Chapter 5
Instrumental Observations

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5.1 History of Early-Instrumental Observations

The region of Poland in both its historical and present boundaries has, in international terms, one of the longest histories of instrumental meteorological observations (e.g. Gorczyński 1934; Rojecki 1956, 1968; Marciniak 1990; Trepińska 1993; Lorenc 2000; see also Table 5.1). The first observations were made in Warsaw in either December 1654 or at the beginning of 1655 (Rojecki 1956, 1966, 1968). Warsaw was one of 11 European stations which were included in the first network of meteorological stations (the so-called 'Rete medicea') organised by Ferdinand II, Grand Duke of Tuscany, and his brother Prince Leopold de Medici (Camuffo 2002). It is known that meteorological observations within this network began on 15 December 1654 and continued until 1667. In Warsaw, meteorological measurements included air temperature records (using the 50° Florentine thermometer) and visual observations of states of the sky. These were recorded either once or three times a day. There is, however, no information available about the precise location of these observations, nor do we know who made them or the precise periods during which they were made. The very eventful history of Poland (involving partitions, wars etc.) is the main reason why much of the valuable meteorological and documentary data concerning weather and climate have been lost. Only a small number of the reported series of observations now survive, covering a period of 7 days (10–16 May 1655), and these are available in the Biblioteca Nationale Centrale in Florence, Italy (Table 5.1). It is notable, however, that these instrumental meteorological observations from Warsaw are the oldest extant instrumental observations (outside Italy) in the world.

The second oldest instrumental observations in Poland were recorded between April 1710 and December 1721 in Wrocław (south-west Poland) by physician David von Grebner (Hellmann 1883, 1914; Landsberg 1983). Observations were

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Table 5.1 Isolated early-instrumental series of meteorological observations in Poland in the seventeenth and eighteenth centuries

L.p.	Site	Period	Observer(s)	Variables measured	Resolution of observations	Source of data	Availability of data/ Electronic form
1	Warsaw	12.1654–1667	unknown	T, SoS	three times a day	Biblioteca Nationale Centrale, Florence, Italy	10–16.05.1655/not available
2	Gubin	01.1697–06.1697	Maria Małgorzata Kirch	T	unknown	Miętus et al. (1999)	?
3	Wrocław	04.1710–1721, gaps for 10.1712–09.1713 and 08.1717	David von Grebner	T, AP	one to three times a day	Library of Wrocław University	WP/DC-NCU
4	Wrocław	1717–1726, 1727–1730	Johann Kanold/A.E. Büchner	T, AP, WD, GWD	three times a day	*Breslauer Sammlung* (Wrocław Collection)	WP/not available
5	Legnica	10.1717–12.1719	unknown	T, AP, H****	unknown	Miętus et al. (2001)	?
6	Kurów-Oława	02.1718–06.1719	unknown	P	three times a day	Miętus et al. (2000a)	?
7	Warsaw	1725–1728	Christian Heinrich Erndtel/G. Rautenberg	AP, WD, SoS, P	twice a day	Erndtel (1730), Warsavia, Physice Illustrata…. For more details see references	WP/DC-NCU
8	Gdańsk	1739–1772	Michael Christoph Hanow	T, AP, H, WD, WS, P, MP	four times a day	Hanow's manuscript Wetterbeobachtungen, von aus Jahren 1739–1772	WP/DMK-GU

9	Toruń	1740–10.06.1767	Samuel Theodor Schönwald	T, AP, WD, SoS, P	twice a day	journal Thornische Wöchentliche, Nachrichten und Anzeigen nebst einem Abhange von Gelehrten Sachen	1760–1767/DC-NCU
10	Gdańsk	1744–1784	Carl Gottfried Minior	T, WD, AP***, MP	twice a day	Minior's manuscript of meteorological records kept, in the Main Library of the Technical University in Gdańsk	WP/DMK-GU
11	Gdańsk	1752–1789	Johann Eilhard Reinick	T, AP, WD, MP	twice a day	Reinick's manuscript of meteorological records kept, in the Main Library of the Technical University in Gdańsk	WP/DMK-GU
12	Warsaw	07.1760–05.1762, 05.1762–03.1763	J. E. Guettard, Rev. J. Delsuc	T, AP, C, P, MP	three times a day, twice a day	Guettard (1768), see references, http://imgbase-scd-ulp.u-strasbg.fr/ displayimage.php?pos=-25308	WP/DC-NCU
13	Gdańsk	1764–1790	Johann Konrad Eichhorn	AP, T#, WD#	two to four times a day	Eichhorn's manuscript of meteorological records kept, in the Main Library of the Technical University in Gdańsk	WP/DMK-GU

(continued)

Table 5.1 (continued)

L.p.	Site	Period	Observer(s)	Variables measured	Resolution of observations	Source of data	Availability of data/ Electronic form
14	Warsaw	1779–1799	Rev. Jowin Fryderyk Bończa-Bystrzycki	T, AP, SoS*, WD**	three times a day	Bończa-Bystrzycki's manuscript of meteorological, records kept in the Archive of the Institute of Meteorology and Water Management in Warsaw	WP/not available
15	Żagań	1781–1792##	Preus?	T, AP, H, P, WD, WS, MP	three times a day	Ephemerides Societatis Meteorologicae Palatinae, 1783–1795, Volumines II–XIII, Mannheimii	WP/DC-NCU
16	Gdańsk	1783–1806, gaps for 1783–84 and 1795	Fülbach	T, AP, WD, H, MP	twice a day, from 1787 3 times a day	Fülbach's manuscript of meteorological records kept, in the Main Library of the Technical University in Gdańsk	WP/DMK-GU
17	Mogiła near Cracow	1783	Filip Carosi	unknown	unknown	Hanik (1972)	probably lost
18	Szczecin	1783–1784.02	unknown	T, AP	three times a day	Miętus et al. (1994); Miętus (1997)	?

19	Twardogóra	1783–1785	Brockshammer	T, AP	unknown	Miętus (2000c)	?
20	Oleśnica	12.1783–1789	unknown	T, AP, WS	six times a day	Miętus (2000b)	?
21	Legnica	10.1783–06.1785	unknown	T	unknown	Miętus (1997); Miętus and Chwalczewska (2001)	?
22	Jasło	1785–1808	Józef Hibl	unknown	unknown	Hanik (1972)	probably lost
23	Gdańsk	1788–1812 some gaps in 1788–89 and 1811	R. Sturke	T, AP, WD, MP	twice a day	Sturke's manuscript of meteorological records kept, in the Main Library of the Technical University in Gdańsk	WP/DMK-GU
24	Cracow	05.1792–05.1794	Jan Śniadecki and others	T, AP, SoS, WD, P, H, MP	three times a day	meteorological records kept in the Department of Climatology, Jagiellonian University	WP/DC-JU

Explanations: T – air temperature, AP – atmospheric pressure, SoS – state of sky, WD – wind direction, WS – wind speed, C – cloudiness, P – precipitation, H – humidity, MP – meteorological phenomena, GDW – general weather description, WP – Whole period, DC-NCU – Department of Climatology Nicolaus Copernicus University in Toruń, DMK-GU – Department of Meteorology and Climatology of Gdańsk University, DC-JU – Department of Climatology, Jagiellonian University, * – from June 1779, ** – from 1784,*** – without 1744–1754 and 1761–1763, **** – from 1st March 1718, # – measurements taken sporadically, ## – for 1787 only observations of WD, WS and MP are available limited to measurements of air temperature and atmospheric pressure (Pyka 2003). Yet von Grebner had begun recording non-instrumental observations of different weather characteristics as early as 1692. Similar to the Warsaw observations, there is no information about the precise location of these measurements. Von Grebner also used the Florentine thermometer, which had a brass scale with a star in the middle, above which were 80° and below which were 100° (Landsberg 1983). The results of these observations are available in unpublished form in the Library of Wrocław University. For purposes of comparison, another Wrocław physician – Johann Kanold (1679–1729) – began meteorological measurements in Silesia (e.g. Wrocław, Oława, and Legnica) and in other European countries in 1717. He recorded measurements in Wrocław up to 1726, and then from 1727 to 1730 they were continued by Andreas Elias Büchner (1701–1769), professor of medicine at Wrocław University (Brázdil and Valášek 2002; Munzar 2003; Brázdil et al. 2008). They included measurements of air temperature, air pressure, wind direction and general descriptions of weather. Measurements were taken three times a day and the results were published in an encyclopaedic series *Sammlung Von Natur- und Medicin-, Wie auch hierzu gehörigen Kunst- und Literatur-Geschichten* (the so-called *Breslauer Sammlung* – Wrocław Collection).

The next extant isolated series of meteorological measurements (1725–1728) comes from Warsaw and mainly concerns atmospheric pressure. Measurements of this variable were recorded by Christian Heinrich Erndtel (1670–1734), with the help of G. Rautenberg, twice a day (in the morning and evening), using a barometer constructed by Jacob Leupold. The barometer had a relative scale of probably 30° or 32° (Rojecki 1968). The meteorological results were published *in extenso* by Erndtel (1730) in a work entitled *Warsavia Physice Illustrata….* In this publication, aside from atmospheric pressure, details are also given of average wind direction, the state of the sky, kinds of precipitation and thermal perception (Fig. 5.1).

Gdańsk is the third place in Poland to have a very rich history of instrumental observations (see Filipiak 2007a, b; Miętus 2007), and documentary evidence is also available for long periods before the start of instrumental observations in 1739. Two such records are especially valuable for climate reconstructions. The first is a publication written by Wilhelm Misocacus entitled *Prognosticum oder Practica auffs Jahr 1577…1595*, giving a description of the weather for each season for the period 1577–1593. The second is *Calendars* written by Fryderyk Büthner between the years 1655 and 1696 and contains mainly astronomical information, but also a daily description of the weather conditions (Miętus 2007).

