TEMPERATURE AND PRECIPITATION CHANGES IN TÂRGU-MURES (ROMANIA) FROM PERIOD 1951-2010

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ABSTRACT. – Temperature and precipitation changes in Târgu Mures (Romania) from period 1951-2010. The analysis was made based upon meteorological data collected at Târgu Mures meteorological station (Romania, Mures county, lat. 46°32'N, lon. 24°32'E, elevation 308 m), between 1951 and 2010. Several climatic parameters were studied (for instance, annual and monthly mean temperature, maximum precipitation in 24 hours, number of summer days, etc). Detected inhomogeneities are not related to instrumental causes or geographical relocation. Positive and statistical significant trends (Mann-Kendall test) are indicated for: mean annual temperatures, mean temperatures of warm months, average of the maximum and minimum temperatures (annual and warm months data), number of days with mean temperature between 20.1-25.0 °C, number of days with precipitation ≥0 mm, and for all parameters of precipitation of September. The sequential version of Mann-Kendall test show a beginning of a trend in 1956 in the case of mean temperature (at same, the two and three parts regression denote this year like a moment of change), years 1965 and 1992 in the case of annual amount of precipitation. CUSUM charts indicate occurs of changes points at 1988, 2005, 2009 (mean temperature) respectively at 1989, 2004 (precipitation), and at 1968, 1992 (daily temperature range). Tendencies of overlapped time series reveal a more important increase at the end of period (mainly for mean temperature). The analysis with RClimDex show for 5 extreme climate indices a significant trend: positive for summer days, warm nights, warm spell duration indicator and negative for cold nights and cold days.

Keywords: Târgu Mures, temperature, precipitation, trend analysis

1. INTRODUCTION

Târgu Mures is located in central part of Transylvania (Romania), in Mures Valley. The meteorological station (lat. 46°32'N, lon. 24°32'E, elevation 308 m) has been worked (with interruptions) since the end of 19th century. For Romania it was established that the mean annual temperature increased over the period 1961-2007 with values between 0.8°C and 1.0°C, and the precipitation decreased in winter for some extra-Carpathian regions and increased in autumn for northwestern and southeastern regions (Busuioc et al., 2010). The aim of this paper is to detect local changes in main climatic parameters from Târgu Mures.

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2. DATA AND METHODS

The analysis was made based upon meteorological data collected at Târgu Mures weather station between 1951 and 2010. The following climatic parameters were studied: annual and monthly mean temperatures, maximum temperatures, minimum temperatures, daily temperature amplitudes, amounts of precipitation. In addition, other series were studied: mean of maximum and minimum temperatures, the number of days with mean temperatures between: -14.9 and -10.0 °C, -9.9 and -5.0 °C, -4.9 and -0.0 °C, 0.1 and 5.0 °C, 5.1 and 10.0 ºC, 10.1 and 15.0 °C, 15.1 and 20.0 °C, 20.1 and 25.0 °C, the maximum amount of precipitation in 24 hours, the number of days with the precipitation equal to or greater than 0.1 mm,0.5 mm, 1.0 mm, 2.0 mm, 5.0 mm, and the 27 climate indices created by RClimDex . In the case of annual average temperature and annual precipitation amount overlapped equal and unequal time periods also were used.

In order to identify discontinuities caused by non-climatic causes, three absolute homogeneity tests were applied: Pettit's test (Pettitt, 1979), Standard Normal Homogeneity Test (SNHT) (Alexandersson, 1986) and Buishand's (Buishand, 1982) tests. Metadata also were taken into consideration.

Trend significance was detected using Mann-Kendall test (Mann, 1945; Kendall, 1975). The linear slopes of trends were calculated using Sen's slope estimator (Sen, 1968). Also the trends of 27 indices of climate extremes included in RClimDex were calculated. Change-point analysis determines if and when a change in a data set occurred, uses cumulative sum and bootstrapping techniques to identify changes (Taylor, 2000). Sequential Mann-Kendall test (Sneyers, 1975) is used to identify the beginning of a trend in a sample. The method of least squares is applied to obtain several parts regression.

