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Seasonal and annual extreme temperature variability and trends of the latest three decades in Romania

[1]Emil Chiţu, [2]Daniela Giosanu, [3]Elena Mateescu

[1] Research Institute for Fruit Growing Piteşti, Romania; [2] Piteşti University, Piteşti, Romania; [3] National Meteorological Administration, Bucharest, Romania. Corresponding author: E. Chiţu, e-mail: emilchitu@gmail.com

Abstract. It was anticipated that every region in Europe will be negatively affected by the future climate changes. The latest European studies concluded that the intensity of extreme temperatures increased more rapidly than the intensity of more moderate temperatures over the continental interior due to increases in temperature variability. At the same time in many regions there is an asymmetry in the warming that undoubtedly will contribute to heterogeneity in ecological dynamics across systems. The objective of this work was to identify spatial variations of the seasonal and annual extreme temperature variability and trends over Romania in the period 1982-2011. Starting with a large climatological database (30 years of daily data for 29 locations from Romania), daily minimum, maximum and amplitude temperature data were condensed into normal probability functions for which the assumption of normal distribution was accepted by the Shapiro-Wilk statistical test (SPSS 14.0, USA). These functions were used to calculate the appearance probability of annual and monthly temperatures values. Temperatures which appear with different probabilities all year long were computed with "NORMDIST" function from Microsoft Office Excel. Based on these values data thematic maps were generated with isolines drawn by geo-statistical interpolation (kriging method of Surfer®, Golden Software, 2009). Comparing the increasing trend per decade expressed by probabilities, we found that the minimum temperature had a faster rate (21.9% in a decade) than maximum temperature (17.0% in a decade). In all cases mean daily temperature amplitude remained unchanged from 1982 to 2011. We identified the presence of an increased variability of annual mean temperature trends between the different stations. It was noted that the level of statistical significance of maximum and minimum temperature linear trends per decade was low during winter, spring and autumn. But this level of significance was very high (between 0.01 and 0.001) for June, July and August months.

Key Words: minimum and maximum temperature, amplitude, extreme.

Introduction. Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (2001) suggests that similarly to many regions of the world, eastern and central European countries could become vulnerable to the global warming. Many investigations support these findings, e.g. in the Carpathian Basin: next to rising temperature means, severe shortage of precipitation occurred in the last few decades, therefore, ecosystems are facing to high risk of ecological changes, as well. Parallel to the changes of precipitation, that are not unequivocal in space (Mika & Balint 2000), frequent extreme events (e.g., floods with fast runoff and persistent droughts) may occur, resulting in unstable climate conditions and increased vulnerability of water management in the region. These facts highlight the importance of detailed climate research of the region.

The trend in climate evolution towards aridization has also been observed in Romania. According to the maps on the vulnerability included in the IVth IPCC report drawn up in 2007, climate change in Romania by the end of this century will result in an increase in mean annual temperatures of 3-3.5ºC and a 10-20% decrease in mean annual precipitations. Romania’s territory, as a whole, has already experienced a 0.5°C increase in average annual temperature since 1901 (higher increase outside the Carpathian arch – up to 2°C, lower increase inside the arch), and over 3°C increase in summer and winter temperatures. Across the country, the average minimum summer temperature is higher, as well as the average maximum summer temperature (up to 2°C in the S and SE). Tropical days are more frequent, and winter days are increasingly rare. Annual quantities of precipitations have been steadily decreasing, especially in the South and South-East of Romania.

The Romania's Fifth National Communication on Climate Change under The United Nations Framework Convention on Climate Change (2010) underlines that the changes in the climate conditions in Romania are part of the global context, taking into account the regional conditions: the temperature increase is expected to be more obvious during the summer. According to the same communication, compared to the baseline (1961-1990), in January, in the 2001-2008 interval, the air temperature increased by 1.6°C, in March by 1.3°C, in July by 1.6°C and in August by 1.6°C. The increasing trend was obvious beginning with 1981.

Sandu et al (2010) showed that at the level of 1901-2008 period, analysis of the values of the annual mean air temperature from a total of 17 meteorological stations with consecutive series of observations over 100 years, shows that the annual mean temperature increased by 0.5°C between 1988-2008 (10.1°C) over the whole period analyzed (9.6°C), a value which is below the global average warming of 0.6°C.

According to the recent EU white paper document "Adapting to climate change: Towards a European framework for action", published on the 26th of November 2010 and modified on the 13th of April 2011, there were thermal differentiations between regions: a more pronounced warming in the southern and eastern regions of the country (up to 0.8°C at Bucharest-Filaret station, Constanţa and Roman, and insignificant warming in the Intra-Carpathian regions, except town Baia Mare, where the effect of the anthropogenic activity led to a 0.7°C increase.

According to IPCC 2012 report 'Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation' (A Special Report of Working Groups I and II of the IPCC), it is very likely that there has been an overall decrease in the number of cold days and nights and an overall increase in the number of warm days and nights at the global scale, that is, for most land areas with sufficient data. It is likely that these changes have also occurred at the continental scale in North America, Europe, and Australia. In the same study was noted that there is medium confidence that droughts will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration. This applies to regions including southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa.

Barriopedro et al (2011) showed that the anomalously warm summers of 2003 in western and central Europe and 2010 in Eastern Europe and Russia both broke the 500-year long seasonal temperature record over 50% of Europe. More recent analyses available since the AR4 include a global study (for annual extremes) by Brown et al (2008) based on the data set from Caesar et al (2006), and regional studies for central and eastern Europe (Bartholy & Pongracz 2007; Kürbis et al 2009). An example of recent extreme heat wave includes the 2007 heat wave in southeastern Europe (Founda & Giannakopoulos 2009). Overall, these studies are consistent with the assessment of an increase in warm days and nights and a reduction in cold days and nights on the global basis, although they do not necessarily consider trends in all four variables, and a few single studies report trends that are not statistically significant or even trends opposite to the global tendencies in some extremes, subregions, seasons, or decades.

Material and Method. In this study, we used a large database collected by the National Meteorological Administration Bucharest which consists of daily minimum and maximum temperatures of the air (2 m from the ground) during 1982-2011 from 29 stations, evenly distributed throughout Romania. In the study we assumed that the average of the 29 stations is representative for Romania.

To highlight the temporal thermal variability over the past 30 years, represented by annual and monthly averages of the 29 stations, but also its spatial deviations, the data was statistically processed using specialized programs SPSS 14.0 and Microsoft Excel Office. To determine the intensity, duration, form and character of thermal variation, we selected as a time for analysis, year and month and as spatial variation Romania and 29 stations.

To do this, daily database was condensed into 4 datasets as follows: 1) for Romania 30 annual values (average of 29 stations) and 360 monthly values (30 years x 12 months) and 2) for each station 868 annual values (30 years x 29 stations, Siria 1982-1983 missing) and 10,416 monthly values (30 years x 12 months x 29 stations, 24 months for Siria missing). Each of the four data sets have undergone the same steps of analysis: for each simple strings of values (maximum temperature (MAXT), minimum temperature (MINT) and mean daily temperature amplitude (MDTA)) were considered: the central tendency by average, median and mode and dispersion indicators were represented by extreme values (absolute minimum and maximum), maximum amplitude of variation, standard deviation, skewness, kurtosis, histogram and normality of data distribution was checked with Shapiro-Wilk and Kolmogorov-Smirnov statistical tests. When the normality hypothesis was accepted, the probability with NORMDIST function from Microsoft Office Excel was computed.

In the case of two-dimensional strings (temperature - year of study), simple correlation coefficients and linear regression of datasets were determined (Y = a + bx equation, where 'Y' was successively MAXT, MINT and MDTA and 'x' year of study) and were compared with the non-linear (curvilinear) equations. Linear trend of average temperatures increasing over 10 years, was computed from the regression coefficient (b) of the linear equation, multiplied by 10 years. For plotting on maps the linear trend of average temperatures increasing over 10 years, we used geostatistical kriging interpolation module of the Surfer 9.0® (Golden Software, 2009) software.

Results and Discussion

***Dynamics of the annual mean temperatures in Romania*.** Central tendency and dispersion indicators of the 30 annual values of maximum temperature (MAXT), minimum temperature (MINT) and mean daily temperature amplitude (MDTA) are presented in Table 1. Mean values during 1982-2011 were: for MAXT 15.93°C, 5.45°C for MINT and for MDTA 10.47°C, maximum range being 3.1°C, 2.83°C and 2.01°C for the same temperatures.

Table 1

Central tendency and dispersion of the annual means of air temperature during 1982-2011 (average values of 29 stations)

		Maximum temperature (°C)	*Minimum temperature (°C)*	*Mean daily temperature amplitude (°C)*
Number of values →	Valid	30	30	30
	Missing	0	0	0
Mean		15.9313	5.4547	10.4753
Median		15.9050(a)	5.3550(a)	10.5350(a)
Mode		14.76(b)	4.86(b)	10.88
Std. Deviation		0.87367	0.65739	0.50581
Skewness		0.065	-0.145	0.079
Kurtosis		-0.850	0.026	-0.429
Range		3.100	2.830	2.010
Minimum		14.450	3.800	9.470
Maximum		17.550	6.630	11.480

(a) Calculated from grouped data; (b) Multiple modes exist. The smallest value is shown.

Histograms from Figure 1 are very similar to the normal distribution, by Kolmogorov-Smirnov and Shapiro-Wilk tests normality hypothesis being accepted (Table 2). There were small deviations from normality: the distribution was platykurtic for MAXT and MDTA and leptokurtic for MINT, and kurtosis was -0.850, 0.026 and -0.429. The distribution skewness was generally poor except for MINT which was negative skewed (left, -0.145) with the predominance in MINT histogram of years with higher than average values.

Table 2

Normality tests for the annual mean of air temperatures distributions (average for 29 localities)

	Kolmogorov-Smirnov(a)			*Shapiro-Wilk*		
	Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Maximum temperature (°C)	0.083	30	0.200(*)	0.967	30	0.450
Minimum temperature (°C)	0.098	30	0.200(*)	0.969	30	0.525
Mean daily temperature amplitude (°C)	0.082	30	0.200(*)	0.983	30	0.888

(*) This is a lower bound of the true significance; (a) Lilliefors Significance Correction.

