Change Point Analysis of Air Temperature in India

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Abstract Change point analysis was performed on air temperature at different pressure levels in the Indian subcontinent to identify the time at which a major change in trend, if any, has occurred. Pettit test, a nonparametric test to identify change points in a time series was used for this purpose. It tests, the null hypothesis that the variable follows one or more distributions that have the same location parameter against the alternate hypothesis that a change point exists. The significance of the change point is determined and if it is greater than the considered level of 90% confidence, then, the change point is considered to be significant. The test was performed on the surface temperature data of the Indian subcontinent for the period 1949–2014, obtained from the NCEP/NCAR reanalysis data set at a resolution of 2.5°. The results of the test for the dry period indicate that the southern, northern and northeastern parts of India exhibited a significant change point in the nineteen seventies. During the wet season and the southwest monsoon season, a significant change was observed in the southern, central and eastern parts of India in the last decade. Analysis of the annual mean temperature revealed that a significant change point occurred in South India in the last decade.

Introduction

It has been observed in many studies that the global climate has taken a significant turn in the recent decades. The impact of climate change is projected to have different effects within a country and between countries. Information about such changes is required at global, regional and basin scales for a variety of purposes. According to the assessments by the Intergovernmental Panel on Climate Change (IPCC) 2001, increase in greenhouse gas concentrations caused an increase in the annual mean

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global temperature by 0.6 ± 0.2 °C since the late nineteenth century (Houghton et al. 2001). According to the estimates by the IPCC (2007), the earth's linearly averaged surface temperature has increased by 0.74 °C during the period 1901–2005 (Pachauri and Reisinger 2007). Weather reports indicate that the global mean surface temperature has risen, approximately by 0.6 °C, since 1850. It is expected that by 2100, the increase in temperature could be in the range 1.4–5.8 °C (Singh et al. 2008).

The study by Srivastava et al. (1992) on decadal trends in climate over India gave the first indication that temperature trends in India are quite different from that observed over various parts of the globe. They observed that the maximum temperatures show much larger increasing trends than a minimum temperature, over a major part of the country and an overall slightly increasing trend of the order of 0.35 °C over the last 100 years. Rupa Kumar et al. (1994) have shown that the countrywide mean maximum temperature has risen by 0.6 °C. Lal et al. (1995) suggested that increase in the annual mean minimum and maximum surface air temperatures would be of the order of 0.7–1.0 °C in the 2040s, when compared to that in the 1980s. Tabari and Hosseinzadeh Talaee (2011) analysed temperature series from 29 stations in Iran for the period 1966–2005 using the Mann–Kendall and Mann–Whitney tests. Results indicated that the annual mean temperature increased at 25 out of 29 stations, of which 17 stations showed significant trends. The analysis also indicated that most of the positive significant change points occurred first in 1972 at all stations except the coastal stations.

Bisai et al. (2014) performed change point analysis for the Krishnanagar weather observatory, West Bengal, India by applying cumulative sum chart and bootstrapping test to the time series of temperature data. They concluded that the major change point in the annual mean temperatures occurred around the year 2001. In this study, change point analysis was performed using Pettit's test for air temperature to identify the time at which major changes have occurred in this during the Indian subcontinent.

Methodology

Study Area

The study area chosen for this study consists of the Indian subcontinent, between 8° 4′ and 37° 6′ north latitude and 68° 7′ and 97° 25′ east longitude. This area contains a variety of geographical features. The Indian subcontinent is surrounded by the Arabian Sea in the west, the Bay of Bengal in the east and the Indian Ocean in the south. South India is a peninsula with two coastal lines at the boundaries and a plateau in the centre. North India occurs in the valley of the Himalayas and northeastern India is mainly the foothills and peaks of the Himalayas. There exists a wide variation in geographical features and this could result in highly varying climatic conditions. The study area is presented in Fig. 1.

