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2 authors:

Adrian Piticar

Ristoiu Dumitru
Babeş-Bolyai University

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ANALYSIS OF AIR TEMPERATURE EVOLUTION IN NORTHEASTERN ROMANIA AND EVIDENCE OF WARMING TREND

Adrian PITICAR & Dumitru RISTOIU
Babeş-Bolyai University, Faculty of Environmental Science and Engineering, 30 Fântânele Street, 400294, Cluj-Napoca, Romania; e-mail adrian.piticar@ubbcluj.ro, dumitru.ristoiu@ubbcluj.ro

Abstract: This paper reports the results of the analysis of monthly, seasonal, and annual mean air temperature series from 10 meteorological stations distributed over Northeastern Romania for a 50-year study period (1961-2010). Various statistical tools were used to detect and characterize significant changes in these series. The Pettitt test, the Standard Normal Homogeneity Test (SNHT), the Buishand range test, the Von Neumann's ratio test have been performed on the data to test the series for homogeneity. The Mann-Kendall test and Sen's slope estimation for trends detection were applied to analyze temperature data sets in the studied area. To explore whether some stations behave similarly or not and if a typology is possible from a spatial point of view, we used spatial hierarchical cluster analysis. The results of the Mann-Kendall test and Sen's slope estimation showed significant increasing trends for air temperature over the Northeastern part of Romania. The values of the statistically significant average slope varied until 0.93°C/decade for the positive slopes and until -0.29°C/decade for the negative slopes. The most important increase in air temperature trend was specific to June, July and August months when nine of the ten weather stations showed statistically significant positive slopes for all 3 months. The spatial hierarchical cluster analysis suggests the existence of two distinctive groups. One of them consists of stations located at lower elevation and the other one includes stations that are located at higher elevation.

Keywords: Northeastern Romania, air temperature trend, homogeneity tests, Mann-Kendall test, cluster analysis.

1. INTRODUCTION

Climate change, particularly temperature variation, is a subject of great topical interest. This problem worries the scientific community, as it could have a major impact on natural and social systems at local, regional and national scales. Even relatively small changes in the means and in variations of air temperature can induce a considerable change in the variability and/or in the severity of extreme events (Hennessy & Pittock, 1995; Colombo et al., 1999; Tahas et al., 2011). Numerous climatologists (Jones et al., 1999; Parker & Horton, 1999; IPCC, 2007; Jones & Moberg, 2003; Vinnikov & Grody 2003) agree that there has been a large-scale warming of the Earth's surface over the last hundred years or so. This warming up of the Earth during the 20th century brought with it a decrease in the area of the world affected by exceptionally cool temperatures, and, to a lesser extent, an increase in the area affected by exceptionally warm temperatures (Rio et al., 2005).

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 (Croitoru et al., 2011b).

In Romania, it is already formed an opinion that in 1901-2007 period the annual mean temperature increased by 0.5°C, with a higher rate in the extra-Carpathians regions (Hobai, 2009). Former studies considering regional temperature trends: Moldavia (Sararu & Tuinea, 2000), Northwestern Romania (Hauer et al., 2003), and Vâlcea County (Vasenciuc et al., 2005) gave different conclusions according to the number of weather stations and the analyzed period. Although, it is quite difficult to compare the results of such studies, in general, most of them showed increasing trends in the majority of the analyzed data series; however, they did not determine the statistical significance of those trends (Croitoru et al., 2011b).

Some studies made on smaller parts of Northeastern Romania (Suceava Plateau, Moldavian Plane) show that the tendency of air temperature evolution is a clear positive one (Mihăilă & Tănasă, 2005), which makes the study area to fit into general tendency of the global warming.

In this study, data from ten weather stations were used. The stations are located in the Northeastern part of Romania in the plain, hilly and mountainous areas. The main purposes of this study were to identify trends in monthly, seasonal, and annual mean temperature for time series of 50 years (1961-2010) as well as to perform some specific homogeneity tests. At the same time, a hierarchical cluster analysis was used to identify whether or not some stations behave similarly from a spatial point of view.

The study area is located in the Northeastern part of Romania and covers the administrative teritory of four counties: Suceava, Botoşani, Neamț and Iaşi and has an area of 24911 km^2 (fig. 1). The study region is bordered on the east by Republic of Moldova, on the north by Ukraine, on the south by Bacău and Vaslui counties and on the west by Harghita County, Mureş County, Bistrița-Năsăud County and Maramureş County. The relief decreases from west to east from mountainous area of Eastern Carpathians to Moldavian Plain. The climate of this region is temperate-continental with a more pronounced continental character in the east (Moldavian Plane) and moderate character westward.

