TRENDS AND FLUCTUATIONS OF TEMPERATURE REGIME OF NORTH EAST INDIA

R.L. Deka[a*], C. Mahanta[a] and K.K. Nath[b]

[a]Centre for the Environment, Indian Institute of Technology Guwahati, Assam
[b]Department of Agrometeorology, Assam Agricultural University, Jorhat, Assam – aas_jorhat@rediffmail.com

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ABSTRACT:

The study examines long-term changes and short-term fluctuations in ambient temperature of North East India during 1901-2003 located in part of the Eastern Himalayan region of the Brahmaputra Basin. Long-term linear trends were examined with the Mann-Kendal rank statistic and moving average method while the short-term fluctuations were studied by applying Cramer's test. The results showed significant warming trend in annual and seasonal maximum temperature. Decrease in minimum temperature during monsoon season and its increase during post-monsoon and winter season is evident. Higher magnitudes of linear trends are observed in the maximum temperature than in the minimum temperature. Maximum temperature showed increasing tendency in the recent five decades. On the contrary, minimum temperature decreased sharply during 1960-90.

1. INTRODUCTION

The global climate has changed rapidly with the global mean temperature increasing by 0.74°C within the last century (IPCC, 2007). However, the rates of climate change are significantly different among regions (IPCC 2007). This is primarily due to the varied types of land surfaces with different surface albedo, evapotranspiration and carbon cycle affecting and responding to the climate in different ways (Snyder *et al.* 2004, Dang *et al.* 2007). Using the all-India mean surface air temperatures during 1901-2000 from a network of 31 well-distributed representative stations over India, Rupa Kumar *et al.* (2002) highlighted that the warming trends were visible during all the four seasons. The results showed higher rate of temperature increase during winter (0.04°C/decade) and post-monsoon (0.05°C/decade) seasons compared to that of annual (0.03°C/decade).

The IPCC has projected that the likely range of global average surface warming over the 21st century will vary from 0.3 to 6.4°C, depending on the model used for simulation. The mean annual increase in temperature by the end of this century is projected to be around 3.8°C in Tibetan plateau, 3.3°C in South Asia and 2.5°C in South East Asia (IPCC, 2007a). Lal *et al*. (2001) projected mean warming between 1.0-1.4°C and 2.23-2.87°C in India by 2020 and 2050, respectively. Comparatively, increase in temperature is projected to be more in winter season than in summer. The study of Rupakumar *et al*. (2003) revealed marked increase in both rainfall and temperature into the 21st century, particularly conspicuous after the 2040s in India. The study also showed a general increase in minimum temperature up to 4°C all over the country, which may however be more in Northeast India. The number of rainy days is likely to increase by 5-10 days in the foot hills of Himalaya and Northeast India.

North East (NE) India (latitude: 21°57´N to 29°30´N and longitude: 89°46´E to 97°30´E) with distinct precipitation and drainage patterns, unique physiographic and hydrogeomorphic regimes presents a distinctive geophysical unit set in the Eastern Himalayan region. Climate of NE India is distinct from that of the rest of India due to special features like orography, alternating pressure cells over NE India and Bay of Bengal, the roving periodic western disturbances and the local mountain and valley winds. The extensive water bodies and forest areas add to its climate individuality. Agriculture is the mainstay of economy accounting for 30% of the region's NSDP - a major source of employment and livelihood. Rice is the single-most dominant crop in the region. The total area under rice during 2006-07 is 3067 thousand ha with a total production of 4585 lakh tones.

Most efforts in climate change studies have focused on the global scale, although regional-scale analysis is important for mitigating its negative effects and the development of adaptation plans. The increase in global temperature identified by the IPCC does not exclude local warming or cooling trend in a small-scale area like the NE region. Therefore, this study is proposed to assess the variations of temperature regime of NE India.