To achieve these analyses the following software were used: XLSTAT (http://www.xlstat.com/) for homogeneity test, AnClim (Stepanek, 2007) for two and three parts' regression, Makesens (Salmi et al., 2002) for Mann-Kendall test and Sen's slope estimator, Change Point Analyzer (Taylor, 2000) for CUSUM charts, RClimDex (Zhang and Feng, 2004) for indices of climate extremes.

3. RESULTS

Several factors can affect the quality of the climate data. The main sources of inhomogeneities are station relocation, changes in instruments, formulae used to calculate mean and many other factors. Breaks detected by statistical homogeneity testing can be confirmed from metadata (Tuomenvirta, 2002). At Târgu Mures meteorological station between 1951-2010 the thermometers were changed every 2-3 year. The station was relocated in 1954 and the automatic water station was activated in 2002. Another important change is the calculation of average temperature from four values starting from 1961. This metadata information combined with the results of homogeneity tests (table1) led us consider all time series homogenous.

Table 1. ***The results of homogeneity tests. Significant breaks at 5% level are shown in bold***

	Mean temperature			Precipitation amount		
	Pettitt's test	SNHT	Buishand's test	Pettitt's test	SNHT	Buishand's test
Annual	**1986**	**1998**	**1986**	1997	2004	1997
January	1983	1986	1986	1989	1989	1989
February	1966	1966	1966	1971	1959	1971
March	1972	1965	1972	2000	2006	2004
April	1983	1998	1983	1997	2010	1997
May	**1982**	**1967**	**1982**	1979	1986	1986
June	**1995**	**1995**	**1995**	1969	1969	1969
July	**1987**	**1987**	**1987**	1966	1960	1966
August	**1985**	**1988**	**1988**	1986	2005	2002
September	1990	1955	1955	**1992**	1992	1992
October	1980	1952	1990	1990	2007	1990
November	1971	1971	1973	2001	2001	2001
December	1983	1961	1983	1970	2009	1970

Mann-Kendall test (Mann, 1945; Kendall, 1975) determines if a time series contains a trend over time. The slope (change per unit time) was estimated with Sen's slope estimator (Sen, 1968). The results are shown in tables 2-4.

Table 2. ***Temperature trends (Sen's slope estimator), significant values are shown in bold (at confidence levels: ***=0.001, **=0.01, *=0.05, +=0.10)***

	Linear trend (Sen's slope estimator)									
	Mean temperature	Maximum of mean temperature	Minimum of mean temperature	Standard deviation of mean temperature	Mean of maximum temperatures	Maximum temperature	Standard deviation of maximum temperature	Mean of minimum temperatures	Minimum temperature	Standard deviation of minimum temperature
Annual	**0.017****	**0.035*****	0.028	0.030	**0.017***	0.020	0.005	**0.015****	0.043	-0.002
Jan	0.023	0.022	0.049	-0.003	0.022	0.029	-0.006	0.037	0.032	-0.006
Feb	0.021	0.019	0.029	-0.003	0.034	**0.057**$^{+}$	0.012	0.018	0.041	-0.009
Mar	0.020	0.006	**0.057**$^{+}$	-0.011	0.024	-0.004	-0.012	**0.031***	0.052	-0.006
Apr	0.014	0.000	**0.047****	-0.009	0.021	-0.009	**-0.015**$^{+}$	0.007	0.000	-0.003
May	**0.033****	**0.004****	**0.047***	0.001	**0.046****	**0.040***	-0.001	**0.016**$^{+}$	0.016	0.005
Jun	**0.022***	**0.034****	0.009	0.007	**0.029**$^{+}$	**0.030***	0.005	0.010	0.011	0.004
Jul	**0.027***	**0.033****	**0.025**$^{+}$	0.005	**0.030***	0.019	0.003	**0.023****	**0.031***	-0.001
Aug	**0.025***	**0.033***	0.000	0.003	**0.027***	0.028	-0.002	**0.022****	0.006	0.000
Sep	-0.004	-0.007	**0.033****	**-0.017****	-0.013	0.000	-0.010	0.008	**0.052****	**-0.013****
Oct	0.008	0.004	**-0.032**$^{+}$	**0.013**$^{+}$	0.001	0.018	**0.016**$^{+}$	0.017	-0.025	0.008
Nov	-0.012	0.014	0.020	-0.009	-0.004	0.041	0.008	-0.008	0.018	-0.009
Dec	-0.011	-0.011	-0.035	0.008	-0.014	0.010	0.005	-0.009	-0.021	0.012

