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ORIGINAL PAPER

Change-point analysis for serially correlated summit temperatures in the Romanian Carpathians

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Abstract Characterizing climatic changes in the high-altitude mountain regions helps scientists and policy makers understand the effects of such changes on water resources, economic development, and the health of ecosystems. This paper proposes a change-point analysis to determine the time and magnitude of summer temperature changes in the summit areas of Romanian Carpathians between 1961 and 2007. Due to their altitude, massiveness, and position, Romanian Carpathians are an important barrier for different types of air masses between Western and Southeastern Europe. The results show that the change in summer temperatures occurred shortly after 1980. The average magnitude of this change is consistent with changes occurring in other parts of Southern Europe in the same time period although the magnitude of changes at individual weather stations may differ substantially. We aided our analysis by a statistical method based on regression models with serially correlated ARMA errors.

1 Introduction

Climate change, particularly temperature trend and variation, is an important topic in climate research. Studies worldwide have shown a trend of increasing air temperature from the second half of the nineteenth century. One of the European Environment Agency reports (EEA 2008), summarizing data from 1850 to 2007, indicated a warming trend of temperature (mostly in spring and summer) for the entire European continent. The increasing of air temperature proved to be nonlinear and nonhomogenous at global scale. Thus, the most abrupt warming occurred in 1920–1944 and after 1975 (Rebetez and Reinhard 2008; Jones and Moberg 2003; Luterbacher et al. 2004). For summer temperature during the twentieth century, Luterbacher et al. (Luterbacher et al. 2004) also reported a warming trend until 1947, a cooling trend until 1977, followed by a very strong warming trend at a rate of 0.7°C (±0.2°C)/decade. Other authors have pointed out that during the latter period, the discrepancy between warming in the Northern and Southern Hemispheres has more than doubled (Jones and Moberg 2003).

Many climate temperature series exhibit trend changes characterized by alternating episodes of cooling and warming. Finding accurately where the transition occurs and the precise values of trend slopes helps scientists understand the phenomena underlying these changes and policy makers to better plan for the future. In this paper, we propose a method for change-point analysis based on statistical models that include serial autocorrelation, increasing the accuracy of trend analysis results. We shall apply this method to perform change-point analyses of summer temperatures in the summit areas of Romanian Carpathian Mountains.

In the last two decades, some studies have focused on the climatic variations and changes in the mountain regions of the planet and on the effects of such changes on water resources, economic development, and the health of the ecosystems (Beniston 1994; Beniston 1997; Beniston 2003; Messerli and Ives 1997; Mountain 1998). According to some authors (Diaz and Graham 1996; Diaz and Bradley 1997), the alpine zone is

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the most exposed to large-scale climatic changes. Mountains cover about one fifth of the Earth's surface and approximately 10% of the global human population live in mountain areas (Price and Graham 2004). Signals of atmosphere warming trends in the alpine region became evident (The Intergovernmental Panel on Climate Change (IPCC) 1990) and a reduction of 10% in the Northern Hemisphere snow covered area induced by strong deviations in the winter global temperature and precipitation (The Intergovernmental Panel on Climate Change (IPCC) 2001) was recorded in the last part of the twentieth century (Micu 2009).

Mountains play major roles in influencing regional and global climate. They force air to rise increasing the amount of rain and snow on their windward side and creating drier areas downwind (Ramaswamy et al. 2006). Romanian Carpathians are arch-shaped and cover more than 70,000 km^2 (one third of Romania's territory). They are located in central and western areas of Romania and are considered a major climate-generating factor. By their altitude, massiveness, and position, Romanian Carpathians are an important barrier for different types of air masses. Thus, they block partially or totally the trajectories of the cold and dry eastern air masses towards western regions during wintertime or slow down the movement of the wet western Atlantic-originated air masses towards Eastern and Southeastern Europe.

Most mountain weather stations in the Romanian Carpathians, especially those located on the summit, began their recordings in 1961 or later. Data from these weather stations were studied only over the last two decades (Busuioc and von Storch 1996; Hauer et al. 2003; Dragne et al. 2004; Micu and Micu 2006; Busuioc et al. 2010) mainly because long series of data from those stations were not centralized and available to the scientific community until then. Our paper offers additional insight into climate trends and variability in the Carpathians using accurate statistical methods that take into account the serial correlation in the temperature data.

