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Research Article

Temperature Trends and Changes in Rize, Turkey, for the Period 1975 to 2007

There is increasing evidence that the global climate is changing as a result of anthropogenic activity. Short-term mean, maximum, and minimum temperatures of the city Rize located at the Eastern Black Sea Coast of Turkey were analyzed to reveal trends, change points, significant warming (cooling) periods, and trend rates per year. An increasing trend of approximately 1.27°C/33 years ($\alpha = 0.001$) in the annual mean temperatures is found during the period from 1975 to 2007. Two periods, averaging 13.78 and 14.66°C, respectively, were detected from fluctuation in the annual mean temperatures. The trend of the first period (1975 – 1993) is towards a cooler climate, whereas the trend of the second period (1994 – 2007) is towards a warmer climate. Summer, autumn and, particularly, the spring mean temperatures have tended to increase strongly, whereas the winter mean temperatures have increased slightly over the whole period. For the winter mean temperature, the trend rate indicates a slight increase, which is insignificant. Maximum temperatures have dramatically increased with 1.61°C ($\alpha = 0.001$) over the last 33 years. However, annual minimum temperatures have increased by 0.99°C ($\alpha = 0.01$) over the same period.

Keywords: Air temperature; Change point; Climate; Climate change; Trend rate

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1 Introduction

There is increasing evidence that the global climate is changing as a result of anthropogenic activity (IPCC, Climate change 2001: Scientific basis. www.grida.no/climate/ipcc_tar/ available date: January 20, 2008). Measurements of surface temperature, primarily over land region, show an approximately 0.6°C warming of global temperatures over the past century [1]. Global circulation models used to study the effects of greenhouse gase concentrations on the earth's climate predict the changes in temperature, in the amount and distribution of precipitation, and other climatic parameters [2]. The Intergovernmental Panel on Climate Change (IPCC) established by WHO and UNEP to assess information relevant for the understanding of climate change showed an increase in the temperature of 0.6 ± 0.2°C over the 20th century, with most of the warming occurring over the past 20 years, while the decade of the 1990s was warmest since 1861 (IPCC, Climate change 2001: Scientific basis. www.grida.no/climate/ipcc_tar/ available date: January 20, 2008). In addition, the IPCC Fourth Assessment Report (AR4) reports an 100 year linear trend (1906 – 2005) of 0.74°C, which is larger than the corresponding trend of 0.6°C (1901 – 2000) given in the Third Assessment Report (TAR).

The temperature increase is widespread over the globe and is greater at higher northern latitudes. One of the characteristics of global warming is that in many locations around the globe, the difference between the maximum and minimum daily temperature is decreasing [3]. Significant changes in many physical and biological systems are reported by AR4, together with surface air temperature changes over the period of 1970 to 2004. The average temperature in Europe has increased by 0.95°C over the past 100 years (EEA Signals 2004, http://reports.eea.europa.eu/signals-2004/en/ENSignals2004-web.pdf available date: January 24, 2008). Figure 1 shows an 0.2 to 1.0°C increase of the air temperature over the period 1970 to 2004 for the continental regions including Turkey (Intergovernmental Panel on Climate Change Fourth Assessment Report, Climate Change 2007: Synthesis Report. http://www.ipcc.ch/ipccreports/ar4-syr.htm available date: January 24, 2008).

Türkes et al. [4] have reported changes for most of the regions of Turkey. The mean diurnal temperature range in winter is controlled greatly by changes in the minimum temperature. On the basis of the results from other studies, a general decrease was dominant in annual and seasonal mean surface temperature series over much of Turkey. Nevertheless, this situation has begun to change in about the last ten years in Turkey, particularly during the warm period of the year [5 – 7]. It was shown that cooling trends in mean and maximum temperature series have been weakening and been less significant [8]. In addition, a change in climate has been documented on many locations throughout the world. To detect and quantify climate change, much emphasis has been placed on the analysis of variability of temperature and precipitations in recent years [9 – 11]. The minimum temperature increased almost everywhere, and the maximum and mean temperature increased in northern and central Europe, in the Russian Federation, Canada [12], and in Australia and New Zealand [13].

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Abbreviations: VC, Variation coefficients

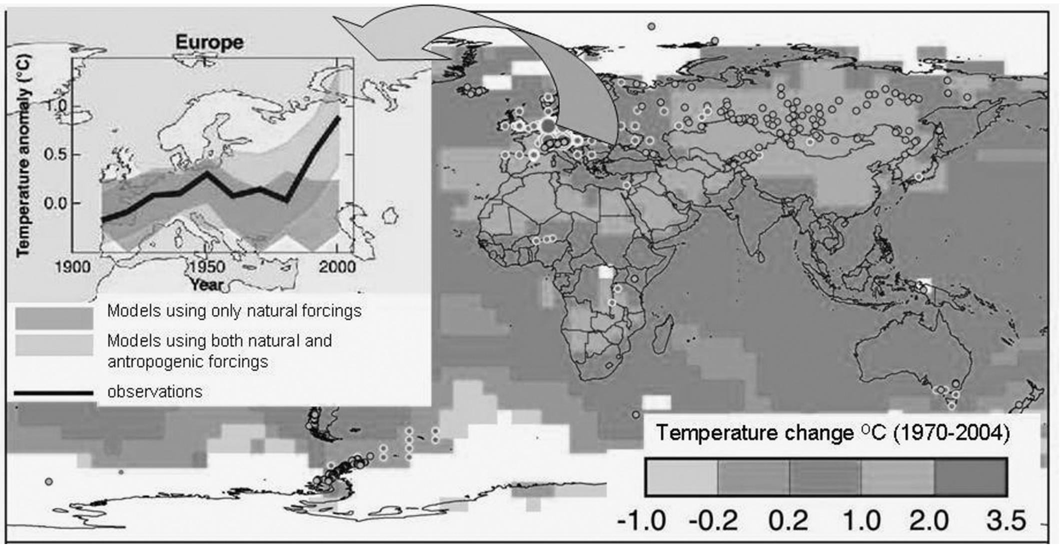


Figure 1. Changes in physical and biological systems and surface temperature, 1970–2004 (www.ipcc.ch/ipccreports/ar4-syr.htm).

