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Brief review of the climatic fluctuations recorded in Zagreb between 1862 and 1990

B. Penzar, I. Penzar, J. Juras and A. Marki

Andrija Mohorovičić Geophysical Institute,
Faculty of Science, University of Zagreb, Croatia

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In reference to the publication Long-term meteorological measurements at Zagreb: 1862–1990 (Penzar et al. 1992) the preliminary information on the climatic trends as well as on the comparison of 30-year averages within the whole period of measurements is given. The changes of the mean annual air temperatures observed in Zagreb in the period of more than a hundred years are proved to be similar to the changes of the mean temperature of the Earth as a whole. A rise in temperature is most obvious during the heating season. From the minima and maxima of the mean values of temperature observed in periods of 30 years it follows that the lowest temperatures took place at the end of the 19th century in all the months except August. In the second and the third quarter of the 20th century the most clouded summers, autumns and winters were observed, and in the second half and at the end of the 19th century a period with the largest number of clear days was registered. The middle of the 20th century was the driest period. It is also evident that the annual values of air pressure and rainfall changed mainly in the opposite direction. The climatic fluctuations in October were most apparent as they were observed on several climatic elements at the same time.

Osvrt na klimatska kolebanja zabilježena u Zagrebu u razdoblju od 1862. do 1990. godine

U vezi s edicijom Long-term meteorological measurements at Zagreb: 1862–1990 (Penzar et al. 1992) daju se prethodna priopćenja o klimatskim trendovima kao i o usporedbi 30-godišnjih srednjaka unutar cijeloga razdoblja mjerenja. Uočeno je da su promjene srednjih godišnjih temperatura zraka u posljednjih stotinjak godina vrlo slične promjenama srednje temperature za Zemlju u cjelini. Porast temperature najvidljiviji je u svim mjesecima sezone grijanja. Iz ekstremnih vrijednosti 30-godišnjih srednjaka proizlazi da su najniže temperature bile krajem prošlog stoljeća u svim mjesecima osim u kolovozu. Najoblačnija ljeta, jeseni i zime imala je druga i treća četvrtina 20. stoljeća, a najvedrije razdoblje bilo je u drugoj polovici i oko svršetka 19. stoljeća. Također se vidi da su se godišnje vrijednosti tlaka zraka i količine oborine mijenjale uglavnom u suprotnom smislu. Kolebanja klime u mjesecu listopadu bila su najizrazitija utoliko što su se očitovala u isto vrijeme na više klimatskih elemenata.

1. Introduction

The climatic data of the Zagreb-Grič Observatory for the period 1862–1990 are going to be published in Geofizika as a Supplement to the Volume 9 (Penzar et al. 1992). The edition contains monthly values of global solar radiation, air temperature, humidity and pressure, wind direction, velocity and force, sunshine duration, rainfall, cloudiness, number of days with various forms of precipitation and some other phenomena, that have been analyzed by elementary statistical methods. The published data are available to the experts for the analysis of the climate in Zagreb as well as for the research of climatic fluctuations in this part of Europe.

Climatic fluctuations in Zagreb have been analyzed several times in the past (Goldberg 1953, 1954, Penzar et al. 1967, Šegota 1969, 1970, Makjanić 1977, Šinik 1980, 1981, Juras 1985, Penzar and Penzar 1986/87). In this paper, the longest series that are now available have been preliminary taken into consideration from two points of view. On the one hand, we tried to find out whether during the whole period of measurements the changes proceeded mainly in the same directions of the increase or the decrease of values. For this purpose the dependence of data on time was examined and – in case it proved to be significant – a corresponding linear trend was determined. Another point of view is the comparison of 30-year averages representing more or less different climates within the whole period of measurements. Namely, according to the internationally adopted standard we consider that a climate can be determined from the period of 30 years and that mean values of climatic elements are its first and most simple representatives. The results and our reflections concerning the analysis are briefly presented in the following text.

