UDK: 551.577.34
Originalni znanstveni rad

Stationarity, Trend and Periodicity of Precipitation at the Zagreb-Grič Observatory from 1862 to 1990

Stacionarnost, trend i periodičnost oborine na opservatoriju Zagreb-Grič u razdoblju 1862-1990.

Marjana Gajić-Čapka

Državni hidrometeorološki zavod, Zagreb, Hrvatska

Primljeno 29. siječnja 1992, u konačnom obliku 16. ožujka 1992.

Abstract

This paper deals with the climatic change in the annual, warm half-year and cold half-year precipitation data during the last 129 years, since the beginning of the series in 1862 to 1990, at the Zagreb-Grič Observatory (φ = 45° 49′, λ = 15° 59′, H = 159 m a.s.l.) located in the northwestern part of Croatia. The analysis has been deduced by using tests for normality, the "quick test" for stationarity according to Schönwiese and Malcher, weighted moving average filters, the Mann-Kendall rank statistic for trend, and the power spectrum analysis.

This analysis shows the stationarity of time series of precipitation amounts. A generally decreasing, not statistically significant trend is present over the entire time interval (1862-1990). The annual and warm half-year precipitation spectra can be fitted by Markov "red noise" continuum and the cold half-year precipitation series by that of "white noise". Quasi-periodic oscillations appear in two spectra ranges: short (2 - 6 years) and medium (16 - 43 years).

Key words: precipitation, stationarity, trend, periodicity, power spectrum, Zagreb, Croatia

Sažetak

Istraživane su klimatske promjene oborinskog režima na području Zagreba. Korišteni su podaci godišnjih količina oborine i količine oborine toplog i hladnog polugodišta opservatorija Zagreb-Grič u posljednjih 129 godina, odnosno od početka mjerenja 1862. godine pa do 1990. godine. Analiza je provedena primjenom testa za normalnost, "brzog testa" za stacionarnost prema Schönwieseu i Malcheru, filtriranja otežanim kliznim srednjacima, Mann-Kendallovog rang testa za trend i analizom spektra snage.

Prema ovoj analizi utvrđena je stacionarnost vremenskih nizova oborine. Prisutan je općenito padajući, ali ne statistički signifikantan, trend u cijelom promatranom dugogodišnjem nizu (1862-1990). Spektri snage godišnjih oborina i oborina toplog polugodišta mogu se prilagoditi kontinuumom "crvenog šuma", a hladnog polugodišta kontinuumom "bijelog šuma". Kvazi-periodične oscilacije javljaju se u dva intervala spektra: kratkom (2-6 godina) i srednjem (16-43 godine).

Ključne riječi: oborina, stacionarnost, trend, periodičnost, spektar snage, Zagreb, Hrvatska

1. Introduction

Precipitation variability influences many branches of human activity. Changes in the annual and seasonal precipitation from one year to the next one are seriously reflected first of all in water management and agriculture. The fact that, according to Zagreb data, the last few decades show less precipitation, with smaller variations than the previous years, has posed the question of the significance of this phenomenon, and attracted attention to the general characteristics of a long-term precipitation series in the north-western part of Croatia (Gajić-Čapka, 1991). As the Zagreb-Grič observatory posseses the longest uninterrupted meteorological data series in Croatia, starting from 1862, precipitation data for the time interval 1862-1990 represent valuable material for this analysis.

Among the papers dealing with climate change in Croatia there are some treating the problem of long-term fluctuations in precipitation. Goldberg (1953) and Juras (1985) analyzed the changes in the annual courses of climatological elements as indicators of climatic changes in Zagreb. The analysis conducted by Juras for the period 1862-1980, stated that no constant trend could be seen over the entire interval, but an exchange of rather different climatic 30-year intervals was present. Penzar et al. (1967) investigated variations of precipitation using the method of moving averages, the method of cumulative deviations from the mean, and the method of gravity centre. The annual amounts of precipitation showed no significant variation, and after the central limit theoreme, there were no well-marked periods of dry and wet years in the time interval 1862-1964. Pleško and Šinik (1968) searched for climatologically stable period, calculated by means of prolonged means, for the Climatic Atlas of Yugoslavia. Investigations of precipitation trends in Zagreb during the time intervals 1862-1980 and 1862-1990 indicated no significant trend over the entire interval (Gajić-Čapka, 1982, 1990, 1991). The works by Maheras and Kolyva-Machera (1990) and Rako (1991) include long-term precipitation data over Croatia in a comparison of the precipitation time series over the Balkans and in Central Europe during the last century.