There are a few possible causes for these decreases in the diurnal temperature range. It is possible that these changes are to a certain extent the result of local anthropogenic land-use modification such as urbanization [14]. Local land cover associated with urbanization pattern largely dictates the energy exchanges that occur between the earth and atmosphere and thus, is one of the primary determinants of a city's microclimate [15]. First, urbanization affects the climate; cities tend to be hotter than the surrounding countryside and create what is known as an urban heat island. Urban areas generally have higher solar radiation absorption and a greater thermal capacity and conductivity because of being covered with buildings, roads, and other impervious surfaces. Heat is stored during the day and released during night. Therefore, urban areas tend to experience a relatively higher temperature compared to the surrounding rural areas [16]. Second, urbanization effects hydrology; cities shed more water as run-off into their streams and rivers. Third, cities are net producers of carbon dioxide and have a lower amount of stored carbon. Fourth, cities are widely regarded as having lower biodiversity [17]. These human settlements determine a distinguished local climate in the cities which is the so-called urban climate [18]. Much research addressed the phenomenon of urbanization or heat island effect on the urban temperature variations and trends [19–21]. In developing countries, e.g., Turkey, urban development has influenced the temperature records of even small rural sites [7]. Karaca et al. [22] and Tayanç et al. [23] investigated the effects of urbanization on the temperature of large cities of Turkey and the relationship between air pollution and the temperature trends and variations in detail.

Tea production plants and tea farms are especially centered around the city of Rize, which is the second biggest of the region. In time, some part of the forest has been cut to convert into agricultural areas for this production. This issue causes increase in the erosion and fast surface streamflow due to heavy rainfall. Floods affected people and displaced house settlements and agricultural crops there. Climate change can affect not only the precipitation and temperature but also the local agricultural production. Although single weather events cannot be usually attributed to climate change, the probability of high temperature events is indicative of the extreme events.

The objective of this paper is to study the temperature change in Rize, Turkey from temperature data set for the period 1975 to 2007. It is aimed to give detailed information on the temperature data, to reveal the nature and magnitude of trends and the change points and significant warming (or cooling) periods and trend rates in the temperature series.

2 Description of Study Area

The climatology station in Rize is located at about 41°00′ N/40°30′ E and height about 4 m above sea level (see Fig. 2). In this area, due to very high slope and very little flat area, there are many short, fast, and unstably flowing rivers. The water of these rivers flows with great speed into the Black Sea. Morphology suddenly gets higher from the coast to the South and reaches a 400 to 500 m level approximately 10 to 15 km away towards South. The heights of the mountains reach 3000 m in the far South. The area consists of 78% mountains, 21% plateau, and 1% plains. Valleys, in general, are deep and steep sided.

Winter and summer seasons are warm in Rize. The annual average temperature does not go below +14°C. The lowest temperature is normally found in January, February averaging 6.51 and 6.25°C and the highest temperature in July, August averaging 22.77 and 23.10°C, respectively. The annual total precipitation is 2300 mm. The rainfall comes in all seasons with the lowest concentration in spring. The humidity is high in all seasons, and the average relative humidity is 80%.

3 Methods

In order to identify recent trends, the change points, and warming or cooling periods in temperature series, a number of databases have been assembled from existing records held by the Turkish

Figure 2. Location of the study area (Rize).

State Meteorological Service. The Rize databases used here consist of annual, seasonal, and monthly mean, maximum, and minimum temperatures from 1975 to 2007. Temperature variations and trends were analyzed by using statistical tests. For the temperature dataset, the annual, seasonal, and monthly time series were computed using SPSS (15.0) software, and many statistical tests were applied to identify a change in the annual, seasonal, and monthly, nonabrupt change, trend, and trend rates.

3.1 Homogeneity Test

The Thom test has been performed on the data to test the series for homogeneity as recommended by the World Meteorological Organization. The Thom test, being a nonparametric test, studies variation in the series with regard to median [24]. Cases with values less than the cut point (the observed median) are assigned to one group, and cases with values greater than the cut point are assigned to another group. In this test, considering x_i, with $i = 1, 2, (, n$, a time series with the length n and the series median x_{med}, as well as a code called "a" is assigned for any value $x_j > x_{\text{med}}$. A code "b" is assigned for any value $x_j < x_{\text{med}}$, and the element x_k is rejected when $x_k = x_{\text{med}}$. The result is a series made up of "a" and/or "b" codes; each uninterrupted series of "a" or "b" is called a "run". For $N \geq 25$, if the series is homogenous, the distribution of the number of runs (R) approximates a normal distribution with the following average (E) and variance (Var):

$$E(R) = \frac{N+2}{2}, \quad \text{Var}(R) = \frac{N(N-2)}{4(N-1)} \tag{1}$$

The Z statistic is defined as:

$$Z = \frac{R - E(R)}{\sqrt{\text{Var}(R)}} \tag{2}$$

For a significance of $\alpha = 0.01$, the null hypothesis of homogeneity is verified when $|Z| \leq 2.58$ [25].

