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Long-term trends and runoff fluctuations of European rivers

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Abstract In this paper the occurrence of dry and wet periods for 18 major European rivers during the period 1850–1997 is analysed. Annual discharge series were standardized for three regions: West/Central Europe, East Europe and North Europe, and for the whole of Europe. The statistical analysis of these series did not confirm any long-term increase or decrease in discharge during the last 150 years. Dry cycles of about 13.5 years and 28–29 years were identified. In East Europe the occurrence of the wet and dry cycles are shifted compared to North and West/Central Europe by a few years. Similar periods have been reported in other world rivers (Amazon, Congo) as well as in the Southern Oscillation, North Atlantic Oscillation and Pacific Decadal Oscillation phenomena. The time shift of cycles in different regions is the regularity related to general oceanic and atmospheric circulation.

Key words long-term trends; discharge; Europe; natural fluctuation; wet and dry cycles

INTRODUCTION

Detection of changes in river discharge is the most important and (at the same time) the most complicated step within water resources prediction. Statistical analysis of periodicity or wet and dry cycles depends on the availability of long-term data series. Systematic measurements of runoff in the modern era started relatively late. The longest time series are available in Europe, but they do not exceed 200 years, e.g. the Göta River (1807), Rhine (1808), Neman (1812), Dnieper (1818), Weser (1821), Danube (1840), Wuoksi (1847), Elbe (1851), Neva (1859) and Loire (1863) (starting date given in brackets).

The aim of this paper is to perform a trend and runoff fluctuation analysis of discharge time series of selected main European rivers. The European runoff data series were obtained from the Global Runoff Data Center in Koblenz, Germany, and from a CD-ROM of World Freshwater Resources prepared by Shiklomanov (2000).

METHODS AND DATA

The basic methods for time series analyses of observed data are exploratory data analysis and statistical tests for step changes, periodicities (cycles) and trends. Generally, the most common assumptions in trend testing are normality (population is distributed normally) and statistical independence (randomness) of observations (Kundzewicz & Robson, 2004; Sheng & Pilon, 2004; Xiong & Guo, 2004; Callède *et al.*, 2004; Radziejewski & Kundzewicz, 2004; Burn *et al.*, 2004). Our main aim was to find whether, and if so when, long-term dry and wet periods occurred in the European runoff series and 18 annual runoff series have been analysed. In addition we analysed the time lag of cycles between different regions, and trend occurrence in the series.

In order to identify the cyclic component in European rivers we used the Hodrick-Prescott filter and combined periodogram (Pekarova & Pekar, 2004; Pekarova *et al.*, 2003; Pekarova, 2003). The Hodrick-Prescott filter technique enables smoothing of the data series by increase of the α parameter value (the result for $\alpha \to \propto$ is the straight line). The combined periodogram method of Pekarova *et al.* (2003) consists in superposition of periodograms of different length of the same data series. Three statistical trend tests (tests of trend appearance, trend existence and for change in trend slope, according to Prochazka *et al.* (2001)) were used to identify a possible linear trend.

Missing data were completed by multiple regression of annual data (hydrological analogy) for the period 1850–1997 and standardized (value minus mean divided by standard deviation) average discharge time series were computed. The following number of discharge time series was used for the selected regions: eleven rivers in West/Central Europe, three rivers in East Europe and four in North Europe. Their locations are given in Fig. 1, and basic hydrological characteristics are presented in Table 1.

Fig. 1 Locations of the selected European rivers.

Table 1 Basic hydrological characteristics.

