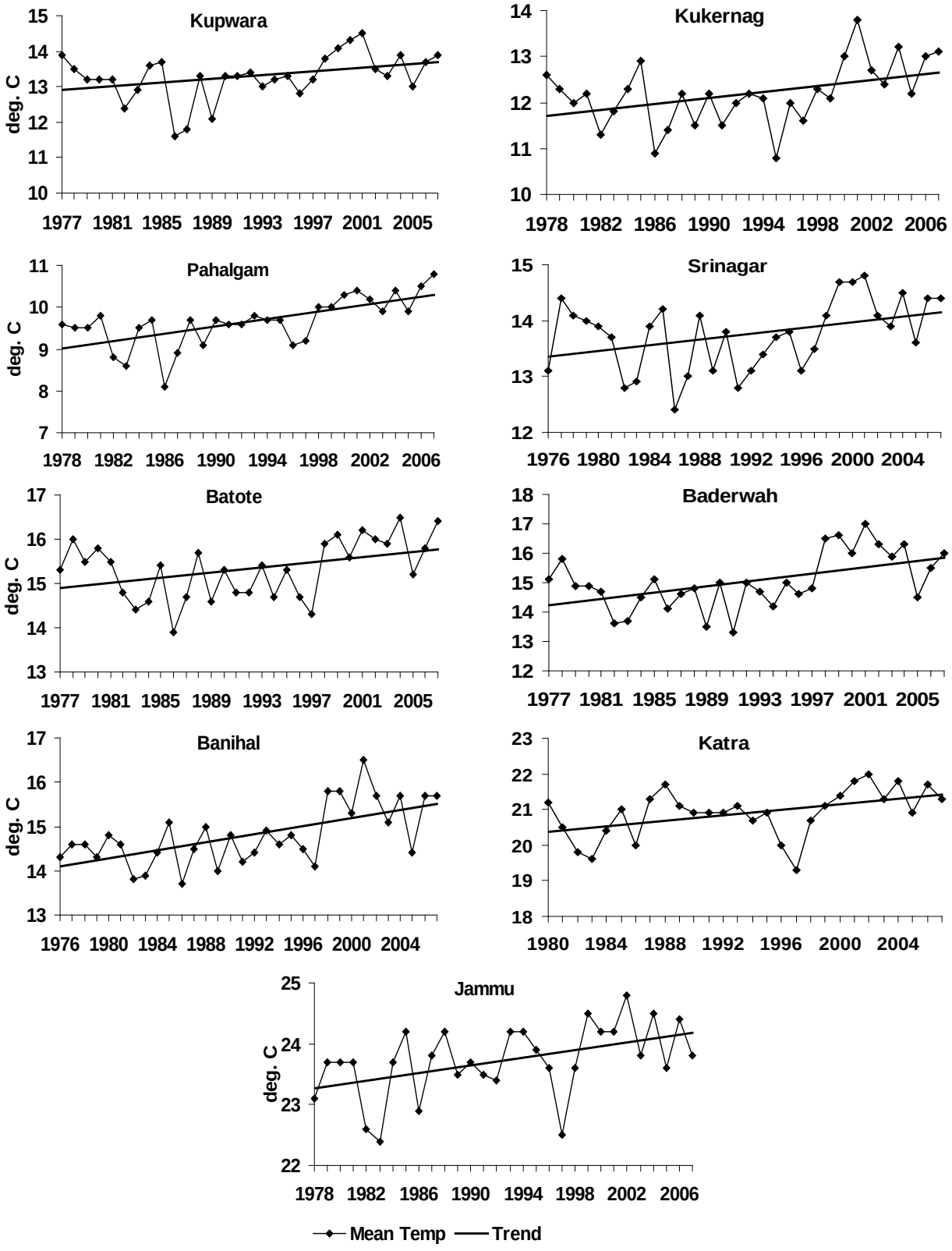

Fig. 4. Annual mean temperature trends for 1976-2007 significant at 95% level

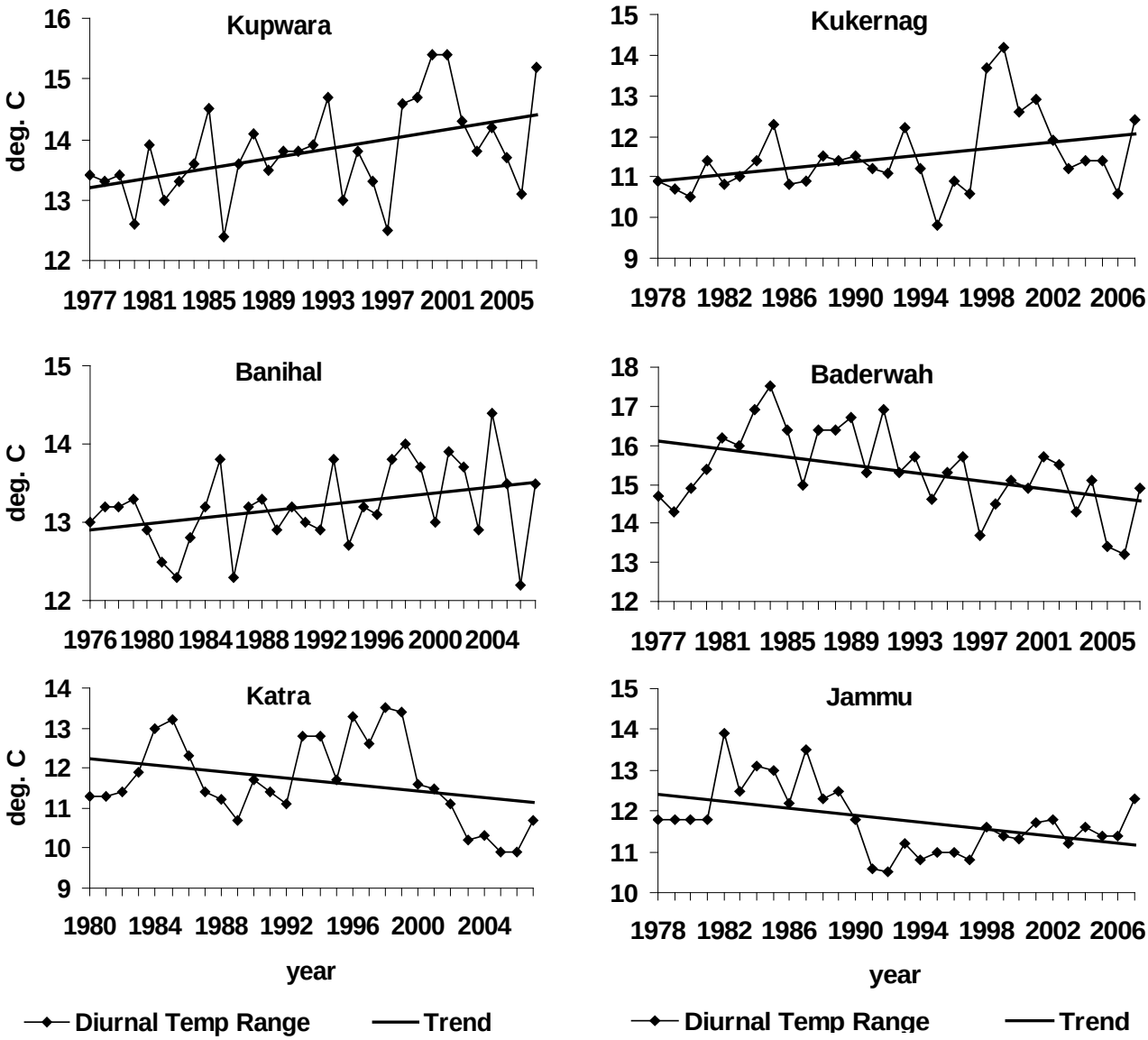

Fig. 5. Annual mean diurnal temperature range trends for 1976-2007 significant at 95% level

Kukernag (+0.03° C/year) and Pahalgam (+0.04° C/year) as shown in Fig. 4. However it is observed from trend values that the maximum temperature is contributing more in the Kashmir region and more rise in minimum temperature is resulting in increase of mean temperature in the Jammu region. It is reported by several investigators that daily minimum temperatures over land have increased at twice the rate of daily maximum temperatures since 1950 (IPCC, 2001).

3.3. *Diurnal temperature range*

Diurnal temperature range is the difference between day-time and night-time temperatures. Changes in DTR are caused by the rapid urbanization leading to growth of the urban heat islands (UHI) in cities around the world (Karl *et al*., 1988; Kalnay and Cai, 2003 and Li *et al*., 2004). Cayan and Douglas (1984) have observed that the urban warming causes more increase in minimum