The objectives of this paper are to examine the stationarity, the trend and the periodicity of the annual, warm half-year (April-September) and cold half-year (October-March) precipitation amounts in Zagreb from 1862 till 1990, using methods that will enable comparison with the same results for Europe.

2. Data analysis and results

2.1. Basic statistics

For each of the three precipitation variables the basic statistical parameters were calculated for the entire time interval 1862-1990 as well as for the subintervals 1862-1960, 1961-1990, 1862-1970 and 1971-1990. Their means, medians, variations and cumulative distribution functions were compared and tested.

In order to use statistical tests in the analysis of the precipitation series, it was necessary to examine the nature of their frequency distribution. Each of the precipitation series was tested for normality at the 95 % confidence level applying the criterion of standardized skewness and standardized kurtosis:

$$-1.96 \le \gamma_1 \,/\, SE(\gamma_1) \le 1.96$$
$$-1.96 \le \gamma_2 \,/\, SE(\gamma_2) \le 1.96$$

where γ_1 is the coefficient of skewness and $SE(\gamma_1)$ its standard error, γ_2 is the coefficient of kurtosis and $SE(\gamma_2)$ its standard error.

The above conditions are not completely fulfilled for all precipitation series. For those marked * in Table 1, the values of standardized skewness exceed the upper limit of the criterion. Therefore, the testing of differences between the means and the ratios of the variances in the two pairs of subintervals: 1961-1990 in relation to 1862-1960, and 1971-1990 in relation to 1862-1970, could give inadequate results when applying the Student's t-test and F-test (Brooks and Carruthers, 1953). In order to avoid the limits of assuming that the data of the series have the normal distribution, two non-parametric me-

Tab. 1. Basic statistics of the annual precipitation amounts (ZY), warm half-year amounts (ZW) and cold half-year amounts (ZC) at Zagreb- Grič for the time interval 1862-1990 and the time subintervals: 1862-1960, 1961-1990, 1862-1970, and 1971-1990.

Tab. 1. Osnovna statistika godišnjih količina oborine (ZY), količina oborine za toplo polugodište (ZW) i hladno polugodište (ZC) na opservatoriju Zagreb-Grič u razdoblju 1862-1990 i podrazdobljima: 1862-1960, 1961 -1990, 1862-1970 i 1971-1990.

	1862-1990		
	ZY*	ZW	ZC
Mean (mm)	887	496	391
% of annual amount		55.9	44.1
Median	878	488	392
Stand. deviation (mm)	148.8	109.8	99.7
Coeff. of variation	0.168	0.222	0.255
Minimum (mm)	581	235	186
Maximum (mm)	1387	765	665
Skewness	0.437	0.278	0.254
Standardized skewness	2.025	1.291	1.175
Kurtosis	0.094	-0.146	-0.229
Standardized kurtosis	0.217	-0.338	-0.529

	1862-1960			1961-1990		
	ZY*	ZW	ZC	ZY	ZW	ZC
Mean (mm)	888	492	395	883	508	377
% of annual amount		55.4	44.5		57.6	42.7
Median (mm)	873	484	390	899	490	403
Stand. deviation (mm)	152.9	111.7	100.2	136.4	104.1	98.1
Coeff. of variation	0.172	0.227	0.253	0.143	0.205	0.260
Minimum (mm)	581	235	186	607	327	203
Maximum (mm)	1387	765	665	1116	753	557
Skewness	0.581	0.216	0.362	-0.294	0.642	-0.153
Standardized skewness	2.361	0.878	1.465	-0.658	1.435	-0.343
Kurtosis	0.197	-0.272	-0.125	-0.632	0.451	-0.874
Standardized kurtosis	0.399	-0.552	-0.252	-0.707	0.504	-0.977

	1862-1970			1971-1990		
	ZY*	ZW	ZC	ZY	ZW*	ZC
Mean (mm)	893	497	397	850	487	360
% of annual amount		55.7	44.5		57.2	42.4
Median (mm)	878	488	393	878	476	353
Stand. deviation (mm)	151.1	108.9	99.2	132.8	117.4	99.0
Coeff. of variation	0.169	0.219	0.250	0.156	0.241	0.275
Minimum (mm)	581	235	186	607	327	203
Maximum (mm)	1387	765	665	1087	753	557
Skewness	0.483	0.100	0.263	-0.184	1.209	0.258
Standardized skewness	2.058	0.428	1.116	-0.337	2.208	0.472
Kurtosis	0.047	-0.252	-0.137	-0.450	1.139	-0.734
Standardized kurtosis	0.100	-0.536	-0.291	-0.411	1.040	-0.670