	River	Station	A	Since	To	Qa	qa	cs	cv	min	max	R
1	Thames	Kingston	10	1883	2000	78	7.9	0.12	0.29	30	132	2
2	Loire	Montjean	120	1863	1986	844	7.1	0.62	0.32	282	1967	27
3	Rhone	Mouth	99	1921	1986	2 052	20.7	–0.19	0.21	851	2932	65
4	Rhine	Koeln	144	1816	2000	2 087	14.5	–0.09	0.19	921	2996	66
5	Po	Pontelagoscuro	70	1918	1985	1 517	21.6	0.83	0.26	905	2617	48
6	Weser	Vlotho	18	1821	1999	172	9.8	0.11	0.26	62	284	5
7	Oder	Gozdowice	109	1900	2000	531	4.8	0.54	0.25	285	890	17
8	Vistula	Tczew	194	1900	1994	1 040	5.4	0.64	0.22	599	1780	33
9	Elbe	Decin	51	1851	2000	304	5.9	0.90	0.30	151	699	10
10	Danube	Orsova (1971:T. Severin)	576	1840	2000	5 583	9.7	0.44	0.17	3471	8265	176
11	Neman	Smalininkai	81	1812	1993	537	10.5	0.37	0.17	349	798	17
		West and Central Europe	1472			14 744	10.0					465
12	Dniepr	Locmanskaja Kamjanka	495	1818	1984	1627	3.3	0.77	0.33	673	3375	51
13	Don	Razdorskaya	378	1891	1990	778	2.1	0.87	0.40	286	1666	25
14	Volga	Mouth	1380	1882	1998	8 038	5.8	0.10	0.18	4541	12330	253
		East Europe	2253			10 443	4.6					329
15	Goeta	Vaenersborg	47	1807	2000	535	11.4	–0.003	0.19	225	855	17
16	Neva	Novosaratovka	281	1859	2000	2 499	8.9	0.24	0.16	1340	3670	79
17	N. Dvina	Ust-Pinega	348	1881	1998	3 332	9.6	0.35	0.19	1796	5245	105
18	Pechora	Mouth	320	1921	1987	4 352	14	–0.11	0.12	3154	5549	137
		North Europe	996			10 688	10.7					338

A – area (10^3 km^2), period of observation (Since – To), Qa – average annual discharge (m^{3}s^{-1}),
qa – mean annual specific yield (L s^{-1}km^2), cs – coefficient of asymmetry,
cv – coefficient of variation, min/max – minimal/maximal mean annual discharge (m^3 s^{-1}), R - annual runoff (10^6 m^{3}year^{-1}).

In recent years many scientists have studied relationships between the atmospheric phenomena of the Southern Oscillation (SO), Pacific Decadal Oscillation (PDO) and North Atlantic Oscillation (NAO), and certain hydroclimatic characteristics including runoff (Pekarova *et al.*, 2003). In this study we tried to identify the relation between the occurrence of dry and wet periods in Europe, and the Amazon and Congo basins. By the way of cross-correlation we were looking for the connection between runoff from these regions and NAO, SO, and PDO phenomena.

LONG-TERM CYCLES OF EUROPEAN DISCHARGE SERIES

The 18 time series of annual average discharge show that the driest year during the period 1850–1997 was the year 1921. Extremely wet years were found in 1926 as well as 1941 (Fig. 2). A correlation matrix of the 18 discharge series is presented in Table 2. Negative correlations exist between discharge series of North and East European rivers and those of West/Central Europe. The time shift in the dry periods between the Danube (West/Central Europe) and Neva (North Europe) runoff is shown in Fig. 3. Dry periods have a time lag of about 12 years. Typically, the dry periods in the Danube basin were accompanied by wet periods in the Neva basin in the 20th Century. Such analysis supports the hypothesis, that the dry periods do not occur in European rivers simultaneously, but they are shifted a few years depending on the location of the basins.

