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Evidence of climate jump in annual temperature in India

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सार – भारत के 50 सुवितरित तापमान वाले स्थानों पर तापमान की प्रवृति और इस तापमान के कारण वहाँ की जलवायु में हुए अकस्मात् परिवर्तनों के कारणों का पता लगाने के लिए उन स्थानों के वार्षिक औसत तापमान का विश्लेषण किया गया है। जलवायु में आए अकस्मात् परिवर्तन का पता लगाने के लिए चार साँख्यिकी परीक्षणों का प्रयोग किया गया है। समय श्रृंखला वाले आँकड़ों के लिए टी–टेस्ट की तुलना में अधिक उपयुक्त माने जाने वाले टेबल लुक अप टेस्ट का अनुप्रयोग पहली बार जलवायु में हुए अकस्मात् परिवर्तनों का पता लगाने के लिए किया गया है। अधिकाँश स्थानों पर वार्षिक औसत तापमान में आई असमानताओं अथवा तापमान में उतार चढ़ाव के कारण जलवायु में अकस्मात् परिवर्तन हुए हैं। यह पता चला है कि उत्तरी भारत की जलवायु में अकस्मात परिवर्तन जहाँ बहुत समय पहले अर्थात् 1931 से 1940 के दशक के दौरान हुए, वहीं प्रायद्वीपीय भारत की सुदूर दक्षिण की जलवायु में अकस्मात् परिवर्तन 1961 से 1963 के बीच हुए हैं।

ABSTRACT. Annual mean temperature of 50 well-distributed stations in India is analyzed for trend and climate jump. Four statistical tests are used to detect the climate jump. Table-look-up test, which is more appropriate than '*t*' test for time series data, has been applied for the first time to detect the climate jump. Sudden changes in climate are noticed by getting discontinuities or jump in annual mean temperature of most of the stations. It was found that while the northern India received climate jump much earlier *i.e.* during the decade 1931-1940, extreme south Peninsular India received climate jump between 1961-63.

Key words – Climate jump, Trend, Temperature.

1. Introduction

Climate is a complex dynamical system influenced by not only immense external factors like solar radiation, topography of the surface of the earth but also by seemingly insignificant phenomena such as butterflies flapping their wings. The idea of nondeterministic theory of climate change was proposed by Lorenz (1968, 1976). Climate controlled by external forcings can be classified in to two categories *viz*. transivity and intransivity due to independency or dependency of the climate for infinite duration upon the initial conditions. Lorenz emphasized that in changes of climate for infinite duration, a regime transition in almost-intransivity should play an important role in such a way that the transition results in some climate change without any change of external forcing. Lorenz (1976) suggested that in actual climate under remarkable seasonal forcing, the regime transition in almost-intransivity would appear in inter-annual variability. This indicates that some abrupt changes would appear in inter-annual variability of climate, if regime transition would happen to be almost-intransivity.

Detection of climate jump in time series of temperature was first reported in Unusual Weather Report (Japan Meteorological Agency, 1984). The hypothesis and concept of climate jump were proposed by Yamamoto *et al.* (1985, 1986). They have found that the time average over a few decades changed abruptly in around 1950 in time series of surface temperature of Japan and Arctic. Vargas *et al.* (1995) have considered the annual precipitation mean in Argentina and obtained a climate jump. Recently Minetti and Vargas (1998) have studied the trends and jumps in annual precipitation data of south America and found typical pattern of change in the long-term averages for 30 years consecutive series of precipitation data.

In the analysis of climate data, it is assumed that climate changes continuously. These changes are usually studied by applying different statistical techniques examining the trend. Trend in the maximum temperature, minimum temperature and the mean temperature for the Indian stations have extensively been studied by several Indian scientists *viz*. Srivastava *et al.* (1992), Rupa Kumar *et al.* (1994), Hingane *et al.* (1985) and Pant and Hingane (1988). Usually any discontinuity of climate parameter is often overlooked. Until recently, most discussion of climate change has assumed that change would occur gradually, with average temperatures slowly increasing

