Trans.Inst.Indian Geographers
ISSN 0970-9851

Detection of anomalies and approximate change point in temperature, Assam, India

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Abstract

A study was carried out in Assam, India to detect the approximate change point and anomalies in temperature. The dataset used was developed by the Indian Meteorological Department (IMD) using a modified version of Shepard's angular distance weighting algorithm for interpolating station temperature data into 10Lat X 10 Long grids. The maximum increase in temperature was observed in December (0.34 oC/decade) and February (0.26oC/decade) respectively. The Mann-Kendall test, Thiel-Sen's slope estimation, and ordinary least square regression analysis were used to detect the trend in temperature during 1971-2007. Cumulative sum charts and bootstrapping along with the Sequential Mann-Kendall test were applied to detect the change point if any. It was observed that the mean annual temperature increased at the rate of 0.15 oC/decade and change point in mean annual temperature was detected to 1994.

Keywords: *Temperature, Mann-Kendall, Thiel-Sen's slope, Assam.*

Introduction

Is the Earth's climate changing? The answer is unequivocal "Yes" (IPCC, 2007). Climate change is no longer a myth, but a reality and has imposed formidable challenges to the Anthropocene. Global surface temperature increased by 0.85 [0.65 to 1.06] °C during 1880-2012 (IPCC, 2013). According to the United States Environment Protection Agency (USEPA), rising global temperatures have been accompanied by changes in weather and climate. Several studies show the detrimental effects of changing climates (Rosenzweig et al., 1995; Parry et al., 1999; Fischer et al., 2002; Hitz and Smith, 2004; Lobell et al., 2008). Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period 1983-2012 was likely the warmest 30-year period in the last 1400 years in the Northern Hemisphere (IPCC, 2014). According to India's National Action Plan on Climate Change, (NAPCC), there are certain observed changes in climate parameters in the northeastern region (NER) of India. At the national level, an increase of ~0.4^{0}C has been observed in surface air temperatures over the past century and warming trends have been observed in the NER. The mean annual temperature (AT) had increased across much of India during 1901-1982 (Hingane et al.1985). PRECIS simulations for the 2030s predicted an allround warming over the Indian subcontinent associated with increasing greenhouse gas concentrations. The annual mean air temperatures are estimated to rise by 1.7°C to 2°C by the 2030s. Indian mean AT showed a significant warming trend of 0.51°C per 100 years, from 1901–2007 (Kothawale et al., 2010). Accelerated warming was observed during 1971–2007, mainly due to intense warming from 1998–2007. The pre-monsoon and monsoon temperatures also indicate a warming trend (INCCA, 2010). According to the regional meteorological centre, in June 2013, the city of Ahmedabad in Gujarat experienced its harshest heatwave, with four months of extreme temperatures reaching 122° Fahrenheit (50° Celsius) in 2010 (NRDC, 2012) resulting in more than 100 heat-related deaths (The Guardian, 2011). Assam recorded a maximum temperature of 38.8°C on 14th June 2013, the highest since 1979.

It was estimated that a 0.5ºC increase in winter temperature would reduce wheat yield by 0.45 tonne per hectare causing a 10 percent reduction in production in the states of Punjab, Haryana, and UP. An estimated 2ºC increase in mean air temperature could decrease rice yields by 0.60 to 0.75 tonne per hectare (Vanaja, 2011). 70% of Assam'spopulation directly depends on agriculture and 15% on allied activities (Bujarbarua and Barua, 2009).

Stuntedcrop development due to warmer temperature or terminal heat stress and drought may cause a reduction in agricultural yield (Lamaoui et al., 2018). Modelling of climatic parameters is a prerequisite for the proper management of the agricultural system at global as well as at the farm level (Rötter et al., 2011).

Database and methodology

Database

The paucity of data and limited spatial coverage from weather stations is a constraint in Assam (Fig.1) as well as the other states of NER. When a sufficiently dense network of weather data stations exists, measurements from such stations are considered the most accurate and reliable source of weather data (Herrmann et al., 2005). Rain gauge data from the India Meteorological Department (IMD) at Borjhar is non-uniformly distributed across the NER and also incomplete (Saikia, 2009). Thus, gridded IMD data (1971-2007) was preferred for the present study. This data used a modified version of Shepard's angular distance weighting algorithm for interpolating the station temperature data into 1^0Lat X 1^0 Long grids (Srivastava et al., 2009).

Methodology

To determine fluctuations over time, the Mann-Kendall (MK) test is useful to assess the level of significance in the analysis of various types of environmental data (Hipel & McLeod, 1994, and McLeod et al. 1990). The test detects if a trend is statistically significant at 0.10 (90%), 0.05 (95%) and 0.01 (99%) significance level (confidence intervals) for a two-sided probability (Mohsin, 2009). Theil-Sen's (TS) slope estimator test is used when the trend is considered to be linear, depicting the quantification of change per unit change. Helsel and Hirsch (1995) showed how to compute a nonparametric estimate of a linear line using the Kendall-Theil method when seasonal differences were absent. The estimate of the slope for the line was first developed by Theil (1950), Sen (1968), and Gilbert (1987). It is possible to estimate the slope if there exists missing data or when less than 20% of the measurements are reported as less than the detection limit (Helsel et al., 1995; VSP, 2016). These tests were applied on the time series average monthly and AT data during 1971-2007 in Assam.