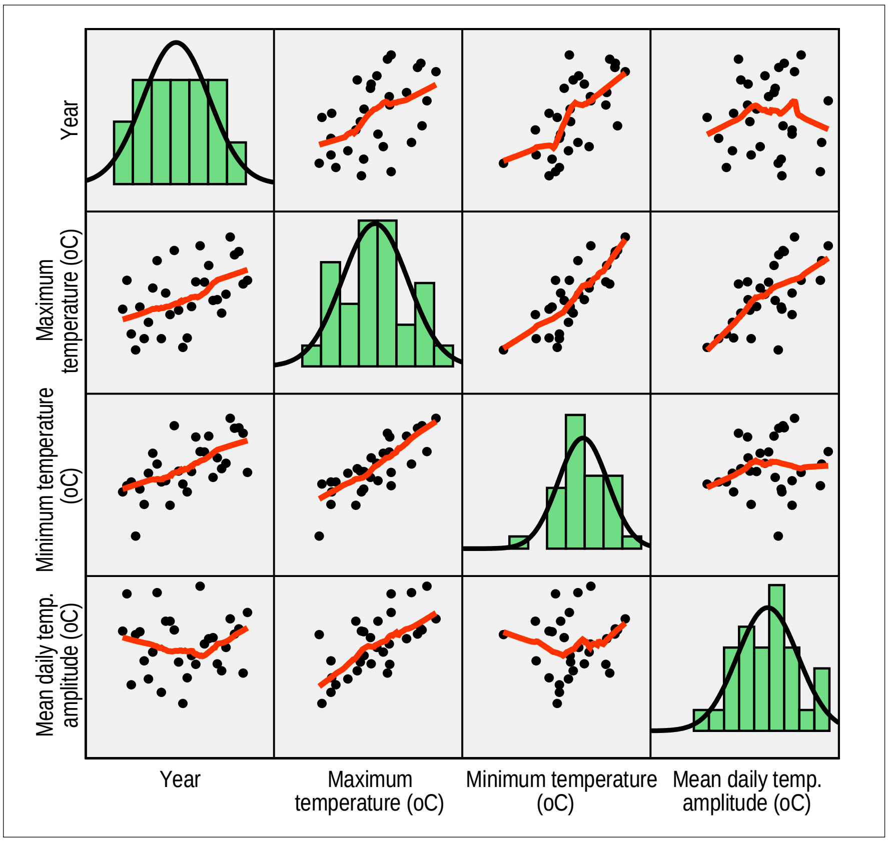

Figure 1. Correlation matrix and histograms of the annual means of air temperature during 1982-2011 (average for 29 stations).

Figures 2 and 3 show the dynamics of the three climatic indicators expressed in degrees Celsius and as probabilities. We selected the presentation as NORMDIST probabilities calculated from MS Office Excel, because it enables us to compare the three temperature dynamics between them. It is noted that in the case of MINT, linear correlation is stronger (R^2 = 0.4144***), versus MAXT (R^2 = 0.243**) but significant in both cases. We can conclude that 41.4% of the MINT values oscillation during 1982-2011 was due to the time variable and for MAXT only 24.3%. Also the increasing rate of the two temperatures was almost equal: 0.41°C in a decade for MINT and 0.49°C for MAXT. If we compare the growth rate per decade but expressed by probabilities, we see that MINT had a faster rate (21.9% per decade) than MAXT (17.0% per decade). In all cases MDTA remained unchanged from 1982 to 2011.

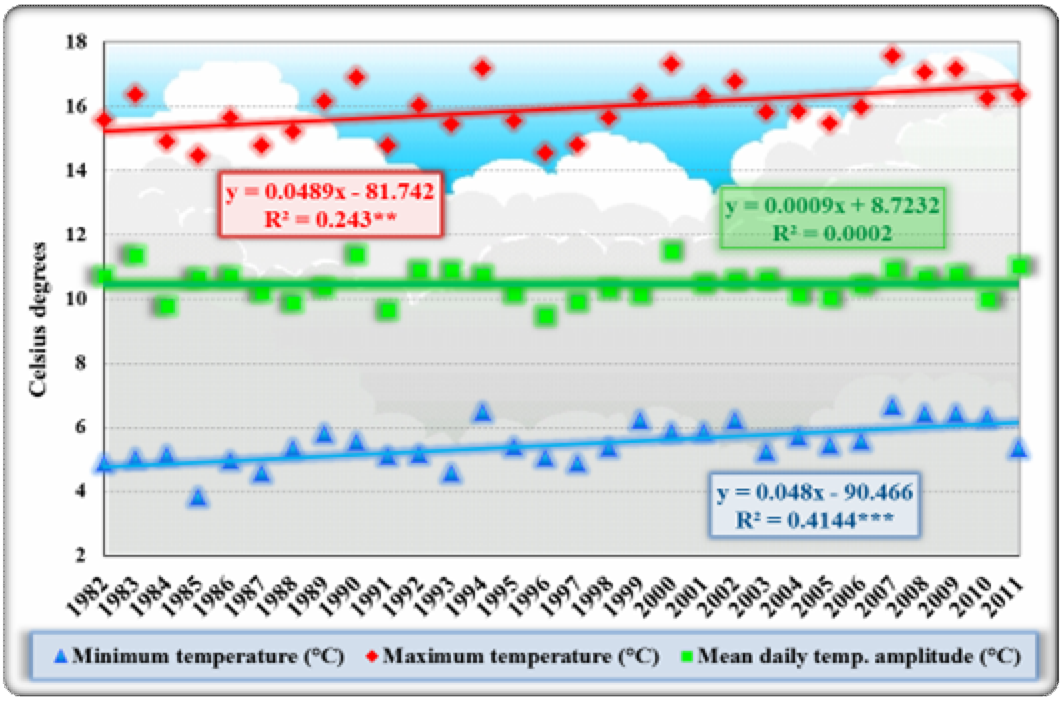

Figure 2. Dynamics of the annual means of air temperature during 1982-2011 (average of 29 stations).

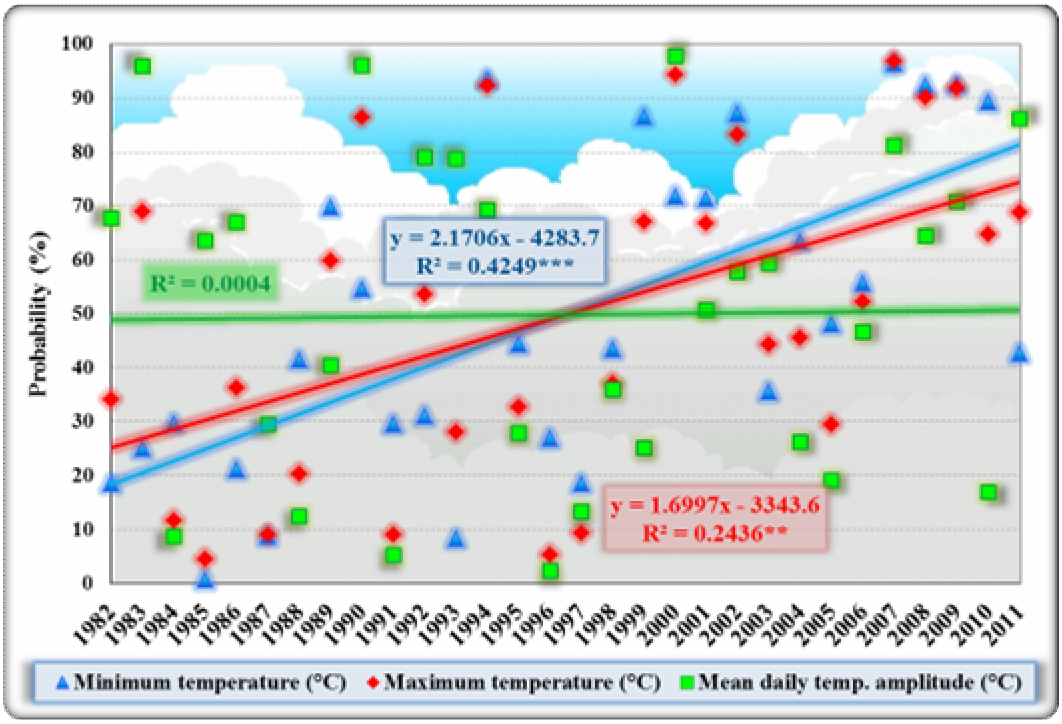

Figure 3. Probability to register annual mean values of the maximum, minimum and daily amplitude temperatures (means of the 29 stations), equals or lower than the ones accomplished during 1982-2011.

Dynamics of the annual mean temperatures for the 29 stations. Table 3 and Figure 4 show the variation of the 868 annual average for the 29 stations in the 30 years analyzed for each temperature separately. MAXT intensely varied between 11.18 and 19.75°C, MINT between -2.04 and 10.10°C and MDTA between 6.41 and 15.09°C. Analyzing histograms showing the division of classes of absolute frequencies, we noted the large positive kurtosis for MINT (1.969) and lower for MDTA (0.794). Positive kurtosis indicates that the observation cluster more and have longer tails than those in the normal distribution. Also skewness had high negative values for MINT (0.935) and MDTA (-0.619), which means that distributions with significant negative skewness have long left tails (appear very small values compared to the means). In these cases normality is rejected by both statistical tests.

Table 3

Central tendency and dispersion of the annual means of air temperature for each of 29 stations, during 1982-2011 (30 years multiplied by 29 stations)

		Maximum temperature (°C)	*Minimum temperature (°C)*	*Mean daily temperature amplitude (°C)*
Number of values →	Valid	868	868	868
	Missing	2	2	2
Mean		15.9314	5.4565	10.4745
Median		16.0440(a)	5.6967(a)	10.6138(a)
Mode		15.34(b)	6.15	10.85
Standard deviation		1.57311	1.89008	1.42806
Skewness		-0.329	-0.935	-0.619
Kurtosis		-0.171	1.969	0.794
Range		8.57	12.14	8.68
Minimum		11.18	-2.04	6.41
Maximum		19.75	10.10	15.09

(a) Calculated from grouped data; (b) Multiple modes exist. The smallest value is shown.