2. Analysis of trend in monthly and annual mean values of the main climatic elements

One of the most important tasks of the analysis of the climatic series is to find out whether the data show tendency to rise or to fall gradually. The fact that the trend exists requires an explanation in terms of a climatic change or perhaps of the changes in the measuring methods. In case of natural changes it must be determined whether they only apply to the area around the place of observation or whether they are characteristic of a wider area. Hence, in order to evaluate the cause and dimensions of the observed trend more easily, the analysis of data recorded at the larger area is necessary. The absence of a significant trend in the time series as a whole does not exclude the existence of significant changes in some of its parts.

From the great number of time series for various climatic elements we wanted to select those showing a significant trend. We have applied here the method of linear regression due to its simplicity, still having in mind its limitations. The coefficient of linear correlation between the mean values of a climatic

Table 1. Linear correlation coefficients (×10^3) between monthly and annual mean values of particular climatic elements and time (the observation years), obtained at the Zagreb-Grič Observatory

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Air temperature	148	121	133	48	32	−24	−10	0	13	43	161	204	228
Air pressure	−111	−129	244	42	44	66	114	65	57	292	33	−18	170
Insolation	−112	−218	−130	−13	−66	−382	−211	−363	−80	60	−77	91	−339
Cloudiness	232	219	194	321	397	327	292	257	214	63	224	197	517
Rainfall	66	70	−90	−138	0	19	21	11	−24	−227	30	30	−77

element and time (the observation year) can serve as a criterion by which the time series showing significant trend may be selected. Most of the time series under consideration contain 129 terms. For this number of terms the significant value of the correlation coefficient at the level 0.05 is 0.17 and at the level 0.01 amounts to 0.22. The obtained correlation coefficients are given in Table 1. The sign and the amount of the coefficients indicate the characteristics of the trend.

The slope a in the equation

$$y - \bar{y} = a\,(x - \bar{x})$$

by which the linear trend is represented demonstrates the intensity of the change in the course of years (x). In Table 2 the values a have been multiplied by 100 so that they represent the average change in the period of hundred years. The quantity $\bar{y}$ is the mean of the climatic element in the period 1862–1990 (for sunshine duration 1889–1990), and $\bar{x}$ is the central year of the period (1926, for sunshine duration 1940).

The data in Tables 1 and 2 enable a good first insight into characteristics of the observed secular sequences. Some of these characteristics have been described in the papers cited in the introduction. Here we shall briefly comment on the trend of mean annual temperatures and cloudiness.

The changes of the mean annual air temperatures observed in Zagreb are very similar to the changes on the Northern Hemisphere in the last period of about a hundred years. The correlation coefficients between values for Zagreb and those given by Vinnikov et al. (1990) for the Northern Hemisphere is

Table 2. Numerical values of the slope a (×10^2) in the trend equations for air temperature T, air pressure P, sunshine duration S, cloudiness C and rainfall R at the Zagreb-Grič Observatory.

	J	F	M	A	M	J	J	A	S	O	N	D	Year
T(°C)	1.1	1.0	0.8	0.2	0.1	−0.1	−0.3	0.0	0.1	0.2	0.9	1.4	0.4
P(hPa)	−1.6	−1.9	2.8	0.3	0.3	0.3	0.5	0.3	0.3	2.4	0.3	−0.2	0.3
S(h)	−10.6	−29.8	−18.5	−1.7	−8.9	−47.4	−28.4	−51.4	−10.9	7.3	−7.5	7.5	−200.5
C(0.1)	0.7	0.9	0.6	0.9	1.0	0.8	0.7	0.8	0.7	0.2	0.7	0.6	0.7
R(mm)	5.5	6.0	−7.0	−9.1	0.0	2.1	2.5	1.5	−2.9	−33.7	4.0	0.6	−30.5

however not particularly large (0.35) because the warmest period on the Earth was recorded about the thirties and in Zagreb about fifties.