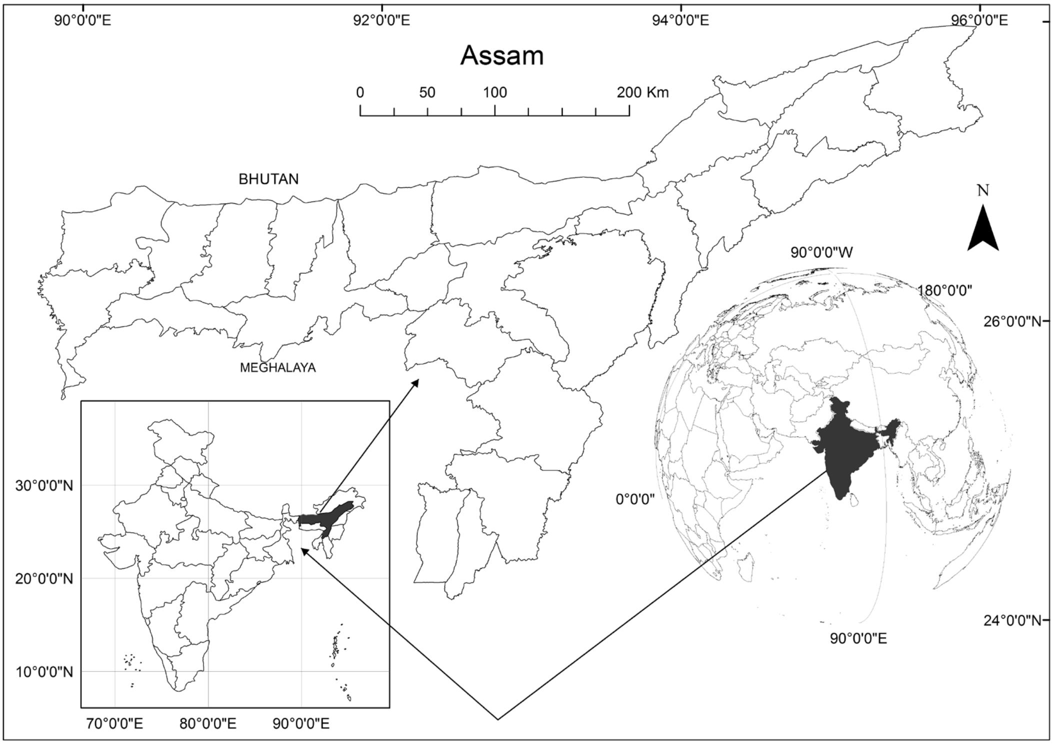

Fig.1 Location of the study area

The Sequential MK (SQ-MK) test statistic allows the detection of the approximate beginning of a developing trend (Sneyres 1990). To determine the approximate year of the beginning of a significant trend, the can be applied to a continuous data series (Lu et al, 2004; Shifteh Some′e et al, 2012; Zarenistanak et al., 2014). The SQ-MK test has been used to detect change points (Mohsin, 2009; Tabari et al, 2011; Bisai, 2014; Chatterjee, 2014) in temperature and precipitation in diverse areas. The graphical representation intersection of u (t) and u (t') curves at a point indicates the start of the abrupt change in the time series, but the overlapping of the u (t) curves several times at the end of the time series to indicate the absence of any significant trend. Higher values of u (t') imply a trend or a change in the time series (Safari, 2012; Zarenistanak et al., 2014). Change-point analysis iteratively uses a combination of time varying cumulative sum charts (CUSUM) and bootstrapping to detect changes (Taylor, 2000a; Taylor, 2000b).1000 bootstraps were performed in each test and only changes with probabilities of >90% are reported. Confidence limits for change-point estimates were 95%. The level 1 change is the first change detected and that which is most visibly apparent in the plots. Level 2 changes are detected on a second pass through the data. Several levels can exist depending on the number of changes found (Taylor, 2000a).

Results and Discussions

Temperature trends

Preliminary linear regression analysis showed the presence of trends in mean monthly (MM) temperature during 1971-2007. The value of the coefficient of determination (R^2) from Ordinary Least Square (OLS) linear regression ranges from 0.0004 to 0.2431 for MM temperatures reveals non-zero values (Table 4). Thus, the presence of trends can be inferred from the time series dataset of MM temperature of Assam. A significant increasing trend was observed in May, February, July, August, September, and December (+ve signs of Kendall's S and Z statistics) during 1971-2007. Very less inference can be made from the Kendall's S statistics at the preliminary level of MK test analysis. Therefore, Z statistics were computed to detect the trend and evaluate the level of significance of the trend.