2. MATERIALS AND METHODS

Observed monthly maximum and minimum temperatures for the period 1901–2003 used in this study are obtained from the Indian Institute of Tropical Meteorology (IITM), Pune website http://www.tropmet.res.in. In order to examine the temperature trend over Northeast India during different seasons, in this study, the entire year has been divided into four seasons namely, pre-monsoon (March to May), monsoon (June to September), post-monsoon (October and November) and winter (December to February). The data were analyzed for long-term trends and short-term fluctuations by using the methods as follows:

2.1 Mann-Kendal Rank Test

The long-term trends are generally tested using Mann-Kendal rank test and the linear trend. The Mann-Kendal rank test, based on the

* r.deka, chandan)@iitg.ernet.in

run test of a ranked time series, is sensitive to non-linear trends. This statistics was used to determine the possible existence of any significant trend in the collected data over a period of time. However, it indicates only the direction and the significance of the trend and cannot quantify the trend. This test was found to be useful and widely used for detecting trends in climate and environment sciences (Sneyers, 1990; Kadiolgu, 1997).

The Mann-Kendall rank statistics (τ) is computed from

$\tau = [(4\sum n_i / N(N-1)] -1$

Where, n_i is the number of values larger than the i^{th} value in the series subsequent to its position in the series of N values. The value of τ is tested for significance by the statistics τ_t, which is given by

$\tau_t = \pm t_g [(4N+10) / (9N (N-1)]^{0.5}$

Where, t_g is is the desired probability point of the Gaussian normal distribution appropriate to a two-tailed test.

2.2 Cramer's t-test

Statistical attempts to identify climatic trends frequently employ the calculation of a moving mean; a ten-year smoothing mean can be utilized to smooth out many of the short-term fluctuations. The decade averages (a decade, two decades and three decades) have been examined in order to see whether the individual decade means differ from the mean of the entire period. The main purpose of applying moving Cramer's test to 10, 20, and 30 year sliding window widths to the time series is to find out significant periods with abnormal averages, if any.

The statistical significance of the moving mean as well as decadal averages was examined using the Cramer's test statistics as follows:

The t-statistics, t_k is computed as

$t_k = \tau_k [(n (N-2) / N-n (1+ \tau_k^2)]^{0.5}$

Where, $\tau_k = \check{R}_k - \check{R} / \sigma$

$\check{R}$ is the mean and σ is the standard deviation of the series for the total number of years (N) under investigation; $\check{R}_k$ is the mean for each successive n-year.

3. RESULTS AND DISCUSSION

3.1 Long-Term Trends

The regression slope estimates and Mann-Kendall (M-K) test statistics for annual and seasonal mean maximum, mean minimum and mean average temperature during 1901-2003 are presented in Table 1, 2 and 3. The trend rate of temperature (°C/100 yr) is shown in Table 4.

The results showed significant increase in annual and seasonal maximum temperature in NE India (Table 1). The annual maximum and mean temperature has increased significantly by a rate of 1.02°C and 0.60°C/100 years, respectively. Maximum temperature has enhanced by about 1.5 and 1.2°C during post-monsoon and winter season, respectively (Table 4).

Minimum temperature showed a significant cooling trend during monsoon season by a rate of -0.32°C per 100 years (Table 4). Significant increasing tendency of minimum temperature during post-monsoon (0.64°/100 years) and winter season (0.61°C/100 years) was noticed. Higher magnitudes of linear trends are observed in the maximum temperature than in the minimum temperature.

Season	Slope	M-K statistics
Pre-monsoon	0.0079	0.2119*
Monsoon	0.0076	0.3771*
Post-monsoon	0.0155	0.4959*
Winter	0.0125	0.3745*
Annual	0.0103	0.5564*

Table 1: Regression Slope (°C/year) and Mann-Kendall (M-K) Statistics for Maximum Temperature (1901-2003) in NE India

** Significant at 5 percent*

Season	Slope	M-K statistics
Pre-monsoon	0.0010	0.0425
Monsoon	-0.0033	-0.1795*
Post-monsoon	0.0064	0.1704*
Winter	0.0062	0.2549*
Annual	0.0018	0.1194