2 Data and methods

2.1 Data

Mean summer temperature data recorded at four high-altitude summit weather stations in the Carpathian Mountains were used in the present study. They are part of a larger network of weather stations in the Romanian Carpathians including almost all types of topography (summit, slope, depression, or valley), although the four stations considered are the only ones above 1,800 m. We have decided to focus on high-altitude summit stations because they are directly exposed to, and the most influenced by, the general air mass movements, which is considered to be the main factor responsible for temperature changes (Busuioc and von Storch 1996; Busuioc et al. 2010). The local human factors such as urbanization or large industrial sites may influence the magnitude of the slope in the lower areas more than at higher elevations. The weather stations considered in this study are representative for the three branches of the Romanian Carpathians: Eastern Carpathians (1), Southern Carpathians (2 and 3), and Western Carpathians (4). The absolute altitude of these stations above Black Sea level ranges from 1,836 to 2,504 m. The stations' coordinates are shown in Table 1 and their geographical positions in Fig. 1. We have analyzed only mean summer temperatures (even though temperature data are available at each month and season of the year) because large-scale climate changes appear to be most articulated during the summer months (e.g., (Toreti et al. 2010; Croitoru et al. 2011)).

In the Romanian Carpathians, like in other mountain areas such as Alps (Disch et al. 2007), the mountain stations do not have very long data series. Most of the mountain stations began their recordings after 1960. At stations where recordings began earlier, most of the nonhomogeneities in the series were found during the first half of the twentieth century (Rebetez and Reinhard 2008; Holobaca et al. 2008). Due to historical and political conditions, some data were lacking, particularly during the two world wars. In addition, before January 1, 1961, the mean daily temperature was calculated as the average of three measured values (08.00 h, 14.00 h, 20.00 h), followed by a correction formula (according to World Meteorological Organization recommendations) in order to get the final value (Clima Republicii Socialiste 1966).

For this paper, we have used 47 year-long series covering the last four decades of the twentieth century and the beginning of the twenty first century recordings: 1961–2007. Ceahlau Toaca station began recordings in 1964 therefore its temperature series is only 44 years long. The mean daily temperature (subsequently used for monthly and seasonal mean values) was computed as the average of four temperature values recorded at 00.00, 06.00, 12.00, and 18.00 UTC at each station.

Homogenized continuous data series for Romanian mountain areas were obtained from different sources (National Meteorological Administration Database (www.meteoromania.ro); Klein Tank et al. 2002). In this paper, we consider mean summer temperature data and identify midterm trends and change points in the evolution of temperature for the time period mentioned.

Table 1 The geographical coordinates of the weather stations in the analysis area

Weather station	Latitude (N)	Longitude (E)	Height (m)
Ceahlau Toaca (1)	46.97750	25.95000	1,897
Vf. Omu (2)	45.44583	25.45667	2,504
Tarcu (3)	45.28111	22.53278	2,180
Vladeasa-1800 (4)	46.75917	22.79417	1,836

Fig. 1 Weather stations considered in this study

2.2 Methods

2.2.1 Statistical models

An established statistical model for change-point analysis is (e.g., (Lund and Reeves 2002; Toreti et al. 2010))

$$Y_t = \begin{cases} \alpha_0 + \alpha_1 t + z_t, \text{ for } 1 \leq t \leq c \\ \beta_0 + \beta_1 t + z_t, \text{ for } c < t \leq n \end{cases}$$

where, Y_t are temperatures indexed by year t, the change in temperature trend slope and/or intercept occurs at time c, and z_t are independent errors with mean zero and variance σ^2. In an equivalent matrix form, this statistical model can be written as

$$\mathbf{Y} = \mathbf{X}\gamma + \mathbf{z},$$

with $\mathbf{Y}$ the vector of temperatures, $\mathbf{z}$ the errors vector, $\gamma = (\alpha_0, \beta_0, \alpha_1, \beta_1)$ and $\mathbf{X}$ a regression matrix of four columns: the first two columns are dummy variables with values 0 (before change), 1 (after change), and 1 (before change), 0 (after change), respectively; the last two columns are 0 (before change), t (after change), and t (before change), 0 (after change) respectively. The model discussed in Lund and Reeves (Lund and Reeves 2002) and Toreti et al. (Toreti et al. 2010) proposes to obtain an estimated value for the change point c by maximizing an F statistic. To determine if the change is statistically significant (i.e., a true change point), Lund and Reeves (Lund and Reeves 2002) compared the observed *max* F statistic with critical values obtained by simulation under a null hypothesis of “no change” at c (see (Lund and Reeves 2002) for more details). In a follow-up paper, Lund et al. (Lund et al. 2007) point out that most climate temperature series exhibit serial correlation and stress the importance of incorporating it into the statistical models. They reported dramatic changes in results when such serial correlation is accounted for and anticipated a "plethora of climate series where previously declared undocumented change points might be erroneously diagnosed, or at least need to be reassessed". Our present study confirms their anticipation by showing substantial changes in results based on statistical models with and without serial correlation. Lund et al. (Lund et al. 2007) generalized the *max F* statistic proposed in their earlier work to identify the change points and suggested critical values obtained again by simulation in the context of the AR(1) model and 95% confidence level. These critical values may depend on time series model parameters, especially for small to moderate series length. Obtaining simulated critical values for more general ARMA models and other confidence levels may not be a trivial undertaking. We present an alternative method to Lund et al. (Lund et al. 2007), which we believe is easier to implement. Specifically, here we use regression models with correlated ARMA errors (e.g., (Brockwell and Davis 2002), Section 6.6). We choose the change point c by minimizing the Akaike Information Criterion (AIC) statistic. Then c is a true change point (as opposed to mere chance variation) if confidence intervals of adjacent slopes and/or intercepts do not overlap. The regression models with correlated ARMA errors allow us to obtain the correct standard errors of slope and intercept estimated values therefore, the resulting confidence intervals will have the correct length. This aspect is crucial in our method.

