Recent winter warming over India – spatial and temporal characteristics of monthly maximum and minimum temperature trends for January to March

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सार – इस शोध पत्र में जनवरी से मार्च माह के मासिक माध्य अधिकतम और न्यूनतम तापमानों में दीर्घ अवधि भिन्नताओं और प्रवृत्तियों की सूचनाओं को तैयार करने के लिए भारत में हाल ही की गर्म ऋतुओं के दौरान तापमान में गिरावट को देखते हुए देश के सुवितरित 174 स्टेशनों की तापमान श्रेणियों का सांख्यिकीय विश्लेषण किया गया। इस प्रवृत्ति का विश्लेषण करने से यह पता चला है कि उत्तरी भारत में फरवरी का महीना शीत ऋतु का सबसे गर्म महीना है जिसके अधिकतम तापमान में असाधारण वृद्धि दक्षिण भारत की औसतन वृद्धि के 1.5 गुणा अधिक होने के साथ–साथ अधिकतम (+0.29°से./दशक) और नयूनतम (+0.38°से./दशक) दोनों तापमानों में सबसे अधिक वृद्धि हुई है। स्थानिक रूप से उत्तरी भारत में फरवरी और मार्च के महीने में न्यूनतम तापमान की प्रवृत्तियों और दक्षिण भारत के सभी महीनों में अधिकतम तापमान की प्रवृत्तियों में अधिक सुसंगतता पाई गई है।

भारत–गांगेय के मैदानी भागों और दक्षिण प्रायद्वीप में दिन के समय और रात्रि के समय दोनों में कुल मेघ राशि में उल्लेखनीय रूप से वृद्धि हो रही है तथा सुदूर मध्य और पूर्व भारत में उल्लेखनीय रूप से कमी हो रही है। तथापि जनवरी और मार्च के महीने में सुदूर दक्षिणी प्रायद्वीप के तापमानों में हुई वृद्धि को अन्य जलवायविक कारकों के प्रबल प्रभावों वाले दिन के समय की कुल मेघ राशि में हुई वृद्धि के आधार पर बताना कठिन है। इसी समय अरब सागर और बंगाल की खाड़ी के समुद्र सतह तापमानों में वृद्धि होती है और भू–सतह तापमानों ओर समुद्र सतह तापमानों के मध्य संबंध प्रबल सकारात्मक होते है जिसके परिणाम स्वरूप समुद्र जल के गर्म होने का पता चलता है। इसके कारण निकटवर्ती क्षेत्रों में प्रमुख जलवायविक प्रभाव पड़ सकते हैं।

ABSTRACT. In the backdrop of recent warmer winters over India, temperature series of 174 stations well distributed over the country were statistically analyzed to document the long term variations and trends in monthly mean maximum and minimum temperatures for January to March. From the trend analysis, February month has emerged as the warmer winter month over North India where increase in both maximum (+0.29° C / decade) and minimum (+0.38° C / decade) temperatures is highest with noteworthy increase in maximum temperature at a rate 1.5 times that of the South India averaged increase. Spatially, North India minimum temperature trends for February and March and South India maximum temperature trends for all months are more coherent.

Both day-time and night-time total cloud amounts are increasing significantly over Indo-Gangetic plains and south peninsula and decreasing significantly in central and east India. However increase in temperatures over extreme south peninsula in January and March is difficult to explain on the basis of increase in day-time total cloud amount indicating strong influence of other climatic factors. At the same time, sea surface temperatures of the Arabian Sea and the Bay of Bengal are rising and there is strong positive correlation between land surface temperatures and sea surface temperatures suggesting significant contribution of warmer sea waters which may have important climatic implications over neighbouring regions.

Key words − Maximum temperature, Minimum temperature, Total cloud amount, Trends, Rabi season, Sea surface temperature.

1. Introduction

Since the 1990s, the abnormal climate events have occurred frequently along with the global warming.

Among them the warmer winters have drawn much attention world over as well as in India. A number of evidences show that the frequent occurrence of warmer winters have directly affected the agriculture, horticulture,

ecosystems, human and animal health. Warm temperatures create an environment in which plant diseases and pests thrive and pose a serious threat to rabi crops. The effect of increasing winter temperatures on rabi crops (wheat, barley, mustard and chickpea) was studied by Kalra *et al.* (2008) who have found signs of stagnation or decrease in yield following rise in temperature at four northern states of India (Punjab, Haryana, Rajasthan and Uttar Pradesh). Also climate changes alter the pattern of blossoming, bearing and the fruit yield of winter season fruit crops. The lack of early cold in December and January adversely affects the chilling requirements of apple, apricot, peach, almond and pear. A chilling requirement averaging ten weeks below 5° C is required to meet the internal conditions necessary for bud-break with the onset of spring temperatures as noted by Abbot (1984).

Out of a wide range of meteorological variables, land surface temperatures are frequently cited as the potential indicator of climate change. Surface temperature trends over India have been studied by number of researchers (Hingane *et al.*, 1985; Sarker and Thapliyal, 1988; Thapliyal and Kulshreshtha, 1991; Srivastava *et al.*, 1992; Rupa Kumar *et al.*, 1994; De and Rajeevan, 1997 and Sahai, 1998) and in general, warming trends in maximum and minimum temperatures over India were noted by them. Some of the recent studies have found strong increasing trends in temperatures over India especially during the last three decades. Kothawale and Rupa Kumar (2005) have found a relatively accelerated significant warming trend of 0.22° C / decade in all-India mean annual temperature for the period 1971-2003. Dash *et al.* (2007) have found increase by 1° C in winter maximum temperature over India during 1901-2003 and have noted sharp decrease in minimum temperature over north India between 1955 and 1972 and sharp increase there after. 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.

