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VARIABILITY OF THE MEAN MONTHLY VALUES OF AIR PRESSURE BASED ON THE CRACOW SERIES OF RECORDS (1792-2000)

Abstract: In this paper the course of the monthly values of air pressure in January, April, July and October as well as the mean annual values of air pressure based on the series of barometer records in Cracow in the period for 1792-2000 has been presented. Such a long series requires a commentary. Therefore, a part of the paper deals with the history of measurements and the method of compensating for the lack of data for 1792-1825. The observed fluctuations in the course of the air pressure are explained by the circulation conditions of the climatic trends.

Key words: mean values of air pressure, series of barometric records, periods of instrumental observations, fluctuations, trend formulae.

1. Introduction

The main purpose of this work is to present the fluctuations in the course of the mean monthly values of air pressure during the period of instrumental observations in Cracow. The Astronomical Observatory, where one of the first meteorological stations in Poland was set up, was founded in 1791. The Cracow series of meteorological records was initiated by the famous Polish researcher, astronomer and mathematician, Professor Jan Śniadecki on 1st May, 1792.

Relatively few climatological works deal with the variability of the course of air pressure, especially of the so-called the Early Instrumental Period (EIP) for 1780-1860. In the second half of the 19th century the method of observations was already homogenous, and the observations since 1861, considered to be the first year of the Modern Instrumental Period (MIP), are treated as being fully correct (Bärring et al. 1999). The Cracow meteorological series is without gaps from 16th August, 1825, i.e. from the time when the working and observation conditions in the Cracow Observatory had been stabilised. During the years from 1792-1825, which consisted of 408 months, the records

were taken on a daily basis (three times a day) during 210 months, while the remaining, less than the half of this period should have been completed.

The authors of this paper are of opinion that for the research purposes all the existing data from the initial years of observations should be utilised (Trepińska 1997a). This work, to which the data for 1792-1825 (i.e. from the EIP) have been included in the long series of observations, could comprise these years because the series of the air pressure records of the period for 1792-1825 was supplemented, compiled and verified by Z. Ustrnul (1997a). Thus, the variability of the mean values of air pressure in Cracow of the period for 1792-2000 in the selected four months, representing the main year seasons, as well as the variability of the mean annual values of air has been presented. These latter values, of course can provide a very general insight into the development of the circulation trends in a multiyear period.

The calculated formulae of the trend and of the increases in the mean monthly values of air pressure normalised for a hundred years (Tab. 1) support the opinion on the fluctuations.

2. Overview of the history of barometric observations

The beginning of the observations, both the astronomic and meteorological ones, coincided with a very difficult political period in Poland. These were the years of partitioning of Poland by the neighbouring emperors. Cracow with Galicia was annexed into Austria and the existence of the Main School of the Crown (the name of the Jagiellonian University at that time) was endangered, also due to financial reasons. An important fact, however, was the launching of weather observations according to the modern approach and the storage of the recordings of these observations in the archive of the Observatory. Thanks to that the records have survived until now. Professor Śniadecki, who studied at several European universities, was an outstanding researcher of the Enlightenment era. He actively used his skills and knowledge in scientific work, i.e. in the field of meteorology. He has left behind him a modern manual for taking meteorological observations in Cracow (Trepińska 1997a), which describes how to read the instruments and determine their location. He presented the scientific deduction, associated with, i.e. observations of the state of the atmosphere, in the work entitled *Jeografia czyli opisanie matematyczne i fizyczne Ziemi (Geography that is a mathematical and physical description of the Earth)* (1839). In this work, he presented the description of the mercury barometer used in the Cracow Observatory and the method of introducing the appropriate corrections.

The instructions are in the first record book (diary) of the weather observations. The detail recordings of the mercury barometer, produced by the Parisian company Fortin, and of the mercury thermometer located nearby the barometer, allow verification of these recordings. In the observation record books of various years there are notes about the installed barometers and their calibration. Although the exact location of these barometers during the first years of observations is not certain, the barometer was certainly not moved outside the building at which the meteorological station was founded. It should be noted that during more than 200 years, only the mercury barometer

was used for reading air pressure. Only in 1994, was the digital sensor for recording air pressure installed in an automatic recording station. Nevertheless, the station mercury barometer and the deformation barometer are still being used.

Out of the EIP, the records for more than the half of the years were preserved. The complete sets of the observations are from the following periods:

– from 1st May, 1792 to 18th May, 1794;
– from 1st September, 1803 to 9th August, 1804;
– from 1st January,1805 to 5th October, 1805;
– from 1st October, 1811 to 30th September, 1823;
– from 1st January, 1824 to 15th July, 1825;
– from 16th August, 1825 until the present.

That provides 52.7% of the reliable source materials with the complete recordings of the everyday readings of the air pressure values. As this material seemed to be so interesting and valuable, the authors decided to include it to the studies on the fluctuations in air pressure.

Based of the series of meteorological observations in Cracow numerous scientific works emerged. The majority deals with air temperature and precipitation. The course of air pressure was a subject of interest less often, although this meteorological element, especially when related to the circulation (Ustrnul 1997b) provides fundamental information about the development of climatic conditions.

The self-recording devices, installed in 1848, are worth mentioning here (Kowanetz 1997). In the archive of the research station of the Department of Climatology there are barograms and elaborations of the hourly values of air pressure from the barometer operating in the later years. The device worked on the principle of the mercury barometer connected with a clock mechanism. Thus, the preserved complete source materials from 1826-2000 allow for a reliable presentation of the pressure for the period of 175 years. Some problems were related to the lack of the records from the years 1792-1825, which had to be completed and verified.