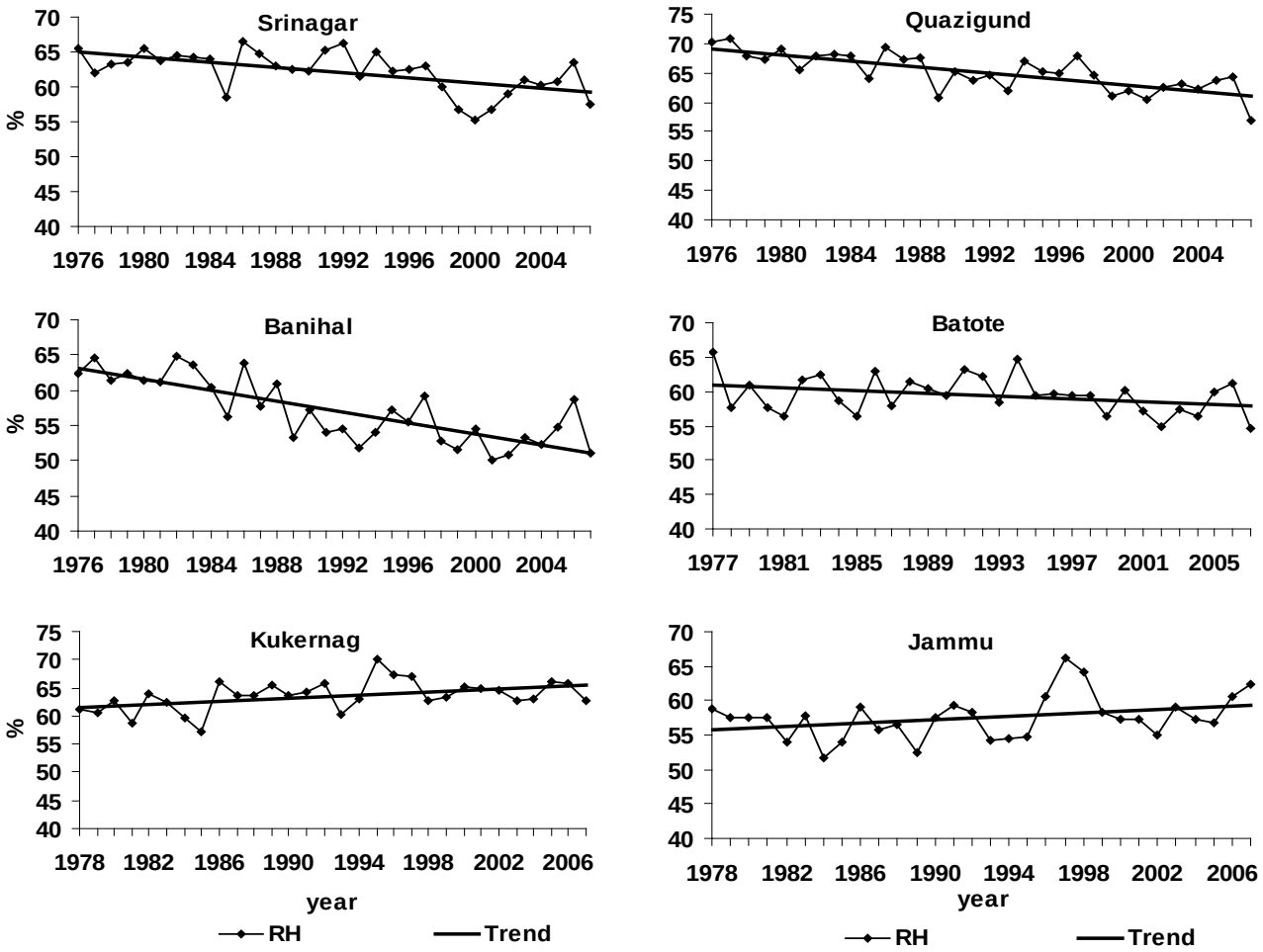

Fig. 6. Annual mean relative humidity trends for 1976-2007 significant at 95% level

temperature to that of maximum temperature. All stations in Kashmir region and Banihal in Jammu region are showing increasing trend in DTR while Batote, Baderwah, Katra and Jammu in Jammu region are showing decreasing trend as shown in Table 3. It is seen from the trends of maximum and minimum temperatures that DTR is increasing over stations in Kashmir region due to more rising trends in the maximum temperature over the region. However higher increasing trend in minimum temperature is contributing more towards the decreasing trend in DTR at stations in Jammu region. Stations having significant trend in DTR are Jammu (-0.04° C/year), Katra (-0.04° C/year), Baderwah (-0.05° C/year), Banihal (+0.02° C/year), Kukernag (+0.04° C/year) and Kupwara (+0.04° C/year) as shown in Fig. 5. Even though Banihal station lies in Jammu region, it is geographically closer to the Kashmir region and thus showing trend similar to the stations in Kashmir region.

3.4. *Relative humidity*

Humidity is an important meteorological and climate variable that affects human comfort and it directly affects the atmospheric visibility, strongly influencing the formation of clouds, fog and smog (Elliot and Angell, 1997). Day-time relative humidity trends are mixed over the state and trend values are in the range -0.38% per year to +0.14% per year. Stations having significant trend are Srinagar (-0.18% per year), Quazigund (-0.26% per year), Banihal (-0.38% per year), Batote (-0.10% per year), Kukernag (+0.14% per year) and Jammu (+0.13% per year) as shown in Fig. 6.