According to Miętus (2007) for the eighteenth century we know of six isolated series of meteorological measurements made in Gdańsk. The observers and periods of observations are as follows: Michael Christoph Hanow (1739–1772), Carl Gottfried Minior (1744–1784), Johann Eilhard Reinick (1752–1789), Johann Konrad Eichhorn (1764–1790), Fülbach (1783–1806), and R. Skurke (1788–1812). The most complete weather information is given by Hanow in the three volumes of his manuscripts (*Wetterbeobachtungen von aus Jahren 1739–1772*). This work presents the results of measurements of air temperature, atmospheric pressure, amount of precipitation, air humidity, and wind direction taken four times a day

Dies.	Barometrum. mane	veſperi	Venti.	Conſtitutio tempeſtatis. *Januarius*, 1725.
1	13	16	S O.	Mite, nive tamen non liqueſcente, nubilo-frigido-ſerenum cœlum,
2	13. 2	15	S S O.	Nubilo-humido-ſerenum cum frigore nocturno,
3	14	14	SSW. SSO.	Admodum frigido, nubilo-ſerenum, noctu nivoſum,
4	15	16	SSW.	Nubilum ad nivem diſpoſitum,
5	13	12	SSW.	Idem - - - noctu frigidum, (tius, frigus,
6	14	13	SSO.	Frigidius, nubilum cum ventis valide ſpirantibus, exin mi-
7	13. 1	11	SSO.	Frigido-nubilo-ventoſum, nive interveniente & in noctem usque durante,
8	12. 2	10	SSO.	Nubilum ad nivem diſpoſitum, frigus mitius, veſperi nivoſo-pluvioſo-humidum,
9	14. 3	14	SO.	Mitius, nubilo-ſerenum, nive liqveſcente, ſub veſperam ſereno-frigidum,
10	15. 1	13	SO.	Nubilum ad nivem diſpoſitum, frigidum, circa meridiem miteſcit, nubilo-tamen ſerenum,
11	14	12	SO.	Eadem conſtitutio, à meridie ſereno-nubilum,
12	17. 2	15	SO.	Nubilo-frigido-ſerenum,
13	18	16	SO.	Frigido-nubilum, miteſcit, cum pluvia inſequente,
14	17	18	SO.	Nubilo-pluvioſum,
15	21	22	SSO.	Nubilo-humidum, poſt meridiem ſereno-nubilum,
16	22	22	SSO.	Nubilum, p. m. humido-frigidum, (frigidum,
17	24. 2	24	SSO.	Nubilo-frigidum, circa meridiem frigidius, noctu humido-
18	24	23	SSO.	Admodum frigido-nubilum, cum vento & frigore aucto,
19	24	25	O.	Idem fere per diem, ſub veſperam ſerenum, noctu frigi-
20	25	25	O.	Sereno-admodum frigidum, (dum,
21	24. 2	22	O.	Frigidius ſerenum,
22	22	21. 1.	O.	Idem - - veſperi nubilum, noctu frigidium,
23	21. 2	21	O.	Idem,
24	21	21	O.	Serenum, frigore aucto,
25	20. 2	19	O.	Idem - - cum ventis,
26	18. 2	19	OSO.	Frigido-ventoſo-ſerenum,
27	19	20	O.	Frigido-ſereno-ſudum,
28	20	21	SO.	Frigidius ſerenum, veſperi nubilum ad nivem diſpoſitum,
29	20. 2	21. 2.	SSO.	Nubilum ad nivem diſpoſitum, nubilo-frigidum,
30	21. 2	18	WSW. W.	Idem - mitius, p. m. nix liqueſcit & ningit,
31	17. 2	19	W.	Noctu venti validi; mane humidum, nix liquefieri cœpit, noctu procelloſum.

NB. Die 24. Viſtula glacie ita obducebatur, ut die ſequenti hominibus, iter facientibus, liberum permitteret tranſitum.

Fig. 5.1 Facsimile of a page of the published records of meteorological observations made in Warsaw in 1725–1728 by C.H. Erndtel (1730) from 1 January 1739 to 30 September 1772 (Filipiak 2007a). The measurements were taken in the centre of Gdańsk, but there is no information given about the exposition of the meteorological instruments. The other series give daily data (usually two or four measurements a day) mainly limited to air temperature, atmospheric pressure and wind direction. For more details see Filipiak and Miętus (2009, this volume).

Instrumental observations began in Toruń in 1740, just 1 year after Gdańsk (Rojecki 1965). Daily observations in the morning and evening hours (precise times are unknown) were conducted up to 10 June 1767, probably in the centre of Toruń in the area of the local *Gymnasium*. Unfortunately, the original observation data for years before 1760 are missing, and thus it is now impossible to know exactly which meteorological observations were made during this period. From the journal *Thornische Wöchentliche Nachrichten und Anzeigen nebst einem Abhange von Gelehrten Sachen* it is known that at least temperature measurements were taken. The second issue of the journal, from 1760, gives a list of the lowest winter temperatures from 1740 to 1759. The journal featured meteorological observations from Toruń from 1760 onwards, and thus they are available up to 10 June 1767. Elements measured included air temperature, atmospheric pressure, wind direction, states of the sky, precipitation, and some other hydrometeors (Fig. 5.2). The observations were probably made by Samuel Theodor Schönwald, a professor of mathematics in the local *Gymnasium*. Air temperature was measured up to January 1 1758 with a Florentine thermometer and from 1758 onwards a second thermometer with a Réaumur scale was also used. The two thermometers were installed outside the building. Air pressure measurements were taken using a glass tube 86.4 cm in length, the open end of which was immersed in a wooden container. The next isolated series of meteorological variables in Toruń are known for the periods 1821–1825 (Hellmann 1883) and 1842–1858 (Rojecki 1965). For the first period we have no information about the elements measured. On the other hand, during the second period, measurements of air temperature and atmospheric pressure were recorded once a day at 8 am. Air temperature data averaged monthly are given in Table II (Rojecki 1965).

The next important series of instrumental meteorological observations in Warsaw was done by two Frenchmen – J.E. Guettard (1715–1786), a naturalist and member of the Royal Academy of Sciences in Paris, and the Rev. J. Delsuc, secretary to the French ambassador to the King of Poland. Guettard made his observations from July 1 1760 to May 5 1762, while Delsuc made his from May 6 1762 to March 31 1763 (Rojecki 1968). Measurements include air temperature and atmospheric pressure, while cloud cover, kinds of precipitation and other atmospheric phenomena were visually observed (Fig. 5.3). Guettard made observations three times a day (in the morning, mainly between 6 am and 7 am, at 3 pm and at midnight), while Delsuc recorded them only twice a day at 3 pm and 10 pm. There is no information available about the detailed location and exposition of the meteorological instruments. For temperature measurements, mercury and alcohol thermometers with the Réaumur scale were used, produced by Cappy, a French technician. For atmospheric pressure, a mercury barometer produced in Warsaw was used, with a scale

Mittwoch, den 9. Jenner.

Morgen- und Abend-Beobachtungen der Luft und Witterung.

Jan. Tage.	Luft-Schwere.		Kälte. Fl.		R.		Winde.		Wetter.
♂. 1	11.	10	29.	27	3/2	2/2	SgW.	SW.	Gewölkt. Regen.
☿. 2	9.	7	28.	27	2/1	2/0	SW.	SO.	Fast klar. Neblicht.
♃. 3	$8\frac{1}{2}$.	9	28.	26	2/0	2/2	NgW.	NNW.	Bewölkt Trüb m. S
♀. 4	12.	$12\frac{1}{2}$	28.	31	2/2	3/2	NNW.	NNW.	Bewölkt mit Schn.
♄. 5	14.	$12\frac{1}{2}$	34.	33	4/2	3/2	NNW.	NNW.	Schnee. Trüb m. S
☉. 6	13.	15	36.	46	4/3	7/2	NgW.	NNW.	Meist helle. ganz klar
☽. 7	16.	16	58.	55	10.	9	NgW.	NNW.	Nebel u. Rauchfrost

Mittwoch, den 16. Jenner.

Morgen- und Abend-Beobachtungen der Luft und Witterung.

Jan. Tage.	Luft-Schwere.		Kälte. Fl.		R.		Winde.		Wetter.
♂. 8	19.	$20\frac{1}{2}$	53.	50	9,	8/2	NgW.	NNW	Rauchfrost. Schnee
☿. 9	22.	22	44.	41	6/3	6/2	NW.	WgN.	Gewölkt. Heller.
♃. 10	22.	$20\frac{1}{2}$	41.	40	6/1	5/3	NW.	WNW.	Gewölkt. meist helle.
♀. 11	20.	23	39.	65	5/2	12,	NW.	NO.	scharfer Wind, helle.
♄. 12	27.	$26\frac{1}{2}$	76.	74	15,	14/2	ONO.	OgN.	Hell u. scharffe Luft
☉. 13	25.	21	78.	68	16,	12/2	O.	OSO.	Helle u. scharffe Luft
☽. 14	18.	$15\frac{1}{2}$	71.	55	14,	10/2	SO.	OSO.	Meist klar. Trüb.

Mittwoch, den 23. Jenner.

Morgen- und Abend-Beobachtungen der Luft und Witterung.

Jan. Tage.	Luft-Schwere.		Kälte. Fl.		R.		Winde.		Wetter.
♂. 15	15.	17	51.	47	9/2	8/2	ONO.	NO.	Schnee, klar. Gemischt.
☿. 16	18.	21	41.	47	6.	8.	NNW.	N.	Trüb m. Schn. hell win.
♃. 17	23.	21	70.	56	13/2	9/3	NO.	W.	Rauchfrost u. Neb. hell.
♀. 18	19.	17	36.	32	5/2	4/2	WgN.	----	Trüb u. etwas windig.
♄. 19	$17\frac{1}{2}$.	22	33.	46	4/3	7/2	NW.	N.	Helle und luftig.
☉. 20	$24\frac{1}{2}$.	24	68.	56	12/2	9/2	ONO.	SW.	Helle den ganzen Tag.
☽. 21	22.	19	38.	34	5/3	4/2	WNW.	WgN	Trüb, wind. trüb m. S.

Mittwoch, den 30. Jenner.

Morgen- und Abend-Beobachtungen der Luft und Witterung.

Jan. Tage.	Luft-Schwere.		Kälte. Fl.		R.		Winde.		Wetter.
♂. 22	$14\frac{1}{2}$.	10	36.	27	5,	3,	W.	WNW.	Schnee, meist hell. win.
☿. 23	12.	16	40.	42	6.	6.2	NW.	----	Gewölkt. starker Wind
♃. 24	$16\frac{1}{2}$.	10	46.	47	7,	7/2	SO.	SW.	Meist helle. Schnee.
♀. 25	5.	4	29.	26	3/2	2/2	SW.	W.	feucht. S. Thauw. St.
♄. 26	8.	7	24.	24	2,	2,	W.	WSW.	Meist hell trüb u. luftig.
☉. 27	$7\frac{1}{2}$.	$8\frac{1}{2}$	22.	25	1,	2,	WSW.	SW.	Gewölkt. Meist hell.
☽. 28	11.	7	25.	24	2,	2,	SSW.	SgO.	Gewölkt. meist h. tr. R.