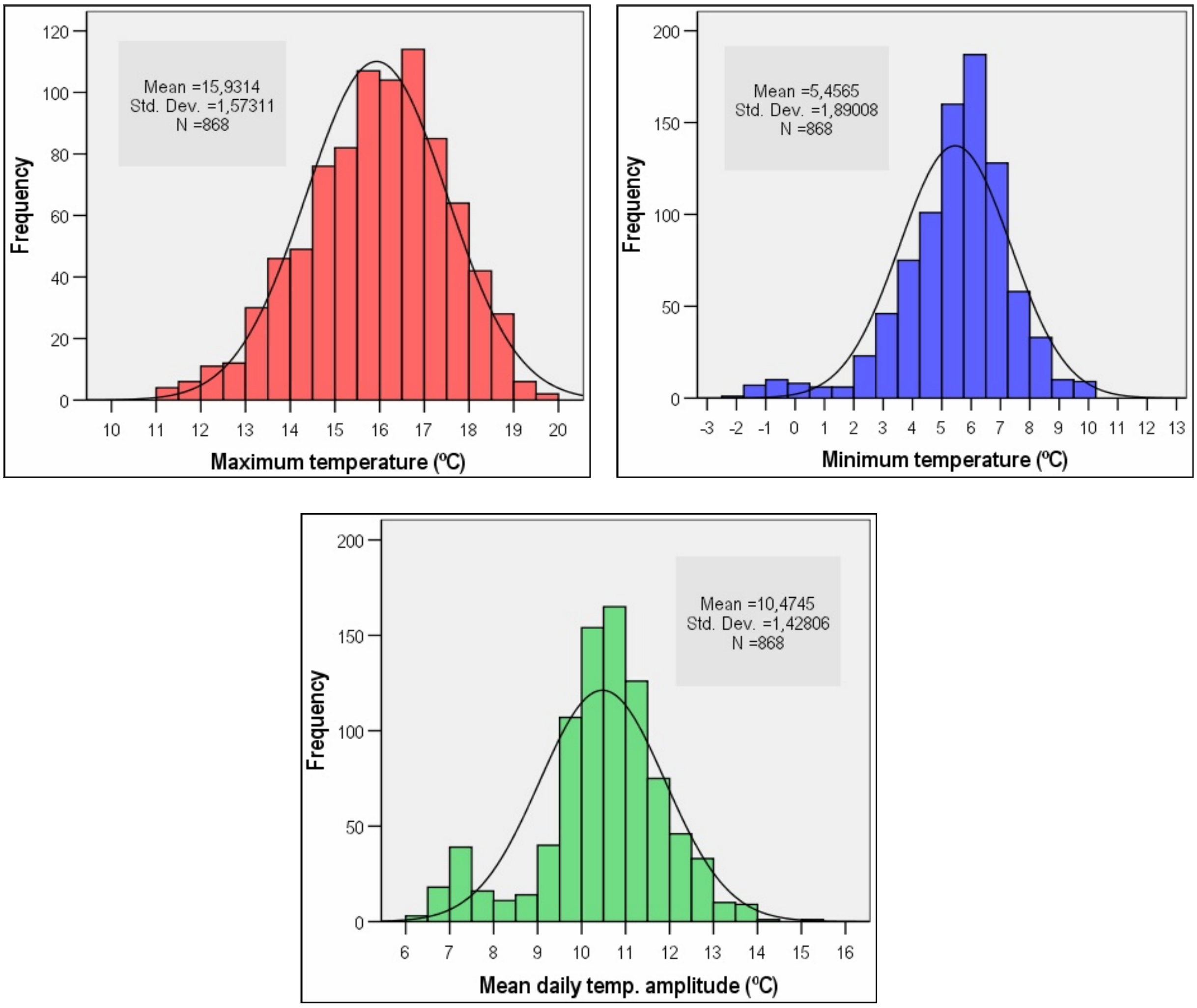

Figure 4. Histograms of the annual mean temperatures of 29 stations during 1982-2011.

By computing correlations and linear regressions of the 3 temperatures and time, resulted indicators from Table 4. The determination coefficients of linear equations (R^2) were compared with those of curvilinear equations (logarithmic, power, polynomial, exponential) and found that in no event approximation growth did not exceed 5%.

Table 4

Linear regression equations indicators, which expresses the dynamics of annual means of air temperatures during 1982-2011 (determination coefficient, significance level and average trend per decade)

Station	*Maximum temperature (°C)*			*Minimum temperature (°C)*			*Mean daily temperature amplitude (°C)*		
	R^2 (%)	*Sig.*	*Mean trends in 10 years (°C)*	*R^2 (%)*	*Sig.*	*Mean trends in 10 years (°C)*	*R^2 (%)*	*Sig.*	*Mean trends in 10 years (°C)*
Alexandria	15.1	0.034	0.43	42.1	0.000	0.48	0.4	0.744	-0.05
Bacău	19.3	0.015	0.53	21.5	0.010	0.39	3.7	0.309	0.14
Baia Mare	35.3	0.001	0.56	24.4	0.006	0.36	8.8	0.111	0.19
Bistriţa	49.3	0.000	0.76	50.5	0.000	0.72	0.5	0.724	0.05
Braşov	20.8	0.011	0.42	29.4	0.002	0.42	0.0	0.974	0.00
Buc. Băneasa	20.2	0.013	0.47	0.6	0.690	0.05	22.4	0.008	0.42
Buzău	9.2	0.104	0.33	49.4	0.000	0.62	14.6	0.037	-0.29
Caransebeş	19.6	0.014	0.43	40.1	0.000	0.45	0.1	0.879	-0.02
Călăraşi	21.5	0.010	0.51	30.5	0.002	0.43	1.3	0.543	0.09
Cluj	31.6	0.001	0.57	39.5	0.000	0.47	2.4	0.411	0.10
Constanţa	32.2	0.001	0.59	41.8	0.000	0.6	0.1	0.865	-0.01
Craiova	10.3	0.084	0.32	22.3	0.008	0.32	0.0	0.976	0.00
Deva	30.7	0.001	0.52	24.1	0.006	0.31	8.3	0.123	0.21
Drobeta Tr. Severin	11.3	0.070	0.33	32.6	0.001	0.39	0.6	0.691	-0.05
Galaţi	22.8	0.008	0.59	52.5	0.000	0.73	5.0	0.236	-0.14
Griviţa	11.3	0.070	0.38	39.3	0.000	0.49	1.8	0.484	-0.11
Iaşi	17.1	0.023	0.55	22.0	0.009	0.42	3.4	0.333	0.12
Miercurea Ciuc	25.5	0.004	0.44	18.9	0.016	0.37	0.9	0.612	0.07
Oradea	23.1	0.007	0.50	34.3	0.001	0.53	0.2	0.821	-0.03
Piteşti	21.1	0.011	0.51	56.9	0.000	0.64	2.1	0.447	-0.14
Rm. Vâlcea	32.0	0.001	0.61	29.7	0.002	0.37	10.2	0.085	0.24
Sf. Gheorghe Delta	35.8	0.000	0.65	30.6	0.002	0.49	5.8	0.201	0.16
Sibiu	26.2	0.004	0.48	41.9	0.000	0.56	1.1	0.578	-0.08
Siria	22.8	0.010	0.55	38.1	0.000	0.61	1.9	0.487	-0.06
Suceava	13.9	0.042	0.45	34.5	0.001	0.56	2.8	0.380	-0.11
Tecuci	14.3	0.039	0.45	38.1	0.000	0.53	1.2	0.563	-0.09
Tg. Jiu	15.3	0.033	0.35	56.9	0.000	0.74	18.4	0.018	-0.40
Tg. Mureş	36.3	0.000	0.60	13.2	0.049	0.27	20.6	0.012	0.32
Timişoara	27.9	0.003	0.55	32.6	0.001	0.39	5.8	0.200	0.16
Average	**23.2**	**0.021**	**0.50**	**34.1**	**0.028**	**0.47**	**4.97**	**0.443**	**0.02**

In Table 4 an important oscillation between stations was noted. From the beginning, we noticed that there was a greater dependence on the time factor of MINT versus MAXT, expressed by much higher values of the determination coefficient (R^2), by higher significantly levels (sig.) and by higher growth trends over 10 years (regression coefficient of equation ($Y = a + bx$) - b multiplied by 10 years). Thus, Maxtor increased significantly in all areas except Buzău (R^2 = 9.2% and an increase of only 0.33°C per decade), Craiova (R^2 = 10.3% and 0.32°C per decade), Turnu Severin (R^2 = 11.3% and 0.33°C per decade) and Griviţa (R^2 = 11.3% and an increase of only 0.38°C per decade). The largest increasing rate of MAXT was recorded in Bistriţa with 0.76°C per decade and R^2 = 49.3% and in St. Gheorghe Delta with 0.65°C per decade and R^2 = 35.8%.

Regarding MINT in many stations the increase is evident and well statistically assured. The highest increasing rate over 0.7°C per decade was recorded in Târgu Jiu station, Galaţi, and in Bistriţa. There are also two stations where MINT has stagnated: Băneasa-Bucharest and Târgu Mureş. In these localities MDTA increased significantly over the last 30 years with 0.42°C per decade in the first case and with 0.32°C in the second. In other stations MDTA remained almost unchanged.

Spatial variation of the linear trends of annual temperature means. Shown in Table 5 and Figure 5, the maximum amplitude of spatial variation was lower for MAXT (0.44°C per decade) and much higher for MINT (0.69°C per decade) and MDTA (0.82°C per decade) for the 29 climatological stations. Histograms are symmetric and very close to normal distributions, but the MINT and MDTA had a large positive kurtosis (0.970 and 0.652), which expresses a leptokurtic distribution (the observations cluster more and have long tails than those in the normal distribution). Even so Kolmogorov-Smirnov and Shapiro-Wilk normality tests (Table 6), accepted the normality assumption.

Table 5

Central tendency and dispersion of the linear trends per decade for air temperatures and each of 29 stations, during 1982-2011

		Maximum temperature trends in 10 years (°C)	*Minimum temperature trends in 10 years (°C)*	*Mean daily temperature amplitude trends in 10 years (°C)*
Number of values →	Valid	29	29	29
	Missing	0	0	0
Mean		0.4976	0.4728	0.0238
Median		0.5067(a)	0.4700(a)	-0.0033(a)
Mode		0.55	0.39	-0.14(b)
Std. Deviation		0.10333	0.15092	0.17350
Skewness		0.188	-0.357	-0.053
Kurtosis		0.184	0.970	0.652
Range		0.44	0.69	0.82
Minimum		0.32	0.05	-0.40
Maximum		0.76	0.74	0.42

(a) Calculated from grouped data; (b) Multiple modes exist. The smallest value is shown.