3.5. *Total cloud amount*

Because of their advective properties, clouds are very important in the Earth's climate system. Clouds exert

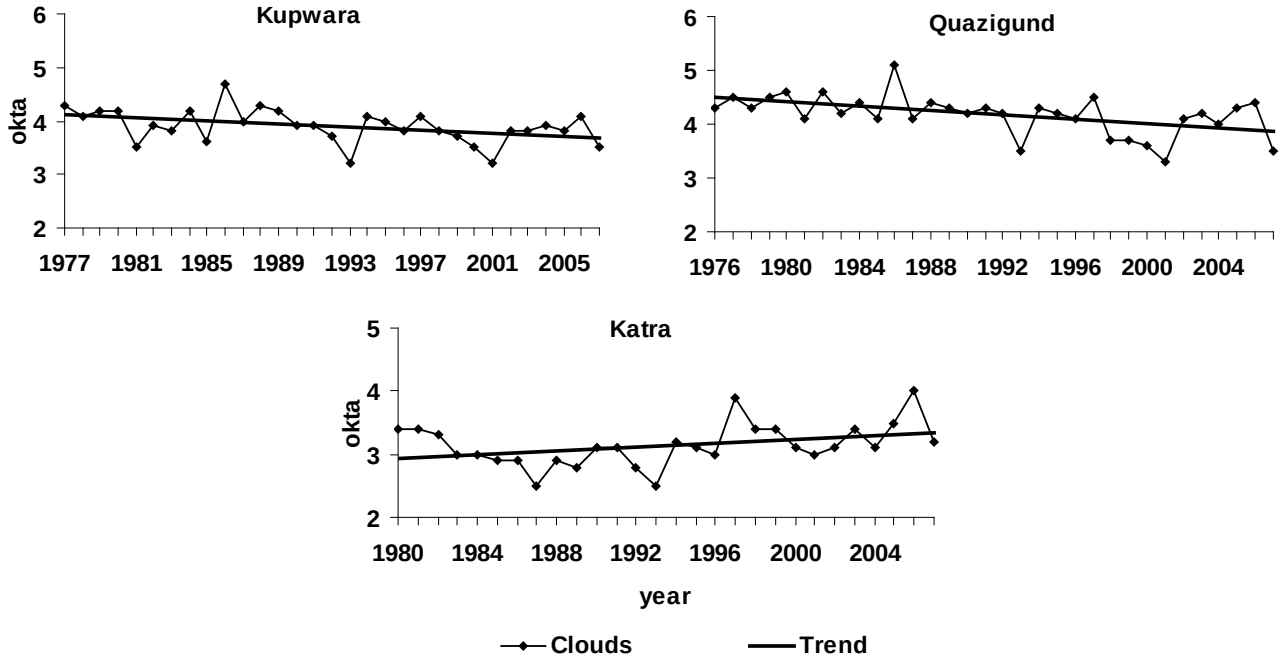

Fig. 7. Annual mean total cloud amount trends for 1976-2007 significant at 95% level