Steigen und Fallen des Weichsel[illegible]

Fig. 5.2 Facsimile of a page presenting tables with meteorological observations made in Toruń in 1760–1767 published in the journal *Thornische Wöchentliche Nachrichten und Anzeigen nebst einem Abhange von Gelehrten Sachen*

ETAT DU CIEL,

A VARSOVIE,

Pendant l'année 1761.

Mois & jours. Janvier 1761.	*Heures où le Thermomètre a été observé.*				*Variations de l'air.*	*Baromètre.*	
1 Jeudi.	Matin	6	1	$\frac{1}{4}$	Couvert.	27	1$\frac{1}{2}$
	Apr. m.	3	5	$\frac{1}{3}$	Couvert.	27	$\frac{1}{2}$
	Soir	12	4	$\frac{1}{2}$	Couvert, un peu de vent.	26	11
2 Vend.	Matin	6	2	$\frac{1}{3}$	Nébuleux.	26	11$\frac{1}{2}$
	Apr. m.	3	4	$\frac{1}{4}$	Couvert.	26	10
	Soir	12	3	$\frac{1}{4}$	Couvert.	26	11$\frac{1}{2}$
3 Sam.	Matin	6	3	$\frac{1}{2}$	Couvert, petite pluie.	27	1$\frac{1}{2}$
	Apr. m.	3	3		Couvert, petite pluie.	27	4
	Soir	12	2	$\frac{1}{4}$	Couvert, vent.	27	5
4 Dim.	Matin	6	4	$\frac{1}{4}$	Couv. g. vent & p. pluie à rep.	27	3
	Apr. m.	3	5	$\frac{1}{2}$	Nébuleux.	27	5
	Soir	12	2		Vaporeux.	27	8$\frac{1}{2}$
5 Lundi.	Matin	6	2		Couvert.	27	10
	Apr. m.	3	3	$\frac{1}{2}$	Nébuleux.	27	8
	Soir	12	5	$\frac{1}{3}$	Petite pluie, vent fort.	27	6
6 Mardi.	Matin	6	2	$\frac{1}{4}$	Nébuleux.	27	7
	Apr. m.	3	3	$\frac{1}{4}$	Nébuleux, vent fort.	27	6
	Soir	12	1		Nébuleux.	27	6
7 Merc.	Matin	6	$\frac{1}{4}$		Nébuleux.	27	7$\frac{1}{2}$
	Apr. m.	3	$\frac{1}{3}$		Vaporeux.	27	10$\frac{3}{4}$
	Soir	12	0	4	Beau.	28	
8 Jeudi.	Matin	6	0	6	Vaporeux.	28	2
	Apr. m.	3	0	1$\frac{1}{2}$	Un peu de nuages & de vent.	28	$\frac{1}{2}$
	Soir	12	0	4	Clair, un peu de vent.	27	10$\frac{1}{2}$
9 Vend.	Matin	6	0		Neige la nuit, nébuleux.	27	10$\frac{1}{2}$
	Apr. m.	3	2		Nébuleux.	27	10$\frac{1}{2}$
	Soir	12	0	2	Beau.	27	11
10 Sam.	Matin	6	0	3$\frac{1}{4}$	Vaporeux.	27	$\frac{1}{2}$
	Apr. m.	3	0		Très-peu de nuages.	27	9$\frac{1}{2}$
	Soir	12	0	1$\frac{1}{2}$	Brouillard, vent fort.	27	7$\frac{1}{2}$

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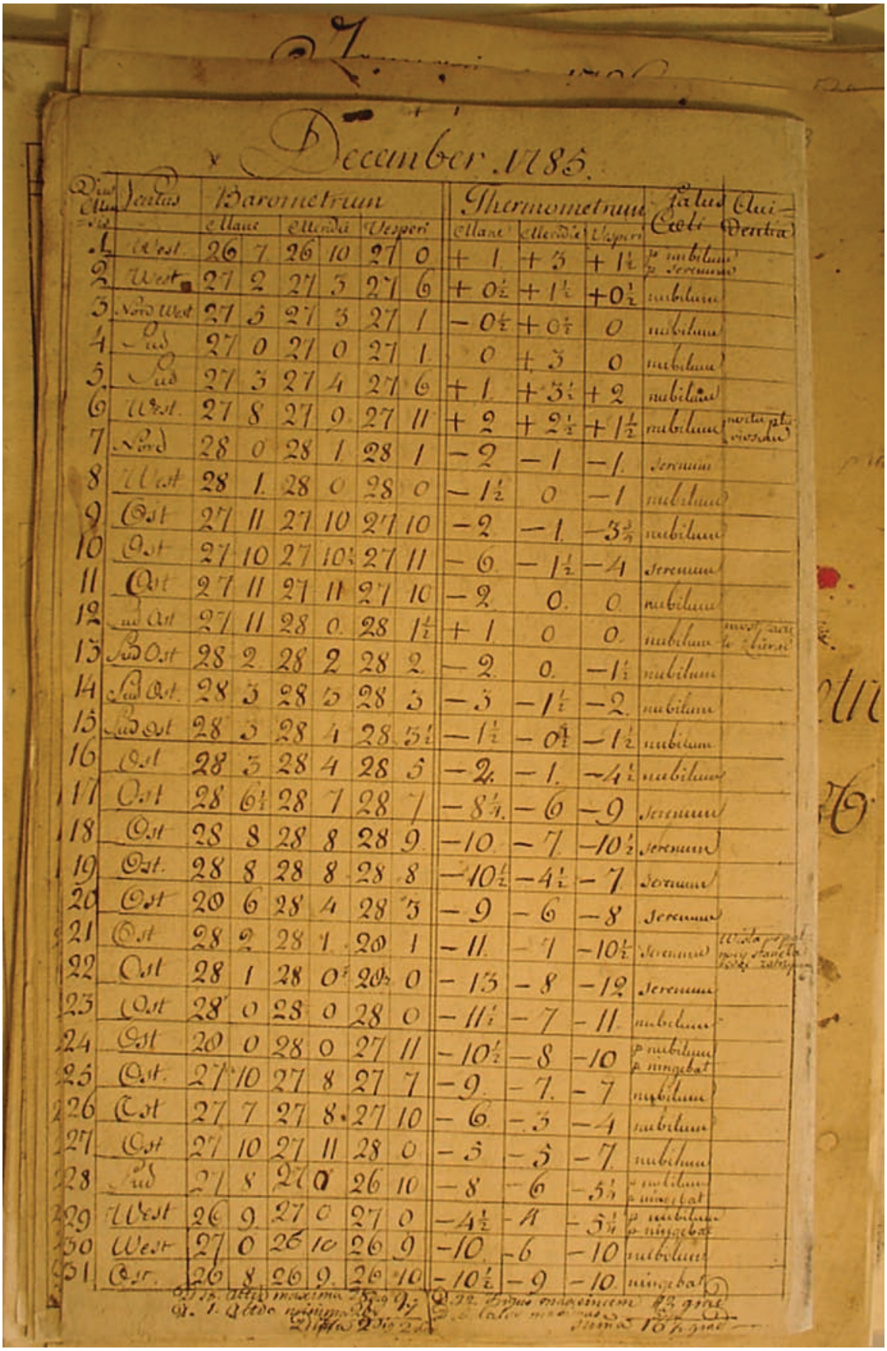
Fig. 5.3 Facsimile of a page of the published records of meteorological observations made in Warsaw in 1760–1762 by J.E. Guettard (1768) in French inches (1 French inch = 27.07 mm). All the results of meteorological measurements were published in a book written by Guettard (1768) and are available at http://imgbase-scd-ulp.u-strasbg.fr/displayimage.php?pos = -25308. Michalczewski (1988), using the regression method and a set of contemporary data from Warsaw, established some statistical relationships which allowed him to homogenise the original air temperature data and to calculate daily means (see Table 2 in Michalczewski 1988).

The last isolated series of instrumental observations in Warsaw in the 18th century was recorded by the Rev. Jowin Fryderyk Bończa-Bystrzycki from 1 January 1779 to 31 December 1799 with two long breaks from 18 September to 25 November 1787 and from 15 September to 14 December 1790. In these periods he conducted observations in Stężyca near Dęblin, not far from Warsaw. In case of air temperature measurements from 1 January 1779 onwards there is an almost continuous record, with a break only from 1 January 1800 to 30 September 1803. There are some indications that Rev. Bończa-Bystrzycki may have started these observations as early as in 1775. In the *Gazeta Warszawska* from 5 March 1785 it is noted that severe frost had been recorded at the Castle Observatory in Warsaw in 1776, and 1777, that is earlier than 1 January 1779. Unfortunately, source data have not survived from this time. Meteorological observations were carried out at the top of the tower of the Astronomical Observatory in the Royal Castle. Temperature observations using a Réaumur scale thermometer, positioned on the east side of the tower, were recorded three times a day: during sunrise, 1 h after midday and in the evening after sunset (Rojecki 1968). Atmospheric pressure was also recorded thrice daily, probably at the same times as for temperature, and using an English barometer. From June 1779 the state of sky was noted (probably its average state during the day), while from the beginning of 1784 daily records of wind direction were measured in the morning, using an eight-direction wind rose (Fig. 5.4).

Rojecki (1968) noted that Löve and Riem (1785) provide a list of absolute minimum temperatures for Warsaw from 1709 to 1785. From this he suggests that air temperature measurements in Warsaw were recorded more or less systematically from this period onwards.

In Vilnius (now the capital of Lithuania) isolated series of instrumental observations were recorded in the 1770s at the Astronomical Observatory founded in 1753. While some of them are missing between 1773 and 1776, there is a continuous series of air temperatures from 1777 onwards (Gorczyński and Kosińska 1916; Gorczyński 1934; Bukantis and Rimkus 2005).

The first instrumental meteorological observations in south-eastern Poland were carried out in 1783 by Filip Carosi in Mogiła near Cracow (Hanik 1972). However, there is no information about the variables measured, the location and exposition of instruments etc. It is also known that between 1785 and 1808 measurements of air temperature and wind direction were recorded in Jasło by the physician Józef Hibl. In both cases there are probably no preserved data. However, the best known meteorological observations come from Cracow, where they were conducted irregularly from 1 May 1792 to 15 July 1825 (for details see Trepińska 1997a). The measurements were made in the Astronomical Observatory founded in 1791 by Jan


December 1785.

