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Janina Bożena Trepińska

CRACOW BAROMETRIC SERIES AS A BASIS FOR LONG-TERM AIR PRESSURE RESEARCH

Abstract: Monthly and annual series of air pressure in Cracow were produced on the basis of barometric measurements from 1792 to 2005. The site of measurements is reliably homogeneous. Each measurement by the mercury barometer was reduced to air temperature of °C, but a reduction to sea level was not applied, moreover each reading of the mercury position in the barometer was adjusted by a set of constant corrections: the instrumental one and adjustments for latitude and Earth's radius. The historical meteorological station of the Jagiellonian University is located at 220 meters a.s.l. A set of 13 Figures illustrates the time variability and fluctuations of the atmospheric pressure. The range of variability of the mean values can be very large, exceeding 25 hPa in winter months. Additionally, cases of particular changes within 3 and 24 hours have been presented according to data from 1951-2000. Rough criteria for distinguishing such changes allow to find out the most of extreme abrupt pressure drops and rises in wintertime.

Key words: long-term air pressure data, homogeneous series, air pressure fluctuations, rapid changes.

Introduction

Air pressure, its annual distribution and long-term trends are relatively seldom investigated. From the point of view of modern dynamic climatology or synoptic climatology, atmospheric pressure is a basis for a typology of cyclonic and anticyclonic systems, together with the direction of movement of air currents and other features of air masses. Changes in air pressure on the synoptic scale are the main indicator of advection and movement of atmospheric highs, lows and fronts, in which case only values reduced to sea level are taken into consideration. In the case of barometric series registered at a single measurement point, reduction to sea level seems unnecessary, as the results of such a study can be used in bioclimatic research. This paper presents the long-term pressure trends, to which the reduction to sea level has not been applied.

Considering the unique importance of the entire series of values of air pressure, in the present study the author has decided to treat it as a whole, comprising the period from the beginning of barometric measurements in Cracow, i.e. from the year 1972, to the end of the year 2005. The series has been presented in the form of mean monthly and annual values. Additionally, cases of pronounced decreases and increases in air pressure throughout the day have been selected on the basis of barograms from the years 1951-2000.

A brief history of air pressure measurements in Cracow

The importance of the barometric series in Cracow has been commonly recognized and appreciated for over 150 years. It has provided a basis for many studies, carried out by astronomers and Polish climatologists. Papers published by M. Weisse (1853) or W. Gorczyński (1916) (the commentaries in Kożuchowski 1990, Tamulewicz 1997, Trepińska 2002, 2007) can be quoted as examples. The missing data – mean monthly values of air pressure from the initial years of the Jagiellonian University's station in Cracow, have been reconstructed and completed on the basis of validated reference data from other European stations (Ustrnul 1997). The reconstruction involves data for 17 years comprised within the period of the station's functioning from 1792 to August 1825 (Trepińska 1997).

The history of measurements of air pressure in Cracow is long and interesting (Trepińska 1982, 1997). The first measurements were conducted by Professor Jan Śniadecki, in the Astronomical Observatory of the Jagiellonian University on 1st May 1792. Without launching forth into details, it is worth mentioning that the Cracow barometric series originates from readings obtained from mercury barometers, which have been used at climatologic stations uninterruptedly for years and are still used today. Over the decades, following the idea of using accessible and easy to operate instruments to carry out meteorological measurements, the long term employment of the mercury barometer in the same exact spot ensured undisputed homogeneity of the barometric series. The first mercury barometer in Cracow installed in the Astronomical Observatory of the Jagiellonian University was one manufactured by the Paris-based company Fortin. The instrument has been well-preserved and can now be seen at the Jagiellonian University Museum. Barometers used subsequently were very carefully maintained, calibrated by the observers working at the Observatory throughout the years. This fact can be corroborated by numerous entries in observation diaries. Moreover, it is worth mentioning that in the middle of the 19th century the first barographs were introduced in Cracow. Barographs were one of the first instruments to continuously register oscillations of air pressure. Series of air pressure measurements carried out every hour, produced by M. Weisse (1853), were published in specially prepared reports. In 1976 the meteorological station became part of the Department of Climatology of the Institute of Geography of the Jagiellonian University, where it has been functioning ever since, known as the "historical station".

Source material and methodology

A mercury barometer should be located at a definite location, for which all necessary barometer corrections to the position of the meniscus of mercury have been determined. The altitude above sea level is crucial, as it can alter the result of the measurement, even in the case of seemingly insignificant relocations: e.g. only two floors higher in a building. From the very beginning, the altitude for the barometer was determined at 220 meters above sea level. Immediately after taking the measurement, all readings from the mercury barometers were reduced to the temperature of 0°C (at first it was 0°R, which does not make any difference whatsoever), and corrected by a constant correction. The correction consists of: a constant instrumental correction, determined by the manufacturer, and a correction for the so-called normal weight, which includes the force of gravity depending on the latitude, and the force of gravity depending on the altitude above sea level, which increases the Earth's radius. It is important not to confuse this correction with the one consisting of reducing the reading in a particular layer of the atmosphere to the level of atmosphere near the surface of the sea. The corrections mentioned above were taken into account by the observer directly upon registering the reading from the barometer. It needs to be remarked that the reduction of the barometer readings to sea level was not carried out, and therefore the entire series has been treated in the present study as one created *in situ* and therefore also presented as such. The value in hPa reducing the mean monthly values to 0 m a.s.l. is known (Trepińska 1988). The difference calculated from the reduction to sea level equals on average from 25.5 to 27.5 hPa, depending on the outside temperature and the current pressure system.