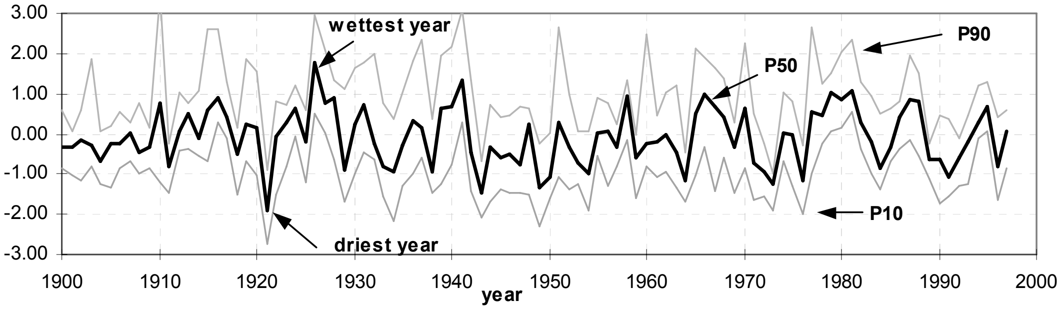

Fig. 2 Course of the 10, 50, and 90 percentiles (P10, P50 and P90) of the 18 standardized annual discharge time series of Europe for the 1900–1997 period. The driest year was 1921 and the wettest year, 1926.

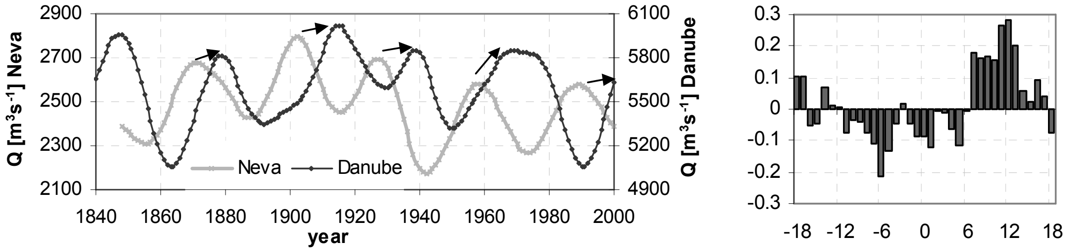

Fig. 3 Course of filtered annual discharge (m^3 s^{-1}) by Hodrick-Prescott filter HP for $\alpha = 400$, Danube and Neva – left. Cross-correlation between Danube and Neva discharge (raw data) – right (time shift in years between the series is given on the x-axis).

Table 2 Correlation coefficients of annual discharge time series 1850–1997, main European rivers.

	Thames	Loire	Rhone	Rhine	Po	Weser	Oder	Vistula	Elbe	Danube	Goeta	Neman	Dnieper	Don	Volga	Neva	Dvina	Pechora
Thames	1.00																	
Loire	0.58	1.00																
Rhone	0.56	0.91	1.00															
Rhine	0.50	0.72	0.73	1.00														
Po	0.44	0.52	0.58	0.23	1.00													
Weser	0.37	0.40	0.40	0.77	0.05	1.00												
Oder	0.36	0.41	0.35	0.56	0.18	0.52	1.00											
Vistula	0.36	0.38	0.32	0.51	0.13	0.46	0.70	1.00										
Elbe	0.30	0.47	0.44	0.66	0.15	0.62	0.82	0.61	1.00									
Danube	0.34	0.47	0.46	0.61	0.17	0.46	0.52	0.67	0.69	1.00								
Goeta	0.35	0.30	0.28	0.33	0.15	0.28	0.12	0.02	0.07	*-0.02*	1.00							
Neman	0.30	0.31	0.34	0.36	0.08	0.36	0.31	0.52	0.25	0.29	0.19	1.00						
Dnieper	0.17	0.19	0.15	0.27	*-0.01*	0.34	0.27	0.45	0.25	0.34	*-0.02*	0.48	1.00					
Don	0.19	0.10	0.13	0.18	0.10	0.22	0.32	0.29	0.30	0.31	*-0.03*	0.27	0.64	1.00				
Volga	0.14	0.02	0.02	0.14	*-0.08*	0.27	0.14	0.19	0.12	0.05	0.03	0.36	0.39	0.49	1.00			
Neva	0.07	*-0.05*	*-0.02*	0.02	*-0.07*	0.11	*-0.20*	*-0.10*	*-0.13*	*-0.09*	0.28	0.27	0.07	*-0.01*	0.21	1.00		
N. Dvina	0.00	*-0.03*	*-0.06*	0.03	*-0.21*	0.10	*-0.06*	*-0.05*	*-0.04*	*-0.09*	0.03	0.22	0.12	0.17	0.58	0.38	1.00	
Pechora	*-0.01*	*0.03*	*-0.01*	0.03	*-0.13*	0.07	*-0.11*	*-0.08*	*-0.08*	*-0.17*	0.01	0.11	*-0.04*	*-0.04*	0.16	0.32	0.36	1.00