Dies Mensis	Ventus	Barometrum Mane		Meridie		Vesperi		Thermometrum Mane	Meridie	Vesperi	Status Coeli	Accidentia
1	West	26	7	26	10	27	0	+1	+3	+1½	p. nubilum p. serenum	
2	West	27	2	27	3	27	6	+0½	+1½	+0½	nubilum	
3	Nord West	27	5	27	3	27	1	−0½	+0½	0	nubilum	
4	Sud	27	0	27	0	27	1	0	+3	0	nubilum	
5	Sud	27	3	27	4	27	6	+1	+3½	+2	nubilum	
6	West	27	8	27	9	27	11	+2	+2½	+1½	nubilum	[illegible]
7	Nord	28	0	28	1	28	1	−2	−1	−1	serenum	
8	West	28	1	28	0	28	0	−1½	0	−1	nubilum	
9	Ost	27	11	27	10	27	10	−2	−1	−3¾	nubilum	
10	Ost	27	10	27	10½	27	11	−6	−1½	−4	serenum	
11	Ost	27	11	27	11	27	10	−2	0	0	nubilum	
12	Sud Ost	27	11	28	0	28	1½	+1	0	0	nubilum	[illegible]
13	Sud Ost	28	2	28	2	28	2	−2	0	−1½	nubilum	
14	Sud Ost	28	3	28	3	28	3	−3	−1½	−2	nubilum	
15	Sud Ost	28	3	28	4	28	5½	−1½	−0½	−1½	nubilum	
16	Ost	28	3	28	4	28	5	−2	−1	−4½	nubilum	
17	Ost	28	6½	28	7	28	7	−8¾	−6	−9	serenum	
18	Ost	28	8	28	8	28	9	−10	−7	−10½	serenum	
19	Ost	28	8	28	8	28	8	−10½	−4½	−7	serenum	
20	Ost	28	6	28	4	28	3	−9	−6	−8	serenum	
21	Ost	28	2	28	1	28	1	−11	−7	−10½	serenum	[illegible]
22	Ost	28	1	28	0½	28	0	−13	−8	−12	serenum	
23	Ost	28	0	28	0	28	0	−11½	−7	−11	nubilum	
24	Ost	28	0	28	0	27	11	−10½	−8	−10	p. nubilum p. ningebat	
25	Ost	27	10	27	8	27	7	−9	−7	−7	nubilum	
26	Ost	27	7	27	8	27	10	−6	−3	−4	nubilum	
27	Ost	27	10	27	11	28	0	−5	−5	−7	nubilum	
28	Sud	27	8	27	0	26	10	−8	−6	−5½	p. nubilum p. ningebat	
29	West	26	9	27	0	27	0	−4½	−4	−5¾	p. nubilum p. ningebat	
30	West	27	0	26	10	26	9	−10	−6	−10	nubilum	
31	Ost	26	8	26	9	26	10	−10½	−9	−10	ningebat	

Fig. 5.4 Facsimile of a one page presenting records of meteorological observations (December 1785) made in the years 1779–1799 by Rev. J.F. Bończa-Bystrzycki at the Royal Castle in Warsaw (original documents are available in the archive of the Institute of Meteorology and Water Management in Warsaw)

Śniadecki (1756–1830), who also gave instructions describing the basic rules for taking measurements. The meteorological station was set up with four meteorological instruments: two Réaumur scale thermometers (located both within and outside the building), a mercury barometer in Paris inches, and a hair hygrometer (Trepińska 1993, 1997b). Observations were recorded by three observers (including Śniadecki) three times a day between 6 am and 7 am, 2 pm and 3 pm, and at around 9 pm the local time. Aside from instrumental measurements, visual observations of the state of the sky, the occurrence of precipitation and other atmospheric phenomena, and wind direction were also recorded (for more details see Trepińska 1993).

It should also be mentioned that the earliest Polish daily non-instrumental weather observations were made at Olkusz (near Cracow) by the Rev. Marcin Biem from 1490 onwards, sporadically at first and then later more systematically between 1502 and 1517 and then again between 1525 and 1540 (for details see the chapter 6 in this volume or Limanówka 2001). Indeed, in international terms these are the oldest non-instrumental meteorological observations in the world, being pre-dated probably only by the meteorological observations from 1269–1270 in a volume of works of Roger Bacon (Long 1974) and kept by the Rev. William Merle at Oxford Driby, in Lincolnshire, England between 1337–1344 (Lawrence 1972).

Hanik (1960, 1972) notes that meteorological observations started in Lviv (now in the Ukraine) at the end of the eighteenth century. However as these data have not survived, it is not possible to specify precisely when these observations began. The earliest extant meteorological data were published in the *Gazeta Lwowska* in October 1811 by a physician called Van Roy. He made observations of atmospheric pressure (using a Heber barometer), temperature (using a wall-mounted thermometer facing north-west), humidity (initially using a Buissart hygrometer in 1815, then later a Saussure hygrometer and, from 1837, an August psychrometer), wind directions and, from 1812, precipitation (Hanik 1972).

In north-west Poland the first instrumental observations of air temperature, atmospheric pressure, and precipitation were recorded for Szczecin in the period from 1 January 1783 to 28 February 1784 (Miętus et al. 1994; Miętus 1997). While we know neither who recorded the observations nor the recording locations, we do know that measurements were made using a barometer scaled in Paris lines (1 Paris line = 2.26 mm), and two thermometers (one with a Réaumur scale and the second with a Rosenthal scale) hanging outside a window on the north side of the building. Temperature measurements were recorded three times a day at 8 am, midday and 8 pm. Miętus et al. (1994) after Klemm (1976) also note that non-instrumental weather observations were recorded in Nowogard from 1561 to 1564 by Abraham Rockenbachs, and in Szczecin from 1635 to 1638 by Wawrzyniec Eichstadt.

In south-west Poland best-known early-instrumental meteorological observations were carried out in Żagań within the network of meteorological stations called the "Societas Meteorologica Palatina" which was established by Charles Theodore, Duke of Bavaria, in 1780. The station used standardised instruments and observations were made up to 1792 according to the regulations established by the Society (e.g. observing times at 0700, 1400 and 2100 h mean local time, see Table 5.1). The results of the observations were published *in extenso* between 1783 and 1795 in volumes II–XIII of the *Ephemerides Societatis Meteorologicae Palatinae* in Mannheim. It is also thought that between 1783 and 1785 (1783–1789 for Oleśnica) instrumental meteorological measurements of atmospheric pressure (Twardogóra and Oleśnica) and air temperature (Legnica, Twardogóra and Oleśnica) were recorded in this part of Poland (Miętus 1997; Miętus et al. 2000b, c; see also Table 5.1).

As the nineteenth century progressed, throughout the territory of Poland there was a growth in the number of stations measuring air temperature, atmospheric pressure, wind direction, the state of the sky and precipitation (see e.g. Gorczyński 1934; Hanik 1960, 1972; Kaczorowska 1962; Miętus 1997). A detailed review of their activities is beyond the scope of the present study. On the other hand, we shall provide a brief summary of the history of measurements of some other meteorological variables (e.g. solar radiation, sunshine duration, humidity, and extreme temperatures) for which measurement instruments were constructed throughout the nineteenth century and even as early as the end of the eighteenth century.

The first measurements of solar radiation in Poland were probably recorded in Puławy (Nowa Aleksandria) in 1894 or earlier (Kolomijcov 1894, after Górski and Górska 2000). Measurements were irregular and their results have been lost. The next known measurements of (direct) solar radiation began in 1900 at the Museum of Industry and Agriculture in Warsaw. The measurements were taken by Władysław Gorczyński, director of the Meteorological Office at the museum. Slightly older are measurements of sunshine duration. The first were recorded on the roof of the Śniadecki College building in the Astronomical Observatory in Cracow in June 1883 using a Campbell-Stokes heliograph (Morawska 1963), which was constructed by John Francis Campbell in 1854 and improved by George Gabriel Stokes in 1879. These Cracow sunshine data records are among the oldest in Europe with measurements beginning at a few sites as early as 1882 (Morawska-Horawska 1985). Later in the 1880s, sunshine duration measurements began to be recorded elsewhere in Poland, for example in Wrocław (from 1 July 1889) as well as in Olecko, Tczew, Szamotuły and Kołobrzeg (1890) (see Table 1 in Wójcik and Marciniak 1993). At the turn of the nineteenth and twentieth centuries measurements were also begun in Warszów-Świnoujście, Poradz, Bydgoszcz, Gorzów Wielkopolski, Zielona Góra, Głubczyce, and Warsaw. These measurements were the basis for the 40-year (1891–1930) mean sunshine duration values published in *Klimakunde des Deutschen Reiches, Band II – Tabellen* (1939), Stenz (1930, data for period 1891–1910) as well as from Table 1 in Wójcik and Marciniak (1993) referred to earlier.

The first measurements of air humidity in Poland started in the Astronomical Observatory in Cracow on 19 May 1792 (at noon) or in the same year in the Astronomical Observatory in Wrocław. Galle (1879) only quotes 1792 as being the first year of such observations in Wrocław. In this work he included tables containing average monthly and annual values of water vapour pressure and relative humidity for the period 1850–1875. In the first decades, probably up to 1850, the measurements were done using a hair hygrometer and later using an August psychrometer. The history of observations of this variable, as far as location and time are concerned, is probably the same as in the case of air temperature, described earlier. We have more details for measurements from Cracow. Again early measurements used a hair hygrometer developed by Horace-Bénédict de Saussure (1740–1799), the Swiss physicist, geologist and early Alpine explorer (MSc A Wypych, 2008, personal communication). From 20 May 1792 the measurements were recorded three times a day, between 6 am and 7 am, 2 pm and 3 pm, and at around 9 pm the local time. Using this instrument relative humidity measurements were carried out here until 1830. From 1 January 1831 to 1 July 1834 Körner's hygrometer was used, which was then replaced by the August psychrometer (Kowanetz 1997; Wypych 2007). Up to December 1862 there are some small gaps in the observations, but subsequently a continuous data series is available. The third oldest series of air humidity measurements comes from Warsaw. Observations began on 1 January 1806 by Antoni Szeliga-Magier (1762–1837), who continued the meteorological observations which had earlier been initiated by Rev. Bończa-Bystrzycki. For measurements, the same instruments were used as in Cracow. Observations were recorded three times a day – in the morning, afternoon, and evening. The afternoon measurements were taken between noon and 1 pm (in winter), 1 pm and 2 pm (in spring and autumn), and 2 pm and 3 pm (in summer); morning and evening observations were recorded 8 h earlier/later, respectively (Jastrzębowski 1841, after Rojecki 1968). A very long series of air humidity measurements is also available from 1 October 1811 for Lviv. In the first half of the nineteenth century these four measurement stations – Puławy, Cracow, Warsaw, and Lviv – were probably the only ones recording humidity. On the other hand, in the second half of the century (though mainly before 1881) humidity observations were recorded in many places (e.g. Szczecin, Świnoujście, Hel, Gdańsk, Koszalin, Bydgoszcz, Toruń, and Poznań. See, for example, *Klimakunde des Deutschen Reiches, Band II – Tabellen* 1939, which lists long-term monthly and annual means [for 2 pm] for the period 1881–1930).