Converting the units of measurement of air pressure from the formerly used millimetres of mercury and even older inches or Paris lines does not present any difficulty (Trepińska 1982, 1997). The position of the mercury barometer, unchanged for decades, is at the height of 220 m a.s.l. and it has been determined by means of trigonometric measurements.

The study uses statistical methods commonly implemented in climatological research. In order to present the variability in the course of the mean monthly values of air pressure, the most important statistical characteristics have been used, such as the multi-annual means, standard deviations, regression equations, as well as the maximum and minimum values. The means calculated for particular periods have been presented in tables (Tab. 1, 2). The long-term course of the mean monthly values has been represented graphically in Figures 1-5.

Aim of the study

The paper's main aim is to present the variability in the long-term course of air pressure in Cracow at a single observation point. The point is representative not only of the area of the city but also for the region of southern Poland, up to the altitude of 500 m a.s.l. Series of validated monthly and annual mean values of air pressure for the years 1792-2005 have served as the basis for achieving the aim mentioned above. The data has also been used to prepare graphs (Fig. 1-5).

Table 1. Monthly mean values of air pressure [hPa] at the level of the Climatological Station in Cracow (1792-2005)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual mean
Max.	1003.9	1004.5	1000.1	996.7	994.6	995.9	994.7	993.8	999.4	1001.7	1001.5	1003.6	993.5
Year	1864	1959	1953	1865	1833	1805	1938	1973	1865	1805	1920	1972	1832
Min.	976.9	977.5	978.5	979.1	981.3	983.1	983.1	983.8	983.3	982.6	980.7	976.4	984.8
Year	1814	1848	1888	1879	1984	1843	1801	1870	1984	1974	1802	1801	1801
Mean	988.9	989.7	988.3	987.1	988.4	988.8	988.6	989.3	991.1	991.0	990.0	989.8	989.4
St. dev.	5.14	5.48	4.21	3.13	2.49	2.15	2.11	1.89	2.69	3.62	4.05	5.18	1.46

Table 2. Monthly mean values of air pressure [hPa] at the level of the Climatological Station in Cracow (1901-2000)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual mean
Max.	1002.5	1004.5	1000.1	993.7	993.7	994.2	994.7	993.8	996.7	999.1	1001.5	1003.6	992.9
Year	1964	1959	1953	1947	1980	1917	1938	1973	1978	1908	1920	1972	1920
Min.	971.6	979.7	981.2	980.1	981.3	983.7	983.2	985.3	983.3	982.6	981.9	976.7	987.6
Year	1914	1955	1988	1998	1984	1933	2000	1945	1984	1974	1910	1981	1915
Mean	991.3	989.5	989.2	987.2	988.9	988.8	988.7	989.4	991.3	991.7	990.2	990.0	989.7
St. dev.	4.87	5.02	4.17	2.80	2.46	2.09	2.07	1.83	2.59	3.51	3.87	4.70	1.26