Table 2: Regression Slope (°C/year) and Mann-Kendall (M-K) Statistics for Minimum Temperature (1901-2003) in NE India

** Significant at 5 percent*

Season	Slope	M-K statistics
Pre-monsoon	0.0044	0.1479*
Monsoon	0.0022	0.1426*
Post-monsoon	0.0010	0.4418*
Winter	0.0094	0.3729*
Annual	0.0060	0.4091*

Table 3: Regression Slope (°C/year) and Mann-Kendall (M-K) Statistics for MEAN temperature (1901-2003) in NE India

** Significant at 5 per cent*

Seasons	Trend Rate of Temperature (°C/100 yr)		
	Maximum	Minimum	Mean
Pre-monsoon	+0.78	+0.09	+0.44
Monsoon	+0.75	- 0.32	+0.21
Post-monsoon	+1.54	+0.64	+1.09
Winter	+1.22	+0.61	+0.92
Annual	+1.02	+0.18	+0.60

Table 4: Trend Rate of Temperature in NE India

The enhancement of the mean atmospheric temperature was highest during post-monsoon (1.09°C) followed by winter (0.92°C) season. During pre-monsoon, an increase of mean temperature by

0.44°C has been observed whereas the temperature enhancement during monsoon season was lowest at 0.21°C (Table 4).

Less increase of maximum and minimum temperature during monsoons may be due to the cooling effect of rainfall. A sizeable percentage of temperature increase may be offset by precipitation. Less amount of precipitation coupled with enhanced GHG contents in the atmosphere have rendered the winter and the post-monsoon significantly warmer.

The 10-year moving average curve and corresponding Cramer's t_k value for annual maximum and minimum temperature with 5 per cent significant line is shown in the Fig 1 (a-d).

The 10-year moving average curve for annual maximum temperature showed a gradual rise up to 1947, then a shorter decreasing tendency up to 1957 and afterwards a continuous increasing tendency. Similar features are noticed in Cramer's t-value moving curve also (Fig 1b). The t_k value was significant at 5% level during 1910-1931, 1933-34, 1936 (below long-term mean); 1966-67, 1973-75, 1981, 1996, and 1999-03 (above long-term mean).

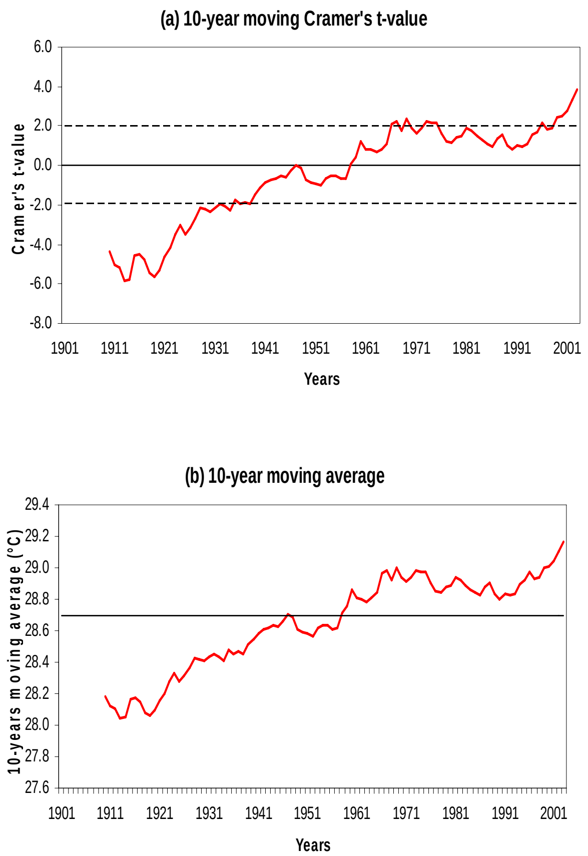

Figure. 1 (a-b) Ten Year Simple Moving Average and Cramer's t-Statistic for Maximum Temperature During 1901-2003

