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Statistical Analysis of Trend and Change Point in Surface Air Temperature Time Series for Midnapore Weather Observatory, West Bengal, India

Bisai D[1], **Chatterjee S**[2], **Khan A**[3]* **and Barman NK**[3]
[1]*Department of Geography, Agra SSB College, Agra, India*
[2]*Department of Geography, Presidency University, Kolkata, India*
[3]*Department of Geography and Environment Management, Vidyasagar University, Midnapore, India*

Abstract

This research article aims to detect the short term as well as long term significant changes in the surface air temperature time series for Midnapore Weather observation station, West Bengal, India. The temperature time series data has been collected from Indian Meteorological station, Kolkata, for the period from 1941-2010. Fluctuations and trends of annual mean temperature, annual mean maximum temperature and annual mean minimum temperature time series were statistically examined. To identify the abrupt change in trend, the cumulative sum chart (CUSUM) and Bootstrapping were employed on the considered data set. The major change point in the annual mean temperature occurred around 2001 at level 1 (Confidence level 100%). On the other hand, the annual mean maximum temperature and annual mean minimum temperatures have level 1 change points in 2001 and 1969 respectively. The results show that, one can be 100% confident that the annual mean maximum temperature significantly changed between 1998 and 2001. Similarly, annual mean minimum temperature changed between 1963 and 1971 as a confidence level of 98%. Before the change in 2001, annual mean temperature was 27.11°C; while after the level 1 change the temperature becomes 25.1°C. The mean of annual maximum temperature for the period from 1941-2010 has been 34.017°C which reduced to 30.25°C for rest of the period in consideration. For the annual mean minimum temperature, the time series can be divided into two segment taking 1968 as the last point of the first segment for which the average value is 22.38°C, while the second segment, the average value is 18.077°C. The analysis has identified 13 abrupt change points in three temperature time series.

Keywords: Change point detection; CUSUM; Bootstrapping; Trend analysis

Introduction

Climate variability and change, and their impacts and associated vulnerabilities are growing concerns worldwide. Global warming induced changes in temperature and rainfall are already evident in many parts of the world, as well as in India. Hazards like floods, droughts, cyclones and others, which may have aggravated due to climate change, are being experienced more frequently in India during the past few decades. In this concern, studies to detect climate change and its various impacts deserve urgent attention. Lowering of agricultural productivity, increased risk of hunger and water scarcity, rapid melting of glaciers and decrease in river flows- all such issues are being discussed in the context of climate change [1]. In the recent past (1971–2003), the warming trend has accelerated at a rate of 0.22°C/10 years [2]. Future projections of climate change using global and regional climate models run by the Indian Institute of Tropical Meteorology (IITM) with different IPCC scenarios indicated a temperature change of about 3-5°C and an increase of 5-10% in summer monsoon rainfall [3,4]. It is also projected that the number of rainy days may decrease by 20-30%, which implies that the intensity of rainfall is likely to increase. Trend analysis and change point detection in different climatological time series for a particular region will lead to a better understanding of the problem of climatic change and future climate scenario. However, the reliable measurements of the climatic parameters are the essential foundation for the quantitative analysis of regional climate. There are several factors affecting the quality of the climate data and these factors must be understood for scientific and climatic analysis. Many researches are globally accepted that recommends that, mode of instrument installation, method of observation, the measurement practices and instruments may differ from station to station in a given country and also there may be change in measuring environment, even for an individual station from time to time [5].

This study aims to determine trends and significant change points in the annual average air temperature, annual mean maximum and annual mean minimum temperature time series. The change-point analysis is capable of detecting multiple changes. For each change it provides detailed information including a confidence level indicating the likelihood that a change occurred and a confidence interval in time scale associated with the change. A large number of studies have been conducted on temperature trend for the Indian subcontinent and several investigators have concluded that the trend and magnitude of warming in India or Indian subcontinent over the past century is broadly consistent with the global trend and magnitude [6,7].

Some studies have shown that, in general, the frequency of intense rainfall events in many parts of Asia has increased, while the number of rainy days and total annual precipitation has decreased [8-12]. In-homogeneity in climatic time series is a much studied issue. In-homogeneous climatic data series can bring inaccuracies and make misinterpretation in the investigation of climate change that is visible apparently. Conrad et al. defined a homogeneous time series as one

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***Corresponding author:** Ansar Khan, Department of Geography and Environment Management, Vidyasagar University, Midnapore, West Bengal, India, Tel: 03222276554; E-mail: khanansargeo@gmail.com

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in which variations are caused only by the weather and the climate [5,13-15]. The factors causing variations on the long term time series are, locations of the stations, instruments, formulae used to calculate means, observing practices and station environment [5]. Hence, it is be essential for detecting significant change points in air temperature time series with the established method.