TABLE 1

List of stations, data availability and results of trend analysis

S. NO.	Station	Station name	Period		No. of years	Gamma calculated	Gamma tabulated	Significant trend(95%)
			From	To				
1.	42083	Simla	1901	1990	90	0.2639	0.1404	Increasing
2.	42111	Dehradun	1929	1987	59	-0.1818	0.1752	Decreasing
3.	42131	Hissar	1914	1992	79	0.1334	0.1503	No trend
4.	42147	Mukteswar	1901	1990	90	0.187	0.1404	Increasing
5.	42182	New Delhi	1901	1991	91	-0.2195	0.1396	Decreasing
6.	42189	Bareilly	1901	1988	88	0.2952	0.1421	Increasing
7.	42273	Bahraich	1901	1988	88	0.2732	0.1421	Increasing
8.	42339	Jodhpur	1901	1992	92	0.0253	0.1388	No trend
9.	42343	Ajmer	1901	1985	85	0.028	0.1447	No trend
10.	42379	Gorakhpur	1901	1991	91	0.2894	0.1396	Increasing
11.	42475	Allahabad	1901	1990	90	0.0092	0.1404	No trend
12.	43081	Nizamabad	1907	1992	86	0.1858	0.1438	Increasing
13.	43105	Kalingapatnam	1910	1992	83	0.0044	0.1465	No trend
14.	43149	Vishakhapatnam	1901	1992	92	0.4214	0.1388	Increasing
15.	43185	Musulipattam	1901	1992	92	-0.0229	0.1388	No trend
16.	43189	Kakinada	1901	1992	92	0.3645	0.1388	Increasing
17.	43213	Kurnool	1901	1992	92	0.1314	0.1388	No trend
18.	43233	Chitradurga	1901	1992	92	0.0865	0.1388	No trend
19.	43245	Nellore	1901	1992	92	0.2599	0.1388	Increasing
20.	43279	Chennai	1901	1992	92	0.2093	0.1388	Increasing
21.	43295	Bangalore	1901	1992	92	0.2269	0.1388	Increasing
22.	43329	Cuddalore	1901	1993	93	0.0243	0.138	No trend
23.	43339	Kodaikanal	1901	1992	92	0.0655	0.1388	No trend
24.	43347	Nagapattinam	1901	1993	93	0.0313	0.138	No trend
25.	43363	Pamban	1901	1993	93	0.266	0.138	Increasing
26	42516	Shillong	1902	1992	91	0.2615	0.1396	Increasing
27.	42571	Satna	1901	1992	92	0.2499	0.1388	Increasing
28.	42587	Daltonganj	1901	1993	93	0.2688	0.138	Increasing
29.	42591	Gaya	1901	1993	93	-0.3001	0.138	Decreasing
30.	42647	Ahmedabad	1901	1990	90	-0.3733	0.1404	Decreasing
31.	42675	Jabalpur	1901	1992	92	0.4568	0.1388	Increasing
32.	42704	Asansol	1921	1990	70	-0.0358	0.1613	No trend
33.	42763	Hoshangabad	1901	1992	92	0.0908	0.1388	No trend
34.	42779	Pendra	1903	1992	90	0.2035	0.1404	Increasing
35.	42807	Kolkata	1901	1990	90	0.4202	0.1404	Increasing
36.	42867	Nagpur	1901	1992	92	0.1108	0.1388	No trend
37.	42875	Raipur	1901	1992	92	0.302	0.1388	Increasing
38.	42895	Balasore	1901	1993	93	0.1992	0.138	Increasing
39.	42909	Veraval	1901	1990	90	0.3663	0.1404	Increasing
40.	43041	Jagdalpur	1909	1992	84	0.2352	0.1455	Increasing
41.	43049	Gopalpur	1901	1993	93	0.2211	0.138	Increasing
42.	43053	Puri	1901	1993	93	0.2707	0.138	Increasing
43.	43057	Mumbai	1901	1991	91	0.2767	0.1396	Increasing
44.	43063	Pune	1901	1993	93	-0.1295	0.138	No trend
45.	43110	Ratnagiri	1901	1991	91	0.222	0.1396	Increasing
46.	43117	Sholapur	1901	1991	91	0.2386	0.1396	Increasing
47.	43311	Amini	1901	1993	93	0.2361	0.138	Increasing
48.	43314	Kozhikode	1901	1993	93	0.3315	0.138	Increasing
49.	43333	Port Blair	1901	1990	90	-0.5446	0.1404	Decreasing
50.	43369	Minicoy	1926	1993	68	0.1914	0.1625	Increasing

