Forum geografic. Studii și cercetări de geografie și protecția mediului
*Volume **XVII**, Issue **1** (**June** 2017), pp. **37-48***
*http://dx.doi.org/**10.5775/fg.2017.040.i***

Analysis of the Mean of Daily Maximum Temperature within the Romanian Plain (1961-2015)

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Received on <20-01-2017>, reviewed on <05-03-2017>, accepted on <25-05-2017>

Abstract

The present study aims at rendering the characteristics of the means of the daily maximum temperature at monthly, seasonal and annual level within the Romanian Plain, as well as their trends. The time series cover a 55-year period (1961-2015) and data come from 8 meteorological stations. In order to assess the distribution of the data, there were calculated two coefficients (Skewness – S and Kurtosis – K) and also applied the Kolmogorov-Smirnov test for normal distribution. The positive S values and negative K values indicate that the distribution is not symmetrical but, taking into account that the values are quite close to 0, we may assume, it is not far from normal. The KS test also indicates a normal distribution. Homogeneity of the annual temperatures was tested by means of Pettitt test, Standard Normal Homogeneity Test (SNTH) and t test, which emphasized that the change point was registered before 2000. At three stations (D.T. Severin, Bechet, Buzău) all three applied tests indicated the same year 1988, respectively 1989 as break point, while at the other stations, it is the same year according to SNHT and T test, and a different one based on MWP. Based on Mann-Kendall test and Sen's slope estimation, there were emphasized temperature trends and their statistical significance. The highest temperature increase and upward trend was registered for mean annual and mean summer values (0.001 level of significance within the entire region). However, except for autumn, which is generally characterized by statistically insignificant negative trends, all the other seasons display significant upward trends. At monthly level, only the summer months registered upwards trends within the entire plain (level of significance oscillating between 0.05 and 0.001), while in autumn months there were not registered any statistically significant trends.

Keywords: *air temperature trends, normal distribution, homogeneity tests, Mann-Kendall test, Romanian Plain, Romania*

Rezumat. Analiza mediei temperaturii maxime zilnice în Câmpia Română (1961-2015)

Prezentul studiu are ca scop stabilirea caracteristicilor valorilor medii de temperatură maximă zilnică la nivel lunar, anotimpual și anual în cadrul Câmpiei Române, precum și a tendințelor de evoluție ale acestora. Serii de date acoperă o perioadă de 55 de ani (1961-2015), iar datele provin de la 8 stații meteorologice. Pentru a evalua distribuția datelor, s-au calculat doi coeficienți (Skewness-S și Kurtosis-K) și s-a aplicat testul Kolmogorov-Smirnov pentru distribuția normală. Valorile S pozitive și valorile K negative indică faptul că distribuția nu este simetrică, dar având în vedere că valorile sunt apropiate de 0, se poate spune că acestea nu sunt departe de normal. Testul KS indică, de asemenea, o distribuție normală. Omogenitatea temperaturilor anuale a fost testată prin testul Pettitt, testul standard de omogenitate normală (SNTH) și testul t, care au subliniat faptul că punctul de schimbare a fost înregistrat înainte de 2000. La trei stații (D.T. Severin, Bechet, Buzău) toate cele trei teste aplicate au indicat același an 1988, respectiv 1989 ca punct de schimbare, în timp ce la celelalte stații, este același an în funcție de testul SNHT și T și unul diferit bazat pe MWP. Pe baza testului Mann-Kendall și a estimării pantei lui Sen, au fost evidențiate tendințele evoluție a temperaturii și semnificația lor statistică. Cea mai mare creștere a temperaturii și tendință ascendentă a fost înregistrată pentru valorile medii anuale și ale anotimpului vara (0,001 nivel de semnificație statistică în întreaga regiune). Cu toate acestea, cu excepția toamnei, care se caracterizează în general prin tendințe negative nesemnificative statistic, toate celelalte anotimpuri prezintă tendințe ascendente semnificative. La nivel lunar, numai lunile de vară au înregistrat tendințe ascendente în întreaga câmpie (nivelul de semnificație variind între 0,05 și 0,001), în timp ce în lunile de toamnă nu s-au înregistrat tendințe semnificative statistic.

Cuvinte-cheie: *tendințe ale temperaturii aerului, distribuâie normală, teste de omogenitate, testul Mann-Kendall, Câmpia Română, România*

Introduction

Most recent climatological studies indicate global temperature increase (IPCC, 2007a; IPCC, 2012). In terms of global average, in the last period, warming occurred in two phases, from the 1910s to the 1940s and more intensely from the 1970s to the present (Busuioc et al., 2007). According to the experts from NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by about 0.8°C since 1880. Starting with 1975, warming occurred at a rate of about 0.15-0.20°C per decade (http://earthobservatory.nasa.gov). Globally, 2016 was declared as the warmest year on record (period 1880-2016), both on land and oceans, registering an anomaly of 0.99°C (https://www.nasa.gov). According to National Oceanic and Atmospheric Administration (NOAA), 14 of the first 15 hottest years were registered after 2000, certifying global warming (www.ncdc.noaa.gov/sotc/global/201513).

In Europe, between 1950 and 2010, the average warming trend was 0.18°C/decade (CRUTEM4v, www.cru.uea.ac.uk/cru/data/temperature).
However, warming intensity registers significant differences, namely, it does not occur linearly in time and space. There are studies indicating that the entire European continent has experienced an obvious warming trend, mainly in spring and summer (EEA, 2008); other researchers (Parey et

al., 2010; Yiou et al., 2009) point out that central and southern Europe registers a significantly increasing variability in summer temperature. IPCC (2007b, p. 545) mentions that warming was stronger in most regions in winter than in summer and there was noticed an increase in warm extremes rather than a decrease in cold extremes.