The correlation coefficients between the annual mean temperatures in Zagreb and corresponding values in Budapest and Vienna are high (0.913 and 0.883 respectively). Thus, it is possible to obtain rather reliable estimations of mean temperature in Zagreb in the years before 1862, when meteorological measurements were performed in Budapest and Vienna. A certain increase in mean annual temperatures can also be ascribed to expansion of the town area. The increase in Zagreb is especially apparent during the heating season. If we compare the mean annual temperatures in Zagreb, Vienna and Budapest in two periods, lasting for 29 years each (at the beginning and at the end of the observation period in Zagreb), we can notice that a rise in temperatures recorded in Zagreb is the least (Tab. 3).

The very explicit positive trend of cloudiness in Zagreb (Fig. 1) that is apparent in the high values of correlation coefficients in Table 1, rises the question of whether the increase is only a consequence of natural changes or is partly influenced by expansion of the town area. The possibility of changing the criterion by the subjective estimation of cloudiness should not be excluded as well.

Table 3. Comparison of the mean annual air temperature (°C) in Zagreb, Budapest and Vienna.

Period	Zagreb	Budapest	Vienna
1862–1890	11.1	10.7	9.2
1961–1989	11.4	11.4	9.9
ΔT	0.3	0.7	0.7

Table 4. Mean monthly and annual cloudiness in Zagreb (in tenths).

Period	J	F	M	A	M	J	J	A	S	O	N	D	Year
1862–1990	6.9	6.1	5.9	5.7	5.3	5.1	4.1	3.9	4.5	5.7	6.9	7.3	5.6
1915–1990	7.6	6.8	6.5	6.4	6.0	5.7	4.6	4.5	5.0	6.2	7.7	7.9	6.2

The last hypothesis seems to be confirmed by the fact that an increase in cloudiness did not take place gradually. We may say that the greatest changes occurred about the second decade of the 20th century The most cloudy 30-year period started in 1915. If the monthly and annual mean values of cloudiness in the periods 1862–1914 and 1915–1990 (Tab. 4) are compared, all established differences according to the t-test can be considered significant at the level 0.05.

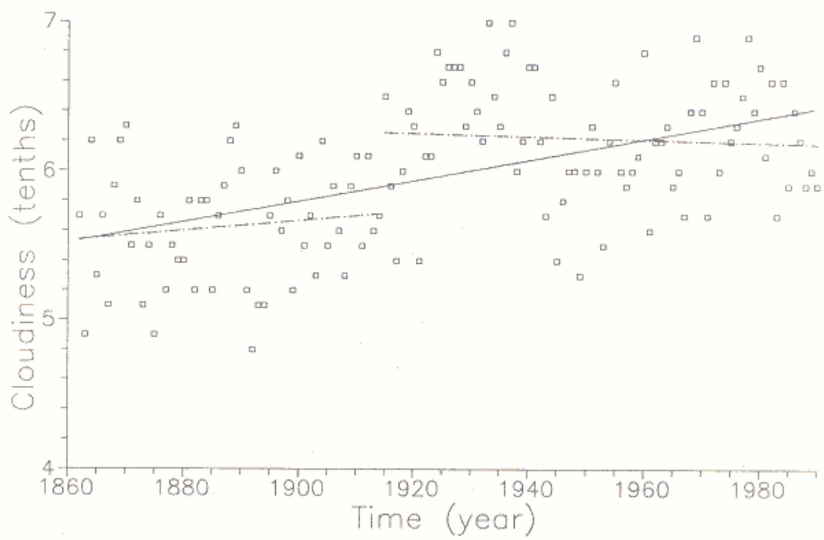

Figure 1. Mean annual cloudiness in Zagreb (points). The full line represents the linear trend for the whole period (1862–1990) and dashed lines represent the trend during the two time intervals separated by the year 1914.

It has been noticed that the significant positive trend of cloudiness does not extend over both the above mentioned periods, neither for the year as a whole nor for any month. Even more, in some of the months (January, November) within these two periods, when observed separately, there is a weak tendency of cloudiness to fall. The slopes in the trend equations for the year for the above mentioned periods amount to 0.003 or to –0.001 and are statistically not significant. This indicates that there is a discontinuity in the rise of cloudiness in Zagreb, the causes of which should be examined in more detail.