Study Area

Midnapore is a district town located at the bank of river Kasai. Geographical location of this station is 22° 25'16.3″ N and 87°19'19.4″E and is situated 90.8 km (56.4 miles) inland from Digha coast. Being located in the coastal area of the state of West Bengal, this place experiences an equable climate throughout the year. The maximum average temperature in summer season is about 32-34°C and the highest temperature is recorded during July. Average monthly minimum temperature goes down even up to 15°C recorded in December. The summer season welcomes wind laden with huge water vapour during May and June, which often creates local depression and small scale cyclonic effect, popularly known as "Kalbaishakhi".

Data Base and Methods

The time series data used in this work includes three variables: annual mean, annual maximum and annual mean minimum air temperature recorded at Midnapore weather observatory, Paschim Midnapur, West Bengal, India. The data series were collected from the IMD (Alipore, Kolkata). The period under consideration ranges from 1941-2010. Primarily, the collected monthly data were statistically processed and finally annual mean values were calculated for further analysis. The studies of long-term climate change require that data be homogenous. Observed climate abrupt changes in a homogenous climate time series are caused by variations in weather and climate [14]. In recent times, several scientific studies have been conducted on quality control and homogenization of climatological data for the detection of climate trends [16-19].

Cumulative sum charts (CUSUM) and bootstrapping

The cumulative sum charts (CUSUM) and bootstrapping were performed as suggested by Taylor [20]. Let x_1, x_2,… x_n, represents n data points of a time series, and Σ_0,Σ_1, Σ_2, Σ_3, ..., Σ_n are iteratively computed as follows

(a) The average of x_1, x_2,… x_n is given by

$$-\quad \frac{x_1 + x_2 + \ldots + x}{} \qquad (1)$$

(b) Let, Σ_0 be equal to zero

(c) Σ_i are computed recursively as follows

$$\Sigma_i = \Sigma_{i-1} + (x_i - \overline{\mathrm{x}}),\ i = 1,2,\ldots,n \qquad (2)$$

Actually, the cumulative sums are not the cumulative sums of the values. Instead they are the cumulative sums of differences between the values and the average. These differences sum to zero so the cumulative sum always ends at zero, $\Sigma_{\mathrm{v}=0}$.

The confidence level can be determined for the apparent change by performing a bootstrap analysis [20-22]. Before performing the bootstrap analysis, an estimator of the magnitude of the change is required. One choice, which works well regardless of the distribution and despite multiple change is, Δ_I which is defined as

$$\Delta_i = \max_{1\le i\le n} \Sigma_j - \min_{1\le i\le n} \Sigma_i \qquad (3)$$

Once the estimator of the magnitude of the change has been selected, the bootstrap analysis can be performed. A single bootstrap is performed by:

(a) Generating a bootstrap sample of n data points of time series, denoted as x_j (j=1, 2, 3,.., n), by randomly reordering the original n values. This is called sampling without replacement (SWOR).

(b) Based on the bootstrap sample, the bootstrap CUSUM is calculated following the same method and denoted as, Σ_j .

(c) The maximum, minimum and difference of the bootstrap CUSUM are calculated and the difference between the maximum and minimum bootstrap CUSUM is defined as,

$$\Delta_j = \max_{1\le j\le n} \Sigma_j - \min_{1\le j\le n} \Sigma_j \qquad (4)$$

(d) Determine whether the, $\Delta_j < \Delta_i$

The bootstrap analysis consists of performing a large number of bootstraps and counting the number of bootstraps for which bootstrap difference Δ_j is less than the original difference Δ_i. Let *N* is the number of bootstrap samples performed and let *K* be the number of bootstraps for which $\Delta_j < \Delta_i$. Then the confidence level that a change occurred as a percentage is calculated as follows:

$$\mathit{Confidence\ Level}\ (CL) = \left\{\frac{K}{N}\right\}100 \qquad (5)$$

Bootstrapping results is a distribution free approach with only a single assumption, that of an independent error structure. Once a change has been detected, an estimate of when the change occurred can be made. One such estimator is the CUSUM estimator. Let *i* = *m*, such that:

$$|\Sigma_m| = max\,|\Sigma_i| \qquad (6)$$

Then m is the point furthest from zero in the CUSUM chart. The point m estimates last point before the change occurred. The point *m*+1 estimate the first point after the change. The second estimator of when the change occurred is the mean square error (MSE) estimator. Let MSE (m) be defined as:

$$MSE\,(\mathrm{m}) = \sum\nolimits_{i=1}^{m} (x_i - \overline{x_1}) + \sum\nolimits_{i=1}^{n} (x_i - \overline{x_2}) \qquad (7)$$