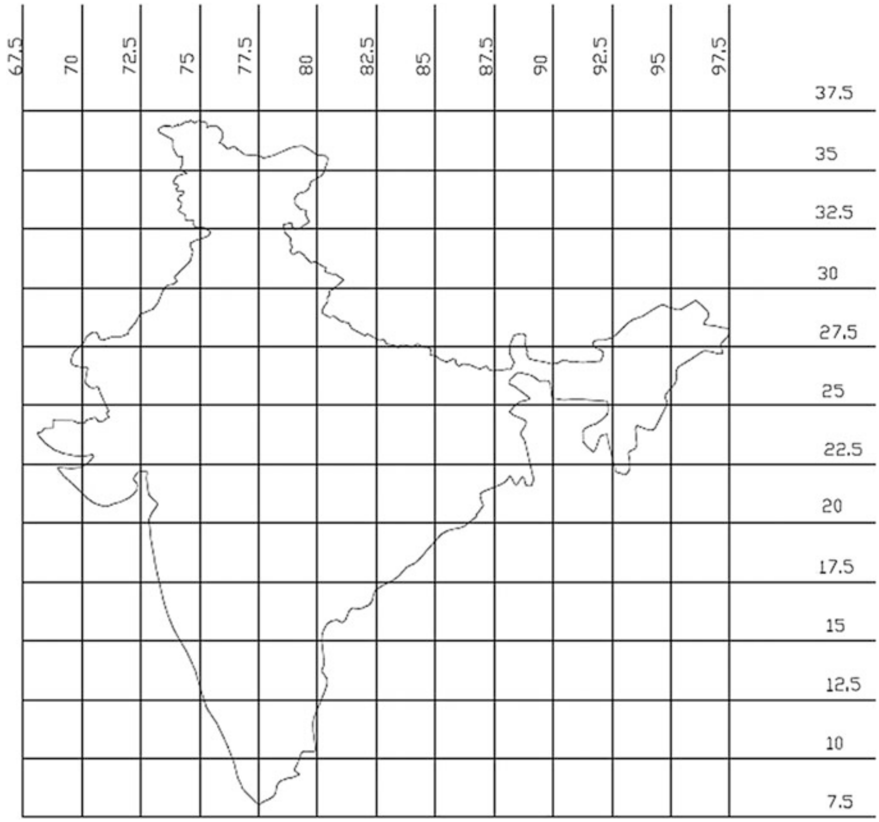

Fig. 1 Latitude and longitude of study area

Data Used

This study uses the National Center for Environmental Protection/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data for the period of 1948–2014. This is the output of an offline run of the T62 operational model in $2.5° \times 2.5°$ grid. As data assimilation has changed considerably in the satellite era, time-dependant in-homogeneities may be present. However, the NCEP/NCAR data is a reliable basis for analysis of the natural variability over the last several decades, especially in the Northern Hemisphere (Rudeva and Gulev 2011). Due to the lack of availability of observed meteorological data in extremes terrains like the north-eastern parts of India, the reanalysis data is considered most complete and a physically consistent data set (Simmonds and Keay 2000; Dell'Aquila et al. 2005). The data assimilation system uses a 3-D variational analysis scheme, with 28 sigma levels in the vertical and a triangular truncation of 62 waves which corresponds to a horizontal resolution of approximately 200 km (Kalnay et al. 1996). As the data points are available only in grids of 2.5°, the Indian subcontinent was divided into grids of the same measure and 47 data points were identified (presented in Fig. 1).

Pettit's Test

The method was proposed by A.N. Pettit in 1979. The Pettit test is a nonparametric method, used to identify a change point in a time series (Pettit 1979). Let $X_1, X_2 \ldots X_n$ be a sequence of random variables; the test statistic $U_{t,T}$ is given by

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \operatorname{sgn}(x_i - x_j) \tag{1}$$

where $\operatorname{sgn}(x) = 1$ if $x > 0$, 0 if $x = 0$, -1 if $x < 0$.

A change point is identified where the value $K_T = |U_{t,T}|$ is maximum. This is performed for each point. The significance of the obtained change point is determined using the formula

$$\rho = \exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) \tag{2}$$

If the value of this parameter is greater than the considered level of 90% confidence (0.90), then the change point is considered significant (Zhang et al. 2009).

Results and Discussions

Change Point Analysis

The Pettit's test was conducted for all grid points at various pressure levels in all seasons in the Indian subcontinent. In the dry season, at surface level, 14 points showed significant change as per Pettitt's test. 10N 77.5E, 12.5N 77.5E, 15N 75E, 25N 87.5E had a change point around the year 1976–'78. 25N 85E, 25N 92.5E, 27.5N 92.5E, 27.5N 95E had a change point around the period 1972–'73.35N 77.5E, 35N 80E had a change point in the year 2004. The other points are 27.5N 82.5E, 25.0N 82.5E, 22.5N 87.5E, 12.5N 80.0E which had a change point at 1970, 1966, 1988 and 1997, respectively. This indicates the presence of a change in trend during the period 1976–'78 in South India and 1972–'73 in northeastern India.

Similarly, a change in trend was detected in level 1000 mb in Southern and Central India during the past decade. Northern Plains had a change in the pattern of temperature during 1973–'75 at the level 850 mb. Almost all points had a change point in the period 2004–'06 at the level 500 mb. The same is illustrated in Fig. 2.

