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STATISTICAL ANALYSIS OF TEMPERATURE CHANGES IN ISRAEL: AN APPLICATION OF CHANGE POINT DETECTION AND ESTIMATION TECHNIQUES

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ABSTRACT

The main goal of this study is to present and apply recently developed nonparametric change point detection and estimation techniques for confirming patterns of regional changes in temperature. Utilizing these methods, monthly temperatures (mean, mean maximum, mean minimum) and diurnal temperature ranges in different regions of Israel have been investigated over a period of 37-years, (1967-2003). The results were supported also by traditional statistical methods. The temperature and the diurnal temperature range analyses reveal a complex pattern of change. In particular, we found an increase in the monthly mean temperatures in the warm season in all areas of Israel approximately from the mid-1980s to the mid-1990s, namely, the summers have become warmer. Also detected was a significant increase in the monthly mean minimum temperature in Israel's coastal plain area for all months of the year. Whereas, in mountainous and desert areas a significant increase in the monthly mean minimum temperature was detected only in months of the warm season. The winters have become warmer in the Israeli coastal plain and have not significantly changed in its mountainous and desert areas. In addition, in Israel's coastal plain the monthly mean DTRs are decreasing, while in mountainous and desert areas the situation is reversed, that is, monthly mean DTRs are increasing.

KEYWORDS: Regional Climatic Changes, Diurnal Temperature Range, Change Point Analysis, Temperature Trends.

1. INTRODUTION

Energy security and global warming are analyzed as 21st century sustainability threats (Nel and Cooper, 2009). Today, the scientific consensus is that global warming is occurring, although political and public debate continues. There seems to be a general agreement among many scientists that global surface temperature has been increasing over the past 100 years by 0.3-0.6 ^{0}C, presumably due to the enhanced greenhouse effect, caused as a result of the increasing concentration of carbon dioxide and other greenhouse gases in the atmosphere. Such gases absorb infrared radiation emitted by the Earth's surface rather than letting it through and thus act as blankets over the surface keeping it warmer than it would otherwise be (Ben-Gai *et al*., 1999; Houghton, 2005). While changes in the global monthly mean surface temperature are a useful indicator of climate change and variability, changes in the monthly mean maximum and monthly mean minimum temperatures provide more information than the monthly mean alone. This is because trends in the mean surface temperature can be due to changes in either the maximum or minimum temperatures, or relative changes in both. An additional useful indicator of climate change is the diurnal temperature range (DTR). Over the last 50 years, observed surface warming over land has been associated with relatively larger increases in the daily minimum temperatures than in the maximum temperatures, though both show significant increases. Hence, there has been a decrease in the observed DTR over land during the last 50 years. This decrease was not observed to be spatially uniform (Braganza *et al.*, 2004). It was reported that the DTRs are decreasing over large areas of the globe.

Results presented by several researchers at the Minimax workshop confirmed this general impression even though many observations may be problematic. New maps of DTR trends were presented and these seem to indicate that certain areas are exceptional since they do not show the negative trends found at most other places around the globe. One of these areas covers the North Sea region including the British Isles (Kaas and Frich, 1995).

Note that since climate conditions vary markedly over short distances, determination of the global average temperature of the Earth's surface is a very complicated task. The difficulty in detecting global temperature trends was clearly recognized in the US National Research Council report, 1983. A suggestion was made that this difficulty might be circumvented by a technique called "fingerprinting". The idea behind this approach is to analyze patterns in regional climate rather than in the global average temperatures. Henceforth, the statistical analysis of regional variations in temperature trends has been dealt with extensively in meteorological and climatological literature. Many studies have been conducted to assess the regional climate of some Southwest Asian countries such as Bahrain, Syria, and the Arab region. The results of these studies have clearly shown the climatic variability in these regions as a result of human interference to the ecosystems (Kousari *et al*., 2010). Kousari *et al*. (2010) studied climatic changes in eastern and central areas of Iran and, to some extent, the northern parts. The monthly and yearly change trends in the minimum, maximum and mean temperatures at 26 synoptic stations in Iran were surveyed over a 55-year period. The results showed the same temperature changes at the central eastern and northern stations. Most of the stations in Zagros showed non significant temperature changes. The upward trend of minimum air temperature had an effect in increasing the mean air temperature in the stations with temperature ascending trend. This effect of minimum temperature was significantly more than that of the maximum temperature. In general, the warm season of Iran has shown more climatic changes than the cold one.