From the 18 discharge series we computed the mean runoff series (annual discharges were summed and then standardized) representing the runoff from the whole of Europe (called representative series). According to the test of normality it follows that the representative series for the whole of Europe are normally distributed. Using the Number of Runs test we can reject the hypothesis H_0 on the significance level 0.05, that is that the representative discharge series from the whole of Europe are independent. The test detected autocorrelations in the series.

In Fig. 4 calculated values of the combined periodogram and autocorrelogram with confidence intervals of the representative discharge series from the whole Europe (1850–1997) are presented. There is a statistically significant negative dependence of the discharge on the value before six years. As we can see from the combined periodogram (Pekarova *et al.*, 2003) in Fig. 4, the statistically significant period in the annual series is of 12.8 years. The other periods are 28.5, 16.4, 9, 4.2, 3.55, and 2.4 years. The non-integer results of the combined periodogram do not indicate a relation to phenomena having a 12 months periodicity (Pekarova & Pekar, 2004). The 28–29 year cycle of runoff variability can be clearly identified in the Neva River series that is naturally regulated by the Russian and Finnish lakes. Similarly, the period of 13 years was found by Kane (1997) in the precipitation series of Brazil where forecasts of droughts based on significant periodicities (13 and 26 years) gave reasonably good results.

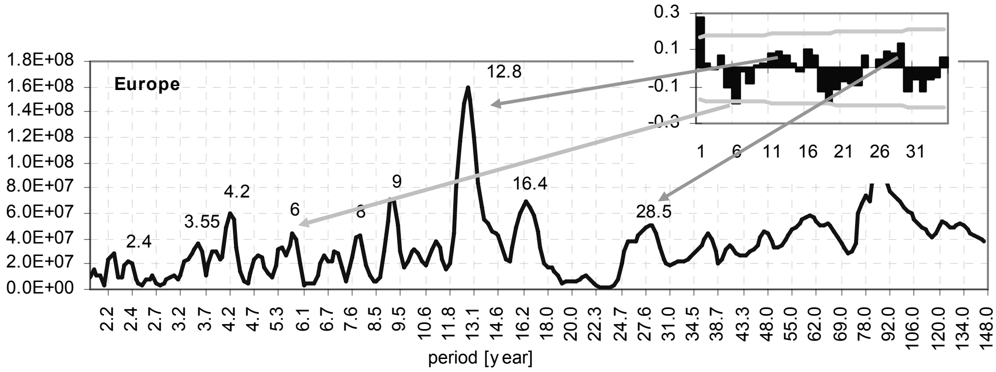

Fig. 4 Relationship between calculated values of combined periodogram (main figure) and auto-correlogram (upper right) for the representative discharge series of Europe.