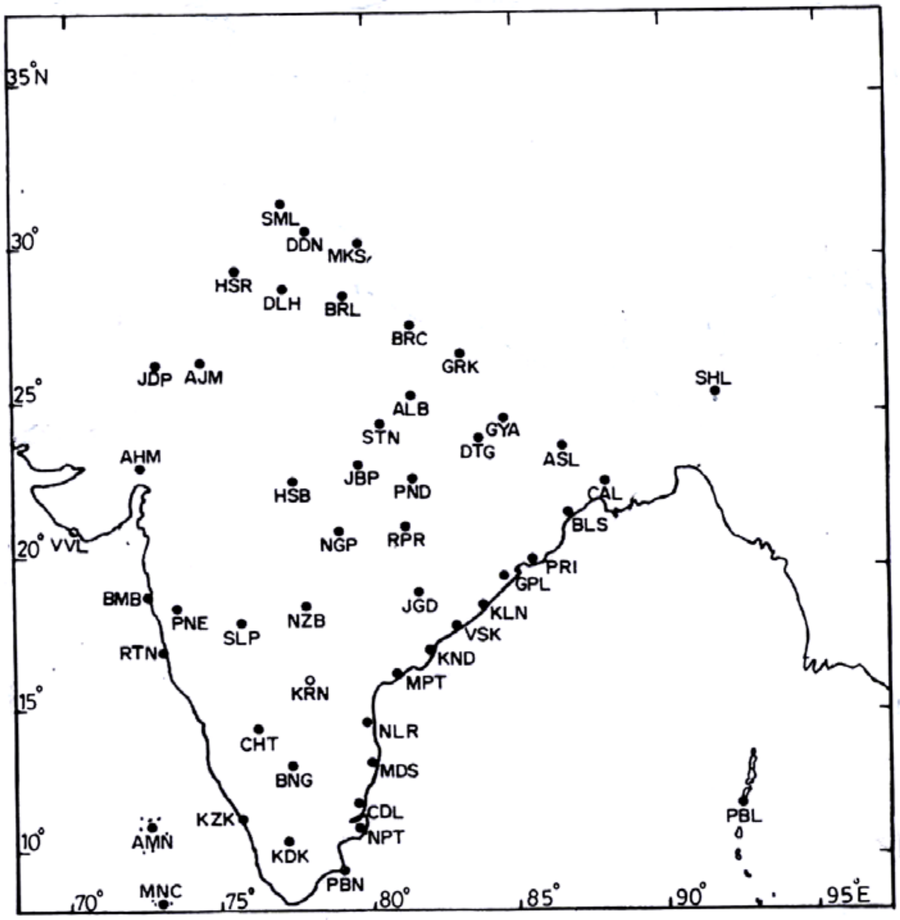


Fig. 1. Geographical locations of the stations considered in this study

over the next century. A climate jump can be statistically defined as the differences between two consecutive averages over a few decades, which is beyond a summation of the noise level for the respective period. Many of the today's models of climate change are too simplistic because they do not include such abrupt change. In the present paper, we have considered annual mean temperature of 50 well-distributed stations over India. Data, definition of climate jump, statistical tests for detecting climate jumps and detailed methodology are presented in section 2. In addition to the three tests *viz.*, test by Leith (1978), test by Yamamoto *et al.* (1985) and student '*t*' test, we have considered a significant statistical test first time in detecting climate jump. This test is more useful and appropriate as we are testing time series data, which are having auto-correlation within the data. The results and discussions are given in section 3 and section 4 ends with final conclusions.

2. Data and methodology

Mean temperature data of 50 well-distributed stations of India are considered here. Basic data have been provided by India Meteorological Department. These data were subjected to quality check as suggested by Sellers and Liu (1988). Values deviating from the mean for a given month by more than (1.76 + 0.08N)S, where N is sample size ($N \geq 5$) and S is the standard deviation of the sample, which are coming even less than 5% of the sample size are replaced by mean value. Table 1 shows the detail of the stations considered and data availability where as Fig. 1 depicts the locations of these 50 stations.

According to WMO (WMO, 1983) at least 30 years of data are required for computation of climatic averages. Therefore, 60 years of data are required to compare two climatic averages coming from consecutive two series of 30 years each.

Trend analysis is done to the mean temperature data of all 50 stations. Trends are estimated with least squares according to Eqn. 1. The slope co-efficient "b" is tested with *t*-statistic given by equation Eqn. 2.

$$\mathrm{b} = \frac{\hat{\mathrm{S}}_{xy}}{\hat{\mathrm{S}}_{xx}} \tag{1}$$

$$"t" = \frac{\mathrm{b} - \beta}{\hat{\mathrm{S}}_e} \sqrt{\frac{\hat{\mathrm{S}}_{xx}}{N}} \approx t_{N-2} \tag{2}$$

with null hypothesis $\mathrm{H}_0 = \beta \neq 0$. 'b' is the slope of the regression obtained by least square method, β is the hypothesis slope, *N* is the number of data.

$$\hat{\mathrm{S}}_{xy} = N\sum_{i=1}^{N} x_i y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i,$$

$$\hat{\mathrm{S}}_{xx} = N\sum x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2 \tag{3}$$

$$\hat{\mathrm{S}}_e = \sqrt{\frac{\hat{\mathrm{S}}_{xx}\hat{\mathrm{S}}_{yy} - \hat{\mathrm{S}}_{xy}{}^2}{N(N-2)\hat{\mathrm{S}}_{xx}}} \tag{4}$$

We have also done Mann Kendal test to see the significance in trend to each of the annual mean temperature series of 50 stations.

A discontinuity of a time series of climate parameter is referred to as a jump of the particular climate parameter. A trend is a slowly continuous increasing or decreasing process where as, a jump is discontinuous indicating a sudden change (increase/decrease). A jump can be tested by comparing the differences of means of two consecutive time series prior and after a specified year. If there is a significance difference of these two means (confirmed by applying some suitable statistical test) we may call that the series has a jump (positive or negative) in that particular reference year. There are already few studies available to test the jump in a climate series. Recent investigations show that the changes in annual mean precipitation and other variables in Argentina as a jump not as a trend (Vargas *et al*., 1995; Minetti and Vargas, 1998).