2. DATA AND METHODS

2.1. Data

Data recorded at ten weather stations in Northeastern Romania were used for the present study. Two of the weather stations are located in mountainous area, five are located in hilly area and three are located in plain area as shown in figure 1 and table 1. The present analysis relies on the observation data recorded for a 50 years period (1961-2010).

Mean annual data were used to identify inhomogeneities in the series, to compare the mean temperature from 1961-1990 period with the mean from 1971-2000 and 1981-2010 periods, to compare the mean of 10 years sub-intervals of the total data, respectively 1961-1970, 1971-1980, 1981-1990, 1991-2000 and 2001-2010 and to perform hierarchical cluster analysis.

Mean annual, seasonal and monthly data were used to identify general trends in the temperature datasets. These data were provided by the National Meteorological Administration.

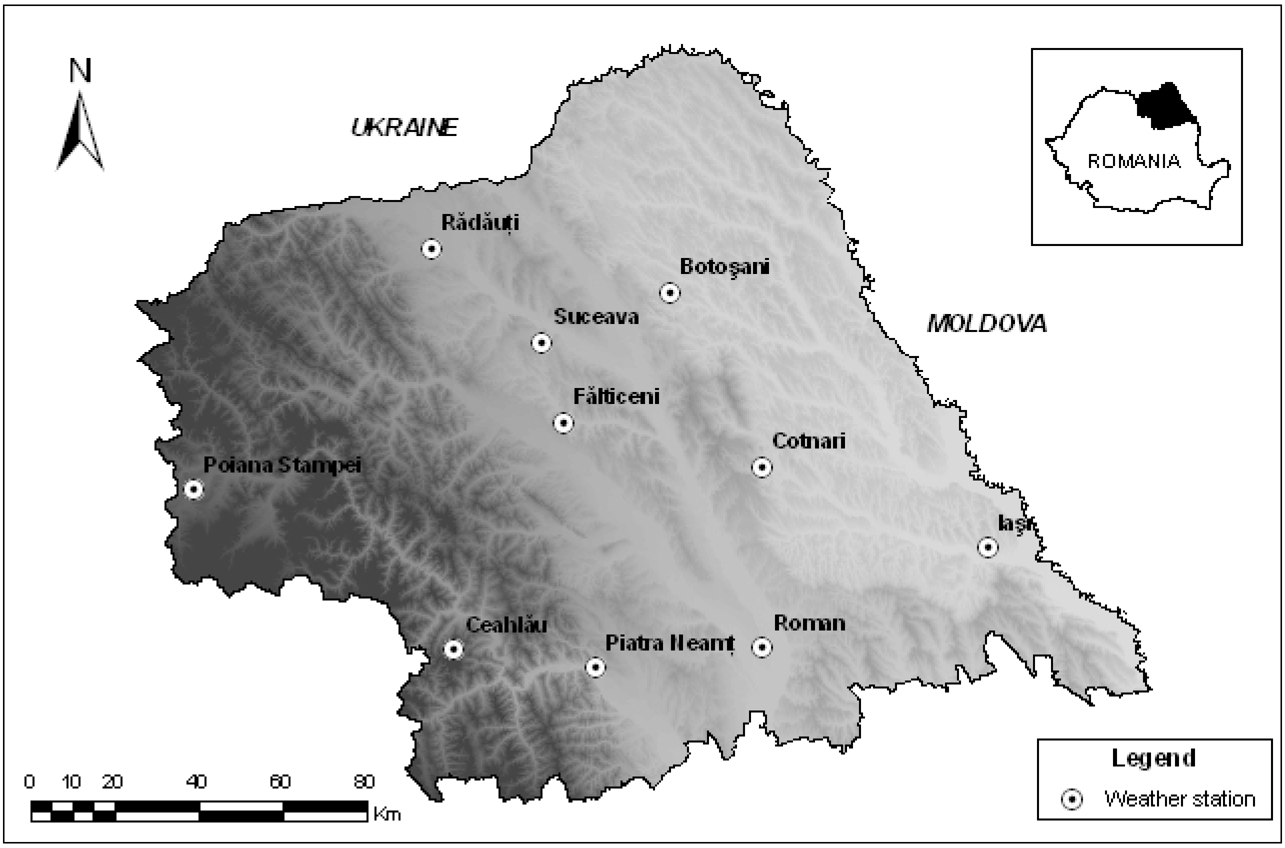

Figure 1. Weather stations used in this study and Northeastern Romania.

