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EXTREME TEMPERATURE CHANGES IN THIS CENTURY IN CROATIA

Promjene ekstremnih temperatura zraka u Hrvatskoj u ovom stoljeću

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Abstract — Long-term series (1901—1992) of mean daily minimum and maximum temperatures and mean daily temperature range, expressed as anomalies from 1961—1990 averages, have been studied at three stations representing the different climatic regions of Croatia: Osijek in the southern Pannonian lowland, Zagreb-Grič at the south-eastern edge of the Alps and Crikvenica on the north-eastern part of the Adriatic coast. The fluctuations and trends of the seasonal and annual values of the anomalies have been analyzed by means of the 11-year binomial average filter, the Mann-Kendall rank test, and a progressive test for the onset of the trends, according to Sneyers.

Key words: mean minimum temperature, mean maximum temperature, daily temperature range, trend, Mann-Kendall statistics, progressive test for trend

Sažetak — U radu su analizirana odstupanja srednjih minimalnih i maksimalnih temperatura zraka i srednjih amplituda temperature zraka u razdoblju 1901—1992. od srednjaka za razdoblje 1961—1990. Odabrane su postaje s dugogodišnjim nizovima mjerenja koje reprezentiraju tri različita klimatska područja u Hrvatskoj: Osijek na jugu Panonske nizine, Zagreb na jugoistočnom rubu Alpa i Crikvenica na sjeveroistočnom dijelu jadranske obale. Fluktuacije i trendovi sezonskih i godišnjih vrijednosti anomalija analizirani su pomoću 11-godišnjeg binomnog kliznog srednjaka, Mann-Kendallovog rang testa i progresivnog testa za trend.

Ključne riječi: srednja minimalna temperatura zraka, srednja maksimalna temperatura zraka, dnevna amplituda temperature zraka, trend, Mann-Kendallova statistika, progresivni test za trend.

1. INTRODUCTION

The fact that the results of climatic temperature changes in Central Europe are often different from global changes (Karl, 1993; Böhm and Auer, 1994; Stefanicki et al., 1994) initiated a further investigation in the temperature parameter variations on a local and regional scale in Croatia. Most of these refer to changes during the last four decades. Climatic changes in the northern Croatian lowland were analyzed for the same period (1951—1992) in order to compare them with the broader European and global results (Gajić-Čapka, Zaninović, 1995). However, as there are some stations in Croatia with long-term data series, from the beginning of the century or even longer, we wished learn more about long-term temperature fluctuations and trends in this part of Europe. Three different climatic regions have been taken into consideration, each of which has one station with long-term data series.

2. DATA AND METHOD

The three meteorological stations were chosen for the analysis are Osijek, for the continental climate of the southern Pannonian lowland, Zagreb-

Grič as a representative of the transitional climate on the south-eastern edge of the Alps, under weak Mediterranean influence, and Crikvenica on the north-eastern Adriatic coast as a representative of maritime climate.

The location of the Zagreb-Grič observatory (157 m a.s.l., 45°49'N, 15°59'E) in the Grič park on the southern slopes of Mount Medvednica has not changed since 1862. New buildings have not been built, and the surrounding parks and promenade have remained untouched. The thermometer screen is situated in the window on the first floor facing north and its position has not been changed during the period analyzed.

The climatological station Crikvenica (2 m a.s.l., 45°10'N, 14°42'E) began taking observations in 1891. In the first 10 years, the data were of dubious quality, and therefore completed and corrected according to data from the neighbouring stations of Bakar, Senj, Rijeka and Trieste. Until 1940 and again in 1963, the station was moved several times, but never further than 25-120 m.

The location of the climatological station Osijek (89 m a.s.l., 45°32'N, 18°44'E) was changed repeatedly in the period 1882—1937 within a distance of 140-750 m, always within the town area, under similar surrounding conditions. Since 1961 data have been taken from the main meteorological station Osijek-sinop, located outside town in the southeastern suburbs.

The temperature time series were homogenized by means of the Zagreb-Grič data set (Galeković, 1995).

