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INCREASE OF MEAN ANNUAL SURFACE AIR TEMPERATURE IN THE WESTERN BALKANS DURING LAST 30 YEARS

Ognjen BONACCI
Faculty of Civil Engineering, Architecture and Geodesy, Split University,
21000 Split, Matice hrvatske 15, Croatia
E-mail: obonacci@gradst.hr

ABSTRACT

Changes in the mean annual air temperature measured at 67 meteorological stations in Slovenia, Croatia, Serbia, Bosnia and Herzegovina and Macedonia during the last 48 (from 1961 to 2008) and 158 (from 1851 to 2008) years were investigated. Methods of Rescaled Adjusted Partial Sums (RAPS), regression and correlation analyses as well as ***F***- and ***t***-tests are used in order to describe changes in air temperature regimes. The analyses indicated that the most frequently statistically significant changes started in 1988 (at 34 gauging station or 50.7 %) and in 1992 (at 16 gauging station or 23.9 %). It was calculated that the increases of average mean annual air temperatures in period before and after warming is 0.807ºC ranging from the minimum value of -0.11ºC (decreasing) to the maximum value of 1.56ºC (increasing).

Keywords: mean annual air temperature, climate change, climate variability, trend, jump, the Balkans

1 INTRODUCTION

IPCC (2007) establishes the increase of approximately 0.8±0.1ºC in the average global temperature near Earth's surface since 1900, and strongly connects it with anthropogenic influences of "greenhouse gasses". The American Geophysical Union position statement on human impacts on climate is: "The complexity of the climate system makes it difficult to predict some aspects of human induced climate change, exactly how fast it will occur, exactly how much it will change, and exactly where those changes will take place" (AGU, 2003). Ma *et al.* (2004) as well as many other scientists consider that global warming during the 20th century is caused mainly by increasing greenhouse gas concentration especially since late 1980s. On the other hand Scafetta and West (2008) suggest that the current anthropogenic contribution to global warming is significantly overestimated. They estimate that the Sun could account for as much as 69 % of the increase in Earth's average temperature. Leroux (2005) considers that the idea of "climate change" has become widely synonymous with that of "global warming". He considers that this is paradoxically, construed in a very negative way as inevitably catastrophic, even in "cold" countries. For the detailed and unbiased analysis of this great global problem one of the obstacles is that the science of climate change is inextricably mixed up with politics and media. For this all the fuss about global warming is grossly exaggerated (Bonacci, 2008; Galvin, 2008).

On the basis of analyses of about 1400 selected stations in Mexico, Pavia ***et al.*** (2009) concluded that the temperature had increased over the period 1970-2004. This warming was more apparent in maxima than in minima and in summer than in other seasons. Analysing twentieth-century trends in the thermal growing season Linderholm ***et al.*** (2008) found an increase of 6 to more than 20 days in the greater Baltic area. However, the only tendency for a shorter growing season was found in Archangelsk (Russia). Bhutiyani ***et al.*** (2007) reveal significant rise in air temperature in the northwest Himalayan region by about 1.6ºC.

The question which torments scientific community is whether and to what extent recent global warming can be ascribed to ongoing natural climate variability or climate change. It is not possible to give the definitive answer to this crucial question on the basis of existing data series of climatic parameters, first of all the surface air temperatures. Whatever their sizes are, they are too short for getting reliable scientifically based conclusion.

The rate of warming of global surface temperature trends is sometimes questioned because of contamination by data from stations within urbane heat islands. For example the city centres of Vienna and London are warmer than surrounding rural locations. Kumar *et al.* (2005) analysed 110 years (1889-1998) of air temperature data for Firenze, Italy. Their conclusion is that annual means of minimum, maximum and mean air temperatures were significantly warmer in the last part than in the early part of the 20th century. Urban-related warming over China is shown to be about 0.5ºC over the 1951-2004 period, with true climatic warming accounting for 0.81ºC over this period (Jones *et al.*, 2008). The contribution of urban effects on recent air temperature trends in Japan was analysed using data at 561 stations for 27 years (March 1979-February 2006) (Fujibe, 2008). There is a warming trend of 0.3-0.4ºC/decade even for stations with low population density (less than 100 people per square kilometre).

During 1977-1981 the Beijing meteorological station was at a suburban location. In 1981 it was moved to a more urban location, but in 1997 it was subsequently moved back to the same suburban location. The annual mean urban-suburban difference was 0.81°C around 1981 and 0.69°C around 1997, indicating a growing urbanisation effect in the suburban compared to the downtown area. Comparing with several rural and less-urban sites Yan *et al.* (2010) suggest that the Beijing records include an urbanisation-related warming bias between 0.20 and 0.54°C/decade, likely about 0.30°C/decade, for the recent few decades.

This paper is an attempt to show variability of regional (part of south-eastern Europe) climate using available relatively long-term time series of mean annual air temperature. In this paper the problem of causes (anthropogenic or natural) of the air temperature increase in the analysed region will not be discussed. The main purpose of this article is to analyse records of air temperature during the 20th century in order to identify timing and magnitude of increase of air temperature observed in last twentieth years.

2 STUDY AREA

The study area of about 220,000 km^2 (Figure 1) is located between 46º38' and 41º03'N and 13º39' and 22º45'E. The 67 data time series of mean annual air temperature data measured at 2 m above ground at gauging stations in Slovenia, Croatia, Serbia, Bosnia and Herzegovina and Macedonia are included in the analyses. The time series have different durations. The longest one is for Ljubljana 158 years (1851-2008), while the shortest are measured over the period 1961-2008 at 14 stations. This is not an obstacle because the main focus of the paper's investigations is on the last thirty years mean annual air temperature variations.

Table 1 presents the main characteristics of all 67 analysed air temperature gauging stations showed in Figure 1 (No. in Figure 1, station name, longitude, latitude, country, altitude, available period). The last three columns in Table 1 ([8], [9], [10]) present the average mean annual air temperature T_{av}, the minimum annual air temperature T_{min} and the maximum annual air temperature T_{max} measured for the whole available period. The altitudes H of analysed set of gauging stations vary from the minimum 2 m above sea level (m a.s.l.) to the maximum of 2514 m a.s.l. Figure 2 shows the relationship between altitude H of the 67 air temperature gauging stations and average air temperature in 1961-2008 period. High coefficient of 2nd order polynomial correlation (R=0.949) is evidence of strong regional relationship between two analysed parameters.

Pepin and Lundquist (2008) suggest that exposed mountain gauging stations, away from the effects of urbanization and topographic sheltering, may provide a relatively unbiased record of the climate. In this paper at least the following four stations fall into this category and are analysed: 1) Kredarica-2514 m a.s.l. (No. 2 in Table 1 and Figure 1); 2) Zavižan-1594 m a.s.l. (No. 19 in Table 1 and Figure 1); 3) Zlatibor-1029 m a.s.l. (No. 49 in Table 1 and Figure 1); and 4) Sjenica-1015 m a.s.l. (No. 50 in Table 1 and Figure 1).

Differences in elevation, proximity to the sea, and exposure to wind lead to significant climatic differences within the analysed area. Climatic conditions in Slovenia vary. There is a continental climate in the northeast, harsh Alpine climate in the high mountain regions, and a sub-Mediterranean climate in the coastal region. Yet there is a strong interaction between these three climatic systems across most of the country. Two main climatic zones dominate Croatia (Zaninović *et al.*, 2004). The Pannonian and para-Pannonian plains and the mountain regions are characterized by a continental climate. The Adriatic Sea coast and the islands have a mild Mediterranean climate. The climate of Bosnia-Herzegovina is continental with Mediterranean influences in the areas closest to the coast. Serbia has a mild continental climate with cold winters and warm summers. Its northern part most clearly exhibits characteristics of the continental climate. Air masses from eastern and northern Europe predominate throughout the year. Only occasionally do Mediterranean air masses reach Serbia from the southeast or south. Macedonia has a transitional climate from Mediterranean to continental. The mountainous climate is present in the all mountainous regions of the analysed area.