3. The series of the Early Instrumental Period (EIP) – 1792-1825

The utilisation of this series is possible owing to the aforementioned completing of the observation materials based on the data from other stations. That task was undertaken by Ustrnul (1997a), who performed a comparative analysis of the series of the air pressure records from Cracow and Prague. The meteorological station located in Prague's Klementinum, founded in 1771, is located on the same latitude as Cracow (50°04'N). Based on this analysis, using the multivariable regression, after performing homogeneity tests, after comparison with the homogenous series of the air pressure records of Basil, the mean monthly values of pressure were calculated for the months in which the records were not taken in Cracow (Ustrnul 1997a). The more details on the performed analyses and homogeneity tests are presented in this author's work. The noticed certain non-homogeneity of the early barometer series may result from the adopted observation method and from the imperfect mercury barometers used at that times. The air pressure measurements are taken without any breaks from 16th August, 1825. Unfortunately, not

all the record books of the 1840s and 1850s survived. A part of the barometric series has been reconstructed from the indirect recordings taken by the astronomers. It should be assumed, that since 1863 the series of the air pressure records does not have non-homogeneous features.

The numerical data of the EIP are characterised by a slightly lower values and slightly higher year-to-year variability (in some months) when compared with the later years. Those data influenced the general trend in the pressure values in particular months.

Despite the stated lack of certain values and the necessity of their completing and correcting, the authors of this paper are of opinion that the verified numerical material presenting the mean monthly values of the air pressure from over a 200-year long period, is so interesting as to be used in the studies on the variability of the air pressure. Thus, the series of 1792-2000 has been treated as a whole in this work.

4. Methodological comments

Values of the air pressure have been analysed at the level of the stations (220 m a.s.l.). As has already been mentioned, the observer had always made a reduction in the barometer readings to the temperature of 0^0C. It is known that the values were converted to the temperature of the zero degrees in the Réaumur's scale, whose value coincides with zero in the Celsius scale. As such, the conversion of the readings of the mercury level in the barometer is being performed until today, hence, in this respect the barometer series can be considered to be homogenous. The Parisian inches and lines were the pressure units used, and then, in the following years, the Parisian lines were used exclusively. Millimetres of mercury (mm Hg) were used only since 1876. The conversion into the currently used hectopascals (hPa) was performed in the Department of Climatology of the Jagiellonian University during 1982-1986.

The analyses of the course and development of the tendencies in the monthly and annual values of air pressure were performed numerically and graphically using the following statistical methods:

– 11-year and 35-year running averages of pressure in selected months: January, April, July, October as well as annual means;
– deviations from the multiyear means and cumulative sums of these deviations for selected months. The cumulative sum of the deviations, a simple statistical method, is sometimes criticised due to the dependence of the whole series by the multiyear mean. Nevertheless, it turns out to be useful in detecting the years in which a change in the tendency direction of the element under study occurred;
– calculations of the trend equations for all the monthly means and the annual mean together with the calculated values of the gradient (increase or decrease) of these values per 100 years. The series have not been divided into time-sub-series having a particular tendency.

5. Variability in the mean values of air pressure during 1792-2000

5.1. Variability of the mean values of air pressure in January

The lowest value of air pressure in January occurred in 1814 and amounted to 976.9 hPa, the highest – in 1864 and 1882, when it reached 1003.9 hPa. In the initial years of the analysed periods, the air pressure values of January were predominately below 900 hPa (Fig. 1). In general, the air pressure values were even over 20 hPa lower than the averages in the following years, i.e. from the 1850s. In the first half of the 19th century, the pressure values were characterised by a much higher year-to-year variability, yet the negative values of the deviations from the multiyear mean prevailed. In the second half of the 19th century, the positive deviations already prevailed. The year-to-year variability was slightly weakened, but it increased again in the 1920s. The pattern of the deviations from the multiyear mean and their course are presented in Fig. 2 and Fig. 3. An outstanding change in the development of the trend in the air pressure in January is visible from the beginning of the 1960s (Fig. 3). These years may be called the years when the trend direction was reversed. That corresponds with the natural circulation processes which might be related to the end of the Little Ice Age. The change in the pressure values also took place in the 1970s (Fig. 3) which corresponds with the progressive warming of the climate in Central Europe associated with the circulation changes. In the 1990s the values of air pressure were higher.

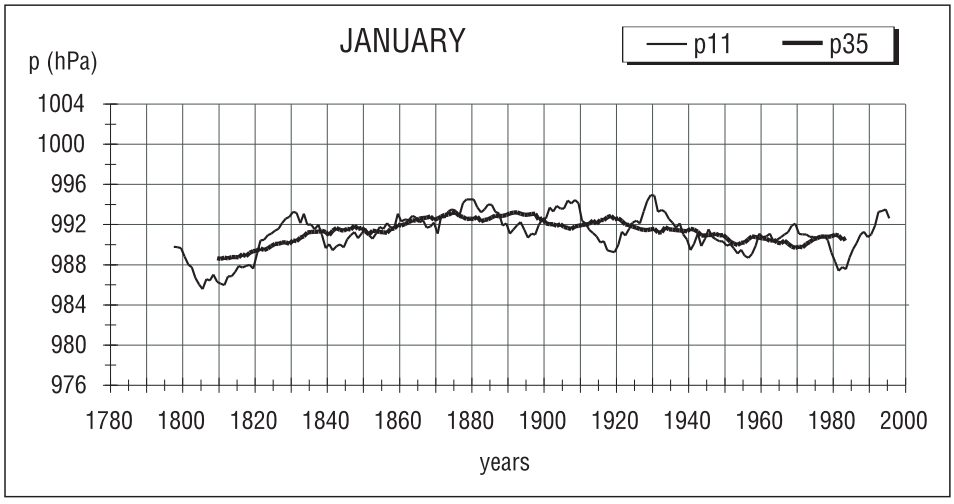

Fig. 1. Multiyear course of air pressure (1792-2000) in Cracow smoothed by 11-year and 35-year running means. JANUARY