A consequence of introducing serial correlation in our statistical models will be that the variances of regression coefficient estimators (slope and intercept) will have smaller values than their counterparts based on independent errors. Therefore, the results are expected to be more precise. Correlation models for temporal (and spatial) temperature data have been discussed, for example, in Drignei et al. (Drignei et al. 2008) and Drignei (Drignei 2009), although not in the context of change-point analysis. The model that includes serial correlation error will still be

$$\mathbf{Y} = \mathbf{X}\gamma + \mathbf{z}$$

but the errors vector $\mathbf{z}$ will have a multivariate normal distribution with mean vector zero and covariance matrix $\mathbf{W}$. The errors vector will be modeled by a time series ARMA(p,q) model (e.g., (Brockwell and Davis 2002)). These ARMA models, in turn, will generate the covariance matrix $\mathbf{W}$. A well-known particular case of ARMA(p,q) is the autoregressive AR(1) model $z_t = \varphi z_{t-1} + \varepsilon_t$ with parameter φ, and independent and identically distributed normal residuals ε with mean zero and variance σ^2. The AR (1) model is an ARMA(p,q) model with p=1 and q=0. In this particular case, the covariance matrix $\mathbf{W}$ is given by

$$\mathrm{W}[i,j] = \frac{\sigma^2}{1-\varphi^2}\varphi^{|i-j|}$$

for $i,j = 1,\ldots,n$. This AR(1) model has been extensively discussed in Lund et al. (Lund et al. 2007), but later we will show that the error correlation for our data is much more complex than that of an AR(1) model. The general ARMA (p,q) models considered in this paper are statistical models commonly used in time series analysis and statistical software packages can compute them (e.g., identify their orders p and q and estimate their parameters). For our analysis, we have used the function "arima" in the open-source and freely available R software widely used in the statistics community (R Development Core Team 2009).

The regression coefficients will be estimated by

$$\hat{\gamma} = \left(\mathbf{X}'\mathbf{W}^{-1}\mathbf{X}\right)^{-1}\mathbf{X}'\mathbf{W}^{-1}\mathbf{Y}.$$

(Here $\mathbf{X}'$ denotes the transpose of $\mathbf{X}$). The covariance matrix of this estimator is

$$\mathrm{cov}(\hat{\gamma}) = \left(\mathbf{X}'\mathbf{W}^{-1}\mathbf{X}\right)^{-1},$$

whose diagonal elements provide the variances of each component of $\hat{\gamma}$. The square roots of these variances provide the standard errors of $\hat{\gamma}$. Statistical theory (e.g., (Brockwell and Davis 2002)) shows that the components of $\hat{\gamma}$ have the smallest possible variances, and therefore $\hat{\gamma}$ is the most precise estimator of γ. For each temperature series, we have used the minimum AIC to choose the optimum orders p, q and the best value for the change-point c. As the results in the next sections will show, introducing error serial correlation leads to change points that are much more consistent for all four regions (slightly above 1980 for all four stations) and to standard errors of new slope estimates that are much smaller indicating a gain in the precision of their estimated values.

The method outlined above is parametric because it uses specific parametric distributions (e.g., normal). Nonparametric methods for change-point analyses have also been developed (e.g., (Pettitt 1979)) and implemented in climate-change problems (e.g., (Busuioc and von Storch 1996; Busuioc et al. 2007; Busuioc et al. 2010; Croitoru et al. 2011)).

2.2.2 Circulation patterns indices

To find the teleconnection between mean summer temperature and circulation patterns, we used monthly indices of East Atlantic Pattern (EA), North Atlantic Oscillation (NAO), East Atlantic–Western Russia (EA-WR), Scandinavian Pattern (SCAND), and Polar Oscillation (POL), provided by the National Oceanic and Atmospheric Administration Climate Prediction Center (www.cpc.ncep.noaa.gov). These were constructed from monthly mean standardized 500 mb height anomalies using rotated principal component analysis (Barnston and Livezey

1987; Toreti et al. 2010). This method extracts the main teleconnection patterns for all months, which results in time series of patterns. The summer values were calculated as the average of the three summer months (June, July, and August). Then, direct correlations were calculated between each summer circulation pattern series and summer temperature anomaly series at each station.