They were selected according to the length and completeness of records, so as to provide a reasonable spatial coverage over Northeastern Romania.

2.2. Methods

Four test methods have been performed on the data to test the annual series for homogeneity as follows: the Pettitt's test (Pettitt, 1979), the standard normal homogeneity test (SNHT) for a single break (Alexandersson, 1986), the Buishand range test (Buishand, 1982), and the Von Neumann's ratio test (Von Neumann, 1941). The first three ones, under the alternative hypothesis, assume that a break in the mean is present and allow identifying the time at which the shift occurs. The Von Neumann ratio test assumes, under the alternative hypothesis, the series is not randomly distributed and not allow detecting the time at which the change occurs (it gives no information on the year of the break).

To see if a change occurs in the annual mean temperature we examined and compared the mean of three sub-periods (1961-1990, 1971-2000, 1981-2010), of 30 years, which is the classical period defined by the World Meteorological Organization. For a more detailed analysis we examined and compared the mean of 10-year sub-intervals of the total data, respectively 1961-1970, 1971-1980, 1981-1990, 1991-2000 and 2001-2010.

To detect and estimate trends in the time series of monthly, seasonal, and annual temperature values, the Excel template MAKESENS (Mann-Kendall test for trend and Sen's slope estimates), developed by researchers of the Finnish Meteorological Institute (Salmi et al., 2002), was used. In Romania, the same method and software have also been used with good results to identify trends in different data series (temperature, precipitations, fog, snow cover, sunshine duration) (Micu & Micu, 2006; Holobaca et al., 2008; Micu, 2009; Mureşan & Croitoru, 2009; Croitoru et al., 2011 a, c, d).

The procedure is based on the non-parametric Mann-Kendall test for the trend and Sen's non-parametric method for the magnitude of the trend (Mann, 1945; Kendall, 1975). The Mann-Kendall test is applicable to the detection of a monotonic trend of a time series. Sen's method uses a linear model to estimate the slope of the trend, and the variance of the residuals should be constant in time.

The MAKESENS software performs two types of statistical analyses: first, the presence of a monotonic increasing or decreasing trend is tested with the non-parametric Mann-Kendall test, and then, the slope of a linear trend estimated with Sen's non-parametric method is computed (Gilbert, 1987). In MAKESENSE, the tested significance levels α are 0.001, 0.01, 0.05, and 0.1. Both methods are used here in their basic forms. At the same time, they offer many advantages: missing values are allowed and data needed are not conferrable to any particular distribution; single data errors or outliers do not significantly affect Sen's method.

The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i, \qquad (1)$$

where $f(t)$ is a continuous monotonic increasing or decreasing function of time, the residuals 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 in time.

Then, the null hypothesis of no trend, H_0, is tested in order to accept or reject it. The x_i observations are randomly ordered chronologically, contrary to the alternative hypothesis H_1, where there is an increasing or decreasing monotonic trend. The statistic test Z (normal approximation) is computed because all time series are longer than ten. The statistic Z has a normal distribution. The absolute value of Z can be compared to the standard normal cumulative distribution to identify if there is a monotone trend or not at the specified level of significance.

Table 1. Geographical coordinates of weather stations in analysis area

Weather station[a]	Latitude (N)	Longitude (E)	Height (m)
Botoşani	47°44'	26°39'	161
Ceahlău	46°59'	25°57'	1897
Cotnari	47°22'	26°56'	289
Fălticeni	47°28'	26°18'	348
Iaşi	47°10'	27°38'	102
Piatra Neamț	46°55'	26°24'	314
Poiana Stampei	47°20'	25°08'	923
Rădăuți	47°50'	25°54'	389
Roman	46°58'	26°55'	216
Suceava	47°38'	26°15'	350

[a]Weather stations are ranged in alphabetical order

An upward (increasing) or downward (decreasing) trend is given by a positive or negative value of *Z*. First the variance of *S* is computed using the following equation (2), which takes into account that ties may be present:

$$VAR(S)=\frac{1}{18}[n(n-1)(2n-5)-\sum_{p=1}^{q} t_p(t_{p-1})(2t_p+5)], \quad (2)$$

where q is the number of tied groups, t_p is the number of data values in the p^{th} group.