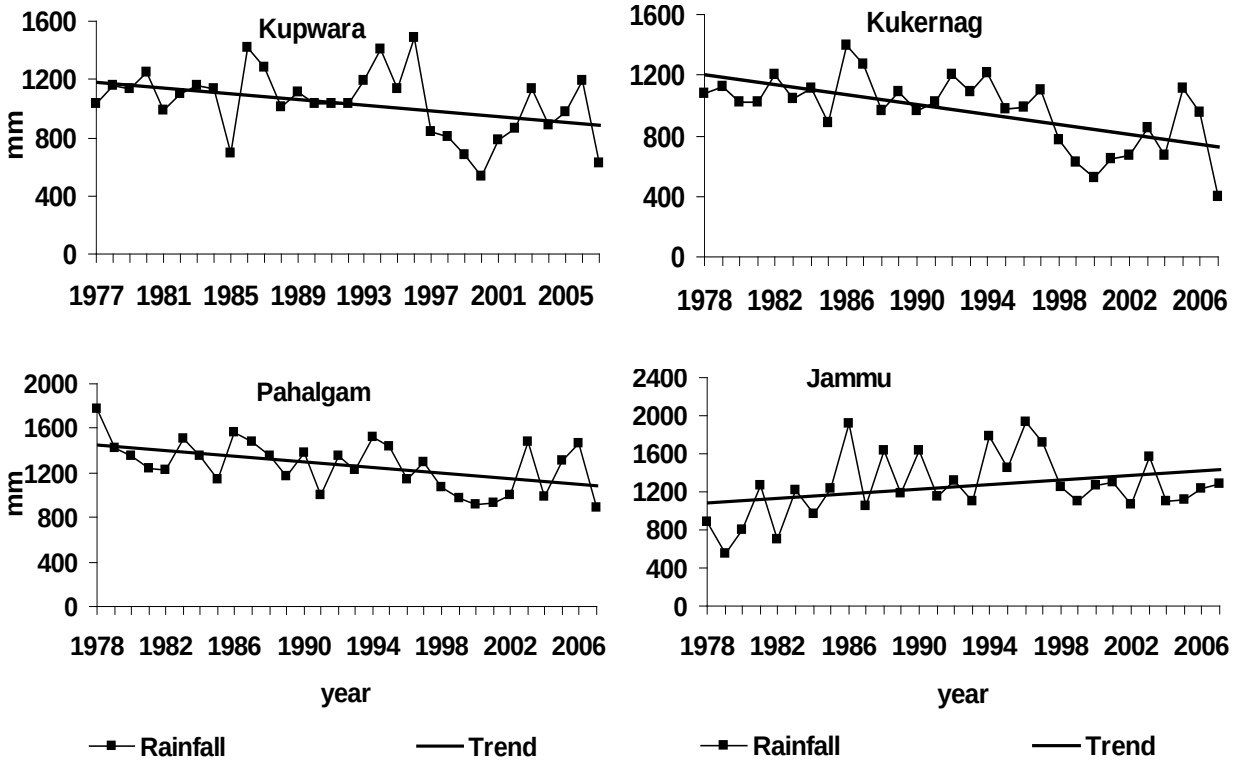

Fig. 8. Annual total rainfall trends for 1976-2007 significant at 95% level

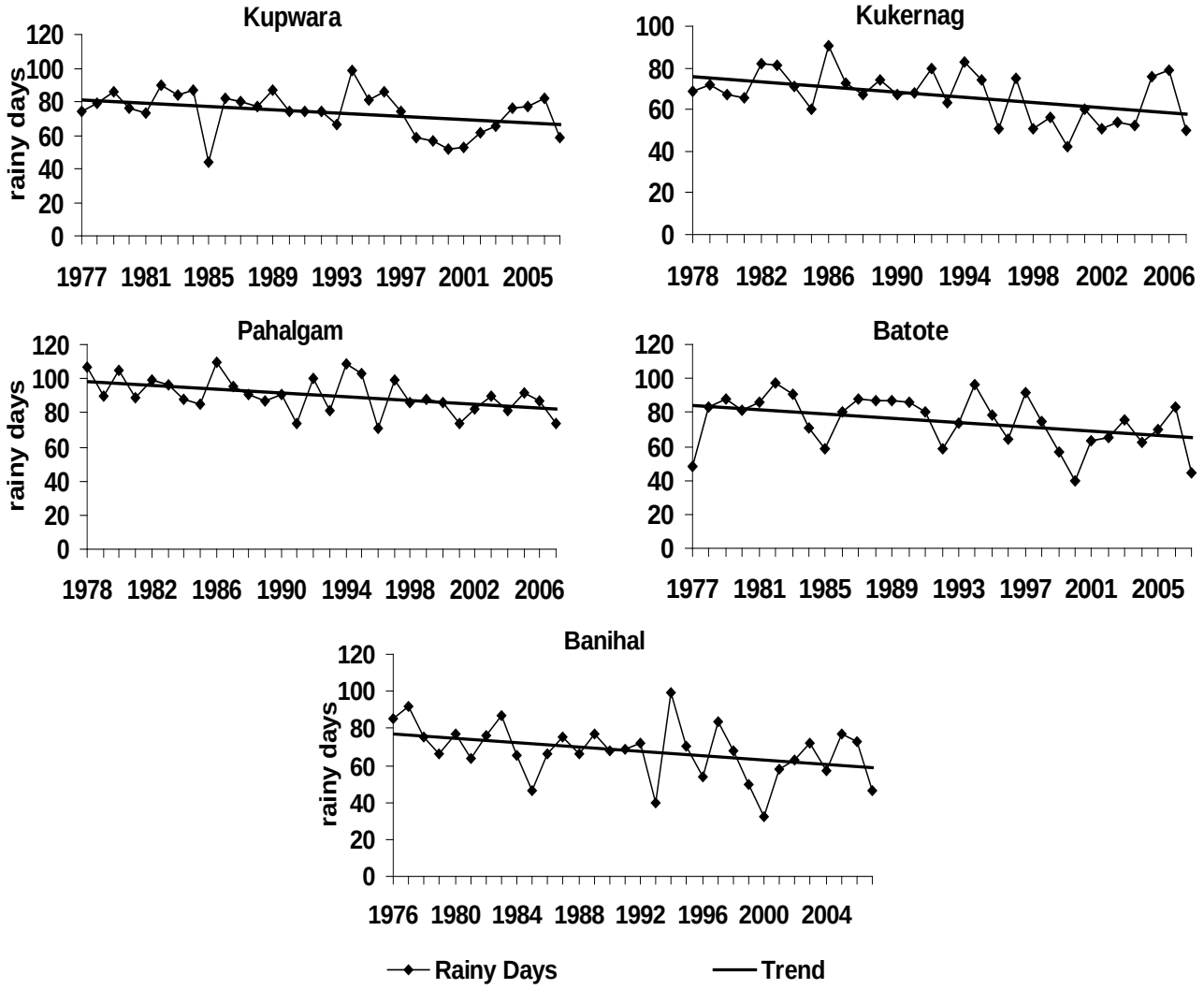

Fig. 9. Annual total rainy days trends for 1976-2007 significant at 95% level

a dominant influence on the energy balance of the earth's climate through the albedo and the greenhouse warming effects (Sun *et al*., 2000). From Table 3, it is seen that in general stations in the Kashmir region are showing decreasing trend in total cloud amount which are similar to trends found over Qinghai-Tibet plateau during 1971-2004 by Zhang *et al*. (2008). Annual mean total cloud amount trends are in the range -0.02 okta per year to +0.02 okta per year (Table 3). Three stations (Srinagar, Pahalgam and Banihal) are showing no trend in annual mean total cloud amount for the study period. Trends are significantly decreasing at Kupwara and Quazigund (-0.02 okta/year) and significantly increasing at Katra (+0.02 okta/year) as shown in Fig. 7.

3.6. *Rainfall and rainy days*

Rainfall is a more easily measured meteorological parameter and as such it has been measured more accurately for a longer time. Along with temperature, rainfall represents the most important parameter of meteorology for any particular region as they can be used as a climatic indicator of the region. All stations except Jammu are showing decrease in rainfall during the study period. The trend values lie between -16.19 mm/year at Kukernag to +12.05 mm/year at Jammu. Fig. 8 shows stations having significant trends in annual rainfall. These are Kupwara (-9.77 mm/year), Kukernag (-16.19 mm/year), Pahalgam (-12.65 mm/year) and Jammu

(+12.05 mm/year). All stations are showing decreasing trend in annual total rainy days. Trends are varying between -0.04 days/year at Katra to -0.64 days/year at Batote. Stations showing significant decreasing trend are Kupwara (-0.50 days/year), Kukernag (-0.62 days/year), Pahalgam (-0.56 days/year), Batote (-0.64 days/year) and Banihal (-0.59 days/year) as shown in Fig. 9. The increase in anthropogenic aerosols in the urban areas may facilitate formation and growth of rain bearing clouds causing enhanced precipitation (De and Rao 2004). The significant increase in annual rainfall and decrease in number of rainy days (though not significant) indicates rise in convective rainfall events over Jammu.