Extreme maximum and minimum temperature measurements began for the first time in the territory of Poland in the Astronomical Observatory in Warsaw in either November 1825 or January 1826 (Lorenc 2007). Two extreme thermometers were located in a small box made from zinc and fastened to the inside side of the northern wall (9.5 m above ground) in an unheated staircase (Gorczyński 1913). This box was exposed at the northern and southern sides and was contained within a larger wooden holder of similar construction. For temperature measurements a Rutherford thermometrograph made by Kappeller in Vienna was used. Unfortunately, data for the period 1826–1914 as well as for some other periods listed in Lorenc (2007) have been lost, at least in Poland. However, Lorenc (2007) suggests that some data may be available in Russian archives. Continuous series of extreme temperatures exist from 1897, when measurements of these temperature parameters started in the Warsaw Museum station, where they were conducted until 1915 (for more details see Lorenc 2007). The next place for which long-term data of extreme temperatures are available (from 1 June 1837) is the Astronomical Observatory of the Jagiellonian University in Cracow. Measurements were taken using a metallic thermometer made by Jürgensen from Copenhagen. It had a round dial with three scales in Réaumur, Celsius, and Fahrenheit degrees (Kowanetz 1997). Thermometers were fixed to a meteorological screen fastened to the wall near the window facing north-northwest. The screen hung at a height of 12 m above the ground (Piotrowicz 2007). The series from Cracow for the period 1836–2007 is presented by Piotrowicz (2009, this volume) and is homogenised and extended to the beginning of 1836 using air temperature readings from four times: 7 am, noon, 3 pm and 9 pm local mean time. Prof. J. Trepińska (2008, personal communication) extended this series to 1826 using the same method.

5.2 History of Some Long-Term Continuous Meteorological Series

5.2.1 Air Temperature

The longest series of continuous air temperature data for the historical area of Poland started on 17 January 1777 in Vilnius. On the other hand, for the area of present-day Poland, the longest extant air temperature series is for Warsaw (from 1 January 1779), only 2 years shorter than the Vilnius series. This series (i.e. mean monthly and annual values) was recently homogenised by Lorenc (2000), using original observations made by the Rev. Bończa-Bystrzycki (1779–1799) mentioned earlier, by Antoni Szeliga-Magier (1803–1828), and by the staff of the Astronomical Observatory (including its first director J. Baranowski) founded in Warsaw in 1826, along with other different sets of data which Lorenc describes in detail. Three of these deserve to be mentioned in particular: Kowalczyk 1881; Gorczyński and Kosińska 1916; Michalczewski 1985. The history of temperature measurements in Warsaw and the methods used to fill gaps in the data and to check for homogeneity are presented in Rojecki (1968); Michalczewski (1985); Lorenc (2000). As noted earlier, for extreme temperatures an homogenised series is available from 1897 (for more details see Lorenc 2007, where monthly and annual mean values are published for the period 1897–2002).

The next long-term air temperature series (from February 1791) is for Wrocław (south-west Poland). The temperature measurements were made continuously at the Astronomical Observatory of Wrocław University up to 1930, and then in a station working within a network organised by the State Meteorological Institute. For the first 10 years measurements were made in the observatory room; then, owing to the bad health of Anton Jungnitz (1764–1831), the first director of the Astronomical Observatory and meteorological observer, they were recorded in his apartment on the second floor of the main university building, in the wing neighbouring the church (Pyka 2003). In 1825 the place of observation moved to the physics laboratory on the third floor, and from 1832 observations returned to the Astronomical Observatory. Two pairs of thermometers were installed in the windows facing north-northeast and east-northeast. Meteorological measurements were carried out regularly three times a day at 6 am, 2 pm and 10 pm until 1837, and then five times a day (6 am, 9 am, noon, 3 pm and 9 pm) until 1845. In 1846 there was a return to thrice-daily measurements, but from 1851 to 1875 two additional measurement times were added (at 10 am and 6 pm). However, the daily mean temperatures from the beginning of observations until 1886 (with the exception of the period 1837–1845) were calculated using only data from the three original observation times. For more details about temperature data, their quality and changes in time, as well as measurement techniques see Galle (1879), Pyka (2003).

Continuous air temperature measurements for Cracow are available from 16 August 1825 (Trepińska 1997a), though as noted earlier they began as early as 1 May 1792. Gaps in the oldest observations (1792–1825) were recently filled using observations from other long-term European stations (Ustrnul 1997). As a result, this series is now available for Cracow with monthly resolution from 1792.

A very long series of continuous temperature measurements is available for Gdańsk (from 1807). Mean monthly temperatures for the period from 1807 to 1910 were published by Momber (1906), while an homogenised series from 1851 onwards is available in Miętus (1998). In Lviv, temperature measurements began on 1 October 1811 (Hanik 1972) and these have generally continued up to the present day, with two main breaks from 1848 to 1850 and during World War II.

For some other stations data are also available from 1836 (Szczecin, see Kożuchowski and Miętus 1996; Wiśniewski et al. 1999), 1848 (Poznań, Koszalin), or from 1851 (for Hel and Bydgoszcz). Recently Kożuchowski and Żmudzka (2003) have calculated the areally averaged mean annual temperature for Poland for the years 1901–2000.

Long-term continuous and generally homogeneous series of average monthly extreme air temperatures (maximum and minimum) are available for Cracow (from 1836, Piotrowicz 2007), Warsaw (1897, Lorenc 2007), Śnieżka (1901, Wibig and Głowicki 2002), Zakopane (1906, Wibig 2000), and for Puławy (1918, for which some small gaps in data exist, Wibig and Głowicki 2002).

5.2.2 *Atmospheric Precipitation*

The longest series of instrumental observations of atmospheric precipitation is available from the Astronomical Observatory of Wrocław University from 1799 with only a few very short breaks (1–2 months) (Pyka 2003). The measurements were conducted first on the observatory terrace up to 1854, when they were transferred to the university courtyard. Pyka (2003) notes that this change of location of the rain-gauge resulted in a 28% increase in the amount of precipitation. In 1858 the rain-gauge was moved again, this time to the Botanical Garden. The monthly and annual totals of precipitation for the period 1851–1930 are published in *Klimakunde des Deutschen Reiches* (1939).

In Warsaw measurements of liquid precipitation began on 1 April 1803. From 1 January 1813 solid precipitation was also measured. Thus, continuous series of complete monthly totals (with the exception of January and February 1835) and annual totals (again excepting 1835) are available for the period 1813–1910 in

Gorczyński (1912). On the other hand, Marciniak and Kożuchowski (1990) have collected and published this series until 1980, without gaps. The homogenisation of both of these long-term series is currently being carried out (Tadeusz Bryś, 2008, personal communication, Halina Lorenc, 2008, personal communication).

Lviv is the third place in the former territory of Poland where measurements of precipitation started very early. Daily data are available from October 1811, though because they contain some gaps it has only been possible to calculate the monthly totals from 1824 (Niedźwiedź and Twardosz 2004). In this series there still exists one gap (from 1842 to 1851) which, in the opinion of the cited authors, it is possible to reconstruct.

In Cracow, instrumental measurements of this very important variable started relatively late, in August 1849 after the founding of the meteorological station in the Astronomical Observatory of the Jagiellonian University (Trepińska 1997a; Twardosz 1997a; Twardosz and Cebulska 2009, this volume). However, information on precipitation types is available from the beginning of observations in 1792, and from 1826 this was supplemented with information on times of occurrence and degrees of intensity. Using all of these data, Twardosz (1999) reconstructed monthly and annual precipitation totals from 1812 for all months and years, and also for some months and years for the period 1792–1811 (see his Table 5). The homogeneity of the series of monthly and annual totals of precipitation from 1850 onwards was checked by Twardosz (1997b). Precipitation measurements were taken on the terrace of Collegium Śniadecki. Rain-gauges were positioned on a corner pillar at a height of 13.6 m above ground at a distance of 4 m from the wall of the building. The measurements have been taken from 1849 to the present, three times a day, in the morning (mainly from 6 am to 7 am), afternoon (from 1 pm to 2 pm), and evening (from 7 pm to 10 pm), and these times were only changed on five occasions during the whole history of observations (for details see Twardosz 1997b).

Kożuchowski (1990, see his Table XVI) and Kożuchowski and Żmudzka (2003) have calculated the areally averaged mean annual precipitation totals for Poland for the years 1881–1980 (for their analysis see Brázdil and Kożuchowski 1986) and 1901–2000, respectively.

5.2.3 Atmospheric Pressure

The longest continuous series of measurements of atmospheric pressure is available from Warsaw from 1 January 1779. The history of these measurements is generally the same as that of air temperature measurements, with only one exception: in the case of temperature there was a break in observations from 1 January 1800 to 30 September 1803, while this is not the case for the atmospheric pressure. In this period this variable was measured by Karol Ludwik Kortum (1749–1808) in his flat three times a day, though no precise information is available on measurement times. He carried out the observations until the end of 1807 using a barometer scaled in Paris lines and located at a height of about 27 m above the average level of water in the river Vistula (Rojecki 1968). Antoni Szeliga-Magier began measurements of atmospheric pressure from 1 January 1803 and continued them until the end of 1828. For measurements he used a mercury barometer of his own construction scaled in Paris lines and located 8 m higher than Kortum's barometer. An homogenised series of monthly values of air pressure exists for the period from 1826 (Ustrnul and Czekierda 2000; Ustrnul and Feliks 2007).

The second longest series of continuous atmospheric pressure measurements is for the Astronomical Observatory of Wrocław University from February 1791 (Pyka 2003). As far as location and times are concerned, the situation is similar to that of air temperature measurements described earlier. Monthly and annual totals of atmospheric pressure for the period 1791–1854 and 1881–1930 are published in Galle (1857) and *Klimakunde des Deutschen Reiches* (1939), respectively.

The third longest series of continuous observations of atmospheric pressure probably comes from Lviv, where observations started on 1 October 1811.

The next continuous series after this is available for the historical meteorological station in Cracow from 16 August 1825. The first measurement was taken here on 1 May 1792 and data exist for the following isolated periods: 1 May 1792 to 18 May 1794; 1 September 1803 to 9 August 1804; 1 January 1805 to 5 October 1805; 1 October 1811 to 30 September 1823; and 1 January 1824 to 15 July 1825 (Trepińska 1997a). Recently, Ustrnul (1997) was able to fill the gaps for mean monthly and annual values using long-term data from the nearest European stations. Thus, at present the series is available from 1792 onwards (see Trepińska 1997c, 2007). It is also worth adding that in Cracow in 1848 the continuous recording of air pressure began. As a result, Cracow is one of only a small number of climatological stations in the world which have an unbroken series of hourly measurements (Obrębska-Starklowa 1993).