Than the values of *S* and *VAR(S)* are used to compute the test statistic *Z,* as is present in (3a, b, c):

$$Z=\frac{S-1}{\sqrt{VAR(s)}}, \text{ if } S>0, \quad (3a)$$

$$Z=0, \text{ if } S=0, \quad (3b)$$

$$Z=\frac{S+1}{\sqrt{VAR(S)}}, \text{ if } S<0. \quad (3c)$$

To estimate the true slope (Q) of an existing trend (as change per year), Sen's non-parametric method was used. Sen's method can be used in cases where trend is assumed to be linear. This means that $f(t)$ is equal to:

$$f(t) + Q_t + B, \quad (4)$$

where Q is the slope and B is a constant.

To determine the Q value, the slope for all values pairs is calculated first:

$$Q_1=\frac{x_j-x_k}{j-k}, \quad (5)$$

where $j>k$. The Q slope represents the median of all Q_i values ranked in ascending order. The constant B is given by the median of n values of $x_i - Q_{ti}$.

Hierarchical cluster analysis using the Ward method for annual temperature data series was also used to identify whether or not some stations behave similarly. Thus, agglomerative hierarchical clustering (AHC) with Ward's method and a Euclidean distance matrix was calculated (Rebetez & Reinhard, 2008; Croitoru et al., 2011 a). Each sample is initially treated as a cluster, and the method proceeds stepwise by systematically merging clusters whose fusion results in a minimum loss of information (i.e. there is a minimum increase in the total within-group error sum of squares). This procedure attempts to identify relatively homogeneous groups of cases (or variables) on the basis of temperature characteristics by using an algorithm that starts with each case (or variable) in a separate cluster and combines clusters until only one is left. Distance or similarity measures are generated by the proximities procedure. Spatial analysis using this method is very helpful in determining regional behavior.

3. RESULTS AND DISCUSSIONS

3.1. Homogeneity tests

The homogeneity of the annual temperature time series for the period 1961-2010 has been tested. Change points appeared, particularly in the late 1980s or 1990s. In table 2, the annual results of the Pettitt, Standard Normal Homogeneity Test (SNHT), the Buishand range and the Neumann tests applied to temperature data are shown.

Examples of change points detected for annual temperature data in Northeastern Romania are presented in figure 2a, b, c and d, along with the mean of the two sub-intervals.

The annual results of the Pettitt, SNHT and the Buishand range tests applied to temperature data series show that the change points were detected at 1988, 1995 and 1998. Two of the tests (the Pettitt and the Buishand tests) show the 1988 shift point as the year at which the change occurs at all stations except Ceahlău station, where shift point was in 1995. According to SNHT the 1988 is the change point for Botoșani, Iași Rădăuți and Suceava, 1995 for Ceahlău and 1998 for Cotnari, Fălticeni, Piatra Neamț, Poiana Stampei and Roman stations. All the change points are significant at 0.01 and 0.001 levels of α.

The significant values of the Von Neumann test indicates that the series is not randomly distributed at all stations except Ceahlău station where α has a value greater than 0.05 and the result is not significant.

The 1988 change point in temperature data as the year at which the change occurs at most stations over Northeastern Romania coincides with the same year in which a significant change point in air temperature was identified in Northern and Central Europe (Donnelly et al., 2009).

Hari et al. (2006), found out that a change point has also been reported in 1988 for air and water temperature in the Alpine region. These change points have been attributed to a shift in the NAO into its present extended positive phase (Beaugrand, 2004; Fealy & Sweeney, 2005; Hari et al., 2006; Donnelly et al., 2009). It was demonstrated in several works (Beaugrand, 2004; Fealy & Sweeney, 2005; Donnelly et al., 2009) that there is evidence that a major change in atmospheric variability occurred in the North Atlantic region at that time which was associated with an abrupt increase in temperature and an increased occurrence of westerly winds.

Table 2. Annual results of the homogeneity tests for mean temperature in Northeastern Romania over the period 1961-2010