* data have no normal distribution

* razdiobe nisu normalne

thods for the comparison of two samples have been applied: the pairs Mann-Whitney test for median and the Kolmogorov-Smirnov two-sample test for the comparison of the maximum absolute deviations between two cumulative distribution functions (Gibbons, 1976; Hollander and Wolfe, 1973). It can be concluded from the high probability of the

Tab. 2. Comparison of precipitation series in the subintervals (A) 1961-1990 and 1862-1960 as well as (B) 1971-1990 and 1862-1970 at Zagreb-Grič.
Tab. 2. Usporedba oborinskih nizova podrazdoblja (A) 1961-1990 i 1862-1960 kao i podrazdoblja (B) 1971-1990 i 1862-1970 za Zagreb-Grič.

	Mann-Whitney test for median		Kolmogorov-Smirnov two sample test	
A	Z statistic	sig. level α	Dn statistic	sig. level α
ZY	-0.120	0.905	0.131	0.822
ZW	-0.742	0.458	0.179	0.453
ZC	0.554	0.580	0.142	0.742
B	Z statistic	sig. level α	Dn statistic	sig. level α
ZY	1.031	0.302	0.184	0.614
ZW	0.765	0.444	0.208	0.459
ZC	1.431	0.153	0.228	0.345

Mann-Whitney sample test statistic Z ($\alpha > 0.05$) that the medians in the two subintervals do not differ significantly from those in the preceding long-term intervals for all three precipitation variables. The application of the Smirnov-Kolmogorov test indicates that the cumulative distributions for all three precipitation variables in the last 20- and 30-year time intervals are not significantly different from the cumulative distributions in the preceding long-term intervals at the 5 % significance level (Table 2).

2.2. Stationarity analysis

The statement of stationarity or non-stationarity of the first moment of the time series was deduced using the "quick test" for stationarity according to Schönwiese and Malcher (1985):

$$st = \pm\, s \sqrt{\frac{n}{l(l-1)}}$$

where s is the standard deviation of a series, n is the size of the series and l is the size of a sub-interval. If the low-pass filtered data fall within the interval st about the long-term mean, it means that there are no statistically significant fluctuations. The precipitation data series were smoothed by means of the 30-year weighted moving average in order to remove the short-term fluctuations. The "quick test" for stationarity points at no significant time variations of annual or warm and cold half-year precipitation amounts in the last 129-year time interval in Zagreb (Fig. 1, left).

The same method applied to the annual precipitation sums at some locations to the north of the Zagreb area, in the Austrian Alps (Auer, 1991) and in Frankfurt on Maine, Germany (Schönwiese and Malcher, 1985) stated some significant time variations, that means non-stationarity, contained in time intervals both in the 19th and 20th centuries.

At the same time the south of the Balkans experienced significant above-average annual rainfall totals around 1920 and in the early 1940's and below-average rainfall amounts in the late 1940's (Flocas et al, 1990).

2.3. Trend analysis

The next step in the analysis of the precipitation time series was the investigation of the trend, to see whether a monotonic increase or decrease exists in the average value between the beginning and the end of the series.The annual, warm and cold half-year precipitation series were subjected to testing for dominant trend using the Mann-Kendall