The Indian subcontinent divides the north Indian Ocean into two basins, the Arabian Sea and the Bay of Bengal. Greenhouse warming not only increases the air temperature, but also increases sea surface temperature (Manabe and Stouffer, 1980). According to IPCC (2001) the increase in sea surface temperature is about half that of land surface temperature increase. Among many different factors affecting the overall climate, sea surface temperatures are expected to influence the atmospheric circulation on a regional to global scale (Kumar *et al.* 2004).
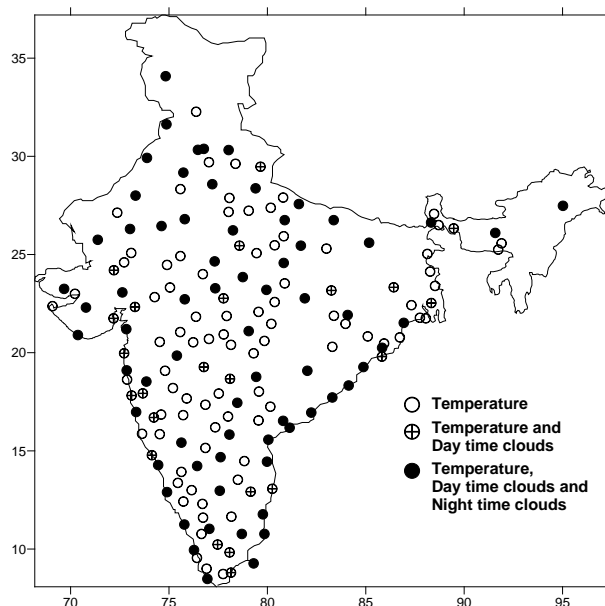

Fig. 1. Location of stations having temperature and cloud data used in the study

All previous studies on temperature trends over India have focused either on annual or seasonal scale but missing important changes on monthly scale. In this study, both maximum and minimum temperatures were examined month wise for January to March and spatial and temporal features of long term changes on monthly scale were brought out. Further, the influence of total cloud amount and sea surface temperature of the Arabian Sea and the Bay of Bengal on land surface temperatures were also examined.

2. Data and methodology

Long term changes in monthly mean temperatures for the period 1970-2007 were examined by studying trends in mean maximum and mean minimum temperatures for January to March based upon 174 stations well distributed over India as shown in Fig. 1. The monthly maximum and minimum temperatures data for these stations were taken from National Data Center (NDC) of India Meteorological Department (IMD), Pune. All India, North India (north of 20° N) and South India (south of 20° N) average anomalies (from 1961-1990 average) of mean maximum and minimum temperatures were prepared for 1970-2007. It may be noted here that out of 174 stations selected for this study, 101 stations fall in North India while 73 stations belong to South India. The effects of cloud amount on surface temperatures were examined by calculating day-time and night-time total cloud amount trends. Surface observations of total cloud

TABLE 1

Mean maximum and mean minimum temperature trends for 1970-2007. Trends significant at 95% level of confidence are shown in bold

| Month	Mean Maximum (°C/decade)			Mean Minimum (°C/decade)		
	All India	North India	South India	All India	North India	South India
January	+ 0.05	- 0.06	**+ 0.22**	+ 0.12	+ 0.08	+ 0.17
February	**+ 0.25**	**+ 0.29**	**+ 0.19**	**+ 0.23**	**+ 0.38**	+ 0.01
March	+ 0.09	+ 0.04	**+ 0.14**	**+ 0.16**	**+ 0.22**	+ 0.07

TABLE 2

Percentage of stations having increasing/decreasing trends in mean maximum temperature and mean minimum temperature for 1970-2007