Weather station	Pettitt's test	Standard Normal Homogeneity Test (SNHT)	Buishand's test	Von Neumann's test
Botoşani	391*** 1988[1]	14.587*** 1988[1]	13.542*** 1988[1]	1.406*
Ceahlău	329** 1995[1]	11.869** 1995[1]	11.277** 1995[1]	1.65
Cotnari	354** 1988[1]	14.266*** 1998[1]	12.681*** 1988[1]	1.343**
Fălticeni	385*** 1988[1]	16.542*** 1998[1]	14.101*** 1988[1]	1.160***
Iaşi	356** 1988[1]	13.146** 1988[1]	12.856*** 1988[1]	1.432*
Piatra Neamț	317** 1988[1]	10.747** 1998[1]	11.086** 1988[1]	1.527*
Poiana Stampei	460*** 1988[1]	19.920** 1998[1]	14.249*** 1988[1]	1.322*
Rădăuți	412*** 1988[1]	16.703*** 1988[1]	14.491*** 1988[1]	1.183***
Roman	370*** 1988[1]	15.426*** 1998[1]	13.087*** 1988[1]	1.381*
Suceava	414*** 1988[1]	16.992*** 1988[1]	14.615*** 1988[1]	1.239**

*Significant at 0.05 level, **significant at 0.01 level, ***significant at 0.001 level.
[1]The year at which the change occurs (break year).

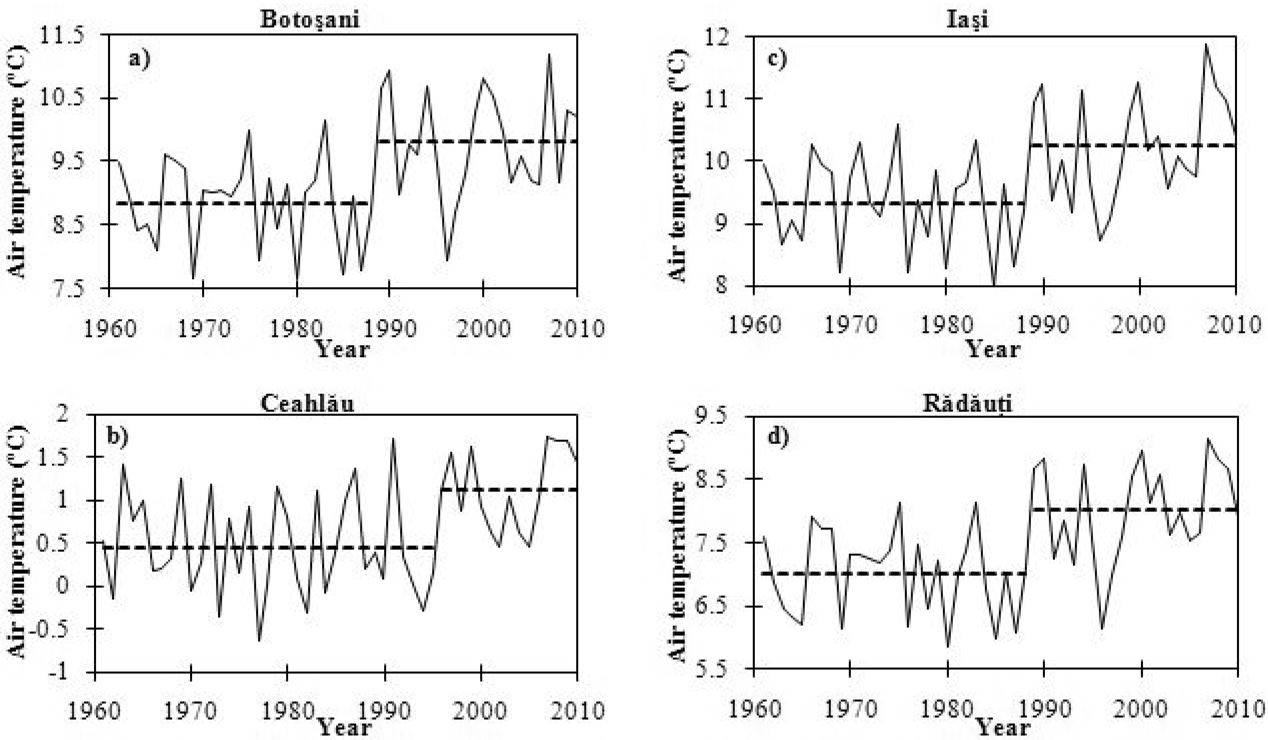

Figure 2. The averages of the two sub-intervals along with the change point detected for annual mean of air temperature at Botoşani, Ceahlău, Iaşi and Rădăuți stations.

3.2. Mean air temperature evolution for 30-year and for 10-year intervals

In order to emphasize the ascending evolution of air temperature from 1961 to 2010 we compared the mean temperature from 1961-1990 period with the mean from 1971-2000 period and with the mean from 1981-2010 period (Table 3).