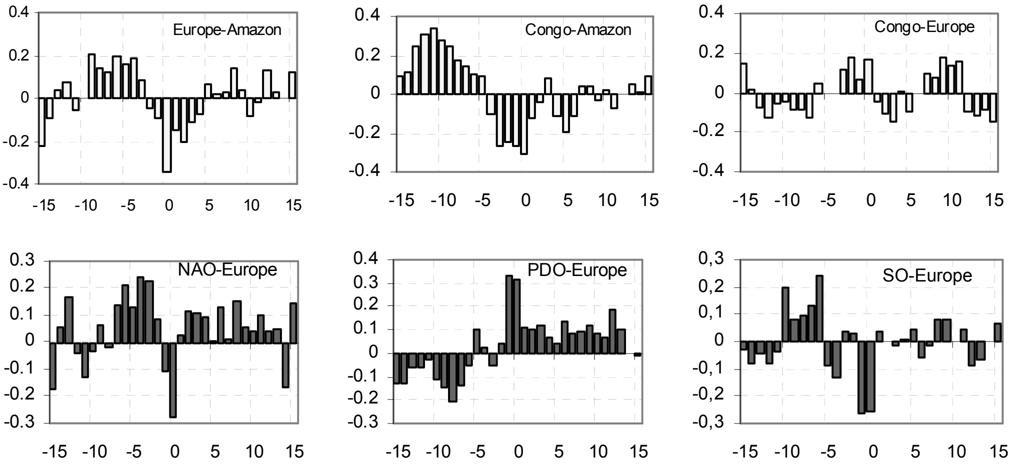

Fig. 5 Crosscorrelation between runoff (Europe, Amazon, Congo) and between runoff from Europe and NAO, PDO, and SO (time shift in years between the series is given on the x-axis).

By using cross-correlation we looked for connections between runoff from Europe and the Amazon and Congo basins, and NAO, SO, and PDO phenomena. The results of the cross-correlation analysis show a noticeable negative relationship between European runoff and the winter NAO index after Jones *et al.* (1997). Figure 5 shows that the cycle of the dry and wet period occurrence in the Amazon basin and Europe is inverse while the dry and wet periods in Europe and in the Congo basin are generally synchronous though sometimes the peaks are shifted by 1–2 years. The analysis shows that the occurrence of dry and wet years is not fully random in individual regions but teleconnection exists between the continents. The detailed analysis of major world rivers shows that the dry and wet periods occur in different periods in different continents.

LONG-TERM TREND OF EUROPEAN DISCHARGE SERIES

For the general analysis of the long term trend of European runoff we used the representative runoff series of the whole Europe and the three regions. The filtered standardized discharge data by Hodrick – Prescott HP filter of the West and Central European time series is presented in Fig. 6(a), that of East Europe in Fig. 6(b), and that of North Europe in Fig. 6(c). Finally, the representative runoff time series for the whole of Europe is presented in Fig. 6(d) for the period 1850–1997. The representative series of Europe was tested for long-term trends.

If we want to identify any trend uninfluenced by the periodicity of the discharge time series (e.g. 13-, or 28–29 years, or any other), we must determine the trend during a closed multiple loop,