Gorczyński (1917) published tables containing mean monthly and annual values of air pressure for the oldest parts of these series, that is for the periods 1779–1910 (Warsaw), 1826–1910 (Cracow), and 1851–1910 (Lviv and Wrocław).

5.2.4 Other Meteorological Variables

Continuous series of other meteorological variables (solar radiation and sunshine duration, cloudiness, air humidity etc.) are markedly shorter and less reliable than described above three main variables. This may be the result of, for example, the late construction of measuring instruments and/or problems with the homogeneity of the obtained data.

Although solar radiation measurements started in Poland at the end of the 19th century, continuous series of, for example, monthly and annual totals of global and diffuse solar radiation are available only since the 1950s for a few stations (for details see Bogdańska et al. 2002). Recently however, Bryś and Bryś (2003, 2005, 2007) have presented analyses of changes of global solar radiation totals (for different periods of the year) in Wrocław for the periods 1901–2000, 1891–2003, and 1875–2004, respectively. Gaps in the measurement of global solar radiation, as well as data for period 1875–1890, were filled using reconstruction methods based on sunshine duration data. It should be added that these data for the period 1875–1890 were also reconstructed using the available measurement data of cloudiness, air temperature and humidity (for details see Bryś and Bryś 2007). Yet the situation for sunshine duration data is markedly better than it is for these other variables. The longest and the most reliable continuous series of monthly totals of sunshine duration is available for Cracow (from June 1883 onwards). Morawska (1963) using the close relationships noted between sunshine and cloudiness in Cracow, reconstructed monthly totals of sunshine duration for the years 1859–1883 for which observations of cloudiness had been made. Recently, Lewik et al. (2009, this volume) have reconstructed the mean monthly and annual values of sunshine duration for the years 1826–1883 on the basis of the number of clear and overcast days. The second longest continuous series of sunshine duration comes from Wrocław (from 1890 onwards, though reconstruction data exist from 1875). Homogenised series of this variable was recently presented by Dubicka and Pyka (2001) for the whole of the twentieth century, and by Bryś and Bryś (2005, 2007) for the periods 1891–2003 and 1875–2004, respectively. Long homogenised series of sunshine duration are also available for Warsaw (from 1903, see Podogrocki 2002) and for Puławy (from 1921, see Górski and Górska 2000).

One of the longest series of nephological observations in Europe (from 1792) is available for Cracow (the Meteorological Station of Department of Climatology at the Jagiellonian University). From 1792 to 1826 observations were irregular, but they are continuous from 1826 onwards. Up until 1853, cloudiness was measured on a 4-degree scale, and later on a 1–10 scale (e.g. Morawska 1963; Morawska-Horawska 1985; Matuszko 2001, 2003, 2007a, b; Lewik et al. 2009, this volume). Until recently, monthly and annual amounts of cloudiness were available from 1859 (e.g. Morawska 1963; Morawska-Horawska 1985; Matuszko 2001). In Chapter 15, Lewik et al. present a reconstruction of this variable to 1826 on the basis of the number of clear and overcast days available for the period 1826–1852 according to Wierzbicki (1873). On the other hand, for the period 1853–1862 mean monthly values of cloudiness were taken from a manuscript written by Franciszek Karliński (see Morawska 1963). Mean monthly and annual values of cloudiness in Cracow for the period 1901–2000 have been presented by Matuszko (2007b). For the whole period they are available in the Department of Climatology of the Jagiellonian University. According to Matuszko (2007b) that series is homogeneous, at least from 1863, and possibly from 1826 (Lewik et al. 2009, this volume). The next very long series comes from Wrocław. Information about the frequency of clear and cloudy days is available from 1791, while average monthly values of cloudiness are available from 1875 (MSc Tadeusz Bryś 2008, personal communication). Rojecki (1968) noted that Antoni Szeliga-Magier began observations of cloudiness in Warsaw in February 1808. The state of the sky was described in brief three times a day – in the morning, afternoon, and evening hours. It is quite probable that this kind of observation is continuous up to the present. Gorczyński and Wierzbicka (1915) and Gorczyński (1938) give long-term average values of cloudiness for Warsaw for the period 1886–1910. So far nobody has undertaken the process of homogenization of this series. The two publications mentioned also provide this kind of data for many other historical Polish stations (e.g. Hel, Poznań, Lviv, Puławy, Opole, Bydgoszcz, Koszalin, and Chojnice). A very long series of cloudiness observations is also available for Śnieżka (1602 m a.s.l.; Sudety Mountains) in south-west Poland and, from 1906, for Zakopane (Tatra Mountains) (Dubicka 1999; Limanówka and Ustrnul 2002). Dubicka (1999) has noted that there have been isolated series of observations at the Śnieżka station dating from 1824. On the other hand, continuous, regular observations (three times a day at 7 am, 1 pm and 9 pm) began in 1885. Using these data, series of monthly, seasonal and annual values of cloudiness have been calculated and homogenised for the period 1885–2007.

The history of measurements of air humidity in Poland was described briefly earlier and we know that the longest series are available for Cracow, Wrocław, Warsaw, and Lviv. However, continuous series of mean monthly values of this variable are only available for Wrocław and Cracow. For Wrocław, a continuous series of all humidity parameters (relative humidity, water vapour pressure and deficit of water vapour pressure) are available from 1850 (Tadeusz Bryś 2008, personal communication). On the other hand, for Cracow such a series is available in the archive of the Department of Climatology of the Jagiellonian University from 1863 (Wypych 2008, personal communication). Recently, Wypych (2007) published a series of mean monthly values of relative humidity for the period 1901–2000.

5.3 Climate Changes in the Instrumental Period

As we have seen from the history of instrumental meteorological observations presented in the previous section, there are quite a large number of long-term continuous and homogenised series of meteorological variables available for the area of Poland. The data available allow us to characterise reliably almost all aspects of the Polish climate and its changes over the last 100–200 years. The aim of this section is to give a brief summary of the characterisations of climate changes in the instrumental period, which have mainly been presented in the Polish literature on the subject. In some cases we have provided updates of these climatic studies.

The issue of climate changes in the area of Poland has been investigated very intensively, particularly since the 1980s, when evidence of global warming began to emerge. Around this time many conferences were organised, prompting Polish climatologists to investigate this issue in greater depth.[1] The majority of the papers presented during these conferences include analyses of different aspects of climate changes in Poland. The results of these investigations have been published in the

[1] These conferences included 'Global Warming and Contemporary Climatic Changes in Poland' (University of Szczecin, 1993), 'Changes and Variability of Climate of Poland' (University of Łódź, 1999), 'Images and Reconstructions of Weather and Climate over the Last Millennium' (Jagiellonian University, 2000), 'Advances in Research on Climatic Change and its Importance for Human Life and Economic Activity' (Warsaw University, 2001), 'Man and Climate in the 20th Century' (Wrocław University, 2003), 'Extreme Hydrologic and Meteorological Phenomena' (Polish Geophysical Society and Institute of Meteorology and Water Management, 2003), 'Climate Variation in Various Scales of Time and Space' (Jagiellonian University, 2007), and 'The Climate of Poland in Historical Times in Relation to the European Climate' (Nicolaus Copernicus University, 2007).

following works: Kożuchowski 1993; Dubicki et al. 1999; Boryczka and Kossowska-Cezak 2001; Pyka et al. 2003; Piotrowicz and Twardosz 2007; Przybylak et al. 2009, this volume. Moreover, other volumes have also appeared mainly presenting different characteristics of long-term changes of individual meteorological variables, in particular air temperature, precipitation, and atmospheric pressure. The majority of studies limit the area of investigation to one site (e.g. Trepińska 1988; Trepińska 1997c; Lorenc 2000; Matuszko, 2007a,b,c), to certain parts of Poland (e.g. Miętus 1996; Wnęk 1999) or to the whole of Poland (e.g. Gorczyński and Kosińska 1916; Gorczyński 1917; Kaczorowska 1962; Kożuchowski 1985a; Boryczka et al. 1992). Moreover, many papers have been published in different journals and other conference proceedings, not listed here. A partial bibliography is provided in the references at the end of this chapter.

5.3.1 Air Temperature

As may be seen from our earlier discussion, our data concerning changes in air temperature in Poland date back to the eighteenth century. The mean annual temperatures for the periods 1779–1998 (Warsaw) and 1792–1995 (Cracow) show upward statistically significant linear trends reaching 0.55°C and 0.52°C per 100 years, respectively (Trepińska and Kowanetz 1997; Lorenc 2000). This means that the air temperature from the end of the eighteenth century to the present day has increased by more than 1°C (Fig. 5.5). Similarly Miętus (1996) has also detected a statistically significant rise in temperature for the period from 1836 to 1990 for the Baltic coast (see also Fig. 5.5). From this Figure it is evident that there is a good correspondence between the Warsaw and Baltic coast series. The areally averaged annual temperature for Poland as a

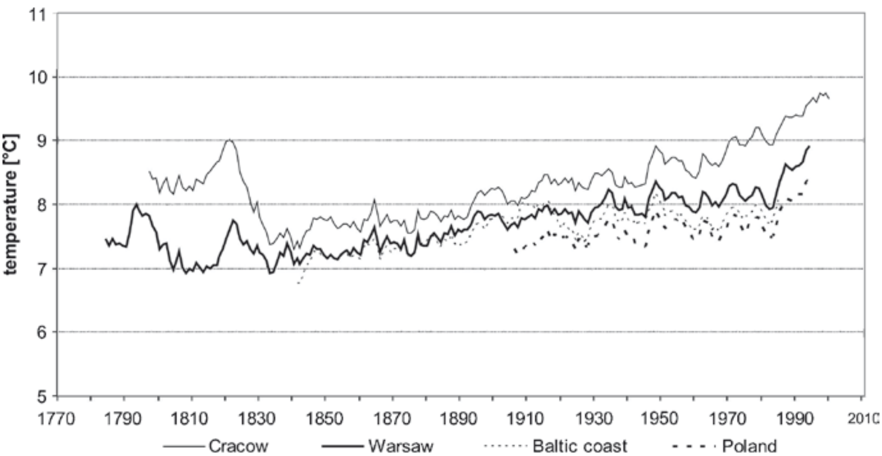


Fig. 5.5 Long-term courses of 11-year running mean annual air temperatures in Poland during a period of instrumental observations. Key: Data for Cracow after Trepińska (1971) and Matuszko (2007d, ed.), for Warsaw after Lorenc (2000), for the Baltic coast after Miętus (1996), and for Poland as a whole (after Żmudzka 2008)

whole reveals a similar statistically significant increase (by 0.89°C) from 1901 to 2000 (Kożuchowski and Żmudzka 2003). These authors calculated that the Warsaw and Cracow series are closely correlated with the areally averaged temperature for Poland (in both cases correlation coefficients for the period 1951–2000 amount to 0.99). Thus data from both of these stations reliably represent temperature changes in Poland (with the exception of the southern mountainous part of the country). The greatest rises in temperature in Warsaw and Cracow clearly occurred in winter (by more than 2°C) and in spring (by about 1.5°C). The Baltic coast shows a comparable temperature increase in winter, while in spring the rate of increase was about half of that for Warsaw and Cracow. On the other hand, out of all of the series analysed, the Baltic coast experienced the greatest increase in air temperature in autumn (Fig. 5.6). The rise in temperature slightly exceeds 2°C and was only a little smaller than in winter (Miętus 1996). Upward trends in areally averaged seasonal temperatures for the whole of Poland can also be clearly seen throughout the twentieth century (see Fig. 5.6). Seasonal trends for all of these sites are statistically significant, with the exception of summer in Warsaw, Cracow and the Baltic coast, and winter for the whole country. Thus, the climate in Poland in both the eighteenth and nineteenth centuries was more continental than it is today.