According to Andres et al. (2014), Romania registered a warming of about 0.5°C in the annual mean temperatures since 1901, while in the south eastern region the trends were estimated to 1°C. Starting with 1970, summer temperatures have increased, the highest deviations corresponding to the northeastern and southwestern regions of the country. Winter temperatures also registered an increase that culminated with the warmest winter in 2006/2007 with an anomaly of about +6°C. Other studies also confirmed this warming trend (Busuioc et al., 2015; Chitu et al., 2015; Croitoru & Piticar, 2013; Hauer et al., 2003; Hobai, 2009; Piticar & Ristoiu, 2012; Prăvălie, 2014; Sandu et al., 2010; Tomozeiu et al., 2002).

The main objective of the present study is the identification of any patterns in terms of spatial and temporal variability of daily maximum temperatures for the period 1961-2015 and rendering the statistical significance of the identified trends.

Material and methods

There were used the means of daily maximum temperature for eight meteorological stations located within the region of interest (Drobeta-Turnu Severin, further referred to as D.T. Severin, Bechet, Craiova, Roşiorii de Vede, Bucureşti Băneasa, Călăraşi, Buzău, Galaţi) (Fig. 1, Table 1) for the period 1961-2015. The distribution and homogeneity of the data series were tested based on the average annual values. The average annual, seasonal and monthly values were used to identify trends and test the statistical significance.

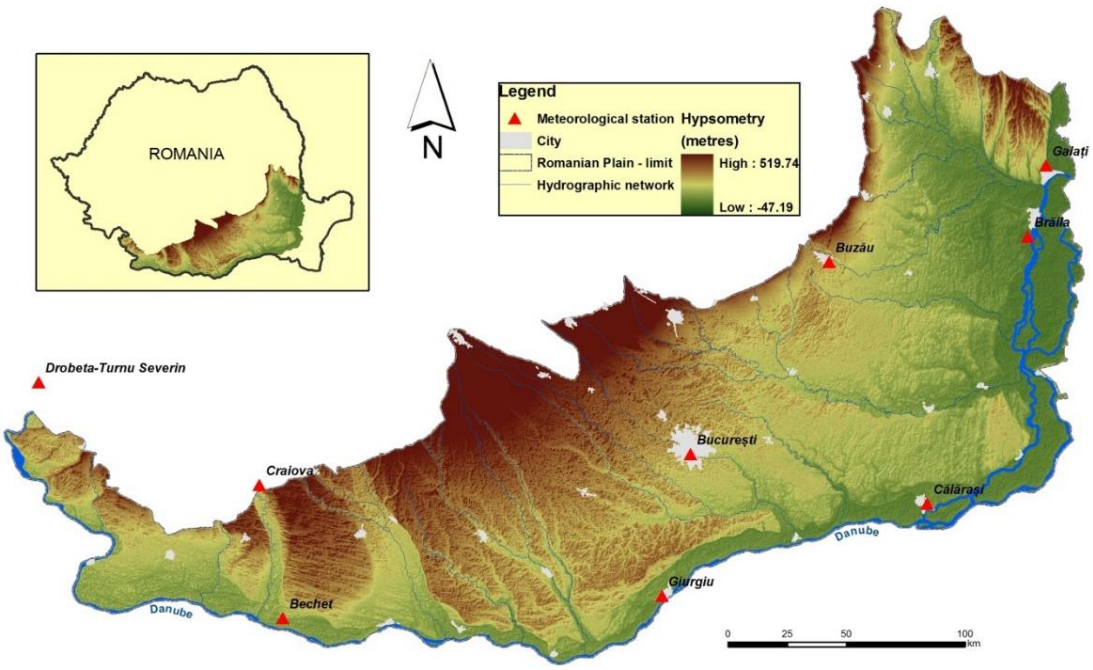

Fig. 1: Location of the meteorological stations within the Romanian Plain

Table 1: Geographical coordinates of the considered meteorological stations

No.	Station	Altitude (m)	Latitude	Longitude
1.	**D.T. Severin**	77	44°37`	22°37`
2.	**Bechet**	36	43°47`	23°57`
3.	**Craiova**	192	44°13`	23°52`
4.	**Roşiorii de Vede**	102	44°06`	24°58`
5.	**Bucureşti Băneasa**	90	44°31`	26°04`
6.	**Călăraşi**	90	44°12`	27°19`
7.	**Buzău**	19	45°07`	26°51`
8.	**Galaţi**	**71**	**45°30`**	**28°01`**

All temperature data come from the following source – Klein Tank, A.M.G. and Coauthors, 2002 (Data and metadata available at http://www.ecad.eu), except Bechet, for which data were provided by the National Meteorological Administration.

Based on two coefficients – Kurtosis (K) and Skewness (S), there were emphasized the characteristics of data distribution.

Kurtosis (K) is a statistical measure that can be used to render the distribution of data around the mean. The resulting curve indicates whether the data are peaked or flat relative to a normal distribution. Peaked distribution is rendered by positive values of K, while flat distribution by negative values. In this case, it is used excess kurtosis, which is simply kurtosis – 3. Thus, normal distribution is indicated by an excess kurtosis equal to 0. The formula is:

$$K = \frac{\sum_{i=1}^{N}\left(Xi - \overline{X}\right)^4}{(N-1)s^4} - 3 \quad (1), \text{ where}$$

X represents the temperature value registered in a particular year, Xi represents the average temperature, s is the standard deviation and N is the sample size.

The lack of symmetry of a frequency distribution is defined by the term of Skewness. The coefficient of skewness (S) was first developed by Karl Pearson by the end of the 19th century. The coefficient is calculated according to the following formula (Wheeler, 2015), the terms having the same significance as mentioned above:

$$S = \frac{\sum_{i=1}^{N}\left(Xi - \overline{X}\right)^3}{(N-1)s^3} \quad (2)$$

Normal distribution is indicated by a S value equal to 0, the marker of perfect symmetry, but such a value is quite unlikely. According to Bulmer (1979), if S is less than -1 or higher +1, the distribution is highly skewed; if S is between -/+1 and -/+1/2, the distribution is moderately skewed, while values between -1/2 and +1/2 indicate an approximately symmetrical distribution.