It can be observed an increasing of air temperature for the last periods of 1971-2000 and 1981-2010 for all weather stations. Also it can be noticed that all weather stations have a higher increasing rate in the temperature means from 1971-2000 to 1981-2010 periods than from 1961-1990 to 1971-2000 periods. For example it can be seen an increasing with 0.2°C by comparing the means of 1961-1990 (7.5°C) and 1971-2000 (7.7°C) periods, while by comparing the means of 1971-2000 (7.7°C) and 1981-2010 (8.1°C) periods it can be seen an increasing with 0.4°C at Suceava station.

Moreover, at all stations analyzed in Northeastern Romania, the mean temperature of 10-year intervals increased almost constantly with values between 0.6°C at Ceahlău station and 1.9°C at Poiana Stampei station (Table 4).

3.3. Temperature trend analysis

The Mann-Kendall test was applied to 17 data sets (monthly, seasonal and annual) for the interval 1961-2010, for all of the analyzed stations. The results of Mann-Kendall test are presented in table 5.

The most important increase was specific to summer months (June, July, August), when nine of the ten locations showed statistically significant positive slopes for all 3 months. July and August indicate positive slopes for all stations where statistically significant values were identified. Annual and summer values also indicate generalized positive slopes in the study area with statistically significant levels of α. Considering also statistically significant trends, data sets with negative trends are found at every station, especially in the autumn.

The significance level for the positive slopes varies from 0.1 to 0.001. At the analyzed stations the strongest significance was characteristic to June, July, August, summer and annual data series where the α level of 0.001 was present. For the negative slopes the significance level is 0.1 in September and autumn series at Piatra Neamț station.

When analyzing slopes for all the 17 data series, the positive values – especially those that are statistically significant – were clearly much higher than negative values.

At the analyzed stations from Northeastern Romania the values of the statistically significant average slope varied until 0.93°C/decade for the positive slopes and until -0.29°C/decade for the negative slopes.

From the total amount of 17 series, 9 have positive slopes in the whole area: January, May, June, July, August, winter, spring, summer and annual data series; while none of the data series have negative slopes in the whole area.

The total positive versus total negative trends and positive versus negative statistically significant trends were compared in order to see which number of cases has greater or lower values (Fig. 3). The number of total positive slopes was more than five times higher that of the total negative ones. For statistically significant trend values, the number of positive slopes was 93, while the number of negative slopes was only 2.

Table 3. Mean air temperature over the 1961-1990, 1971-2000, and 1981-2010 periods

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamț	Poiana Stampei	Rădăuți	Roman	Suceava
1961-1990	9.0	0.5	9.1	8.0	9.5	8.7	4.1	7.1	8.5	7.5
1971-2000	9.2	0.6	9.3	8.2	9.6	8.8	4.3	7.3	8.7	7.7
1981-2010	9.5	0.8	9.7	8.6	10.0	9.0	4.9	7.7	9.0	8.1

Table 4. Mean air temperature evolution over 10-year intervals

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamț	Poiana Stampei	Rădăuți	Roman	Suceava
1961-1970	8.9	0.5	9.1	8.0	9.4	8.6	4.0	7.0	8.6	7.5
1971-1980	8.9	0.4	8.9	7.9	9.4	8.6	4.1	7.0	8.5	7.4
1981-1990	9.2	0.4	9.3	8.2	9.6	8.8	4.2	7.3	8.6	7.7
1991-2000	9.6	0.8	9.5	8.6	9.9	9.0	4.7	7.7	8.9	8.1
2001-2010	9.9	1.1	10.2	9.2	10.4	9.4	5.9	8.2	9.6	8.6

Table 5. Sen's slope estimate (Q) and their statistical significances (SS) for air temperature trends in Northeastern Romania for the period 1961-2010 (°C/decade)