3. Comparison of the mean values for periods of 30 years

Range of time between 1862 and 1990 consists of 98 periods of 30 years and consequently of the same number of climates that are more or less similar. In order to compare them the method of moving averages of size 30 and with a shift of one year has been applied to the monthly and annual values of the main climatic elements. Table 5 displays the greatest ranges within the particular climatic element as well as the time when the minima and maxima set in. The ranges of global radiation are expressed not only in absolute amounts but also as the parts of the average 1862–1990 for the corresponding month or for a year. In this way the comparison of months with unequal duration of the part of the day from sunrise to sunset was made easier.

We shall mention here some facts apparent from Table 5:

- The greatest ranges in temperature are observed in winter months.
- The lowest temperatures were recorded at the end of the 19th century in all the months except August.
- The maxima of global radiation and the majority of clear days were recorded mainly at the end of the 19th century.
- The smallest number of clear days and the largest number of cloudy days during the summer months occurred in the third quarter of the 20th century.

Table 5. Maximum range between the averages recorded in the periods of 30 years and the time intervals when the minima and maxima set in.

	Air pressure				*Air temperature*		
	Range hPa	Minimum	Maximum		Range °C	Minimum	Maximum
J	3.4	1934–1963	1880–1909	J	2.3	1868–1897	1910–1939
F	3.5	1950–1970	1862–1891	F	1.7	1870–1899	1961–1990
M	3.2	1862–1891	1938–1967	M	1.5	1865–1894	1909–1938
A	2.5	1907–1936	1942–1971	A	1.4	1888–1917	1939–1968
M	1.1	1871–1990	1942–1971	M	1.1	1873–1902	1921–1950
J	1.0	1898–1927	1935–1964	J	0.9	1880–1909	1935–1964
J	1.0	1907–1936	1961–1990	J	0.9	1890–1919	1921–1950
A	0.9	1862–1891	1891–1920	A	1.0	1953–1982	1927–1956
S	0.8	1876–1905	1943–1972	S	1.4	1887–1916	1926–1955
O	2.9	1867–1896	1943–1972	O	0.6	1877–1906	1942–1971
N	2.6	1943–1972	1879–1908	N	1.8	1873–1902	1923–1952
D	2.0	1954–1983	1879–1908	D	2.2	1870–1899	1901–1930
Year	0.5	1912–1941	1880–1909	Year	0.9	1874–1903	1923–1952

	Cloudiness				*Number of clear days*		
	Range tenths	Minimum	Maximum		Range days	Minimum	Maximum
J	1.1	1874–1903	1917–1946	J	3.0	1919–1948	1879–1908
F	1.2	1893–1922	1960–1989	F	3.0	1951–1980	1891–1920
M	1.2	1871–1900	1959–1903	M	3.2	1959–1988	1874–1903
A	1.2	1865–1894	1915–1944	A	3.5	1915–1944	1865–1894
M	1.2	1862–1891	1925–1954	M	3.0	1925–1954	1862–1891
J	0.8	1872–1901	1961–1990	J	2.4	1960–1989	1885–1914
J	0.9	1876–1905	1953–1982	J	3.0	1954–1983	1876–1905
A	1.4	1877–1906	1955–1984	A	4.4	1955–1984	1878–1907
S	1.1	1863–1892	1909–1938	S	3.8	1912–1941	1879–1908
O	1.1	1884–1913	1915–1944	O	2.8	1914–1943	1942–1971
N	1.2	1865–1894	1918–1947	N	2.6	1919–1948	1865–1894
D	1.1	1871–1900	1916–1945	D	2.0	1926–1955	1865–1894
Year	0.8	1865–1894	1915–1944	Year	25.7	1915–1944	1879–1908

- The smallest number of cloudy days and the minimum of cloudiness were observed in the second half and by the end of the 19th century.
- The maxima of cloudiness in autumn and at the beginning of winter were recorded in the second quarter of the 20th century.
- The minimum rainfall during the summer months was recorded in the middle of the 20th century.
- The annual minimum of air pressure and the annual maximum of rainfall belong to the same period, 1912–1941.