Several studies regarding the long-term variations and trends in the surface air temperatures have been carried out for the Mediterranean basin and the surrounding countries, particularly during the last fifteen years. Note that the Mediterranean region is especially sensitive to climatic changes, since extreme temperatures and water shortage are health issues of serious concern, and the local economies are strongly dependent on agriculture and summer tourism. The Mediterranean climate is the focus of a number of circulation influences: the North Atlantic Oscillation, the South Asian Monsoon, the Siberian High-Pressure System and the Southern Oscillation (Good *et al*., 2008). Ben-Gai *et al.* (1999) have analyzed daily maximum and minimum temperatures at 40 stations in Israel to detect long-term trends and changes in temporal and spatial distribution patterns during the second half of the 20th century. The authors concluded that the seasonal temperature range exhibits a trend of increase: the summers have become warmer while the winters have become colder. The increase in the minimum summer temperature is more pronounced than the increase in the maximum temperature, while the decrease in the maximum temperature in winter is greater than the decrease in the minimum, thus resulting in a significant decline in the diurnal air temperature range in both seasons. It appears also that the frequency of occurrence of extreme temperature events, with lower winter and higher summer temperatures, has increased. Brunetti *et al.* (2000) found a positive trend in both the monthly average maximum and minimum temperature series in Italy over the period 1865-1996, which was greater in southern Italy than in northern Italy. Hasanean (2001) investigated trends and periodicity of surface air temperature series in the Eastern Mediterranean. Based on a series taken over one hundred years at four synoptic weather stations, and over fifty years at four additional stations, this study has revealed increasing and decreasing surface temperature trends. These trends, however, are only significant for Malta, Jerusalem and Tripoli at the 99% confidence level (positive trends), and for Amman at the 95% confidence level (negative trend). Türkes and Sümer (2004) studied spatial and temporal patterns of trends in the DTRs and the role of maximum and minimum temperatures in the year-to year variability and the long-term trends of the DTRs in Turkey over the period 1929-1999. In particular, they pointed out that the daytime maximum temperatures have shown weak warming and cooling in comparison with the significant warming of the nighttime minimum temperatures in many regions of Turkey and over most seasons. In addition, the DTRs have significantly decreased in most of the urbanized and rapidly urbanizing regions of Turkey throughout the seasons except partly in winter, without showing an apparent north/south (west-east) and land/sea gradient. Maheras *et al.* (2006) examined the spatial and temporal relationship between temperature extremes in the Greek area with regional atmospheric circulation by using daily maximum and minimum temperature series obtained from 20 Greek stations evenly distributed over Greece over the period 1958-2000. Particularly they found that there was an overall interannual increase (decrease) in maximum (minimum) extreme temperatures over the Greek area, with spatial and seasonal variations. Also Good *et al.* (2008) identified significant changes in the regional climate in and bordering the Aegean during 1961-2002 by investigating a very large number of parameters describing the surface temperature climate measured at 9 Greek island and coastal stations.

The common statistical instruments used to analyze temperature trends during the last 40-50 years are Kendall’s tau and Spearman’s rank correlation coefficients, a simple linear regression and a two-phase regression, in which the linear term associated with a continuous exposure in a standard linear regression is replaced by a two-segmented linear function with an unknown change point (Solow, 1987; Kaas and Frich, 1995; Ben-Gai *et al.,* 1999; Hasanean, 2001; Braganza *et al*., 2004; Kousari *et al.,* 2010). It can be presumed that ignoring a possible change in temperature over the last few decades as well as estimating a change point without testing its existence may yield erroneous conclusions (Gurevich and Vexler, 2005).

This article aims to provide and apply efficient recently developed nonparametric change point detection and estimation techniques for confirmation patterns of regional temperature changes. Utilizing these methods, we studied monthly temperatures (mean, max, min and diurnal temperature range) in different regions of Israel between the years 1967-2003. Monte Carlo experiments were carried out to obtain the p-values of the proposed tests. The results were supported also by traditional statistical methods.

The paper is organized as follows. In Section 2, we introduce the climatic data considered and the change point detection and estimation methodologies. In Section 3, a step by step application of the proposed change point techniques is outlined, as well as traditional statistical tools for two representative examples. Section 4 presents final computational results of the proposed statistical analysis for all the data considered accompanied by short comments and conclusions. Concluding remarks are provided in Section 5.

Figure 1. Israel's map and the distribution of the 6 weather stations:
1. Mount Canaan, 2. Sde- Dov, 3.Beit-Dagan, 4. Jerusalem, 5.Hatzerim, 6. Eilat

2. MATERIALS AND METHODOLOGY

2.1. Database

The climatic data from 6 synoptic weather stations of the Israeli Meteorological Service were used in this study (Figure 1). The monthly mean, mean minimum, mean maximum temperatures and monthly mean DTRs of 37 years (1967-2003) were taken from the stations' data. It should be stated that the stations are spread out over quite different climatic regions, even though the total N-S distance is less than 500 km. (Ben-Gai *et al*., 1999).

2.2. Methodology: The Change Point Detection and Estimation Techniques

Since the mid twentieth century, the retrospective change point problem has been extensively addressed in statistics and engineering literature (Chernoff and Zacks, 1964; James *et al*., 1987; Gombay and Horvath, 1994, Gurevich and Vexler, 2005, 2010). This problem is directly connected to process capability and is important in biostatistics, education, economics and other fields (Sen and Srivastava, 1975). We believe that the climatology is an additional natural field of application for the change point problem since during the last few decades it has become very important to test suspicions regarding possible changes in temperature, humidity and analyze different climate trends over time.

Formally, the problem is that of a hypothesis testing:

H_0, the null: $X_1, X_2, ..., X_n \sim F_1$ versus (1)
H_1, the alternative: $X_i \sim F_1$, $X_j \sim F_2$, $i = 1, ..., \nu - 1$, $j = \nu, ..., n$,

where $X_1, X_2, ..., X_n$ is a sample of independent observations, F_1 and F_2 are distribution functions with density functions f_1 and f_2, respectively. The distribution functions F_1 and F_2 are not necessary known. The unknown parameter ν, $2 \le \nu \le n$, is called a change point. In accordance with the statistical literature, the problem (1) has been investigated in parametric and nonparametric forms, depending on assumptions regarding the distribution functions F_1 and F_2. In the parametric case of (1), it is assumed that the distribution functions F_1 and F_2 have known forms that can contain certain unknown parameters (James *et al.,* 1987; Gombay and Horvath, 1994). In the nonparametric case of (1), the functions F_1, F_2 are assumed to be completely unknown (Wolfe and Schechtman, 1984; Ferger, 1994; Gurevich, 2006).

The parametric case of testing the change point problem (1) has been dealt with extensively in both the theoretical and applied literature (Chernoff and Zacks, 1964; Sen and Srivastava, 1975; James *et al.,* 1987; Gombay and Horvath, 1994; Gurevich and Vexler, 2005; 2010). However, we would like to avoid assumptions regarding distributions when considering the climate observations over time (e.g., monthly mean temperatures or humidity over several years). Therefore, this paper concentrates on the nonparametric form of the problem.