	Botoşani		Ceahlău		Cotnari		Fălticeni		Iaşi		Piatra Neamț		Poiana Stampei		Rădăuți		Roman		Suceava	
	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS
J	**0.93**	*	**0.06**		**0.87**	**	**0.80**	*	**0.50**	+	**0.88**	**	**0.64**	*	**0.80**	*	**0.64**	*	**0.79**	*
F	0.56	+	-0.04		0.72	*	0.68	*	0.43		0.50		0.44	+	0.63	+	0.55	+	0.59	+
M	0.45		-0.15		0.62	*	0.64	*	0.43		0.58	*	0.40	*	0.54	*	0.55	*	0.50	+
A	0.00		0.17		0.16		0.18		0.04		-0.03		0.27	+	0.21		0.14		0.20	
M	**0.23**		**0.20**		**0.25**		**0.30**		**0.17**		**0.18**		**0.31**	*	**0.27**	+	**0.27**		**0.25**	
J	**0.24**	+	**0.33**	*	**0.29**	*	**0.38**	**	**0.21**	+	**0.14**		**0.50**	***	**0.33**	*	**0.33**	*	**0.33**	*
J	**0.44**	**	**0.57**	***	**0.49**	***	**0.52**	***	**0.41**	**	**0.24**	*	**0.52**	***	**0.51**	***	**0.49**	***	**0.50**	***
A	**0.23**	+	**0.50**	***	**0.34**	*	**0.43**	***	**0.25**	*	**0.25**	+	**0.53**	***	**0.45**	***	**0.38**	**	**0.44**	***
S	-0.18		0.00		-0.12		-0.01		-0.10		-0.27	+	0.00		-0.04		-0.05		-0.05	
O	0.00		0.17		0.09		0.15		0.06		-0.06		0.26	+	0.07		0.06		0.08	
N	-0.25		0.20		-0.17		-0.20		-0.26		-0.29		-0.05		-0.08		-0.09		-0.09	
D	0.21		0.00		0.21		0.24		0.13		0.23		0.27		0.20		0.08		0.23	
Annual	**0.23**	**	**0.16**	*	**0.27**	**	**0.30**	**	**0.25**	**	**0.20**	*	**0.33**	***	**0.29**	**	**0.23**	**	**0.27**	***
DJF	**0.45**	+	**0.01**		**0.66**	**	**0.52**	*	**0.33**		**0.47**	*	**0.30**	*	**0.53**	*	**0.44**	*	**0.54**	*
MAM	**0.23**	+	**0.10**		**0.33**	*	**0.39**	**	**0.22**	+	**0.29**	+	**0.33**	**	**0.36**	**	**0.33**	**	**0.33**	*
JJA	**0.27**	**	**0.44**	***	**0.36**	***	**0.42**	***	**0.28**	**	**0.18**	*	**0.49**	***	**0.40**	***	**0.36**	***	**0.39**	***
SON	-0.08		0.09		-0.04		-0.02		-0.07		-0.18	+	0.07		0.00		0.00		0.03	

+Significant at 0.1 level, *significant at 0.05 level, **significant at 0.01 level, ***significant at 0.001 level; values in bold represent generalized trend (increasing or decreasing) in the area.

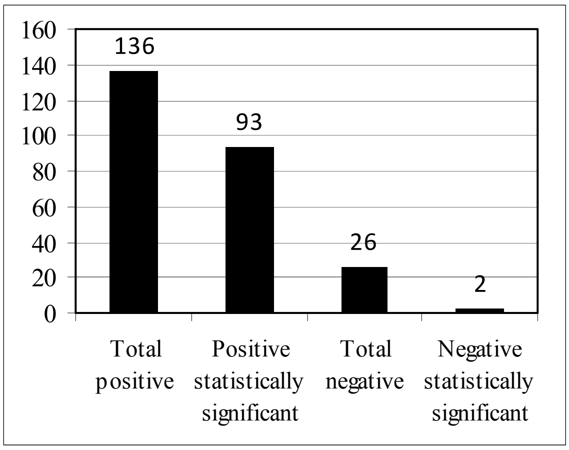

Figure 3. Total number of positive and negative trends and number of statistically significant positive and negative trends.

3.4. Hierarchical cluster analysis

To explore if the clustering results make sense from a spatial point of view, we used aglomerative hierarchical clustering (AHC) with Ward's method and a Euclidian distance matrix (Legendre & Legendre, 1998; Rebetez & Reinhard, 2008).

As shown in figure 4, two important groups have been identified: the first group which consists of stations located at lower elevation (Botoşani, Cotnari, Fălticeni, Iaşi, Piatra Neamț, Rădăuți, Roman, Suceava) and the second group which consists of stations located at higher elevation (Ceahlău, Poiana Stampei). The best connection, of 1, is estabilished between subgroups of stations of first group which are located, in general, in the same relief unit type. The distance between the subgroups of first group were less than 6, which led us to consider them as a single major group. The major difference between the behaviours of first and second group was given by the rescaled distance of 25. Thus, two major groups were identified from a spatial point of view: the high elevation group with two locations in mountainous western area of the studied territory (Ceahlau and Poiana Stampei) and another group of low elevation covering the rest of the study area consisting of hilly and plain relief.