Table 5. Continued

Number of cloudy days				*Rainfall*			
	Range days	Minimum	Maximum		Range mm	Minimum	Maximum
J	4.4	1892–1921	1917–1946	J	16	1882–1911	1934–1963
F	4.6	1893–1922	1960–1989	F	18	1882–1911	1929–1958
M	5.1	1871–1900	1958–1987	M	18	1933–1962	1862–1891
A	4.6	1862–1891	1913–1942	A	20	1926–1955	1903–1932
M	5.2	1862–1891	1925–1954	M	14	1881–1910	1873–1902
J	3.9	1872–1901	1958–1987	J	18	1924–1953	1870–1899
J	2.9	1863–1892	1953–1982	J	28	1921–1950	1951–1980
A	3.6	1875–1904	1954–1983	A	21	1933–1962	1960–1989
S	3.4	1864–1893	1904–1933	S	32	1932–1961	1899–1928
O	4.5	1884–1913	1915–1944	O	53	1943–1972	1867–1896
N	4.7	1865–1894	1939–1968	N	29	1880–1909	1940–1969
D	5.2	1870–1899	1916–1945	D	15	1919–1948	1954–1983
Year	37.9	1865–1894	1919–1948	Year	63	1929–1958	1912–1941

Number of days with rainfall ≥ 1 mm				*Global radiation*				
	Range days	Minimum	Maximum		Range MJ/m^2	Range rel.	Minimum	Maximum
J	1.8	1882–1911	1912–1941	J	28	0.24	1917–1946	1874–1903
F	2.3	1862–1891	1928–1957	F	55	0.28	1955–1984	1893–1922
M	2.3	1929–1958	1899–1928	M	49	0.15	1918–1947	1871–1900
A	2.4	1926–1955	1903–1932	A	54	0.12	1913–1942	1862–1891
M	2.1	1862–1891	1924–1953	M	68	0.12	1925–1954	1862–1891
J	2.0	1950–1979	1881–1910	J	50	0.08	1920–1949	1873–1902
J	2.1	1862–1891	1890–1919	J	43	0.07	1940–1969	1873–1902
A	1.4	1939–1968	1954–1983	A	52	0.09	1955–1984	1878–1907
S	2.2	1944–1973	1899–1928	S	47	0.11	1909–1938	1863–1892
O	3.8	1961–1990	1867–1896	O	31	0.12	1914–1943	1865–1894
N	2.4	1879–1908	1937–1966	N	36	0.29	1939–1968	1865–1894
D	2.1	1871–1900	1941–1970	D	29	0.32	1943–1972	1862–1891
Year	8.0	1961–1990	1897–1936	Year	372	0.09	1915–1944	1871–1900