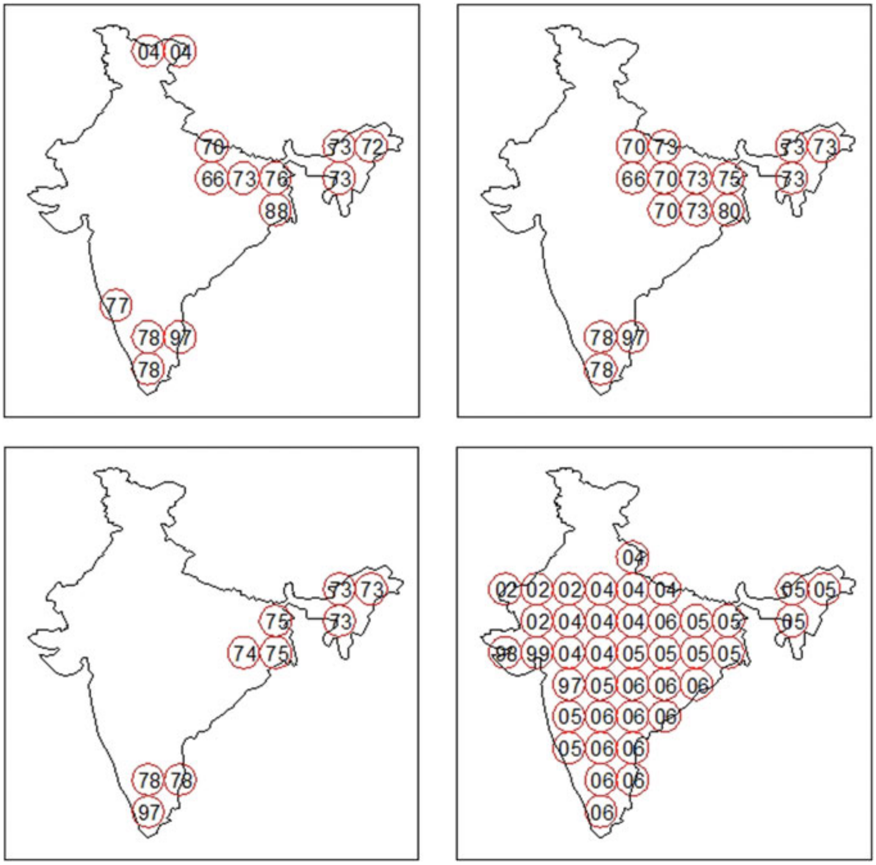

Fig. 2 Significant change points (year) in monthly mean temperature during the dry season estimated using Pettit's test (*clockwise from left top* level surface, level 1000, level 500, level 850)

For the wet season, at surface level, it can be concluded that all of southern India and eastern coastal area exhibit a major change in the trend of temperature during the past decade. At level 1000 mb, it is observed that southern India showed a significant change point in the last decade and Kashmir showed a significant change point during 1970–'71. Southern and northeastern India has a significant change point in 2004–'12 at 850 mb level. The region comprising the states of Kerala, Karnataka, Andhra Pradesh and Tamil Nadu has a change in pattern in the period 2006–'08 and the region consisting of Maharashtra, Madhya Pradesh and Orissa has a change in the period of 1976–'79 at 500 mb level (illustrated in Fig. 3).

During the southwest monsoon season, at surface level, the conclusion drawn is that all of south India, an eastern coastal region extending till West Bengal and northeast region show a significant change of pattern in the last decade. It is observed that, at 1000 mb level, a change in pattern exists in southern India, the