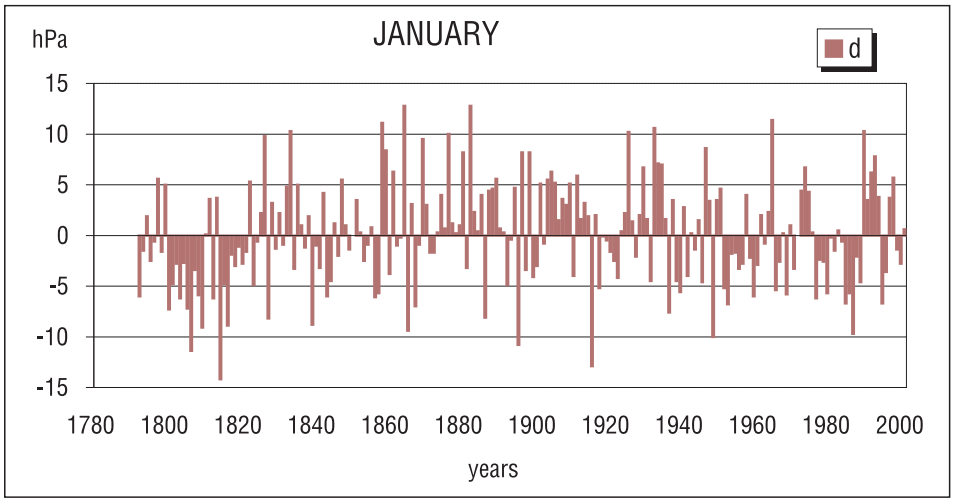

Fig. 2. Deviations from the multiyear mean air pressure (1792-2000) in Cracow. JANUARY

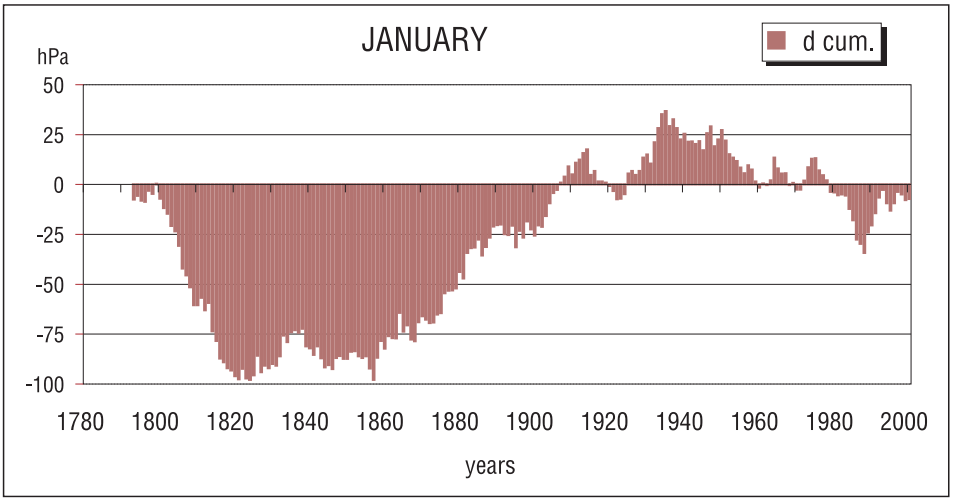

Fig. 3. Cumulative deviations from the multiyear mean air pressure in Cracow. JANUARY

5.2. Variability of mean values of air pressure in April

The lowest value of air pressure in April occurred in 1879 and amounted to 979.1 hPa. The highest mean monthly values was in 1865 – 996.7 hPa. The lower oscillations in air pressure occurred in April (Fig. 4). Until the 1820s a certain descending trend in air pressure can be determined. The change in the trend into an ascending one

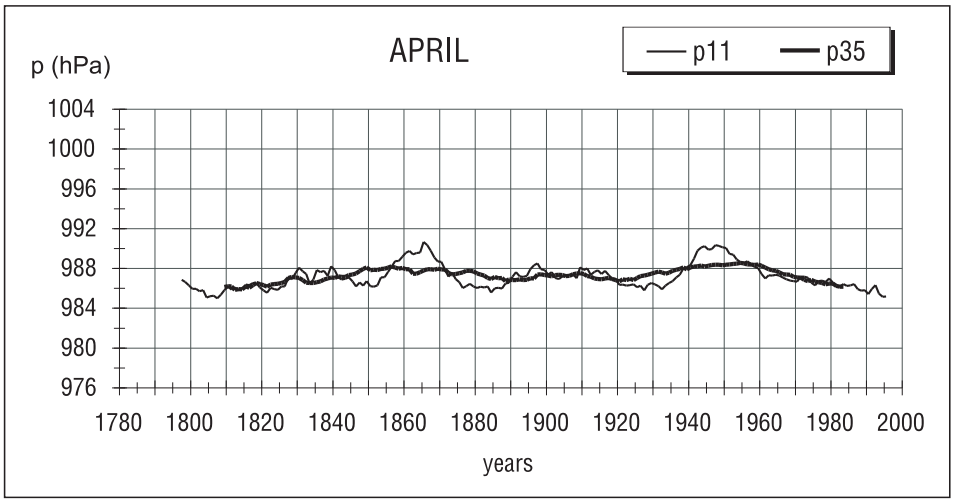

Fig. 4. Multiyear course of air pressure (1792-2000) in Cracow smoothed by 11-year and 35-year running means. APRIL