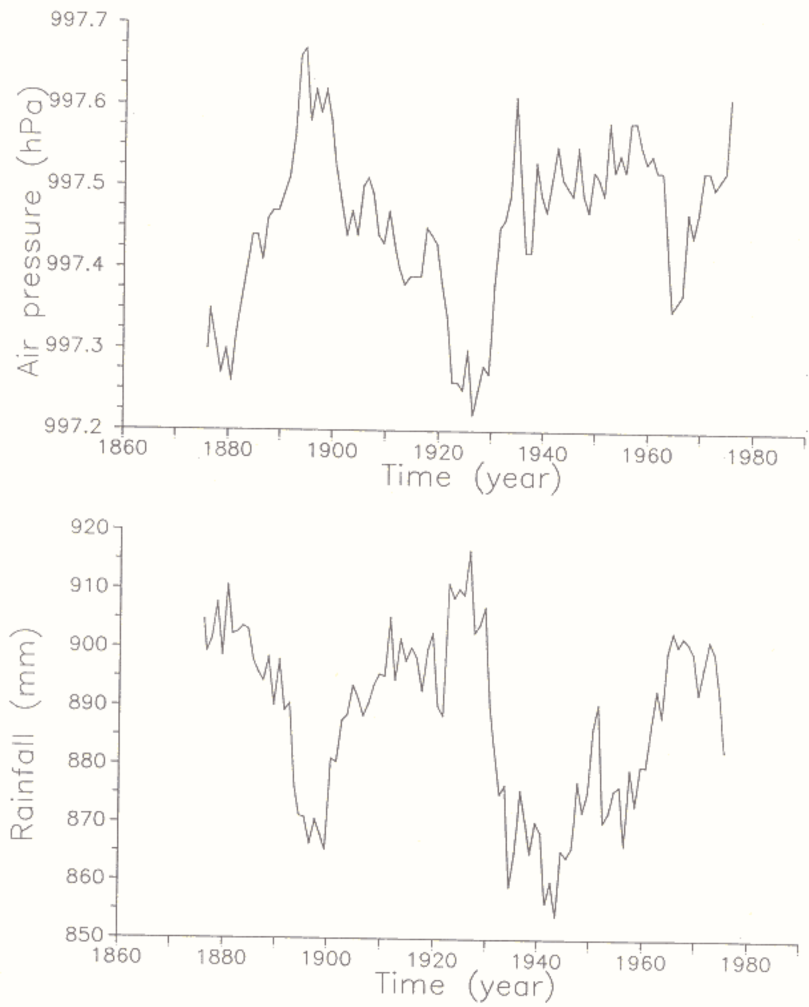

Figure 2. Moving averages of the annual values of air pressure and rainfall in Zagreb. The values are placed above the middle of the corresponding period of 30 years.

At the same time the method of moving averages has produced the smoothed curves of the time series, by means of which it is easier to compare simultaneous changes of various climatic elements. Such a comparison has shown that the annual values of air pressure and rainfall changed mainly in the opposite direction (Fig. 2) and that the fluctuations of the climate in October were more explicit, as they were observed on several climatic elements at the same time (Fig. 3).

From the position of the main or secondary extremes on the smoothed curves for October, six climates can be distinguished since the beginning of the measurements (Tab. 6). The climate number I stands out by low pressure, the