3.2 Normality Test

All time series have been checked for normality with the skewness and kurtosis coefficients. Skewness measures the symmetry of the sample distribution; kurtosis measures its peakedness. These measures are centered at zero; however, even for samples from a normal distribution, these values fluctuate around zero. The ratio of each statistic to its standard error can be used as a test of normality, i.e., it can reject normality if the ratio is < -2 or $>+2$. A large positive value for skewness indicates a long right tail; an extreme negative value, a long left tail. A large positive value for kurtosis indicates that the tails of the distribution are longer than those of a normal distribution; a negative value for kurtosis indicates shorter tails.

3.3 Climate Changes Analysis

The frequency distribution functions were constructed for the annual, seasonal, and monthly temperature data of the period 1975 to 2007. Seasons were defined using the standard meteorological definition (i.e., winter = December + January + February). Temperature was considered "normal" between the first (P_{25}) and third quartile (P_{75}), under P_{10} as "lower event" than normal and over P_{90} as "higher event" than normal. The 1st, 5th, 10th, and 90th, 95th, 99th percentiles were considered thresholds for extreme values.

A set of temperature suitable indices was chosen for detecting climatological changes, trends, and trend rates. The following three basic terms of climatological changes is used:

(i) *Nonabrupt change*: a change caused by normal climatic fluctuations.

(ii) *Trends:* when there is an increase or decrease throughout the series.

(iii) Trends rates.

3.4 Nonabrupt Changes

The cumulative sums of deviations were calculated over the 33-years period, in order to analyze nonabrupt changes in the temperature series and differentiate hot and cool periods. The cumulative sums of deviations were calculated according to the following equation:

$$Sk = \sum_{i=1}^{k} di \quad k = 1, 2, \ldots, n \tag{3}$$

A climatic change in the series can be detected by a change in the slope of the progression of points representing S_k; k denotes the maximum, $|S_k|$ a point of change [26]. A *t*-test was performed to test differences between the means of the periods before and after the possible changing point.

3.5 Trends

It is becoming more and more common to use nonparametric tests of trend for climatological data. These tests do not assume normally distributed errors; however, the Mann–Kendall test assumes independent data points. In a null hypothesis always no trend exists. The Mann-Kendall test is used to test the presence of a monotonic increasing or decreasing trend. This test is widely used in environmental science, because they are simple, robust, and can cope with missing values and values below detection limit [27, 28].

The nonparametric Mann-Kendall test detailed by Salmi et al. [27] was used for estimating trend, and the nonparametric Sen's method, for the magnitude of the trend. The Mann-Kendall test is used in cases when the data values x_i of the time series can be assumed to obey the model; $x_i = f(t_i) + \varepsilon_i$, where $f(t)$ is a continuous monotonic increasing or decreasing function of time and the residual ε_i can be assumed to be from the same distribution with zero mean. It is, therefore, assumed that the variance of the distribution is constant with time. Considering a time-series of length *n*, the Mann–Kendall test statistics *S* [29] is calculated using the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}(x_j - x_k) \tag{4}$$

where x_j and x_k are the annual values in years *j* and *k*, with $j > k$, respectively.

This sum, under the null hypothesis (stable climate is characterized by a simple random series), presents a normal distribution with an average and variance (Var(*S*)). However, if there are equal values in the time series, it may reduce the validity of the normal approximation. First, the variance of *S* is computed by the following equation that takes into account that equal values may be present:

$$\operatorname{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \tag{5}$$

where *q* is the number of equal values and t_p is the number of data values in the *p*th group. The values of *S* and Var(*S*) are used to compute the test statistics *Z* as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{6}$$

The value of *Z* is compared directly to the theoretical normal distribution for different significance levels, which is usually $\alpha = 0.05$ [30]. A positive value of *Z* indicates an increase in trend, and a negative value of *Z* indicates a decrease in trend.

3.6 Trend Rates

Several tests are available for the detection and/or quantification of trend rates. To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used. The Sen's method allows missing data and makes no assumptions on distribution of the data. The trend can be assumed to be linear as in equation:

$$f(t) = Q(t) + B \tag{7}$$

Q denotes the slope, *B* a constant.

The Sen's method proceeds by calculating the slope of the line using all data value pairs, as shown in the following equation:

$$Q_i = \frac{x_j - x_k}{j - k} \text{ where } j > k \tag{8}$$

If there are *n* values x_j in the time series we get as many as $N = n(n\ (\ 1)/2$ slope estimate Q_i. The Sen's estimator of slope is simply given by the median of these *N* values of Q_i.

$Q = Q_{[(N+1)/2]}$, if *N* is odd

$Q = (Q_{[N/2]} + Q_{[(N+2/2]})/2$, if *N is even*

The Sen's method also allows determination of whether the median slope is statistically different from zero. A confidence interval is developed by estimating the rank for the upper and lower confidence interval and using the slopes corresponding to these ranks to define the actual confidence interval for *Q*. To estimate the range of ranks for the specified confidence interval, C is calculated by:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{\operatorname{Var}(S)} \tag{9}$$

Var(*S*) has been defined in Eq. (5), and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution. Using the value of Eq. (9), $M_1 = (N - C_\alpha)/2)/2$ and $M_2 = (N + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, $Q_{\min}$ and $Q_{\max}$, are the M_1th largest and the $(M_2 + 1)$th largest of the *N* ordered slope estimates Q_i. If M_1 is not a whole number, the upper limit is interpolated.