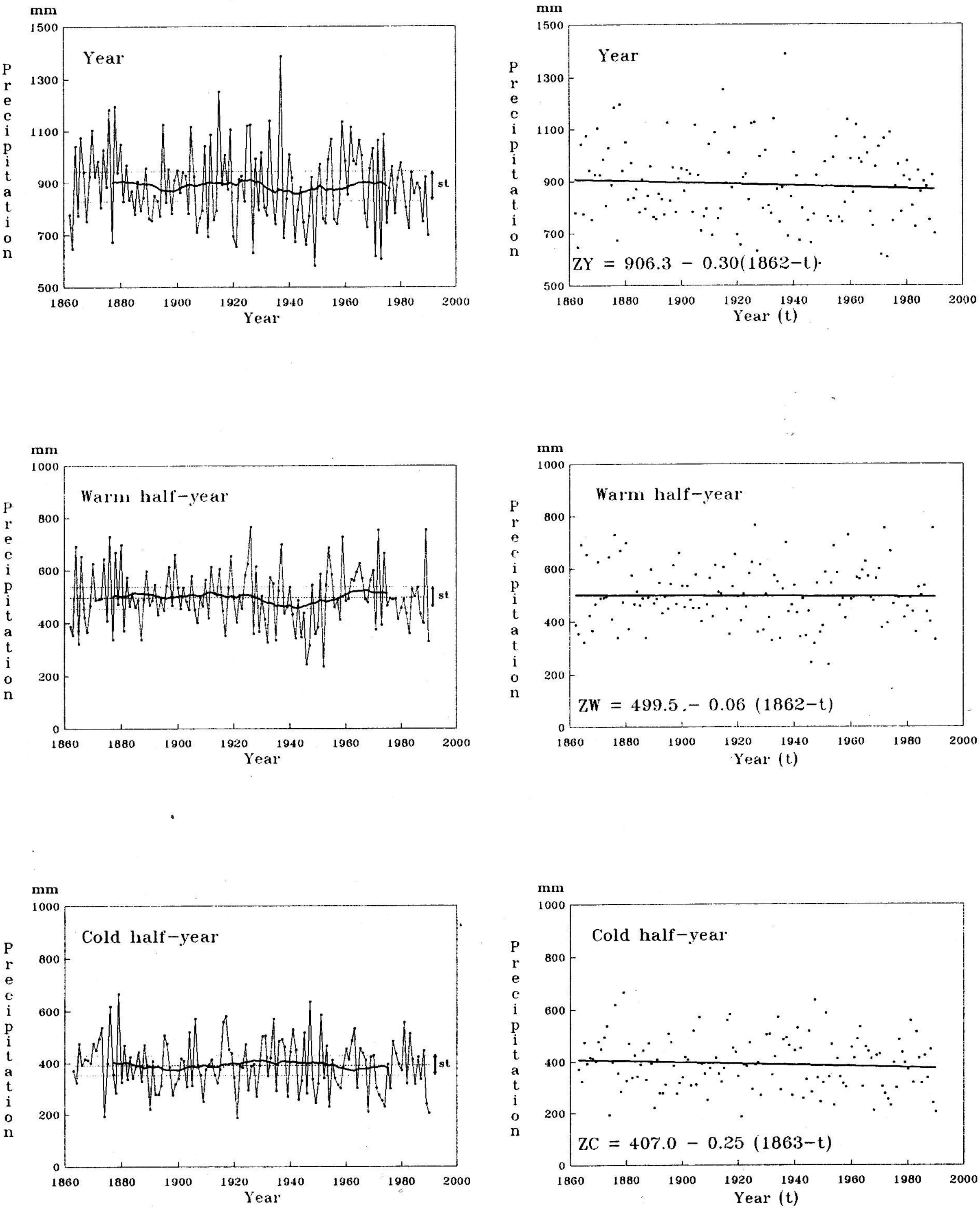

Fig. 1. Precipitation amounts and their 30-year weighted moving average series with the corespondent stationarity intervals (left) and linear trends (right) in the time interval 1862–1990 at Zagreb-Grič.

Sl. 1. Količine oborine i njihovi 30-godišnji otežani klizni srednjaci s pripadnim intervalima stacionarnosti (lijevo) i linearni trendovi (desno) u razdoblju 1862–1990. na Zagreb-Griču.

Tab. 3. Mann-Kendall rank coefficients (τ), and their significance levels (α) for annual (ZY), warm half-year (ZW), and cold half-year (ZC) precipitation amounts at Zagreb-Grič in the period 1862-1990.

Tab. 3. Mann-Kendallovi koeficijenti ranga (τ) i njihove razine signifikantnosti (α) nizova količine oborina za godinu (ZY), toplo polugodište (ZW) i hladno polugodište (ZC) za Zagreb-Grič u razdoblju 1862-1990.

	τ	α
ZY	-0.053	0.37
ZW	-0.009	0.88
ZC	-0.059	0.32

rank statistic (Kendall and Stuart, 1961; Mitchell et al, 1966; Sneyers, 1975). The results appear in Fig. 1 (right) and Table 3, and clearly show a general tendency of decrease in precipitation over the time interval considered. A decreasing trend, although not significant at the 95% confidence level was present over the entire time interval 1862-1990. According to the linear curve slopes, the cold half-year precipitation decrease mainly contributed to the decrease of the annual precipitation amounts, i.e. an estimate of the changes in the mean annual precipitation amounts during the last 129 years, expressed in mm, amounts to 0.30 mm per year; of which 0.24 mm in the cold half-year (October to March) and 0.06 mm in the warm half-year (April to September). Compared with the long-term mean amounts it means that the annual precipitation was decreasing by 0.03% per year and the half-year amounts by 0.06% per year in the cold half-year and by 0.01% per year in the warm half-year. The general results in the trend in the Zagreb annual data are in accordance with the results by Maheras and Kolyva-Machera (1990) deduced for the Balkans.