Pandžić and Likso (2010) analyzed homogeneity of average annual air temperature time series for 22 stations in Croatia. Their investigation indicates that the spatial average of the mean annual temperature for the whole territory of Croatia is not dependent on inhomogeneities present in a particular time series.

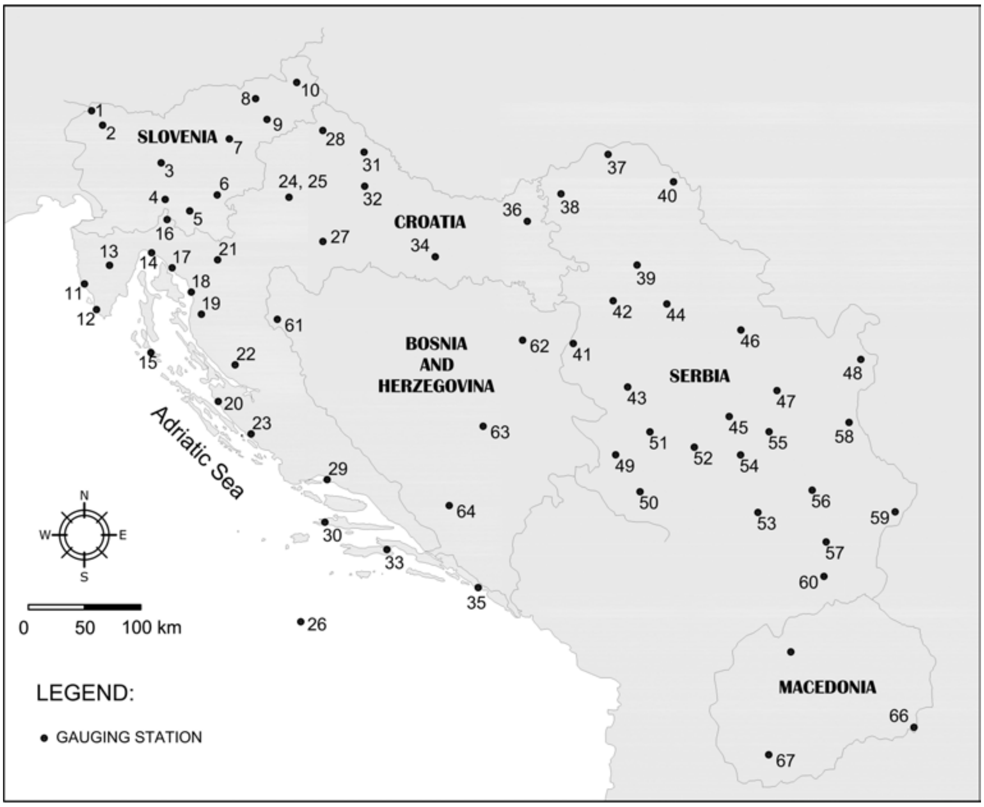

Figure 1. Location map indicating the study area and the sites of 67 air temperature gauging stations, which characteristics are given in Table 1

Table 1. Main characteristics of 67 analysed air temperature gauging stations

No.	Station name	Longitude	Latitude	Country	Altitude H (m a.s.l.)	Available period	T_{av} (ºC)	T_{min} (ºC)	T_{max} (ºC)
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
1	Rateče	46° 30’	13° 43’	Slovenia	864	1948-2008	6.10	4.60	7.60
2	Kredarica	46° 23’	13° 51’	Slovenia	2514	1955-2008	-1,38	-2.70	0.00
3	Ljubljana	46° 23’	14° 31’	Slovenia	299	1851-2008	9.66	7.73	12.17
4	Nova Vas	45° 46’	14° 31’	Slovenia	722	1961-2008	7.18	5.80	8.80
5	Kočevje	46° 04’	14° 52’	Slovenia	467	1872-2008	7.70	5.58	9.98
6	Novo Mesto	45° 48’	15° 11’	Slovenia	220	1951-2008	9.86	8.3	12.0
7	Celje	46° 15’	15° 14’	Slovenia	242	1851-2008	9.01	6.89	11.44
8	Maribor	46° 32’	15° 39’	Slovenia	275	1948-2008	9.94	8.19	12.02
9	Starše	46° 28’	15° 46’	Slovenia	240	1961-2008	9.58	8.10	11.70
10	Murska Sobota	46° 38’	16° 11’	Slovenia	184	1950-2008	9.58	8.02	11.50
11	Rovinj	45° 05’	13° 39’	Croatia	5	1949-2008	13.54	12.10	14.90
12	Pula	44° 52’	13° 51’	Croatia	30	1961-2008	14.10	13.00	15.50

(continiou of table 1)

13	Pazin	45° 14’	13° 56’	Croatia	291	1961-2008	11.30	10.30	12.60
14	Rijeka	45° 20’	14° 27’	Croatia	104	1948-2008	13.97	12.70	15.30
15	Mali Lošinj	44° 32’	14° 28’	Croatia	53	1961-2008	15.35	14.50	16.50
16	Parg	45° 36’	14° 38’	Croatia	863	1951-2008	7.26	5.80	9.10
17	Crikvenica	45° 10’	14° 42’	Croatia	2	1892-2008	14.27	12.80	16.00
18	Senj	44° 59’	14° 54’	Croatia	26	1948-2008	14.78	13.30	16.40
19	Zavižan	44° 49’	14° 59’	Croatia	1594	1954-2008	3.71	2.40	5.10
20	Zadar	44° 08’	15° 13’	Croatia	5	1961-2008	14.99	14.10	16.30
21	Ogulin	45° 16’	15° 14’	Croatia	328	1949-2008	10.08	8.70	12.00
22	Gospić	44° 23’	15° 22’	Croatia	564	1902-2008	8.68	7.00	10.50
23	Šibenik	43° 44’	15° 55’	Croatia	77	1949-2008	15.39	14.30	16.50
24	Zagreb - Grič	45° 49’	15° 59’	Croatia	157	1862-2008	11.50	9.70	13.80
25	Zagreb - Maksimir	45° 49’	16° 02’	Croatia	123	1949-2008	10.71	9.30	12.70
26	Palagruža	42° 24’	16° 16’	Croatia	98	1949-2008	16.41	15.60	17.80
27	Sisak	45° 30’	16° 22’	Croatia	98	1949-2008	10.99	9.30	12.90
28	Varaždin	46° 18’	16° 23’	Croatia	167	1949-2008	10.21	8.70	12.10
29	Split	43° 31’	16° 26’	Croatia	122	1926-2008	16.10	14.40	17.40
30	Hvar	43° 10’	16° 27’	Croatia	20	1929-2008	16.49	15.30	17.50
31	Koprivnica	46° 11’	16° 49’	Croatia	141	1949-2008	10.43	8.80	12.20
32	Bjelovar	45° 54’	16° 51’	Croatia	141	1949-2008	10.62	8.70	12.90
33	Korčula	42° 58’	17° 09’	Croatia	15	1948-2008	16.51	15.32	17.90
34	Požega (Croatia)	45° 20’	17° 41’	Croatia	152	1901-2008	10.61	8.40	12.40
35	Dubrovnik	42° 39’	18° 06’	Croatia	49	1961-2008	16.48	15.40	17.80
36	Osijek	45° 32’	18° 44’	Croatia	89	1899-2008	10.96	8.80	12.90
37	Palić	46° 06’	19° 46’	Serbia	102	1949-2008	10.86	9.30	12.70
38	Sombor	45° 46’	19° 09’	Serbia	87	1950-2008	10.87	9.30	12.80
39	Novi Sad	45° 15’	19° 52’	Serbia	132	1949-2008	11.14	9.50	13.00
40	Kikinda	45° 51’	20° 28’	Serbia	81	1949-2008	11.05	9.60	13.00
41	Loznica	44° 33’	19° 14’	Serbia	121	1952-2008	11.26	9.70	13.10
42	Sremska Mitrovica	44° 58’	19° 38’	Serbia	81	1949-2008	11.05	9.40	12.60
43	Valjevo	44° 17’	19° 55’	Serbia	175	1949-2008	11.12	9.70	12.80
44	Beograd	44° 58’	20° 28’	Serbia	132	1936-2008	12.10	9.70	14.20
45	Kragujevac	44° 02’	20° 56’	Serbia	190	1949-2008	11.32	9.90	13.10
46	Smederevska Pal.	44° 22’	20° 57’	Serbia	121	1949-2008	11.32	9.90	13.10
47	Veliko Gradište	44° 45’	21° 31’	Serbia	79	1949-2008	11.15	9.70	12.70
48	Negotin	44° 14’	22° 33’	Serbia	42	1949-2008	11.43	9.90	13.50
49	Zlatibor	43° 44’	19° 43’	Serbia	1029	1951-2008	7.40	6.10	9.20
50	Sjenica	43° 16’	20° 01’	Serbia	1015	1947-2008	6.40	4.80	7.90
51	Požega (Serbia)	43° 31’	20° 02’	Serbia	311	1961-2008	9.53	8.60	10.70
52	Kraljevo	43° 44’	20° 41’	Serbia	219	1949-2008	11.24	9.80	12.90
53	Kuršumlija	43° 08’	23° 16’	Serbia	380	1961-2008	10.13	9.00	11.50
54	Kruševac	43° 34’	21° 21’	Serbia	166	1949-2008	11.69	10.40	13.50
55	Čuprija	43° 56’	21° 23’	Serbia	123	1961-2008	10.95	9.80	12.40
56	Niš	43° 20’	21° 54’	Serbia	202	1949-2008	11.69	10.40	13.50
57	Leskovac	43° 01’	21° 57’	Serbia	224	1961-2008	10.93	9.80	12.50
58	Zaječar	43° 53’	22° 18’	Serbia	137	1949-2008	10.72	9.20	12.30
59	Dimitrovgrad	43° 01’	22° 45’	Serbia	446	1949-2008	9.94	8.80	11.50
60	Vranje	42° 33’	21° 55’	Serbia	433	1949-2008	11.02	9.80	12.50
61	Bihač	44° 49’	15° 53’	Bos. & Her.	246	1961-2008	10.89	9.60	12.80
62	Tuzla	44° 33’	18° 42’	Bos. & Her.	305	1961-2008	10.24	9.10	12.00
63	Sarajevo	43° 52’	18° 26’	Bos. & Her.	630	1888-2008	9.61	7.75	11.57
64	Mostar	43° 21’	17° 48’	Bos. & Her.	99	1961-2008	14.86	13.60	16.20
65	Skopje	41° 97’	21° 38’	Macedonia	232	1926-2008	12.33	10.82	14.27
66	Nov Dojran	41° 13’	22° 43’	Macedonia	180	1961-2008	14.43	13.15	16.33
67	Bitola	41° 03’	21° 22’	Macedonia	586	1926-2008	11.40	10.12	13.22