Where, $\bar{x}_1 = \dfrac{\sum_{i=1}^{m} x_i}{m}$, *and* $\bar{x}_2 = \dfrac{\sum_{m+1}^{n} x_i}{n-m}$

In MSE error estimation, the data series is split into two segments, 1 to m, and m+1 to n, then it is estimated that how well the data in each segment fits their corresponding averages. The value of m, for which MSE (m) is minimized, gives the best estimate of the last point before change, while the point m+1 denote the first point after change. In the same way, data of each segment can be passed through the above method to find level 2 change points that divides corresponding segments into sub-segments. Repetition of the procedure mentioned above helps finding significant change points at subsequent levels for each of which associated confidence limits and levels can be determined by bootstrapping. In this manner multiple change points can be detected by incorporating additional change points each at successive passes that will continue to split the segments into two. Once the change points, along with associated confidence levels, have been detected a backward elimination procedure is then used to eliminate those points that no longer qualify test of significance. To reduce the rate of false detection, when a point is eliminated, the surrounding change points are re-estimated along with their significance level. Thus the significant change points have been detected for the temperature time series considered for this study.

Variations and trends of annual mean temperature, annual mean minimum temperature and annual minimum temperature time series were examined following the method mentioned above. The cumulative sum charts (CUSUM) and bootstrapping were used for the detection of abrupt changes. Section of the CUSUM chart with an ascending trend indicates a period when the values remaining above the overall average. Likewise, a section with a descending trend indicates a period of time where the values lie below the overall average. The confidence level can be determined by performing bootstrap analysis.

Results and Discussion

The results of the analysis for detection of change points and trend in annual mean temperature, annual mean maximum temperature and annual mean minimum temperature of Midnapore weather observatory are presented in Figure 1. The shaded background in this figure indicates the events of change over the considered period and maximum range of temperature fluctuation indicated by red lines under the situation of no change in trend. The confidence levels of those changes are presented in Figures 2 and 3. According to this method, the level 1 change signifies the first change that admittedly present in the CUSUM chart. The year in which level 1 change in mean annual temperature occurred is 2001 (Figures 2 and 3). Prior to the level 1 change, there are many changes found at level 3, level 4, and level 5. By excuse of the change point analysis from the independent error structure, no outlier's assumptions were made in annual maximum and annual minimum temperature trend. The annual mean temperature appears to violate the assumption of independence error. Conforming this method, the error are positively correlated, meaning that if the single value is above the average temperature trend, the next several values will also stoop to be above average. After all, the analysis may incorrectly indicate that a change has taken place. But the associated level of confidence obtained from bootstrapping may confirm the change to have occurred. It can be noted that, none of the changes have attained the 100% confidence level. For the level 1 change, the confidence interval is restricted within one year only. Prior to this change in 2001, the annual mean temperature was 27.11°C; while after the change, the average annual temperature became 25.09°C. The amount of change of annual mean temperature is 2.02°C. It should be noted that, it is the maximum amount of change found in the whole analysis. The widest interval is associated with the change that occurred in 1980 (confidence interval 1950-1981) at level 5. For the annual mean maximum temperature time series there are also distinct change points. The annual mean maximum temperatures time series exhibits a level 1 change in 2001(confidence interval 1998, 2001) at a confidence level of 100%. Prior to the level 1 change of annual mean maximum temperature time series in 2001, the annual mean maximum temperature was 34.02°C; while often the change, average annual maximum temperature became 30.25°C. The amount of change of annual mean maximum temperature is 3.77°C.

In case of the annual mean minimum temperature, the level 1 change has been found in 1983 (confidence interval 1975, 1989) at the 98% confidence level. Prior to the level 1 change in 1983, the average annual temperature was 22.38°C; while subsequently the average becomes 18.08°C for the rest of the period. Over the entire period of consideration (1941-2010), 13 forward and backward changes were found. Among the 13 changes, there are 6 (Six) changes (1949, 1980, 1985, 1991, 1996 and 2001) in annual mean temperature, 3(Three) changes (1951, 1961, 2001) in annual mean maximum temperature and remaining 4 (four) changes (1951, 1964, 1969 and 1983) in annual mean minimum temperature. The trend of annual mean temperature exhibits almost stability over the entire period (Figure 3). The trends of annual mean maximum and annual mean minimum temperature have been indicated abrupt fluctuations after 1960 and it continued till 2001. The CUSUM chart for the standard deviations of mean annual temperature, mean annual maximum temperature and mean annual minimum temperature are presented in Figures 4a-4c and 5.