The Kolmogorov-Smirnov test (KST) was developed by Kolmorov (1933) and Smirnov (1948) as mentioned by Massey (1951). The KS one-sample test for normality emphasizes weather a sample comes from a population with a specific distribution. KS test is based on the maximum difference between the sample cumulative distribution and the hypothesized cumulative distribution (http://documentation.statsoft.com).

Three methods have been applied to test the homogeneity of the annual series: the Mann-Whitney Pettitt's test (MWP), the standard normal homogeneity test (SNHT) for a single break and T-test (based on AnClimfree software available on-line www.climahom.eu/software-solution/anclim). MWP test is a nonparametric test used to emphasize changes in the mean distribution of a parameter either in hydrology or climatology. The T-test (one sample) is used to test hypotheses about the mean – μ when the population standard deviation is unknown. SNHT was developed first in 1984, 1986 by Alexandersson who applied it in case of precipitation datasets and then on temperature series (Alexandersson & Moberg, 1997; Moberg & Alexandersson, 1997; Moberg & Bergström, 1997). These tests highlight the year when the break occurs.

Besides the multiannual mean values of the daily maximum temperatures, there were calculated the means for 30-year and 10-year intervals and emphasized the highest values registered at monthly, seasonal and annual level.

Mann-Kendall test (Mann, 1945; Kendall, 1975) and Sen's slope estimates, applied by the researchers of the Finnish Meteorological Institute (Salmi et al., 2002) was used to test the significance of temperature trends. The test statistically assesses if there is a monotonic upward or downward trend of a variable, in this case, temperature, within a predetermined level of significance (a positive value of test Z indicate an increasing/upward trend, while a negative value of test Z marks a decreasing/downward trend). A major advantage of this test is that it presents a reduced sensitivity to abrupt breaks induced by the inhomogeneity of the time series.

Results and discussions

Distribution and homogeneity tests

Distribution and homogeneity tests were performed for annual temperature values. The asymmetry coefficient Skewness (S) displays positive values within the entire plain region, underlining an asymmetrical distribution with a longer tail to the right, namely a positive skew. However, taking into account that the values are close to 0, we can assume that the distribution is quite symmetrical (Table 2). Kurtosis (K) describes the shape of a probability distribution rendering if the considered data display a peaked or flat distribution relative to a normal distribution. According to the obtained results, K values are negative, which means that the distribution is platykurtic (flatter than a normal distribution with shorter tails). However, all the values are in the range -1/2 and +1/2, which indicate an approximately symmetrical distribution. The distribution was also tested with Kolmogorov-Smirnov test. The values of *p* above the threshold of

0.05 indicate a normal distribution in all the stations taken into account.

Table 2: Results of the distribution tests applied on annual mean maximum temperature datasets in the Romanian Plain (1961-2015)

Station	S	K	KST
D.T. Severin	0.389	-0.560	D= 0.099 (p=0.659, O.K.)
Craiova	0.328	-0.748	D= 0.098 (p=0.671, O.K.)
Bechet	0.114	-0.365	D= 0.092 (p=0.792, O.K.)
Roşiorii de Vede	0.342	-0.652	D= 0.087 (p=0.796, O.K.)
Bucureşti Băneasa	0.212	-0.636	D= 0.094 (p=0.718, O.K.)
Călăraşi	0.271	-0.788	D= 0.094 (p=0.712, O.K.)
Buzău	0.373	-0.444	D= 0.083 (p=0.846, O.K.)
Galaţi	0.272	-0.690	D= 0.096 (p=0.697, O.K.)

There was tested the homogeneity of the annual temperature series based on three tests. It resulted that the data are homogenous. The results of the homogeneity tests indicate that the change points are registered before 2000 in most of the cases (Table 3). In case of two stations located in the west (D.T. Severin and Bechet), all the tests indicated the same change point, 1988, while in the north-east, at Buzău, the change point is registered in 1989. At the other meteorological stations, two of the tests, namely SNHT and T test indicated the same change point – 1999 at Craiova, 1989 at Roşiorii de Vede, 2000 at Bucureşti Băneasa, 1998 at Călăraşi and Galaţi. As for MWP test, it emphasizes the change point in 1988 in the western part (D.T. Severin, Craiova, Bechet and Roşiorii de Vede) and 1989 in the east (Bucureşti Băneasa, Călăraşi, Galaţi and Buzău) (Table 3). The change point (1988 and 1998) in daily maximum temperature data generally coincides with the one identified in the northeast of the country (Piticar & Ristoiu, 2012).

Mean daily maximum temperatures within the Romanian Plain

The monthly mean maximum temperatures display positive values during the entire year, the lowest values being characteristic to January and the highest to July. Thus, January mean for the entire plain is 2.4°C (varying between 3.5°C at D.T. Severin in the west and 1.6°C at Galaţi, in the east), while July average value is 29.6°C (varying between 30.1°C at Bechet, in the south, and 28.9°C at Galaţi, in the east). The southern part of the plain, which corresponds to the Danube Alluvial Plain, has higher values compared to the other sectors of the analysed unit, no matter the season. Generally, the lowest maximum values are registered at Galaţi, in the east of the plain (Fig. 2).

Table 3: Results of homogeneity tests applied on annual mean maximum temperature datasets in the Romanian Plain (1961-2015)

Meteorological station	MWP test	SNHT	Student T test
D.T. Severin	K=520 1988	19.306; 0.954 1988	5.431 1988
Craiova	K=458 1988	15.288; 0.903 1999	4.575 1999
Bechet	K=463 1988	20.563; 1.289 1988	5.891 1988
Roşiorii de Vede	K=464 1988	14.619; 0.997 1989	4.436 1989
Bucureşti Băneasa	K=488 1989	17.969; 1.072 2000	5.141 2000
Călăraşi	K=532 1989	21.203; 1.201 1998	5.854 1998
Buzău	K=466 1989	15.819; 0.989 1989	4.686 1989
Galaţi	K=556 1989	22.011; 1.367 1998	6.039 1998