When the problem (1) is stated nonparametrically, the common components of change point detection policies are proposed to be based on signs and/or ranks and/or U-statistics (Wolfe and Schechtman, 1984; Ferger, 1994; Gombay, 2001; Gurevich, 2006). Bhattacharyya and Johnson (1968) focused on the problem (1) with the unknown distributions $F_1(x)$, $F_2(x) = F_1(x - \beta)$, $\beta > 0$. The authors suggested rejecting H_0, for large values of the statistic $\sum_{k=2}^{n} U_{k-1,n-k+1}$, where $U_{k-1,n-k+1} = \sum_{i=1}^{k-1} \sum_{j=k}^{n} I(X_i \le X_j)$, ($I(\cdot)$ is the indicator function), is the Mann-Whitney statistic for two samples of respective sizes $k-1$ and $n-k+1$. Setting the problem (1) in a similar manner to Bhattacharyya and Johnson (1968), Sen and Srivastava (1975) suggested rejecting H_0, for large values of the statistic

$$D = \max_{2 \le k \le n} \left\{ \left[U_{k-1,n-k+1} - (k-1)(n-k+1)/2 \right] / \left[(k-1)(n-k+1)(n+1)/12 \right]^{\frac{1}{2}} \right\} \tag{2}$$

For the same problem, Pettitt (1979) used the statistic

$$\max_{2 \le k \le n} \left\{ -\sum_{i=1}^{k-1} \sum_{j=k}^{n} Q_{ij} \right\}, \; Q_{ij} = sign(X_i - X_j) = \begin{cases} 1 & X_i > X_j \\ 0 & X_i = X_j \\ -1 & X_i < X_j \end{cases}$$

to propose a change point detection policy. Wolfe and Schechtman (1984) showed that this statistic can be presented as

$$K = 2 \max_{2 \le k \le n} \left\{ U_{k-1,n-k+1} - (k-1)(n-k+1)/2 \right\}. \tag{3}$$

Gurevich (2009) modified the statistic proposed by Bhattacharyya and Johnson (1968) and suggested rejecting H_0 for large values of the statistics

$$MD = \sum_{k=1}^{n-1} \frac{U_{k,n-k} - k(n-k)/2}{\sqrt{k(n-k)(n+1)/12}}, \tag{4}$$

$$MK = \sum_{k=1}^{n-1} \left(U_{k,n-k} - k(n-k)/2 \right). \tag{5}$$

Csorgo and Horvath (1988) have very slightly modified the statistic (2) and evaluated asymptotically $(n \to \infty)$ the type I error of the corresponding test. Ferger (1994) and Gombay (2001) studied the asymptotic behavior of U-statistics, in particular, the asymptotic properties of the test based on statistic (3). Gurevich (2009) evaluated asymptotically $(n \to \infty)$ the type I error of the tests based on the statistics (4), (5). Wolfe and Schechtman (1984), Gurevich (2006, 2009) as well as Gurevich and Vexler (2010) compared the powers of various nonparametric retrospective tests for the problem (1). Their study confirmed that the tests based on statistics (2)-(5) are usually very efficient, especially for stochastically ordered alternatives. These tests provide rather high powers even for average and small sample sizes ($n \approx 40$, $n \approx 20$) with insignificant real changes in the observations' distributions. Moreover, it turned out that there is no globally preferable test. For $\nu \approx n/2$ it seems that the test based on the statistic (3) is better than the test based on the statistic (2); and for values of ν close to edges ($\nu \approx 2$ or $\nu \approx n$), the test based on the statistic (2) is better than the test based on the statistic (3). The tests based on the statistics (4) and (5) are more powerful than the test based on (2) but are inferior to the test based on (3), for $\nu \approx n/2$. For ν that is close to edges, the tests based on (4), (5) are more powerful than the test based on (3) but are inferior to the test based on (2). The final conclusion was that that the tests based on the statistics (2)-(5) demonstrate a good performance even for average sample sizes ($n \approx 40$) and can be recommended for practical application. Note that, under H_0 the distribution of the statistics (2)-(5) does not depend on the distribution of the observations. That is, the tests based on these statistics are exact and corresponding critical values can be tabulated for fixed sample sizes and any desirable significance level.

When the two-sided alternative $F_2(x) = F_1(x - \beta)$ with $\beta \neq 0$ is assumed, the absolute values under the operator max in the statistics (2) and (3) and absolute values of the statistics (4), (5) should be considered (e.g., Gurevich and Vexler, 2010). Thus, the tests for the two-sided alternative reject H_0 for large values of the statistics

$$DD = \max_{2 \le k \le n} \left| U_{k-1,n-k+1} - (k-1)(n-k+1)/2 \right| / \left[(k-1)(n-k+1)(n+1)/12 \right]^{\frac{1}{2}}, \tag{6}$$

$$KK = 2 \max_{2 \le k \le n} \left| U_{k-1,n-k+1} - (k-1)(n-k+1)/2 \right|, \tag{7}$$

$$MDD = \left| \sum_{k=1}^{n-1} \frac{U_{k,n-k} - k(n-k)/2}{\sqrt{k(n-k)(n+1)/12}} \right|, \tag{8}$$

$$MKK = \left| \sum_{k=1}^{n-1} \left(U_{k,n-k} - k(n-k)/2 \right) \right|. \tag{9}$$

These tests, as well as similar tests for the one-sided alternatives, are exact and corresponding critical values can be tabulated for fixed sample sizes and any desirable significance level.