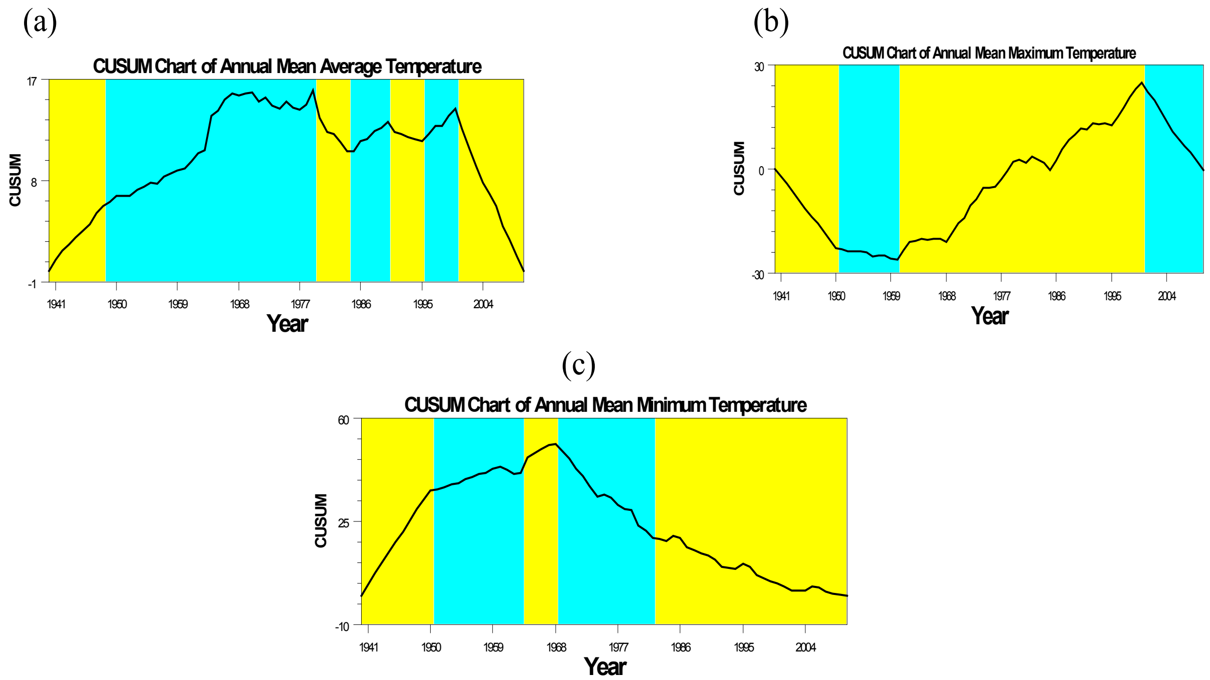
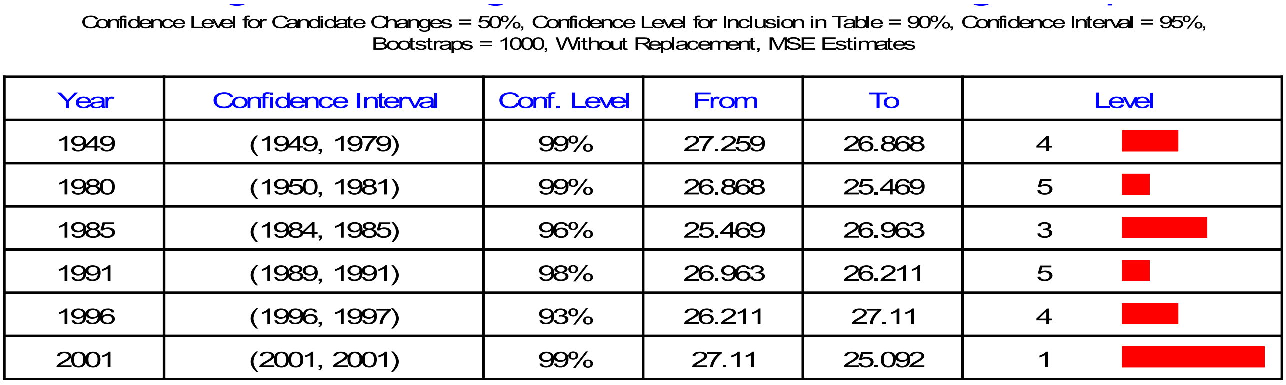