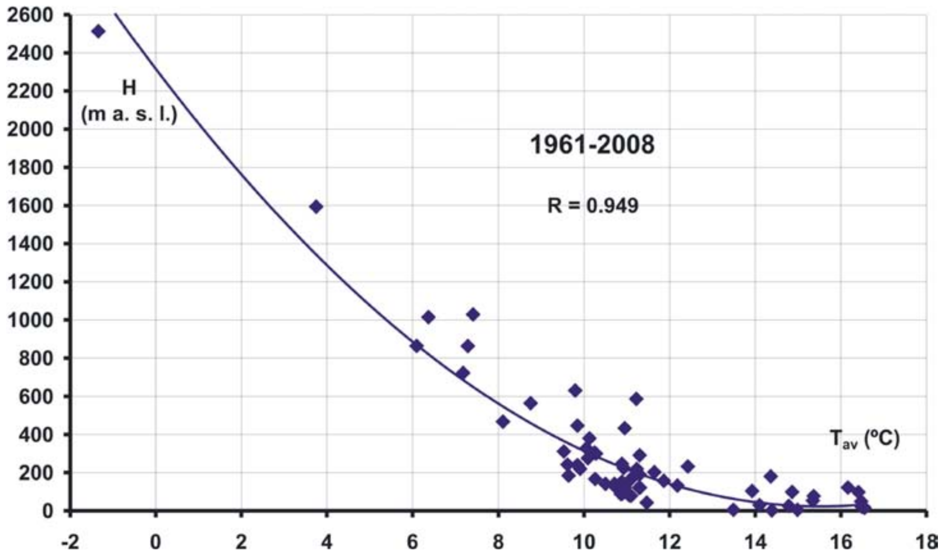

Figure 2. Relationship between altitude H of 67 analysed air temperature gauging stations and average air temperature in 1961-2008 period

3 ANALYSIS OF TRENDS IN TIME SERIES

Trend detection in this paper employs linear and 2nd order polynomial equations.

Linear equation is:

$$T_t = a \times t + b$$

while the 2nd order polynomial equation is:

$$T_t = c + d \times t + e \times t^2$$

where T_t is mean annual air temperature in year t, a, b are linear regression coefficients, c, d and e are 2nd order polynomial regression coefficients. All five regression coefficients (a, b, c, d and e) are calculated using a least squares. The functional relationships describe the general trend or nature of relationship between the T_t and t. Using this procedure, it is possible to precisely describe the trend in the mean annual air temperatures in terms of its component parts.

If there is a linear trend, than the regression estimate of the slope parameter a will be statistically different from zero (Adeloye and Montaseri, 2002). Hameed *et al.* (1997) warn that the problem with this approach is that it does not distinguish between trend and persistence. In this paper the statistical significance of linear trends is judged using Spearman Rank Order Correlation (SROC) nonparametric test (McGhee, 1985).

Columns [4], [5], [6] of Table 2 present the regression coefficient of linear trend lines (slope parameter a), linear correlation coefficient r, and 2nd order polynomial correlation coefficient R, calculated for the whole available period of the 67 analysed gauging stations. The dimension of the slope parameter a is ºC/year.

By bold, italic and red numbers in Table 2 in the columns [4] are designated 12 (17.9 %) gauging stations which linear correlation coefficients r is not statistically significant ($p<0.05$). It means that statistically significant linear trend exist in other 55 (82.1 %) analysed gauging stations. In two cases (gauging stations No. 59 and No. 67) linear trend is negative and give evidence that in these cases exist decreasing trend of mean annual air temperatures during the available periods. In all other 65 cases trend is positive which means that increasing trend is present.

It should be stressed that in all the 67 analysed cases the 2nd order polynomial correlations coefficient R are significantly higher than the linear correlations coefficient r. The average value of the 67 linear correlations coefficient r is 0.397 (ranging between 0.045 and 0.689), while the average value of the 67 2nd order polynomial correlations coefficient R is 0.572 (ranging between 0.240 and 0.786) which is a statistically significant difference ($p<0.01$). It can be explained by the fact that behaviour of analysed time series is more complex and cannot be understood using only linear model.

Table 2. Available periods, regression coefficients of linear trend lines (slope parameters) a, linear correlation coefficients r, 2nd order polynomial correlation coefficients R, and years of beginning of warming all calculated for the whole available period of the 67 analysed gauging stations