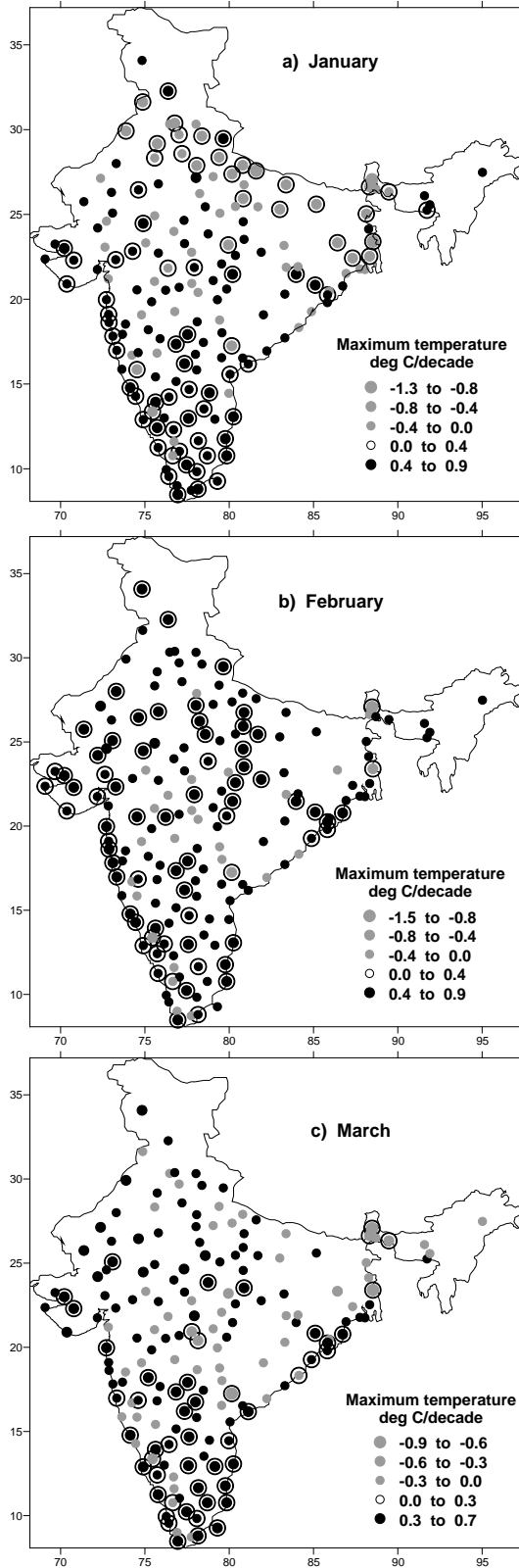|	Mean maximum temperature						Mean minimum temperature					
	Increasing			Decreasing			Increasing			Decreasing		
	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
All India	61	84	60	39	16	40	68	70	68	32	30	32
North India	47	86	63	53	14	37	60	78	71	40	22	29
South India	82	81	55	18	19	45	78	58	63	22	42	37
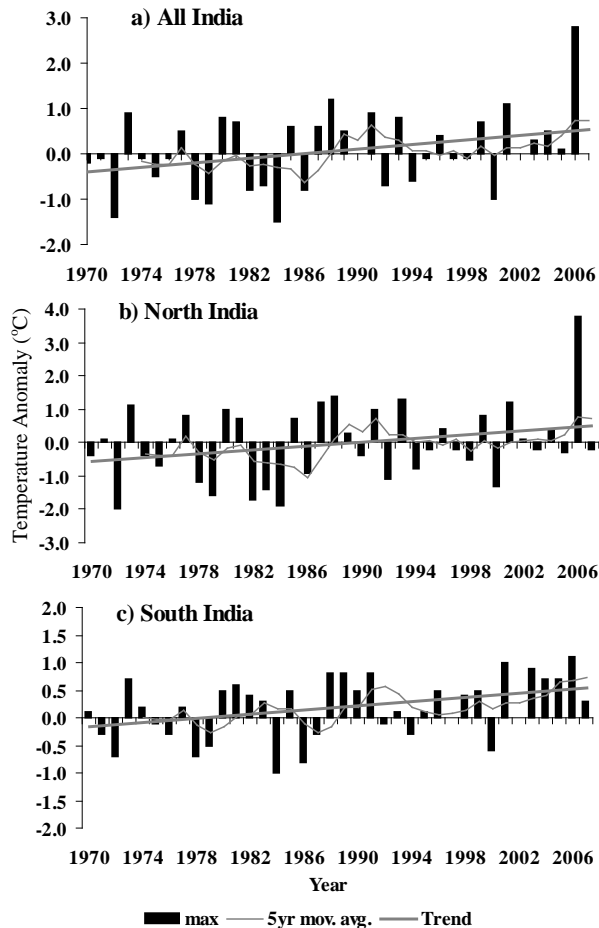
Figs. 2(a-c). Mean maximum temperature trends for February for (a) all India and (b) North India and (c) South India significant at 95% level of confidence. Data series are anomalies from 1961-1990 average
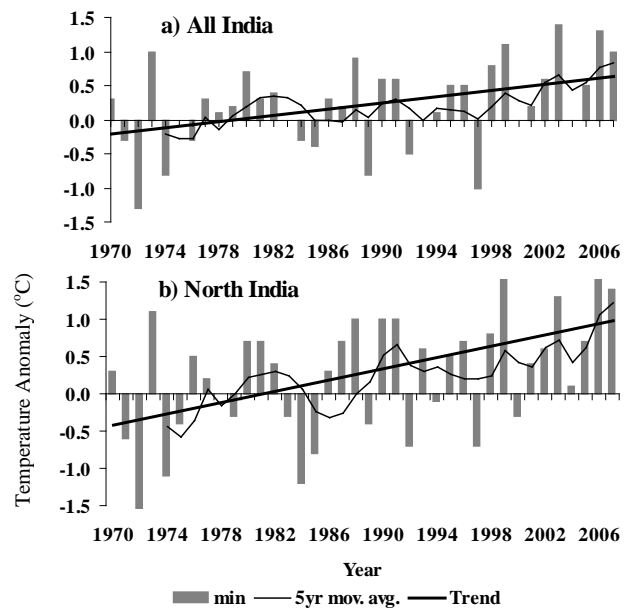

Figs. 3(a&b). Mean minimum temperature trends for February for (a) all India and (b) North India significant at 95% level of confidence. Data series are anomalies from 1961-1990 average

amount recorded at 0300, 0600, 0900 and 1200 UTC were used for preparing mean day-time total cloud amount and observations recorded at 1500, 1800, 2100 and 0000 UTC were taken for mean night-time total cloud amount. Mean day-time and night-time total cloud amount (in okta) were prepared for only those stations which recorded at least

Figs. 4(a-c).   Spatial patterns of mean maximum temperature trends for January to March based upon 1970-2007 data. Trends significant at 95% are shown by outer circle
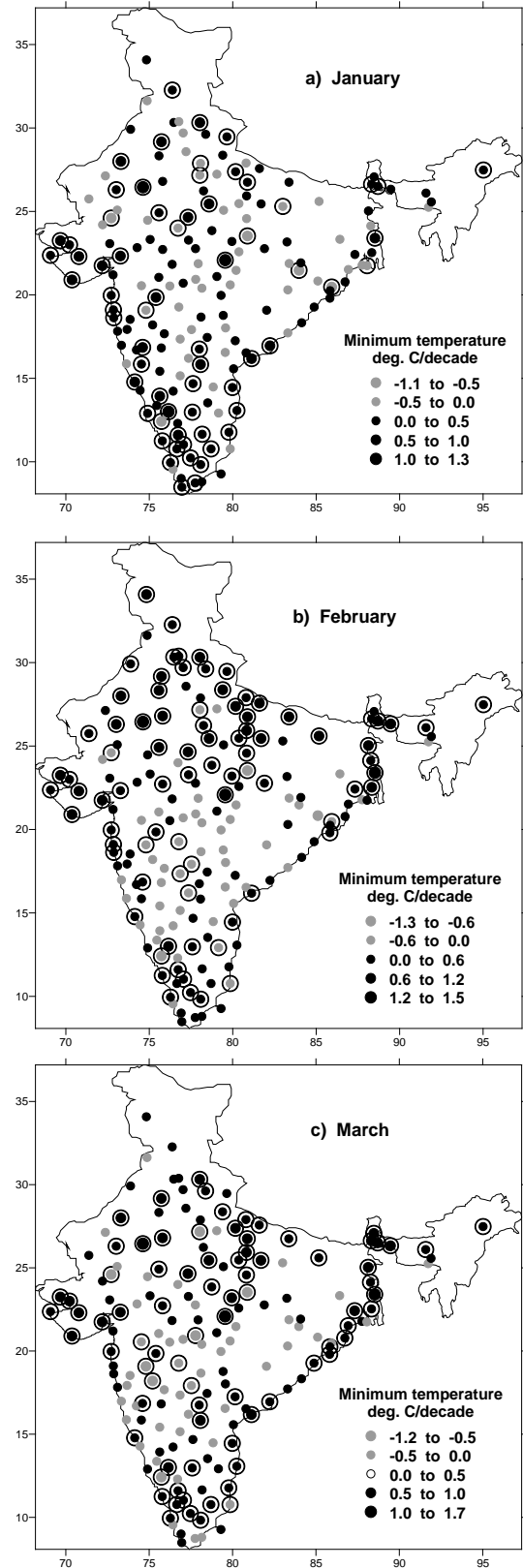
Figs. 5(a-c).   Same as in Figs. 4(a-c) but for mean minimum temperature