Table 6

Normality tests for the linear temperature trends per decade for 29 climatological stations

	Kolmogorov-Smirnov(a)			*Shapiro-Wilk*		
	Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
Maximum temperature trends per decade (°C)	0.073	29	0.200(*)	0.973	29	0.651
Minimum temperature trends per decade (°C)	0.090	29	0.200(*)	0.965	29	0.439
Mean daily temperature amplitude trends per decade (°C)	0.106	29	0.200(*)	0.983	29	0.903

(*) This is a lower bound of the true significance; (a) Lilliefors Significance Correction.

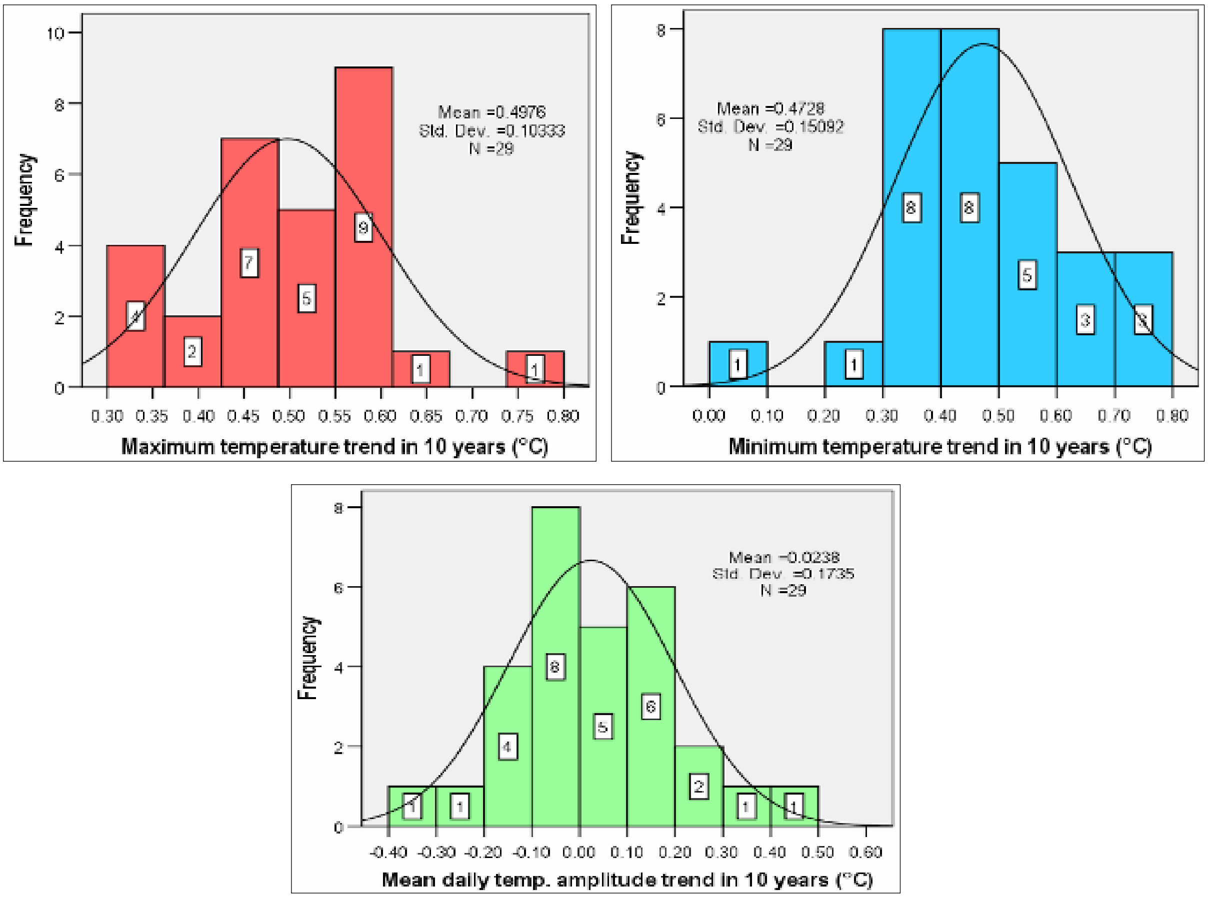

Figure 5. Histograms of the linear trends per decade of air temperature annual means for 29 stations during 1982-2011.

By correlating the values of the three linear trends of variation per decade between them (Table 7 and Figure 6), we have found that there is no correlation between MAXT and MINT, but the MDTA was intense negatively influenced by MINT (r = - 0.804***) and positive by MAXT (r = 0.501***).

Table 7

The Pearson simple correlation coefficients of the annual mean temperature linear trends per decade for each of the 29 stations (1982-2011)

		Maximum temperature trend in 10 years (°C)	*Minimum temperature trend in 10 years (°C)*	*Mean daily temp. amplitude trend in 10 years (°C)*
Maximum temperature trends in 10 years (°C)	Pearson Correlation	1	0.110	0.501(**)
	Sig. (2-tailed)		0.569	0.006
	N	29	29	29
Minimum temperature trends in 10 years (°C)	Pearson Correlation	0.110	1	-0.804(**)
	Sig. (2-tailed)	0.569		0.000
	N	29	29	29
Mean daily temperature amplitude trends in 10 years (°C)	Pearson Correlation	0.501(**)	-0.804(**)	1
	Sig. (2-tailed)	0.006	0.000	
	N	29	29	29

(**) Correlation is significant at the 0.01 level (2-tailed).

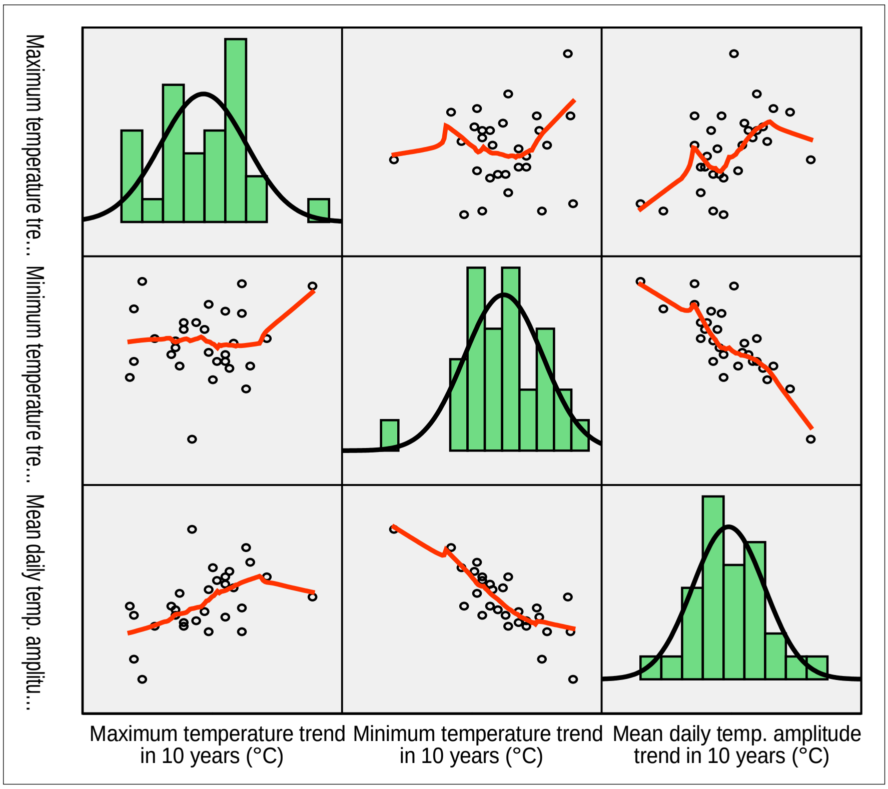

Figure 6. Correlation matrix and histograms of the annual means temperature linear trends per decade during 1982-2011 (29 stations).

Figures 7, 8 and 9 are maps made by geostatistical kriging interpolation using the program Surfer 9.0 (Golden Software). They delimit areas with linear trends per decade for MAXT, MINT and MDTA of equal intensity. It was noted the existence of areas with increased heating rate, both in southeastern and in northern part of Romania (Bistriţa station). For the south-western part of Romania, the situation was different: although MINT (Figure 8) increased rapidly, MAXT remained low (Figure 7). In Figure 9 were found two areas of significant increase of mean daily amplitudes centered on Târgu Mureş and Bucharest-Băneasa stations.

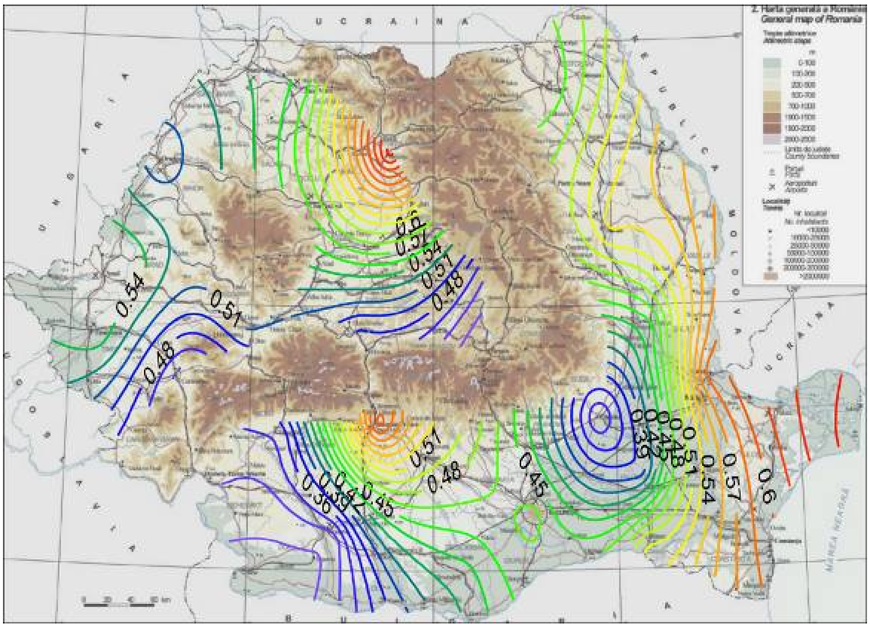

Figure 7. Distribution of the annual means of maximum temperature trends per decade in Romania (1982-2011).