To obtain an estimate of *B* in Eq. (7), the *n* values of the differences $x_i - Q_{ti}$ are calculated. The estimates for the constant *B* of lines the 99 and 95% confidence intervals are calculated by a similar procedure [27].

4 Results

In this study, temperature change, trends, and trend rates for Rize, Turkey, were investigated. Results are presented as the annual, sea-

Table 1. The statistical analysis of annual (mean, maximum and minimum) and seasonal (mean) temperature values for the period 1975–2007.

Statistics	Mean	Minimum	Maximum	Winter	Spring	Summer	Autumn
N	33	33	33	33	33	33	33
Mean	14.16	10.98	18.08	6.97	11.95	22.06	15.69
Median	14.23	10.99	17.89	7.13	11.90	22.03	15.70
Std. deviation	0.63	0.56	0.79	1.06	0.86	0.97	0.84
Variance	0.40	0.31	0.62	1.12	0.73	0.94	0.71
Vairation coeff. (%)	4.46	5.09	4.36	15.15	7.16	4.40	5.35
Minimum	13.00	9.70	16.90	4.60	9.90	20.10	14.00
Percentiles: 1	13.02	9.73	16.87	4.57	9.90	20.07	13.97
5	13.06	9.88	16.88	4.78	10.51	20.21	14.27
10	13.26	10.26	16.97	5.19	10.93	20.64	14.54
25	13.70	10.59	17.57	6.22	11.29	21.42	14.98
50	14.23	10.99	17.89	7.13	11.90	22.03	15.70
75	14.61	11.45	18.68	7.73	12.63	22.72	16.20
90	15.04	11.70	19.31	8.39	13.13	23.51	16.91
95	15.21	11.84	19.61	8.65	13.35	23.79	17.33
99	15.44	12.08	19.66	8.83	13.40	23.85	17.45
Maximum	15.40	12.10	19.70	8.80	13.40	23.90	17.50
Range	2.40	2.40	2.80	4.30	3.50	3.80	3.50
Skewness[a]	0.05	−0.15	0.38	−0.52	−0.15	−0.07	0.15
Std. err. of skewness	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Kurtosis[a]	−0.79	−0.49	−0.67	−0.04	−0.58	−0.35	−0.31
Std. error of kurtosis	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Thom's Z[b]	−2.30	−2.30	−3.71	0.53	−1.59	−3.01	−1.24

[a] Skewness/std. error of skewness, kurtosis/ Std. error of kurtosis must be between −2 and +2.

[b] Critical value for Thom's test was $|Z| \le 2.58$ at $\alpha = 0.01$.

sonal, and monthly time series changes and various statistical test applications.

4.1 Annual and Seasonal Temperature

Table 1 shows the statistical analysis of the annual and seasonal temperature values for the period 1975 to 2007. According to homogeneity test (Thom's Z test), annual and seasonal time series may be considered homogeneous series. The temperature series for the 33-years period followed a normal distribution, since the ratio of skewness and kurtosis coefficients to its standard errors are between −2 and +2.

Figure 3(a) shows the time series for the mean temperature and its trend in the studied period. There was variability among the years, with a standard deviation of 0.63°C where the average for the 33-years period is 14.16°C. According to the variation coefficient, there was a change of about 5% in intrayear and intraseason conditions, except winter. The highest fluctuation is observed in winter with 15.15% among seasons (see Tab. 1).

For a better understanding of the changes in the temperature series, the cumulative sums of the deviations were plotted in Fig. 3(b). Two periods were detected by the cumulative sums of deviations: 1975–1993 and 1994–2007, which had an average temperature of 13.78 and 14.66°C, respectively. A *t*-test analyzing paired samples shows that the positions of the means of the first and second periods are significantly different ($\alpha = 0.01$) (see Tab. 2). The paired samples *t*-test compares the means of two variables. It computes the difference between the two variables for each case, and tests to see if the mean difference is significantly different from zero. The trend of the first period is towards a cooler climate, whereas the trend of the second period is toward a warmer climate. Annual series showed a decreasing trend until approximately 1993 and an increase after that year, which had a perfect agreement with the recent results by Türkes et al. [8] compared with cooling trends found by Türkes et al. [4]. Figure 4 shows a change in climate interperiods depending on their statistical distribution (means and variability). In this study,