The following statistical tests are considered to study the discontinuities (jump) of climate :

(*i*) The Leith (Leith, 1978) test 'L' given as follows :

$$\mathrm{L} = \frac{\Delta\mu}{\mathrm{S}} \tag{5}$$

where, $\Delta\mu$ = changes in averages = $|\mathrm{A_b} - \mathrm{A_a}|$, $\mathrm{A_a}$ and $\mathrm{A_b}$ are averages after and before the reference year.

S = standard deviation of averages

$$= \frac{\mathrm{S}_m}{\sqrt{N}} \tag{6}$$

S_m= standard deviation of the sample

$$= \sqrt{\frac{(N-1)\mathrm{S_b^2} - (N-1)\mathrm{S_a^2}}{2N-2}}$$

$$= \sqrt{\frac{\mathrm{S_b^2} + \mathrm{S_a^2}}{2}} \tag{7}$$

Here, we have assumed that the two samples of size $N = 30$ are drawn from a normal population having same variance. $\mathrm{S_a}$ and $\mathrm{S_b}$ are the standard deviation of the samples after and before the reference year.

Jump is occurred when the signal to noise ratio L is greater than or equal to 1.0.

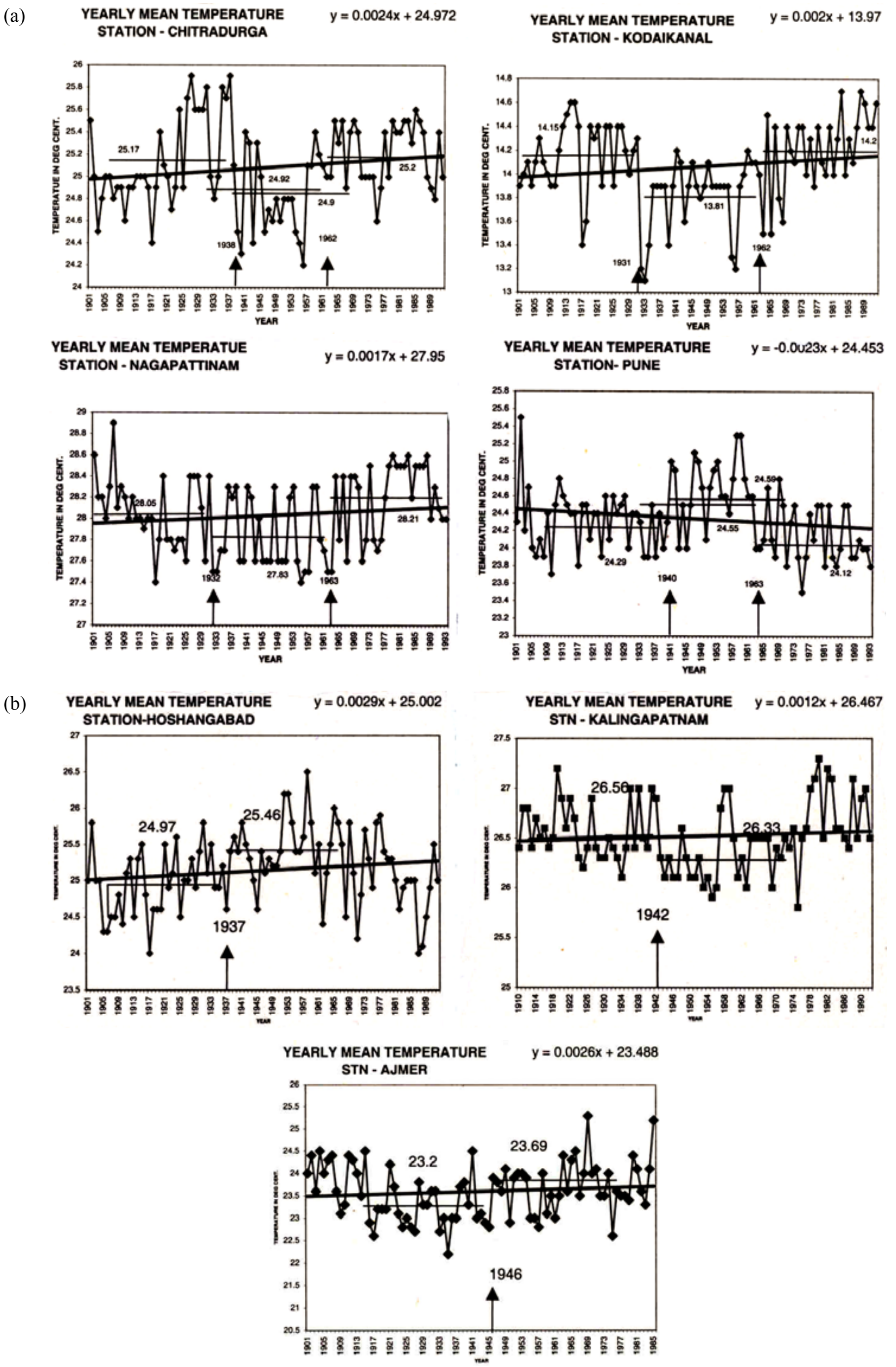
(*ii*) '*Y*' test used by Yamamoto *et al.* (1985) is given by

$$Y = \left|\frac{\mathrm{A_a} - \mathrm{A_b}}{\mathrm{C_a} - \mathrm{C_b}}\right| \qquad \text{where} \quad \mathrm{C} = \frac{\mathrm{S}_x t_q}{\sqrt{N-1}} \tag{8}$$