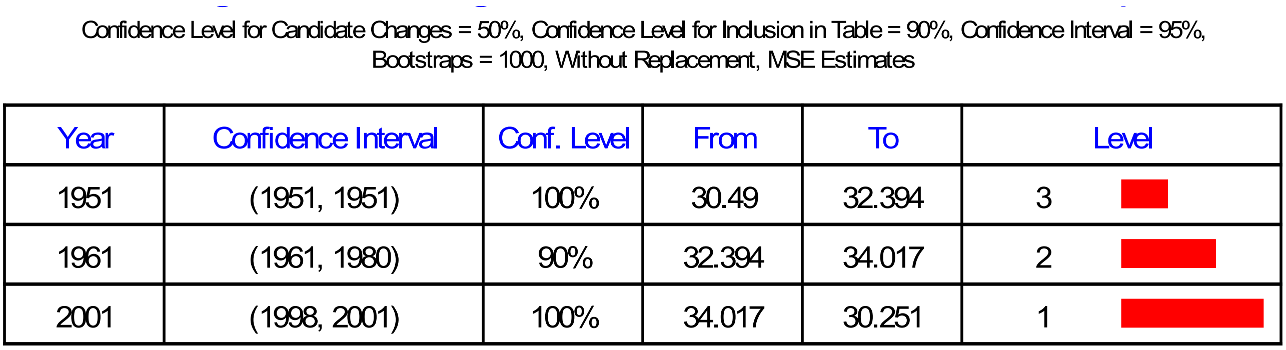
Figure 1: CUSUM chart for (a) mean annual temperature, (b) mean annual maximum temperature, (c) mean annual minimum temperature.



Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Year	Confidence Interval	Conf. Level	From	To	Level
1949	(1949, 1979)	99%	27.259	26.868	4
1980	(1950, 1981)	99%	26.868	25.469	5
1985	(1984, 1985)	96%	25.469	26.963	3
1991	(1989, 1991)	98%	26.963	26.211	5
1996	(1996, 1997)	93%	26.211	27.11	4
2001	(2001, 2001)	99%	27.11	25.092	1

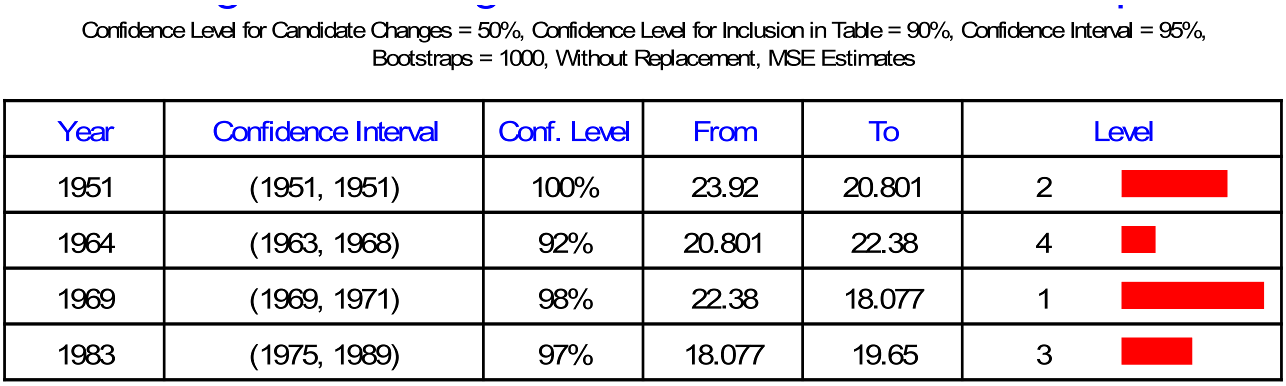
Figure 2a: Significant Changes in mean annual average temperature series.



Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Year	Confidence Interval	Conf. Level	From	To	Level
1951	(1951, 1951)	100%	30.49	32.394	3
1961	(1961, 1980)	90%	32.394	34.017	2
2001	(1998, 2001)	100%	34.017	30.251	1

Figure 2b: Significant Changes in mean annual maximum temperature series.



Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Year	Confidence Interval	Conf. Level	From	To	Level
1951	(1951, 1951)	100%	23.92	20.801	2
1964	(1963, 1968)	92%	20.801	22.38	4
1969	(1969, 1971)	98%	22.38	18.077	1
1983	(1975, 1989)	97%	18.077	19.65	3

Figure 2c: Significant Changes in mean annual minimum temperature series.