three out of four possible observations. Out of 174 stations under study, 93 and 70 stations satisfied this criterion for day-time and night-time total cloud amount respectively and locations of these stations are shown in Fig. 1.

Linear trend analysis by the method of least square was used in this study and the trends were tested at 95% level of confidence using Student's t-test. All India, North India and South India averaged maximum and minimum temperature trends for January to March are given in Table 1 while percentage of number of stations showing increasing (decreasing) trends are shown in Table 2. The temporal variations of all India, North India and South India mean maximum temperature for February significant at 95% are shown in Figs. 2(a-c). All India and North India mean minimum temperature variations for February significant at 95% are shown in Figs. 3(a&b). Spatial pattern of monthly trends in maximum temperature, minimum temperature, day-time total cloud amount and night-time total cloud amount are shown in Figs. 4(a-c) to Figs. 7(a-c).

The effects of sea surface temperature (SST) of the Arabian Sea and the Bay of Bengal on land surface temperatures were examined by using SST data recorded by ships which were obtained from the archives of NDC. The SST anomalies from 1961-1990 average were calculated for the Arabian Sea (7° - 24° N, 63° - 75° E) and the Bay of Bengal (7° - 21° N, 78° - 92° E) for January to March for 1970-2007. Temporal variations of SSTs and all India, North India and South India averaged maximum and minimum temperatures significant at 95% level are shown in Figs. 8 to 11.