From the results presented above, it is found that temperatures are increasing over both the regions of the state. Maximum temperature is increasing more over Kashmir region while minimum temperature is increasing more over the Jammu region. The rise in temperature over the state is consistent with rise in temperature over northwest Himalaya reported by Bhutiyani *et al*. (2007). There is sharp increase in temperatures in both the regions of the state during later half of 1991-2000 decade which has seen three warmest years (1995, 1997 and 1998) globally (WMO, 2003). DTR is increasing over Kashmir region because of more rise in maximum temperature relative to the minimum temperature which is consistent with the results obtained by Bhutiyani *et al*. (2007). But DTR is decreasing over Jammu region because of higher rise in minimum temperature which can be attributed to urbanization in and around Jammu city. Zhou *et al*. (2004) have estimated 0.05° C per decade warming in mean temperature over China attributable to urbanization. An increased greenhouse effect due to humidity, greenhouse gases, aerosols or clouds is expected to produce a relative increase of minima with respect to maxima and a decrease of the DTR. Taking horizontal visibility as a proxy for presence of aerosols in the atmosphere, De *et al*. (2001) have found sharp decline in atmospheric visibility during winter months over many Indian cities. Minimum DTR is possible due to the presence of clouds which prevent the shortwave solar radiations in the daytime to heat the surface and longwave radiation in the night-time to emit the heat, resulting in lower temperature range. During the period of study, total cloud has decreased over the Kashmir region along with rise in maximum temperature and total cloud has increased over Jammu region accompanied by strong rise in minimum temperature. Consequently, a reduced diurnal temperature range can lead to a variety of impacts, for example on crop regimes, ecosystems and may be on human health.