A significant change in annual mean maximum temperature can be detected in 1971 at level 2. The confidence interval for this change is with 40 years (1969-2009). Prior to this change the estimated standard deviation is 0.24°C; while after the change the standard deviation became 0.61°C, with Confidence level of 97% in Figures 1, 2 and 6. The annual mean maximum temperature standard deviation had been increasing since 1971 till 1995. CUSUM chart of the mean annual minimum temperature standard deviation does not indicate any significant change point, but the results have indicated a rising trend of temperature since 1971-1995, after that the standard deviation has not increased or decreased significantly (Figure 4c).

Conclusion

In this paper, we adopted a globally scalable approach and used CUSUM and bootstrapping for detecting changes in air temperature time series data that can be caused by a variety of sources. Detection of change points can be carried out by use of CUSUM with the added capability of identifying the period of increasing or decreasing trend in temperature and quantifying the magnitude of change. The method is more robust in detecting the presence of noise and spurious changes. Efficacy of the method has been validated by using it in case of temperature time series for Midnapore weather station, India. We

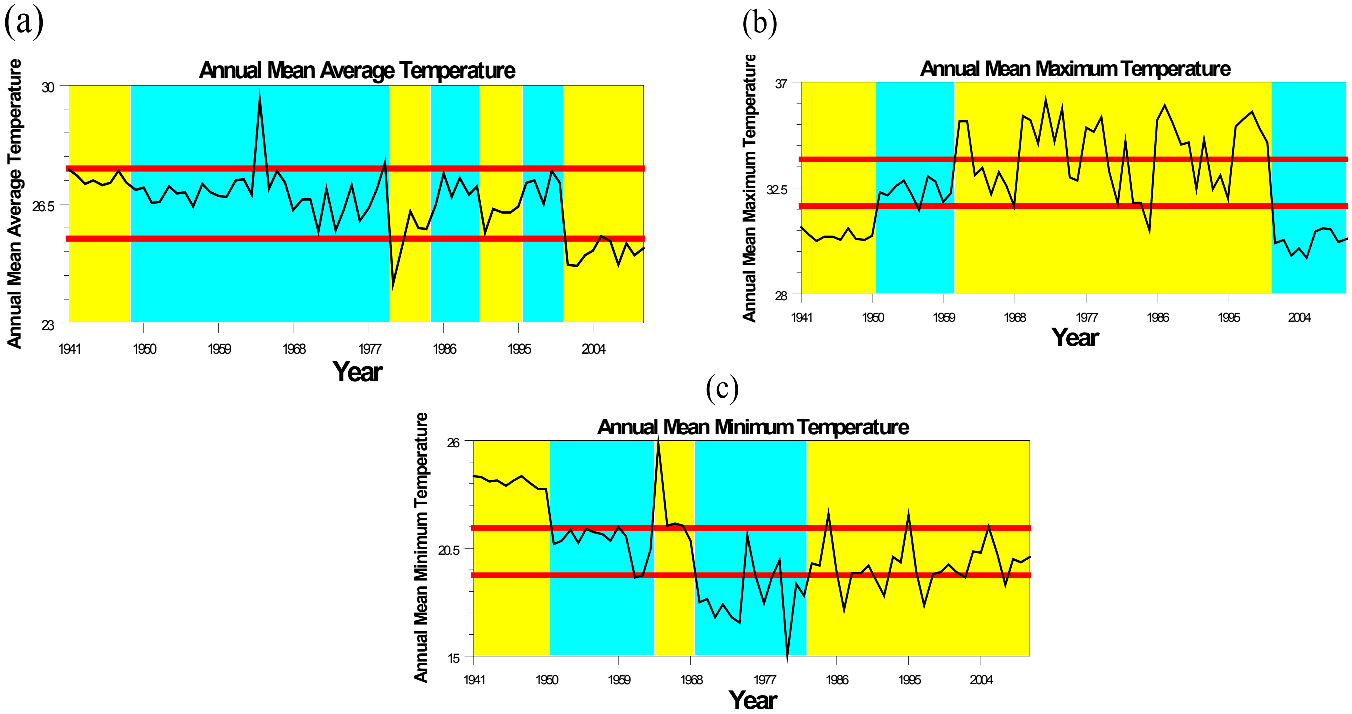


Figure 3: Temperature trends for (a) mean annual temperature (b) mean annual maximum temperature (c) mean annual minimum temperature.