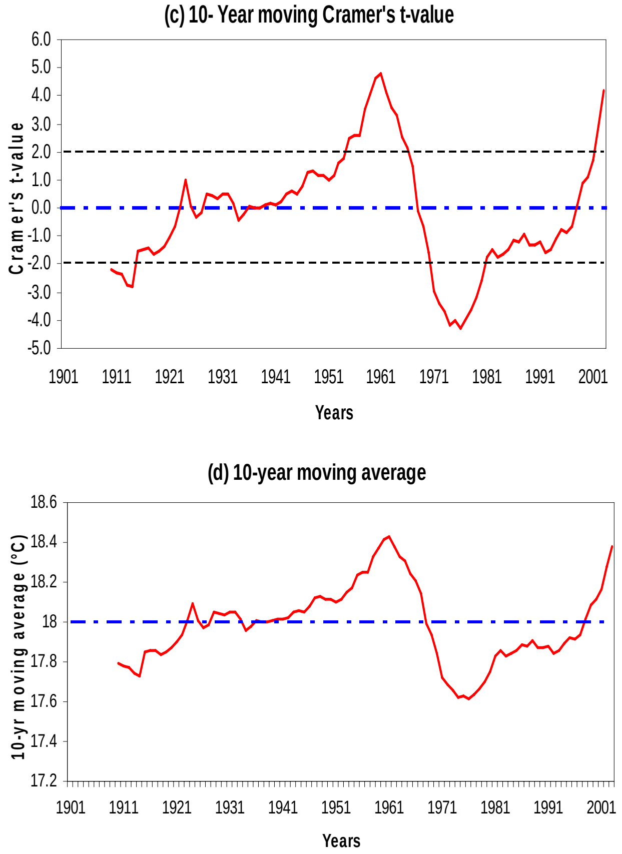

Figure. 1 (c-d) Ten year Simple Moving Average and Cramer's t-Statistic for Minimum Temperature During 1901-2003

In case of annual minimum temperature, a gradual increasing tendency up to 1924, a decreasing tendency from 1960 to 1990 followed by an increasing tendency up to 2003 was noticed. The t_k value was significant during the period from 1910-1914, 1955-1966, 1971-1980 and 2002-03 (Fig 1 c & d).

3.2 Short-Term Fluctuations

The 10-, 20- and 30-year averages (window lengths) have been examined in order to ascertain whether the sub-period means differ from the mean of the entire period. Temperature anomalies during different sub-periods are presented in Table 5.

The annual maximum temperature was below the overall mean (28.6°C) during the first five decades (1901-1910 to 1941-50) with significant values during 1901-1910 and 1911-1920. The recent five decades showed a warming tendency. Except the decade 1981-1990, the Cramer's t value was found to be significant in all other decadal periods (Table 5). There are two 20-year periods, 1961-1980 and 1981-2000 which showed positive anomalies and one 20-year period of 1901-1920 which showed negative anomaly from the overall mean and were significant at 5% level. Similarly, decrease of maximum temperature during 1901-30 and increase during 1961-90 was also found to be significant.

Period	**Temperature anomaly (°C)**		
	Maximum	**Minimum**	**Mean**
10-year window			
1901-10	-0.45*	-0.19*	-0.32*
1911-20	-0.54*	-0.11	-0.33
1921-30	-0.23	0.05	-0.09
1931-40	-0.08	0.04	-0.02
1941-50	-0.04	0.13	0.05
1951-60	0.22	0.43*	0.33*
1961-70	0.31*	-0.14	0.09
1971-80	0.26*	-0.23*	0.01*
1981-90	0.17	-0.11	0.03
1991-00	0.38*	0.13	0.25
20-year window			
1901-20	-0.49*	-0.15*	-0.32
1921-40	-0.15	0.04	-0.06
1941-60	0.09	0.28*	0.19
1961-80	0.28*	-0.18*	0.05
1981-00	0.28*	0.01	0.14
30-year window			
1901-30	-0.41*	-0.08	-0.24*
1931-60	0.03	0.20*	0.12*
1961-90	0.25*	-0.16*	0.04