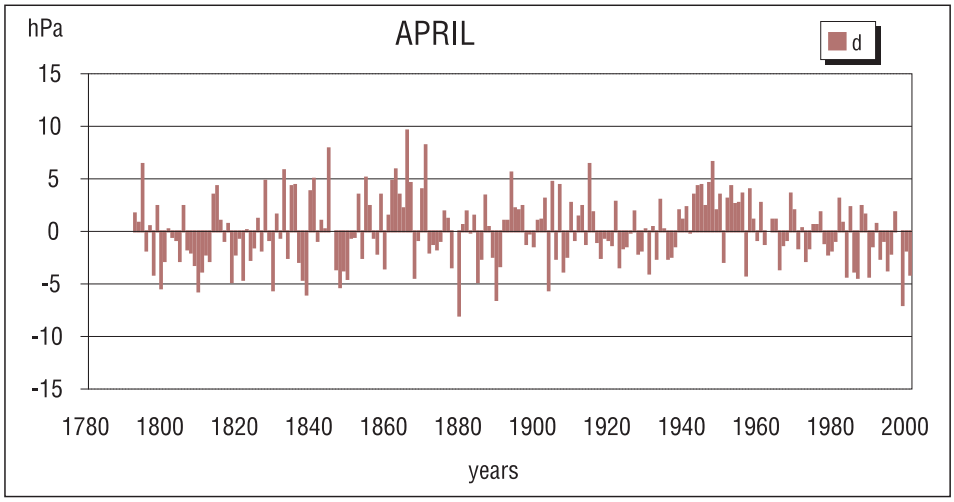

Fig. 5. Deviations from the multiyear mean air pressure (1792-2000) in Cracow. APRIL

marked itself in the mid 19th century (Fig. 5 and Fig. 6). The differentiation of variability in the 20th century is also interesting. The beginning of the 20th century until the 1940s is the period of the lower values of air pressure. In the 1970s there was a descending tendency which lasted until the end of the 20th century.

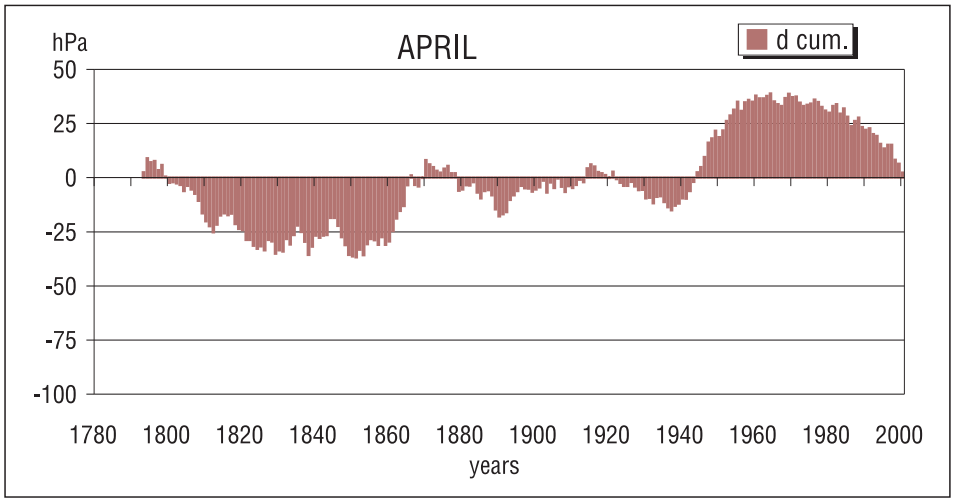

Fig. 6. Cumulative deviations from the multiyear mean air pressure in Cracow. APRIL

5.3. Variability of mean values of air pressure in July

The lowest mean value of July occurred in the year 2000 – 983.0 hPa. The mean value of 1801 – 983.1 hPa was very close to the above value. The highest value occurred in 1938 – 994.7 hPa. Already the first look on the graphs in Fig. 7 allows to state that the variability in the air pressure in July is about three times as small as in other months.

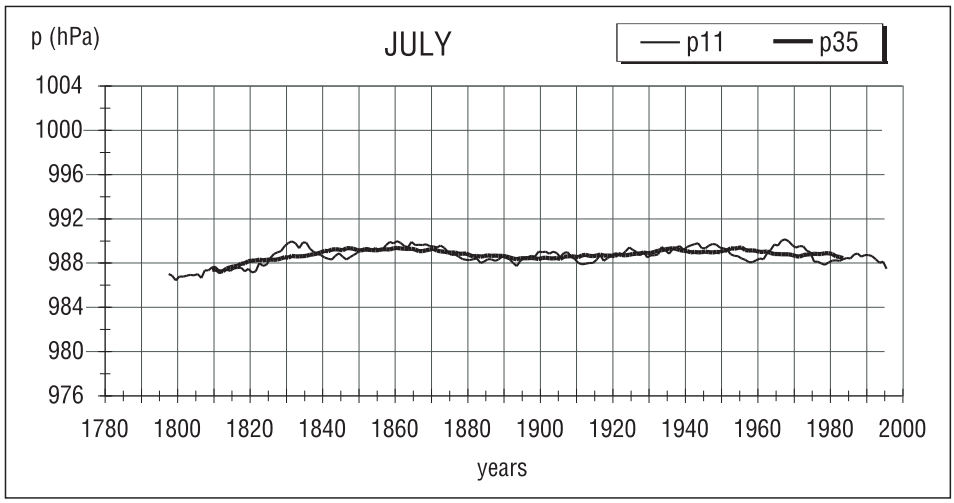

Fig. 7. Multiyear course of air pressure (1792-2000) in Cracow smoothed by 11-year and 35-year running means. JULY