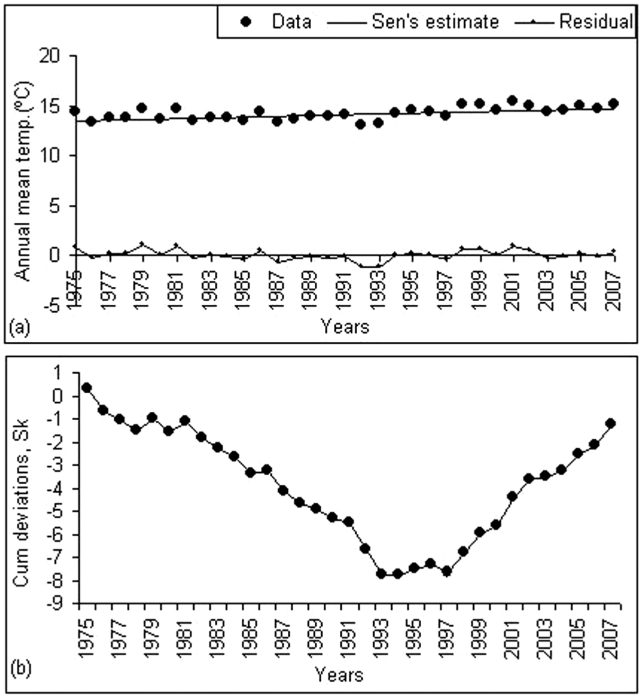
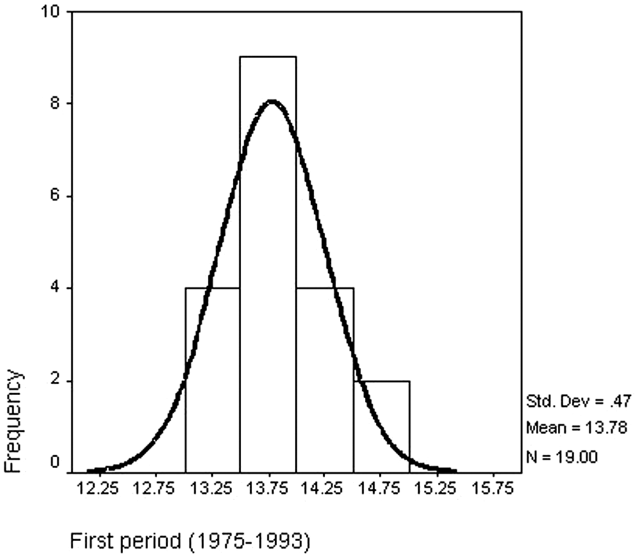


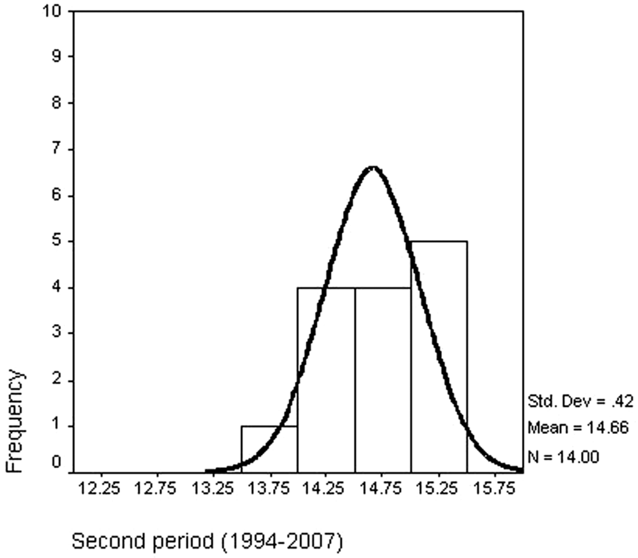
Figure 3. Time series for annual mean temperature records. (a) Annual mean temperature and its trend (b) cumulative sum of deviations from the average of annual mean temperature.

Table 2. *t* Test results of paired two periods.

Paired samples test	Paired differences							
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper	t	df	Sig.
Second period (1994 – 2007) First period (1975 – 1993)	0.814	0.6163	0.1647	0.4585	1.1701	4.944	13	0.000



First period (1975-1993)



Second period (1994-2007)

Figure 4. Schematic showing the temperature of each period when both the mean and variance increase for a normal distribution.

both the mean and the variability increased after 1993 (second period). This shows that temperature and warmer extremes increased during the second period.

Trend Rates in Temperature Series

The changes per year are calculated using Sen's nonparametric method. For annual mean temperature, the Mann-Kendall test confirmed that the positive trend is significant with a 95% confidence limit (see Tab. 3). The trend is toward a warmer climate, with an estimated increase of about 1.27°C/33 years in the whole period. The annual maximum temperature indicates a dramatic increase of 1.61°C (0.049°C/year) over the past 33 years. Significant positive trends are evident in the warming of climate. Stronger warming trends of annual maximum temperatures are observed by a significant Mann-Kendall test, the probability of which is the 0.001 significance level. However, the annual minimum temperature has increased slightly by 0.99°C over the same period at 0.01 levels. For annual mean, maximum, and minimum temperatures, the trend of the series is statistically significant (see Tab. 3 and Figs. 3a, 5a, and b).

The seasonal series showed a similar trend of the annual mean temperature. The Mann-Kendall test confirmed that the positive trend observed is significant with a 99 and 95% confidence limit for the summer and autumn mean temperatures, respectively. For these seasons, a general warming is seen over the whole period. Slightly increasing trends characterize the winter and spring mean temperature. For the winter and spring mean temperature, the Mann-Kendall test coefficients are not statistically significant (see Tab. 3). The trend rates of the winter mean temperature have revealed an increasing trend, which is weak and insignificant. For the spring mean temperature, the trend rate indicates a slight increase, which is insignificant, with 0.033°C/year (≅1.10°C/33 years). The highest significant warming season is summer, with a trend rate of 0.069°C/year (≅2.26°C/33 years) at the 0.001 level. This trend rate is the highest warming among seasons. The autumn mean temperature has shown an increasing trend. The trend is statistically significant at a 0.01 level, with a trend rate of 0.04°C/year (≅1.55°C/33 years) (see Tab. 3 and Fig. 6).