The analysis of the highest mean maximum temperatures within the Romanian Plain revealed certain patterns. Thus, at annual level, within most of the plain, the hottest year was 2007. The western part of the analysed region, generally overlapping Oltenia Plain, registered higher values in the last years, 2012 and 2015, while in the north-east, at Buzău, the hottest year was 1990. Positive deviations exceeded 2.4°C varying between 2.9°C at Galaţi, in the east and 2.4°C at Craiova, in the west. However, in winter half year (WHY) and summer half year (SHY), the highest values were registered in the same years, 1990 respectively 2012. At seasonal level, there emerged certain differences. Thus, the hottest winter was that of 2006-2007, except for the eastern part of the plain, where the values registered in 1988-1989 exceeded those registered in the previously mentioned interval. In spring, there is a greater variability – in the west, 2007 displays the highest mean maximum mean, in the east, 1989, while within most of the plain 1983 marked the warmest spring. Summer mean maximum temperatures are above 31.5°C and 2012 is the hottest summer for most of the plain (except for Bucureşti Băneasa and Galaţi, 2007). 2012 also marks the greatest temperature values for autumn, except for the northeastern part (1963) (Table 4).

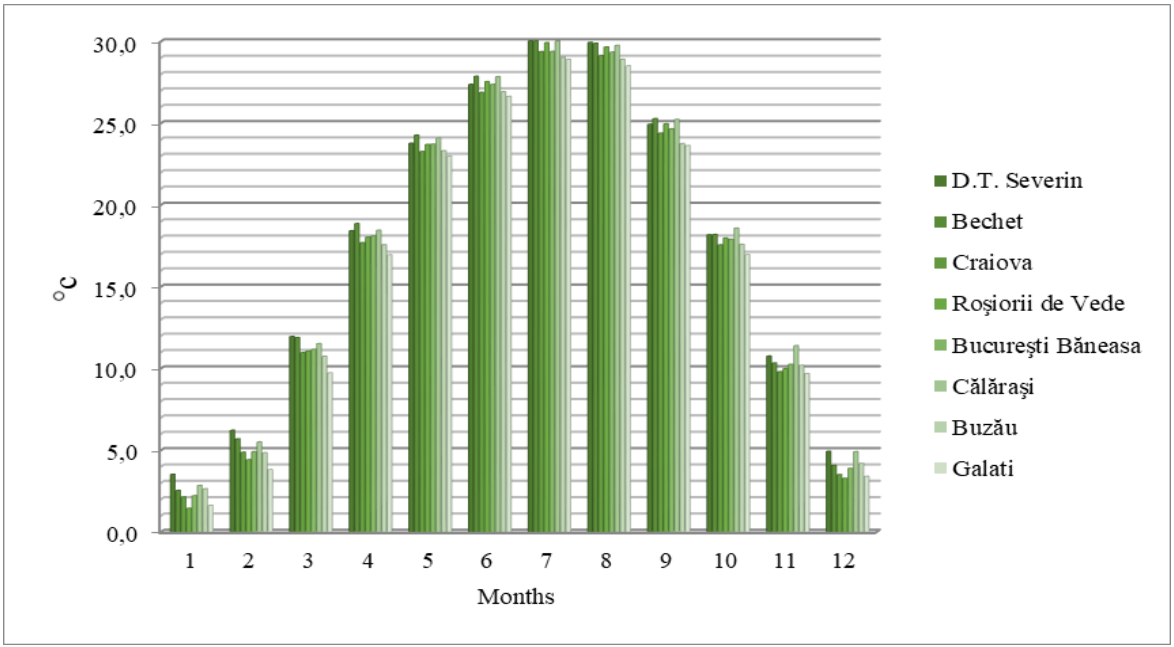

Fig. 2: Mean monthly maximum temperatures within the Romanian Plain (1961-2015)

Table 4: The highest maximum temperature values within the Romanian Plain (1961-2015)

Station	Y	WHY	SHY	W	SP	SM	A
D.T. Severin	**19.5**	**11.6**	**29.0***	**8.5**	**20.9**	**33.2***	**20.7***
	2015	1990	2012	2007	2007	2012	2012
Bechet	**19.8***	**11.7***	**28.4**	**9.4***	**21.6***	**32.4**	**20.4**
	2007	2008	2000	2007	1983	2000	1963
Craiova	**18.6**	**10.5**	**28.5**	**7.5**	**20.0**	**32.9**	**20.3**
	2012	1990	2012	2007	1983	2012	2012
Roşiorii de Vede	**18.9**	**10.3**	**28.6**	**7.3**	**21.1**	**32.9**	**20.6**
	2007	1990	2012	2007	1983	2012	2012
Bucureşti Băneasa	**19.1**	**10.8**	**28.2**	**7.1**	**20.8**	**32.6**	**20.4**
	2007	1990	2012	2007	1983	2007	2012
Călăraşi	**19.6**	**11.4**	**28.9**	**8.1**	**21.2**	**32.8**	**21.1**
	2007	1990	2012	2007	1983	2012	2012
Buzău	**18.7**	**11.7**	**27.9**	**8.2**	**20.0**	**31.8**	**19.8**
	1990	1990	2012	1989	1990	2012	1963
Galaţi	**18.5**	**10.8**	**28.2**	**6.7**	**19.7**	**32.0**	**19.5**
	2007	1990	2012	1989	1990	2007	2012

* - the highest maximum temperature within the entire plain region

At monthly level, 55.2% of the highest means of the maximum daily temperatures were registered after 2000. 2007 and 2012 are the years with the greatest percents, 17.7% (17 cases), respectively 9.37% (9 cases). In terms of territorial distribution, generally, the highest monthly values are registered in the same years, certifying the action of the same air masses within the entire plain region. Thus, for January, 2007 marks the greatest values, varying between 13.2°C (Bechet) and 9.4°C (Galaţi), which means deviations between 11.0°C and 7.8°C. 2002 marks the hottest February, while 1990 the hottest March. The highest mean maximum temperatures of April correspond to 1968 and of May to 2003. The hottest June and July were registered in 2007 and 2012, in July, all monthly values exceeding 34°C. In August, we remark 1992 for the central and western parts of the plain, while in the east, 2010 values are the highest. In September, the highest temperatures were registered in 1994, in October in 1966, while in November, there is a greater variability – 2012, 2010, 1969 and 1963. The hottest December was in 2015 in the central and western sectors of the analysed region, and in the east in 1982 (Table 5). However, the maximum temperature values decrease from west to east and from south to north

in winter and summer. The most significant positive deviations are registered in the winter months, while the most reduced in summer.