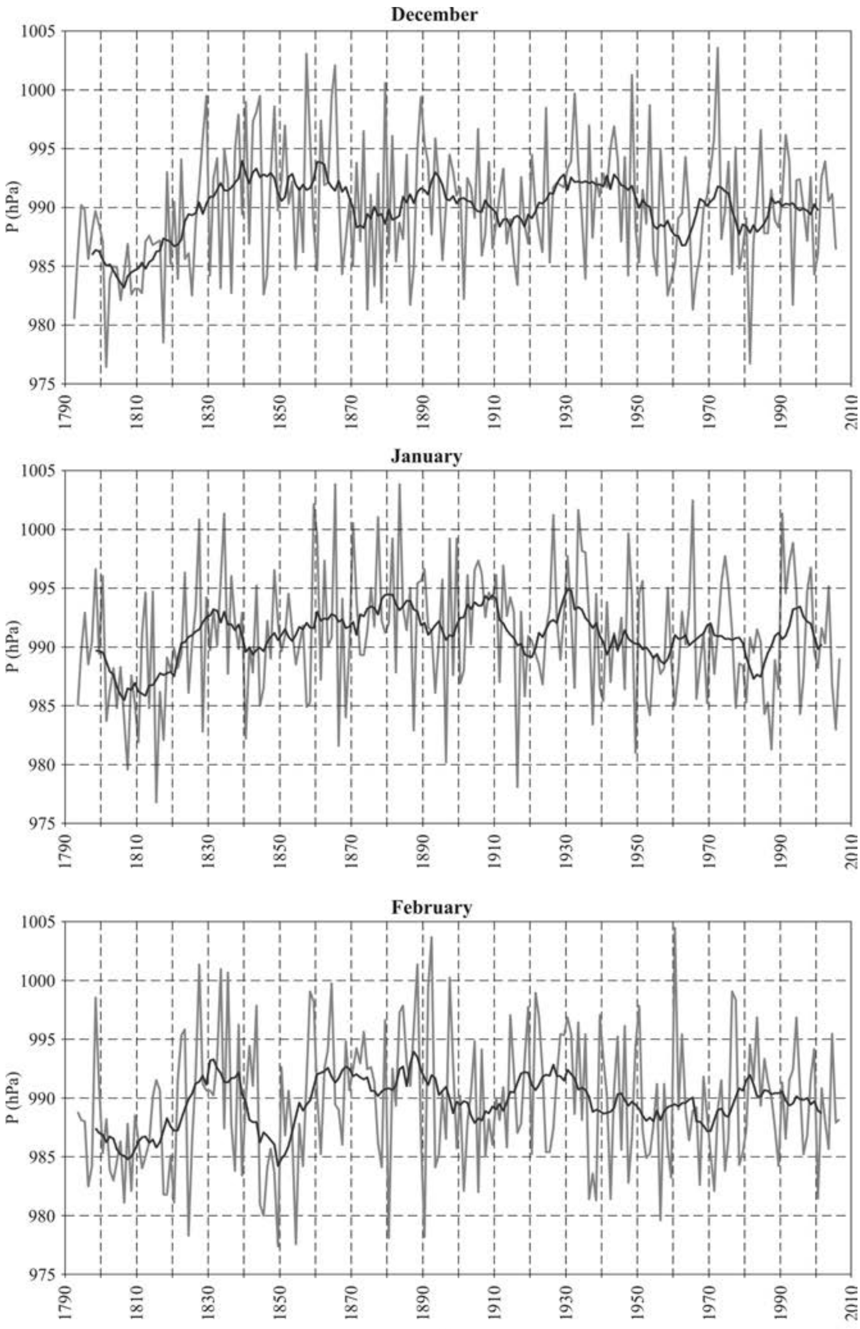

Fig. 1. Mean monthly air pressure (hPa) in winter months in Cracow in 1792-2005

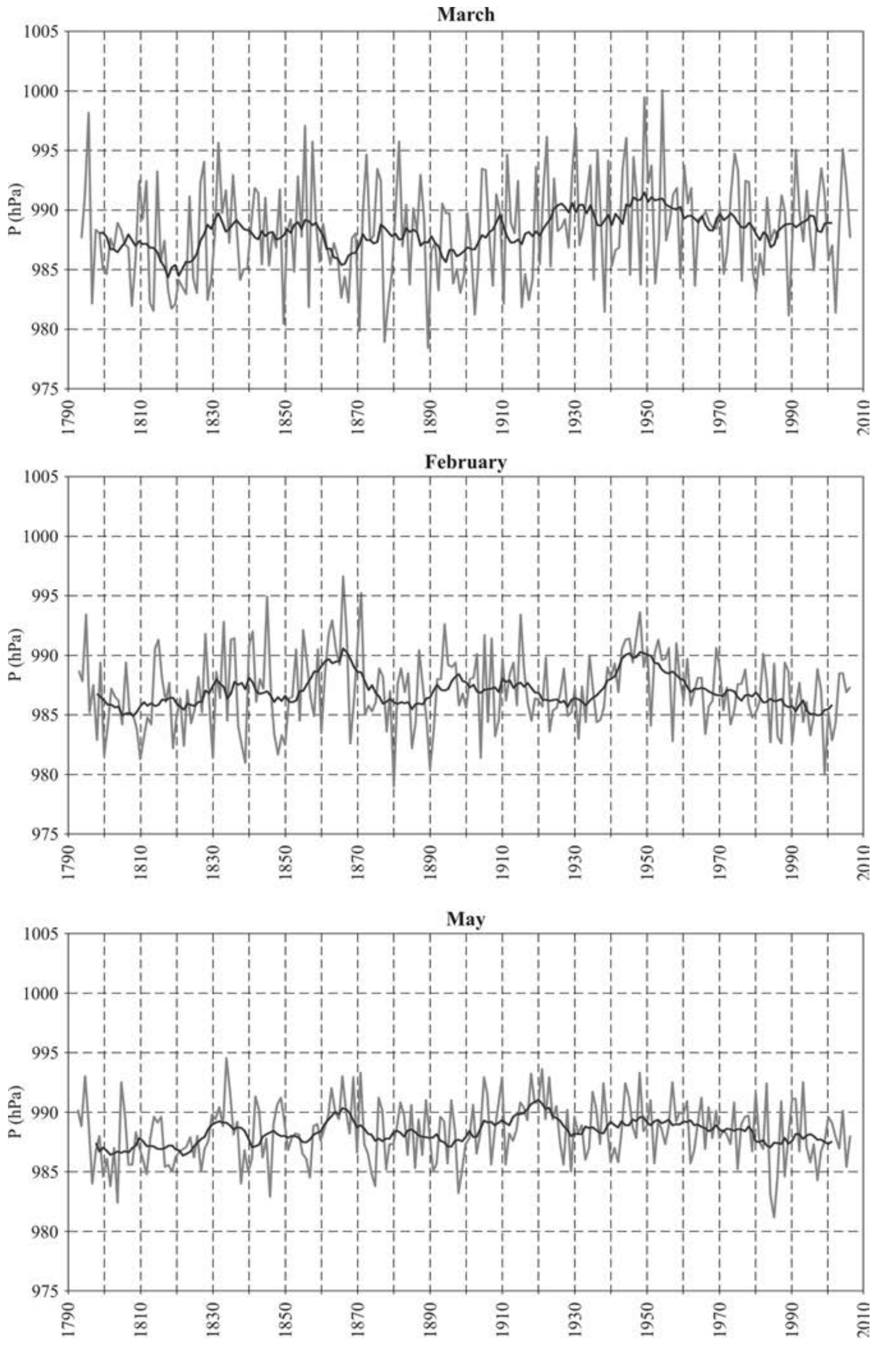

Fig. 2. Mean monthly air pressure (hPa) in spring months in Cracow in 1792-2005

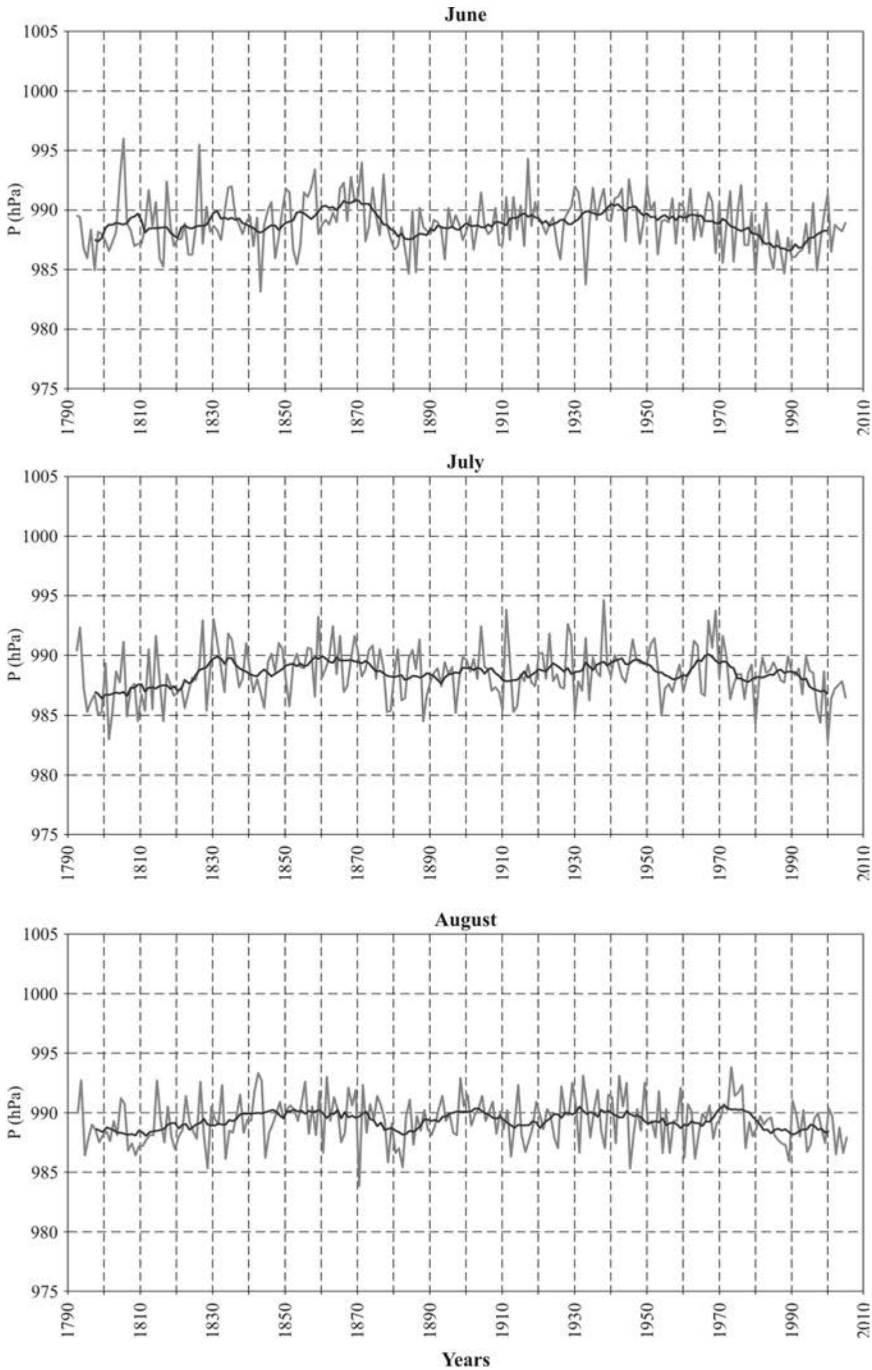

Fig. 3. Mean monthly air pressure (hPa) in summer months in Cracow in 1792-2005

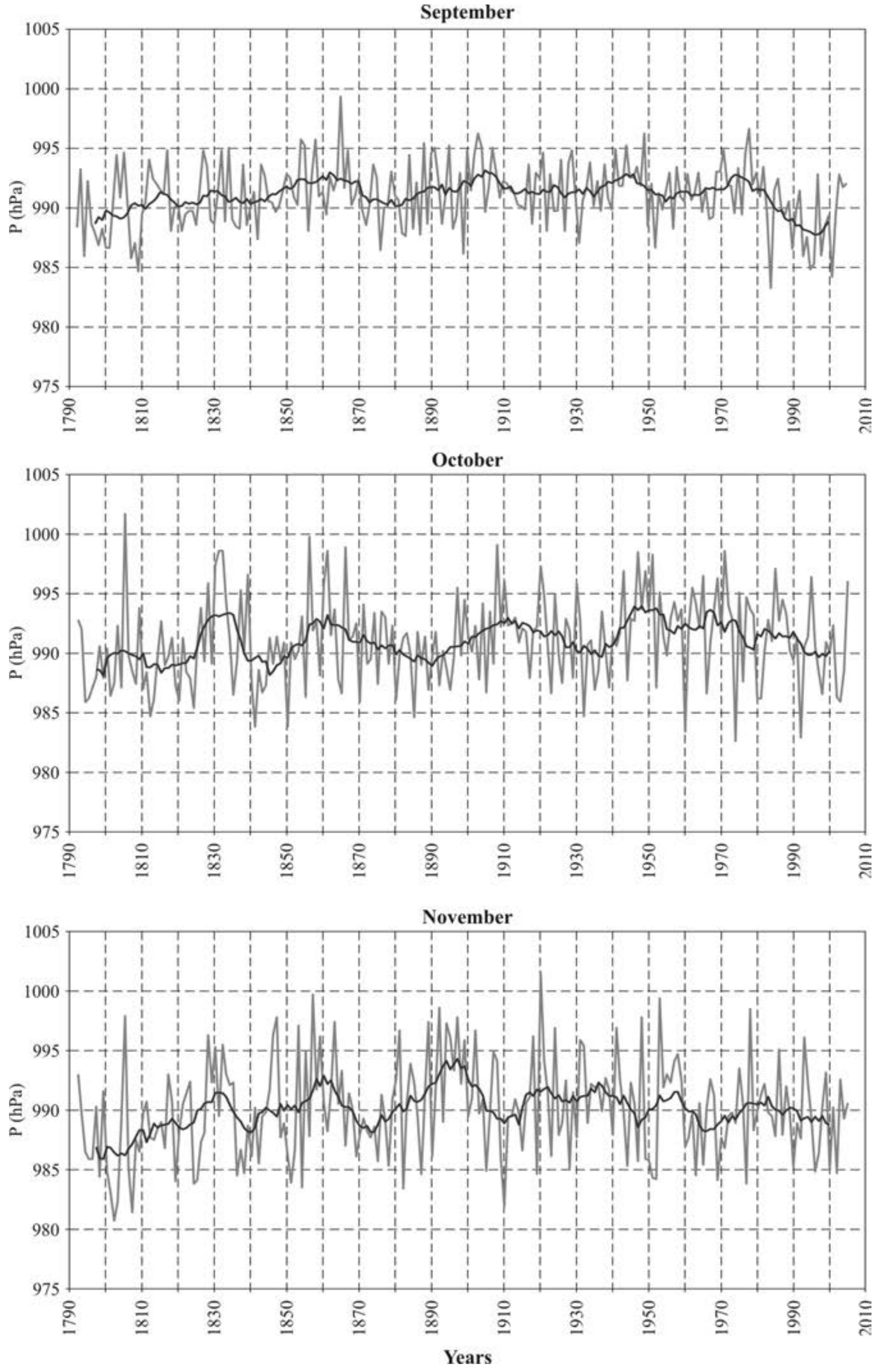

Fig. 4. Mean monthly air pressure (hPa) in autumn months in Cracow in 1792-2005

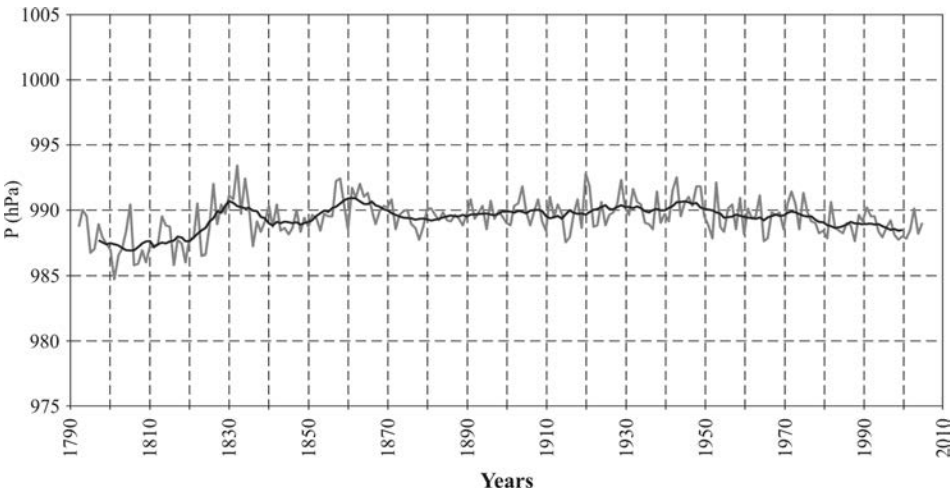

Fig. 5. Mean annual air pressure (hPa) in Cracow in 1792-2005

A separate chapter has been dedicated to the maximum and minimum barometer readings, which can be counted among climatic extremes. A detailed analysis of all of the extremes would take up too much space; therefore extreme values have only been represented by means of examples. In Cracow, values considered extreme are relatively seldom registered. Nevertheless they can considerably affect human comfort, as well as the human physical and psychological condition. Particular attention has been paid to sudden increases and decreases in air pressure, which, seen from the point of view of bioclimatology, can be included in the set of factors regarded as strong stimuli. This issue has become an additional point of interest of the study. Material from the years 1951-2000 has been used (Czarnota 2006) for this purpose.