4.2 Statistical Analysis and Trend Rates of Monthly Temperature

A statistical summary for each month is shown in Tab. 4. Frequency distribution of all months' temperature was not positively or negatively skewed according to the ratio of the skewness coefficient to its standard error. The ratios of the kurtosis coefficients to their standard errors indicate that the tails of the distribution of all months' temperature are a normal distribution. The variation coefficients (VCs) indicate a higher variability in the winter months (December, 21.21%; January, 23.03%; February, 26.89%), March (19.60%), November (11.26%), and April (10.99%) than in the other months. From Fig. 7, it was seen that a maximum temperature in

Table 3. The results of the trend statistics for annual (mean, max., min.) and seasonal (mean) temperatures.

	Mann–Kendall trend		Sen's slope estimate									
Time series	Test Z	Sig.	Q	$Q_{min}99$	$Q_{max}99$	$Q_{min}95$	$Q_{max}95$	B	$B_{min}99$	$B_{max}99$	$B_{min}95$	$B_{max}95$
Annual mean	3.38	***	0.039	0.010	0.066	0.020	0.059	13.47	14.03	13.03	13.77	13.17
Annual min.	2.99	**	0.030	0.004	0.053	0.011	0.046	10.48	10.90	10.18	10.75	10.23
Annual max.	3.60	***	0.049	0.018	0.083	0.025	0.074	17.18	17.61	16.69	17.53	16.80
Winter	0.29		0.004	−0.047	0.068	−0.037	0.054	6.99	8.12	5.66	7.88	6.04
Spring	1.53		0.033	−0.017	0.071	−0.007	0.061	11.53	12.02	10.88	11.95	11.00
Summer	4.05	***	0.069	0.024	0.111	0.035	0.100	21.02	21.72	20.27	21.58	20.37
Autumn	3.18	**	0.047	0.010	0.088	0.020	0.077	14.85	15.54	14.38	15.35	14.54

** If trend at α = 0.01 level of significance.
*** If trend at α = 0.001 level of significance.

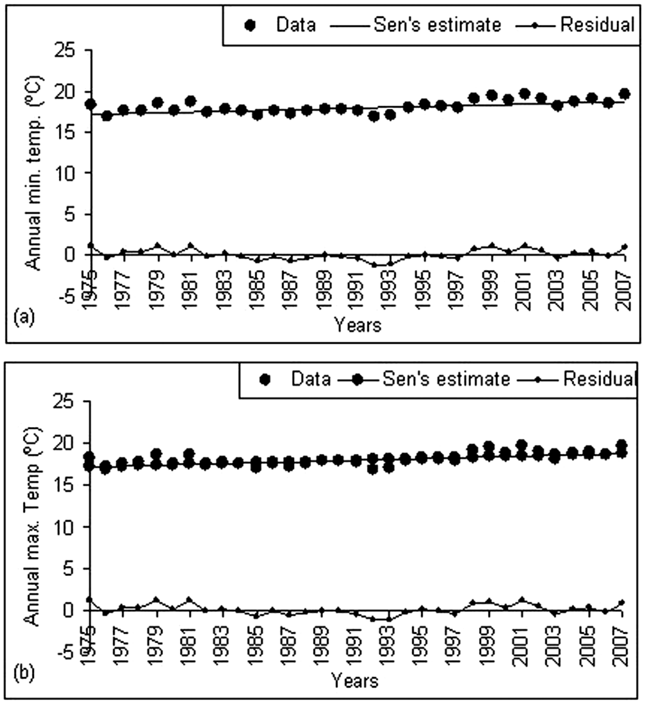


Figure 5. Linear trends over the annual (a) minimum and (b) maximum temperatures series.

July–August and a minimum in January–February were recorded, according to the percentiles. June and May are the months with the least dispersion while February, March, and December are those with the highest dispersion. July and August have a greater probability of having the highest temperature values. In these months, the 90th, 95th, 99th percentiles had the highest temperature. The normal values (25th–75th percentile) for July were between 21.80 and 23.70°C, and for August between 22.25 and 24.14°C. In winter, the normal values were between 4.95 and 7.50°C for February.

The calculated trend rates per year using Sen's nonparametric method are shown in Tab. 5. The trend rate of August is the highest warming among the months, with a trend rate of 0.109°C/year (≅3.59°C/33°years). The trend is statistically significant at the 0.001 level. Other months that showed a significant increase trend are October, September, and July. For the October mean temperature, the trend rate indicates a significant increase with 0.084°C/year (≅2.78°C/33 years) at the 0.01 level. The September, July, and May mean temperatures indicate an increase of 0.051°C (≅1.67°C/33 years), 0.060°C (≅1.98°C/33 years), 0.040°C (≅1.32°C/33 years) per year, respectively. The trends of other months are insignificant statistically.

5 Summary and Conclusions

The analysis of short-term temperature observations recorded at only one station was carried out for the period 1975 to 2007 with respect to the local climatic variability. Annual mean temperature changes of Rize, Turkey, are characterized by a warming trend. Since 1975, there has been an increase in the annual mean temperature of about 1.27°C/33 years. These trend rates are verified by a significant Sen's nonparametric test.

The use of cumulative deviations detected two main periods in the temperature. A relatively cool period from 1975 to 1993 has been succeeded by a warm period on record from 1994 to present. In addition, the *t*-test has shown that the means of the two periods are significantly different. Statistical distributions of the two periods (mean and variability) have shown a change in the climate interperiods (see Fig. 4). It is reported that 11 of the last 12 years (1995–2006) rank among the 12 warmest years in the instrumental record of global surface temperature (Intergovernmental Panel on Climate Change Fourth Assessment Report, Climate Change 2007: Synthesis Report. www.ipcc.ch/ipccreports/ar4-syr.htm, available date: 24 January 2008). An increase in variability without a change in the mean implies an increase in the probability of both cool and warm extremes as well as the absolute value of the extreme. Increases in both the mean and the variability are also possible which affects the probability of extremes [31].