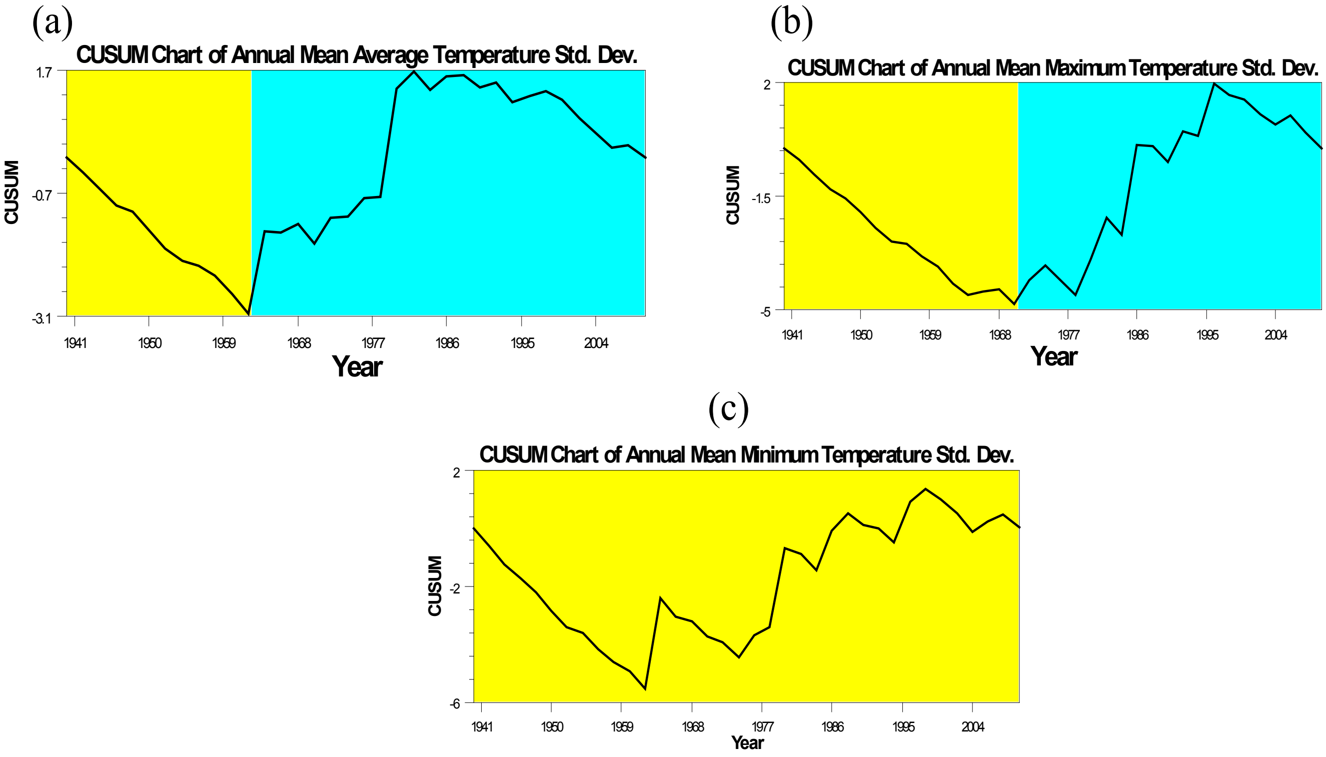


Figure 4: CUSUM chart for (a) mean annual temperature standard deviation, (b) mean annual maximum temperature standard deviation, (c) mean annual minimum temperature standard deviation.

