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PLUVIAL CONDITIONS IN CRACOW AT THE END OF THE LITTLE ICE AGE

Abstract: The article presents an analysis of the variability of pluvial conditions in Cracow at the end of the Little Ice Age, based on the number of days with precipitation and precipitation totals. Monthly and yearly data were used from the period 1812-1998. The following statistical characteristics of the precipitation were calculated: variability coefficients, standard deviations, mean values. The study showed the dissimilarity of pluvial conditions in the early nineteenth century as compared to later periods, which showed a high interannual variability of precipitation, and a higher intensity of extreme precipitation events.

Key words: precipitation, number of days with precipitation, Little Ice Age, Cracow, Poland.

1. Introduction and Objective

The aim of this study is to define the variability of pluvial conditions in Cracow in the early 19th century. Recently, many scientists have been interested in this period which coincided with the end of the Little Ice Age. Many authors agree that this Little Ice Age ended ca. 1850 (Lamb 1966; Obrębska-Starkłowa 1997). The existing studies on the climate at the end of the Little Ice Age have shown diversity of thermal relations at the turn of the 19th century as compared to the later period (Trepieńska, Kowanetz 1997). The diversity consisted of high variability of the average annual air temperature, especially in the 1840's, and high thermal continental influence. A characteristic feature of the first decades of the nineteenth century in Cracow was the increase in the frequency and intensity of the extreme thermal conditions, which was visible in the form of cold winters and hot summers. On the other hand there were also warm winters and cool summers. It was not therefore a homogeneously cold period of an abnormal climatic character, which the name "Little Ice Age" could suggest.

2. Source Materials

The unique character of the meteorological data from the Cracow meteorological station relies on both the length of the series, and its high quality. It is one of the longest series of records in Poland, still continued at the same place. Because of the length of the series it stands as a reference point for studies on the evolution of climate in the Central Europe. The instrumental measurements of precipitation were launched in August 1849. Since the station's founding in 1792, visual observation records have been maintained, which thus included precipitation. The manner of recording such observations was described in detail in the instruction manual written by Śniadecki – the founder of the station. The records such as: light rain, rain, heavy rain, dew, and other were entered into the records under the heading 'atmosphere status'. Owing to Śniadecki's instruction manual, the precipitation observation records were homogenous despite the long period, which increases the data quality due to the homogeneity of time and place. Such records have been preserved complete, without disruptions, since 1812. Based on the number of days with precipitation, the monthly and annual precipitation totals have been reconstructed for the period between 1812 and 1849 (Twardosz 1999). This allows the scientists to use the precipitation data for Cracow from 1812.

3. Results

The number of days with precipitation is an important coefficient for assessment of pluvial conditions. The coefficient is more sensitive to diversity of circulation factors as compared to precipitation totals (Twardosz 1997). The course of annual number of days with precipitation shows rather regular fluctuations (Fig. 1a). In the early 19th century there was very high variability of the number of days with precipitation in a year, and there were periods of high and low frequency of precipitation. Especially high precipitation frequency was observed in the 1830's and 1840's. A record number of days with precipitation (231) was noted in 1844, which means that in 63% of days precipitation occurred. In July, there were 30 such days, in August – 27. The archive records show that rain occurred very often in July, and precipitation was noted during three observation times. The high numbers of days with precipitation, exceeding 200 (over 55% days in a year) also occurred in the following years: 1840 (201), 1845 (209), 1849 (219), 1850 (205). The second and third decade of the nineteenth century was the period of very low frequency of precipitation. And thus, the lowest number of days with precipitation amounted to 106, which equals to 29% of total days. This situation was observed in 1819. This value is paralleled by low numbers for particular months, from 4 days in September to 13 days in March. The low annual number of days with precipitation occurred in the following years: 1814 (127), 1816 (124), 1818 (108), 1824 (118), 1825 (108). Such high variability of pluvial conditions in the first half of the nineteenth century was also observed in the summer period (Fig. 1b), especially July (Fig. 1c) and August.