No.	**Station name**	**Available period**	**a (°C/year)**	**r**	**R**	**Beginning of warming**
[1]	[2]	[3]	[4]	[5]	[6]	[7]
1	Rateče	1948-2008	0.0172	0.419	0.664	1988
2	Kredarica	1955-2008	0.0270	0.582	0.614	1988
3	Ljubljana	1851-2008	0.0104	0.576	0.639	1988
4	Nova Vas	1961-2008	0.0376	0.681	0.705	1988
5	Kočevje	1872-2008	0.0111	0.540	0.607	1988
6	Novo Mesto	1951-2008	0.0310	0.610	0.715	1988
7	Celje	1851-2008	0.0103	0.554	0.602	1987
8	Maribor	1948-2008	0.0339	0.689	0.732	1988
9	Starše	1961-2008	0.0362	0.618	0.632	1988
10	Murska Sob.	1950-2008	0.0262	0.540	0.647	1988
11	Rovinj	1949-2008	0.0096	***0.268***	0.662	1988
12	Pula	1961-2008	0.0034	0.676	0.786	1992
13	Pazin	1961-2008	0.0248	0.618	0.632	1992
14	Rijeka	1948-2008	0.0073	***0.203***	0.654	1992
15	Mali Lošinj	1961-2008	0.0233	0.610	0.685	1988
16	Parg	1951-2008	0.0190	0.420	0.551	1989
17	Crikvenica	1892-2008	0.0069	0.331	0.337	1997
18	Senj	1948-2008	0.0131	0.334	0.601	1988
19	Zavižan	1954-2008	0.0161	0.402	0.439	1988
20	Zadar	1961-2008	0.0272	0.684	0.732	1992
21	Ogulin	1949-2008	0.0149	0.323	0.591	1988
22	Gospić	1902-2008	0.0060	0.247	0.353	1988
23	Šibenik	1949-2008	0.0074	***0.241***	0.557	1988
24	Zagreb - Grič	1862-2008	0.0083	0.424	0.473	1988
25	Zagreb - Ma.	1949-2008	0.0015	0.521	0.707	1988
26	Palagruža	1949-2008	0.0087	0.325	0.596	1992
27	Sisak	1949-2008	0.0198	0.431	0.601	1988
28	Varaždin	1949-2008	0.0181	0.397	0.536	1988
29	Split	1926-2008	0.0076	0.318	0.378	1992
30	Hvar	1929-2008	0.0181	0.397	0.536	1992
31	Koprivnica	1949-2008	0.0241	0.531	0.621	1988
32	Bjelovar	1949-2008	0.0297	0.581	0.700	1988
33	Korčula	1948-2008	0.0180	0.508	0.733	1992
34	Požega (Cr.)	1901-2008	0.0107	0.442	0.496	1988
35	Dubrovnik	1961-2008	0.0153	0.419	0.573	1992
36	Osijek	1899-2008	0.0045	0.195	0.240	1988
37	Palić	1949-2008	0.0159	0,360	0,568	1988
38	Sombor	1950-2008	0,0144	0,317	0,564	1988
39	Novi Sad	1949-2008	0.0122	0.285	0.443	1989
40	Kikinda	1949-2008	0.0135	0.314	0.536	1988
41	Loznica	1952-2008	0.0213	0.487	0.565	1988
42	Srem. Mitr.	1949-2008	0.0086	***0.225***	0.411	1989
43	Valjevo	1949-2008	0.0131	0.338	0.561	1989
44	Beograd	1936-2008	0.0133	0.351	0.471	1988
45	Kragujevac	1949-2008	0.0111	0.269	0.582	1990
46	Smed. Pal.	1949-2008	0.0096	***0.228***	0.543	1988
47	Vel. Gradište	1949-2008	0.0043	***0.108***	0.515	1992
48	Negotin	1949-2008	0.0206	0.437	0.643	1988
49	Zlatibor	1951-2008	0.0158	0.382	0.572	1990

(continiou of table 2)

50	Sjenica	1947-2008	0.0099	0.269	0.528	1987
51	Požega (Ser.)	1961-2008	0.0154	0.422	0.565	1992
52	Kraljevo	1949-2008	0.0079	***0.207***	0.466	1992
53	Kuršumlija	1961-2008	0.0131	0.333	0.528	1999
54	Kruševac	1949-2008	0.0093	***0.224***	0.577	1994
55	Ćuprija	1961-2008	0.0165	0.362	0.546	1992
56	Niš	1949-2008	0.0071	***0.169***	0.552	1992
57	Leskovac	1961-2008	0.0114	***0.225***	0.619	1992
58	Zaječar	1949-2008	0.0138	0.326	0.559	1988
59	Dimitrovgrad	1949-2008	-0.0030	***-0.084***	0.501	1998
60	Vranje	1949-2008	0.0016	***0.045***	0.488	1993
61	Bihač	1961-2008	0.0285	0.535	0.583	1988
62	Tuzla	1961-2008	0.0208	0.434	0.571	1989
63	Sarajevo	1888-2008	0.0080	0.384	0.388	1987
64	Mostar	1961-2008	0.0266	0.596	0.696	1988
65	Skopje	1926-2008	0.0049	0.186	0.292	1995
66	Nov Dojran	1961-2008	0.0295	0.584	0.770	1992
67	Bitola	1926-2008	-0.0055	-0.189	0.418	1994

Figure 3 depicts a time series of mean annual air temperature for Murska Sobota for the 1950-2008 period, and includes linear and 2nd order polynomial trend lines. A linear trend of 0.0262ºC/year, is evident, but the 2nd order polynomial trend provides a better fit to the data than a linear one.

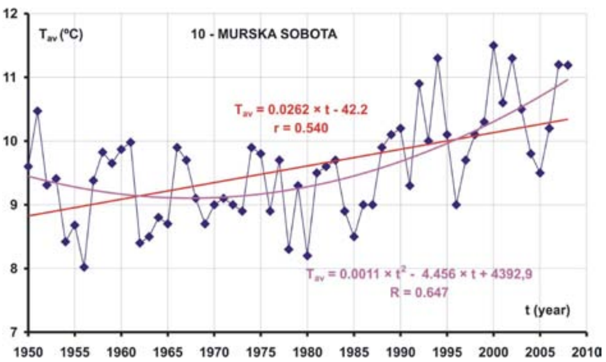

Figure 3. Time series of mean annual air temperatures at Murska Sobota (No. 10 in Fig. 1 and Table 1) for the period 1950-2008, with linear and 2nd order polynomial trend lines

Figure 4 depicts a time data of mean annual air temperature for Zagreb-Grič for the 1862-2008 period, and includes linear and 2nd order polynomial trend lines. A linear trend of 0.0083ºC/year, is evident, but the 2nd order polynomial trend provides a better fit than a linear one.

Figure 5 depicts a time data of mean annual air temperature for Ljubljana for the 1851-2008 period, and includes linear and 2nd order polynomial trend lines. A linear trend of 0.0104ºC/year, is evident, but the 2nd order polynomial trend provides a better fit than a linear one.

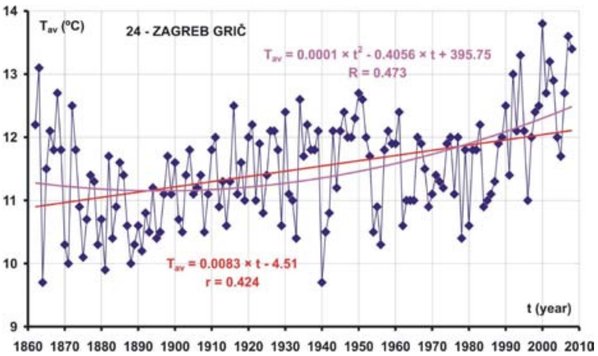

Figure 4. Time series of mean annual air temperatures at Zagreb-Grič (No. 24 in Fig. 1 and Table 1) for the period 1862-2008, with linear and 2nd order polynomial trend lines

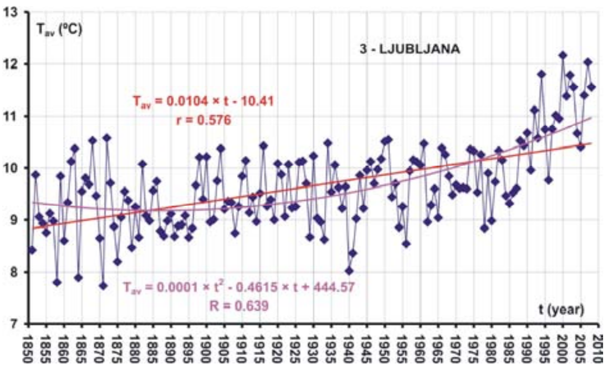

Figure 5. Time series of mean annual air temperatures at Ljubljana (No. 3 in Fig. 1 and Table 1) for the period 1851-2008, with linear and 2nd order polynomial trend lines

Figure 6 depicts a time data of mean annual air temperature for Osijek for the 1899-2008 period, and includes linear and 2nd order polynomial trend lines. A linear trend of 0.0045ºC/year, is evident, but the 2nd order polynomial trend provides a better fit than a linear one.