In July the values of the air pressure are marked by a descending tendency until the 1820s; in the following years the pressure was higher but less variable. The higher fluctuations showed only from the 1950s (Fig. 8 and Fig. 9). A certain analogy to the course of the mean air temperatures can be noticed here – the variability of this element in summer months was also three times smaller than in the winter months.

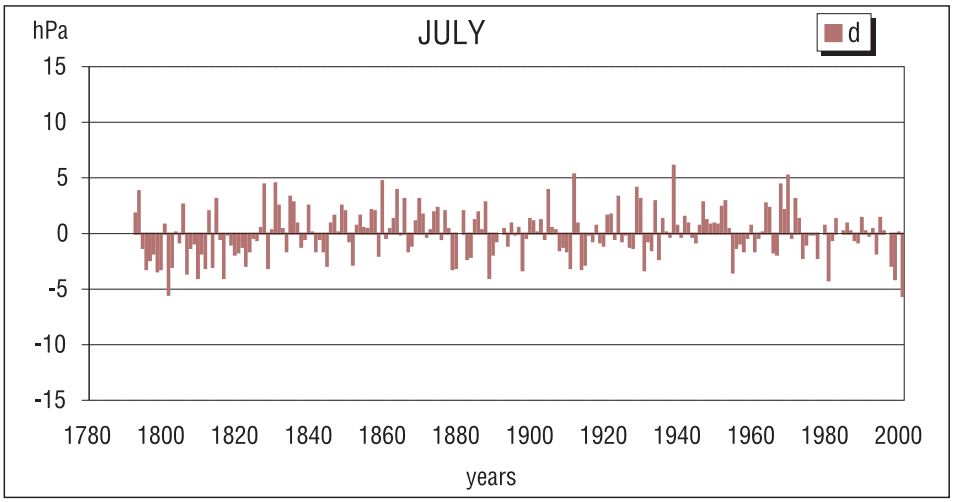

Fig. 8. Deviations from the multiyear mean air pressure (1792-2000) in Cracow. JULY

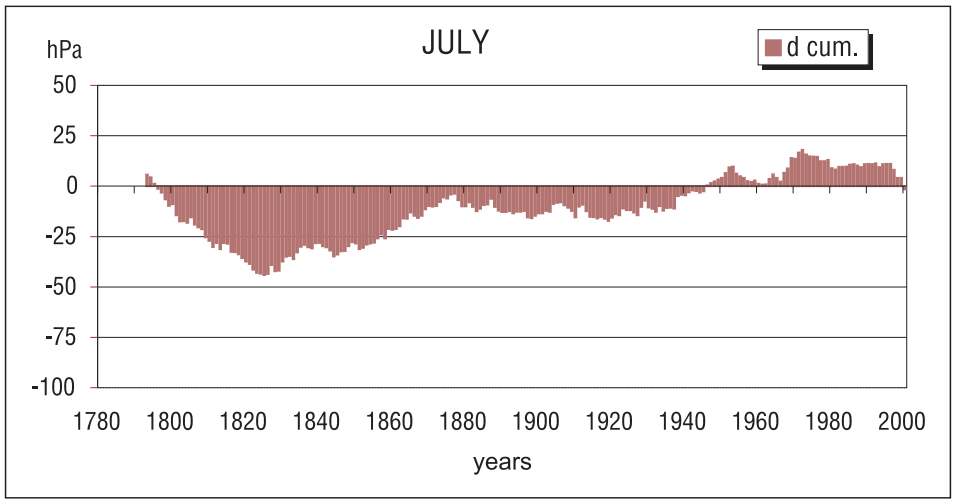

Fig. 9. Cumulative deviations from the multiyear mean air pressure in Cracow. JULY

5.4. Variability of the mean values of air pressure in October

The lowest value of the mean pressure in October was 982.6 hPa in 1974 and the highest one – 1001.7 hPa in 1805. The values of air pressure in October (Fig. 10) had a different pattern when compared to the ones formerly described. Particularly large