For this purpose, the assumption for the null hypothesis (H_0: No trend) is accepted, if $Z< Z_{critical}$ (Z_C) and the alternate hypothesis (H_A) was rejected. March and April exhibited no trend (null hypothesis accepted) even at the lowest level of significance (H_0 accepted

Table 1. The trend of mean AT based on the Mann-Kendall test statistic and the level of significance

Months	Mann-Kendall Statistic		Kendall Tao (τ)	Value from Normal distribution table (ND)	p value	α			Evidence Against Null Hypothesis
	S	Z				0.1	0.05	0.01	
Jan	54	0.69	0.0810	0.7549	0.4902	A	A	A	No Evidence
Feb	130	1.69	0.1950	0.9545	0.091	R	A	A	Weak
Mar	-14	-0.17	-0.0210	0.5675	0.865	A	A	A	No Evidence
Apr	-6	-0.07	-0.0090	0.5279	0.9442	A	A	A	No Evidence
May	162	2.11	0.2430	0.9826	0.0348	R	R	A	Modedrate
Jun	100	1.30	0.1500	0.9032	0.1936	A	A	A	No Evidence
Jul	150	1.95	0.2250	0.9744	0.0512	R	A	A	Weak
Aug	186	2.42	0.2790	0.9922	0.0156	R	R	A	Moderate
Sept	170	2.21	0.2550	0.9864	0.0272	R	R	A	Moderate
Oct	108	1.40	0.1620	0.9192	0.1616	A	A	A	No Evidence
Nov	114	1.48	0.1710	0.9306	0.1388	A	A	A	No Evidence
Dec	230	3.00	0.3450	0.9987	0.0026	R	R	R	Strong
Annual	210	2.73	0.3150	0.9968	0.0064	R	R	R	Strong

at ≤ 75 %) (Table 3). An increasing trend was observed in February, May, July, August, September (significant at ≥ 90 % confidence level), December, and AT (significant at ≥ 99.5 %) (Table 1 & 3). At ≤ 75-90% level of significance January, June, October, and November temperatures show a significant increasing trend. The evidence against the null hypothesis (H_0) is very weak (≥75-90%) for these months and hence, we accept the alternative hypothesis (Table 3). These trends are further confirmed by Kendall's correlation coefficient 'Kendall's Tau' (τ).

Table 2 Class interval of p values with level of evidence against the Null Hypothesis (H_0)

$p > 0.10$	No evidence against H_0
$0.05 < p < 0.10$	Weak evidence against H_0
$0.01 < p < 0.05$	Moderate evidence against H_0
$0.001 < p < 0.01$	Strong evidence against H_0
$p < 0.001$	Very Strong evidence against H_0

Table 3. Trend of mean AT based on Z statistics and Z critical values at different significance levels

Months	**Z**	**Level of Significance (%)**									**Null Hypothesis**
		70	**75**	**80**	**85**	**90**	**95**	**97.5**	**99**	**99.5**	
		Z critical									
		1.04	**1.13**	**1.29**	**1.4**	**1.65**	**1.96**	**2.24**	**2.58**	**2.81**	
Jan	0.69										Accepted
Feb	1.69										Rejected
Mar	-0.17										Accepted
Apr	-0.07										Accepted
May	2.11										Rejected
Jun	1.30										Accepted
Jul	1.95										Rejected
Aug	2.42										Rejected
Sept	2.21										Rejected
Oct	1.40										Accepted
Nov	1.48										Accepted
Dec	3.00										Rejected
Annual	2.73										Rejected

Null Hypothesis		
	Accepted	Error
	Rejected	Accuracy

Slope estimated by Thiel-Sen's (TS) slope estimation method indicates magnitude (change per unit time) as well as direction (increasing, decreasing, or no trend). By comparing the slopes computed, the correlation coefficient is estimated to be 0.67. Sen's slope is accepted over OLS linear regression (Fig.2) because in Sen's method neither the estimate of the slope or intercept is strongly affected by missing data, outliers, or single data errors (Ohlson et al., 2014; Sen, 1968). The TS method is easily understood, and it circumvents the two problems in an elegant, direct way. TS and OLS are roughly equally efficient under OLS-ideal conditions. In fact, TS would be more efficient under non-ideal conditions (Ohlson et al., 2014).