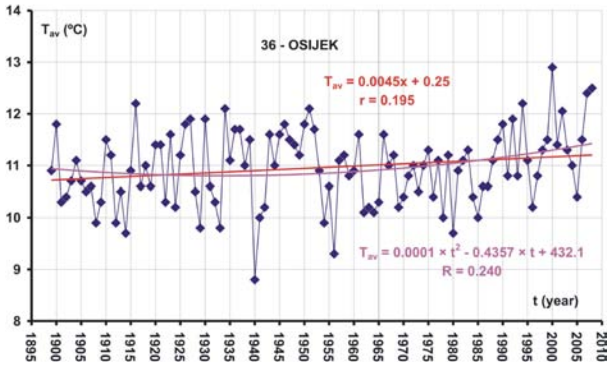

Figure 6. Time series of mean annual air temperatures at Osijek (No. 36 in Fig. 1 and Table 1) for the period 1899-2008, with linear and 2nd order polynomial trend lines

Figure 7 depicts a time data of mean annual air temperature for Skopje for the 1926-2008 period, and includes linear and 2nd order polynomial trend lines. A linear trend of 0.0049ºC/year, is evident. In this case the 2nd order polynomial trend shows completely different behaviour than in all other 66 analysed gauging stations. It has convex shape, while in all other cases the shape is concave. The convex shape of the 2nd order polynomial trend shows that at Skopje there is decreasing trend in last decades.

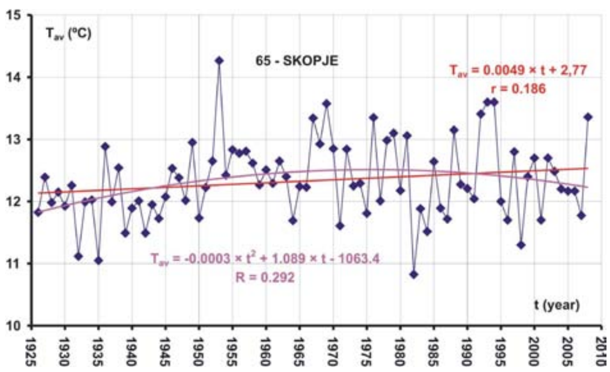

Figure 7. Time series of mean annual air temperatures at Skopje (No.65 in Fig. 1 and Table 1) for the period 1926-2008, with linear and 2nd order polynomial trend lines

The convex shape of the 2nd order polynomial trend found in 66 (98.5 %) of 67 analysed gauging stations, as well as statistically significant correlation coefficients of the 2nd order polynomial term in the best fit line show that it is not possible to accept a linear trend as reliable explanation of the behaviour of the time series of mean annual air temperature in the analysed region during the full available periods. The process of variability of time series is definitely more complex. In the next section an attempt to explain it better will be given.

4 ANALYSIS OF SHIFT (JUMP) IN TIME SERIES

A time series analysis can detect and quantify trends and fluctuations in records. In this paper the Rescaled Adjusted Partial Sums (RAPS) method (Garbrecht and Fernandez, 1994, Bonacci *et al.*, 2008) was used for this purpose. A visualisation approach based on RAPS overcomes small systematic changes in records and variability of data values. The RAPS visualisation highlights trends, shifts, data clustering, irregular fluctuations, and periodicities in the record (Garbrecht and Fernandez, 1994). It should be objective and stress that the RAPS method is not without shortcomings. The value of RAPS in year k is given by:

$$RAPS_k = \sum_{t=1}^{k} \frac{Y_t - \overline{Y}}{S_Y}$$

where $\overline{Y}$ and S_Y are the sample mean and standard deviation over the entire n values in the time series, and (k=1, 2…,n) is the counter limit of the summation for the k-th year. The plot of the RAPS versus time provides an alternative visualisation of trends and fluctuations in the Y_t.

Time data series of the RAPS for mean annual air temperature at the Murska Sobota for the period 1950-2008 is given in Figure 8. On the basis of this analysis, the data series was divided into two subsets: 1) 1950-1987; 2) 1988-2008 (Figure 9). The RAPS method shows that a linear increase in Murska Sobota mean annual air temperatures does not exist over the study period, 1950 to 2008. It indicates the increases of air temperature at the study meteorological station started in 1988 and lasted until 2008. During the first sub-period temperatures did not increase. In order to investigate statistically significant differences between the averages of two time sub-series for air temperatures the *t*-test was used. The difference between the averages 9.18ºC for 1950-1987 sub-period, and 10.32ºC for 1988-2008 sub-period are statistically significant (p<0.01).

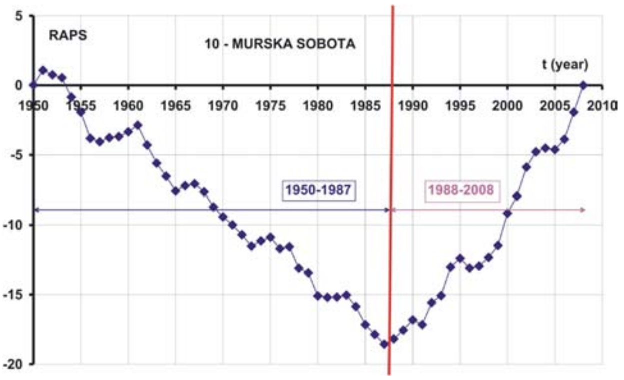

Figure 8. Time data series of the rescaled adjusted partial sums (RAPS) for the mean annual air temperature at Murska Sobota (No. 10 in Fig. 1 and Table 1) for the period 1950-2008

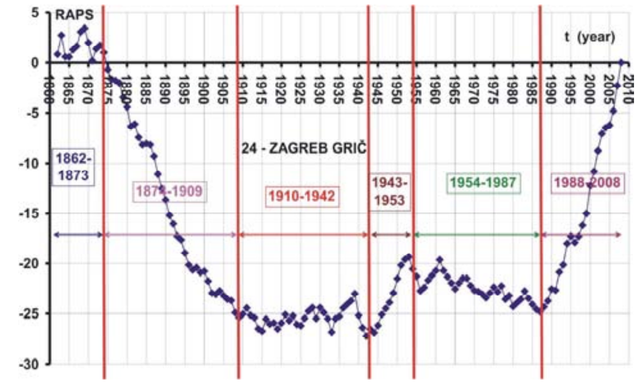

Figure 10. Time data series of the rescaled adjusted partial sums (RAPS) for the mean annual air temperature at Zagreb-Grič (No. 24 in Fig. 1 and Table 1) for the period 1862-2008

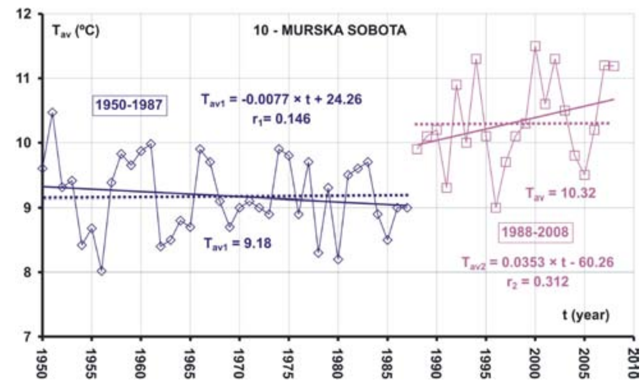

Figure 9. Trends in mean annual air temperatures at Murska Sobota (No. 10 in Fig. 1 and Table 1) in the two sub-periods are defined in Figure 8

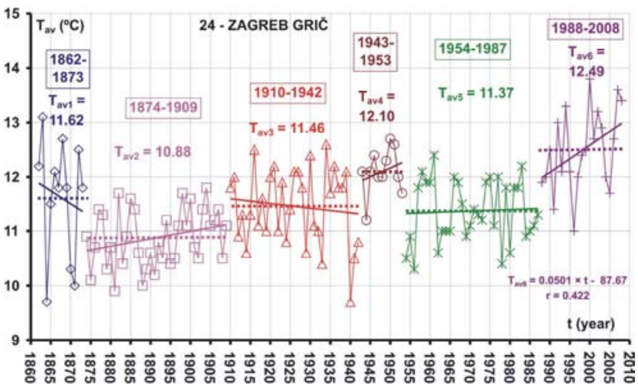

Figure 11. Trends in mean annual air temperatures at Zagreb-Grič (No. 24 in Fig. 1 and Table 1) in the six sub-periods are defined in Figure 10

Time data series of the RAPS for mean annual air temperature at the Zagreb-Grič for the period 1862-2008 is given in Figure 10. On the basis of this analysis, the data series was divided into six subsets: 1) 1862-1873; 2) 1874-1909; 3) 1910-1942; 4) 1943-1953; 5) 1954-1987; 6) 1988-2008 (Figure 11). The RAPS method shows that a linear increase in Zagreb-Grič air temperatures does not exist over the long-term study period, 1862 to 2008. It indicates that increases of air temperature at the study meteorological station started in 1988 and lasted until 2008. During the first five sub-period temperatures did not statistically significantly increase. In order to investigate statistically significant differences between the averages of six time sub-series for air temperatures the *t*-test was used. The averages for all neighbouring sub-periods are statistically significant (p<0.01).