The seasonal and annual mean daily temperature maximum (TMAX), minimum (TMIN) and the daily temperature range (DTR), i.e. the difference between TMAX and TMIN, related to the 1961—1990 averages have been calculated for the period 1901—1992.

In order to remove short-term fluctuations in the temperature data series they have been smoothed by means of the 11-year binomial moving average filter. The linear trends have been tested for significance by means of the nonparametric Mann-Kendall rank statistics, according to the recommendations of the WMO (Mitchell et al., 1966; Sneyers, 1990).

In such cases where the significant annual trend was indicated by means of the Mann-Kendall coefficient *t*, progressive analysis of the time series by means of the statistic *u(t)* has been used to identify the beginning of these phenomena (Sneyers, 1990). The *t* value statistic has been calculated:

$$t_i = \sum_{j=1}^{i} n_j$$

where n_j is the number of series element x_k $(k<j)$, greater than the series element x_j $(x_k>x_j)$ and preceding. These test values are normally distributed for a long series and their mean and variance are:

$$E(t_i) = \frac{i(i-1)}{4}$$

$$var(t_i) = \frac{i(i-1)(2i+5)}{72}$$

They make possible the determination of standardized values:

$$u_i = \frac{t_i - E(t_i)}{\sqrt{var(t_i)}}$$

When the values u_i exceed the stated significance limit for more than one point, the trend can be recognized. Where u_i's are positive, they point at an increasing trend, and where they are negative they point at a decreasing trend. In order to identify the beginning of the possible trend, u_i is calculated for all i's, from the first to the last datum, forming the progressive onward test series. The backward test series u_i' is formed in the same manner, calculating it from the last to the first term. Their intersection points designate the beginning of the trend.

3. RESULTS

3.1. Long-term fluctuations

Due to an increase in *TMIN* and a simultaneous decrease in *TMAX* a sharp decrease in *DTR* occured in Osijek developing from the beginning of the century until the mid-1920's (Figures 1-3). After a sharp increase in *DTR* towards beginning of 1930's, smaller increase and decrease changes in *DTR, TMIN* and *TMAX* appeared with a continuos negative linear trend continuing to the end of the period analyzed. It has to be emphasized that, during the last decade, *DTR* has been increasing coinciding with an increasing *TMAX* and a slighter increase in *TMIN*.

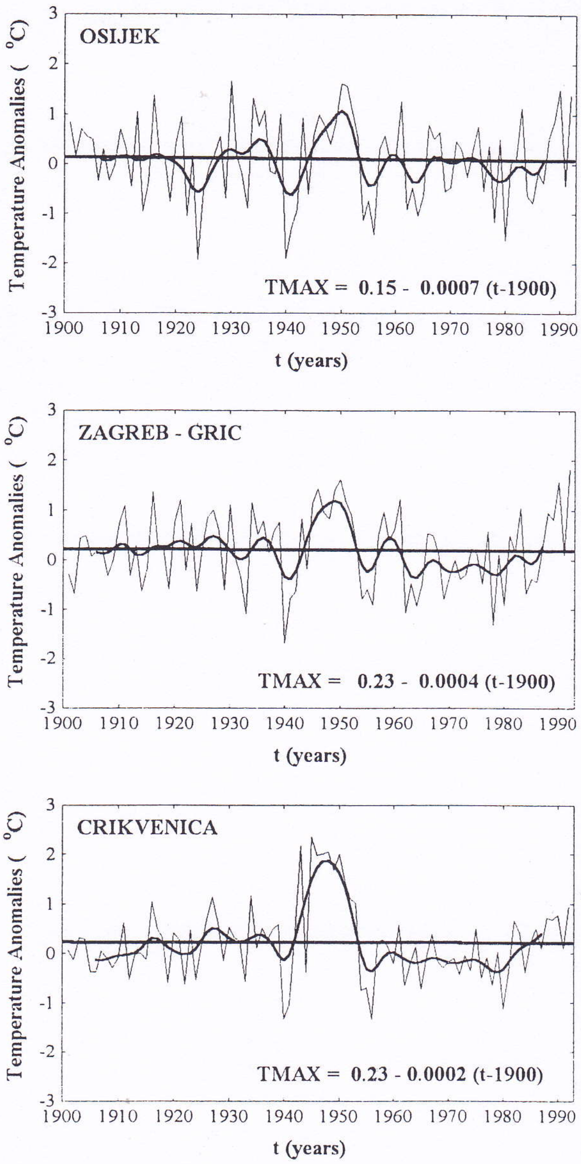

Figure 1. Variations of the mean maximum temperature *(TMAX)*, 11-year binomial moving average series and linear trends during the period 1901—1992.