2.4. Autocorrelation and power spectra

In order to gain knowledge about the periodicities involved in the precipitation series, the variance spectra of the annual, warm half-year and cold half-year totals have been calculated from the autocorrelations, which measure the correlation between precipitation data with different time lags (Mitchell et al., 1966). In these calculations of autocorrelation coefficients, a maximum time lag of 30 years was used. Autocorrelation coefficients vary from -0.25 to 0.19 (year), -0.24 to 0.16 (warm half-year) and -0.21 to 0.20 (cold half-year). They rarely exceed the correspondent confident limits: for the time lags $\tau = 1$ year and $\tau = 16$ years (year), and for $\tau = 1$ year (warm half-year) (Fig. 2, left). Autocorrelation coefficients exceeding the limits of significance can change according to the analyzed time interval. This can possibly be an explanation for the presence of a peak at a time lag of 7 years in the autocorrelogram of the annual precipitation amounts in Zagreb in the analysis by Maheras and Kolyva-Machera (1990), for the period 1894-1985.

Next the "row estimates" of the power spectrum with a maximum lag m=64 have been calculated by means of the Fast Fourier Transform procedure. In order to determine the significant peaks in the calculated variance spectra, the theoretical curve with its 95% confidence level have been fitted as described by Mitchell et al (1966). In the series of the annual and warm half-year precipitation totals, the lag-one autocorrelation coefficients r_1 differ significantly from zero, and so both spectra may be interpreted as spectra of the Markov "red noise" process. This means that these series are in fact non-random at the 95% significance level, and that they contain a sort of periodicity. In the series of cold half-year precipitation the lag-one autocorrelation coefficient r_1 does not differ significantly from zero. In this case the "null" continuum is that of "white noise", defined as a straight line the values of which are always equal to the "average" of all $m+1$ values of "row spectral estimates" in the calculated spectrum. The "row estimates" with the corresponding "null" continuum curves along with their 95% confident limits, derived for a degree of freedom $\nu = 3.5$ (Mitchell et al, 1966), are plotted against frequency f and presented in Fig. 2 (right).