3. Results and discussion

3.1. *All India, North India and South India averaged trends*

All India, North India and South India averaged trends in mean maximum and mean minimum temperatures for January to March are shown in Table 1. All India mean maximum temperature trends are significant for February (+0.25° C / decade). The warmest February month during 1970-2007 was 2006 which had mean maximum temperature 2.8° C above the 1961-1990 average as shown in Fig. 2(a). Mean maximum temperature trends for North India are decreasing for January and increasing for February and March and the trend is significant for February (+0.23° C / decade) as shown in Fig. 2(b). It is interesting to note that since 1995, North India mean maximum temperature anomalies for January (Fig. not included) were negative on 10 occasions which coincided with years of poor horizontal visibility
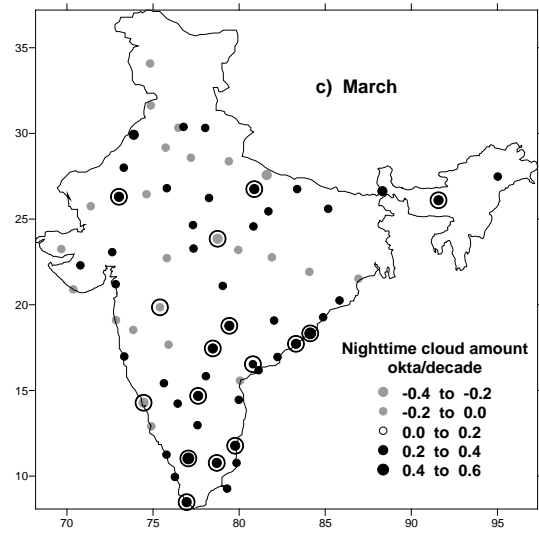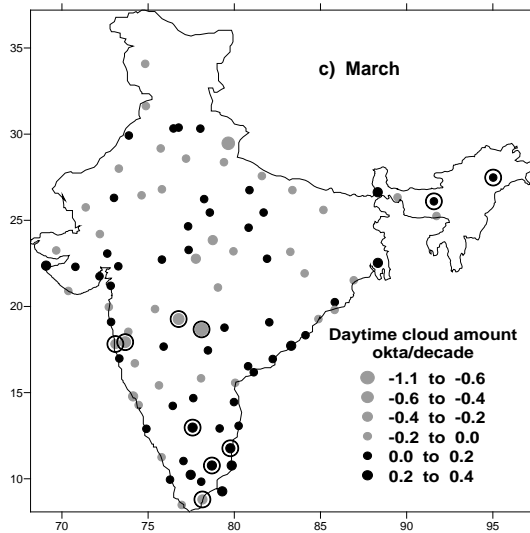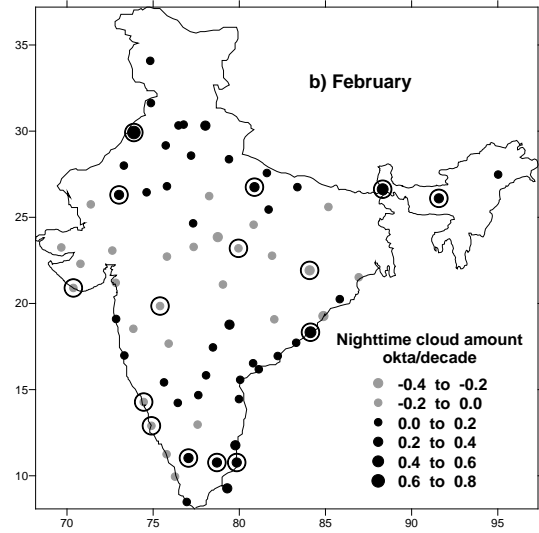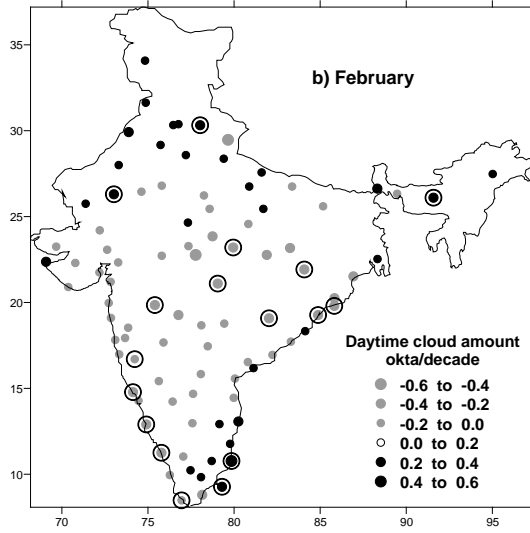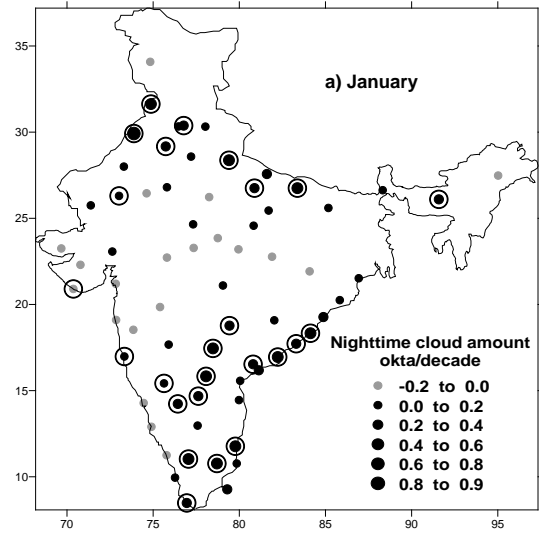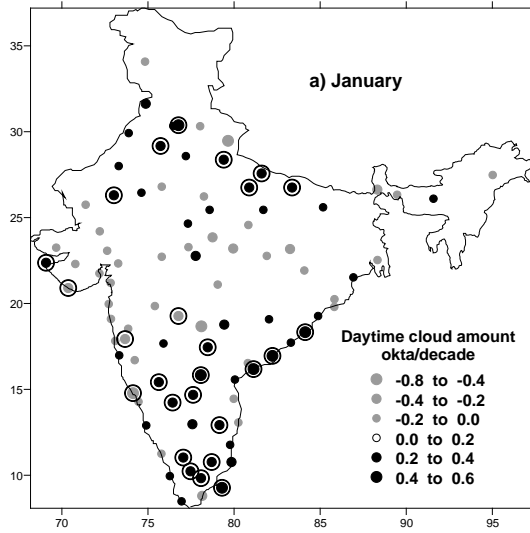
(De *et al*., 2001) and decline in incoming solar radiation (Kumari *et al*., 2007). The lowest mean maximum temperature for North India for January was in 1998 with mean maximum temperature 1.3° C below normal. South India averaged mean maximum temperatures are showing significant increasing trends for all three months and the trend values are +0.22° C / decade (January), +0.19° C / decade (February) and +0.14° C / decade (March). The temporal variations of South India mean maximum temperature for January to March [Fig. 2(c)] indicates steady rise in temperature from 1990s except on three occasions (1992, 1994 and 2000) when anomalies were negative.

All India averaged minimum temperature trends are significantly positive for February (+0.23° C / decade) and March (+0.16° C / decade) as listed in Table 1 and temporal variations indicate steady rise in temperature during last two decades [Figs. 3(a&b)]. Similar to all India trends, North India averaged mean minimum temperature trends are significant for February (+0.38°C/decade) and March (+0.22° C / decade). Temporal variations of minimum temperature for February and March over North India indicate warming since mid 1990s which is similar to results obtained by Dash *et al*. (2007).

3.2. *Spatial patterns of monthly trends*

3.2.1. *Mean maximum temperature*

Out of 174 stations under study, numbers of stations showing increasing trends during January to March are 61%, 84% and 60% respectively as given in Table 2. Spatial patterns of trends suggest overall significant warming over coastal and peninsular India [Figs. 4(a-c)]. Stations in the Indo-Gangetic plains are having significant decrease in maximum temperature during January as shown in Fig. 4(a) which can be attributed to decrease in day time heating of the atmosphere due to increase in fog events over the region as reported by De *et al*. (2001) and Jenamani (2007). All stations in the Indo-Gangetic plains have significant decrease in maximum temperature for January and the highest decrease has occurred at Krishnanagar (-1.2° C / decade) in the Gangetic West Bengal. It is interesting to note that hill stations Dharamshala and Mukteswar in North India are having significant increase in maximum temperature (+0.64° C / decade and +0.46° C / decade respectively) for January. The highest increase in maximum temperature over south India for January has occurred at Raichur (+0.8° C / decade). Trends of maximum temperature for February indicate overall strong warming over India where 84% stations are reporting increase in temperature as given in Table 2. The spatial distribution of trends for February indicates significant warming over north, central and

Figs. 6(a-c). Same as in Figs. 4(a-c) but for daytime total cloud amount.