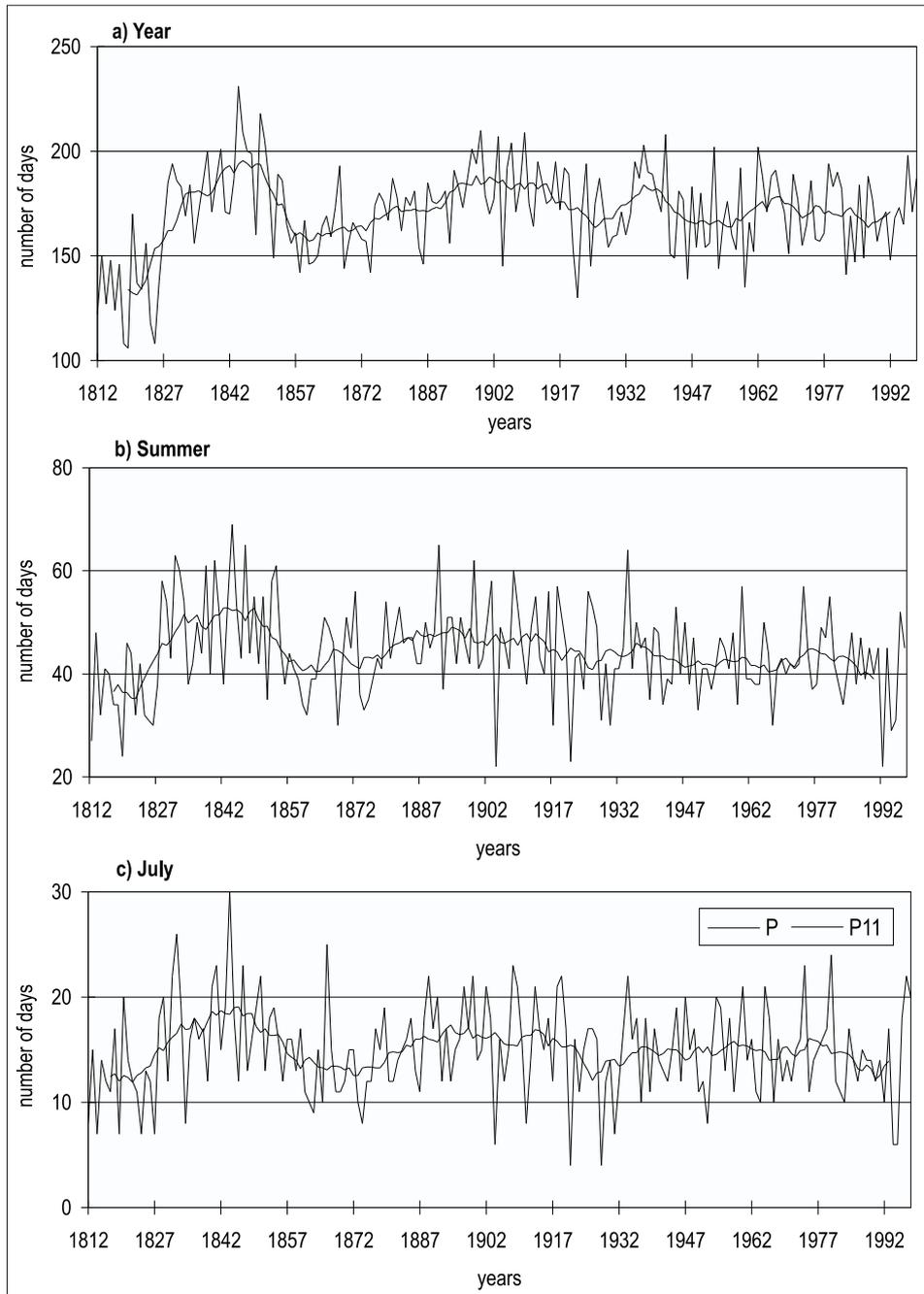


Fig. 1. Long-term variability of the number of days with precipitation in Cracow (1812-1998): P – values for each year, P11 – 11-year moving averages.