The results show that the quasi-periodic

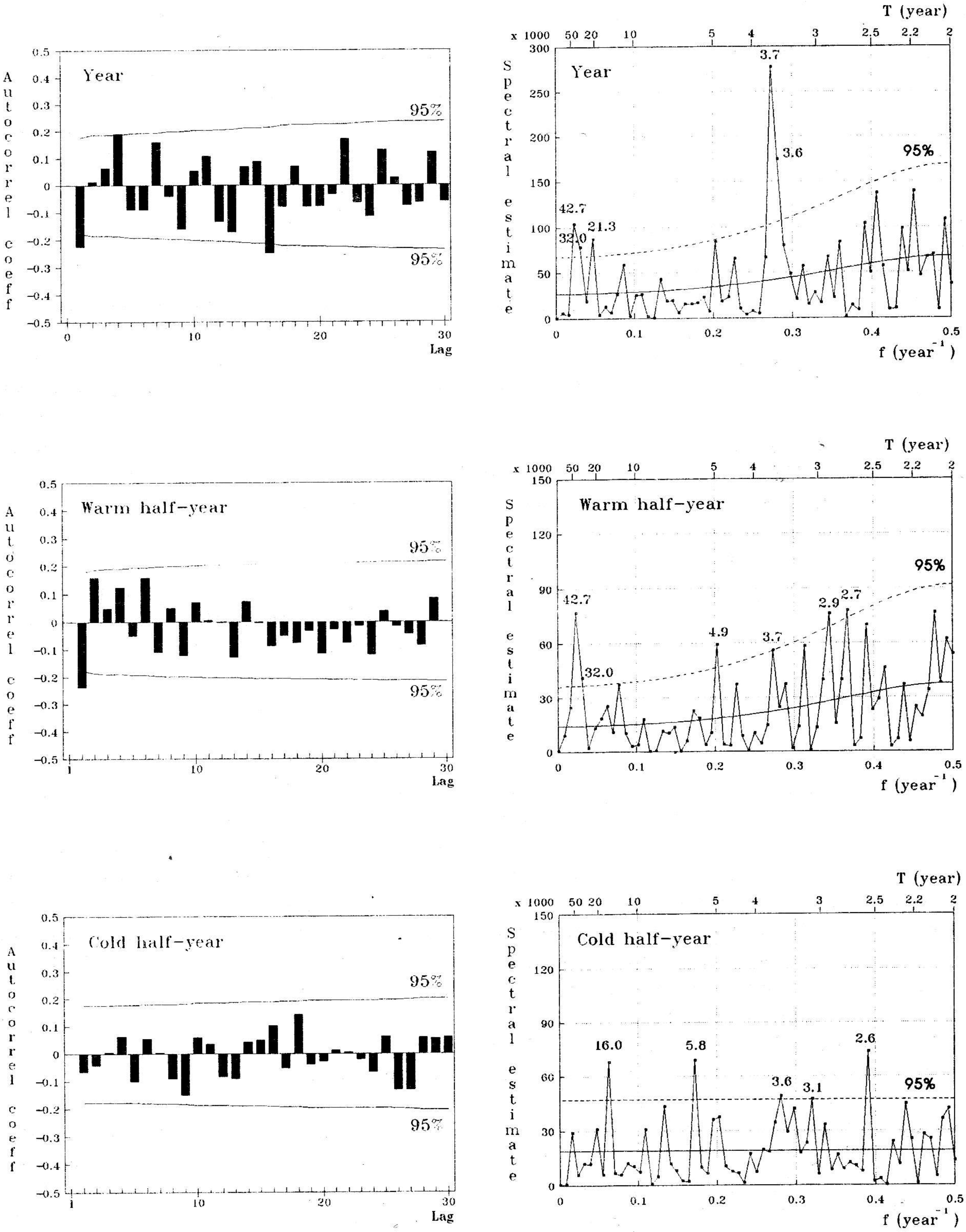

Fig. 2. Autocorrelograms with the corresponding 95% confidence limits (left) and the power spectra with their "null" continuum curves and 95% significance limits (right) of the precipitation series at Zagreb-Grič in the period 1862-1990.

Sl. 2. Hod koeficijenata autokorelacije s pripadnim 95% granicama povjerenja (lijevo) i spektri snage s izglađenim krivuljama i pripadnim 95% granicama povjerenja za nizove oborine na Zagreb-Griču u razdoblju 1862-1990.

Tab. 4. Statistically significant periods (year) of power spectra at the 95% significance level; • denotes the highest value of power spectrum in the frequency interval f = 0.0 - 0.5 year^{-1}.

Tab. 4. Statistički signifikantni periodi (god) u spektru snage na 95% nivou signifikantnosti; • označuje najveću vrijednost spektra snage u intervalu frekvencija f = 0.0 - 0.5 god^{-1}.

Precipitation	Periods											
Annual					3.6	3.7•				21.3	32.0	42.7
Warm half-year		2.7•	2.9			3.7	4.9				32.0	42.7
Cold half-year	2.6•			3.1	3.6			5.8	16.0			

oscillations identified for the three precipitation series are concentrated mainly in the two spectra ranges: short periods (2-6 years) and medium periods (16-43 years). Long periods (> 50 years) are absent.

The results in Table 4 also show that the quasi-biennial oscillations that appear in the half-year precipitation series, are absent in the annual one. The best pronounced period in the warm half-year series is that of 2.7 years. The ≈ 2.5 period could probably be related to the quasi-biennial oscillation of the zonal wind. The quasi-triennial oscillation of ≈ 3.5 years is common for all series and the peak of 3.7 years is best pronounced for the annual precipitation series. The quasi-periodic oscillation of ≈ 5-6 years identified in the warm and cold half-year series, does not appear as significant in year one. The presence of a large number of peaks at small periods up to 5 years, reflects a large inter-annual variability of precipitation. The quasi-biennial oscillation and the oscillation within the 4-5 year period range exist in most spectra of the European annual precipitation series (Neuber and Schönwiese, 1985). It is worth to mention that this analysis has been done without the data over the Balkans. Therefore, the results of this study add to the knowledge about precipitation variability in this part of Europe.

Oscillations of medium periods (21 and 43 years) are contained in the spectrum of the annual and warm half-year series and those of 16 years in the cold half-year spectrum. The periods of 9 to 12 years, being the characteristic length of the sunspot "cycles", are not involved as significant peaks in the Zagreb precipitation series studied. The results of Dehsara and Cehak (1970) stated no direct influence of solar activity on meteorological elements (precipitation and temperature) on a large time scale worldwide. A more recent study of central Europe indicates that short and medium periods with lengths of 2-5 years and 10-16 years, appear as significant (Brazdil, 1985). Over northern Europe there exists a 16 year cycle and in southern central Europe there is a longer "cycle" of 20-22 years while periods of about 6-7 years (short term) and 10-12 years (medium term) are evident over much of the continent (Camuffo, 1984; Neuber and Schönwiese, 1985; Vines, 1985; Colacino and Purini, 1986). According to them the 11 year period could probably be related to the solar cycle while the 20-22 year period could be linked to the double sunspot cycle. In the considered precipitation data in Zagreb and over Greece (Flocas et al, 1990) the 11 year period does not distinguish itself as a significant one. It is probably covered by the noises of the same or greater magnitude, that can deform the amplitude and the period of the disturbance, but can not destroy its presence.