The monsoon rains over Jammu and Kashmir are uncertain, erratic and highly variable over time and space. Long dry spells before and after monsoons are also common, which adversely affect rain-fed crops and the perennial water sources and cause acute water scarcity. Annual rainfall is decreasing in both the regions of the state except at Jammu where it is significantly increasing. All stations are showing decreasing trend in number of rainy days. With no significant increasing trend in total cloud amount and decreasing (but not significant) trend in rainy days, significantly increasing trend in annual rainfall at Jammu indicates rise in heavy precipitation events. In the tropics where rainfall is convective, increased rainfall may not necessarily be associated with increased general cloudiness.

There are several possible causes for the increase in temperature during the study period but the major factors are urbanization, land-use modification and the associated population growth in the two regions of the state. According to Environmental and Social Assessment report by the Jammu and Kashmir government (http://jammukashmir.nic.in/), large areas around Kashmir villages have been depleted of their forest cover and tree lines are receding to upper peaks. The Shivalik and mid-Himalayan regions are fragile ecosystems and due to topography soil erosions are caused by high intensity rainfall which occurs mostly in the three monsoon months *i.e*., July, August and September. There is sharp increase in population in the two main cities (Srinagar and Jammu) of the state during 1981-2001. According to City Development Plan 2007 for Jammu prepared by National Institute of Urban Affairs, New Delhi, there is steep rise in population in and around Jammu city. While population in Srinagar has increased by 50% during 1981 to 2001, the increase at Jammu is 83% during the same period.

4. Conclusions

This work has been undertaken as an exploratory analysis to determine whether changes in temperature and precipitation over the two regions of Jammu and Kashmir have occurred, and if so, what has been the magnitude of this change. The observational data for the period of study over the state provides a general picture of warming and decrease in precipitation (except at Jammu where rainfall is increasing). The results can be summarized as follows:

(*i*) Annual mean maximum temperature is increasing over Kashmir region (+0.01° C to +0.05° C per year) and is significant at all stations except at Quazigund.

(*ii*) The significant warming trend in minimum temperature over Jammu region (+0.03° C to +0.08° C per year) can be attributed to urbanization which has taken place in the last two decades.

(*iii*) The observed increase in DTR in Kashmir region is resulting from a larger significant increase in maximum temperature (+0.04° C to +0.05° C per year) relative to minimum temperature and the decrease in Jammu region (except Banihal where it is significantly increasing) is resulting from a larger significant increase in minimum temperature relative to maximum temperature.

(*iv*) All stations in the state are having decreasing trend in total number of rainy days and rainfall except at Jammu where rainfall is significantly increasing (+12.05 mm per year).

Increasing temperature and decreasing rainfall trends over the state will adversely affect the availability of water and other natural resources. However, small number of stations and shorter period of data make it difficult to ascertain whether these changes in temperature and rainfall are indeed the result of long-term climatic changes.

Acknowledgements

The authors are thankful to DGM for allowing the lead author to present the preliminary results in the conference.

References

Bhutiyani, M. R., Kale, V. S. and Pawar, N. J., 2007, "Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century", *Climatic Change*, **85**, 159-177.

Cayan, D. R. and Douglas, A. V., 1984, "Urban influences on surface temperatures in the southwestern United States during recent decades", *J. Clim. Appl. Meteor*., **23**, 1520-1530.

De, U. S., Rao, G. S. P. and Jaswal, A. K., 2001, "Visibility over Indian airports during winter season", *Mausam*, **52**, 4, 717-726.

De, U. S. and Rao, G. S. P., 2004, "Urban climate trends-The Indian Scenario", *J. Ind. Geophys. Union*, **8**, 3, 199-203.

De, U. S. and Rajeevan, M., 1997, "Identification of Anthropogenic climate change: A Review", *Vayu Mandal*, **21**, 3-4, 69-82.

Easterling, D. R., Horton, B., Jones, P. D., Peterson, T. C., Karl, T. R., Parker, D. E., Salinger, M. J., Razuvayev, V., Plummer, N., Jamson, P. and Folland, C. K., 1997, "Maximum and Minimum Temperature Trends for the Globe", *Science*, **277**, 364-367.

Elliot, W. P. and Angell, J. K., 1997, "Variations of cloudiness, precipitable water and relative humidity over the United States: 1973-1993", *Geophys. Res. Lett.*, **24**, 41-44.