The very high dispersion of precipitation in the first half of the nineteenth century is confirmed by the course of the 11-year series of average values of variability coefficients of the annual number of days with precipitation (Fig. 2). In the late nineteenth century the variability in the number of days was smallest for the entire period between 1812 and 1998. Therefore the mid-nineteenth century marks a

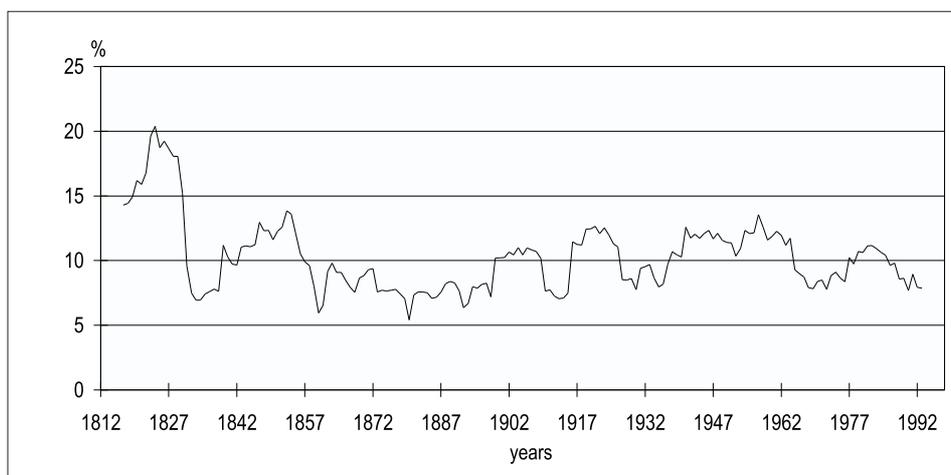


Fig. 2. 11-year moving averages of the variability coefficient values (in percent) of annual number of days with precipitation in Cracow (1812-1998).

Tab. 1. Statistical characteristics of the number of days with precipitation in Cracow in the years 1812-1849 (A) and 1850-1998 (B).

Months	Average value		Max.-Min.		σ^*		V**	
	A	B	A	B	A	B	A	B
I	13.1	14.9	19	17	4.6	4.5	34.8	30.3
II	11.7	13.4	17	23	5.1	4.5	43.5	33.6
III	14.2	14.1	20	22	4.6	4.5	32.5	32.3
IV	13.9	13.8	17	20	4.1	3.9	29.1	28.2
V	15.2	14.6	16	18	4.3	3.9	28.1	27.0
VI	15.5	15.1	19	23	4.6	4.1	29.3	27.0
VII	15.3	14.8	23	21	5.5	4.1	36.1	27.7
VIII	14.4	13.9	22	19	4.8	3.9	33.0	27.8
IX	11.7	12.7	17	18	4.8	3.9	40.7	30.4
X	12.7	14.1	18	27	5.3	5.2	41.5	37.1
XI	13.4	15.2	17	20	4.4	3.9	32.4	25.9
XII	13.9	15.7	21	21	4.5	4.4	32.2	27.6
Year	165	172	125	80	32.3	17.6	19.6	10.2

* σ - standard deviation, **V (in percent) – variability coefficient (standard deviation / average value)

borderline between the two periods of a different level of dispersion in pluvial conditions.

The main differences between the pluvial conditions in the early nineteenth century at the background of the long period are defined by the statistical course of days with precipitation. Therefore the series was divided into two sub-series covering the period between 1812-1849, and 1850-1998. In the light of the course of statistical characteristics (Table 1), it seems that the period between 1812 and 1849 is characterised by:

- a lower average of the annual number of days with precipitation, but very high range of deviations (125 days),
- higher average values of the number of days with precipitation from March to August,
- higher values of dispersion, i.e. standard deviation and variability coefficients for all months, especially for the summer and the entire year.

In the long-term course, there are also regular fluctuations (Fig. 3a). 1840's belonged to the especially wet years. The years with high precipitation totals predominated in a rather long period 1828-1855. On the other hand, the second and third decade and the turn of the 1860's were the periods of very low annual precipitation totals, with the lowest total reaching 429 mm in 1819. When we compared the course of wet and dry periods at the time of the end of the Little Ice Age in Cracow with the analogous periods in Prague (Fig. 3b), we observed a certain shift in time in their occurrence. The common feature of the course of precipitation is the low precipitation total in Cracow and Prague in the 1850's and the 1860's. Low precipitation totals at that time were also observed in other regions of Europe (Jones, Bradley 1992). In Prague, the wettest years included the 1830's. Therefore, the course of annual precipitation totals in Cracow and Prague points to the existence of regional differences in Central Europe as concerns the time of occurrence of wet and dry years at the end of the Little Ice Age. This may also be a result of the special differentiation of effects of the impact of circulation on the territory of Central Europe.