Over the whole period, the summer mean temperature series show the most significant increasing trend. The significant trend rate in summer is 0.069°C (≅2.26°C/33 years), at the 0.001 level. Türkes et al. [8] found that the summer mean temperature series have shown a slight warming at many stations over the western part of Turkey, whereas the rest of the country has experienced a general cooling. Autumn and spring mean temperatures have shown an increased trend.

The annual maximum temperature series of Rize indicates a dramatic increase of 2.26°C (0.049°C/ year) over the past 33 years. However, the annual minimum temperature has increased, which is significant at the 0.01 level, by 0.99°C over the same period. The signifi-

Table 4. The statistical analysis of monthly mean temperature values for the period 1975–2007.

Statistics	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
N	33	33	33	33	33	33	33	33	33	33	33	33
Mean	6.51	6.25	7.94	11.91	16.00	20.30	22.77	23.10	19.81	15.89	11.37	8.03
Median	6.80	6.70	7.70	12.00	16.00	20.20	22.90	23.00	19.80	15.80	11.70	7.90
Std. deviation	1.50	1.68	1.56	1.31	1.02	0.92	1.24	1.39	1.15	1.28	1.28	1.70
Variance	2.25	2.82	2.43	1.71	1.05	0.84	1.54	1.94	1.31	1.63	1.64	2.90
Variation cff (%)	23.03	26.89	19.60	10.99	6.40	4.51	5.45	6.03	5.78	8.03	11.26	21.21
Minimum	3.50	3.10	5.10	9.40	14.20	18.30	20.10	20.30	17.80	12.90	8.10	4.50
Percentiles1	3.50	3.10	5.10	9.40	14.20	18.30	20.10	20.30	17.80	12.90	8.10	4.48
5	3.71	3.17	5.17	9.82	14.34	18.79	20.59	20.44	18.01	13.53	8.66	5.06
10	4.46	3.62	5.73	10.31	14.50	19.24	21.06	21.12	18.26	14.40	9.34	5.71
25	5.26	4.95	6.95	10.85	15.35	19.71	21.80	22.25	18.90	14.90	10.53	6.90
50	6.80	6.70	7.70	12.00	16.00	20.20	22.90	23.00	19.80	15.80	11.70	7.90
75	7.85	7.50	9.30	12.65	16.68	20.87	23.70	24.14	20.41	16.87	12.30	9.10
90	8.42	8.15	10.12	13.96	17.47	21.50	24.46	24.87	21.65	17.83	12.84	10.12
95	8.60	9.34	10.60	14.37	18.06	22.17	25.02	25.74	22.19	17.99	13.25	11.52
99	8.83	9.90	11.20	15.00	18.68	22.79	25.30	26.08	22.40	18.00	13.50	11.80
Maximum	8.80	9.90	11.20	15.00	18.70	22.80	25.30	26.10	22.40	18.00	13.50	11.80
Range	5.30	6.80	6.10	5.60	4.50	4.50	5.20	5.80	4.60	5.10	5.40	7.30
Skewness[a]	−0.32	−0.08	0.06	0.32	0.38	0.44	−0.08	0.02	0.41	−0.08	−0.71	0.11
SE of skew.	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Kurtosis[a]	−1.05	−0.45	−0.64	−0.23	0.32	0.74	−0.44	−0.25	−0.14	−0.38	0.09	−0.15
SE of kurtosis	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80

[a] skewness/std. error of skewness, kurtosis/ Std. error of kurtosis must be between −2 and +2.

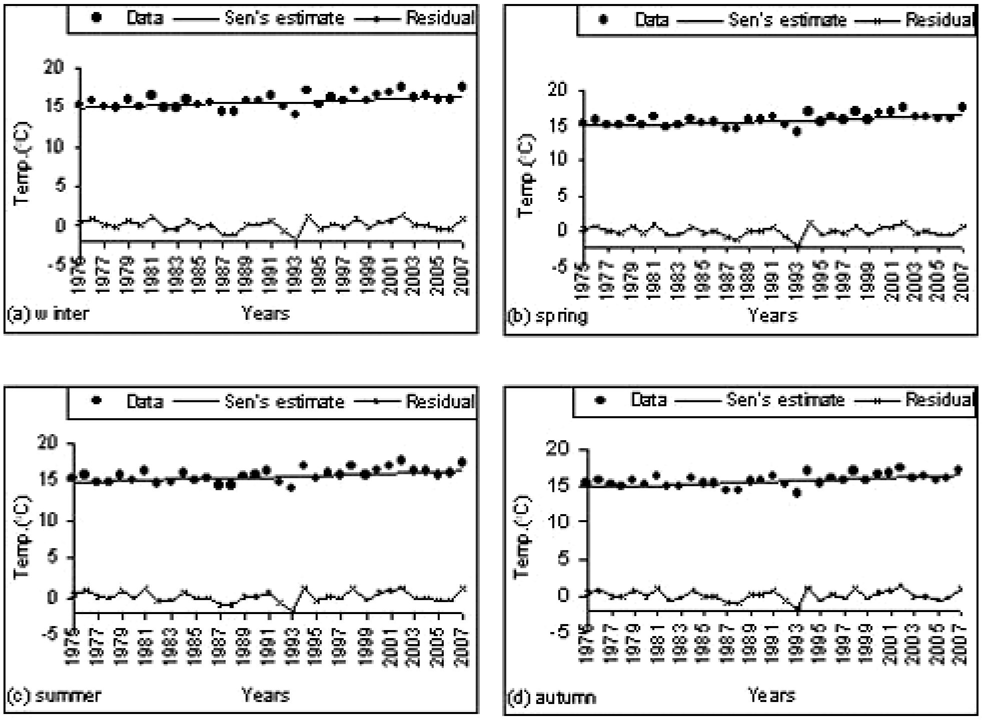


Figure 6. Linear trends over the seasonal mean temperatures series.

cant increase in the minimum temperatures (night-time) may have occurred due to a combination of increased greenhouse gases, increased cloud cover, and urbanization. Minimum temperatures show the highest year-to-year variability with 5.09% according to the VC.