Giorgi, F., 2002, "Variability and trends of sub-continental scale surface climate in the twentieth century. I - Observations", *Climate Dynam*., **18**, 675-691.

IPCC, 2001, "Climate Change 2001: The scientific basis", Cambridge University Press, Cambridge, U.K.

Jones, P. D., New, M., Parker, D. E., Martin, S. and Rigor, I. G., 1999, "Surface air temperature and its changes over the past 150 years", *Revs. Geophys*., **37**, 173-199.

Jones, P. D., Osborn, T. J., Briffa, K. R., Folland, C. K., Horton, E. B., Alexander, L. V., Parker, D. E. and Rayner, N. A., 2001, "Adjusting for sampling density in grid box land and ocean surface temperature time series", *J. Geophys. Res*., **106**, 3371-3380.

Jones, P. D. and Moberg, A., 2003, "Hemispheric and large-scale air temperature variations: An extensive revision and update to 2001", *J. Climate*, **16**, 206-223.

Kalnay, E. and Cai, M., 2003, "Impact of urbanization and land-use change on climate", *Nature*, **423**, 528-531.

Karl, T. R., Diaz, H. F. and Kukla, G., 1988, "Urbanization: its detection and effect in the United States climate record", *J. Climate*, **1**, 1099-1123.

Karl, T. R., Jones, P. D., Knight, R. W., Kukla, G., Plummer, N., Razuvayev, V., Gallo, K. P., Lindseay, J., Charlson, R. J. and Perterson, T. C., 1993, "Asymmetric trends of daily maximum and minimum temperature", *Bull. Am. Meteorol. Soc*., **74**, 1007-1023.

Kothawale, D. R. and Rupa Kumar, K., 2005, "On the recent changes in surface temperature trends over India", *Geophys. Res. Lett*., **32**, L18714, doi:10.1029/2004GL023528.

Li, Q., Zhang, H., Liu, X. and Huang, J., 2004, "Urban heat island effect on annual mean temperature during the last 50 years in China", *Theor. Appl. Climatol*., **79**, 165-174.

New, M., Hulme, M. and Jones, P. D., 2000, "Representing twentieth century spac-time climate variability. Part II : Development of 1901-96 monthly grids of terrestrial surface climate", *J. Climate*, **13**, 2217-2238.

New, M., Todd, Hulme, M. and Jones, P. D., 2001, "Precipitation measurements and trends in the twentieth century", *Int. J. Climatol*., **21**, 1899-1922.

Roy, S. S. and Balling Jr., R. C., 2005, "Analysis of trends in maximum and minimum temperature, diurnal temperature range, and cloud cover over India", *Geophys. Res. Lett.*, **32**, L12702, doi:10.1029/2004GL022201.

Rupakumar, K., Krishnakumar, K. and Pant, G. B., 1994, "Diurnal asymmetry of surface temperature trends over India", *Geophys. Res. Lett*., **21**, 8, 677-680.

Sahai, A. K., 1998, "Climate change: A case study over India", *Theor. Appl. Climatol*., **61**, 9-18.

Sen Roy, N. and Prasad, K., 1991, "Climate change and global scientific response", *Vayu Mandal*, **21**, 3-4, 69-82.

Sinha Ray, K. C., Mukhopadhyay, R. K. and Chowdhury, S. K., 1997, "Trends in maximum and minimum temperatures and sea level pressure over India", INTROMET, New Delhi.

Srivastava, H. N., Dewan, B. N., Dikshit, S. K., Rao, G. S. P, Singh, S. S. and Rao, K. R., 1992, "Decadal trends in climate over India", *Mausam*, **43**, 7-20.

Sun, B., Groisman, P. Ya., Bradley, R. S. and Keimig, F. T., 2000, "Temporal changes in the observed relationship between cloud cover and surface air temperature", *J. Climate*, **13**, 4341-4357.

WMO, 2003, "World Meteorological Day 2003 : Our future Climate", WMO Bulletin, **1.**

Zhang, J. Y., Dong, W. J., Wu, L. Y., Wei, J. F., Chen, P. Y. and Lee, D. K., 2005, "Impact of land use changes on surface warming in China", *Adv. Atmos. Sci.*, **2**, 169-189.

Zhang, X., Peng, L., Zheng, D. and Tao, J., 2008, "Cloudiness variations over the Qinghai-Tibet Plateau during 1971-2004", *Jou. Geog. Sci.*, **18**, 2, 142-154.

Zhou, L., Dickinson, R. E., Tian, Y., Fang, J., Li, Q., Kaufmann, R. K., Tucker, C. J. and Myneni, R. B., 2004, "Evidence for a significant urbanization effect on climate in China", *Proc. Natl. Acad. Sci.*, **101**, 9540-9544.