EOF analysis on the data set consisting of four temperature series (mean summer temperature at each station considered) has been conducted and the first EOF has been retained. The main EOF has only been used to establish the common variation of the temperature series in order to emphasize the general summer warming that is specific to the entire area under consideration. For the change-point analysis, we used the summer temperature data at each of the four stations.

3 Results

Mountains play major roles in influencing regional and global climates. They force air to rise, increasing the amount of rain and snow on their windward side, thus creating drier areas or "rain shadows" downwind. Mountain areas are considered early indicators of climate change. Some climate researchers believe that changes occurring in mountain ecosystems provide an early glimpse into what may occur later in lowland environments (Ramaswamy et al. 2006).

Since all the stations considered here are located on the summit, they may be directly influenced by the general air mass movements, with the local factors (e.g., topography and vegetation) having a weak influence. The first EOF (computed as described in Section 2.2.2) was responsible for 96.14% of the total variation and thus the variation of summer temperature on the summit in Romanian Carpathians has one major cause as identified by Busuioc et al. (Busuioc et al. 2010). The relationship between summer temperatures and five teleconnection patterns NAO, EA, EA–WR, SCAND, and POL influencing European climate was investigated using the direct correlation between mean summer temperature anomaly series and circulation patterns as explained above. The strongest connection was established with East Atlantic Pattern, especially for the eastern stations (1 and 2; Table 2). Direct correlation indicated statistically significant values above 0.50. These findings are similar to those identified in the lowlands of Romania by Tomozeiu et al. (Tomozeiu et al. 2002). The lowest correlation was found for the NAO index. According to previous studies (Toreti et al. 2010), lack of correlation (no significant correlation value) does not necessarily imply independence of two time series. It may only indicate the absence of a simple linear relationship between them; perhaps a more complex, nonlinear relationship exists between temperatures and this pattern (Pozo-Vázquez et al. 2001).

Table 2 Correlation coefficients between mean summer temperature anomaly series at each station and each circulation pattern index series

Weather station	EA	NAO	EA-WR	SCAND	POL
Ceahlau Toaca (1)	0.55[a]	−0.10	−0.34[b]	−0.32[b]	0.25
Vf. Omu (2)	0.58[a]	−0.14	−0.43[b]	−0.33[b]	0.21
Tarcu (3)	0.53[a]	−0.06	−0.28[c]	−0.30[b]	0.23
Vladeasa-1800 (4)	0.51[a]	0.00	−0.24	−0.26[c]	0.29[c]
Overall average	0.54	−0.08	−0.32	−0.31	0.24

Statistically significance (not calculated for averages): [a] 0.01 level, [b] 0.05 level, [c] 0.1 level

We have implemented first the model with independent errors of Lund and Reeves (Lund and Reeves 2002), for the four summer temperature series. Figure 2 shows these series along with the fitted regression lines. Table 3 shows the estimated change points and slopes along with their margins of error. The change points detected by this statistical model appear to be quite different across the four stations despite an expected similarity due to a large-scale relative proximity of the weather stations. Also, some of the slopes are not statistically significant (e.g., stations 1 and 3 before the change point).

A possible reason for these inconsistent and imprecise results is that serial correlation has not been included in the regression model. We have computed the autocorrelation and partial autocorrelation functions for residuals of each such regression model (Fig. 3) and noticed that their values at some time lags were either very close to, or outside, the critical regions (dashed lines). This is evidence that serial correlation exists in our data, which needs to be included in the statistical models.

We reanalyzed the temperature data with the proposed method and the results are shown in Table 4. At each of the four stations, one change point has been identified in the summer data series. The change point occurs slightly after 1980 at all four stations. From the beginning of 1960s until the early 1980s, decreasing trends were found while subsequently increasing trends were identified until the end of the period. Similar findings were reported for other regions in Southern Europe (Toreti and Desiato 2008; Brunetti et al. 2006; Toreti et al. 2010). The change points are also similar to those identified for French Pyrenees (National Centre for Meteorological Research 2009).