Intra-annual variability is characterized by a maximum, often in February and a minimum in June. The highest temperatures were seen in June–August and lowest temperatures in December–March were recorded, according to the percentiles. In these months, the 90th, 95th, 99th, and the 10th, 5th, 1st, percentiles had the highest and the lowest temperatures, respectively. At Rize the mean temperature trend in August over the study period is quite obvious towards a warmer climate. The trend rate is about 3.59°C/33 years. This trend rate is statistically significant at the 0.001 level. Also, October

Table 5. The results of the trend statistics for monthly mean temperatures.

	Mann – Kendall-trend		Sen's slope estimate									
Time series	Test *Z*	Sig.	*Q*	$Q_{min}99$	$Q_{max}99$	$Q_{min}95$	$Q_{max}95$	*B*	$B_{min}99$	$B_{max}99$	$B_{min}95$	$B_{max}95$
JAN	0.74		0.021	−0.053	0.104	−0.038	0.082	6.46	7.81	5.19	7.47	5.34
FEB	0.20		0.005	−0.083	0.108	−0.060	0.085	6.54	7.93	4.56	7.48	4.91
MAR	0.54		0.025	−0.075	0.108	−0.043	0.086	7.18	9.03	6.05	8.41	6.60
APR	0.26		0.005	−0.063	0.076	−0.045	0.058	11.91	12.85	10.38	12.73	10.92
MAY	2.11	*	0.040	−0.009	0.093	0.000	0.075	15.28	16.22	14.34	16.00	14.68
JUN	1.61		0.030	−0.015	0.078	−0.006	0.067	19.82	20.47	19.04	20.33	19.23
JUL	2.53	*	0.060	0.000	0.125	0.014	0.107	21.90	22.90	20.97	22.62	21.19
AUG	4.84	***	0.109	0.062	0.158	0.073	0.148	21.28	22.01	20.47	21.81	20.63
SEP	2.55	*	0.051	0.000	0.116	0.014	0.100	18.90	19.80	17.91	19.70	18.10
OCT	3.58	***	0.084	0.027	0.138	0.043	0.122	14.42	15.32	13.67	15.13	13.89
NOV	0.37		0.009	−0.050	0.078	−0.039	0.064	11.57	12.40	10.13	12.26	10.25
DEC	−0.09		−0.001	−0.101	0.100	−0.080	0.081	7.92	9.22	6.60	9.00	6.79

* If trend at $\alpha = 0.05$ level of significance.
*** If trend at $\alpha = 0.001$ level of significance.

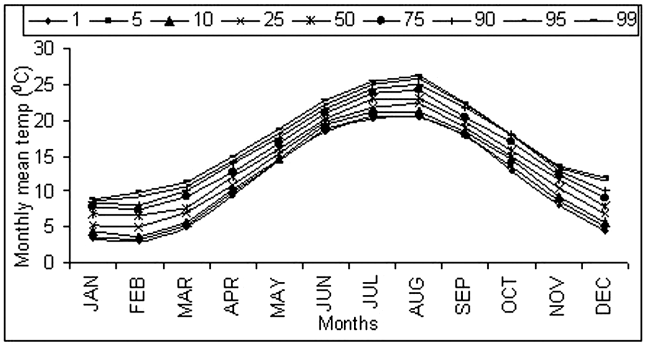


Figure 7. The percentiles of monthly temperature records.

and July temperatures show significant increases over the past 33 years, with the October mean temperature increasing 2.78°C and the July mean temperature 1.98°C over this period. For September and May the mean temperatures and the trend rate indicate a relatively slight increase with 1.67°C/33 years, and 1.32°C/33 years at the 0.1 level, respectively. The December mean temperatures indicate an insignificant negative trend.

The summer months' mean temperatures have generally increased at a larger rate than winter and autumn months' mean temperatures. Owing to the urban warming, the energy consumption for air conditioning is expected to increase in the summer months. Similar results are reported by Tayanç and Toros [7], where urban warming is found to be more or less equally distributed over the year with a slight increase in the autumn month for four large cities of Turkey. These appear to be possibilities for explaining the rapid change in the temperatures at this city: urbanization resulting in a heat island effect, or climate change resulting from more aerosol and cloud cover, possibly connected to the 20th century global warming trends. In the last 50 years, the population of Rize approximately increased by 100%. Significant and very rapid nighttime warming trends over much of the country can be related to the widespread, rapid and increased urbanization in Turkey, in addition to long-term and global effects of the human climate change on air temperatures [7]. Potential changes in the mean climate state as well as in the climate variability are expected to lead to significant changes in the incidence of weather extremes, e.g., intense cold and hot spell, storms, heavy precipitations, and droughts, implying great risks and hazards with regard to the urban population and ecosystems [32].

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