Annual trends in mean air pressure

Daily or multi-annual trends in air pressure can hardly be approximated by any mathematical curve. Only the annual distribution, calculated on the basis of a very long series of monthly values, shows certain traits which can be considered typical of the central European climate. One of the characteristics which are especially worth noticing is the relatively small variability of the mean values of air pressure in the months of the warm half-year and their great variability in the months of the cold half-year.

Mean monthly values of air pressure, as well as its minimum and maximum values are shown in tables 1 and 2. It seems worthwhile to notice the relatively small differences between the averaged values of air pressure in particular months of the year, compared with other meteorological elements, e.g. air temperature. In the 19th century these differences were slightly smaller. The differences between the mean values and the maximum ones varied from 4.5 to 15.0 hPa. However the differences between the mean values and the smallest ones varied from 5.5 to 13.4 hPa. Even such a general observation confirms the results of more detailed research, which states that systems characterized by higher air pressure tend to dominate in Cracow. The numerical boundary between the value of high and low pressure is purely arbitrary, with the assumed value of 1015 hPa at 0 m a.s.l., which at the altitude of the climatologic station in Cracow corresponds to a value of 989 hPa. There is a remarkable similarity between this figure and the mean annual value of air pressure calculated based on the entire Cracow series, which equals 989.2 hPa.

In the very even annual distribution of mean values of air pressure a very interesting feature can be noticed. September and October are distinguished by higher mean values (Tab.1, Tab 2), whereas April is characterized by the lowest mean. The differences between mean monthly values are small, but they reflect the characteristics of the distribution of high and low patterns throughout the year, i.e. the predominance of lows in the spring and of anti-cyclones in early autumn (September – October). Such traits are also exhibited by the annual distribution of air pressure in other places, e.g. in Warsaw or Budapest (Trepińska 1988). However, there are some years during which a pronounced predominance of either anti-cyclonic or cyclonic systems can be observed in winter months. It can be seen on the example of the maximum and minimum values of monthly means, presented in Tables 1 and 2.

Long-term changes in mean monthly air pressure

When analyzing this aspect, it is necessary to refer to figures 1-5. The mean monthly values of air pressure presented in them are distinguished by significant year-to-year deviations. Even if the 11-year-long moving averages are applied in order to make them more level, it is still impossible to obtain a clear image. An analysis of multi-annual mean values of air pressure in the winter months, which includes November, December, January and February, has allowed some multi-annual periods to be identified, during which the year-to-year variability was greater or smaller. On the whole, the variability of air pressure was greater in the 19th century. The oscillations of air pressure were slightly smaller from the end of the said century to the 1960s. However, it was precisely in this decade when the differences between the mean values decreased. In March it is possible to observe an increase in air-pressure values throughout the 20th century, with a slight decrease in the 1970s. A similar decrease in air pressure was also registered in April in the second half of the 20th century. In the months of the warm half-year, from May to September, no significant changes in the mean values of air pressure occurred. However, in October, some fluctuations could be observed in the first half of the 19th century. In the second half of the same century and in the first half of the following one, the mean values of air pressure were more level, and their greater variability can be seen from the 1960s.

