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Change point analysis of mean annual air temperature in Iran

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ABSTRACT

The existence of change point in the mean of air temperature is an important indicator of climate change. In this study, Student's t parametric and Mann–Whitney nonparametric Change Point Models (CPMs) were applied to test whether a change point has occurred in the mean of annual Air Temperature Anomalies Time Series (ATATS) of 27 synoptic stations in different regions of Iran for the period 1956–2010. The Likelihood Ratio Test (LRT) was also applied to evaluate the detected change points. The ATATS of all stations except Bandar Anzali and Gorgan stations, which were serially correlated, were transformed to produce an uncorrelated pre-whitened time series as an input file for the CPMs and LRT. Both the Student's t and Mann–Whitney CPMs detected the change point in the ATATS of (a) Tehran Mehrabad, Abadan, Kermanshah, Khoramabad and Yazd in 1992, (b) Mashhad and Tabriz in 1993, (c) Bandar Anzali, Babolsar and Ramsar in 1994, (d) Kerman and Zahedan in 1996 at 5% significance level. The likelihood ratio test shows that the ATATS before and after detected change points in these 12 stations are normally distributed with different means. The Student's t and Mann–Whitney CPMs suggested different change points for individual stations in Bushehr, Bam, Shahroud, and Gorgan. However, the LRT confirmed the change points in these four stations as 1997, 1996, 1993, and 1996, respectively. No change points were detected in the remaining 11 stations.

1. Introduction

The analysis of change in the mean of air temperature is an important concept in climate change studies (Stocker et al., 2013). Understanding the historical changes in the air temperature is essential in water resources management, water supply prediction, and environmental studies. The change in air temperature is studied either by trend or change point analysis. Trend analysis of the air temperature has been carried out in various regions of the world. ElNesr et al. (2010) studied air temperature trends in the past thirty years in the Kingdom of Saudi Arabia. They reported a warming trend in the maximum, minimum and average temperatures throughout the year except in the winter months of November to January where non-significant cooling trends were observed. Ceppi et al. (2012) reported that the seasonal trends of temperature in Switzerland are all positive and mostly significant with an annual average warming rate of 0.35 °C per decade. Gocic and Trajkovic (2013) investigated the annual and seasonal trends of seven meteorological variables for twelve weather stations in Serbia during 1980–2010. They showed the increasing trends in both annual and seasonal minimum and maximum air temperature time series. Sun et al. (2014) studied the trend of global and regional surface air temperature and precipitation over the period of 1948 to 2010. They showed that 65.34 % of the study area exhibits significant warming trends while only 3.18 % of the area exhibits significant cooling trends. They also reported the greatest warming trends in Antarctica (0.32 °C per decade) and Middle Africa (0.21 °C per decade).

Tabari et al. (2011) studied the trends of the annual minimum, maximum and mean air temperature and precipitation for 13 synoptic stations in the west, south and southwest of Iran for the period 1966–2005. They reported a significant increasing trend in annual minimum, maximum and mean air temperature at the majority of stations, which mostly begins in the 1970s. Tabari and Talaee (2011) studied trends in minimum and maximum air temperature for 19 synoptic stations in the arid and semi-arid regions of Iran during 1966–2005. They showed increasing trend in the annual, seasonal and monthly minimum and maximum air temperature over the last decades in most of stations. Saboohi et al. (2012) showed that annual mean temperature in western and southern parts of Iran had significant positive trend.

Kousari et al. (2013) investigated trends of maximum air temperature for 32 synoptic stations in Iran during 1960–2005. They showed that there are considerable significant positive trends of maximum air temperature in warm months including April, June, July, August and September and warm seasons. Recently, Araghi et al. (2015) applied Mann–Kendall test to the discrete wavelet transform outputs in order to detect the predominant trend analysis and time scales affecting the gridded surface temperature data over Iran for the period 1956–2010. They divided the study region into 12 regular zones (of dimensions 5° × 5°) and found an increasing trend in all of the zones especially in the spring and summer seasons. The above mentioned studies indicate that air temperature has increased in most parts of Iran.

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Mann–Kendall nonparametric test has been traditionally used for trend analysis in most of previous research including the above mentioned studies. Despite previous research on air temperature trend in Iran, fewer attempts have been made in detecting air temperature change point. The goal of trend analysis is to evaluate the existence of monotonic trends but the goal of change point detection is to monitor for distributional shifts or abrupt changes in distribution of a time series data. Abrupt changes in the mean and variance of underlying distribution is evaluated in a change point problem. If a change point exists at time τ, then the distribution of observations before τ is different from the distribution of observations after τ. The change point problem has been widely considered in various areas in the previous research, such as segmentation of speech signals in audio processing (Andre-Obrecht, 1988), intrusion detection in computer networks (Lévy-Leduc and Roueff, 2009), ribonucleic acid (RNA) transcription analysis in biology (Caron et al., 2012), Gross domestic product data and percentage return series in economic studies (Jeong and Kim, 2013), fatality data in transport (Bauwens et al., 2014; Fitzpatrick, 2014), rainfall in meteorology (Beaulieu et al., 2012; Itoh and Kurths, 2011; Jandhyala et al., 2010), and hydrological time series (Buishand, 1984; Salas, 1993; Socrates Ngongondo, 2006). Reeves et al. (2007) compared change point detection techniques including the standard normal homogeneity test, Wilcoxon's nonparametric test, two-phase regression procedures, inhomogeneity tests, information and Sawa's Bayes criteria procedures. They suggested that the two-phase regression and Sawa's Bayes criteria procedures are appropriate for climate time series, however, the standard normal homogeneity procedure and its nonparametric variant are appropriate when trend and periodic effects can be diminished by using homogeneous reference series.