Time data series of the RAPS for mean annual air temperature at the Ljubljana for the period 1851-2008 is given in Figure 12. On the basis of this analysis, the data series was divided into three subsets: 1) 1851-1942; 2) 1943-1987; 3) 1988-2008 (Figure 13). The RAPS method shows that a linear increase in Ljubljana air temperatures does not exist over the long-lasting study period, 1851 to 2008. It indicates that increases of air temperature at the study meteorological station started in 1988 and lasted until 2008. During the first two sub-period temperatures did not statistically significantly increase. In order to investigate statistically significant differences between the averages of three time sub-series for air temperatures the *t*-test was used. The averages for all neighbouring sub-periods are statistically significant (p<0.01).

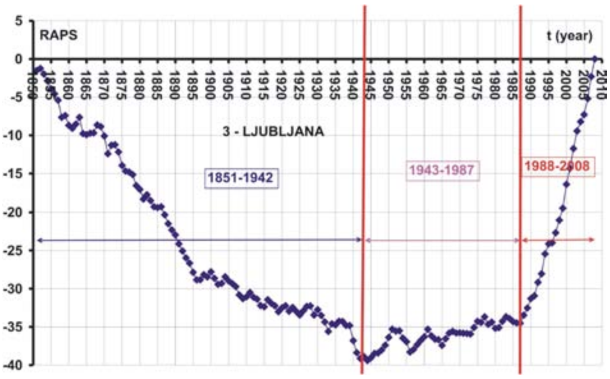

Figure 12. Time data series of the rescaled adjusted partial sums (RAPS) for the mean annual air temperature at Ljubljana (No. 3 in Fig. 1 and Table 1) for the period 1851-2008

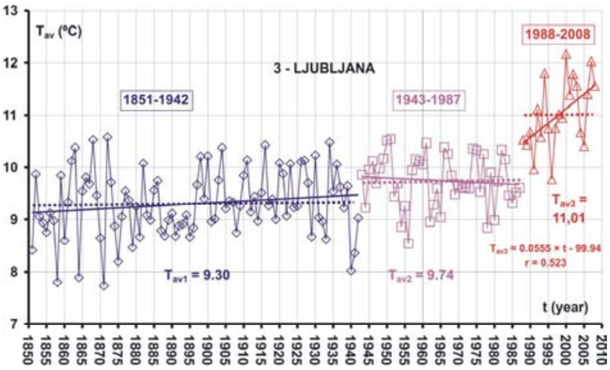

Figure 13. Trends in mean annual air temperatures at Ljubljana (No. 3 in Fig. 1 and Table 1) in the three sub-periods are defined in Figure 12

On the basis of the RAPS analysis, the data series of Osijek was divided into four subsets: 1) 1899-1942; 2) 1943-1952; 3) 1953-1987; 4) 1988-2008 (Figure 14). The RAPS method shows that a linear increase in Osijek air temperatures does not exist over the long-lasting study period, 1899 to 2008. It indicates that increases of air temperature at the study meteorological station started in 1988 and lasted until 2008. It should be noted that average air temperatures during the second sub-periods (1943-1952) of 11.57ºC is higher than average air temperature of 11.45ºC measured in last sub-period (1988-2008). During the first three sub-period temperatures did not statistically significantly increase. In order to investigate statistically significant differences between the averages of four time sub-series for air temperatures the *t*-test was used. The averages for all neighbouring sub-periods are statistically significant ($p<0.01$).

Behaviour of time series of mean annual air temperatures for Skopje is completely different than in all other 66 analysed cases. On the basis of the RAPS analysis, the data series of Skopje was divided into five subsets: 1) 1926-1945; 2) 1946-1981; 3) 1982-1987; 4) 1988-1994; 5) 1995-2008 (Figure 15).

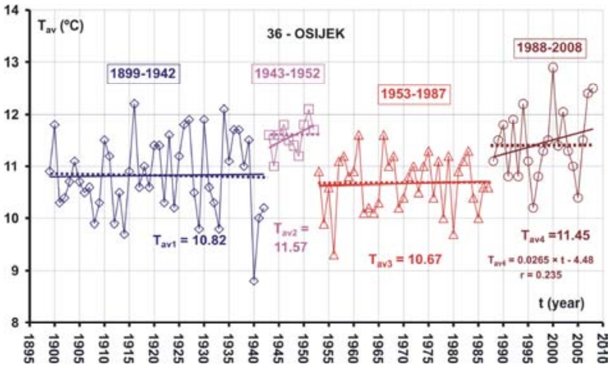

Figure 14. Trends in mean annual air temperatures at Osijek (No. 36 in Fig. 1 and Table 1) in the four sub-periods

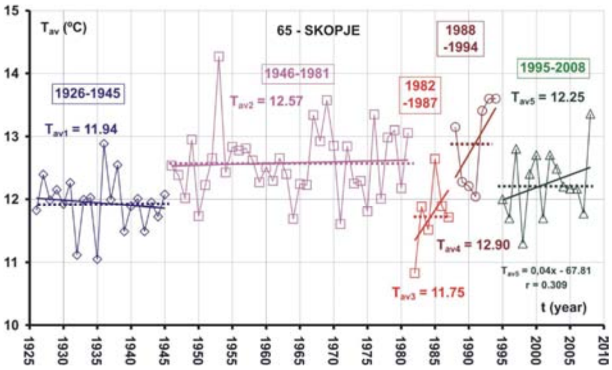

Figure 15. Trends in mean annual air temperatures at Skopje (No. 65 in Fig. 1 and Table 1) in the five sub-periods

The RAPS method shows that a linear increase in Skopje air temperature does not exist over the long-lasting study period, 1926. to 2008. It indicates that there is no increase of air temperature at the study meteorological station in recent years. The average air temperatures during the last sub-period (1995-2008) of 12.25ºC is lower than average air temperature measured in second (1946-1981) and fourth (1988-1994) sub-periods. In fact, behaviour of Skopje mean annual air temperature time series in last twentieth years is more complex. It should be noticed that before the drop of 0.65ºC, which appeared in 1995, was the jump of 1.15ºC which occurred in 1988. In order to investigate statistically significant differences between the averages of four time sub-series for air temperatures the *t*-test was used. The averages for all neighbouring sub-periods are statistically significant ($p<0.01$).

All previously reported analyses (as well as others non-reported in this paper) indicate that in the analysed time series there is a statistically significant sudden change (in 66 cases the changes occurred as a jump) in the mean annual air temperature record. The first year in which this sudden change occurs could be considered as the year of the beginning of warming.

Figure 16 shows the location map indicating the years of the beginning of the warming at the 67 analysed gauging stations. The same information is given in the last column [7] of Table 2. Figure 17 presents relationship between number of air temperature gauging stations N and the years of beginning of the warming. The 1988 year is beginning of warming for 34 (50.7 %) gauging stations, while in 1992 warming started in 16 (23.9 %) gauging stations.