Slika 1. Varijacije srednje maksimalne temperature zraka *(TMAX)*, 11-godišnji binomni klizni srednjaci i linearni trend u razdoblju 1901—1992.

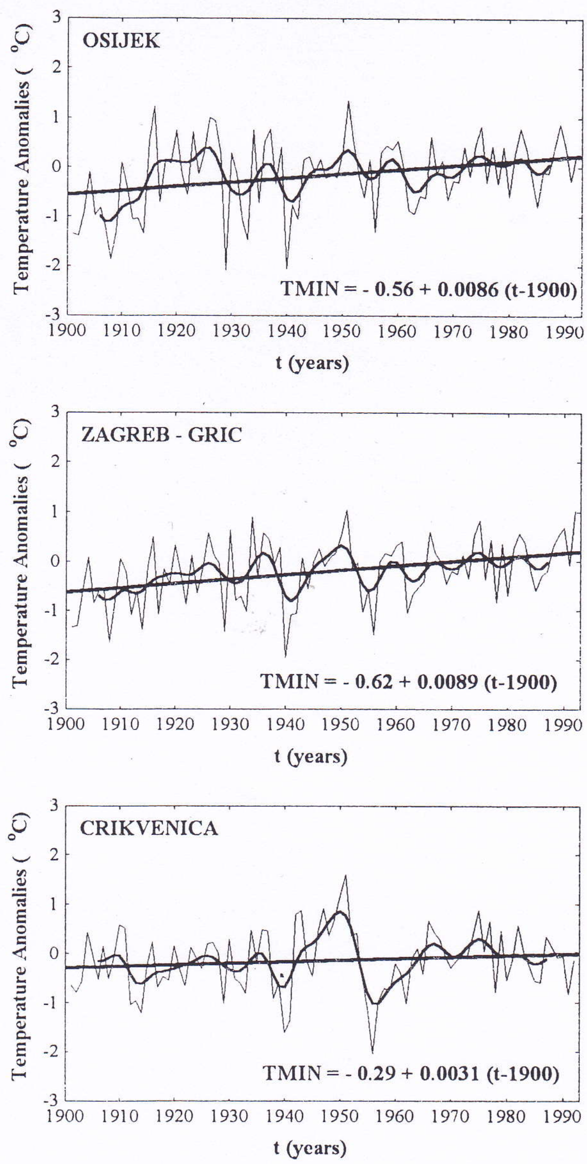

Figure 2. Variations of the mean minimum temperature *(TMIN)*, 11-year binomial moving average series and linear trends during the period 1901—1992.

Slika 2. Varijacije srednje minimalne temperature zraka *(TMIN)*, 11-godišnji binomni klizni srednjaci i linearni trend u razdoblju 1901—1992.

The continuous decrease in *DTR* in Zagreb from the beginning of the century was interrupted only twice: in 1940's, by dramatic increase in *TMAX*, and in the period from the mid-1970's until today, due to a faster increase in *TMAX* than in *TMIN* during these last decades.

On the coast (Crikvenica), a slight increase in *DTR* appeared from the beginning of the century until 1950's due to the increase in *TMAX* and reached its maximum in this century around 1950. The decreasing tendency from 1950 until 1980 was caused by an increase in *TMIN* and a decrease in *TMAX*. In the last decade, *DTR* has again shown an increasing tendency.