In Romania, the entire decade of the 1970s and the beginning of the 1980s was extremely rainy even resulting in three of the most important four catastrophic floods of the twentieth century that were recorded in Romania's lowlands (Dragota 2006; Croitoru 2006). Therefore, the

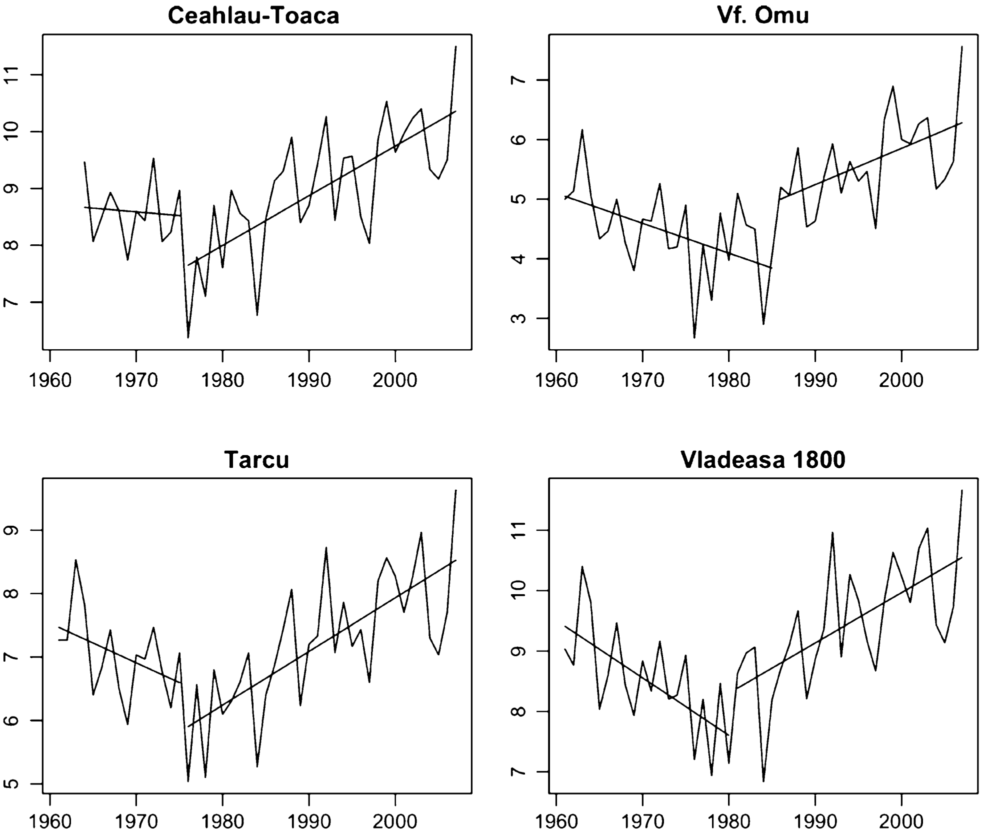


Fig. 2 Summit temperature series and change-point regression model fit with independent errors

decade mentioned was characterized by high cloudiness and relative humidity together with low sunshine duration. The situation was generated mainly by the high frequency of the very intense Atlantic depressions circulation over Romanian territory (Ion-Bordei 1983; Fracas 1983). This decade-long cyclonic activity was able to generate a decreasing trend of air temperature both in lower and higher elevations. Thus, the position of the change point seems to be appropriately identified in the early to mid 1980s.

Busuioc et al. (Busuioc et al. 2010) analyzed the connection between summer temperature variability over the Romanian territory at a very high-density station network and large-scale climate variability. Using Pettitt' test, they found a similar change point which seems to be determined by changes in frequency of positive anomaly patterns of the temperature at 850 hPa and geopotential heights at 500 hPa centered over the Romanian territory.

In our study, the negative slopes range from −0.829°C to −0.530°C/decade while the positive slopes vary between 0.613°C and 0.813°C/decade. The overall averages for both negative and positive slopes recorded before and after, respectively, the change point show similar values (−0.685°C/decade and 0.683°C/decade; Table 4).

Regarding the differences among slopes identified at each station, it is remarkable that the lowest negative and the highest positive slopes were obtained at the same station (2), which is the highest weather station in Romania. At station (1), the most intense cooling and the weakest warming were identified. For the western stations (3 and 4), the negative and positive slopes were very close.

Probably the most remarkable difference between the results based on independent errors in Fig. 2 and those based on serially correlated errors in Fig. 4 occurs at station (1). In Fig. 2, the lowest temperature occurred in 1975 making it the prime candidate for a change point even though the slope of the prechange series is statistically insignificant. By contrast, the regression model with

Table 3 Change points and slopes for summer data series in Romanian Carpathians (°C/decade) for the statistical model with independent errors

Weather station	Change point year	Negative slope before c.p.	Positive slope after c.p.
Ceahlau Toaca (1)	1975	−0.128 (±1.244)	0.874 (±0.286)
Vf. Omu (2)	1985	−0.503 (±0.370)	0.610 (±0.450)
Tarcu (3)	1975	−0.625 (±0.848)	0.846 (±0.272)
Vladeasa-1800 (4)	1980	−0.951 (±0.584)	0.833 (±0.372)