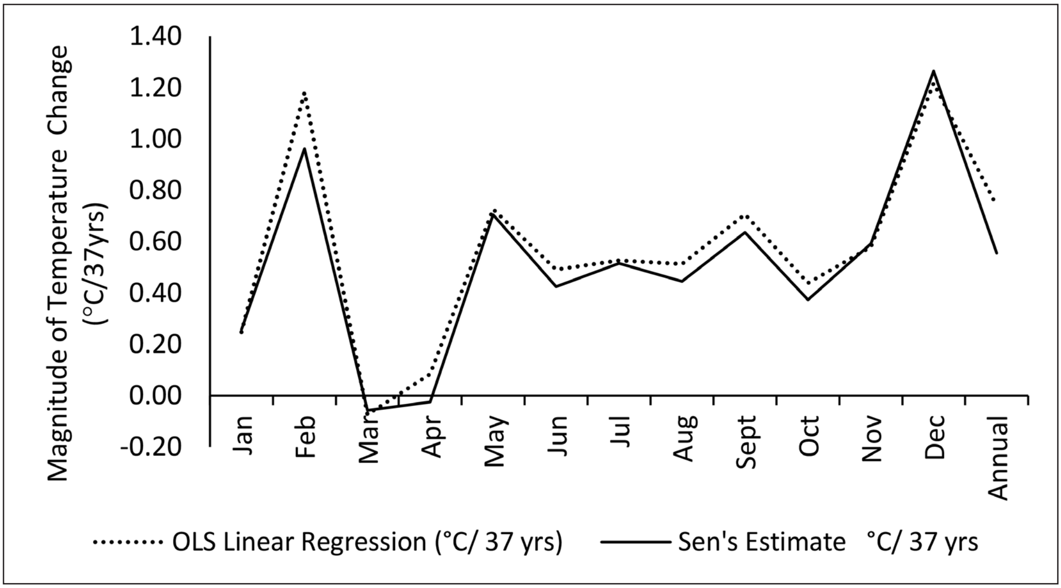

Fig 2. The magnitude of temperature change computed by OLS linear regression and Sen's slope estimator 1971-2007

The results indicate that December (0.34 ^{0}C/decade) and February (0.26 ^{0}C/decade) showed a significant and high rate of increase in temperature across all the months while, May, July, August, and September showed a relatively moderate rise in temperature between 0.12 - 0.19 ^{0}C/decade during 1971-2007. The mean AT was observed to be increasing at 0.15^{0}C/decade (Table 5). Similar results were observed using linear regression analysis in comparison to the Sen's estimate, where December and February showed high rates of warming.

Table 4. Decadal rate of change in temperature (slope) computed by linear regression (R) and TS estimator

Month	Rate of change in temperature	
	(R) ^{o}C/decade	(TS) ^{o}C/decade
January	0.067	0.07
February	**0.319****	**0.260***
March	-0.02	-0.016
April	-0.023	-0.007
May	**0.196***	**0.190****
June	0.133	0.115
July	**0.142***	**0.139***
August	**0.139*****	**0.120****
September	**0.191*****	**0.172****
October	0.119	0.101
November	0.157	0.16
December	**0.329*****	**0.342*****
Annual	**0.150*****	**0.150*****

Significance level ***=0.01, **=0.05, *=0.1

Change in temperature per part

The results of three parts regression analysis for the MM and AT reveals (Fig.4) a dichotomous pattern of temperature for each month in three parts (Table 5 & Fig.3).

Table 5 Three parts regression for MM and AT significant values are shown in bold (at confidence levels: **=0.01, *=0.05, +=0.10)

Three parts Regression Mean Temperature 1971-2007							
Jan	**1971-1980**	**1981-1990**	**1991-2007**	July	**1971-1983**	**1984-1994**	**1995-2007**
	-0.0419	0.0812	0.0612		0.0287	0.1099	0.0385
Feb	**1971-1985**	**1986-1997**	**1998-2007**	Aug	**1971-1982**	**1983-1993**	**1994-2007**
	-0.0401	-0.1192	0.09838		**0.0689 ***	-0.0268	0.0163
March	**1971-1983**	**1984-1993**	**1994-2007**	Sept	**1971-1981**	**1982-1993**	**1994-2007**
	-0.0979***	-0.1425	0.0405		0.0544	0.0017	**-0.0032**
April	**1971-1980**	**1981-1997**	**1998-2007**	Oct	**1971-1980**	**1981-1994**	**1995-2007**
	0.1996	0.091	-0.0345		-0.0768	-0.052	-0.0208
May	**1971-1982**	**1983-1993**	**1994-2007**	Nov	**1971-1981**	**1982-1994**	**1995-2007**
	0.059	-0.0115	-0.0292		0.05524	0.0054	-0.0405
June	**1971-1983**	**1984-1993**	**1994-2007**	Dec	**1971-1984**	**1985-1994**	**1995-2007**
	0.0739	**-0.1322****	**-0.0158**		0.003	-0.1189	**0.0168**
				Annual	1971-1980	1981-1993	1994-2007
					0.0434*	**-0.0436****	0.0088