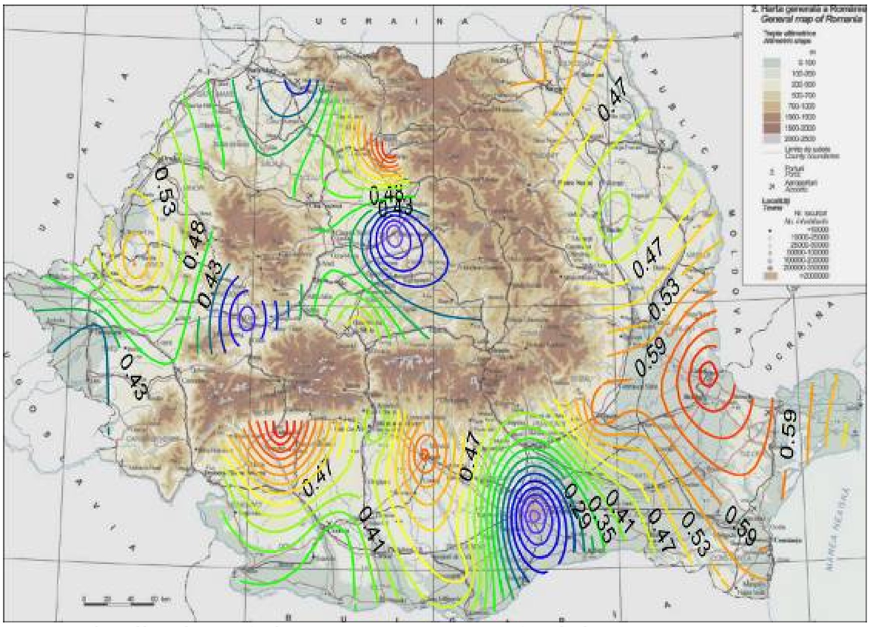

Figure 8. Distribution of the annual means of minimum temperature trends per decade in Romania (1982-2011).

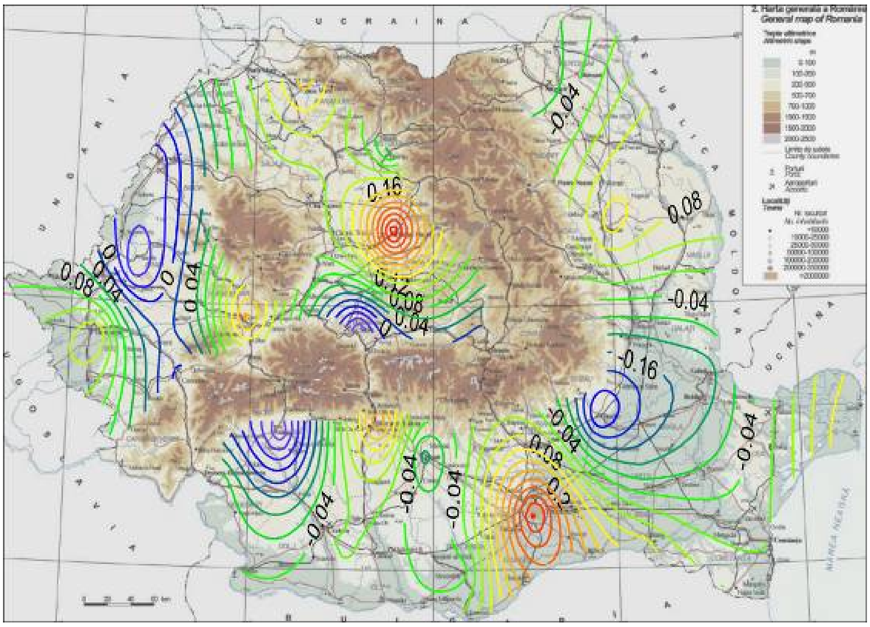

Figure 9. Distribution of the annual trends per decade of the mean daily temperature amplitude in Romania (1982-2011).

***The dynamics of the monthly means linear trends per decade for Romania*.** Starting with Figure 10 the analysis of temperature variations has been done at the level of month (12 months x 30 years of study). In this figure, histograms are presented with the division on the classes of absolute frequency of the three temperatures. There is great deviation from normal due to the four seasons of the year. In the histograms of MAXT and MINT were defined three modes (classes with high frequencies, or values that occurs most often), which belong to the seasons of winter, spring - autumn and summer.

MDTA histogram is less divided into three modes (only two are apparent), but the mode with values of 11.5-12.0°C has a much higher frequency (36 cases) than the one with values of 7.0-7.5°C (22 cases).

The information presented in Table 8 is very important because it gives us the time of year where MAXT and MINT increased significantly. It was noted that in general, the level of significance of maximum and minimum temperature linear trends per decade was low during winter, spring and autumn. But this level of significance was very high (between 0.01 and 0.001) for June, July and August months. The degree of statistical assurance of MINT trends was higher (sig. less than 0.003) than of MAXT (sig. between 0.001 and 0.046). MDTA trends were not statistically assured for any month of the year. MINT growth was determined by time in percentages between 26.7% in July and 44.5% in August.

Table 8

Linear regression equations indicators, which expresses the dynamics of monthly means of air temperatures during 1982-2011 (determination coefficient, significance level and average trend per decade)

Month	Maximum temperature (°C)			Minimum temperature (°C)			Mean daily temperature amplitude (°C)		
	R^2 (%)	Sig.	Mean trend in 10 years (°C)	R^2 (%)	Sig.	Mean trend in 10 years (°C)	R^2 (%)	Sig.	Mean trend in 10 years (°C)
January	0.1	0.869	0.09	0.6	0.680	0.22	1.6	0.509	-0.14
February	6.0	0.194	0.90	8.2	0.125	0.94	0.1	0.892	-0.04
March	5.7	0.203	0.78	3.9	0.298	0.41	5.2	0.225	0.36
April	3.2	0.341	0.39	3.1	0.353	0.25	1.5	0.523	0.14
May	2.9	0.365	0.34	2.3	0.421	0.18	1.8	0.484	0.17
June	30.7	0.001	0.88	35.4	0.001	0.61	6.5	0.174	0.27
July	24.9	0.005	0.82	26.7	0.003	0.67	2.1	0.444	0.15
August	13.5	0.046	0.70	44.5	0.000	0.75	0.1	0.855	-0.05
September	1.4	0.532	-0.28	4.7	0.250	0.3	11.0	0.074	-0.57
October	0.1	0.891	-0.04	4.4	0.267	0.3	7.3	0.148	-0.35
November	13.9	0.042	1.10	13.0	0.051	0.94	2.2	0.439	0.17
December	0.9	0.626	0.23	1.0	0.602	0.25	0.0	0.913	-0.02
Average	**8.6**	**0.343**	**0.49**	**12.3**	**0.254**	**0.49**	**3.3**	**0.473**	**0.01**

In the same Table 8 and also in Figures 12-17, was noted the increasing rate of temperatures in the summer months but also the level of statistically assurance of linear trends. The increasing rate for June was 0.88°C per decade for MAXT (R^2 = 0.3068***) and 0.61°C per decade for MINT (R^2 = 0.3553***). Comparing trends expressed by probabilities, we noticed that it's were reduced for MAXT (18.4% per decade) versus MINT (20.4% per decade).

For July (Figures 14 and 15) the increasing trend per decade was similar to the previous month: 0.82°C per decade for MAXT and 0.67°C per decade for the MINT, but weaker statistically assured. For the month of august (Figures 16 and 17) the increasing trend was lower for MAXT (0.70°C per decade) and weaker statistically assured ($p \leq 0.05$). For MINT the trend was the highest of the summer with 0.74°C per decade and the best statistically assured (R^2 = 0,444**). Also, the trend toward increasing probabilities of MINT (21.8% over one decade) is almost double from that of MAXT (13.6% per decade). In November MAXT and MINT increased sharply by 1.1°C per decade and 0.94°C per decade respectively (Figures 18 and 19), but with large fluctuations from one year to another, thus less safer than in the summer months.

The same situation also met in February (Figure 11) although the linear growth rate was higher, 0.9°C per decade for MAXT and 0.94°C for MINT, this it was not uniform (being statistically non assured due to large dispersion of the values). This month growth trend was accelerated between 1983 and 1993 (as played by polynomial regression equations of 4 degrees, Figure 11) and then decreased.