Lorenc (2000) distinguished four different periods in the Warsaw temperature series: 1779–1800, 1801–1889, 1890–1980 and 1981–1998 (certain thermal characteristics of the last period are still observable, see Figs. 5.5 and 5.6). The first period was very warm, with a maximum decade temperature of 7.8°C in the years 1791–1800. The second period was the coldest one in the history of temperature observations in Warsaw. The coldest decade was 1811–1820 (7.0°C). It was during this period that the coldest year – 1829 – was noted, with an average temperature of only 4.7°C. A downward trend in temperature was observed in Warsaw up to 1890, and since then an increase in air temperature has been evident (particularly in winter), with significant amplification after 1980.

Generally speaking, time changes of extreme temperatures in the period in question are similar to those noted for mean temperatures. However, because the homogenised series of extreme temperatures are shorter (e.g. from 1836 for Cracow and from 1897 for Warsaw) and because their starting points are in a cold period, their calculated trends are higher than for mean temperatures. For the common period of homogenised data available for Warsaw and Cracow (1897–2002), Lorenc (2007) has detected positive trends for all months, seasons and for the year as a whole (see also Figs. 5.7, 5.8, and 20.1 in Piotrowicz 2009, this volume). Annual average extreme temperatures increased during this period at a rate of 1.5°C/100 years (with the exception of the minimum temperature for Cracow, which rose by 1.7°C/100 years). In the case of the maximum temperature, the greatest increases occurred in spring (up to 2°C/100 years) and summer (1.6°C/100 years), while the lowest were in autumn (about 1°C/100 years). On the other hand, the greatest rise in minimum temperature was in autumn (in Warsaw and Cracow 1.6°C/100 years and 1.9°C/100 years, respectively) while the lowest was in summer (about 1.5°C/100 years in both cities). The two series, as Lorenc (2007) shows, are closely correlated. Correlation coefficients for all seasons (except summer for minimum temperature) and for the year as a whole even exceed 0.9. Thus, these two series reliably represent

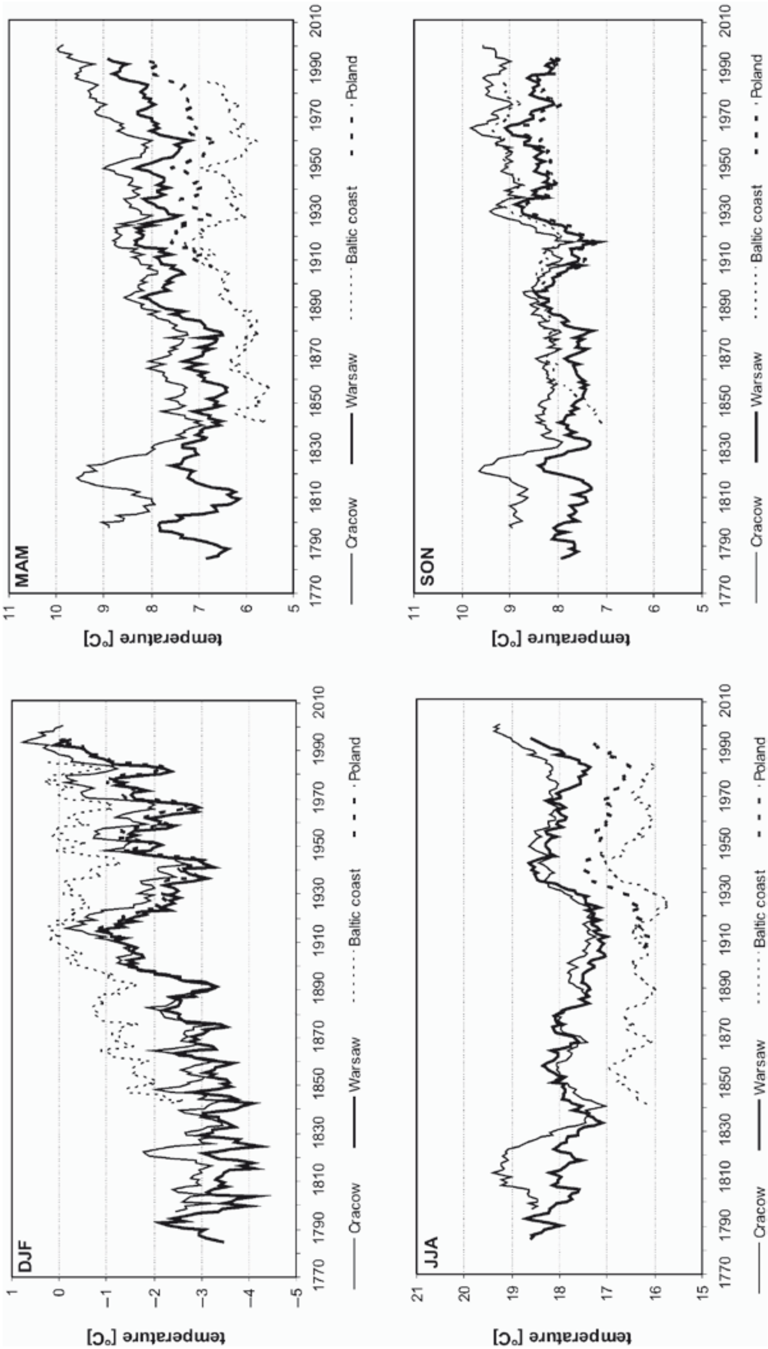


Fig. 5.6 Long-term courses of 11-year running mean seasonal air temperatures in Poland during a period of instrumental observations. Key: DJF – winter, MAM- spring, etc. Other explanations as in Fig. 5.5

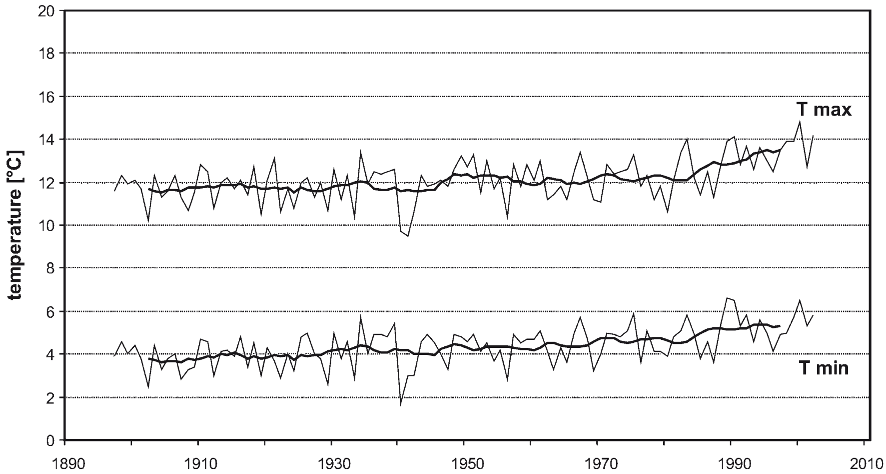


Fig. 5.7 Long-term courses of mean annual extreme air temperatures in Warsaw, 1893–2002 (based on data published in Lorenc 2007). Key: *solid line* – year-to-year courses, *bold line* – 11-year running mean

temperature changes at least for the central and southern parts of Poland. Piotrowicz (2009, this volume) analyses in detail the whole period of the Cracow series (1836–2007). Mainly due to the difference in the starting points (1897 and 1836) of both the analysed series, the trends calculated for the period 1836–2007 are smaller than for the period 1897–2002. For example, annual trends for maximum and minimum temperatures decreased to 1.0°C/100 years and 1.48°C/100 years respectively. Differences are also noted in the pattern of trend changes for the seasons. In the study period the greatest positive trends occurred in winter (1.79°C/100 years and 2.25°C/100 years for maximum and minimum temperatures respectively) and in spring (1.38°C/100 years and 1.48°C/100 years), while the lowest were for summer (0.17°C/100 years and 0.96°C/100 years). All trends are statistically significant at the level of 0.05 (except for the maximum temperature in summer). Wibig and Głowicki (2002) have analysed the problem for more stations, though these have shorter series of data limited to the twentieth century, and particularly from around 1950 onwards. The majority of the calculated trends are positive, and this feature is very well observed mainly in winter and spring and for the year as a whole. Minimum temperature clearly shows the greatest rise in comparison to maximum temperature. The latter even experienced a decrease in some of the sites analysed by the authors. As a result of this asymmetry, they found a statistically significant decrease in the mean annual diurnal temperature range for all the sites analysed, with a rate close to 0.06°C/decade. The strongest statistically significant decreases occurred in autumn and spring. They also found statistically significant decreases in the frequency of occurrence of cold days (minimum temperature below 0°C) and statistically significant increases in the frequency of occurrence of warm days (maximum temperature above 20°C) in the twentieth century. The rate of changes of the