Table 3. ***Precipitation trends (Sen's slope estimator), significant values are shown in bold (at confidence levels: **=0.01, *=0.05, +=0.10)***

	Linear trend (Sen's slope estimator)							
				Number of days with precipitation:				
	Precipitation amount	**Maximum 24 hours precipitation**	**Standard deviation of precipitation amounts**	**>0.1 mm**	**>0.5 mm**	**>1.0 mm**	**>2.0 mm**	**>5.0 mm**
Annual	0.741	-0.017	**0.005+**	**0.258***	0.157	0.071	0.101	0.048
Jan	-0.121	-0.046	**-0.016+**	0.033	0.000	0.000	0.000	0.000
Feb	-0.094	**-0.058***	**-0.013+**	0.000	0.000	0.000	0.000	0.000
Mar	0.192	**0.064+**	0.018	0.032	0.043	0.023	0.024	0.000
Apr	-0.033	-0.022	-0.001	0.000	0.000	0.000	0.000	0.000
May	-0.318	**-0.111***	-0.016	0.000	-0.021	0.000	-0.031	0.000
Jun	0.179	0.020	0.022	0.000	0.000	0.000	0.000	0.000
Jul	0.248	0.057	0.011	**0.054***	0.034	0.000	0.000	0.000
Aug	-0.190	-0.134	-0.020	0.000	0.000	0.000	0.000	0.000
Sep	**0.459***	**0.111***	**0.036+**	**0.059***	**0.051***	**0.043+**	**0.042+**	**0.037****
Oct	0.181	0.011	-0.003	0.034	0.030	0.029	0.000	0.000
Nov	0.081	0.001	0.003	0.026	0.000	0.000	0.000	0.000
Dec	-0.021	0.028	0.008	0.000	0.000	-0.028	0.000	0.000

Table 4. ***Trends of number of days between different values (Sen's slope estimator), significant values are shown in bold (at confidence level:*=0.05)***

Linear trend (Sen's slope estimator)							
Number of days with mean temperature between::							
-14.9 and -10.0 °C	**-9.9 and -5.0 °C**	**-4.9 and 0.0 °C**	**0.1 and 5.0 °C**	**5.1 and 10.0 °C**	**10.1 and 15.0°C**	**15.1 and 20.0 °C**	**20.1 and 25.0 °C**
-0.032	0.000	-0.078	0.000	**-0.228***	0.082	-0.133	**0.283***

Statistically significant positive trends were found in the annual and warmer months' mean temperatures, maximum of mean temperatures, mean of maximum temperatures, and mean of minimum temperatures. Spring months also present an increasing significant trend for minimum of mean temperatures. Tendencies of standard deviations are mainly negative and not significant. As regards the precipitations, there are only a few statistically significant trends, namely the increases of number of days/year with precipitation > 0.1 mm, the decrease of maximum 24 hours precipitation in February and May, respectively an increase in March and September. All the eight precipitation values for September have a positive and significant trend. The number of days with mean temperatures between 5.1 and 10.0 ºC denotes a decreasing significant trend, while the number of days with mean temperature between 20.1 °C and 25.0 °C shows a positive significant trend. Overlapped 30 years trends provide positive and significant values in annual mean temperature for the last periods and negative significant values in precipitation for the middle periods (table 5, fig. 1). Overlapped, unequal periods (with decreasing length) have significant upward trends for all periods of mean temperature and for last four periods of precipitation (table 5).