The description presented above is very general, and an explanation of such a distribution requires a reference to the macrocirculation periods in Central Europe or a correlation with the types of synoptic situations, at least for southern Poland.

Further studies are being continued. Many studies concerning the variability of air pressure have tried to account for fluctuations in air pressure (Trepińska 1988), which have always indicated a predominance of western circulation in Central Europe and, in certain periods increased meridian circulation (northeastern or southeastern). This fact is obviously connected to the characteristics of air masses in anti-cyclones and in anticyclone systems, whose dynamics is the factor determining their situation over Europe. Moreover, it is worthwhile to mention the fact that the east-west orientation of the Northern Carpathians mountain range can be a cause of an accumulation of air masses, which tend to move freely over lowlands and low highland areas of central and southern Poland from the north, the northeast and the northwest. This causes air pressure values in Cracow to be somewhat higher in comparison with other places in Poland (Lorenc [ed.] 2005).

Abrupt daily changes in atmospheric pressure

Changes in air pressure within 24 or even within several hours can be substantial, which is especially strongly connected to abrupt weather changes which accompany the passing of atmospheric fronts. According to selected criteria, cases of increases and decreases in air pressure registered on barograsms have been selected. A compensation barograph, placed in the observation room next to the mercury barometer, records the continuous state of air pressure on a weekly basis. However, changes in air pressure within a few hours and especially within a day (24 hours) can be easily reconstructed. Usually, changes in air pressure ≥ 8 hPa within a day are examined (Kozłowska-Szczęsna *et al.* 2004). This paper uses stricter criteria, which have been presented below. Characteristic rapid changes in air pressure have been selected from the years 1951 and 2000, according to the following criteria:

A: changes in air pressure cap_3 equal or greater than 10 hPa within 3 hours ($cap_3 \geq 10$ hPa),

B: changes in air pressure cap_{24h} equal to or greater than 24 hPa within 24 hours ($cap_{24} \geq 24$ hPa).

The set of criteria presented above characterizes the so-called abrupt changes in air pressure. The criteria have proven to be quite strict, as within the 50-year-long barograph records it was possible to register only 12 cases of extreme increases or decreases in air pressure pertaining to category A and 16 cases of abrupt changes from category B. These cases have been presented in tab. 3 and tab. 4. A description of some of them can be found below (Czarnota 2006, Trepińska 2007).

Rapid increases and decreases in the values of air pressure $cap_3 \geq 10$ hPa (A) were observed only in the cold half-year, from October to April. Among all 12 cases registered, there was only one example of a decrease in air pressure, the rest were characterized by a rapid increase.

An abrupt decrease in air pressure occurred on February 8, 1965 (Tab.3), from midnight to 3.00 CET. The weather during that day, as well as on the previous one, was extremely dynamic. There was a wind blowing from the north and the northeast, with an average speed of 10m/s and at night with gusts of 15 m/s. Air temperature within the 24 hour period increased by over 20°C. The change in weather, accompanied by an abrupt decrease in air pressure, was caused by an advection of a fresh polar maritime air mass from the Atlantic Ocean and the North Sea.

The greatest change in air pressure within 3 hours was registered on January 2, 1976 (Tab.3). The fluctuation in air pressure was recorded between 12.00 and 15.00 CET. Air pressure increased by 12 hPa. Initially, there was a weak wind from the west and the southwest, but it gradually grew stronger and was blowing from the northwest at a speed of 12 m/s. The cloudiness, initially complete and made up of *Nimbostratus* and *Cumulonimbus* clouds, decreased in the afternoon. *Stratocumulus* and *Altostratus* clouds appeared, causing weak snowfall in the evening.

Rapid changes in air pressure classified as category B ($cap_{24} \geq 24$ hPa), tended to occur mainly in the winter months: it was true for as much as 81% of the cases. Other isolated events were registered in March, April and November. In this category, cases of decreases in air pressure predominated. The greatest decrease within 24 hours was observed on December 9, 1965 (Tab.4). The synoptic situation on that day was changing rapidly, from one dominated by a high-pressure area to a cyclonic one. Moreover, it was accompanied by an advection of air from the southwest. However, no significant change in weather was observed: the sky was slightly overcast by high clouds, air temperature was near 0°C and there was no precipitation.

The greatest increase in air pressure within a 24-hour-long period was read from barograms on December 9, 1973 (Tab.4). At first, it was possible to observe a cyclonic trough over southern Poland, the air was foggy and dusty and a rainfall occurred. sThe following day, the area was taken over by a high, initially coming from central regions. The wind was moderate, blowing from the northwest.