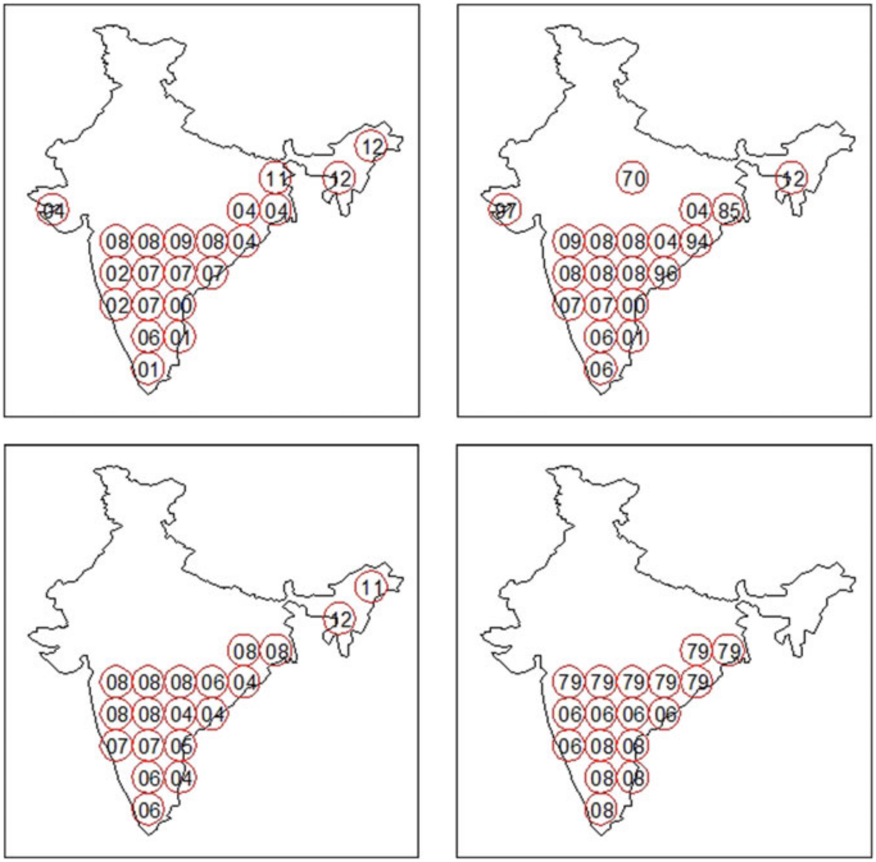

Fig. 3 Significant change points (year) in monthly mean temperature during the wet season estimated using Pettit's test (*clockwise from left top* level surface, level 1000, level 500, level 850)

eastern coastal region extending till West Bengal and northeast India during the last decade. Kashmir region showed a significant change point during the year 1971. At 850 mb level, southern India, eastern and western coastal regions and northeast India showed a significant change in the pattern of temperature during the period 2004–'12 (refer Fig. 4).

From these results, it can be observed that the major change points exist in the past decade. In order to identify any other significant pattern before this period, an annual analysis was performed till the year 1999. The monthly data was averaged to obtain annual data for the years and Pettit's test was performed. The result obtained indicates that, on a surface level, south India showed a significant change point in the period 1976–'84. Central India had a significant change of pattern in the period of 1960–'73. North and northeastern India showed a significant change point in the period 1970–'80. Similarly at 1000 mb pressure level, south India showed a