Table 5. ***Temperature and precipitation trends (Sen's slope estimator) for overlapped time periods, significant values are shown in bold (at confidence levels: ***=0.001, **=0.01, *=0.05, +=0.10)***

Time periods (overlapped, equal)	**Linear trend (Sen's slope estimator)**		Time periods (overlapped, unequal)	**Linear trend (Sen's slope estimator)**	
	Mean annual temperature	Precipitation amount		Mean annual temperature	Precipitation amount
1951-1980	0.002	2.927	1951-2010	**0.017***	0.758
1952-1981	0.010	**3.533**$^{+}$	1952-2010	**0.018***	0.745
1953-1982	0.013	2.800	1953-2010	**0.020****	0.745
1954-1983	0.013	0.263	1954-2010	**0.020****	0.493
1955-1984	0.007	0.191	1955-2010	**0.019***	0.400
1956-1985	-0.003	1.325	1956-2010	**0.019***	0.507
1957-1986	-0.005	-0.050	1957-2010	**0.017***	0.486
1958-1987	-0.005	-1.448	1958-2010	**0.018***	0.661
1959-1988	0.004	-1.747	1959-2010	**0.020***	0.773
1960-1989	0.005	-2.815	1960-2010	**0.019***	0.606
1961-1990	0.015	-2.800	1961-2010	**0.021***	1.071
1962-1991	0.017	-3.584	1962-2010	**0.022***	0.644
1963-1992	0.015	**-4.220**$^{+}$	1963-2010	**0.023***	0.682
1964-1993	0.004	**-4.950***	1964-2010	**0.023***	0.400
1965-1994	0.009	**-5.914***	1965-2010	**0.021***	0.097
1966-1995	-0.001	**-6.592**$^{++}$	1966-2010	**0.020***	-0.082
1967-1996	0.007	**-5.519**$^{+}$	1967-2010	**0.023***	0.409
1968-1997	-0.001	**-4.936**$^{+}$	1968-2010	**0.023***	0.424
1969-1998	0.001	-2.771	1969-2010	**0.025***	0.903
1970-1999	0.004	-1.728	1970-2010	**0.024***	1.380
1971-2000	0.016	-2.100	1971-2010	**0.026***	2.167
1972-2001	0.020	-1.589	1972-2010	**0.028***	1.890
1973-2002	**0.031***	-0.592	1973-2010	**0.031***	2.225
1974-2003	0.027	-0.909	1974-2010	**0.031***	2.555
1975-2004	**0.029**$^{+}$	0.63	1975-2010	**0.034***	3.64
1976-2005	**0.031***	3.175	1976-2010	**0.038***	4.118
1977-2006	0.023	4.180	1977-2010	**0.035***	4.690
1978-2007	**0.032***	5.508	1978-2010	**0.040***	**4.965**$^{+}$
1979-2008	**0.029***	**6.575**$^{+}$	1979-2010	**0.035***	**6.066***
1980-2009	**0.042***	5.982	1980-2010	**0.044***	**6.575**$^{+}$
1981-2010	**0.038***	**7.757**$^{+}$	1981-2010	**0.038***	**7.757***

The result of two (annual and monthly) and three (annual) parts regression are shown in table 6. Except September, all trend values of mean temperature in the second parts are positive, but only five are significant. A strong negative (not significant) trend of precipitation amount in August is present in the last six years (2005-2010). Annual precipitation amount shows an increased significant trend for **period** 1986-2010. Except September, we have a significant positive trend for period 1951-2010, but for the last ten years, there is a decreasing tendency. A negative significant trend in mean temperature in the first five years is followed by a significant positive trend, (two parts regression) respectively by a moderate downward and then an upward significant trend (three parts regression) (fig. 2).