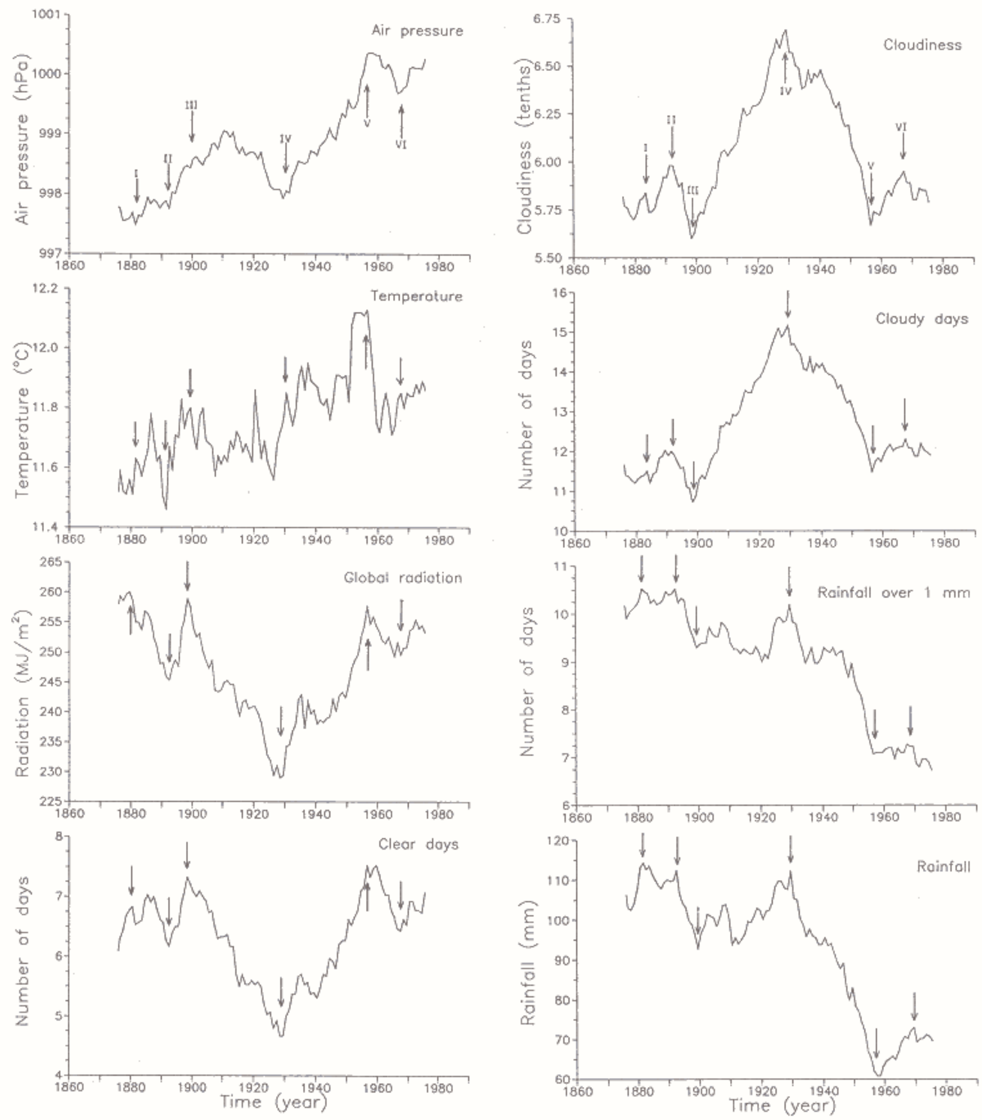

Figure 3. Moving averages of some climatic elements in Zagreb for October.The values are placed above the middle of the corresponding period of 30 years.

great amount of rainfall and many rainy days. The climate number II was relatively cold with the increased number of cloudy days and with decreased amount of global radiation. The climates number III and V are sunny (low mean cloudiness, few cloudy days, high global radiation) and dry (little rain and few rainy days), and the latter is besides warm, with the higher air pressure. The

Table 6. Most distinguished climates in October, observed between 1862 and 1990.

Ordinal number	Period	
I	1867–1896	
II	1876–1905 to 1878–1907	
III	1884–1913,	1885–1914
IV	1914–1943,	1915–1944
V	1942–1971,	1943–1972
VI	1854–1983,	1955–1984

climate number IV is characterized by the lower air pressure, little sunshine and rainy weather. The climate number VI is similar to the climate number IV, only the values of particular elements are not so conspicuous.

Other months also display the changes of some climatic elements occurring in the same direction. For example, in December an increase in temperature, cloudiness and the number of days with rainfall started in the period 1871–1900. This increase ended in the period 1898–1927 for temperature, and in the period 1904–1933 for cloudiness and the days with rainfall. In no other month, however, there is such a great correspondence of so many peaks on so many different curves as it is recorded in October.

4. Conclusion

The elementary analysis, by simple methods, shows that secular meteorological time series in Zagreb contain various climatic variations. A few of them are already known from papers dealing with climatic changes in Zagreb or at some other secular meteorological stations. We did not examine the immediate causes of the variations here. One should look for them firstly in changes of the prevailing atmospheric circulations over the middle and southern Europe because of the known fact that the zonal flow causes the different weather than the meridional one. Even more, during the prevailing meridional flow the different position of the blocking high could perhaps produce the difference similar to the one we have found in October between the climate III and the climate V. For the time series with significant trend it will be necessary to examine a relation between the expansion of the town area and the climatic series in question.

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Corresponding author's address: B. Penzar, Andrija Mohorovičić Geophysical Institute, Faculty of Science, University of Zagreb, Horvatovac bb, 41000 Zagreb, Croatia.