Figure 18 presents two duration curves (percentage of stations in which given ΔT is exceeded) of differences $\Delta T_1=T_{(YB-2008)}-T_{(YF-YA)}$ and $\Delta T_2= T_{(YB-2008)}-T_{(1961-YA)}$ between average annual air temperatures in two sub-periods at the 67 analysed sites gauging stations (YF - first available year at the gauging station; YA - year before the beginning of warming; YB - year of beginning of warming). Figure 19 shows the location map indicating differences ΔT_1 and ΔT_2 between average annual air temperatures in two sub-periods at the 67 analysed sites gauging stations (ΔT_1 is upper figure). ΔT_1 is calculated including the whole available period while in the second difference ΔT_2 is based on the period from 1961-2008. The results are similar.

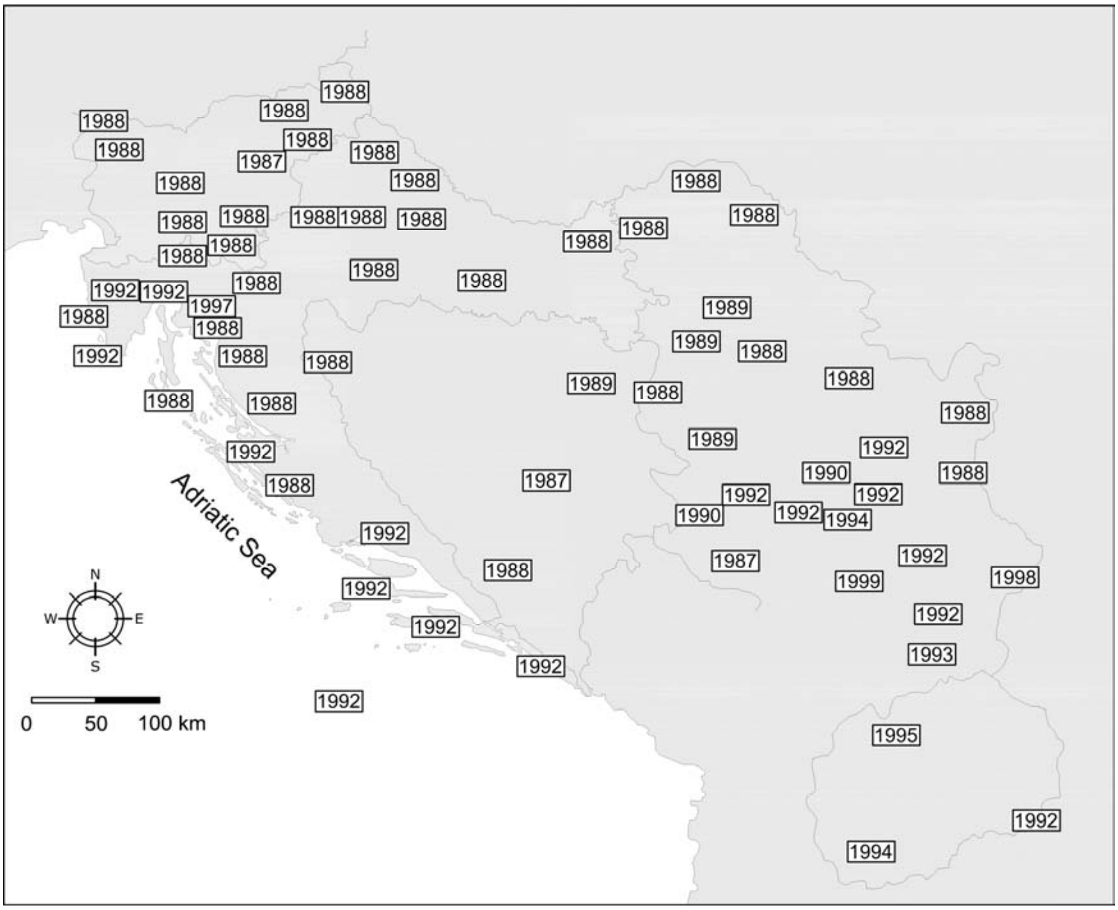

Figure 16. Location map indicating the years of beginning of the warming at the 67 analysed gauging stations

Average differences are: 1) ΔT_{av1}= 0.807ºC (ranging between -0.11 and 1.56); 2) ΔT_{av2} = 0.862ºC (ranging between -0.25 and 1.32).

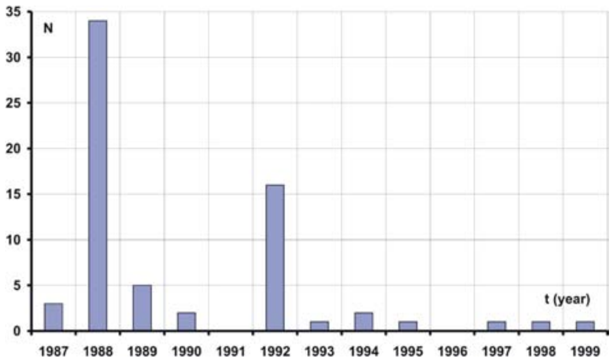

Figure 17. Relationship between number of air temperature gauging stations N and the years of beginning of the warming

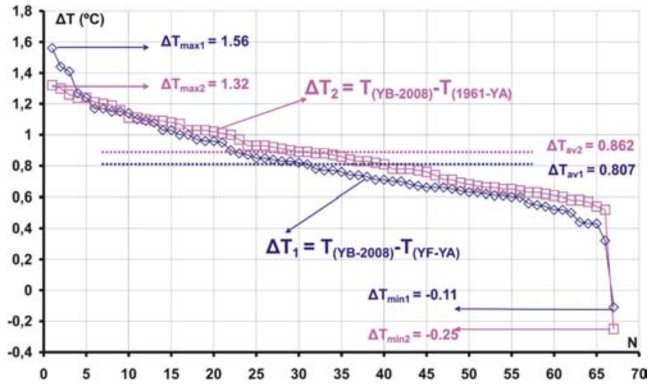

Figure 18. Two duration curves of differences ΔT_1 and ΔT_2 between average annual air temperatures in two sub-periods at the 67 analysed sites gauging stations (YF – first available year at the gauging station; YA – year before the beginning of warming; YB – year of beginning of warming)