3.2. Linear trend analysis

In the continental lowland (Osijek), a slightly negative *TMAX* annual trend (-0.01°C per 10 years) and a significant *TMIN* positive trend (0.09°C per

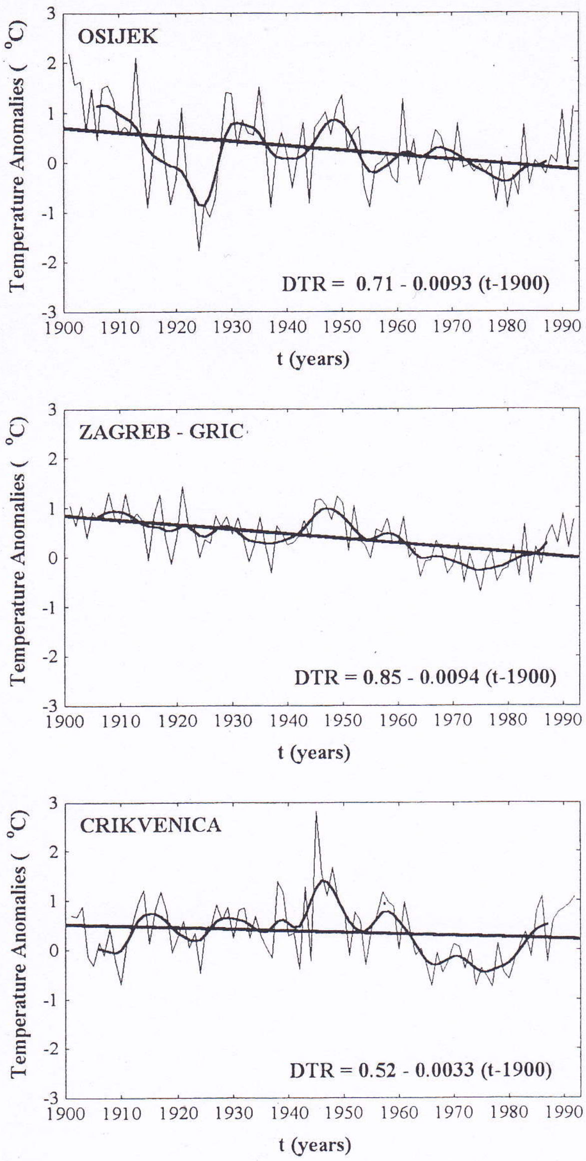

Figure 3. Variations of the mean daily temperature range *(DTR)*, 11-year binomial moving average series and linear trends during the period 1901—1992.

Slika 3. Varijacije srednje amplitude temperature zraka *(DTR)*, 11-godišnji binomni klizni srednjaci i linearni trend u razdoblju 1901—1992.

Table 1. Seasonal and annual trends (°C/10 years) of mean maximum *(TMAX)*, mean minimum *(TMIN)* and daily temperature range *(DTR)*. The shading denotes trends significant at the 0.05 level according to Mann-Kendall rank statistics.

Tablica 1. Sezonski i godišnji trendovi (°C/10 years) srednje maksimalne *(TMAX)* i srednje minimalne temperature zraka *(TMIN)* i srednjih amplituda temperature zraka *(DTR)*. Sjenčanjem su označeni trendovi signifikantni na nivou 0.05 prema Mann-Kendallovom rang testu.

OSIJEK (1901—1992)			
Seasons	*TMAX*	*TMIN*	*DTR*
SPRING	0.00	0.07	-0.07
SUMMER	-0.10	0.09	-0.19
AUTUMN	0.03	0.08	-0.05
WINTER	0.03	0.08	-0.05
ANNUAL	-0.01	0.09	-0.09

ZAGREB-GRIČ (1901—1992)			
Seasons	*TMAX*	*TMIN*	*DTR*
SPRING	-0.01	0.07	-0.08
SUMMER	-0.09	0.09	-0.18
AUTUMN	0.04	0.08	-0.04
WINTER	0.03	0.08	-0.06
ANNUAL	-0.00	0.09	-0.09

CRIKVENICA (1901-1992)			
Seasons	*TMAX*	*TMIN*	*DTR*
SPRING	-0.02	-0.02	-0.00
SUMMER	-0.08	0.09	-0.17
AUTUMN	0.05	0.03	0.02
WINTER	0.03	-0.00	0.03
ANNUAL	-0.00	0.03	-0.03

10 years) have resulted in a significant negative trend in *DTR* (-0.09°C per 10 years) in the last 92 years (Figures 1-3). The same trend patterns appear for *DTR* and *TMIN* in all seasons, while for *TMAX* they only appear in summer (Tab 1). It has to be pointed out that, according to Mann-Kendall statistics, all parameters *(TMIN, TMAX* and *DTR)* have significant trends in summer but only *TMIN* has them in spring also.