$\mathrm{C_a}$ and $\mathrm{C_b}$ are the confidence limits of probability (*p* %) after and before the occurrence of climate jump. S_x represents a variable whose values may be represented by $\mathrm{S_b}$ and $\mathrm{S_a}$ to define the respective confidence limits. $\mathrm{S_b}$ and $\mathrm{S_a}$ are computed for samples of size *N* before and after the reference year. t_q is the value in Student distribution with probability *q* %(100-*p*).

A discontinuity of the time series could be detected with *p*% confidence at the reference year, when signal to noise ratio '*Y*' is greater than unity.

(*iii*) Student '*t*' test for the difference between two consecutive means:



Figs. 2(a&b). Climate jump of 7 stations having no significant trend in the complete period

$$t = \frac{(\mathrm{A_b} - \mathrm{A_a}) - (\mu_b - \mu_a)}{\mathrm{S_m}(1/N_b - 1/N_a)} \qquad (9)$$

where, $\mu_b - \mu_a$ is the expected difference between $\mathrm{A_a}$ and $\mathrm{A_b}$ according to the "null hypothesis" which for this case of randomness, is set as equal to zero. N_b and N_a

(a)

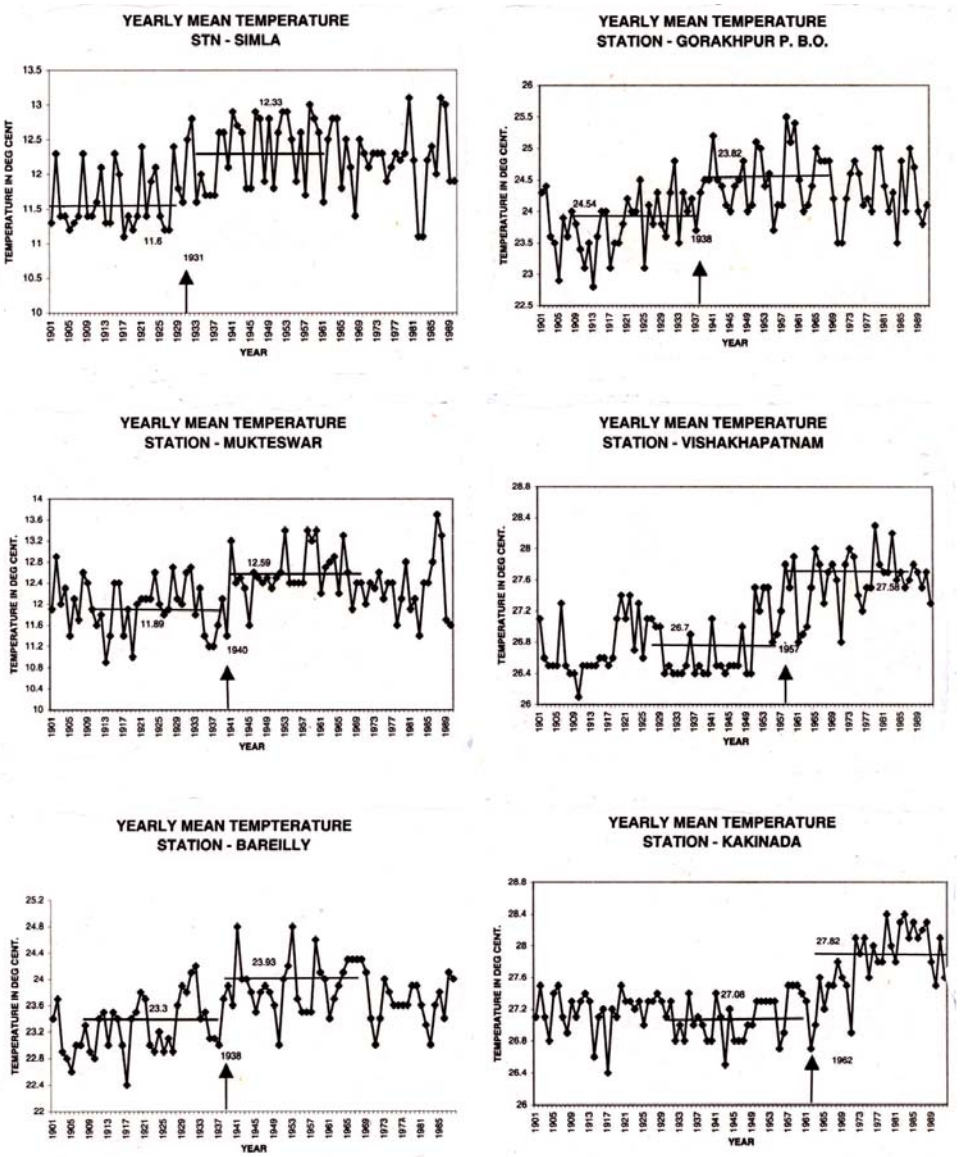


Fig. 3(a). Climate jump of 6 stations having more than 0.6° C change in 30 years averages