4. Conclusions

The Cracow series of precipitation records, because of its length and uniformity of observation point, presents a perfect material for analyses and comparisons aiming at learning about the past climatic conditions in Central Europe. It is also significant for formulating climatic forecasts, the definition of which is facilitated by rather regular fluctuations in the long-term course of precipitation.

The study showed the diversity of pluvial conditions in the early nineteenth century as compared to later periods, which showed a high variability of precipitation each year, and a higher intensity of extreme precipitation events.

The analysed variations in the pluvial regime ca. 1850 were most drastically observed in the annual and summer precipitation. The results obtained are in accordance with other studies concerning the period analysed.

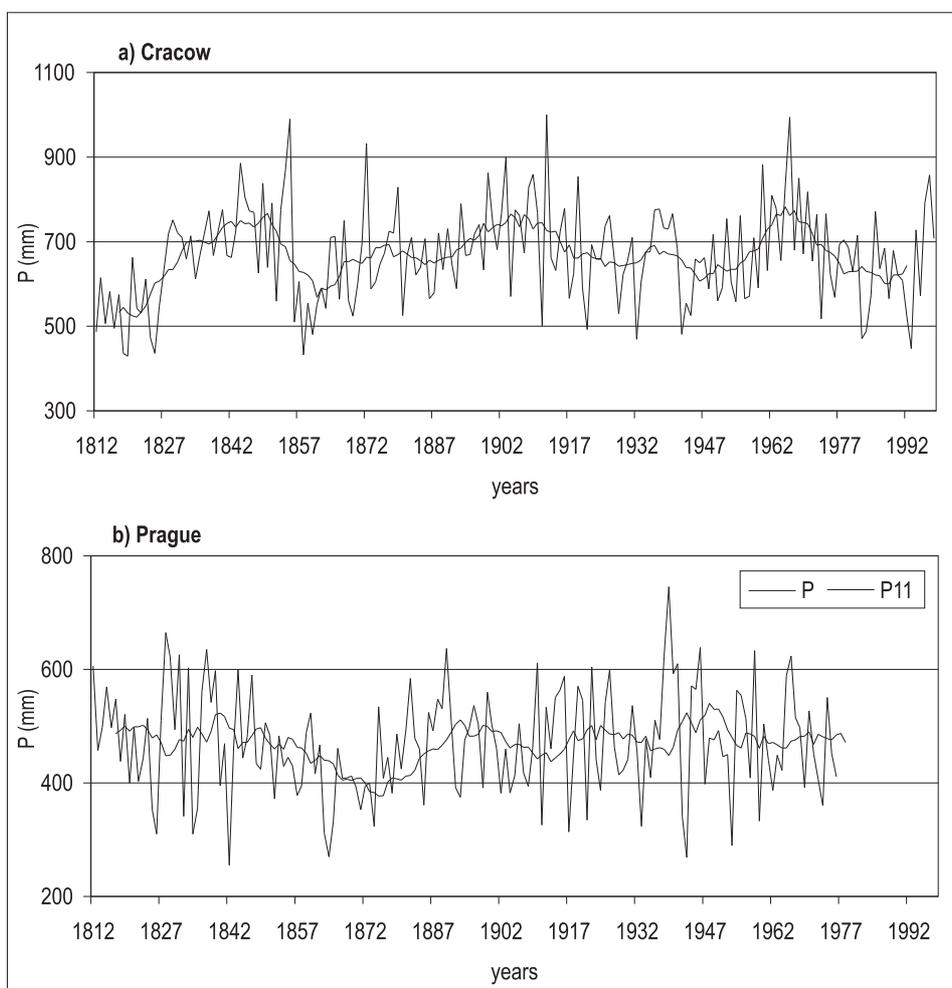


Fig. 3 Long-term variability of the annual totals of the precipitation (1812-1998): P – values for each year, P11 – 11-year moving averages.

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