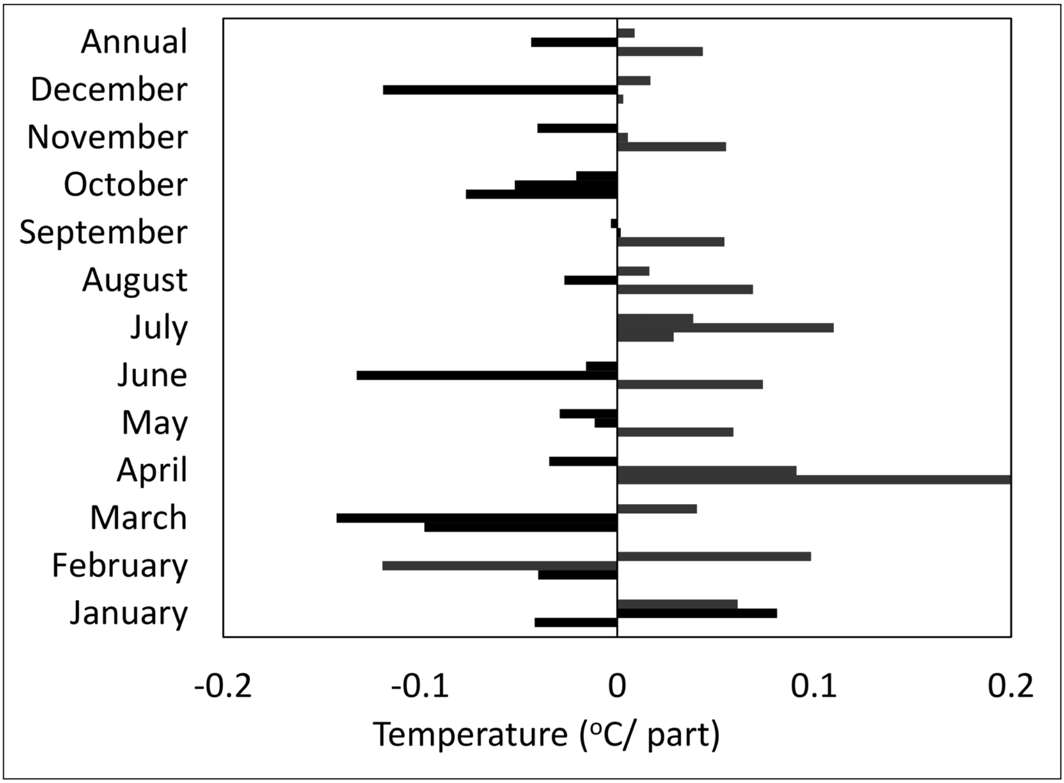

Fig. 3. Magnitude of change in temperature (°C/ part) in three-part regression

The only months with significant trends were March (1971-1980), June (1984-1993), August (1971-1982), and annual mean temperature (MT) (1971-1980; 1984-1994). Trends with a high magnitude of temperature change were February 1986-1997 (-0.1192 C°/part), March 1984-1993 (-0 .1425 C°/part), April 1971-1980 (0.1996 °C/part), June 1984-93 (-0.1322C°/part), July 1984-94 (0.1099 C°/part), and December 1985-1994 (0.1189C°/part). The frequency of warmer periods was higher than cooler periods during 1971-2007 as evident from the three-part regression (Fig. 3). The mean AT per part 1971-1980, 1981-1993, 1994-2007 and 1971-2007 were 22.9, 22.7, 23.2 and 22.98 (C°/part) respectively. Thus, the mean AT declined in the 2nd part (1971-1980) but there was a steep increase in MT in the 3rd part (1994-2007). The annual MT in the 3rd part was much higher than the 1st and 2nd part of regression and the temperature of most months increased in the 3rd part of the regression (Fig. 5).

Detection of change point

The shift in temperature was detected using CUSUM and bootstrapping along with MK-SQ. CUSUM and MK-SQ statistics for the MM and AT shown in graphical representation of curves u (t) and ú (t), indicate abrupt changes in the trend. The

CUSUM and bootstrapping test analysis revealed no significant change point from January to June and November. The only significant potential change points detected were July (1994), August (1978 & 2001), September (1994), October (1995), December (1993), and annual (1994). The change point in annual MT was similar to annual evapotranspiration, which was detected in the year 1994 (Baruah, 2018). During December temperature prior to the first change, the monthly MT was 16.844 ^{o}C while after the first change (1993) it was 17.605 ^{o}C; this was the highest among all the months (96 % Confidence). September, October, and annual MT increased moderately (confidence level of 98, 92 and 100 %). Similarly, July and August MM temperatures had an increase of approximately 0.4^{o}C after change in 1994, 1978, and 2001 respectively (confidence level of 94, 100, and 96 %). Level 5 changes, highest among all months, were detected on a fifth pass through the data for August.