Figs. 7(a-c). Same as in Figs. 4(a-c) but for nighttime total cloud amount

	January		February		March	
	Arabian Sea SST	Bay of Bengal SST	Arabian Sea SST	Bay of Bengal SST	Arabian Sea SST	Bay of Bengal SST
All India T_{MAX}	**+ 0.34**	+ 0.03	**+ 0.38**	**+ 0.38**	+ 0.15	- 0.11
North India T_{MAX}	+ 0.11	- 0.18	**+ 0.30**	+ 0.26	+ 0.09	- 0.20
South India T_{MAX}	**+ 0.61**	**+ 0.37**	**+ 0.50**	**+ 0.59**	+ 0.24	+ 0.17

peninsular India [Fig. 4(b)] and the highest trend values are found at Srinagar (+0.86° C / decade), Nimach (+0.73° C / decade) and Raichur (+0.74° C / decade) respectively. Spatial patterns of trends for March are weak and mixed over north and central India [Fig. 4(c)] while trends are significantly decreasing at some stations in northeast India. It may be noted that trends are significantly increasing over stations in south peninsula where highest increase of +0.69° C / decade is found at Raichur.

3.2.2. *Mean minimum temperature*

Trends for January are increasing at 68% stations (Table 2) out of which 46% stations are showing significant increase in minimum temperature. Almost all coastal stations are showing significant increasing trend. Stations showing more than 1° C / decade rate of increase in minimum temperature for January are Seoni, Hassan and Ajmer. Spatial patterns of trends for January show increase over large regions in north, northeast, west and south India while some pockets over these regions have decreasing trends as shown in Fig. 5(a). Trends for February are increasing at 70% of stations and stations having higher increase in minimum temperature are Ajmer (+1.48° C / decade), Krishnanagar (+1.44° C / decade), Seoni (+1.34° C / decade) and Bikaner (+1.12° C / decade). Spatial patterns of trends for February show significant increase in northern half of India and extreme south peninsula while stations in north peninsula are showing decrease in minimum temperature [Fig. 5(b)]. Mean minimum temperature trends for March are increasing at 68% stations and the trend values lie between -1.13° C / decade and +1.65° C / decade. Fig. 5(c) shows spatial patterns of trends for March which are almost similar to patterns of February.

3.2.3. *Day-time total cloud amount*

Cloud amount variations significantly alter the heat balance of the earth's climate system while effects of

clouds on the earth's radiation budget are generally negative in the day-time but positive at night. Out of 93 stations reporting day-time clouds, 48 stations reported increase for January which is significant for 22 stations. Spatial patterns of trends for January indicate significant increase in the Indo-Gangetic plains and south peninsula and decrease over central and east India and north peninsula as shown in Fig. 6(a). The trend values for January range between -0.8 okta/decade at Karwar and +0.49 okta/decade at Pamban. The increase in day-time total cloud amount over Indo-Gangetic plains in January is in agreement with decrease in maximum temperature but increase in maximum temperature over south peninsula is difficult to explain as there is increase in day-time cloud amount over the region. Trends for February are decreasing at 68% stations and geographically these stations are spread over all regions of the country except in northwest and along the eastern coast as shown in Fig. 6(b). The trends obtained are compatible with increasing trends in maximum temperature over these regions. Stations having significant decrease are located in central and adjoining east India where trends are in the range -0.34 okta/decade and -0.27 okta/decade. Trends in day-time total cloud amount for March are mixed and range between -1.04 okta/decade at Nizamabad and +0.32 okta/decade at Kolkata. Spatial patterns of trends for March [Fig. 6(c)] indicate strong increase over northeast (+0.17 okta/decade at Guwahati) and extreme south peninsula (+0.23 okta/decade at Cuddalore) and decrease over north and central India which agrees with corresponding changes in maximum temperature.

3.2.4. *Night-time total cloud amount*

Increase in minimum temperature is possible due to the presence of clouds during night which prevent longwave radiation to emit the heat, resulting in higher minimum temperature. Night-time total cloud amount for January are increasing at 70% stations. Spatial distribution of trends for January [Fig. 7(a)] indicates significant increase over Indo-Gangetic plains and south peninsula.
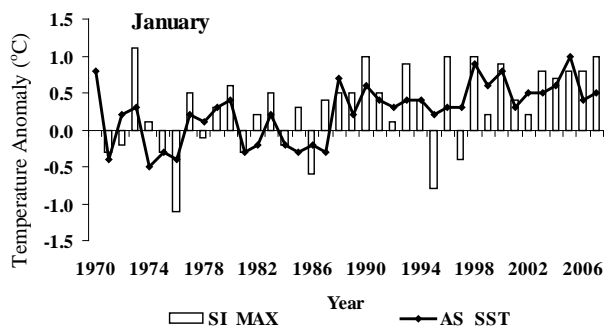
Fig. 8. Temporal variations of mean maximum temperature of South India (SI_MAX) and sea surface temperature of Arabian Sea (AS_SST) for January for 1970-2007. Data series are anomalies from 1961-1990 average
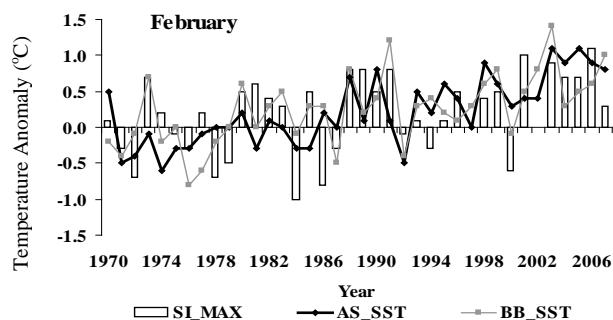

Fig. 9. Temporal variations of mean maximum temperature of South India (SI_MAX) and sea surface temperature of Arabian Sea (AS_SST) and Bay of Bengal (BB_SST) for February for 1970-2007. Data series are anomalies from 1961-1990 average

TABLE 4

Correlation between land surface mean minimum temperature (T_{MIN}) and sea surface temperature (SST) of Arabian Sea and Bay of Bengal. Correlation values significant at 95% level of confidence are shown in bold