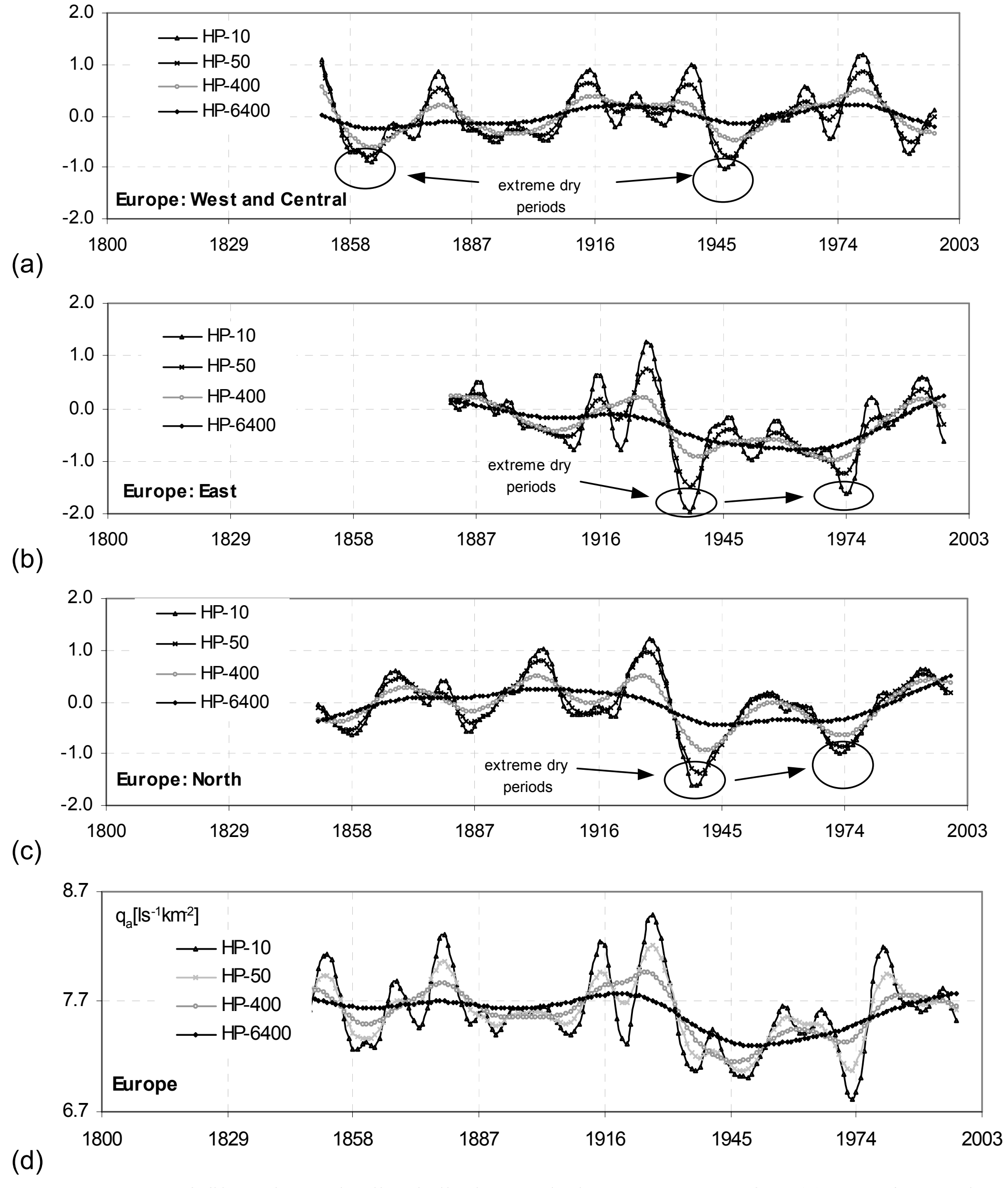

Fig. 6 Course of filtered standardized discharge during 1851–1997 for: (a) West/Central Europe; (b) East Europe; (c) North Europe; (d) Specific runoff from Europe, smoothed by Hodrick-Prescott filter HP for α = 10, 50, 400, 6400.

starting and terminating by either a minimum (e.g. 1858–1974 in Central Europe) or maximum (e.g. 1874–1988 in Central Europe). Trends determined for other periods are influenced by the periodicity of the series and depend on the position of the starting point on the raising or falling limb of the curve. In all trend tests, the H_0 hypothesis (the series fluctuates along its constant mean) was not rejected. The trend analysis does not show any significant linear trend in the long-term discharge series (1850–1997) in representative European discharge series.

From the analysis it follows that there is no statistically significant long-term continuous decrease or increase in the runoff. We can identify only dry and wet periods in river runoff series. In the case of cyclic series (and hydrological series are such) we cannot express the trend simply by the linear function and expect the continuation of the linear development in the future. If we want to apply the linear trend function, we must relate it to a specific period.

CONCLUSIONS

In this study, long-term trends and cyclicity in discharge time series of European rivers are identified. In Western Europe, extremely dry periods were those around the year 1860 and 87 years later around the year 1947. The runoff extremes (dry and wet periods) in West/Central Europe precede by 12 years the peaks in North Europe. The time lag increases with the distance between the basins. We can estimate the length of the cycles of dry periods as 12.8 and 28–29 years in both West/Central and North Europe regions. Generally, we can comment that the trend analysis did not show any significant trends in cumulative runoff series of the major European rivers in last 150 years.

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