Table 5: Temperature Anomalies During Different Sub-Periods

** Significant at 5 per cent*

In case of annual minimum temperature, the decades 1901-10, 1911-20, 1961-70, 1971-80, and 1981-90 showed a decreasing tendency from the overall mean of 18.0°C while the remaining decades showed increasing tendency. Decrease in minimum temperature during two decades (1901-1910 and 1971-1980) and increase in the decade 1951-60 was found to be statistically significant (Table 5). There are two 20-year periods, 1901-20 and 1961-1980 in which minimum temperature was decreased and one 20-year period, 1941-60 in which it increased significantly from the overall mean. Similarly, decrease of maximum temperature during the 30-year period of 1961-90 and increase during 1931-60 was found to be significant.

The annual mean temperature was below the overall mean during the first four decades of 20th century with significant values during 1901-1910. The recent six decades (1941-50 to 1991-2000) showed a warming tendency. It may be noted that the decade 1951-60 was the warmest decade due to abrupt rise in minimum temperature followed by last decade (1991-2000) during 20th century in NE India.

The results clearly showed significant warming in the NE India. The causes are thought to be mostly anthropogenic. The increase in population is also related to urbanization and other developmental activities which may have many interactions and interventions on the local environment. The human population in NE India is steadily increasing from 0.42 crores during 1901 to 3.9 crores in 2001 (Census of India, 1901, 2001). The chemical composition of the atmosphere over India has been changing for the past few decades (Mitra, 1992), initially as a result of agriculture, more recently due to industrial activities. The annual per capita CO_2 emission has increased gradually in India from 0.06 to 1.2 metric tons from 1950 to 2004 (Sharma *et al*, 2006). There is considerable decline in forest cover in NE India due to deforestation, land-use conversion and land degradation. There has been a decrease of about 1800 km^2 in the forest cover of this region between 1991 and 1999 (Forest Survey of India, 2001). Shifting (*jhum*) cultivation is a major cause of deforestation and has a disastrous impact on the region's ecology. According to the information compiled by the Ministry of Agriculture, nearly 1.9 mha of land has so far been affected by *jhum* cultivation. The estimated area annually brought under this cultivation is about 4.7 mha involving nearly 4.4 lakh families of over a 100 of tribal ethnic minorities. Methane (CH_4) is an important GHG since large pockets of forests have been cleared and converted into agriculture for meeting the food demands of the increasing population.

The implication of climate change is already visible although, impact assessment studies on climate change on agriculture of NE India are quite limited to arrive at concrete conclusions. It is apprehended that the winter crops will be affected most due to warming. Shorter and warmer winter may make the existing varieties of winter crops less productive. Increasing temperatures in post-monsoon and winter will lead to season shift with earlier and faster crop ontogenetic development. Water requirement of the crops will be more due to increased evaporation rate. With more flooding predicted due to initial glacial melt and enhancement in monsoon rainfall, the hazards of flooding might increase in all proportions in the next few decades in the floodplains of NE India. Increased frequency of heavy rainfall events will increase flood risk, which would damage standing crops, increase soil erosion and make productive lands waterlogged.

CONCLUSION

Detailed analysis of observed data during 1901-2003 clearly indicated that the maximum and mean temperature of NE India showed significant increasing tendencies. The current rate of increase in annual maximum temperature was 1.02°C/100 yr. Minimum temperature showed a significant cooling trend during monsoon season by a rate of -0.32°C/100 yr. Post-monsoon and winter season were predominant in causing the overall annual rise in the surface air temperatures of NE India. Less amount of precipitation coupled with enhanced GHG contents in the atmosphere might have rendered the winter and the post-monsoon significantly warmer.

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