	January		February		March	
	Arabian Sea SST	Bay of Bengal SST	Arabian Sea SST	Bay of Bengal SST	Arabian Sea SST	Bay of Bengal SST
All India T_{MIN}	+ 0.29	+ 0.11	**+ 0.69**	**+ 0.62**	**+ 0.49**	+ 0.03
North India T_{MIN}	+ 0.24	0	**+ 0.70**	**+ 0.54**	**+ 0.39**	- 0.03
South India T_{MIN}	+ 0.25	+ 0.24	+ 0.26	**+ 0.38**	**+ 0.44**	+ 0.22

The highest increase in Indo-Gangetic plains is at Sriganganagar (+0.84 okta/decade) and in south peninsula is at Kakinada (+0.59 okta/decade). For February, 53% stations are having increasing trends and the significant increasing trends range between +0.2 okta/decade and +0.77 okta/decade. Spatial patterns of trends for February indicate increase over northwest, northeast and extreme southeast peninsula while large parts over central and southwest India are showing decreasing trends as shown in Fig. 7(b) which agrees with changes in minimum temperature over these areas. 60% stations are showing increasing trends for March and spatial patterns of trends indicate increase over northwest and northeast India and southeast peninsula as shown in Fig. 7(c). Night-time total cloud amount trends are decreasing over some pockets in north, east and southwest India. The increasing (decreasing) trends in night-time clouds are in close agreement with increase (decrease) of minimum temperature.

3.3. *Arabian Sea and Bay of Bengal Sea Surface Temperature correlation*

Tables 3 shows correlations between all India, North India and South India averaged maximum temperatures and SST of Arabian Sea (AS) and Bay of Bengal (BB) for January to March. All India averaged maximum temperature is having significant positive correlation with SST of AS for January and February and with SST of BB for February. North India averaged maximum temperature is having significant positive correlation with SST of AS for February. South India averaged maximum temperature is showing significant positive correlation with SST of AS and BB for January and February. The highest positive correlation (+0.6) is found between South India maximum temperature and SSTs of AS (January) and BB (February) as given in Table 3. Temporal variations of South India maximum temperature and SST of AS for January as anomalies from 1961-1990 averages are having strong
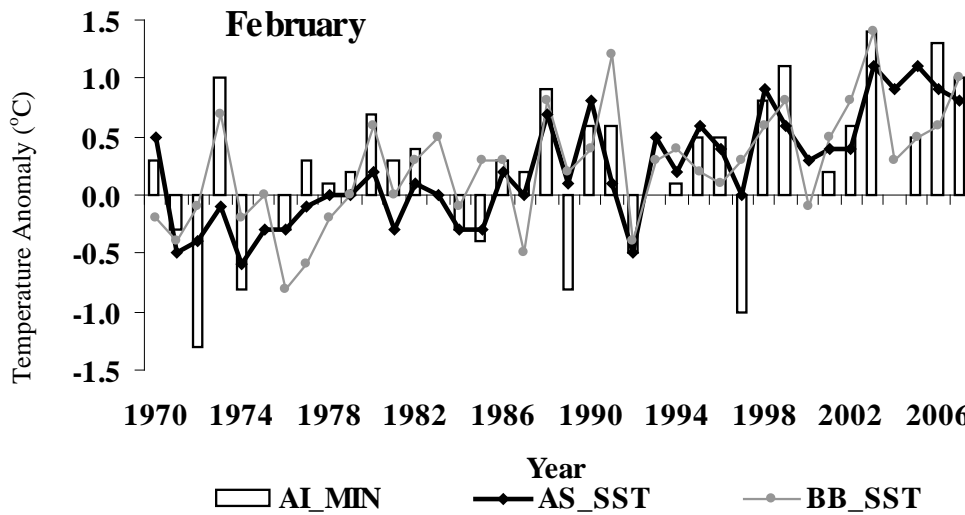
Fig. 10. Temporal variations of all India mean minimum temperature (AI_MIN) and sea surface temperature of Arabian Sea (AS_SST) and Bay of Bengal (BB_SST) for February for 1970-2007. Data series are anomalies from 1961-1990 average
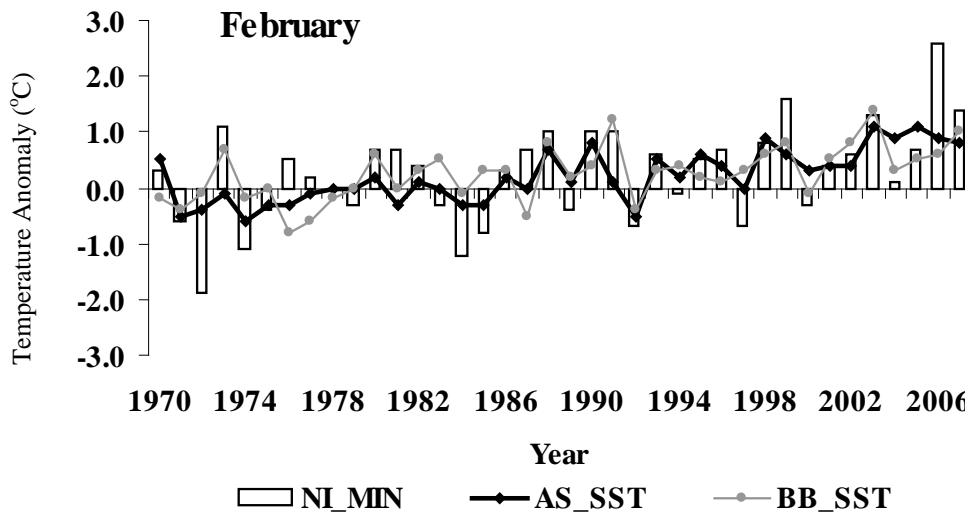

Fig. 11. Temporal variations of mean minimum temperature of North India (NI_MIN) and sea surface temperature (SST) of Arabian Sea (AS_SST) and Bay of Bengal (BB_SST) for February for 1970-2007. Data series are anomalies from 1961-1990 average

positive correlation as shown in Fig. 8. It is evident from the time series that South India maximum temperature and SST anomalies of AS for January have shifted to warming phase since mid-1990s. South India averaged maximum temperature anomalies for February are having strong positive correlation with SST anomalies of AS and BB as shown in Fig. 9.