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

In order to highlight the increase of daily maximum temperature, there was made a comparison between the mean multiannual values for different time intervals. Thus, it can be noticed that an increase for the last two periods, 1971-2000 respectively 1981-2010 for all the analysed meteorological stations compared to the first period, 1961-1990. If in the period 1961-1990, there were only two stations, both located in the south of the plain, within the Danube Alluvial Plain, where the mean maximum temperature exceeded 17°C (D.T. Severin and Călăraşi, 17.04°C), in the last period, namely 1981-2010, there were only three stations with values below 17°C, all located in the northern part (Craiova, Buzău, Galaţi). In case of the difference between the first two periods, the highest values were registered in the western part of the Romanian Plain (D.T. Severin and Bechet, 0.3°C and 0.4°C); if taking into account the difference between the last two periods, there were noticed first of all higher values, more homogenous values (ranging between 0.4°C and 0.6°C), as well as an increase of the difference in the east of the plain (Table 6).

When reducing the comparison period, the emphasized situation generally registered the same pattern of evolution, namely the increase of the mean values towards the end of the period. However, the decade 1971-1980 was cooler than the previous decade with two exceptions – Galaţi, where it was registered a slight increase of 0.04°C, and Bechet, an increase of 0.05°C. If comparing the mean values for the first and last decades it can be noticed that in the first one, there was only one case with temperatures above 17°C, while in the last one, only one case with values below 17°C (Table 7), but three cases with values above 18°C, all stations being located along the Danube. The differences between the last two intervals were the highest registered during the entire period of analysis. They ranged between more than 0.8°C (Galaţi – 0.9°C, Bechet – 0.8°C) and less than 0.6°C (D.T. Severin – 0.5°C, Craiova – 0.5°C). Consequently, the linear tendency of evolution is clearly positive within the entire plain (Fig. 3).

Table 5: The highest monthly means of the maximum daily temperatures

Station	1	2	3	4	5	6	7	8	9	10	11	12
D.T. Severin	**11.6**	**13.7**	**18.1**	**21.9**	**27.6**	**30.8**	**34.9**	**35.2***	**30.3**	**21.7**	**15.8**	**11.0***
	2007	2002	1990	2000	2003	2012	2012	1992	2012	1966	2012	2015
Bechet	**13.2***	**13.5**	**18.8***	**22.4**	**28.1**	**30.8**	**35.3**	**34.4**	**31.1***	**21.9**	**16.9**	**8.2**
	2007	2002	1990	1968	2003	2007	2007	1992	1994	1966	2010	1979
Craiova	**11.3**	**13.5**	**17.5**	**22.0**	**27.1**	**30.1**	**35.0**	**33.6**	**29.5**	**21.9**	**15.8**	**8.7**
	2007	2002	1990	1968	2003	2012	2012	1992	1994	1966	1963	2015
Roşiorii de Vede	**10.8**	**13.7**	**17.4**	**22.4**	**27.6**	**30.8**	**35.4***	**33.6**	**30.6**	**22.7**	**16.1**	**8.0**
	2007	2002	1990	1968	2003	2007	2007	1992	1994	1966	1963	2015
Bucureşti Băneasa	**10.6**	**13.8**	**17.6**	**22.6**	**28.3**	**31.4**	**35.0**	**33.0**	**29.8**	**22.2**	**16.0**	**8.5**
	2007	2002	1990	1968	2002	2007	2007	1992	1994	1984	1969	2015
Călăraşi	**11.3**	**14.4***	**17.6**	**22.4***	**28.6***	**31.5***	**35.0**	**33.9**	**30.4**	**23.5***	**18.1***	**9.3**
	2007	2002	1990	1998	2003	2007	2012	2010	1994	1966	2010	1982
Buzău	**11.2**	**13.8**	**17.5**	**21.8**	**28.0**	**30.0**	**34.1**	**32.8**	**28.6**	**22.0**	**16.2**	**7.9**
	2007	2002	1990	1968	2003	2007	2012	2010	1994	1966	1969	1982
Galaţi	**9.4**	**12.6**	**17.3**	**21.1**	**28.0**	**30.9**	**34.0**	**32.7**	**28.0**	**21.2**	**16.3**	**7.5**
	2007	2002	1990	1968	2003	2007	2012	2010	1994	1966	2010	1982

* - the highest maximum monthly temperature within the entire plain region

Table 6: Mean annual maximum temperature over the 1961-1990, 1971-2000, 1981-2010 periods

Period /Station	D.T. Severin	Bechet	Craiova	Roşiorii de Vede	Bucureşti Băneasa	Călăraşi	Buzău	Galaţi
1961-1990	17.0	16.9	16.2	16.4	16.5	17.0	16.3	15.5
1971-2000	17.3	17.3	16.4	16.6	16.6	17.2	16.5	15.8
Increase	**0.3**	**0.4**	**0.2**	**0.2**	**0.1**	**0.2**	**0.2**	**0.3**
1981-2010	17.7	17.9	16.8	17.1	17.1	17.7	16.9	16.3
Increase	**0.4**	**0.6**	**0.4**	**0.5**	**0.5**	**0.5**	**0.4**	**0.5**

Table 7: Mean annual maximum temperature evolution over 10-year intervals

Period /Station	D.T. Severin	Bechet	Craiova	Roşiorii de Vede	Bucureşti Băneasa	Călăraşi	Buzău	Galaţi
1961-1970	16.9	16.6	16.3	16.4	16.6	17.0	16.1	15.4
1971-1980	16.8	16.7	15.9	16.1	16.2	16.9	16.0	15.4
1981-1990	17.5	17.5	16.6	16.8	16.7	17.2	16.8	15.8
1991-2000	17.6	17.7	16.7	16.9	16.9	17.6	16.7	16.1
2001-2010	18.1	18.5	17.1	17.4	17.6	18.3	17.3	17.0