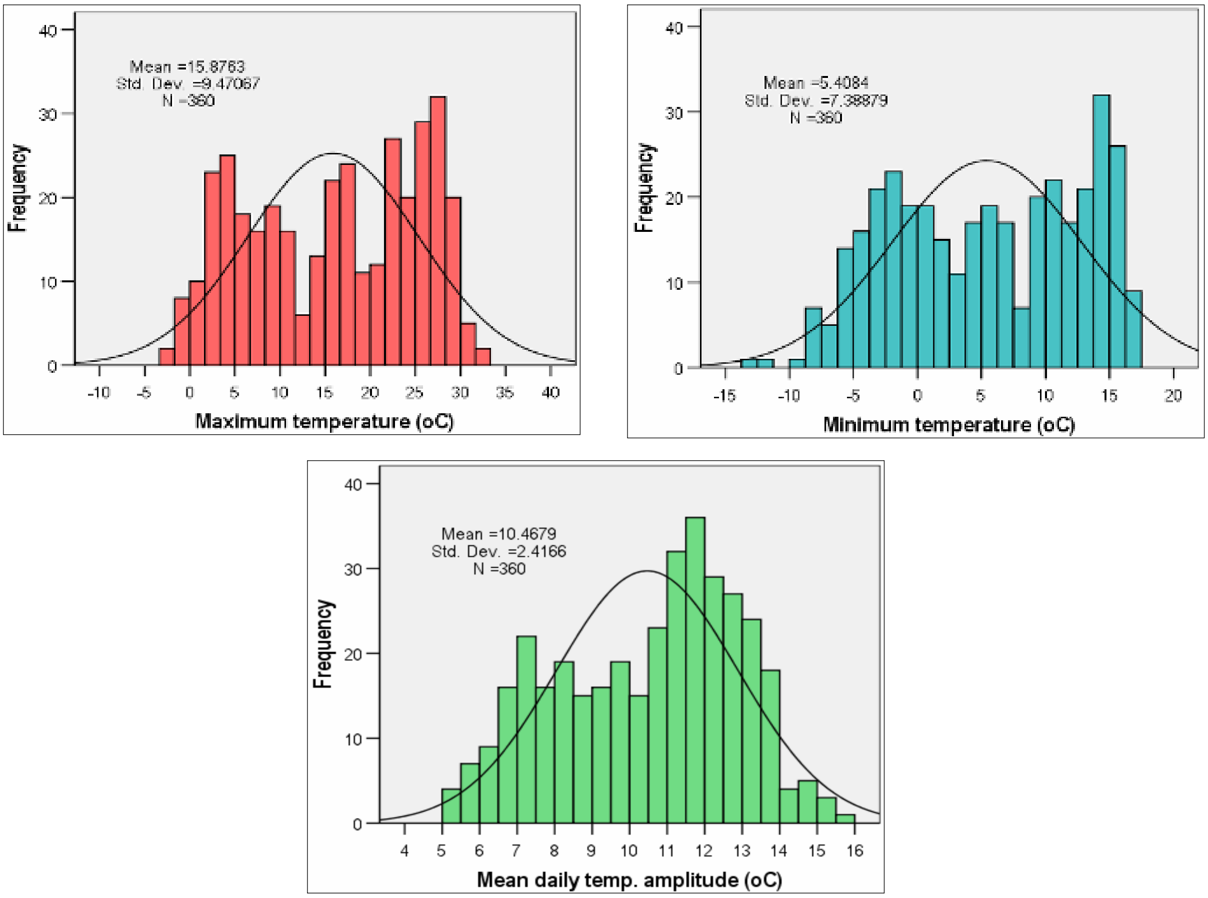

Figure 10. Histograms of the monthly means trends per decade for 29 stations during 1982-2011 (station means for 12 months multiplied by 30 years).

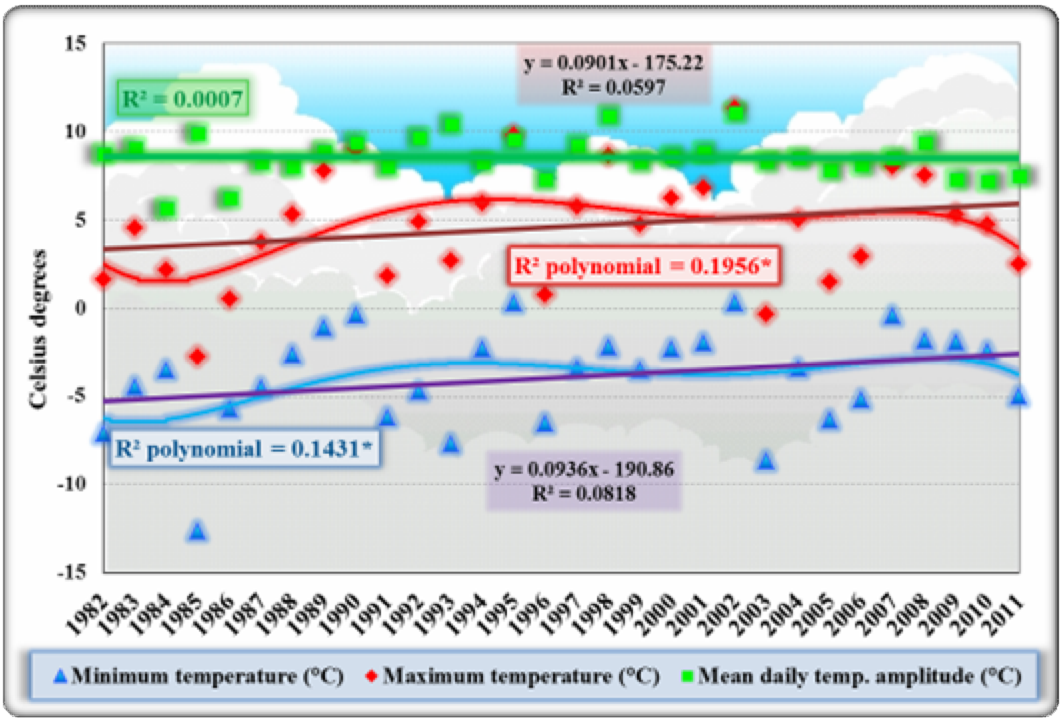

Figure 11. Dynamics of the February air temperature monthly means during 1982-2011 (average of 29 stations).

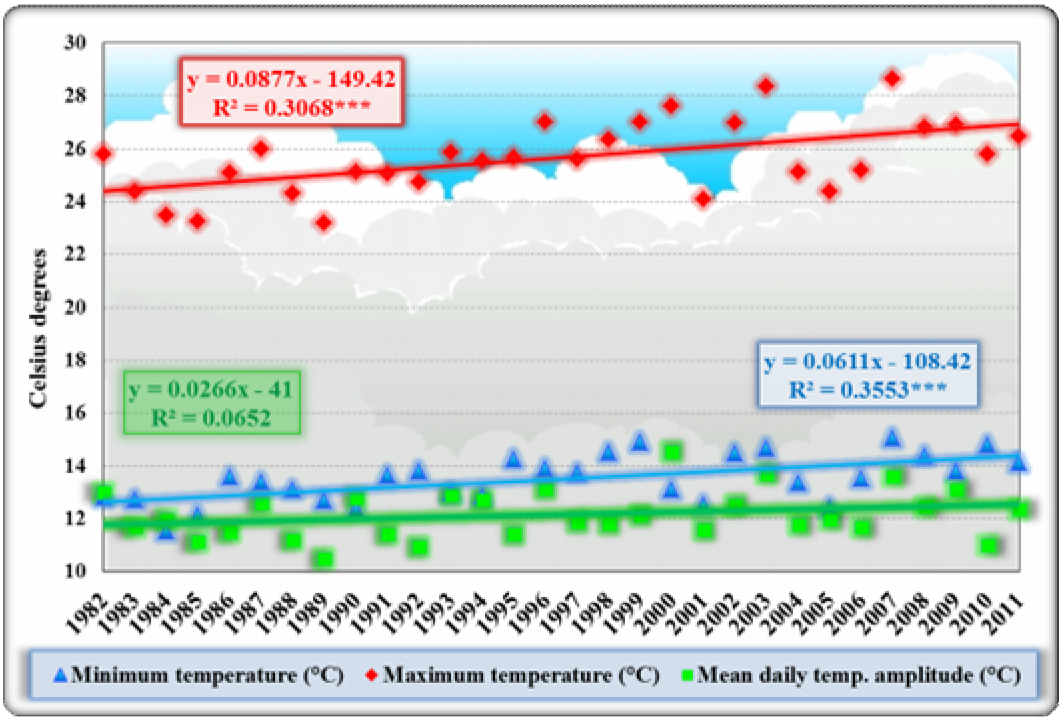

Figure 12. Dynamics of the June air temperature monthly means during 1982-2011 (average of 29 stations).

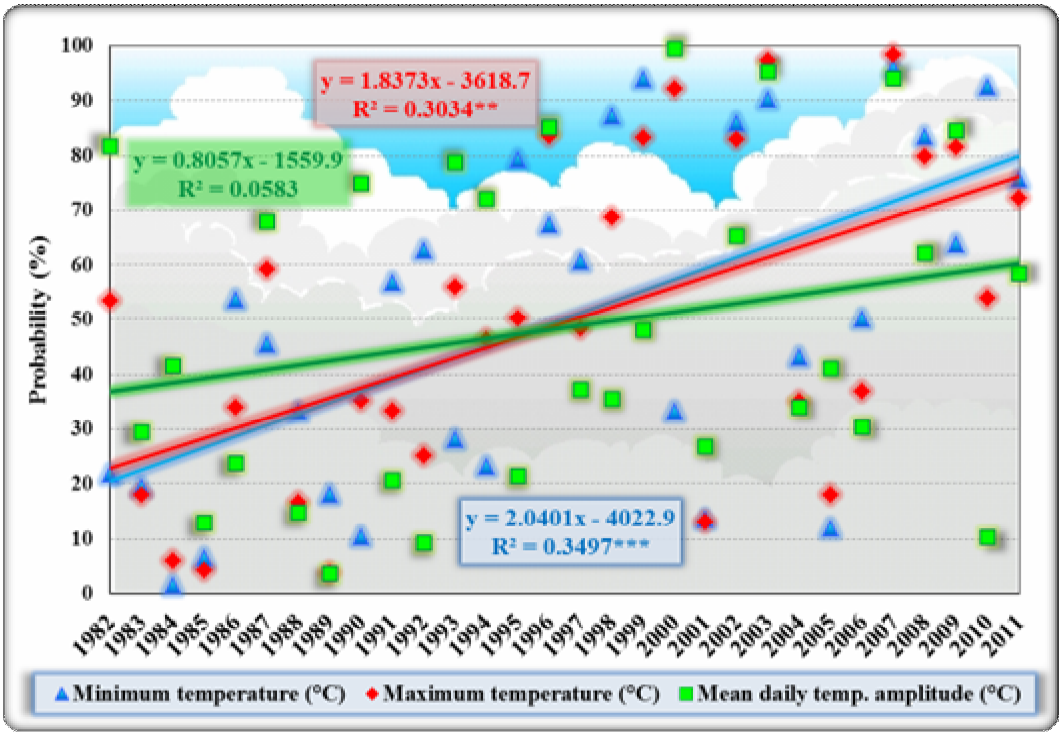

Figure 13. Probability to register June mean values of the maximum, minimum and daily amplitude temperatures (means of the 29 stations), equals or lower than the ones accomplished during 1982-2011.