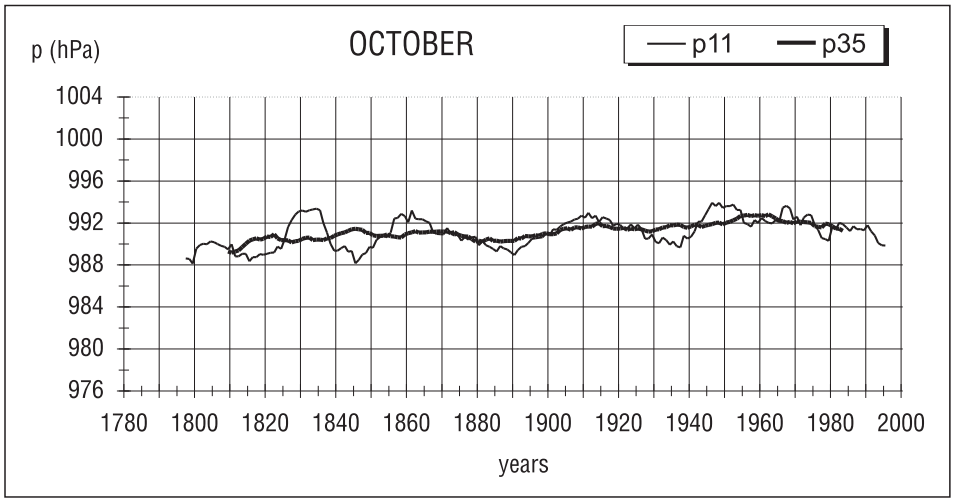

Fig. 10. Multiyear course of air pressure (1792-2000) in Cracow smoothed by 11-year and 35-year running means. OCTOBER

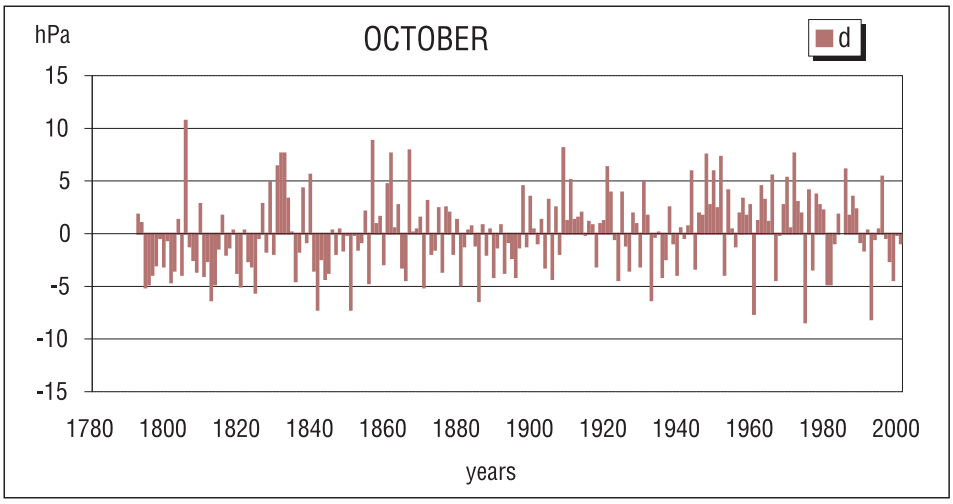

Fig. 11. Deviations from the multiyear mean air pressure (1792-2000) in Cracow. OCTOBER

oscillations of pressure occurred until the 1850s. The years with pressure values lower than the multiyear average prevailed (Fig. 11 and Fig. 12). In the middle part of the analysed multiyear period a decline in the oscillations can be noticed, which is reflected in the lower values of the deviations from the multiyear mean as presented in Fig. 11. In the 1930s and 1940s, the mean values of air pressure increased, but in the last forty years the pressure of October shows a certain declining trend with a simultaneous year-to-year variability increase (Fig. 11).

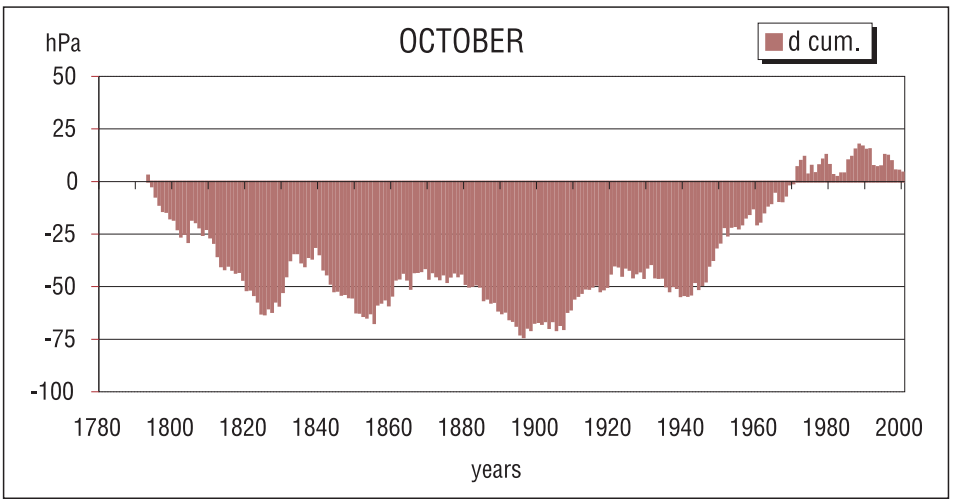

Fig. 12. Cumulative deviations from the multiyear mean air pressure in Cracow. OCTOBER

5.5. Variability of the mean annual air pressure

The range of the changes in the mean annual air pressure is small and does not exceed 10 hPa. The lowest value was 984.9 hPa in 1804 while the highest 993.5 hPa in 1832. The mean annual values can provide a very general view of the course of this element (Fig. 13). The smoothing by the 11-year running means show, however, larger fluctuations since the second half of the 19th century, lower oscillations in the middle part of the series and the increase in the fluctuations in the second half of the 20th century. The very even course of the 35-year running means points to a general course of air pressure. The lowest pressure was at the turn of the 18th and 19th century. The increase took place in the mid 19th century and lasted until the 1960s. During the last forty years there was a decrease in the mean annual values. This general pattern is confirmed by the graphs in Fig. 14 and in Fig. 15. The pressure values of all the months lower than the multiyear means and their larger variability obviously affect the mean monthly values.