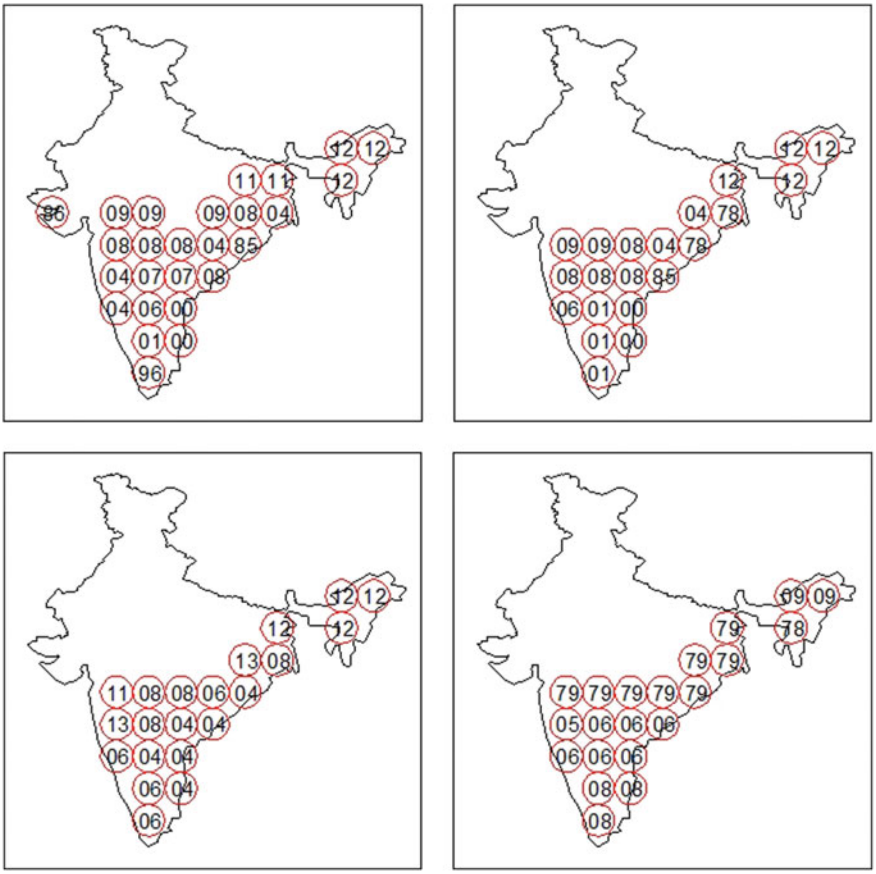

Fig. 4 Significant change points (year) in monthly mean temperature during the southwest monsoon season estimated using Pettit's test (*clockwise from left top* level surface, level 1000, level 500, level 850)

significant change point in 1976–'97, central India showed a change in pattern in the period of 1960–'74 and north and northeastern India showed a significant change point in 1970–'88. At 850 mb pressure level, south India had a change point during the period 1976–'97, central India showed a change in the period 1960–'74', whereas north and northeastern India showed a change point in the period 1970–'88. At 500 mb level, south India showed a change point in the year 1979, central India showed a change point during the period 1982–'83, north and northeastern India had a change point during the period 1957–'69. This is illustrated in Fig. 5.

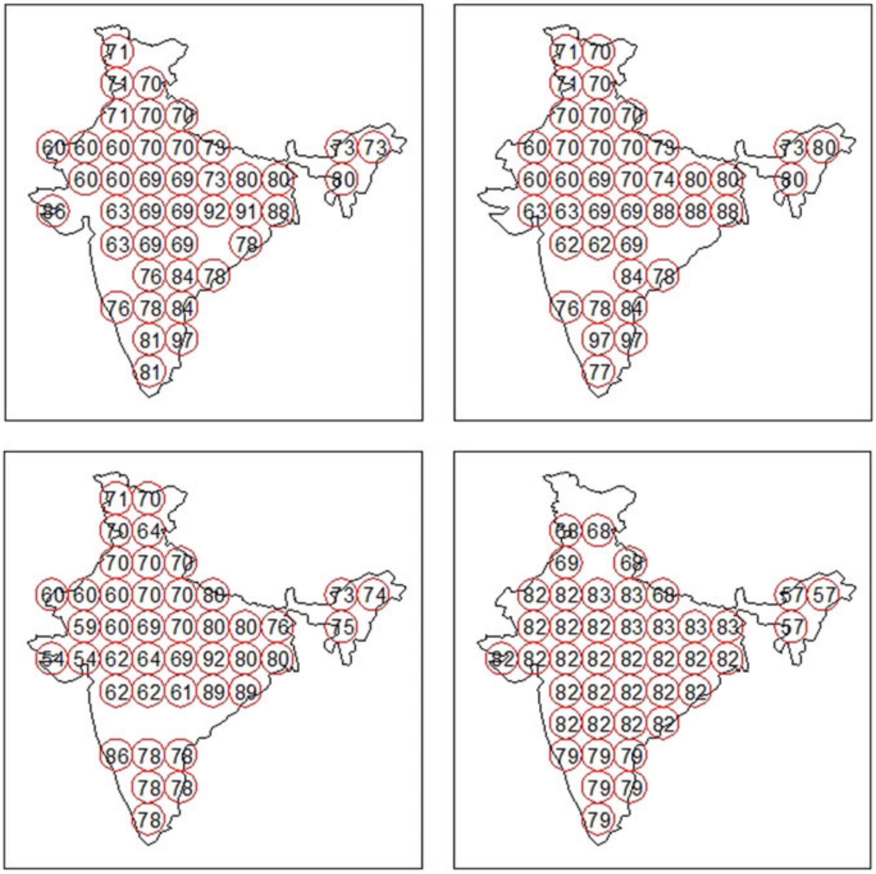

Fig. 5 Significant change points (year) in annual mean temperature (excluding 2000–2014) estimated using Pettit's test (*clockwise from left top* level surface, level 1000, level 500, level 850)

Summary and Conclusions

In this study, change point analysis using Pettit's test was performed on air temperature at different pressure levels. The test was first done on the seasonal subsets and then on the whole data taken annually.

The results indicated that except for the dry season, all other seasonal data showed a change point during the period of 2000–'14 in the southern peninsula and northeastern India. Results for the dry season showed a change point during the 1970s for this region. Further, on analysis of the data, excluding the data for the period since 2000, it is observed that South India had a change of pattern in 1974–'84, Central India experienced the same in the 1960s and North and Northeastern India experienced this during the 1970s.

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