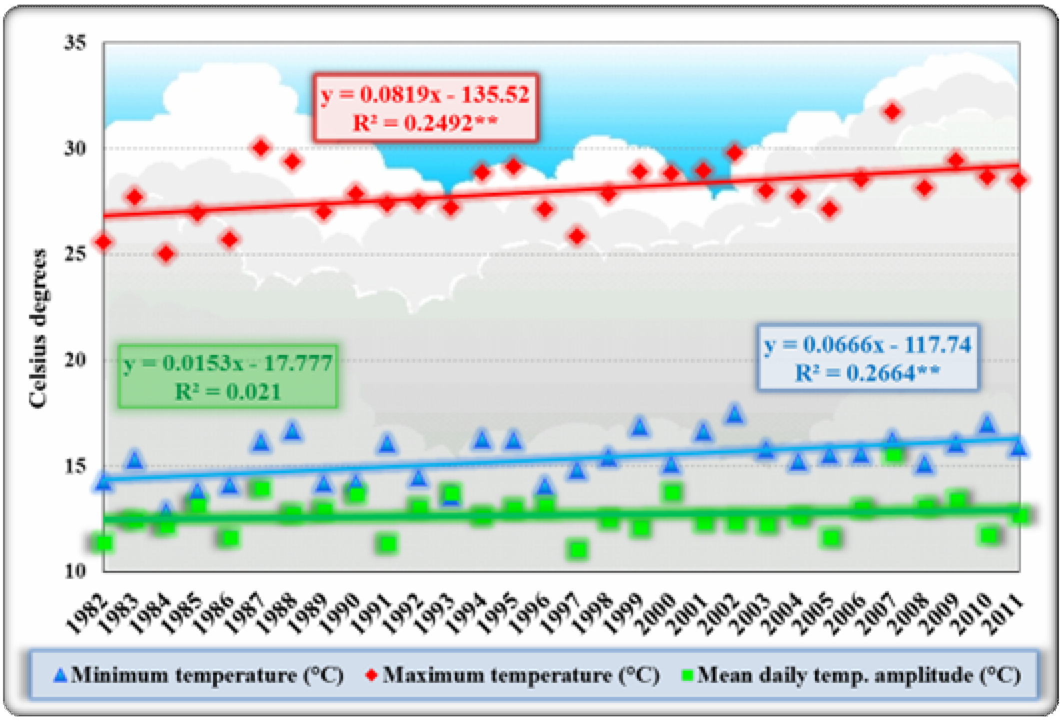

Figure 14. Dynamics of the July air temperature monthly means during 1982-2011 (average of 29 stations).

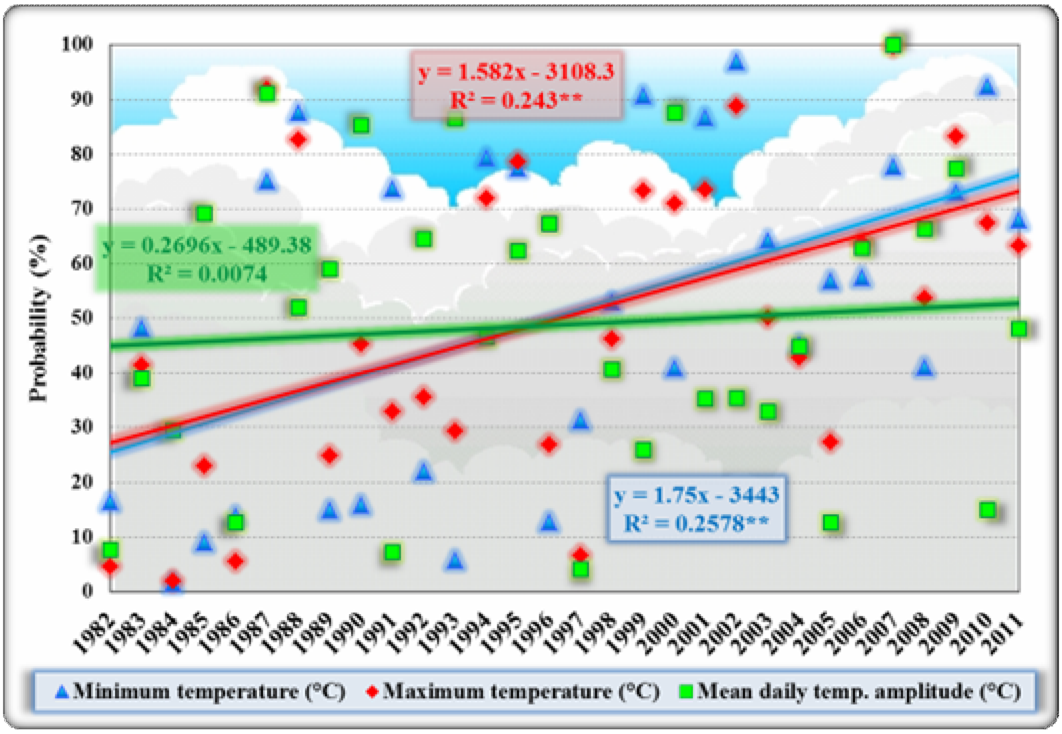

Figure 15. Probability to register July mean values of the maximum, minimum and daily amplitude temperatures (means of the 29 stations), equals or lower than the ones accomplished during 1982-2011.

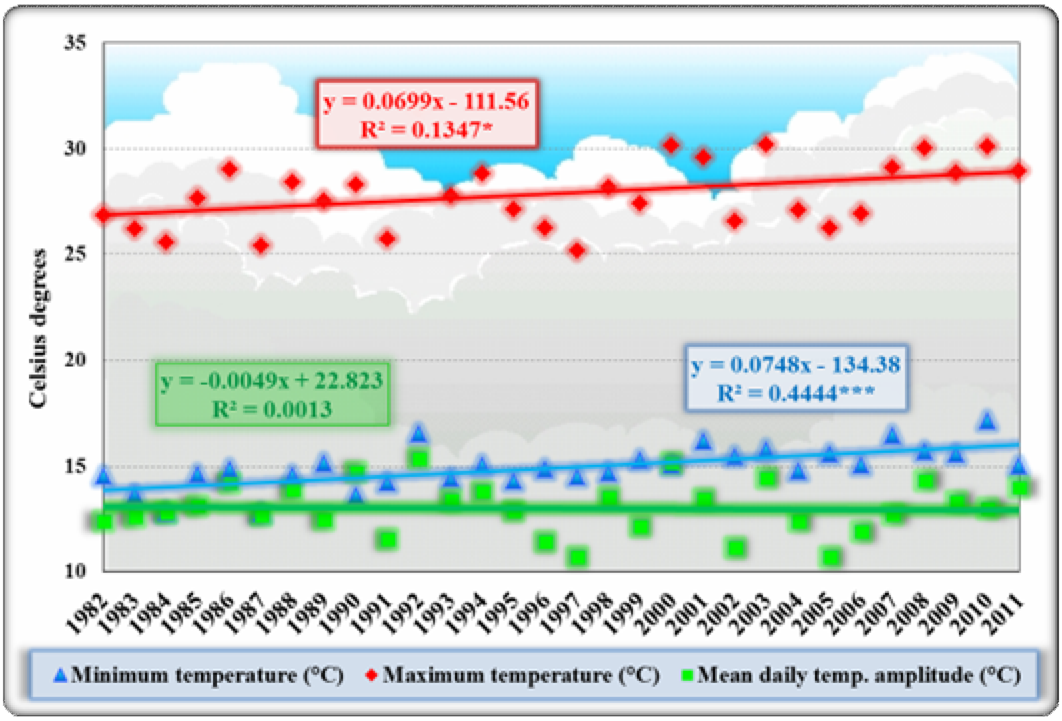

Figure 16. Dynamics of the August air temperature monthly means during 1982-2011 (average of 29 stations).

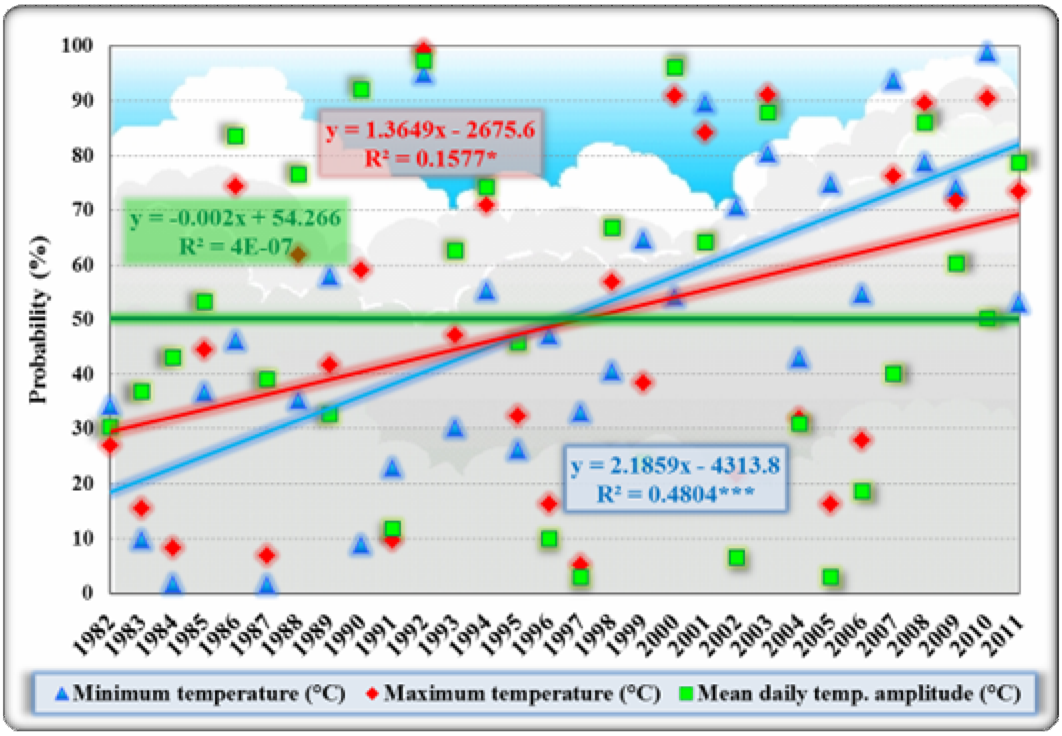

Figure 17. Probability to register August mean values of the maximum, minimum and daily amplitude temperatures (means of the 29 stations), equals or lower than the ones accomplished during 1982-2011.