All India and North India averaged minimum temperatures are having significant positive correlation with SST of AS for February and March and with SST of BB for March as given in Table 4. Significant positive correlation is also found between South India averaged minimum temperature and SST of BB for February and SST of AS for March. The highest correlation is found between all India and North India averaged minimum temperature and SST of AS for February and between all India averaged minimum temperature and SST of BB for February. Temporal variations of SST anomalies of AS and BB and all India averaged minimum temperature are

shown Fig. 10. All India averaged minimum temperature has increased sharply after 1999 and this rise is in phase with the rise in SST of AS and BB. North India averaged minimum temperature is having significant positive correlation with SST of AS and BB as shown in Fig. 11. It is clear from the anomaly time series that North India minimum temperature has increased since late 1990s but the rise is sharp in recent years.

4.   Conclusions

The analysis of variations and trends in monthly mean maximum and minimum temperatures for January to March highlight important features of changing winter climate of India. Even though the impact of climate change differs from one region to other over geographically diverse country like India, most regions show increase in maximum and minimum temperatures which generally agrees with temperature trends for winter season found by Kothawale and Rupa Kumar (2005) and Dash and Hunt (2007). During the period of study, day-time total cloud amount has decreased over extreme north and central India. Strong declines in maximum temperature are evident across Indo-Gangetic plains for January where large numbers of stations are having significant decreasing trends [Fig. 4(a)] which can be attributed to increase in day-time total cloud amount [Fig. 6(a)] and increase in fog days (De *et al*. 2001 and Jenamani 2007) leading to decrease in incoming solar radiation. An important point to note is that North India averaged maximum temperature for February has increased at a rate 1.5 times that of the South India averaged increase (Table 1) indicating strong warming signals for the month over North India. The decrease in day-time total cloud amount over central, east and northwest India is in agreement with corresponding increase in maximum temperature. There are significant warming trends in both maximum and minimum temperatures over South India during February to March. However South India averaged maximum temperature trend is significant for all three months indicating persistent warming over the region. Increasing trends of minimum temperature over North India for February and March is compatible with decreasing trends in frequencies of minimum temperature below 10° C during winter season found by Rao *et al*. (2000). All India minimum temperature is rising significantly for February and March which agrees with winter season trend obtained by Kothawale and Rupa Kumar (2005). As minimum temperatures have increased more over North India with the corresponding night-time cloud amount increase, it appears that cloud amount is playing a role. The sharp rise in mean maximum and minimum temperatures observed over stations in the Himalayan region (Srinagar, Shimla,

Dharamshala and Mukteswar) is consistent with the rise in temperatures over northwestern Himalaya reported by Bhutiyani *et al*. (2007).

During the last 50 years, sea surface temperatures (SSTs) over the tropical oceans have increased (Hoerling *et al*., 2006) and the warmer tropical waters store large amount of heat as compared to land surfaces thus exerting a profound influence on climate through their ability to transport heat from one location to other. The rise in SST over AS and BB is 0.8° C during last 100 years (Dash and Hunt, 2007) which is 50% more than that in the ocean temperatures over rest of the globe (Webster *et al*., 2005). SST variations control meteorological processes as when an air mass moves over an oceanic region it takes on the characteristics of that region. Already there is evidence of significant contribution of SSTs towards the widespread terrestrial and global tropospheric warmth as shown by Hoerling *et al*. (2006). SSTs in the tropical latitudes have increased during the past 50 years and as a response to this increase in ocean water temperature, tropical land surface temperatures as well as tropical tropospheric temperatures have also trended upward as reported by Kumar *et al*. (2004). The higher magnitude of positive correlation found between land surface temperatures and SSTs of AS and BB suggest strong relationship between them which requires further study.

Among all climatological parameters, temperature plays an important role during the vegetative growth and grain formation of the wheat crop which is the major rabi crop in India. According to Wardlaw *et al*. (1989), an average temperature of 15° C during grain formation is optimum for maximum grain weight. Grain numbers and weight are reduced due to prolonged high temperature and drought conditions while prolonged lower temperature enhance grain formation period resulting in higher grain weight (Wardlaw *et al*., 1989). According to Kalra *et al*. (2008), there is a decrease in grain yield of wheat in four northern states of India *viz*., Haryana (4.29 q/hectare), Rajasthan (2.49 q/hectare), Punjab (0.62 q/hectare) and Uttar Pradesh (0.56 q/hectare) for per degree seasonal rise in temperature. The observed increasing trends in the monthly mean temperatures over the country may result in shortfall of food grain and fruit production in rabi season affecting the Indian farmers adversely.

On the basis of above discussions the results of this study are summarized below:

(*i*)   All India and North India averaged mean maximum temperature trends are significantly increasing for February (+0.25° C / decade and +0.29° C / decade respectively), while South India mean maximum

temperature trends are increasing significantly for all three months (+0.22° C / decade, +0.19° C / decade and +0.14° C / decade respectively). All India and North India averaged minimum temperature trends are increasing significantly for February (+0.23° C / decade and +0.38° C / decade respectively) and March (+0.16° C / decade and +0.22° C / decade respectively). The increasing trends in maximum and minimum temperatures are highest for North India during February suggesting decrease in duration of winter season over the region.

(*ii*) Spatial distribution of trends in maximum temperature for January to March indicates significant increase over coastal and peninsular India where large numbers of stations are having significant rise in temperature. Spatial patterns of January to March trends of minimum temperature indicate significant increase over north, northwest, northeast and extreme south peninsula.

(*iii*) All India, North India and South India averaged maximum and minimum temperatures are having significant positive correlation with SSTs of AS and BB suggesting contribution of warming sea water surrounding the Indian landmass in the rise of land surface temperatures.

India is a big country having a considerable portion of land mass and size of population of the world. The effects of observed increasing trends of monthly temperatures for January to March on crop growth and yield during rabi season in India need detailed analysis.

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