Table 3. Rapid changes in air pressure during 3 hours in Cracow (1951-2000)

Change (hPa) Rise (+) Fall (-)	Date	Pressure system and direction of travel	Air mass: (A, mA, cA, mP, cP, mT, cT) Front: cold [c] warm [w] occlusion [o]
+12.0	02.01.1976	trough of low pressure	different masses and fronts
+10.5	03.04.1968	SW cycl.	mP warm, different fronts
+10.0	09.12.1973	trough of low pressure	different masses and fronts
+10.0	08.11.1979	W cycl.	different masses and fronts
+10.0	12.12.1979	N cycl.	mP, A, [c]
+10.0	18.10.1981	SW cycl.	different masses and fronts
+10.0	01.03.1990	W cycl.	different masses and fronts
+10.0	12.01.1993	W cycl.	different masses, [c]
+10.0	06.04.1997	centr. cycl.	different masses, [c]
+10.0	17.02.1998	N cycl.	A, [c]
+10.0	12.03.2000	NE anticycl.	A, [c]
-10.7	08.02.1965	centr. of low pressure	different masses, [c]

Źródło: Circulation types and air masses according to T. Niedźwiedź (2005)

Table 4. Rapid changes in air pressure during 24 hours in Cracow (1951-2000)

Change [hPa] Rise (+) Fall (-)	Date	Pressure system and direction of travel	Air mass: (A, mA, cA, mP, cP, mT, cT) Front: cold [c] warm [w] occlusion [o]
+34.2	09.12.1973	trough	different masses and fronts
+32.4	12.12.1979	N cycl→N anticycl.	cA and [c]
+29.9	28.11.1989	N cycl→centr. antic.	cA
+29.0	04.01.1976	N cycl→undefined	mP and [o]
+27.4	06.04.1997	Centr. cycl→N antic.	different masses, A and [c]
+27.0	01.03.1990	W cycl.→NW cycl.	different masses and fronts
+26.1	14.12.1957	Centr.cycl→NEcycl.	mT, different fronts
-30.5	09.12.1965	W antic.→SW cycl.	mP
-29.4	12.02.1962	W cycl.→W cycl.	mP and [w]
-26.6	14.01.1981	Wedge of high. →W cycl W	mP
-26.5	13.12.1973	anticycl.→trough	mP
-26.0	05.01.1958	Centr.antic.→SWcycl.	cP
-25.6	26.12.1991	W anticycl.→trough	mP
-24.9	15.12.1962	W cycl.→W cycl .	mP
-24.8	07.02.1965	Wedge of high →centr.low	cP
-24.2	03.12.1973	W antic.→W cycl.	A

Źródło: Circulation types and air masses according to T. Niedźwiedź (2005)

Most cases of increases and decreases in air pressure within a day took place in December, which is related to a great variability of weather types in that particular month.

Summary and conclusions

Fluctuations in air pressure appear to be a good supplement to the description of the climate in a certain region. The analysis of the Cracow series of barometric observations was carried out without the reduction of data to the level of 0 m a.s.l. The chapter titled "Annual course of mean air pressure values" presents the averaged distribution of these values, on the basis of the mean monthly values of air pressure recorded at the Research Station of the Institute of Climatology, Department of Geography and Spatial Management of the Jagiellonian University. The mean monthly values of air pressure have been calculated using data collected at the station since the beginning of its operation, i.e. from 1792. Although said distribution is representative of Central Europe, with the characteristic higher value of air pressure in October, it does not reflect the highly variable values of air pressure in particular months. These means can be distinguished by their wide range of variability, which can exceed 30 hPa in winter months. Substantial fluctuations can also occur in the daily (24-hour-long) course of air pressure. Examples of such fluctuations have been presented in the study.

Changes in air pressure in the 19th and in the 20th century have been compared. The differences between the values from year to year were greater in the 19th century, but it was also possible to notice characteristic phases over the long-term. In order to explain these phases, detailed studies of the variability of circulation of air masses on a European scale and of the variability of macrocirculation patterns are required. Such an investigation was carried out by the author in a paper from 1988 (Trepińska 1988).

The chapter „Abrupt daily changes in air pressure" presents the frequency of occurrence of cases of certain changes within 3 and within 24 hours. Strict criteria applied to the delimitation of such changes make their number quite small: only as little as about 0.15% of the data for the years 1951-2000 can be classified as cases of this type. They include both rapid increases and decreases in air pressure. The vast majority of the cases was recorded in wintertime. Drawing conclusions about the frequency of the daily changes is not based on extensive statistical analysis, and therefore the study is only limited to mentioning the occurrence of such unusual weather phenomena.

When considering biometeorological conditions, changes in air pressure over a short period of time, i.e. within a few or even within 24 hours, are very significant. The examples included in the paper, based on the time period 1951-2000, confirm the hypothesis that abrupt changes in air pressure affect some individuals sensitive to changes in the weather.

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Janina Trepińska
Jagiellonian University
Institute of Geography and Spatial Management
Gronostajowa 7, 30-387 Kraków, Poland
e-mail: j.trepinska@geo.uj.edu.pl