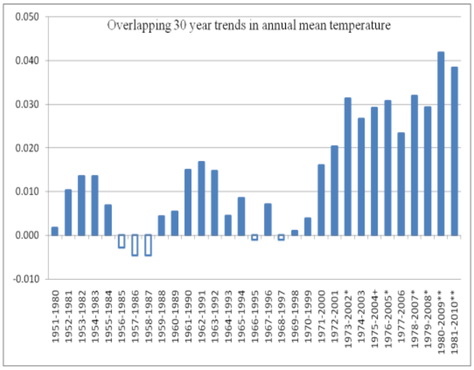

Fig. 1. ***Temperature trends (Sen's slope estimator) for overlapped time periods, significant values are shown in bold (at confidence levels: ***=0.001, **=0.01, *=0.05, +=0.10)***

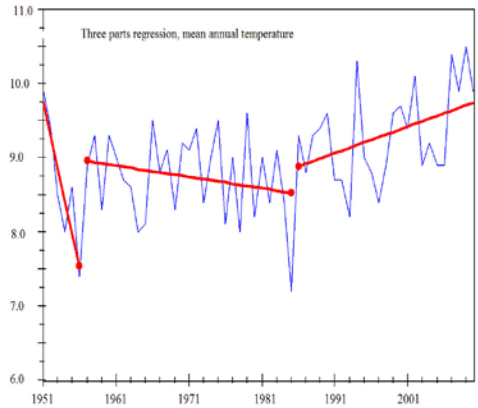

Fig. 2. ***Three parts regression for mean annual temperature***

Table 6. ***Two and three parts regression for mean temperature and precipitation significant values are shown in bold (at confidence levels: ***=0.001, **=0.01, *=0.05, +=0.10)***

Two parts regression					
Mean temperature			Precipitation amount		
Annual	1951-1956 (**-0.499***)	1957-2010 (**0.017****)	Annual	1951-1985 (2.130)	1986-2010 (**11.753****)
Jan	1951-1969 (**-0.357****)	1970-2010 (0.019)	Jan	1951-1988 (0.129)	1989-2010 (**0.750***)
Feb	1951-1956 (-2.317)	1957-2010 (0.015)	Feb	1951-1958 (2.650)	1959-2010 (0.115)
Mar	1951-1995 (0.049)	1996-2010 (0.231)	Mar	1951-1966 (1.702)	1967-2010 (**0.504***)
Apr	1951-1955 (**-1.694+**)	1956-2010 (0.015)	Apr	1951-1958 (4.810)	1959-2010 (0.131)
May	1951-1986 (**0.070***)	1987-2010 (**0.066***)	May	1951-1985 (-0.227)	1986-2010 (1.144)
Jun	1951-1983 (-0.013)	1984-2010 (**0.102*****)	Jun	1951-1975 (1.734)	1976-2010 (0.725)
Jul	1951-1986 (**-0.040***)	1987-2010 (0.023)	Jul	1951-1981 (**2.211****)	1982-2010 (1.154)
Aug	1951-1981 (**-0.051***)	1982-2010 (**0.054+**)	Aug	1951-2004 (-0.322)	2005-2010 (-40.380)
Sep	1951-1960 (**-0.475****)	1961-2010 (-0.003)	Sep	1951-2000 (**0.445+**)	2001-2010 (**-8.1***)
Oct	1951-1967 (0.088)	1968-2010 (**0.035+**)	Oct	1951-1982 (0.432)	1983-2010 (**1.241+**)
Nov	1951-1970 (0.113)	1971-2010 (0.045)	Nov	1951-1977 (0.613)	1978-2010 (**0.737***)
Dec	1951-1960 (0.530)	1961-2010 (0.005)	Dec	1951-1999 (0.052)	2000-2010 (**3.700****)

Three parts regression							
Mean temperature				Precipitation amount			
Annual	1951-1956 (**-0.499***)	1957-1985 (-0.011)	1986-2010 (**0.030***)	Annual	1951-1985 (2.130)	1986-1999 (**21.440****)	2000-2010 (16.317)

Change points were highlighted with CUSUM charts (table 7). The main changes in mean temperature (fig. 3) and precipitation amount were recorded at the end of the '80s and in the middle of the last decade.