In Zagreb, *TMAX* shows practically no trend during this century, while *TMIN* has increased significantly (0.09°C per 10 years), resulting in a significant negative trend in *DTR* (-0.09°C per 10 years). Furthermore, the decrease in *DTR* is significant in all seasons (-0.08 to -0.16°C per 10 years), except in autumn. This is the result of a positive trend in *TMIN* throughout the year (0.07 to 0.09°C per 10 years) (significant in spring and summer), and a slighter increase (in autumn and winter) or even a decrease (slight in spring, and significant in summer) in *TMAX*.

On the north-eastern Adriatic coast (Crikvenica), a slight annual negative trend in *DTR* (-0.03°C per 10 years) is the result of practically no trend in *TMAX* and a small positive trend in *TMIN* (0.03°C per 10 years). Significant trends appear only in summer, when *TMIN* has a positive trend (0.09°C per 10 years) and *DTR* a negative trend (-0.17°C per 10 years).

3.3 Progressive test for trend

The progressive trend test has been applied to the annual values of *TMIN* and *DTR* at the continental stations Zagreb and Osijek, for which the Mann-Kendall statistics showed significant changes.

When considering *TMIN*, it can be seen from the courses of the onward (u) and backward (u') test series that minimum temperatures showed relative stability only during the first two decades in this century. In Osijek, there have been no intersection points since 1915, and a positive trend became significant in 1919 with only short periods with non-significant values. In Zagreb, there have been no intersection points since the beginning of 1940's, and a significant increasing trend has been present from 1946 as shown by the u values are continuously being above the significance level of 1.96.

The progressive test for *DTR* in Osijek shows the beginning of a negative trend in 1910 becoming significant in 1914 and continuing to the present with an exception in the period 1951—1954. In spite of the presence of a negative trend in Zagreb since the beginning of the century, the last intersection point was observed in 1951, while the negative trend became significant ($u < -1.96$) in 1962 (Fig. 4).

4. CONCLUSIONS

Temperature fluctuations in Croatia show a visible warming about 1950's, more evident in the maximum than in the minimum temperatures and stronger on the coast than in the continental region.

The often emphasized global decrease in *DTR*, as a result of asymmetric trends between maximum and minimum temperatures, appears also in the annual values for Croatia, but are significant only at the continental locations. Significant seasonal negative trends in *DTR* are present at all locations in summer, and at Zagreb-Grič also in spring and winter.