are the number of observations in two samples, which are equal to N here. For the "null" hypothesis of randomness, the distribution of 't' follows the student 't' distribution for $N_a + N_b - 2$ degrees of freedom. The test is based on a comparison of magnitude of 't' with the 95% probability points of 't' distribution with $N_a + N_b - 2$ degrees of freedom approximate to a two tailed form of test.

If the value of 't' lies beyond the tabulated value of 't', the difference between the two means is regarded as a climate jump.

(*iv*) The Table-look-up test [Zwiers and Storch, 1995; Storch and Zwiers, 1999] is an alternative to the conventional 't' test that avoids the difficulties of estimating an equivalent sample size. The test is more useful than student 't' test for comparison of means of two samples if the samples are drawn from a time series.

The two sample case (assuming $\sigma_x = \sigma_y$ and lag -1 correlation $\alpha_x = \alpha_y$) : to test H_0: $\mu_y = \mu_x$ using the X and Y sample of size N_x and N_y respectively, compute

$$t = \frac{\bar{x} - \bar{y}}{S_m \sqrt{\frac{1}{N_x} + \frac{1}{N_y}}} \qquad (10)$$

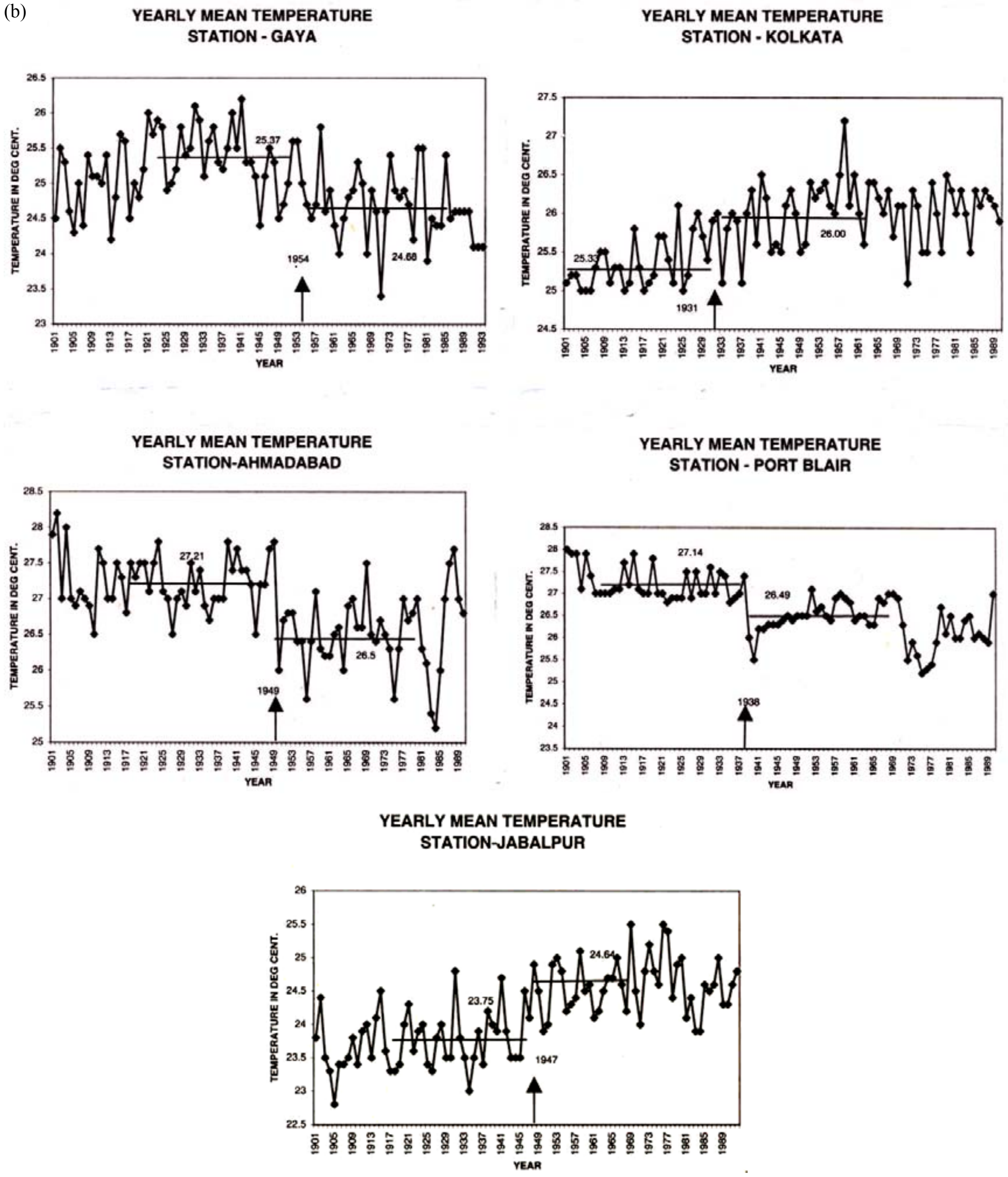


Fig. 3(b). Climate jump of 5 stations having more than 0.6° C change in 30 years averages

where, $\bar{x}, \bar{y}$ are the sample means and S_m is the pooled sample variance given by Eqn.7. The pooled sample lag-1 correlation coefficient $\hat{\alpha}$ is computed by

$$\hat{\alpha} = \frac{\sum_{i=2}^{N_x} x_i' x_{i-1}' + \sum_{i=2}^{N_y} y_i' y_{i-1}'}{(N_x + N_y - 2)S_m^2} \qquad (11)$$

where,

$$x_i' = x_i - \bar{x}, \; y_i' = y_i - \bar{y}$$

Critical value of 't' that is appropriate for a sample of size N_x + N_y, which has a lag-1 correlation $\hat{\alpha}$ is available in [Storch and Zwiers, 1999]. A discontinuity (jump) in time series is detected if $\hat{\alpha}$ exceeds the critical value.