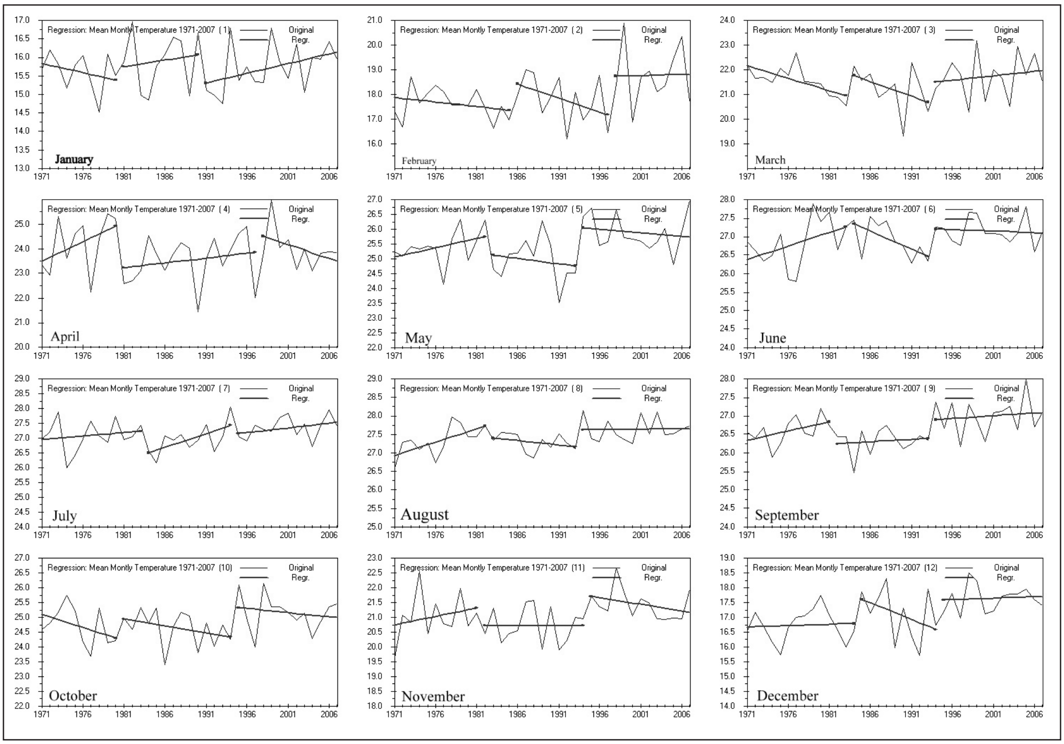

Fig. 4 Three-part regression for MM temperature; the y-axis represents the mean annual monthly temperature in (^{0}C) and x-axis represents the time-period, 1971-2007.

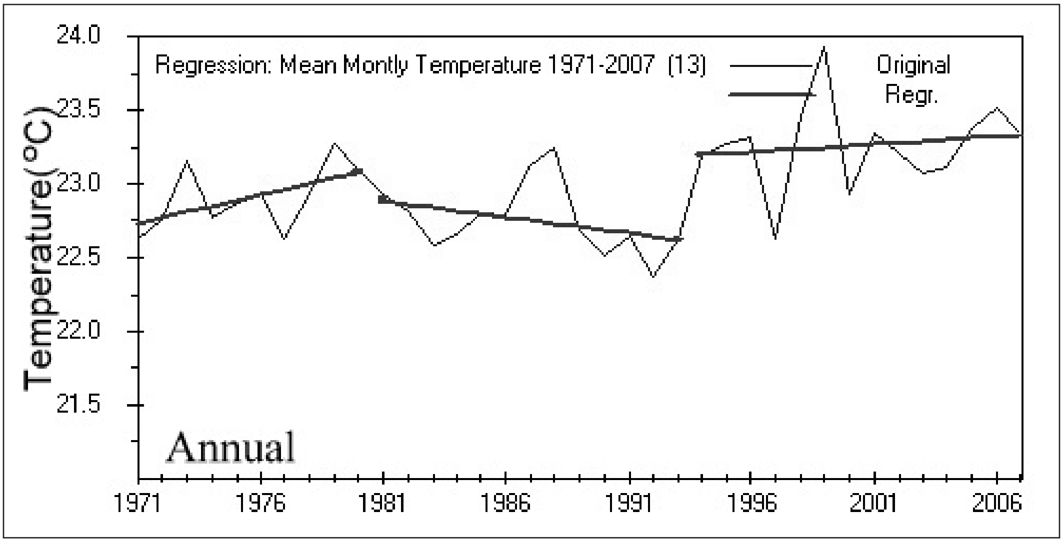

Fig.5 Three parts regression for mean AT during 1971-2007

Table 6 Change points detection of temperatures in Assam after (Taylor, 2000a)

	Confidence Interval (period)	Change Point (year)	Confidence Level (%)	Temperature (°C) Before Change	After Change	Difference	Level of Data Pass	
Jan	ND							
Feb	ND							
Mar	ND							
Apr	ND							
May	ND							
Jun	ND							
Jul	1978-2001	1994	92	26.987	27.396	0.409	1	
Aug	1973-1993	1978	100	27.073	27.449	0.376	3	
	1981-2006	2001	95	27.449	27.726	0.277	5	
Sept	1990-2001	1994	98	26.45	26.994	0.544	1	
Oct	1974-2004	1995	92	24.669	25.165	0.496	1	
Nov	ND					0		
Dec	1982-1997	1993	94	16.844	17.605	0.761	4	
Annual	1978-1989	1989	90	22.888	22.57		2	
	1994-1996	1994	96	22.57	23.261		1	

*ND= No significant change point detected

Similar results were derived using the SQ-MK test considering that most of the change points remained within the confidence interval of CUSUM and bootstrapping results. The change points detected in the series by the intersection of u (t) and u' (t) graphical plots were within the confidence interval estimated by the bootstrapping method. The statistically significant change points were detected in July (1996), September (1995) October (1997), December (1993), and annual (1995) (90% confidence level) in the SQ-MK test. P-value was much lower than the accepted level of significance ($p < 0.1$), which indicates weak evidence against the null hypothesis (no trend) and in favour of the alternative. The change point detected using CUSUM bootstrapping and SQ-MK tests were close to each other and within the same confidence interval period.