While the literature on the change point relies mainly on testing the hypotheses (1), rather scant work has been done on the problem of estimating the change point ν. Gurevich and Vexler (2005, 2010) showed that, in general, the process of estimating the change point parameter ν should be started if necessary, provided that just the null hypothesis of (1) is rejected. When H_0 is rejected, the issue of estimating the unknown parameter ν can be stated. Borovkov (1999) as well as Gurevich and Vexler (2005) investigated different estimators of the change point parameter ν in a parametric framework. Ferger (2001) studied the behavior of change point estimators in a nonparametric framework under the null hypothesis. Gurevich and Raz (2010) considered several nonparametric change point estimators as the maximizing point of the statistics (2), (3), (6), and (7). They conducted a broad Monte Carlo study comparing the behavior of these estimators and investigating their properties. Simulation results presented in Gurevich and Raz (2010) confirm the efficiency of the proposed estimators even for small and average sample sizes ($n \approx 40$). However, the performance of the estimators based on the statistics (2) and (6) seems to be slightly better than that of the other presented estimators. Thus, for the one-sided alternative (when one assumes the observations after a possible change are stochastically larger than before the change) the authors have recommended the estimator based on the statistic (2):

$$\hat{\nu}_D = \arg\max_{2\le k\le n}\left\{\left[U_{k-1,n-k+1} - (k-1)(n-k+1)/2\right]/\left[(k-1)(n-k+1)(n+1)/12\right]^{\frac{1}{2}}\right\}. \tag{10}$$

It is also recommended to apply the estimator based on the statistic (6):

$$\hat{\nu}_{DD} = \arg\max_{2\le k\le n}\left|U_{k-1,n-k+1} - (k-1)(n-k+1)/2\right|/\left[(k-1)(n-k+1)(n+1)/12\right]^{\frac{1}{2}} \tag{11}$$

when the two-sided alternative is considered.

3. APPLICATION

In this section, the proposed change point methodology was applied as well as traditional statistical tools to analyze the considered climatic data obtained over 37 years (1967-2003). For the sake of the presentation's simplicity we introduce here the detailed analysis of September's mean maximum temperatures from weather station no. 3 (near Rishon LeZion) and August's mean DTRs from the weather station no. 6 (Eilat). The final results (without all intermediate computational details) of the similar analyses for the rest of the data are presented in Section 4.

3.1. An analysis of September's mean maximum temperatures from the weather station no. 3

Following Ben-Gai *et al.* (1999) one can expect an increase in September's mean maximum temperatures. Therefore, the change point tests described in Section 2.2 for a one sided alternative based on the statistics (2)-(5) were applied. The following values of these statistics were straightforwardly obtained:

$$D = 2.97,\ K = 170,\ MD = 51.59,\ MK = 1448$$

As noted in Section 2.2, under the null hypothesis the distribution of the statistics (2)-(5) does not depend on the distribution of the observations. Therefore, p-values of the tests based on the statistics D, K, MD, MK can be evaluated as $P_{X_1,\dots,X_{37}\sim Unif(0,1)}(D > 2.97)$, $P_{X_1,\dots,X_{37}\sim Unif(0,1)}(K > 170)$, $P_{X_1,\dots,X_{37}\sim Unif(0,1)}(MD > 51.59)$, $P_{X_1,\dots,X_{37}\sim Unif(0,1)}(MK > 1448)$, respectively. To calculate these p-values the following *Monte Carlo* experiments were conducted: 25,000 samples $X_1,\dots,X_{37}$ were taken from the uniform $Unif(0,1)$ distribution. For each sample, the statistics D, K, MD, MK were evaluated and proportions of cases when these statistics exceed the values 2.97, 170, 51.59, 1448, respectively, served as the *Monte Carlo* estimates of the corresponding p-values. Thus, the simulated p-values of the tests based on the statistics D, K, MD, MK were found to be 0.01, 0.02, 0.02, 0.02, respectively. Consequently, since the p-values of all four tests are less than 5% the conclusion is that there was a change in the distribution of the observations.

In the general case, we suggest to tentatively conclude that there was a change in the distribution of the observations if at least one of the above four p-values is less than 5%. The next stage would be estimating the date of change by virtue of the estimator (10). However, for the sake of correctness, we propose to use the standard two sample Wilcoxon test as well as the Student's t-test for verification that the temperatures from the two defined periods (before and after the estimated date) are indeed differently distributed.

Straightforwardly using (10), $\hat{\nu}_D = 1998$ was obtained for the considered data. Applying the Wilcoxon test and the Student's t-test for two samples of observations (the considered temperatures in the years 1967-1997 and 1998-2003), the one sided p-values of the tests are found to equal 0.00 and 0.01, respectively. Thus, the final conclusion is that at 1998 there was a change in September's mean maximum temperatures measured at the weather station no. 3 and the temperatures after the change are significantly higher than before the change. Figure 2 depicts the observations indicating their mean and standard deviation as well as the first observation after the change.

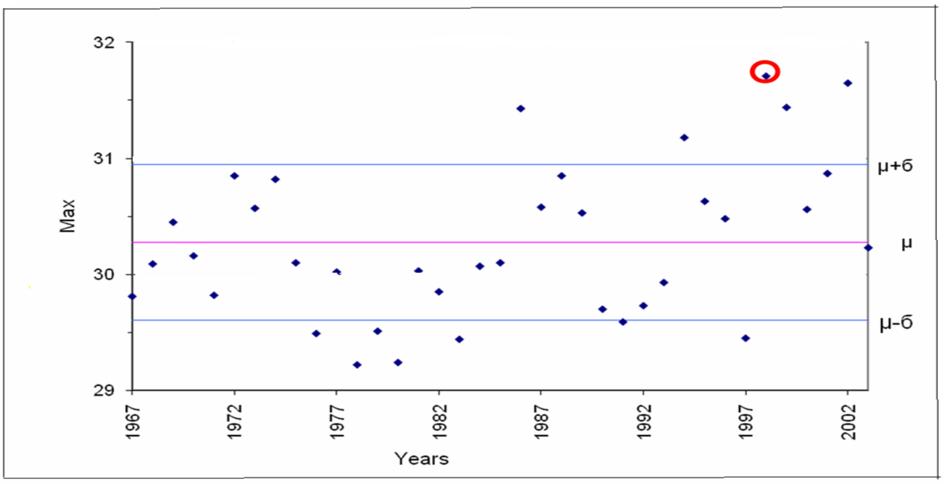

Figure 2. September's mean maximum temperatures between the years 1967-2003 obtained at the Beit-Dagan weather station, μ and σ denote the sample mean and standard deviation, respectively.