4. CONCLUSIONS

The analysis of air temperature recorded over a 50-year period at 10 stations located in the Northeastern part of Romania confirms the current general warming that characterizes many other regions in Europe and world-wide. It was found that during that period, the temperature showed significant warming trend.

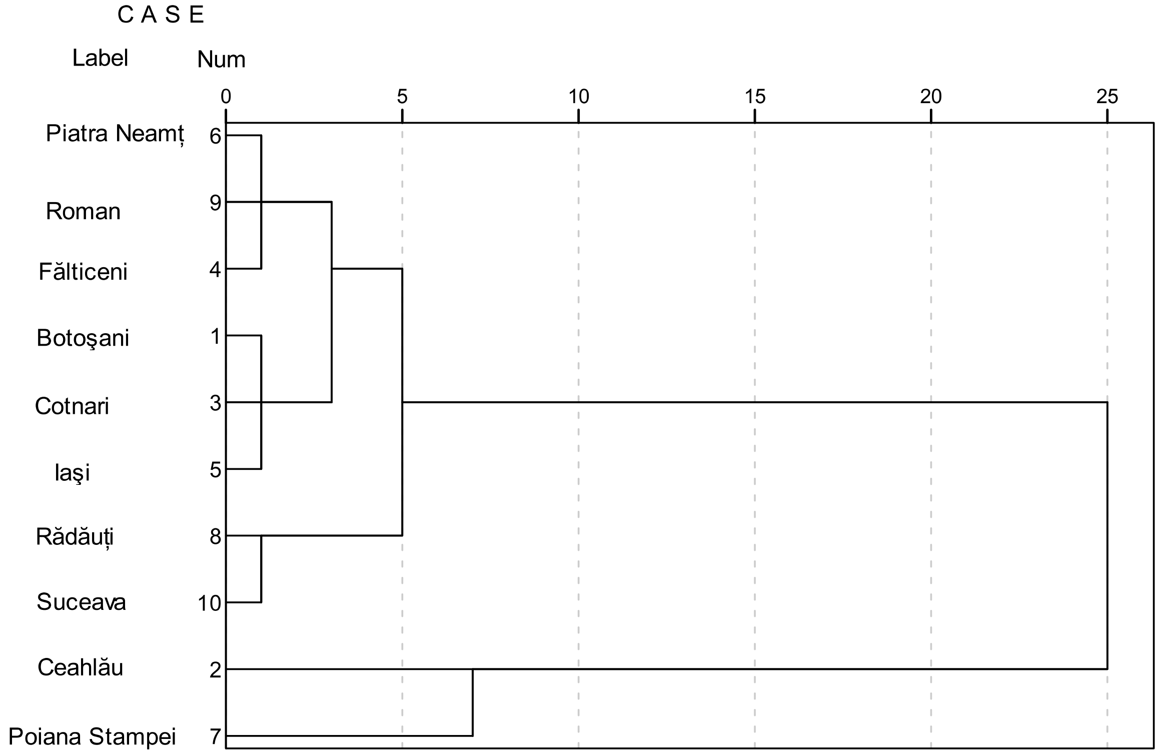

Figure 4. Spatial hierarchical cluster analysis.

The Mann-Kendall test applied to 17 data sets (monthly, seasonal and annual) for the interval 1961-2010, for all of the analyzed weather stations indicated that the most important increase in air temperature was specific to summer months (June, July, August), when nine of the ten stations have shown statistically significant positive slopes for all 3 months. Only in few months are found negative trends especially in the autumn at Piatra Neamț. Annual and summer data series also indicate generalized statistically significant positive slopes in the study area.

Our analysis show high connection between stations, indicating that synoptic factors may dominate over local factors: the observed trends indicate a general warming at all stations and cannot be related to locally changing conditions alone. There was no difference between the isolated high elevation stations and those influenced by the urban heat islands.

By comparing the annual mean of air temperature for different time intervals it can be observed an increasing of air temperature almost constant for the last decades confirming the general warming trends.

Spatial hierarchical cluster analysis indicated the existence of two distinctive groups: a large one that covers most of the study area and includes eight stations with lower elevations and a smaller group with two stations located in the west and characterized by higher elevations.

The annual results of the homogeneity tests show that 1988 is the year at which the change point occurred at the most stations over Northeastern Romania. This coincides with the same year in which a significant change point in the air temperature was identified in many regions of Europe (Beaugrand, 2004; Fealy & Sweeney, 2005; Hari et al., 2006; Donnelly et al., 2009).

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