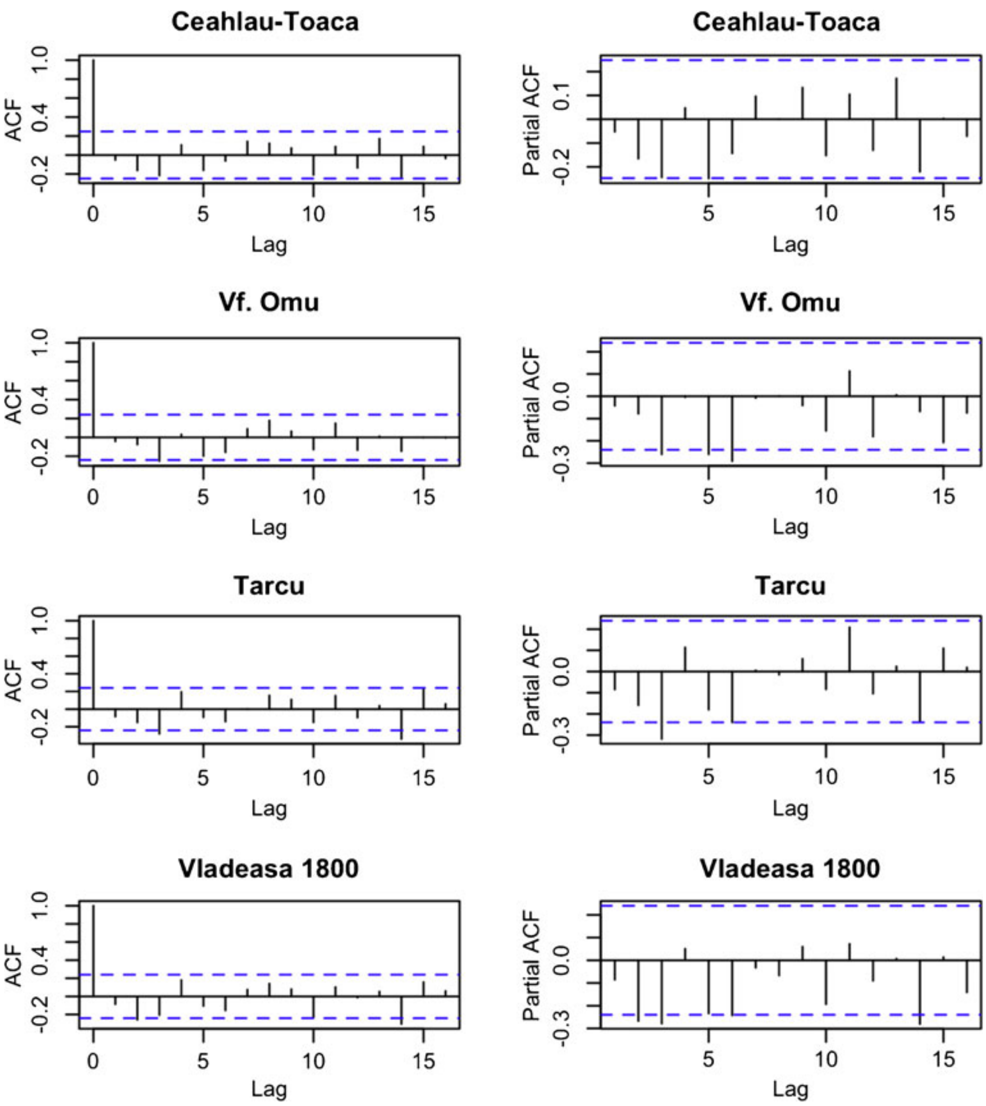


Fig. 3 Autocorrelation and partial autocorrelation functions for each of the four temperature series. The *dashed lines* represent critical regions to determine the statistically significant autocorrelations and/or partial autocorrelations

serially correlated errors in Fig. 4 finds that the change point occurred in 1981. The results at all four stations are more consistent with each other due mostly to a change in the large-scale behavior.

The 95% confidence intervals for the negative and positive slopes at each station in Table 4 do not overlap. This is evidence that the two slopes are statistically different and the change is statistically significant (i.e., a true change point). For example, at weather station (4), the 95% confidence interval for the negative slope is (−0.741 and −0.577) and the 95% confidence interval for the positive slope is (0.675 and 0.695). Since these intervals do not overlap, this is evidence of a statistically significant change.