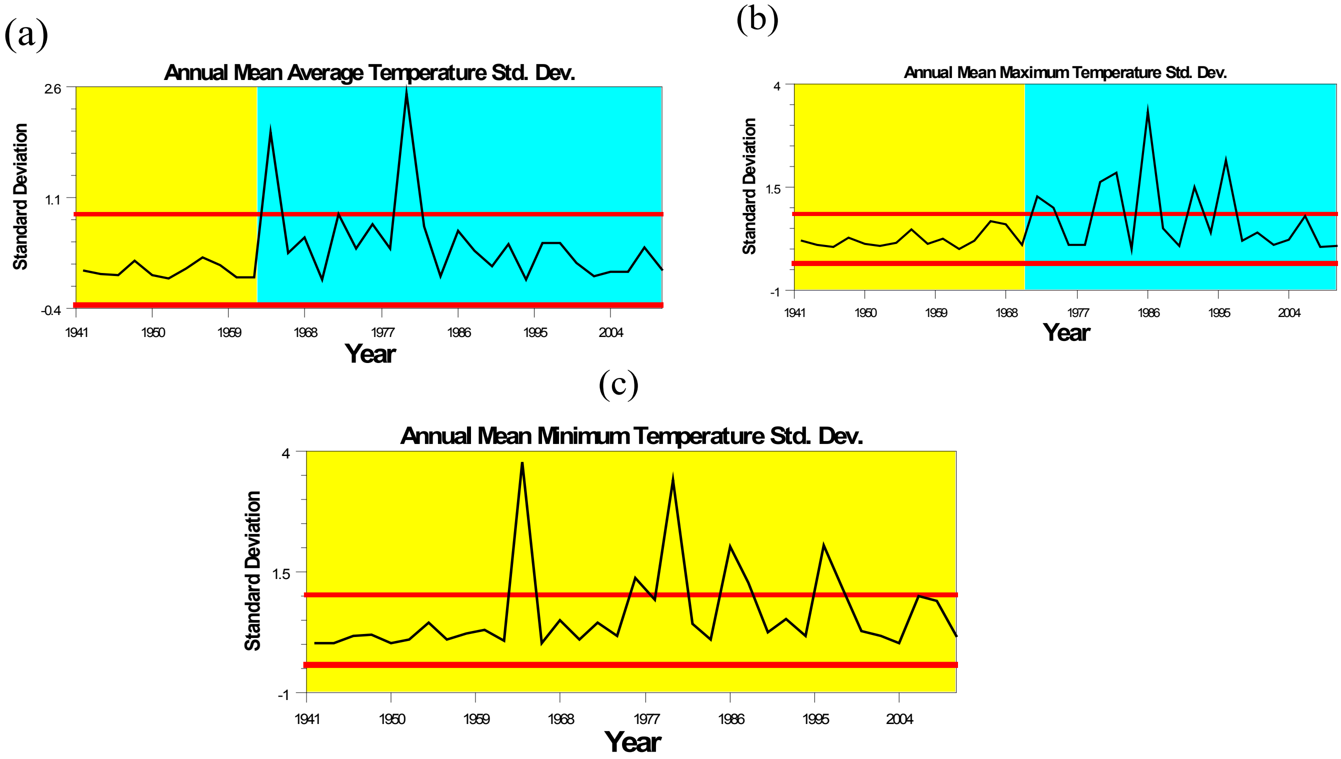
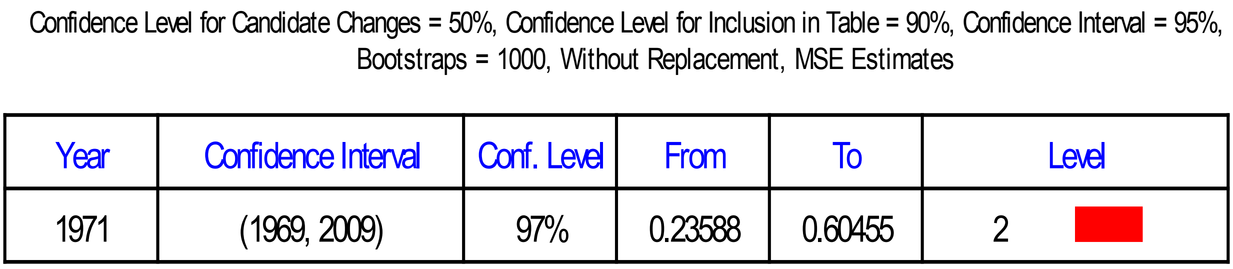


Figure 5: Temperature trends for (a) mean annual temperature standard deviation (b) mean annual maximum temperature standard deviation, (c) mean annual minimum temperature standard deviation.


Confidence Level for Candidate Changes = 50%, Confidence Level for Inclusion in Table = 90%, Confidence Interval = 95%, Bootstraps = 1000, Without Replacement, MSE Estimates

Year	Confidence Interval	Conf. Level	From	To	Level
1971	(1969, 2009)	97%	0.23588	0.60455	2 🟥

Figure 6: Significant change for mean annual maximum temperature standard deviation.

comparatively evaluated results from CUSUM and the bootstrapping technique. Finally, while this paper focuses on identifying the single most significant change by CUSUM in a time series, bootstrapping is able to identify multiple forward and backward segments in entire period. Thus, other segments could also be identified as separate changes if the change within them is also significant (multiple change detection). The analysis suggests that, annual mean temperature in case of Midnapore, India, has significantly declined since 2001. The average of annual mean temperature for the period from 1941-2001 was 27.11°C while that for the rest of the period under consideration was 25.092°C. Hence, the magnitude of change is more than 2°C. Several other change points have also been detected at subsequent levels. In the annual mean maximum temperature time series, a level-1 change point has been identified also in 2001. Once can conclude, at the 100% confidence level, that the change has occurred sometime point between 1998 and 2001. Average of annual mean maximum temperature for the period from starting of the time series till the change took place was 34.014°C; while that for the period from 2001-2010 was 30.251°C. The annual mean minimum temperature at Midnapore has decreased since 1971. Thus, it can be conclude from the results that Midnapore is currently experiencing a cooling trend, in general, since 2001.

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