It is important to note that the slope of the regression line ($Y = a + bX$, where Y and X represent the analyzed temperatures and years, respectively) fitted to the 37 observations considered is statistically significant at the 5% confidence level ($b = 0.023$, $P_{value} = 0.02$). However, the slopes of the regression lines fitted to the 31 observations before the change and 6 observations after the change are not statistically significant ($b = 0.005$, $P_{value} = 0.67$ and $b = -0.185$, $P_{value} = 0.25$, respectively). Thus, the conclusion is that ignoring the change in the analyzed temperatures would yield an erroneous conclusion on the increasing trend in September's mean maximum temperatures in the years 1967-2003. In fact, the presented analysis demonstrates a non significant decreasing trend in September's mean maximum temperatures within the last 6 observations, in the years1998-2003.

3.2. An analysis of August's mean DTRs from the weather station no. 6

Since there was no preliminary opinion regarding a decrease or increase in August's mean DTRs after a possible change, change point tests for the two sided alternative based on the statistics (6)-(9) were applied. The following values of these statistics were straightforwardly obtained:

$$DD = 4.04,\ KK = 228,\ MDD = 69.81,\ MKK = 1878.$$

As aforementioned, under the null hypothesis the distribution of the statistics (6)-(9) does not depend on the distribution of the observations. Therefore, p-values of the tests based on the statistics DD, KK, MDD, MKK can be evaluated as $P_{X_1,\dots,X_{37}\sim Unif(0,1)}\left(DD > 4.04\right)$, $P_{X_1,\dots,X_{37}\sim Unif(0,1)}\left(KK > 228\right)$, $P_{X_1,\dots,X_{37}\sim Unif(0,1)}\left(MDD > 69.81\right)$, $P_{X_1,\dots,X_{37}\sim Unif(0,1)}\left(MKK > 1878\right)$, respectively. Based on similar *Monte Carlo* experiments as described in Section 3.1, using 25,000 samples of uniformly distributed observations, the simulated p-values of the tests based on the statistics DD, KK, MDD, MKK are found to be equal to 0.00, 0.00, 0.00, 0.01, respectively. Consequently, it can be concluded tentatively that there was a change in the distribution of the observations. Utilizing the estimator of the change point (11), $\hat{v}_{DD} = 1995$ has been straightforwardly obtained. In addition, the two sided p-values of the Wilcoxon test and the Student's t-test for two samples of observations (the considered August's mean DTRs in the years 1967-1994 and 1995-2003) are close to zero (0.00). Thus, the final conclusion is that in 1995 there was a change in August's mean DTRs measured at the weather station no. 6 and the values of August's mean DTRs after the change are significantly smaller than before the change. Figure 3 depicts the observations indicating their mean and standard deviation as well as the first observation after the change.

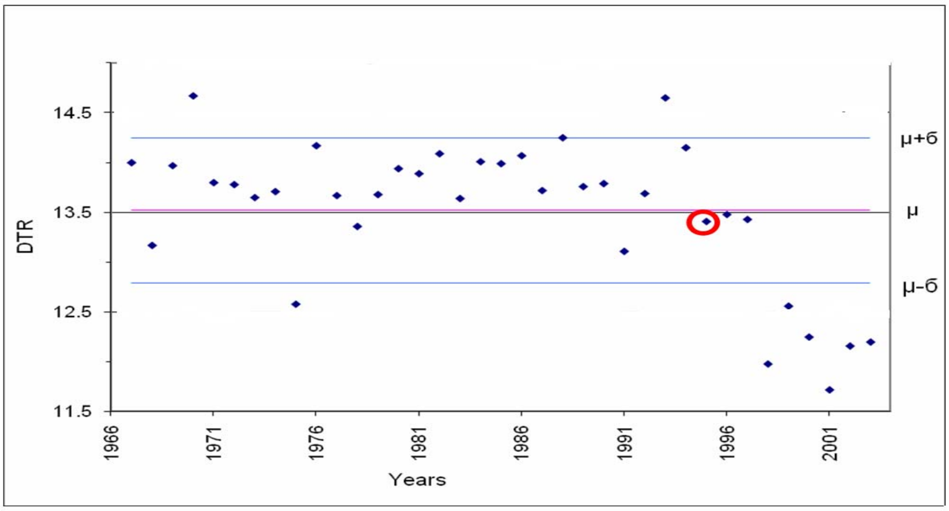

Figure 3. August's mean DTRs between the years 1967-2003 obtained at the Eilat weather station, μ and σ denote the sample mean and standard deviation, respectively.

Note that the slope of the regression line fitted to the 37 observations considered is statistically significant at the 5% confidence level ($b = -0.036$, $P_{value} = 0.00$), indicating a slight trend of decrease in August's mean DTRs from the weather station no. 6 in the years 1967-2003. However, the slope of the regression line fitted to the 28 observations before the change is not statistically significant ($b = 0.008$, $P_{value} = 0.42$). At the same time, the slope of the regression line fitted to the 9 observations after the change is statistically significant ($b = -0.199$, $P_{value} = 0.01$), indicating a strong trend of decrease in August's mean DTRs from the weather station no. 6 in the years 1995-2003.