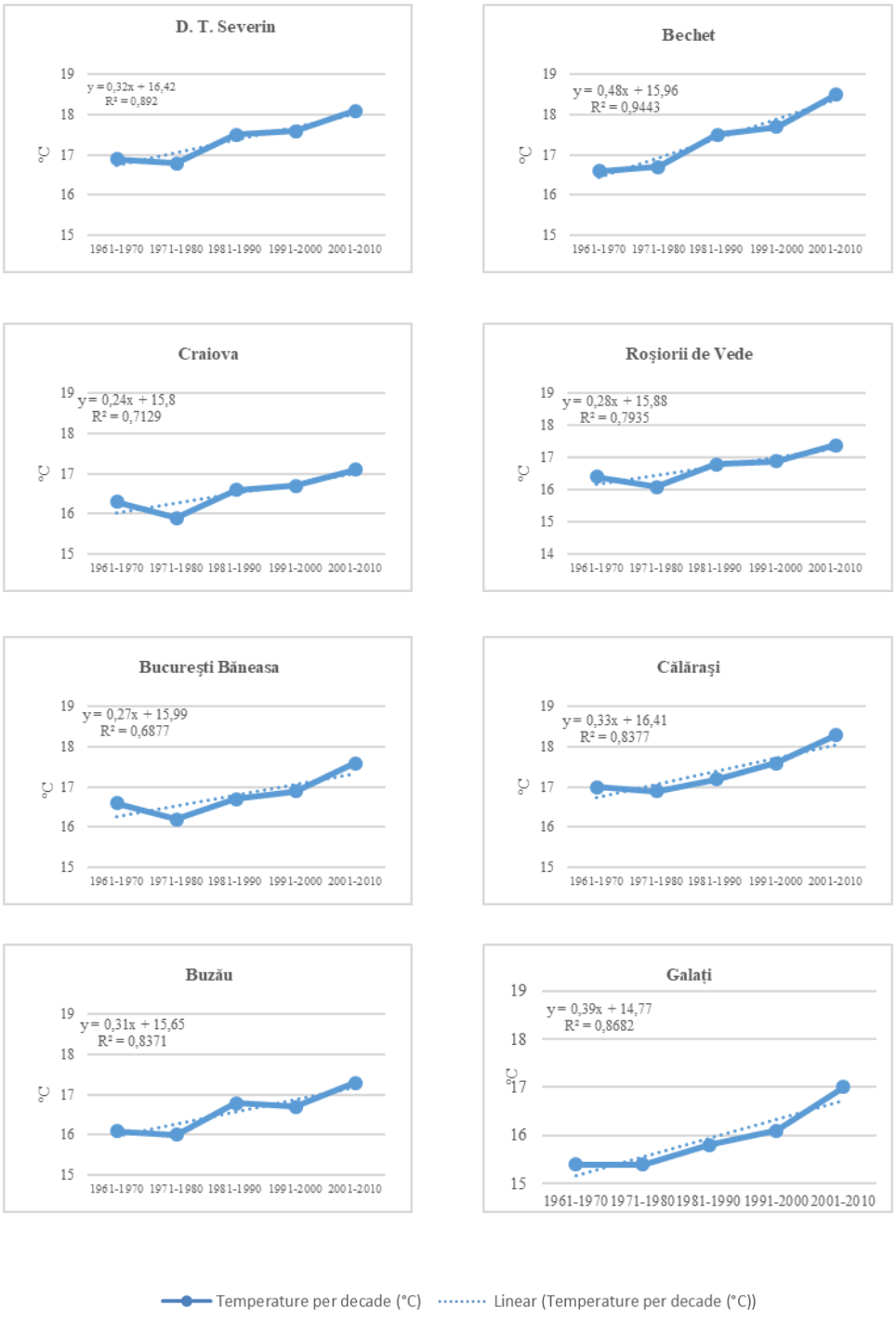

Fig. 3: Mean maximum temperatures per decade and their tendency of evolution

Temperature trend analysis

The Mann-Kendell test was applied to 19 data sets (annual – Y, winter half year – WHY, the interval October - March, summer half year – SHY, the interval April - September, winter – W, Spring – Sp, summer – Sm, autumn – A, and months) for each station (Table 4). Upward trends (Z) and positive slopes (Q) clearly predominate within the entire region, 15 series of the 19 analysed series displaying positive values at all the meteorological stations (Y, SHY, Sp, Sm, A, January, February, March, April, May, June, July, August, December).

At annual level, there are registered upwards trends within the entire plain. The trend is statistically significant – α= 0.001 level of significance, at all the analysed meteorological stations, indicating the clear increase in daily maximum temperatures in the southern part of Romania (Fig. 4).

The WHY also displays an upward trend, even if there are differences in terms of level of significance. Thus, the most obvious increase of the daily maximum temperature corresponds to Bechet (α= 0.001), while the most reduced level of significance (α= 0.05) is registered at Roşiorii de Vede and Călăraşi. The other stations present positive trends the level of significance being 0.01.

In case of the SHY, the upward trends are obvious, the level of significance varying between 0.001 and 0.01 (the central sector of the plain).

At seasonal level, trends are positive in case of three seasons but there does not emerge clear territorial differences within the analysed region. The only season that registered both positive and negative trends, but not statistically significant, is autumn. Winter displays an upward trend with a level of significance α= 0.01 within most of the plain. The level of significance is higher in case of Bechet, 0.001, and lower in case of Buzău, 0.05. In spring, the trend is statistically significant at a level of 0.01 except for the central part where it is registered the lowest increase (α= 0.05 level of significance) and the eastern extremity, at Galaţi, with a highest level of significance, 0.001. Summer is the season characterized by the most obvious and uniformly distributed upward trend, the level of significance reaching 0.001 within the entire analysed region.