3. Conclusions

Investigation of the annual and half-year precipitation series in Zagreb since 1862 presents a contribution to the knowledge about fluctuations in precipitation amounts during more than a hundred year, following earlier papers for Europe, which in most cases, did not include data about precipitation in Croatia. The fluctuation of precipitation in Zagreb, both annual and warm and cold half-year amounts, has remained within the stationarity interval over the past 129 years according to the 30-year weighted moving averages.

The study of trend has demonstrated that there was a continuing but not pronounced or significant decrease in precipitation over the considered long-term interval. The presence of quasi-biennial oscillation (≈ 2.5 years) is evident in half-year precipitation amounts, while it does not appear to be significant in annual precipitation spectrum. The quasi-triennial oscillation (≈ 3.5 years) is common for all three series and is the most pronounced one for annual amounts. Oscillations with longer periods belong to the range 16-43 years. Of the two spectral bands (≈ 3.5 years and 21-43 years) identified in the annual precipitation series, the quasi-triennial oscillation and the oscillation with a period of about 22 years are consistent with the quasi-periodic oscillation reported in other studies on the fluctuations of European annual precipitation, while the quasi-periodic oscillations with periods of 32 and 43 years are not commonly found. Quasi-periodic oscillations of 6-7 years and 10-16 years found elsewhere in annual precipitation have not been identified in this study for Zagreb.

Acknowledgment Thanks are due to the Ministry for Science, Technology and Information of the Republic Croatia for financial support.

References:

Auer, I., 1990: Zeitliche Variationen von Niederschlags Summen in Alpinen Regionen Osterreichs. Veröffentlichungen der Schweizerischen Meteorologischen Anstalt, 48. 21. Internationale Tagung für Alpine Meteorologie, Tagungsbericht, 1. Teil, Engelberg, Schweiz, 323-326.

Brazdil, R., 1985: Variation of spatial annual precipitation sums in Central Europe in the period 1881-1990. J. Climatol., 5, 617-631.

Brooks, C. E. P., and N. Carruthers, 1953: Handbook of statistical methods in meteorology, Meteorological Office, London, 412 pp.

Camuffo, D., 1984: Analysis of the series of precipitation at Padova, Italy. Climatic Change, 6, 57-77.

Colacino, M. and R. Purini, 1986: A Study on the Precipitation in Rome from 1782 to 1978. Theor. Appl. Climatol. 37, 90-96.

Dehsara, M. and K. Cehak, 1970: A Global Survey on Periodicities in Annual Mean Temperatures and Precipitation Totals. Arch. Met. Geoph. Biokl., Ser. B, 18, 253-268.

Flocas, A.A., Bloutsos, A.A. and B.D. Giles, 1990: Trends and periodicities of rainfall over Greece. In: Climatic Change in the Historical and the Instrumental Periods, ed. R. Brazdil, Masaryk University, Brno, 298-302.

Gajić-Čapka, M. 1982: Varijabilnost prosječnog oborinskog režima šire zagrebačke regije (Variability of the Zagreb area mean precipitation regime, Summary in English). Rasprave 17, Zagreb, 23-40.

Gajić-Čapka, M., 1990: Precipitation variability in Zagreb, Yugoslavia. In: Climatic Change in the Historical and the Instrumental Periods, ed. R. Brazdil, Masaryk University, Brno, 280-282.

Gajić-Čapka, M., 1991: Trend of precipitation at the SE edge of the Alps. Proceedings of the 21 th International Conference on Carpathian Meteorology, Uzhgorod, USSR, 337-344.

Gibbons, J.D., 1976: - Nonparametric methods for quantitative analysis. New York: Holt, Rinehart and Winston, 350 pp.

Goldberg, J., 1953: Prilozi istraživanju klimatskih fluktuacija u Jugoslaviji (Contribution to the examination of climatic fluctuations in Yugoslavia) Papers III, 3, Geophysical Institute, Zagreb,

Hollander, M. and D. A. Wolfe, 1973: Nonparametric statistical methods, New York, Wiley, 275 pp.

Juras, J.,1985: Neke karakteristike promjene klime Zagreba u posljednjem tridesetljeću (Some characteristics of climate change in Zagreb during the last thirty years). Geofizika 2, Zagreb, 93-102.