Table 7. ***Statistically significant changes (at 0.05 confidence level) established after Taylor's method (2000)***

Mean temperature	St.Dev of mean temperature	Maximum temperature	St.Dev of max. temp.erature	Mean Max	St.Dev of mean maximum	Minimum temperature	St.Dev of min. temperature	Mean minimum	St.Dev. of mean min	Temperature range	St.Dev. of temperature range	Precipitation amount	St.Dev of precipitation	Max 24 hours precipiation	St.Dev of max 24 hours precipitation
1988 2005 2009	---	1972 1993	---	2001	---	---	---	1973	---	1968 1992	---	1989 2004	1969	---	---

Sequential version of Mann-Kendall test indicates a beginning of a positive trend in1956 for mean annual temperature (fig. 4) and 1965 and 1992 for annual precipitation. Of all 27 extremely climatic indices used by RClimDex (Zhang and Feng, 2004), only five have a significant trend (slope values are in parentheses): positive for summer days (0.271), warm nights (0.099), warm spell duration indicator (0.172) and negative for cold nights (-0.085) and cold days (-0.06)

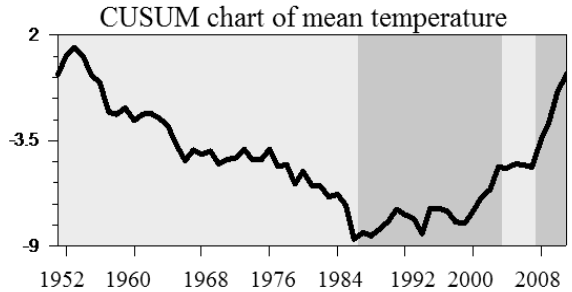

Fig. 3. ***CUSUM chart applied to mean temperature. Significant changes (at 0.05 level) are represented by changes in the background color***

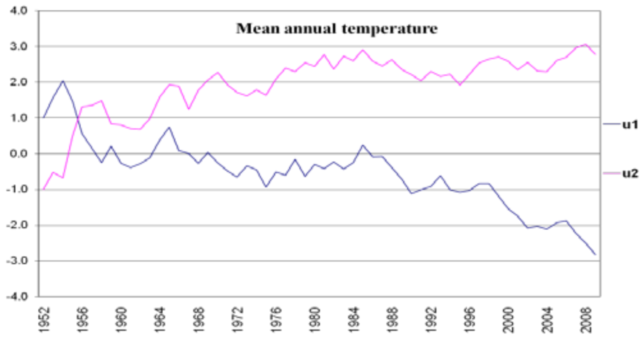

Fig. 4. ***Abrupt changes in the mean annual temperature as derived from the sequential Mann-Kendall (u1 forward sequential statistic, u2 backward sequential statistic)***

4. CONCLUSIONS

A warming trend characterized several temperature time series from the meteorological station of Târgu-Mures, positive and significant trend were found for mean annual temperatures, mean temperature of warmer months, annual mean of the maximum temperatures, mean of warmer months maximum temperatures, annual mean of the minimum temperatures, mean of warmer months minimum temperatures, number of days with mean temperature between 20.1-25.0 °C, number of summer days and warm nights, warm spell duration indicator. As regards the precipitation, an increasing trend characterized the annual account of days when precipitation ≥ 0 mm and standard deviation of annual precipitation amount (denoting that the rainfall became more variable). The beginning of a positive trend in case of mean annual temperature is 1956, and 1965 and 1992 for precipitation. CUSUM charts reveal three (mean annual temperature) and two (precipitation) change-points at the second part of the studied period (1951-2010). At same, the overlapped (equal and unequal) time series show an increase in trends in the latter half of period, mainly for mean annual temperature.

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