At monthly level, 9 of the 12 data series display positive values at all the meteorological stations, emphasizing upward trends. Winter months present positive Z values, but trends are generally not statistically significant. January is the only winter month registering a statistically significant upward trend. Temperature increase is higher in the southern part of Oltenia Plain (0.01 level of significance) compared with the central and eastern sectors of the Romanian Plain where the level of significance oscillates between 0.01 and 0.05. Only in the north-eastern part of the analysed region January does not present a statistically significant positive trend. December and February register positive slopes but the increase of the daily maximum temperatures is not statistically significant in most of the cases. Along the Danube, the level of significance of the increase registered in February varies between 0.01 at Bechet and 0.1 at Galaţi.

Among the spring months, only March and May register significant positive slopes significant at most of the stations. Thus, in March there is registered α= 0.05 level of significance within the entire plain except for Bechet with 0.01, while in May the upward trend is more obvious along the Danube (α= 0.01 at Bechet, Călăraşi, Galaţi).

The most important increase is characteristic to summer months (June, July, August), when all the stations show statistically significant positive slopes. The highest statistical significance corresponds to July (α= 0.001 except for Bucureşti Băneasa with α= 0.01). In June, the level of significance is 0.001 only in the southern part of Oltenia plain (D.T. Severin and Bechet), while in the rest of the region it is 0.01. In August, the 0.001 level of significance is characteristic to the western extremity (D.T. Severin) and the eastern sector of the plain (Table 8). In autumn, there predominate negative trends, but they are not significant. In September, the slope is positive only at Bucureşti Băneasa, in October at Bechet and Galaţi, while in November, the slopes are positive with one exception, Bechet.

Conclusion

The analysis of mean of daily maximum temperatures within the Romanian Plain for a 55-year period emphasized a significant upward trend, confirming the results obtained by other researchers. The distribution tests indicate that the data series display an asymmetrical distribution but the values of Skewness (S) are quite close to 0 and of Kurtosis (K) are in the range -1/2 and +1/2, which means that the distribution is not far from symmetrical. However, in case of Kolmogorov-Smirnov test, the values of p above the threshold of 0.05 indicate a normal distribution. Homogeneity (MWP test, SNHT, Student T test) tests emphasized that the break points are generally recorded before 2000.

In terms of the highest values (Y, WHY, SHY, W, SP, SM, A), only about 32% were registered before 2000, most of the values being registered in 2007 and 2012. The analysis revealed that all maximum

temperatures were registered in the western half of the plain, at D.T. Severin and Bechet, as it follows: Y – 19.8°C/2007, Bechet; WHY – 11.7°C/2008, Bechet; WSH – 29.0°C/2012, D.T. Severin; W – 9.4°C /2007, Bechet; SP – 21.6/1983, Bechet; SM – 33.2°C /2012, D.T. Severin; A – 20.7°C/2012, D.T. Severin.

Table 8: Sen's slope estimate (Q) and their statistical significances (SS) for air temperature trends

Station /Month	D.T. Severin			Craiova			Bechet			Roşiorii de Vede			Bucureşti Băneasa		
	Z	SS	Q	Z	SS	Q	Z	SS	Q	Z	SS	Q	Z	SS	Q
Y	4.59	***	0.034	3.77	***	0.032	4.56	***	0.047	3.56	***	0.027	3.69	***	0.027
WHY	3.05	**	0.033	3.03	**	0.035	3.75	***	0.059	2.45	*	0.029	2.70	**	0.032
SHY	3.91	***	0.041	2.95	**	0.031	4.39	***	0.042	3.11	**	0.034	3.15	**	0.032
W	3.21	**	0.046	3.09	**	0.043	4.07	***	0.072	2.81	**	0.036	3.09	**	0.039
Sp	3.12	**	0.042	2.67	**	0.039	3.23	**	0.052	2.12	*	0.036	2.39	*	0.035
Sm	4.54	***	0.062	3.66	***	0.046	4.49	***	0.059	4.17	***	0.050	3.67	***	0.044
A	-0.01		-0.001	-0.52		-0.008	0.16		0.003	-0.42		-0.006	-0.06		-0.001
J	2.85	**	0.064	2.25	*	0.063	3.04	**	0.089	1.71	+	0.046	2.25	*	0.046
F	1.21		0.044	1.28		0.045	2.59	**	0.096	1.45		0.040	1.94	+	0.053
M	2.08	*	0.060	2.11	*	0.059	2.59	**	0.088	2.05	*	0.055	1.84	+	0.051
A	1.81	+	0.034	1.29		0.020	1.31		0.022	0.57		0.011	0.77		0.013
M	2.50	*	0.036	1.79	+	0.028	2.62	**	0.052	1.68	+	0.031	2.03	*	0.033
J	3.78	***	0.049	2.71	**	0.039	3.71	***	0.055	3.03	**	0.043	2.40	*	0.032
J	3.98	***	0.057	3.39	***	0.042	4.03	***	0.060	3.55	***	0.049	3.16	**	0.044
A	3.32	***	0.070	2.97	**	0.057	3.00	**	0.063	3.08	**	0.060	3.22	**	0.060
S	-0.12		-0.002	-0.62		-0.012	-0.45		-0.007	-0.05		-0.002	0.14		0.001
O	-0.57		-0.010	-1.34		-0.020	0.50		0.009	-1.23		-0.020	-0.74		-0.011
N	0.04		0.001	0.04		0.001	-0.11		-0.003	0.17		0.007	0.41		0.008
D	1.30		0.023	1.50		0.026	1.48		0.038	1.42		0.026	1.26		0.023