4. RESULTS

This section presents final results (without all computational details) of the analysis outlined in Section 3 for the monthly mean, mean minimum, mean maximum temperatures and mean DTRs from the 6 stations considered throughout the 37 years, 1967-2003. Short comments and conclusions are also provided.

The following Table 1 depicts average monthly mean temperatures for the full period considered. In addition, for the cases where a change in temperatures was detected, the table presents also the estimators of a year of the change as well as the average monthly mean temperatures for periods before and after the change.

Table 1 shows an increase in the monthly mean temperatures in the warm season in all areas of Israel. The changes in the temperatures have occurred approximately from the mid-1980s through the early 1990s. The summers have indeed become warmer. This conclusion conforms to the research results of Ben-Gai *et al*. (1999), obtained using traditional statistical methods. The analysis of the monthly mean temperatures at the beginning of the cold period (November-January) reveals a rather complex pattern of change. It seems that in the mid-1990s there was an increase in the monthly mean temperatures in the coastal plain areas of Israel. However, in mountainous and desert areas any change in the monthly mean temperatures in 1967-2003 was insignificant. In all other months of the cold season (February-April), significant changes in the monthly mean temperatures in most areas of Israel were not detected.

Table 1. Average monthly mean temperatures in 1967-2003 (Total Mean), estimated change point (year of CP), average monthly mean temperatures from 1967 to year of CP (Mean before CP) and from year of CP to 2003 (Mean after CP) for the 6 weather stations considered

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Canaan Mount	Total Mean	6.92	7.63	10.18	14.78	19.49	22.56	24.18	24.02	22.55	19.36	13.67	8.70
	year of CP	-	-	-	-	1994	1990	1996	1985	1981	1990	-	-
	Mean before CP	-	-	-	-	19.05	22.23	23.81	23.36	21.98	18.82	-	-
	Mean after CP	-	-	-	-	20.68	23.10	25.51	24.64	22.90	20.24	-	-
Sde-Dov	Total Mean	13.52	13.89	15.63	18.63	21.07	23.93	26.04	26.68	25.63	22.96	19.00	15.04
	year of C.P	1994	-	-	1998	1996	1993	1993	1985	1986	1990	1989	1996
	Mean before CP	13.23	-	-	18.44	20.79	23.58	25.65	26.00	25.06	22.4	18.56	14.79
	Mean after CP	14.31	-	-	19.61	22.08	24.77	26.98	27.32	26.24	23.88	19.64	15.95
Beit-Dagan	Total Mean	12.48	12.90	14.83	18.09	20.80	23.52	25.60	26.03	24.68	22.05	17.97	14.07
	year of CP	1994	-	-	-	1988	1993	1993	1985	1986	1990	1989	1996
	Mean before CP	12.21	-	-		20.33	23.15	25.16	25.40	24.12	21.48	17.44	13.75
	Mean after CP	13.22	-	-		21.41	24.39	26.64	26.63	25.26	22.99	18.76	15.23
Jerusalem	Total Mean	9.09	9.93	12.33	16.72	20.48	22.65	24.02	24.18	23.09	20.62	15.59	10.95
	year of CP	-	-	-	-	1994	1977	1995	1985	1981	1990	1996	-
	Mean before CP	-	-	-	-	20.13	22.02	23.66	23.53	22.54	20.19	15.26	-
	Mean after CP	-	-	-	-	21.45	22.88	25.13	24.8	23.43	21.33	16.77	-
Hatzerim	Total Mean	12.10	12.94	15.17	19.24	22.29	24.79	26.47	26.66	25.08	22.50	18.03	13.64
	year of CP	-	-	-	-	-	1993	1995	1985	1985	1990	1996	-
	Mean before CP	-	-	-	-	-	24.63	26.17	26.19	24.72	22.11	17.77	-
	Mean after CP	-	-	-	-	-	25.17	27.39	27.08	25.42	23.16	18.97	-
Eilat	Total Mean	15.26	16.73	19.90	24.33	28.50	31.29	32.79	32.78	30.61	26.97	21.45	16.60
	year of CP	1994	-	-	-	1994	1991	1995	1992	1986	1990	1996	1996
	Mean before CP	14.93	-	-	-	28.22	30.98	32.42	32.35	30.16	26.56	21.16	16.33
	Mean after CP	16.15	-	-	-	29.25	31.87	33.94	33.65	31.08	27.65	22.51	17.57

The following Table 2 displays average monthly mean minimum temperatures for the full period considered. For cases where a change in temperatures was detected, the table presents the estimators of the year of change as well as the average monthly mean minimum temperatures for periods before and after the change.

Table 2. Average monthly mean minimum temperatures in 1967-2003 (Total Min), estimated change point (year of CP), average monthly mean minimum temperatures from 1967 to year of CP (Min before CP) and from year of CP to 2003 (Min after CP) for the 6 weather stations considered