The last two columns in Table 4 show the orders p and q of the regression residual ARMA model at each station and

Table 4 Change points and slopes for summer data series in Romanian Carpathians (°C/decade) for the statistical model with serially correlated errors

Weather station	Change point year	Negative slope before c.p.	Positive slope after c.p.	Net warming after c.p.	(p, q)	AIC
Ceahlau Toaca (1)	1981	−0.829 (±0.084)	0.613 (±0.006)	1.594	(3, 5)	90.10
Vf. Omu (2)	1982	−0.530 (±0.030)	0.813 (±0.002)	2.032	(4, 5)	75.58
Tarcu (3)	1983	−0.722 (±0.008)	0.619 (±0.002)	1.486	(5, 3)	63.52
Vladeasa-1800 (4)	1984	−0.659 (±0.082)	0.685 (±0.010)	1.575	(5, 4)	94.75
Average	-	−0.685 (±0.051)	0.683 (±0.005)	1.672	–	–

Fig. 4 Summit temperature time series and change-point regression model fit with serially correlated errors

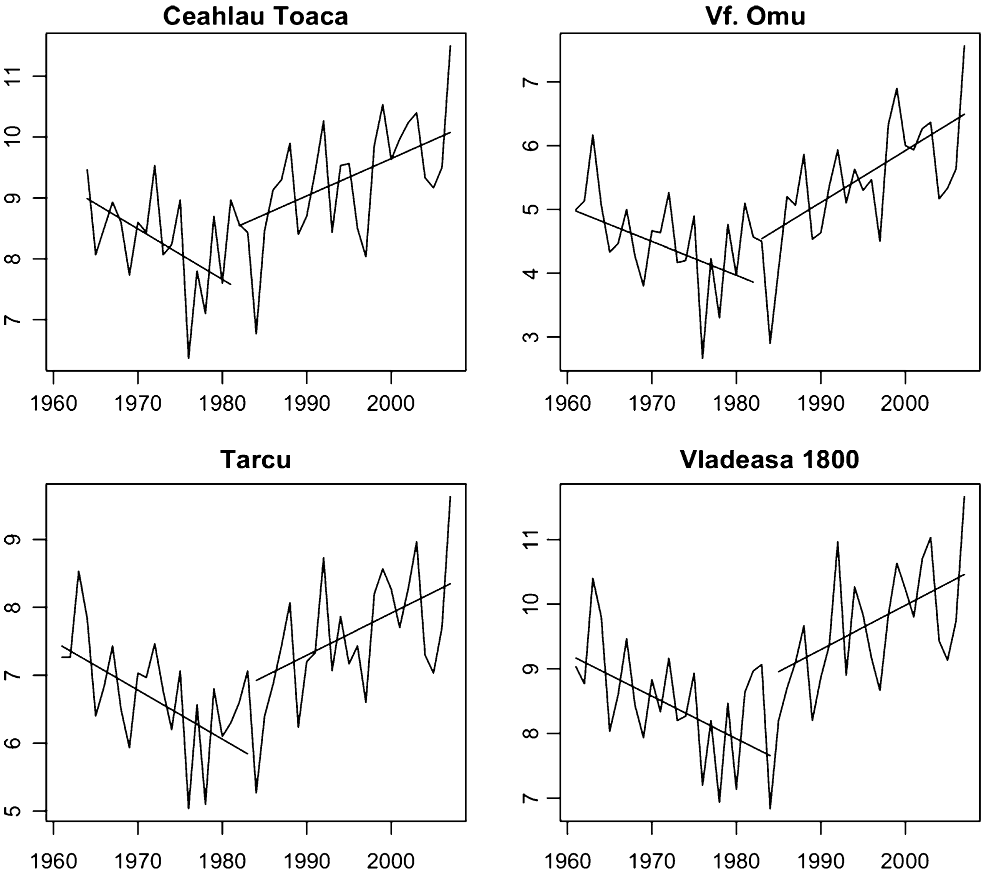
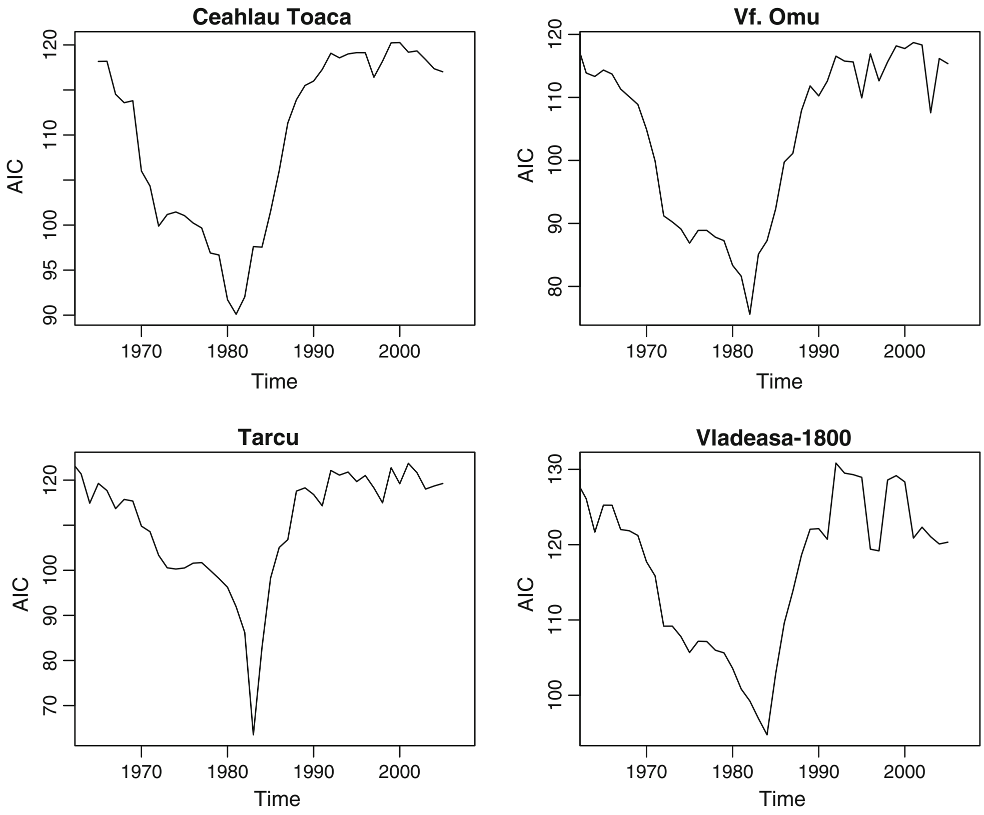