Station / Month	Călăraşi			Buzău			Galaţi		
	Z	SS	Q	Z	SS	Q	Z	SS	Q
Y	4.23	***	0.032	3.68	***	0.028	4.41	***	0.040
WHY	2.51	*	0.029	2.63	**	0.027	3.05	**	0.035
SHY	4.21	***	0.037	3.51	***	0.032	5.15	***	0.049
W	2.82	**	0.038	2.13	*	0.033	2.90	**	0.042
Sp	2.63	**	0.039	2.94	**	0.044	3.33	***	0.055
Sm	4.51	***	0.054	4.46	***	0.056	5.60	***	0.064
A	0.09		0.003	-0.28		-0.003	1.31		0.012
J	2.03	*	0.048	1.58		0.034	1.95	+	0.046
F	1.43		0.051	1.73	+	0.054	2.03	*	0.055
M	1.77	+	0.047	2.54	*	0.073	2.42	*	0.069
A	0.79		0.017	1.24		0.023	1.74	+	0.032
M	2.82	**	0.046	2.18	*	0.034	3.22	**	0.059
J	3.22	**	0.043	2.74	**	0.039	3.22	**	0.047
J	3.63	***	0.050	3.80	***	0.050	4.66	***	0.069
A	3.80	***	0.066	3.75	***	0.069	4.52	***	0.077
S	0.81		0.013	-0.46		-0.005	1.15		0.018
O	-0.44		-0.008	-0.04		-0.001	0.28		0.005
N	0.20		0.005	0.13		0.004	0.75		0.014
D	1.19		0.028	0.54		0.010	1.53		0.027

*** if trend at α= 0.001 level of significance; ** if trend at α= 0.01 level of significance; * if trend at α= 0.05 level of significance, + if trend at α= 0.1 level of significance; values in bold represent generalized trend (increasing) in the region.

At monthly level, 2007 and 2012 are the years with the greatest percents, 17.7% (17 cases), respectively 9.37% (9 cases), 55.2% of the highest means of the maximum daily temperatures being registered after 2000. In this case, it should be noted that Călăraşi is the station with the most numerous cases – February 2002, April 1998, May 2003, June 2007, October 1966 and November 2010, while Bechet registered the highest values for January 2007, March 1990 and September 1994 and

D.T. Severin for August 1992 and December 2015. The highest monthly value is 35.4°C and it was registered at Roşiorii de Vede in 2007. There is clearly a greater heterogeneity in terms of registration years.

In order to assess the significance of the upward trends resulted from 30-year and 10-year interval analysis, there was used the Mann-Kendall test on 19 data sets for each station taken into consideration. The results confirmed the general upward trend for the entire region at annual, winter half year, summer half year, winter, spring and summer level when all the stations showed statistically significant positive slopes; upward trends were detected also for May, June, July and August for the entire plain. In terms of statistical significance, annual, and summer values showed generalized statistically significant positive slopes in the study area (α= 0.001 level of significance). Summer months also displayed statistically significant increases, especially July, which presented α=0.001 level of significance, except for Bucureşti Băneasa with α=0.01. Generally, the positive slopes and upward trends are more significant during summer months in the eastern part of the plain compared to the western part. It should be mentioned that negative trends are registered in autumn, September and October, but not at all the stations and they are not statistically significant. Thus, we can consider that the increasing trend of the mean of daily maximum temperatures is confirmed within the entire plain area without highlighting significant temporal and spatial differences.

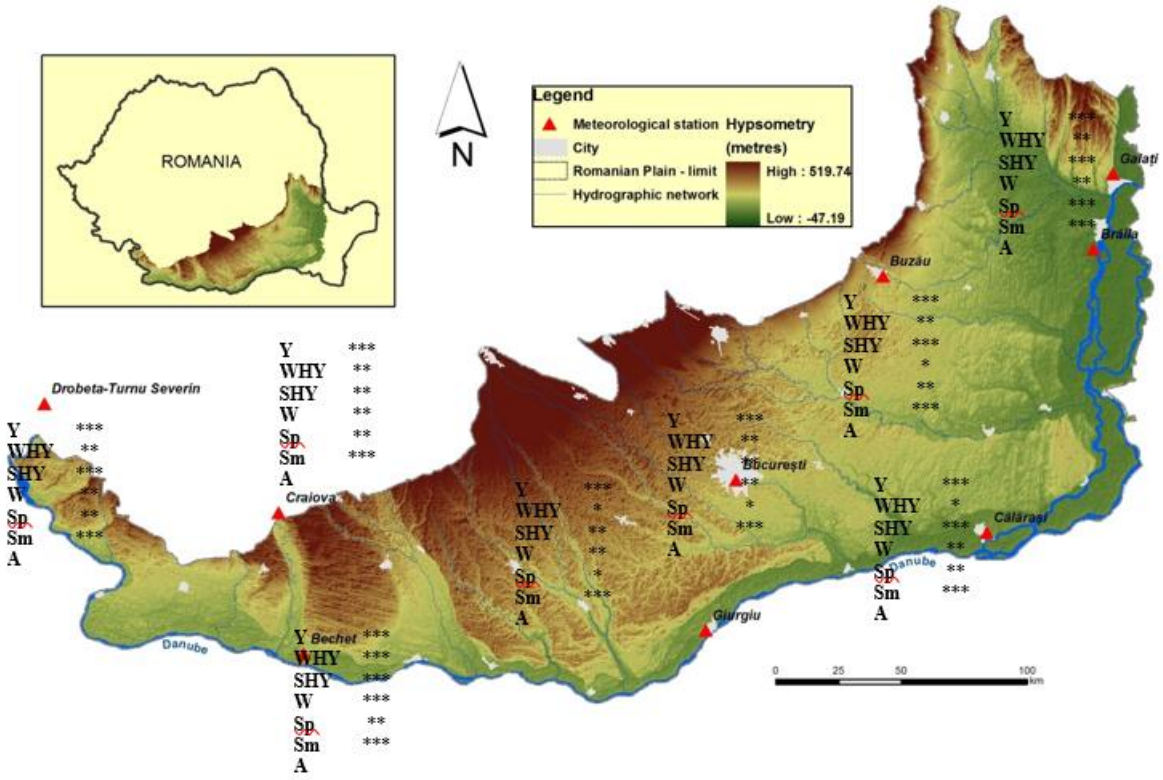

Fig. 4: The statistical significances (SS) for annual, semester and seasonal daily maximum temperature trends

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