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Canaan Mount	Total Min	4.42	4.67	6.64	10.33	14.19	16.93	18.68	18.60	17.40	15.03	10.47	6.22
	year of CP	-	-	-	-	1994	1990	1996	1985	-	1990	-	-
	Min before CP	-	-	-	-	13.81	16.61	18.32	18.03	-	14.61	-	-
	Min after CP	-	-	-	-	15.23	17.46	19.97	19.14	-	15.72	-	-
Sde-Dov	Total Min	9.38	9.77	11.59	14.29	17.22	20.56	22.82	23.43	22.14	18.82	14.53	10.95
	year of CP	-	1973	1994	1998	1996	1993	1996	1985	1985	1990	1996	1996
	Min before CP	-	8.84	11.30	14.02	16.88	20.16	22.4	22.66	21.46	18.17	14.20	10.7
	Min after CP	-	9.95	12.38	15.69	18.43	21.5	24.33	24.17	22.79	19.89	15.72	11.88
Beit-Dagan	Total Min	7.03	7.15	8.91	11.58	14.52	17.77	20.36	20.81	19.05	15.89	11.7	8.57
	year of CP	1994	1994	1994	1998	1991	1993	1988	1985	1989	1990	1989	1996
	Min before CP	6.70	6.86	8.55	11.26	13.87	17.15	19.52	19.80	18.34	15.08	10.93	8.20
	Min after CP	7.94	7.92	9.88	13.23	15.73	19.25	21.46	21.76	20.11	17.21	12.82	9.93
Jerusalem	Total Min	6.41	6.83	8.71	12.27	15.70	17.78	19.24	19.31	18.35	16.52	12.34	8.22
	year of CP	-	-	-	-	-	1977	1996	1985	1981	1972	-	-
	Min before CP	-	-	-	-	-	17.18	18.95	18.81	17.92	15.12	-	-
	Min after CP	-	-	-	-	-	18.00	20.29	19.79	18.61	16.73	-	-
Hatzerim	Total Min	7.40	7.84	9.59	12.73	15.42	18.29	20.29	20.68	19.18	16.59	12.55	8.81
	year of CP	-	-	-	-	-	1985	1987	1985	1985	1990	1989	1996
	Min before CP	-	-	-	-	-	17.97	19.93	20.13	18.80	16.18	12.18	8.62
	Min after CP	-	-	-	-	-	18.60	20.72	21.16	19.53	17.30	13.07	9.48
Eilat	Total Min	9.59	10.84	13.89	17.82	21.57	24.06	25.78	25.98	24.28	20.95	15.60	11.05
	year of CP	1994	-	-	-	1994	1991	1994	1985	1993	1990	1996	1996
	Min before CP	9.17	-	-	-	21.19	23.62	25.27	25.22	23.91	20.38	15.23	10.72
	Min after CP	10.74	-	-	-	22.59	24.89	27.17	26.70	25.15	21.9	16.94	12.26

Table 2 demonstrates that from the mid-1980s to the mid-1990s there was a significant increase in the monthly mean minimum temperature in the coastal plain areas of Israel over all months of the year. Whereas, in mountainous and desert areas a significant increase in the monthly mean minimum temperature is detected only in months of the warm season (here also the estimators of the changes belong approximately to the same period, between the mid-1980s and the mid-1990s). These results completely contradict the conclusion of Ben-Gai et al. (1999) that the winters have become colder. In fact, the winters have become warmer in the Israeli coast and have not significantly changed in mountainous and desert areas of Israel.

Table 3 shows average monthly mean maximum temperatures for the full period considered. For cases where a change in temperatures was detected, the table presents the estimators of the year of change as well as the average monthly mean maximum temperatures for periods before and after the change.

Analyzing the results provided in Table 3 it can be concluded that in almost all months of the cold season (January-April) there was no change in the monthly mean maximum temperatures in all areas of Israel. Whereas, in almost all months of the warm season monthly mean maximum temperatures have increased in all areas of Israel and the change in the temperatures has occurred approximately between the mid-1980s and the mid-1990s.

Table 3. Average monthly mean maximum temperatures in 1967-2003 (Total Max), estimated change point (year of CP), average monthly mean maximum temperatures from 1967 to year of CP (Max before CP) and from year of CP to 2003 (Max after CP) for the 6 weather stations considered

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Canaan Mount	Total Max	9.42	10.59	13.74	19.24	24.83	28.18	29.68	29.43	27.70	23.68	16.86	11.19
	year of CP	-	-	-	-	1994	1993	1996	1985	1981	1990	1996	-
	Max before CP	-	-	-	-	24.34	27.87	29.30	28.70	27.03	23.03	16.42	-
	Max after CP	-	-	-	-	26.14	28.92	31.06	30.13	28.11	24.76	18.45	-
Sde-Dov	Total Max	17.52	18.02	19.66	22.97	24.80	27.31	29.26	29.93	29.11	27.09	23.46	19.12
	year of CP	-	-	-	-	1994	1993	1988	1987	1986	1990	1990	1996
	Max before CP	-	-	-	-	24.53	27.02	28.84	29.39	28.62	26.64	23.11	18.88
	Max after CP	-	-	-	-	25.55	28.01	29.82	30.56	29.63	27.84	24.04	19.98
Beit-Dagan	Total Max	17.93	18.65	20.76	24.60	27.08	29.26	30.85	31.25	30.28	28.22	24.25	19.56
	year of CP	-	-	-	-	-	-	1995	1998	1998	1990	-	-
	Max before CP	-	-	-	-	-	-	30.61	31.06	30.12	27.88	-	-
	Max after CP	-	-	-	-	-	-	31.58	32.27	31.08	28.78	-	-
Jerusalem	Total Max	11.78	13.03	15.94	21.17	25.25	27.52	28.79	29.04	27.83	24.72	18.83	13.68
	year of CP	-	-	-	-	1994	1990	1996	1985	1981	1990	1996	1995
	Max before CP	-	-	-	-	24.84	27.15	28.4	28.22	27.16	24.21	18.42	13.27
	Max after CP	-	-	-	-	26.38	28.12	30.23	29.80	28.23	25.57	20.31	14.96
Hatzerim	Total Max	16.80	18.04	20.74	25.77	29.15	31.30	32.65	32.65	30.98	28.37	23.54	18.49
	year of CP	-	-	-	-	-	1995	1995	1993	1994	-	1996	-
	Max before CP	-	-	-	-	-	31.15	32.28	32.33	30.71	-	23.20	-
	Max after CP	-	-	-	-	-	31.76	33.78	33.35	31.78	-	24.69	-
Eilat	Total Max	20.92	22.62	25.91	30.84	35.44	38.52	39.79	39.50	36.93	32.99	27.30	22.15
	year of CP	-	-	-	-	-	1977	1995	1985	1984	-	-	-
	Max before CP	-	-	-	-	-	38.09	39.55	38.99	36.50	-	-	-
	Max after CP	-	-	-	-	-	38.68	40.55	39.98	37.30	-	-	-