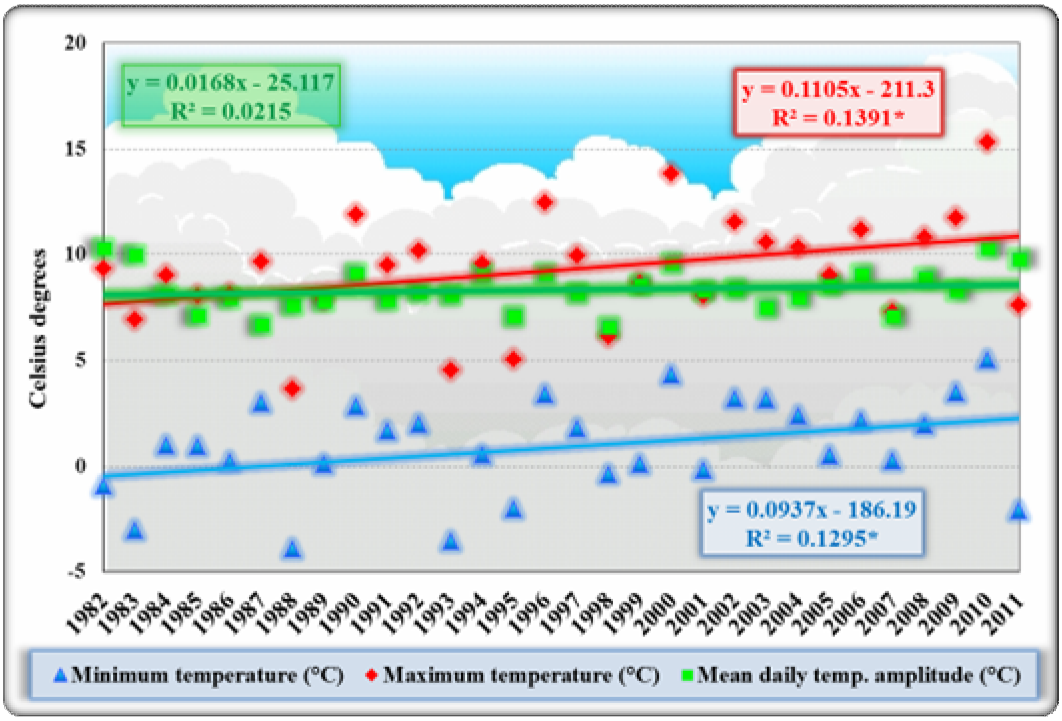

Figure 18. Dynamics of the November air temperature monthly means during 1982-2011 (average of 29 stations).

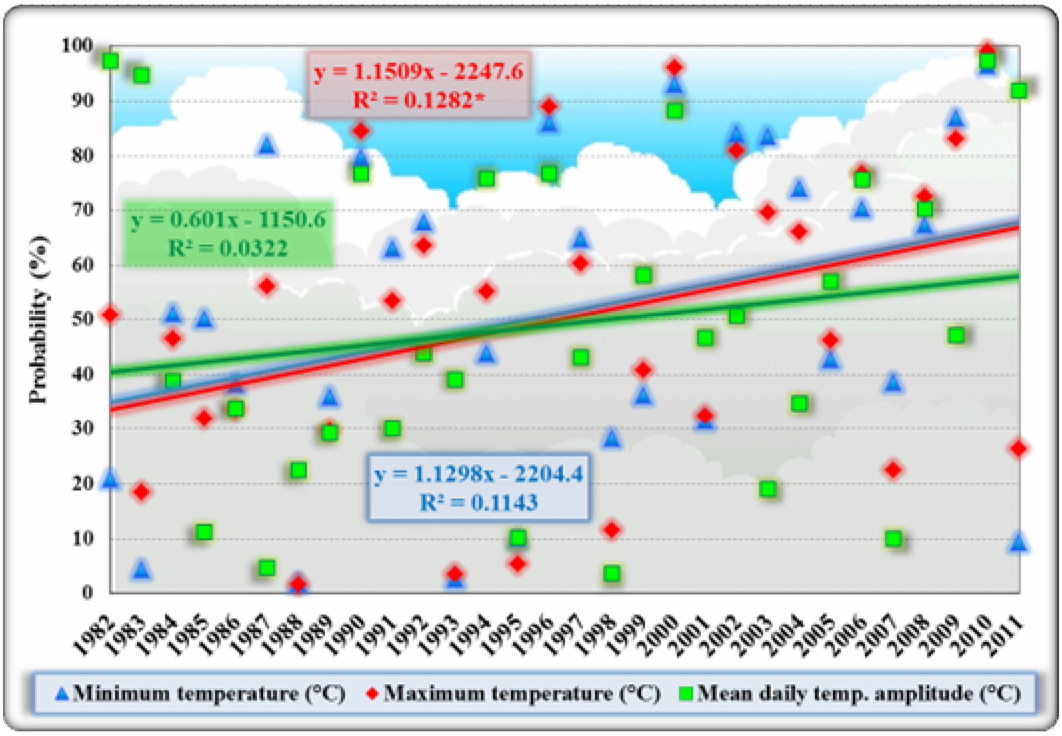

Figure 19. Probability to register November mean values of the maximum, minimum and daily amplitude temperatures (means of the 29 stations), equals or lower than the ones accomplished during 1982-2011.

Conclusions. There were characterized the increasing trends of annual and monthly maximum, minimum and daily amplitudes of the air temperatures, of the last 30 years in Romania and of the 29 climatological stations studied.

In terms of annual means for Romania (means for 29 stations) were found for MINT, that linear correlation with year of study variable, was stronger (R^2 = 0.4144***), versus MAXT (R^2 = 0.243**), but significant in both cases. For MINT 41.4% of oscillation during 1982-2011 was due to the time and for MAXT only 24.3%. Also the increasing rate of the two temperatures was almost equal: 0.41°C in a decade for MINT and 0.49°C for MAXT. If we compare the growth rate per decade but expressed by probabilities, we found that the MINT had a faster rate (21.9% in a decade) than MAXT (17.0% in a decade). In all cases MDTA remained unchanged from 1982 to 2011.

We identified the presence of an increased variability of annual mean temperature trends between the different stations. Thus MAXT increased significantly in all areas except Craiova (0.32°C per decade), Buzău and Turnu Severin (0.33°C per decade) and Griviţa (0.38°C per decade). The highest MAXT growth rate was recorded at Bistriţa with 0.76°C per decade and at St. Gheorghe Delta 0.65°C per decade. Regarding MINT in many stations the increasing trend was high and well statistically assured. The highest growth rate, over 0.7°C per decade, was recorded in Târgu Jiu, Galaţi and in Bistriţa. There are also two places where the MINT has stagnated: Băneasa-Bucharest and Târgu Mureş. In the same localities MDTA increased significantly over the last 30 years with 0.42°C per decade in the first case and with 0.32°C in the second. In other localities MDTA remained almost unchanged.

It was noted that in general, the level of significance of maximum and minimum temperature linear trends per decade was low during winter, spring and autumn. But this level of significance was very high (between 0.01 and 0.001) for June, July and August months. The increasing rate for June was 0.88°C per decade for MAXT and 0.61°C per decade for MINT. For July the increasing trend per decade was similar to the previous month. For the month of august the increasing trend was lower for MAXT (0.70°C per decade) and weaker statistically assured ($P \leq 0.05$). For MINT the trend was the highest of the summer with 0.74°C per decade and the best statistically assured (R^2 = 0,444 **). Also, the trend toward increasing probabilities of MINT (21.8% over one decade) is almost double from that of MAXT (13.6% per decade).

In November and February MAXT and MINT increased sharply by 0.9 up to 1.1°C per decade, but with large fluctuations from one year to another, thus less safer than in the summer months (near the limit of the statistically assurance).

References

Barriopedro D., Fischer E. M., Luterbacher J., Trigo R. M., García-Herrera R., 2011 The hot summer of 2010: redrawing the temperature record map of Europe. Science 332(6026):220-224.

Bartholy J., Pongracz R., 2007 Regional analysis of extreme temperature and precipitation indices for the Carpathian Basin from 1946 to 2001. Global and Planetary Change 57:83-95.

Brown S. J., Caesar J., Ferro C. A. T., 2008 Global changes in extreme daily temperature since 1950. Journal of Geophysical Research – Atmospheres 113 D05115, doi:10.1029/2006JD008091.

Caesar J., Alexander L., Vose R., 2006 Large-scale changes in observed daily maximum and minimum temperatures: creation and analysis of a new gridded data set. Journal of Geophysical Research – Atmospheres, 111 D05101, DOI: 10.1029/2005JD006280.

Founda D., Giannakopoulos C., 2009 The exceptionally hot summer of 2007 in Athens, Greece – a typical summer in the future climate? Global and Planetary Change 67(3-4):227-236.

Kürbis K., Mudelsee M., Tetzlaff G., Brazdil R., 2009 Trends in extremes of temperature, dewpoint, and precipitation from long instrumental series from central Europe. Theoretical and Applied Climatology 98(1-2):187-195.

Mika J., Balint G., 2000 Rainfall scenarios for the Upper-Danube catchment. XXth Conf. Danubian Countries, Bratislava, Slovakia, 4-8 September, 2000. CD-ROM, pp. 990-995.

Sandu I., Mateescu E., Vatamanu V. V., 2010 Changes observed in the agroclimatic conditions of Romania. Climate changes in Romania and the effects on agriculture. SITECH Publishing House, Craiova, 406 pp.

*** EU, 2009 EU white paper document "Adapting to climate change: Towards a European framework for action". SEC(2009) 386, SEC(2009) 387, SEC(2009) 388. Brussels, 1.4.2009, COM(2009) 147 final, 17 pp; http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:PDF.

*** EU, 2010 Romania's Fifth National Communication on Climate Change under The United Nations Framework Convention on Climate Change. Ministry of Environment and Forests, Bucharest, 191 pp.

*** IPCC, 2001 Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report, http://www.grida.no/publications/other/ipcc_tar/.

*** IPCC, 2007 Climate Change 2007 - Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R. K. Pachauri, and A. Reisinger (eds.)]. IPCC, Geneva, Switzerland, 104 pp. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/contents.html.

*** IPCC, 2012 Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field C. B., V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

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Authors:
Emil Chiţu, Research Institute for Fruit Growing Piteşti, 117450 Mărăcineni, 402, Mărului Str., Argeş County, Romania, e-mail: emilchitu@gmail.com
Daniela Giosanu, Piteşti University, Târgu din Vale 1, 110040 Piteşti, Argeş County, Romania, e-mail: giosanu@yahoo.com
Elena Mateescu, National Meteorological Administration, Bucharest-Ploieşti Str., no. 97, code 113686, Romania, e-mail: mateescu@meteo.inmh.ro

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