The question arises: are the lower values in the EIP and their large variability a result of the instruments used at that time? The authors of the elaborated pressure

series of Lund (Bärring et al. 1999) have similar doubts. However, introducing the groundless correction to the pressure series is pointless, as one would receive a series more similar to the present-day measurements. However, the interpretation of the natural phenomena would be only a presumption. Thus, the preserved series of records will be kept as the study objectives and the presentation of the noticed fluctuations will be attempted.

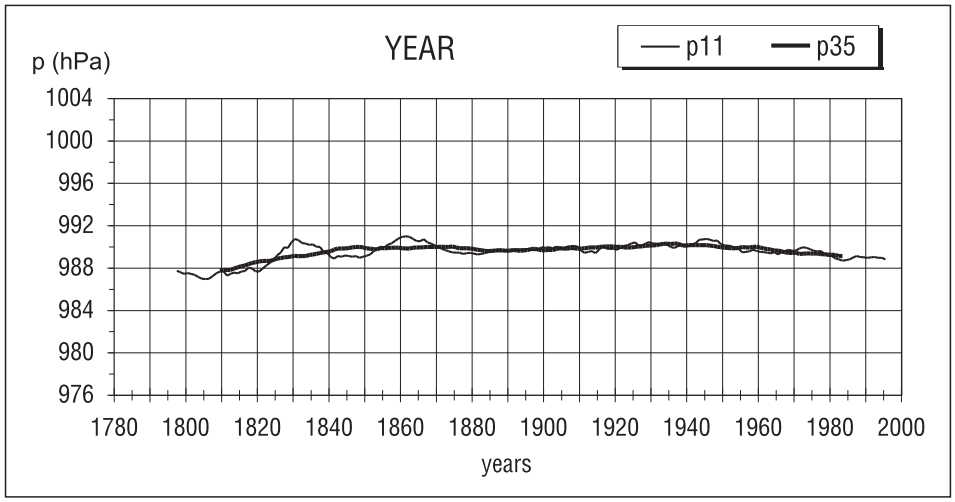

Fig. 13. Multiyear course of air pressure (1792-2000) in Cracow smoothed by 11-year and 35-year running means. YEAR

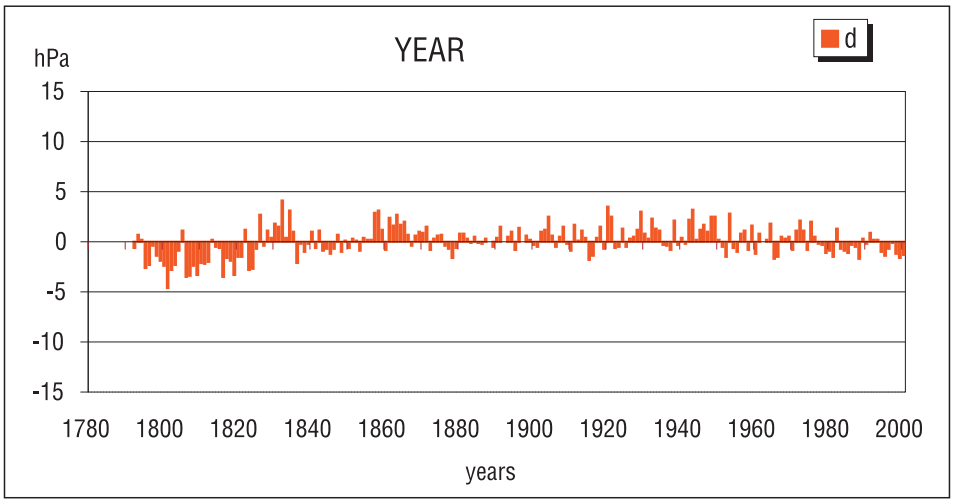

Fig. 14. Deviations from the multiyear mean air pressure (1792-2000) in Cracow. YEAR

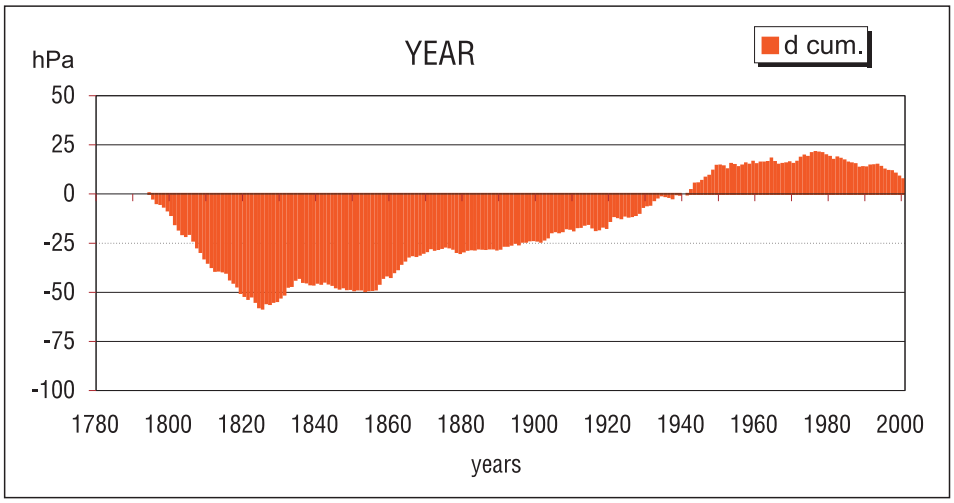

Fig. 15. Cumulative deviations from the multiyear mean air pressure in Cracow. YEAR

5.6. Tendencies in the course of the mean monthly values of air pressure

The trend equations and the calculated gradients (increases or decreases) as normalised per 100 years are presented in Table 1. There is a small number of increases, but it is emphasised that the calculations were performed for the whole series. The subdivision of the series into time sub-series would require a more far reaching explanation and more detailed relationship to the types of macro-circulation in Europe. Simultaneously, the statement that in such a long series the descending and ascending fluctuations "balance each other out" and, thus the trend line leans toward the line parallel to the time axis, seems logical. Small positive or negative values can gain in importance as they show an averaged two-hundred year trend direction.