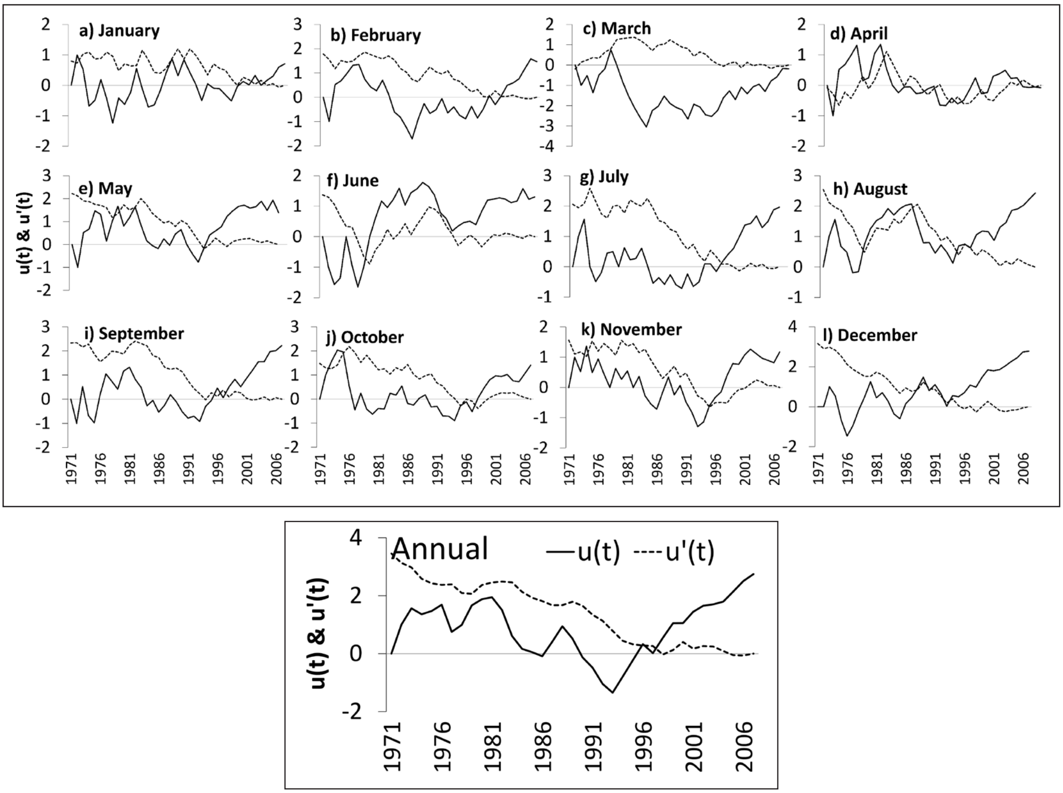

Fig. 6. Abrupt changes in mean AT derived from MK-SQ test, u(t) forward sequential statistic was drawn in solid line and u'(t) backward sequential statistic drawn in dotted line**.**

The mean AT anomaly was detected for the period 1971-2007 (Fig.7), which showed significant variations in the trend. The number of positive anomaly or warmer periods increased post-1993. The anomaly was as high at 1°C during 1999. The variation in the mean AT was high during 1971-2007, with a minimum and maximum temperature anomaly of -0.62°C (1992) and 0.94°C (1999) respectively.