Kendall M. J. and A. Stuart, 1961: The advanced theory of statistics. Vol. 2, 3rd ed., New York, 676 pp.

Maheras, P. and F. Kolyva-Mahera, 1990: Temporal and spatial characteristics of annual precipitation over the Balkans in the twentieth century. Int. J. Climatol, 10, 495-504.

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

Neuber, E. und C.-D. Schönwiese, 1985: Spektral--statistische Charakteristika europeischer Niederschlagsreihen 1874-1980. Meteorol. Rdsch. 38, 54-62.

Penzar, B., Volarić, B. and I. Penzar, 1967: Prilog poznavanju sekularnih kolebanja temperature i oborine u Jugoslaviji (Contribution to the knowledge of secular fluctuations of temperature and precipitation in Yugoslavia). Papers of Hydrometeorological Institute of Yugoslavia, Belgrade, 63-89.

Pleško, N. and N. Šinik, 1968: Sekularne varijacije oborine u primjeni na Atlas klime SFRJ (Secular variations of precipitation according to the Climate Atlas of Yugoslavia), unpublished. Hydrometeorological Institute of Croatia, Zagreb.

Rako, L., 1991: Usporedba vremenskog niza oborina u Zagrebu s prilikama u Češko-Slovačkoj i Mađarskoj (Comparison of Zagreb precipitation timeseries with the conditions in Cheko-Slowakia and Hungary). Diplomski rad (B.D. Theses), Sveučilište u Zagrebu, Prirodoslovno-matematički fakultet, 69 pp.

Schönwiese, C.-D. and J. Malcher, 1985: Nicht-Stationarität oder Inhomogenität Analyse Klimatologischer Zeitreihen. Wetter u. Leben, 37, 181-193.

Sneyers, R., 1975: Sur l'analyse statistique des series d' observations. Note Technique, No 143, OMM-No 415, Geneve, 192 pp.

Vines, R.G., 1985: European rainfall patterns. J. Climatol, 5, 607-616.

Kratak sadržaj

Istraživanje vremenskih nizova godišnjih i polugodišnjih količina oborine za Zagreb--Grič od 1862. do 1990. godine provedeno je radi dopune znanja o kolebanju oborine na području jugoistočne Europe u proteklih više od sto godina, odnosno od kada postoje organizirana instrumentalna mjerenja.

Rezultati ove analize ukazuju da fluktuacije, kako godišnjih tako i polugodišnjih količina oborine, procijenjene prema hodu 30-godišnjih otežanih kliznih srednjaka, ostaju unutar njihovog intervala stacionarnosti (sl. 1, lijevo).

Ispitivanje trenda, odnosno postoji li monotoni pad ili porast u srednjim vrijednostima između početka i svršetka niza, utvrdilo je općeniti pad oborine za sve tri varijable u cijelom vremenskom intervalu 1862-1990, ali ne statistički značajno na 95% razini povjerenja (sl. 1, desno i tab. 3).

Autokorelogrami pokazuju da se vrijednosti koeficijenata autokorelacije za korak jedan razlikuju značajno od nule za godišnje količine oborine i količine oborine toplog polugodišta. Stoga se oba spektra snage mogu interpretirati kao spektri Markovljevog procesa "crvenog šuma", što u stvari znači da nizovi nisu slučajni i da sadrže neku vrstu periodičnosti. Kod oborine hladnog polugodišta koeficijent autokorelacije za korak jedan ne razlikuje se značajno od nule i njezin "nul" kontinuum spektra snage je onaj "bijelog šuma" (sl. 2).

Prisutnost kvazi- bijenijalne oscilacije (≈ 2.5 godine) očita je kod polugodišnjih količina oborine. Kvazi-trijenijalna oscilacija (≈ 3.5 godine) zajednička je za sva tri niza i najjača za godišnje količine. Oscilacije s duljim periodima pripadaju intervalu 16-43 godine. Od dvije spektralne vrpce (≈ 3.5 godine i 21-43 godine) uočene kod niza godišnjih količina oborine, kvazi-trijenijalna oscilacija i oscilacija s periodom oko 22 godine, zajedničke su s kvazi-periodičkim oscilacijama utvrđenim u drugim studijama o fluktuacijama godišnjih oborina u Europi, dok kvazi-periodičke oscilacije s periodima 32 i 43 godine nisu drugdje nađene. Kvazi-periodičke oscilacije od 6-7 godina i 10-16 godina nađene drugdje nisu utvrđene kao značajne u analizi godišnje oborine za Zagreb.