6. Conclusions

Mean monthly and annual values of air pressure are characterised by a large variability in the winter months. The variability in the winter seasons essentially influences the fluctuations in the mean annual values of air pressure. In the spring and summer months this variability is much lower. Thus, one can attempt to determine certain types of variability in the mean values of air pressure.

The winter type, depicted by the values of pressure in January, is characterised by a large year-to-year variability. This variability was much higher in the periods of large "disturbances" in circulation, i.e. at the turn of the 18th and 19th centuries, in the 1820s and 1840s and then in the second half of the 20th century. The spring type is represented by the course of the mean pressure in April. It is characterised by a larger variability in

Tab. 1. Trend equations of the mean values of air pressure (hPa) in Cracow (1792-2000)

Month	Equation	S_T
January	y = 990.33 + 0.007x	0.7
February	y = 988.78 + 0.0087x	0.87
March	y = 987.03 + 0.012x	1.2
April	y = 987.03 + 0.0007x	0.07
May	y = 987.89 + 0.005x	0.5
June	y = 988.92 – 0.0011x	-0.11
July	y = 988.29 + 0.0029x	0.29
August	y = 989.16 + 0.0015x	0.15
September	y = 990.89 + 0.002x	0.2
October	y = 989.93 + 0.0104x	1.04
November	y = 989.2 + 0.0078x	0.78
December	y = 988.8 + 0.0097x	0.97
Year	y = 988.85 + 0.0055x	0.55

Explanation:
y = ax + b – regression equation, y – mean value of air pressure (hPa)
x – sequential year from the beginning of series
S_T – increase or decrease of mean value of air pressure per 100 years (in hPa)

the thirties and fifties of the 19th century as well as in the 1930s and 1950s, i.e. when the chilliest (19th century) and the warmest springs (20th century) occurred. In the summer type (July) a large variability in the mean values of pressure is characteristic, from the 1830s followed by a slight variability until the 1930s and 1950s. In the 1980s there was a persistent rising trend in the mean values which have lasted until recent years. In October, representing the autumn type of variability in pressure, one can observe a relatively large differentiation until the 1870s. This was followed by a falling trend until the 1930s and then there was a large year-to-year variability with a descending trend.

The inter-relationship between the course of the air pressure and temperature values (Trepińska, Kowanetz 1997; Trepińska 1997b) is unequivocal. During the years of the increased thermal continentality, the values of the air pressure should be higher while in the years of oceanicity the pressure should show a descending tendency. The mean annual values of pressure depend mainly on the pressure in the winter months, thus the severe winters when stable high pressure areas are developed should have a pressure higher than the multiyear average. During oceanicity phase of the climate, i.e. since the last decade of the 19th century, the pressure values should be lower. Such a general tendency is noticeable. Commonly, the decease in temperature is correlated with the increase in pressure while the increase in temperature with an decreasing trend in pressure. Only the very even courses of these climatic elements exhibit such relations (Trepińska, Kowanetz 1997; Trepińska 1997), but in particular years such a correlation is not always significant. This provides the evidence that weather conditions depend not only on the pressure systems but also on the widely understood circulation of air masses and components of the heat balance.

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Zmienność średnich miesięcznych wartości ciśnienia powietrza na podstawie krakowskiej serii pomiarów (1792-2000)

Streszczenie

W opracowaniu przedstawiono przebieg miesięcznych wartości ciśnienia powietrza w styczniu (ryc. 1), kwietniu (ryc. 4), lipcu (ryc. 7), październiku (ryc. 10) i średnich rocznych wartości na podstawie serii pomiarów barometrycznych w Krakowie w latach 1792-2000 (ryc. 13). Część opracowania poświęcono historii pomiarów i metodzie uzupełnienia brakujących danych z lat 1792-1825. Wartości ciśnienia rozpatrywano na poziomie stacji (220 m n.p.m.).

Analizę przebiegu i kształtowania się tendencji miesięcznych i rocznych wartości ciśnienia wykonano numerycznie i graficznie przy zastosowaniu podstawowych metod statystycznych (ryc. 2-3, ryc. 5-6, ryc. 8-9, ryc. 11-12, ryc. 14-15). Średnie miesięczne i roczne wartości ciśnienia odznaczają się dużą zmiennością w miesiącach zimowych. Zmienność w porze zimowej w zasadniczy sposób wpływa na fluktuacje średnich rocznych wartości ciśnienia. W miesiącach wiosennych i letnich zmienność ta jest dużo mniejsza (tabela 1).

Podjęto zatem próbę określenia pewnych typów zmienności średnich wartości ciśnienia. Zaobserwowane fluktuacje mają swoje uzasadnienie w cyrkulacyjnych uwarunkowaniach trendów klimatycznych.

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