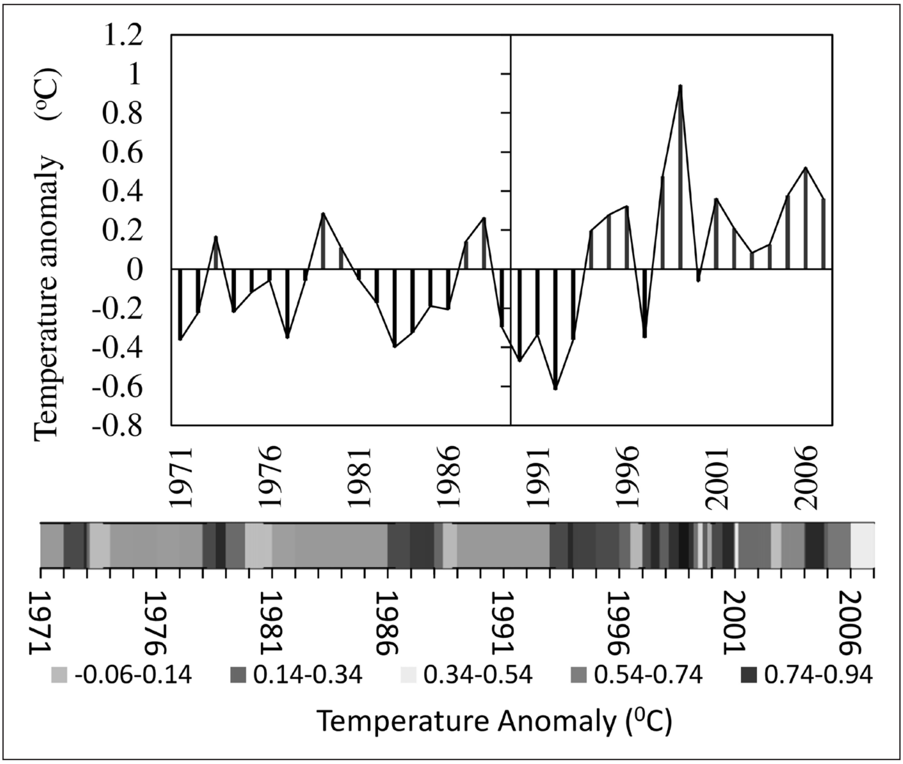

Fig. 7 Mean AT anomalies for 37 years during 1971-2007

Summary and Conclusion

This study used 37 years of gridded temperature data in Assam and analysed monthly and AT trends, change points, and anomalies using the MK, TS slope, and MK-SQ tests. For all the months, the MT showed a statistically significant rising trend for the five months from 1901-2003. Temperature data also showed significant rising trends for eleven months. Similar results were derived from our study as the value of S statistics showed the presence of an increasing trend (+ve) from May-Feb except for March and April, which showed no trends per se. In addition, derived Z statistic was used to detect the presence of any trends along with the level of significance. The Z and Kendall's Tau (τ) statistics showed no trends (null hypothesis accepted) for March and April, even at the lowest levels of confidence (≤75%). The most significant increase in temperature was observed during December and February (0.342 ^{0}C and 0.260 ^{0}C per decade respectively).

Historical records of NER for the past 90 years suggest that the frequency of occurrence of the number of days with temperatures above 30^{0}C and 35^{0}C had increased during the last 30 years (Baruah et al., 2012). The frequency of warmer years also increased post-1993 (change point). Similar results were derived for Indian annual MT, where accelerated warming was observed during 1971–2007. The mean annual temperature in India increased by about 0.2°C per decade (1971–2007), with a sharper increase in minimum rather than maximum temperature (INCCA, 2010). Indian annual mean, maximum and minimum temperatures showed significant warming trends of 0.51, 0.72, and 0.27°C 100 yr–1, respectively, from 1901–2007 (Kothawale et al., 2010). Similar results accrued for Assam, where annual mean temperature increased by 0.15^{0}C per decade.

The warming in Assam may be a part of the global phenomenon and process likely influenced by global drivers of climate change. On a seasonal scale, pronounced warming trends in mean temperature were observed in winter and monsoon seasons, and a significant influence of El Niño Southern Oscillation events on temperature anomalies during certain seasons across India was observed (INCCA, 2010). There is additionally an influence of large radiative effects of black carbon(BC) aerosols emissions on the climate of the Brahmaputra valley (BRV) (Chakrbarty, 2012; Gogoi et al. 2009 & 2011; Dahutia et al., 2018). Although the impact of the aerosols on the Asian monsoon climate is inconclusive (Ramanathan et al., 2001; Lau et al, 2006; Kuhlmann and Quaas, 2010), the slower temperature increase than expected from the global warming has been well established by analysis of satellites and ground-based instruments (Gogoi et al., 2017; Dahutia et al., 2018). Seasonal maximum of aerosols concentration in the lower troposphere has been found in the pre-monsoon season in NER (Gogoi et al., 2011; Dahutia et al., 2018), suggesting that the increasing trend of temperature may be slower in pre-monsoon season. These results are consistent with the analysis in the present study. The range of median BC values measured in Guwahati, Assam are much higher than values measured elsewhere. Values in Guwahati are much higher (by a factor of 3 to 10 times) than those at urban locations in the USA and Europe (Chakrabarty et al., 2012). The high BC values during the afternoon period at high-altitude sites can be attributed to the vertical transport of aerosols from nearby polluted urban and valley regions, which were initially confined to lower heights during the night and early morning hours due to the low-level inversions, but are released to greater heights (̃approx. 2 km) as the boundary layer evolves (Bhugwant et al. 2000, 2001). At night, most of the aerosol concentrations are trapped by the low-level capped inversions, and as the land gets heated up during the day (Satheesh et al., 2008). Large elevated warming close to the Himalayan region is a disturbing fact (Satheesh et al., 2008; Lau et al., 2006). Strong radiative heating due to wintertime BC aerosols in the Brahmaputra River contributes to the warming of the region (Chakrabarty et al., 2012). The Assam valley is located on the foothills of Himalayas, to an extent is most likely affected by this global phenomenon and requires further attention.

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