Table 4 depicts the average monthly mean DTRs for the full period considered. For cases where a change in monthly mean DTRs was detected, the table presents also the estimators of the year of change as well as the average monthly mean DTRs for periods before and after the change.

Table 4. Average monthly mean Diurnal Temperature Ranges in 1967-2003 (Total DTR), estimated change point (year of CP), average monthly mean Diurnal Temperature Ranges from 1967 to year of CP (DTR before CP) and from year of CP to 2003 (DTR after CP) for the 6 weather stations considered

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Canaan Mount	Total DTR	5.00	5.92	7.09	8.88	10.63	11.25	11.00	10.83	10.31	8.65	6.39	4.97
	year of CP	1999	-	-	-	-	-	1972	-	1984	1992	1998	-
	DTR before CP	4.91	-	-	-	-	-	11.67	-	10.10	8.39	6.18	-
	DTR after CP	5.58	-	-	-	-	-	10.90	-	10.49	9.20	7.46	-
Sde - Dov	Total DTR	8.13	8.26	8.07	8.68	7.61	6.75	6.45	6.49	6.97	8.28	8.93	8.16
	year of CP	-	1975	1994	1995	-	1996	1975	1973	1977	1999	-	-
	DTR before CP	-	9.19	8.36	8.96	-	6.92	7.04	7.38	7.51	8.50	-	-
	DTR after CP	-	8.00	7.29	7.81	-	6.15	6.28	6.32	6.78	6.90	-	-
Beit-Dagan	Total DTR	10.90	11.5	11.85	13.02	12.55	11.48	10.49	10.45	11.22	12.34	12.55	10.99
	year of CP	-	1980	1987	1995	1990	1990	1991	1991	1990	1994	1989	-
	DTR before CP	-	12.54	12.71	13.47	13.16	12.1	11.04	11.04	11.76	12.75	13.01	-
	DTR after CP	-	10.94	10.84	11.62	11.55	10.47	9.48	9.35	10.34	11.24	11.88	-
Jerusalem	Total DTR	5.37	6.21	7.23	8.90	9.56	9.74	9.55	9.71	9.48	8.21	6.49	5.47
	year of CP	1995	-	-	1989	1994	1989	1996	1985	1981	-	1995	1994
	DTR before CP	5.21	-	-	8.62	9.43	9.51	9.45	9.40	9.25	-	6.29	5.28
	DTR after CP	5.87	-	-	9.30	9.91	10.08	9.93	9.99	9.62	-	7.10	5.95
Hatzerim	Total DTR	9.40	10.20	11.14	13.03	13.72	13.01	12.36	11.97	11.82	11.76	10.96	9.68
	year of CP	-	-	-	-	-	-	1998	-	-	-	1995	-
	DTR before CP	-	-	-	-	-	-	12.20	-	-	-	10.78	-
	DTR after CP	-	-	-	-	-	-	13.15	-	-	-	11.49	-
Eilat	Total DTR	11.33	11.78	12.03	13.03	13.86	14.46	14.01	13.52	12.66	12.03	11.70	11.1
	year of CP	1988	1992	1998	1997	1998	1997	1990	1995	1998	1993	1993	2000
	DTR before CP	11.71	12.06	12.19	13.23	14.09	14.72	14.39	13.82	12.84	12.36	11.93	11.23
	DTR after CP	10.83	11.21	11.2	12.14	12.69	13.35	13.38	12.58	11.74	11.26	11.16	10.07

The analysis of the monthly mean DTRs based on Table 4 shows a complex design of change. In the coastal plain areas of Israel and the Jerusalem district there were changes in the behavior of the monthly mean DTRs throughout most of the year. Whereas, in the north of Israel changes have occurred only in months of the warm season and in the desert areas the changes were detected only for July and November. There is no approximately common period in which the changes in the monthly mean DTRs have occurred in different areas of Israel. However, it is interesting to note that in the coastal plain areas of Israel the monthly mean DTRs are decreasing, while in mountainous and desert areas the situation is reversed, that is, the monthly mean DTRs are increasing. Thus, our results confirm the known phenomenon about different trend behavior of DTRs in different areas (Kaas and Frich, 1995).

5. CONCLUDING REMARKS

In this article we have provided recently developed nonparametric change point detection and estimation methods to confirm regional changes in temperatures, DTRs and other climatic parameters.
The step by step application of this technique has been outlined as well as traditional statistical tools to study the behavior of September's mean maximum temperatures and August's mean DTRs in different areas of Israel over the period of 1967-2003. It was demonstrated that ignoring a possible change in temperatures over the last few decades would yield erroneous conclusions regarding the current temperature trends. Final computational results, obtained by applying the same methods to analyze the monthly mean, mean minimum, mean maximum temperatures and monthly mean DTRs collected by 6 synoptic weather stations in Israel in the years 1967-2003 are also provided.

The presented analysis confirms the practical applicability of the proposed change point detection and estimation methodology. Therefore, this change point technique can be utilized as an additional and a very efficient statistical instrument in climate investigations.

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