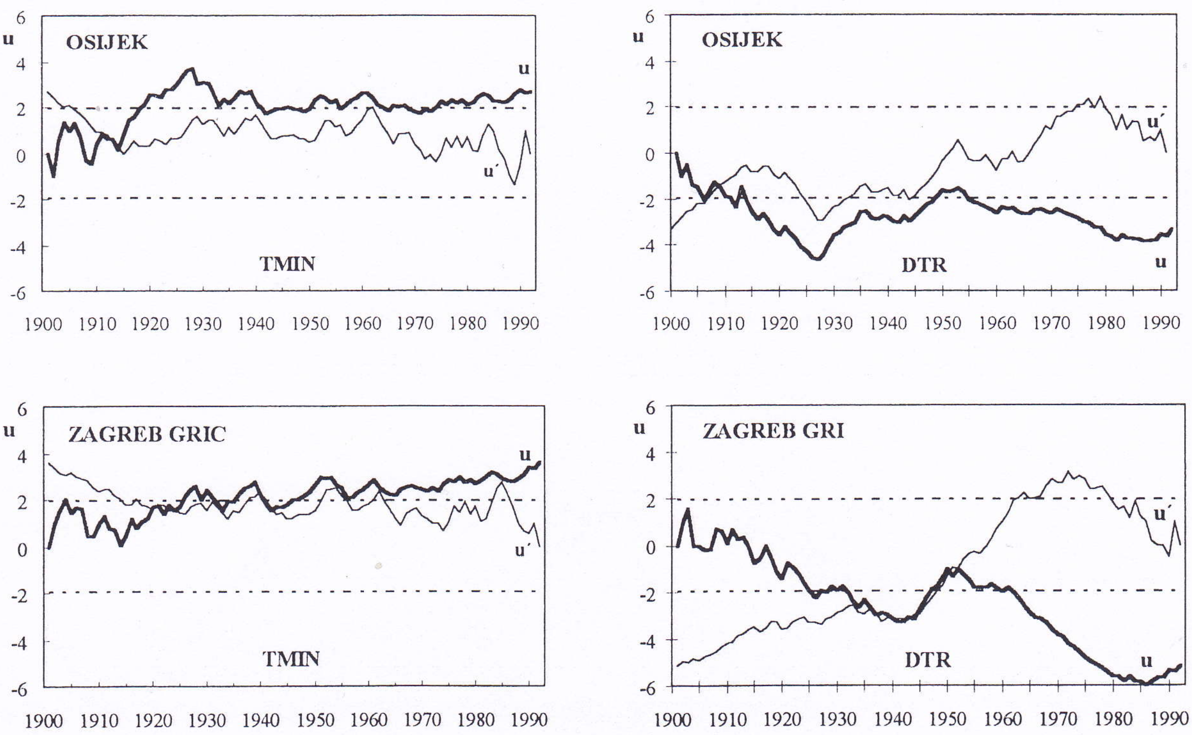

Figure 4. Progressive trend test for the annual values of *TMIN* and *DTR* at Zagreb-Grič and Osijek.

Slika 4. Progresivni test trenda za godišnje vrijednosti *TMIN* i *DTR* na postajama Zagreb-Grič i Osijek.

The results for Croatia are similar to those for the Central Europea region obtained from low-lying Alpine stations during this century (Stefanicki et al., 1994). However, on a regional scale, different patterns of climatic change can be expected as can be seen for Austria (Böhm, 1994) and high-lying Alpine stations (Stefanicki et al., 1994) where an almost parallel increase in minimum and maximum temperature exists.

5. REFERENCES

Böhm, R., I. Auer, 1994: A Search for Greenhouse Signal Using Daytime and Nighttime Temperature Series, in: Heino: Climate Variations in Europe, *Proceedings of the European Workshop on Climate Variations,* Finland, 141-151.

Gajić-Čapka, M., K. Zaninović, 1995: Fluctuations and Trends of Temperature Extremes in Southern Pannonian Lowland, *Proceedings of the 6th International Meeting on Statistical Climatology,* 263-266.

Galeković, G., 1995: Homogenization of Osijek and Crikvenica Extreme Temperature Time Series, *Manuscript*

Karl, T.R., et al 1993: A New Perspective on Recent Global Warming: Asymmetric Trends of Daily Maximum and Minimum Temperature, *Bull. Amer. Meteor. Soc.,* **74**, 1007-1023.

Mitchell, J. M.Jr. et al., 1966: Climatic Change, WMO, *Tech. Note* **79**, Geneva, 79 pp.

Penzar, I., J. Juras, A. Marki, 1992: Long-Term Meteorological Measurements at Zagreb: 1862-1990. *Geofizika,* **9**, [Suppl.], 11-171.

Sneyers, R., 1990: On the Statistical Analysis of Series of Observations. *Technical Note No* **143**, WMO No *415*, Geneva, pp 192.

Stefanicki, G., P. Talkner, R.O. Weber, 1994: Temperature Trends af the Alpine Region in this Century, *Proceedings of the Internationale Tagung für Alpine Meteorologie, Ann. Meteorol.,* Offenbach, **30**, 221-224.