Fig. 5 AIC curves whose minima are achieved at the optimum change-points



the corresponding AIC values. The relatively high orders p and q confirm the complex correlation structures visible in Fig. 3. The change point results for regression models with serially correlated errors are shown in Fig. 4. One can see that these change points are much more consistent with each other than their counterparts in Fig. 2.

Finally, Fig. 5 presents the AIC curves at each station when conducting the search for the optimum change point. These AIC curves are functions of time, and the AIC value at each year t is obtained from the regression model with serially correlated ARMA errors assuming t is a change point. One can see that the method proposed identifies very sharply and unequivocally the optimum change points that minimize the AIC curves.

4 Discussions and conclusions

The analysis of summer temperatures recorded over a 47-year period at four high-altitude summit stations located in the Romanian Carpathians confirms the current general warming that characterizes many other regions in Europe and worldwide. A change point was identified for each station in the early to mid 1980s. Even if the change point moment differs from one station to another with 1 or 2 years, it is close to the change points identified for other regions, in both high and low areas, especially in Southern Europe (Busuioc et al. 2010; Toreti et al. 2010).

The highest positive slope was recorded at the highest station in agreement with findings for other mountain regions on the globe. For example, the annual mean temperature increase in the Alps was almost twice the mean temperature of Germany (Disch et al. 2007). As another example, the higher elevations of the Northern Rocky Mountains have experienced three times the global average temperature increase (Northern Rocky Mountain Science Center 2011) over the past century.

It is worth mentioning that increasing average trend slopes calculated for both Northern Italy (Toreti et al. 2010) and for the four summit stations in the Romanian Carpathians are very similar, 0.640°C/decade and 0.683°C/decade, respectively. Over the period studied, this leads to an average net warming of 1.67°C in the alpine Romanian Carpathians and 1.6°C in Northern Italy. The slightly higher value may be due to the fact that in this paper we only included summit weather stations, in general characterized by a more accelerated warming. Using a linear trend method (Mann–Kendall test) for Romanian mountainous areas and for the same period (1961–2007), the net warming varied from 1.4°C to 1.8°C if homogenized data series were used and from 0.9°C to 1.6°C if original data series were considered (Busuioc et al. 2010).

For the Romanian Carpathians summit area, the overall averages for both negative and positive slopes are similar (−0.685°C/decade and 0.683°C/decade). On the contrary, the situation reported by Toreti et al. (Toreti et al. 2010) for the Alps area (Northern Italy) is quite different, with the increasing trend after the change point much more abrupt (+0.64°C/decade) than the decreasing trend before the change point (−0.39°C/decade).

The calculation of correlation indices for five teleconnection patterns revealed a statistically significant (at 0.01 level) linear correlation with the East Atlantic pattern and statistically significant correlations (at 0.05 and 0.1 levels) with the Scandinavian pattern and with East Atlantic–Western Russia pattern. The only exception is station (4), located in the northwestern part of Romania, not showing a significant correlation with EA–WR. At the same time, it is the only station that established a significant correlation with the polar pattern. No significant linear correlation with NAO index during summer was found for mean temperature.

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