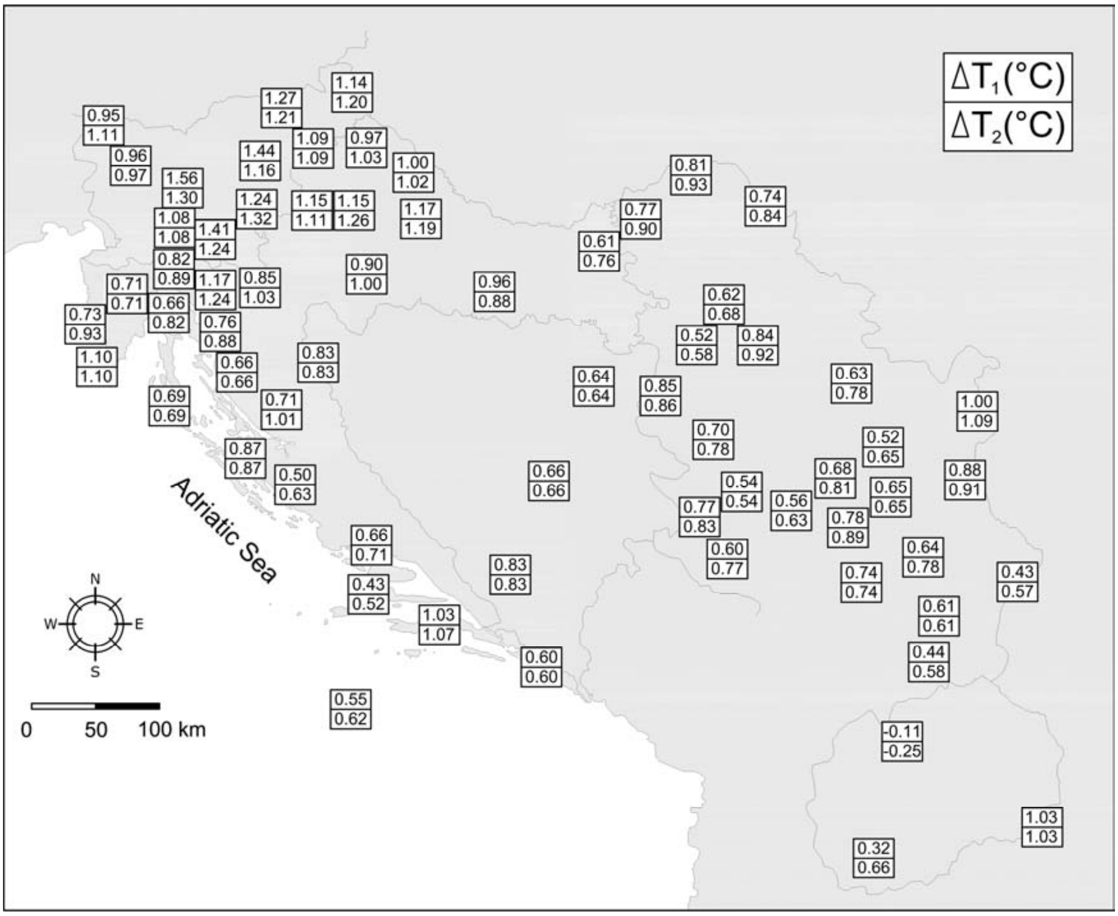

Figure 19. Location map indicating differences ΔT_1 and ΔT_2 between average annual air temperatures in two sub-periods at the 67 analysed sites gauging stations (ΔT_1 is upper figure)

A similar nearly identical conclusion about the existence of a statistically significant shift (mainly jump) in the air temperature time series, i.e. the beginning of warming in last twentieth years is reported in several papers. Practically the same result was achieved with analysis time series of mean annual air temperatures in the Yellow River basin (China) during the 1956-2000 period (Li, 2010). Figure 20 shows trends in mean annual air temperatures in the Yellow River basin in the following two sub-periods: 1) 1956-1986; 2) 1987-2000. The beginning of warming (the jump in the analysed time series) started in 1987. The increase of average mean annual air temperatures in period before and after warming is 0.70ºC.

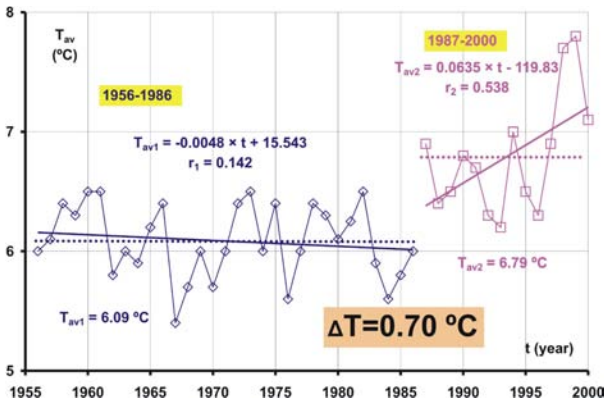

Figure 20. Trends in mean annual air temperatures in the Yellow River basin in the following two sub-periods: 1) 1956-1986; 2) 1987-2000

Levi (2008) stresses that scientists studying the time series of many climate-related variables had been noticing a rather sudden change, an inflection point, around the mid 1980s. Repapis *et al.* (2007) investigated whether the abrupt increase of the National Observatory of Athens (NOA) air temperature time series, which appears during the last few years, is the finger-print of the broader scale climatic change or if it is the result of a discontinuity in the record of urban effect or some other problem with the station. They show that the record displays a statistically significant discontinuity in 1995. For this reason authors concluded that these records must be treated with caution for long term air temperature trends detection. Kothawale and Kumar (2005) consider that all-India mean annual air temperature has shown significant warning trend of 0.05ºC/10 year during the period 1901-2003, the recent period 1971-2003 has seen a relatively accelerated warning of 0.22ºC/10 year.

Between 67 analysed gauging stations 10 of them are located in large cities with more than 200,000 inhabitants. An urban effect for Zagreb is evident from the comparison of Zagreb-Grič (No. 24) with Zagreb-Maksimir (No. 25). The first is located in the centre of Zagreb (with about 800,000 inhabitants) while the second is located in the suburbs (about 4 km distant). In the 1949-2008 period the average annual air temperatures for Zagreb-Grič was 11.84ºC and for Zagreb-Maksimir it was 10.71ºC. The difference of 1.13ºC is statistically significant.

5 CONCLUSIONS

The conclusions given in this paper are restricted to concerned region. It should be stressed that all analysed data are official ("governmental") data. There was not a change in instrumentation or other factors in and after 1988.

On the basis of analyses made in this paper seems that in the analysed Balkans region warming started in period between 1987 and 1997, mostly in 1988. Differences of average mean annual air temperatures before and after warming are about 0.807ºC. Increases in the last twentieth years should be explained not by the anthropogenic influence only. In this moment we have no reliable answer to this question. It means that reasonable conclusion is that these records must be treated with caution for long term air temperature trends detection (Repapis *et al.*, 2007). On the bases of available data it seems that during 1943-1952 mean annual air temperatures in the region were higher than average. Unfortunately, disruptions during the 2nd World War mean there are too few measured data to confirm this.

Efforts to understand mechanism that influence jump and/or trend (variability) of mean annual air temperatures in analysed as well as any other region should be enhanced using reliable and long lasting time data series, and multidisciplinary approaches and methods. It means research on data with higher time resolution, looking into seasonal aspects, using different statistical approaches, and analyses of annual extremes. In addition more detailed research is needed to better explain the changes, especially the increasing of mean annual air temperatures over the past twenty years. For the sustainable development (especially drought control and management), it is extremely important to establish pre-requisites for the definition of precise causes of the above mentioned processes.

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PORAST SREDNJIH GODIŠNJIH TEMPERATURA VAZDUHA NA PROSTORU ZAPADNOG BALKANA U POSLEDNJIH 30 GODINA

by

Ognjen BONACCI

Fakultet građevinarstva, arhitekture i geodezije, Sveučilište u Splitu,
21000 Split, Matice hrvatske 15, Hrvatska
E-mail: obonacci@gradst.hr

Rezime

Analizirano je 67 nizovi srednjih godišnjih temperatura zraka merenih na području bivše Jugoslavije. Cilj rada je bio da se istraže promene u režimu srednjih godišnjih temperatura zraka u raspoloživom razdoblja mjerenja koje se kreće od 156 godina do 47 godina. Statistički značajne promene, tj. nagli porasti temperatura, započeli su u razdoblju 1987.-1999. (1988. godine na 51 % stanica te 1992. na 24 % stanica). Srednje godišnje temperature zraka u razdoblju poslije naglog porasta temperatura povećane su prosječno za 0,807 ºC. Ovaj zaključak nije u skladu s najnovijim zaključcima IPCC (Intergovernmental Panel on Climate Change) koji je ustanovio da porast prosječne globalne temperature zrak na Zemlji počevši od 1900. godine iznosi oko 0,8±0,1 ºC te da se taj trend javlja u 20. stoljeću. Treba naglasiti da je na nekim od analiziranih stanica razdoblje 1942.-1953. imalo slične (čak i više) prosečne srednje godišnje temperature vazduha u uporedbi s onima opaženim u posljednjih tridesetak godina, posle naglog porasta temperatura zraka. Analize upućuju na potrebu detaljnijeg izučavanja fenomena zagrijavanja kako na izučavanom području tako i šire. Čini se da nije vrijeme za donošenje konačnih zaključaka već za intenzivno, nezavisno naučno izučavanje ove krajnje složene i jednako tako značajne problematike za budućnost života na planeti. Za osiguravanje održivog razvoja od ključnog je značaja stvoriti uvete za davanje pouzdanih naučno zasnovanih odgovora na pitanje da li se radi o globalnom zagrijavanju izazvanom prvenstveno antropogenom emisijom stakleničkih plinova, kako to tvrdi IPCC, ili je reč o uobičajenoj varijaciji klime kako to tvrdi sve veći broj nezavisnih naučenjaka.

Ključne reči: srednja godišnja temperatura vazduha, klimatske promene, varijacija klime, trend, skok, Balkan

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