In this study, we apply the Student's t parametric and Mann–Whitney nonparametric change point models (CPMs) to test whether a change point has occurred in the mean of annual air temperature anomalies time series at 27 meteorological stations, which are distributed in different regions of Iran, over 55 years starting 1956. The applied CPMs in the present study have been developed by Ross (2013). To evaluate the CPM results, the likelihood ratio test (LRT), as a parametric approach, was used, which compares the data distribution before and after the detected change point.

2. Data

The monthly air temperature data were extracted from the Islamic Republic of Iran Meteorological Office web site (IRIMO; http://www.irimo.ir/). Twenty seven synoptic stations were selected for the period 1956–2010, which was the longest available period for these data sets. The quality of data is controlled by IRIMO. Air temperature data is available for more than 150 stations; however because of the effect of inhomogeneity, missing data, and inadequate data length in some stations, only around 20% of these stations were analyzed in the previous studies (Rahimzadeh et al., 2009) and current study. For example, Rahimzadeh et al. (2009) removed Khoramabad station air temperature time series from their analysis due to station relocation. In the present study, the Alexandersson test (Alexandersson, 1986; Peterson et al., 1998) was applied to test the homogeneity on a monthly basis and correct inhomogeneity in Khoramabad station. In order to perform the Alexandersson test, three candidate stations were selected among the neighboring stations with high Pearson correlation coefficient. The reference time series with the highest correlation was chosen to estimate the adjusted temperature time series for Khoramabad station.

The monthly air temperature anomalies are computed with respect to the whole period monthly average to eliminate seasonal variations. The annual air temperature anomalies time series (ATATS) are then computed for the change point analysis. The selected stations are distributed over different regions of Iran. Fig. 1 shows the location map for the synoptic stations. Iran is mostly categorized in arid or semi-arid climates with more dryness severity over southern and eastern districts.

The country lies within the western Alpine-Himalayan chains with two major mountain systems, the Alborz and Zagros ranges. These two mountain ranges have significant effect on the Iranian atmospheric systems. They also play an influential role in determining the amount and distribution of precipitation over the country. The areas of the country located in the Alborz and Zagros ranges have cold and snowy winters (December-January-February) due to higher elevation; while southern parts of the Zagros mountain have moderate and rainy winters (Saboohi et al., 2012).

3. Methods

3.1. Change point models

Let $X_1, \ldots, X_n$ be a finite sequence of independent random variables and x_t be a particular realization of X_i observed at time $t = i$, to test whether a change point has occurred at some particular time $\tau = k$, the observed time series is divided into two subseries $\{x_1, \ldots, x_k\}$ and $\{x_{k+1}, \ldots, x_n\}$, then, a two sample hypothesis test is used to identify whether these two subseries have equal means. In the parametric content, the hypothesis of the change point test can be written as $H_\circ : X_t \sim F_\circ(x, \theta_\circ)$, for $t = 1, 2, \ldots, n$, against $H_1 : X_t \sim \begin{cases} F_\circ(x, \theta_\circ) & \text{if} \quad t = 1, 2, \ldots, k, \\ F_1(x, \theta_1) & \text{if} \quad t = k+1, k+2, \ldots, n, \end{cases}$ where θ_i; $i = 0, 1$ denotes the unknown parameters of each distribution. The above null hypothesis represents a single distribution, $F_\circ$, for the whole time series. Let $N_{k,n}$ represents an appropriate test statistic to test whether the means of two subseries are equal (i.e., $\theta_i = \mu_i$; $\mu_\circ = \mu_1$). If the observations are assumed to follow the normal distribution, the appropriate test statistic, $N_{k,n}$, will be Student's t test (Hawkins et al., 2003). Whenever no information is available about the distribution of the observed data (e.g. the data is skewed or the sample size of divided data is small), a nonparametric test such as Mann–Whitney test is used to detect the change point. A change point is detected at time k, if $N_{k,n}$ is more than quantile t-distribution. The value of k is unknown since no information is available concerning a time of the change point. So, the unknown change point k should be estimated.

Pettitt (1979) suggested computing $N_{k,n}$ for all values of $k = 2, \ldots, n-1$ and then using the maximum value. It is concluded that the time series have a change point, if the maximum value of $N_{k,n}$ (i.e., $N_n = Max_k N_{k,n}$) is more than the chosen threshold, h_n. Ross (2013) used standardized statistic to detect the change point as follows

$$N_n = \left| Max_k \frac{N_{k,n} - \mu_{N_{k,n}}}{\sigma_{N_{k,n}}} \right|, \; 2 \le k \le n-1,$$

where $\mu_{N_{k,n}}$, $\sigma_{N_{k,n}}$ are the mean and standard deviation of the test statistic $N_{k,n}$, respectively. The distribution of $N_{k,n}$ has been derived in the following studies. Hawkins (1977) derived this distribution when the test statistic $N_{k,n}$ associated with the Student's t. Also, Pettitt (1979) derived the distribution for Mann–Whitney statistics, and proposed a general procedure for asymptotically bounding N_n for other classes of test statistic which are given by Worsley (1982).

Nevertheless, when the sample size is small, the asymptotic distribution of N_n is not accurate. Ross (2013) used numerical Monte-Carlo simulation to estimate N_n distribution for all the above cases, and in particular when the sample size is small. He developed the change point model (CPM) package in R and implemented the parametric and nonparametric change point detection methods. Here, the Student's t parametric and Mann–Whitney nonparametric test of the CPM were applied to statistically test whether a change point has occurred in the air temperature anomalies time series.