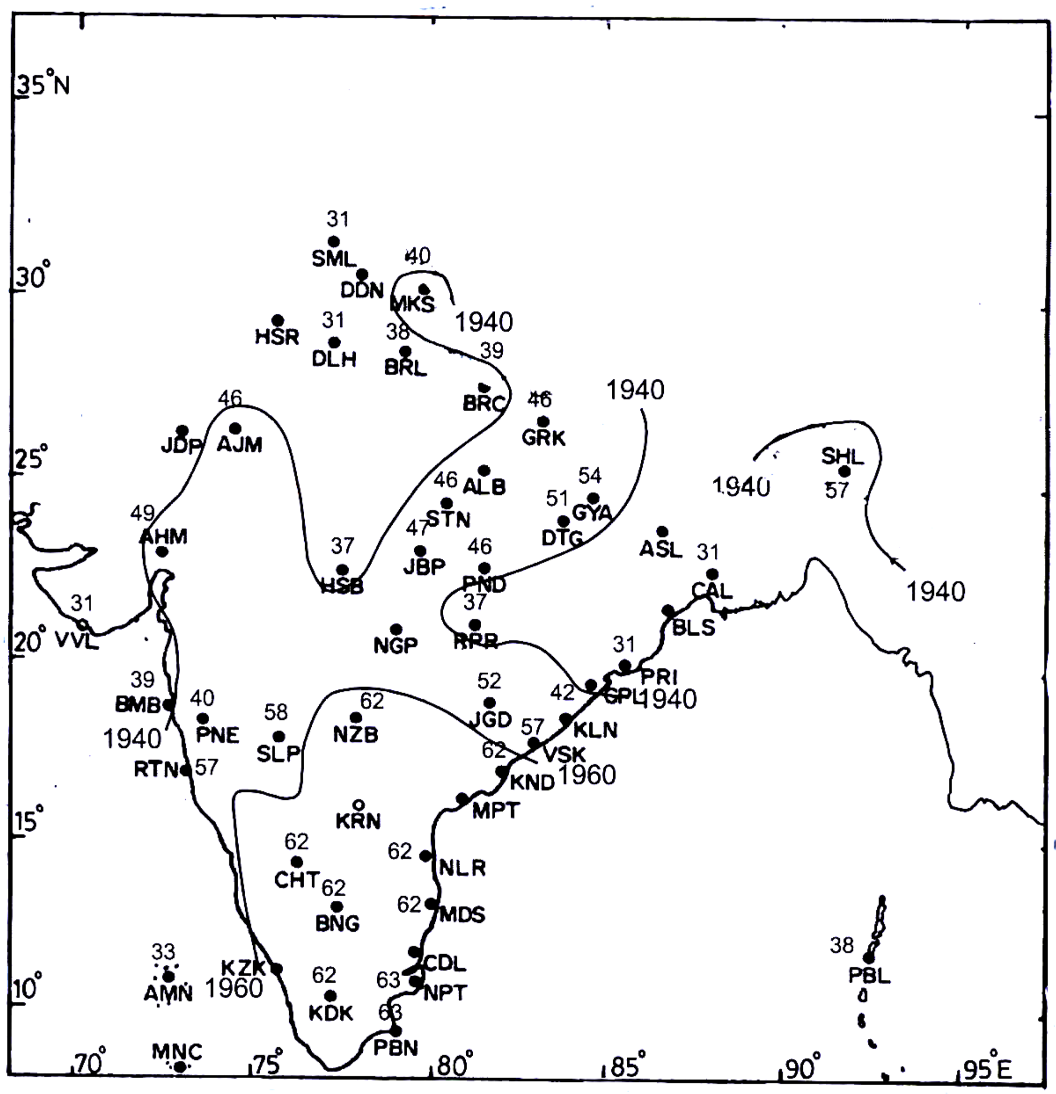


Fig. 4. Isochrones of years registering the jump in annual mean temperature. The year of the climate jump (last two digits) has been indicated against the name of the stations

3. Results and discussion

We have considered two 30 years consecutive time series of mean temperature before and after a reference year starting from the reference year 1931, since data are available from 1901. For reference year 1931, difference of means of 1901-30 and 1932-61 is tested. If all of the four tests mentioned in section 2 *i.e.*, Leith test, '*Y*' test, '*t*' test and Table-look-up test are simultaneously significant, a jump is detected. Similarly, reference year 1932 is checked by considering means of 1902-31 and 1933-62 and so on.

Mann Kendal test shows that out of 50 stations, 15 stations have no significant trend during the period 1901-93. Out of these 15 stations, Ajmer, Kalingapatnam, Chitradurga, Kodaikanal, Nagapattinam, Hosangabadad and Pune have jump in temperature data (Fig. 2). Chitradurga, Kodaikanal, Nagapattinam and Pune have two jumps both negative and positive so that over the complete period trends have become insignificant. For Pune we can see that a positive jump of temperature occurred in 1940 where mean temperature increased by 0.3° C. In 1963 the temperature over Pune had a negative jump as the mean temperature decreased by 0.42° C between two consecutive 30 years.

Fig. 3 shows the jump in temperature of 11 stations which have more than 0.6° C difference of means between two consecutive 30 years means. Maximum jump occurred in Jabalpur (0.89° C in two consecutive 30 years mean). All these stations (except one station *i.e.*, Port Blair), from Visakhapatnam, station in east coast to Shimla, station in north of the country are located north of 17° N. These reflect that sudden changes in the natural and ecosystem caused major changes or discontinuity in temperature field in the northern parts of the country than Peninsular India.

The few stations which do not show any jump or temperature discontinuity are Hissar, Jodhpur, Allahabad, Kurnool, Cuddalore, Asansol, Nagpur, Balasore, Gopalpur, Kozhikode and Minicoy. It can be inferred that the temperature of these cities have adjusted with changes in natural and managed ecosystem.

We have plotted the years registering the main changes/jumps in the mean annual temperature. Isochrones are drawn to see the spatial distribution of the jump year (Fig. 4). considered in southern Peninsular India in or around 1962. It may be seen that the climate jump was first noticed in north of the country at Simla and eastern part at Calcutta as early as in 1931. Most of stations of the north and eastern parts of the country had experienced climate jump in the decades 1931-40 where as the central India experienced climate jump in the decade 1941-50. The regions getting climate jump between 1951-60 are very small and are mostly confined in extreme north Peninsular India.. Some areas of Gujarat, Delhi and Bihar got negative climate jump between 1931-55). Further, it is interesting to find that states of Peninsular India experienced positive jump in or around the year 1962. Significantly we can conclude that around the year 1962 sudden changes in the natural and human activities might have attributed this sort of very noticeable jump.

To see whether all India mean annual temperature had a significant climate jump, we have constructed the all India mean temperature time series using these 50 stations. These time series was tested using four statistical tests for climate jump by comparing the difference of two consecutive 30 years mean for each of the reference year starting from 1931. But no jump was detected. This is probably due to the sudden changes occurred in temperature in different times over the different regions of the country as a result mean temperature of all the stations had no climate jump or discontinuity.

4. Conclusions

Changes in annual mean temperature in India showed up as a jump. The country as a whole does not show any significant climate jump. Stations like Chitradurga, Pune, Hosangabad, Kodaikanal, Nagapattinam show no significant trend but climate jumps are significantly noticed. Sudden changes in ecosystem caused by natural and human activities occurred in different time scale over the country as a result discontinuities (jump) in climate occurred in India on different time. Isochrones analysis shows that northern and eastern parts of the country experienced climate jumps earlier (1931-40), while the central India faced main changes between 1941-59 and the Peninsular India received main changes between 1960-63. 11 stations received climate jump which have more than 0.6° C difference of mean temperature between consecutive 30 years. Except Port Blair, all these stations are in the north of 17° N, which indicates that northern India received more changes in climate than Peninsular India. More studies are required in this field to find the causes, which may be the triggering mechanism for such abrupt changes in inter-annual variability in climate, which happen to be almost-intransivity.

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