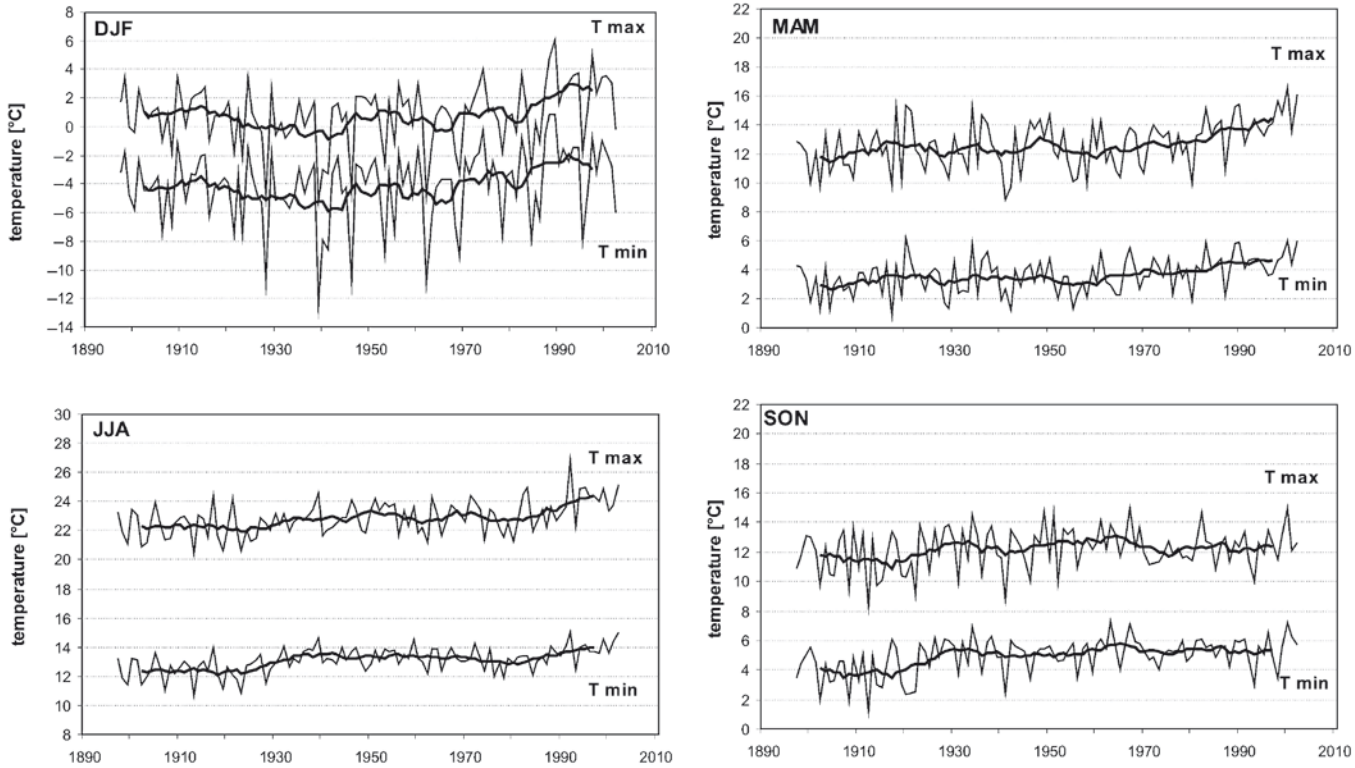


Fig. 5.8 Long-term courses of mean seasonal extreme air temperatures in Warsaw, 1893–2002 (based on data published in Lorenc 2007). Key: DJF – winter, MAM- spring, etc. Other explanations as in Fig. 5.7

temperature characteristics they investigated intensified markedly in the second half of the twentieth century, particularly after 1980.

5.3.2 Atmospheric Precipitation

Temporal and spatial changes of atmospheric precipitation are the greatest out of all the meteorological variables. Frequent fluctuations and abrupt changes in tendencies are common phenomena. As a result, the magnitude of the linear precipitation trends (and even their sign) strongly depends on the sites of the series as well as the starting and ending points. This fact should be taken into account when considering the results presented here. The majority of the papers which analyse the long-term changes in precipitation in Poland focus on small areas or even on one site in particular (e.g. Gorczyński 1912; Trepińska 1969; Hohendorf 1970; Kożuchowski 1985b; Twardosz 1999, 2007; Twardosz and Niedźwiedź 2001; Filipiak 2007b). However, there are also quite a large number of papers dealing with the whole of Poland or some of its regions (e.g. Kaczorowska 1962; Kożuchowski 1985a; Miętus 1996; Kożuchowski and Żmudzka 2003; Twardosz and Cebulska 2009, this volume).

The longest homogeneous series of precipitation from the area of Poland is available for Cracow. The seasonal and annual totals of precipitation for the period 1812–1900 are presented in Figs. 23.6 and 23.7 in Twardosz and Cebulska (2009, this volume), and a continuation of these series to 2007 is shown in Figs. 5.9 and 5.10. The first reconstructed part of series (up to the end of the 1820s), based on the available number of days with precipitation, does not seem to be entirely reliable. If we exclude

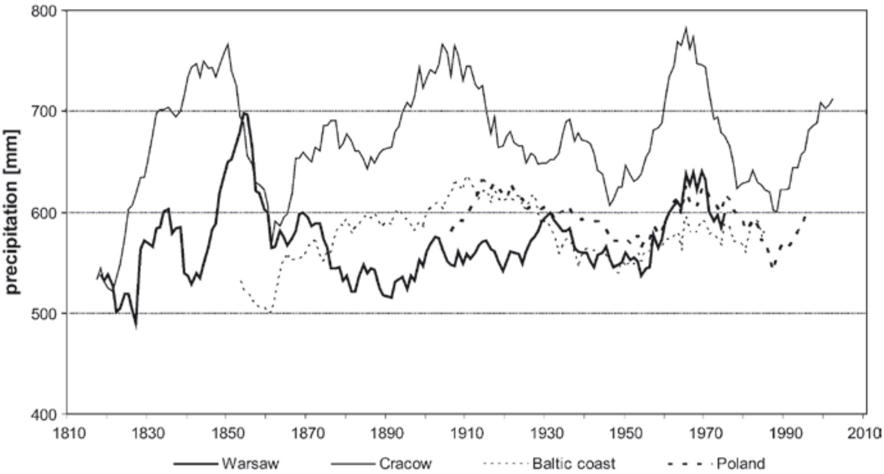


Fig. 5.9 Long-term courses of 11-year running mean annual precipitation in Poland during a period of instrumental observations. Key: Data for Warsaw after Kożuchowski (1990, ed.), for Cracow after Twardosz (1999, updated), for the Baltic coast after Miętus (1996), and for Poland (after Kożuchowski and Żmudzka 2003)

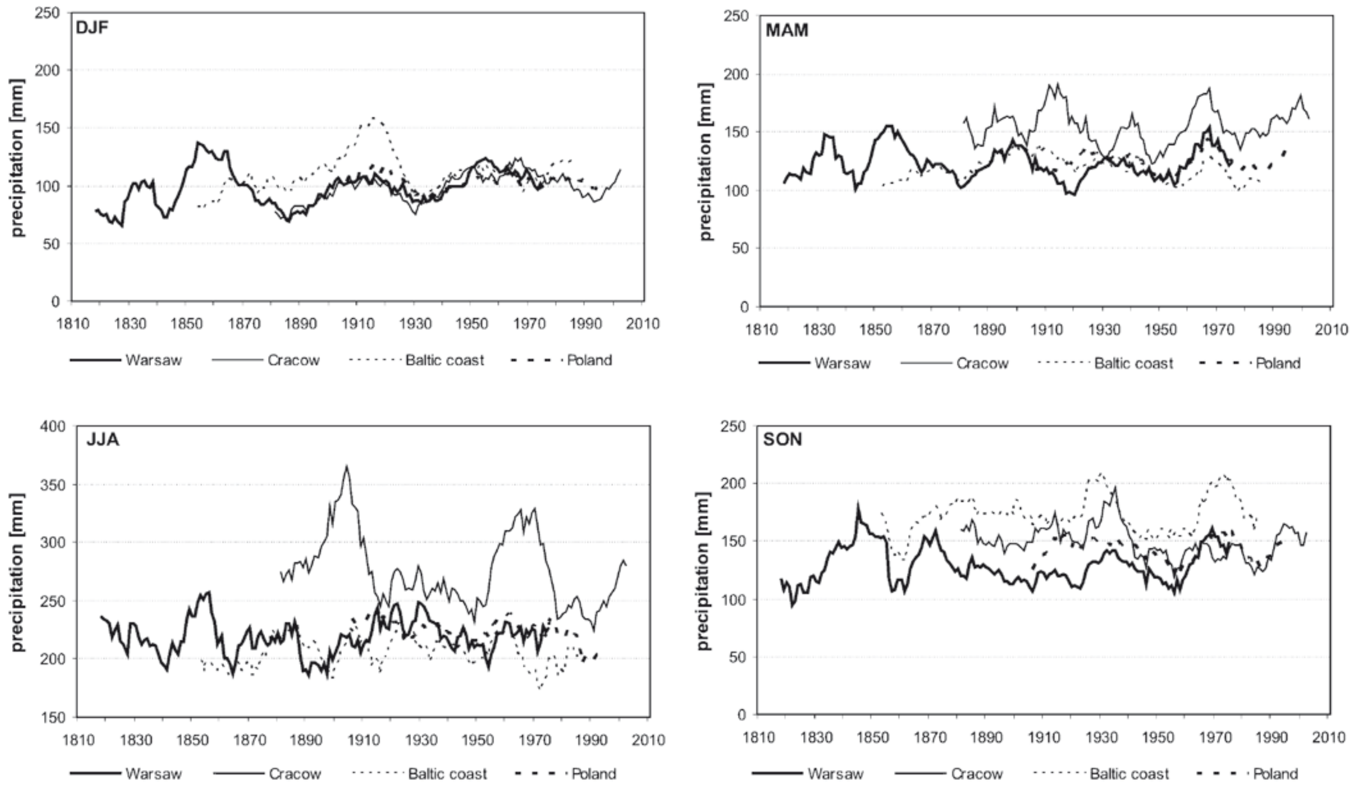


Fig. 5.10 Long-term courses of 11-year running mean seasonal precipitation in Poland during a period of instrumental observations. Key: DJF – winter, MAM- spring, etc. Other explanations as in Fig. 5.9, except for the Cracow station for which data were taken from Kożuchowski (1990, ed.) and Twardosz (2007, updated)

this part, then the annual precipitation totals in the nineteenth century show only small and insignificant changes. There was a wet period noted in all seasons from the 1830s to 1850s and then significantly lower precipitation amounts were recorded almost to the end of the century. At the turn of nineteenth and twentieth centuries there was another wet period ending in 1919 (Figs. 5.9 and 5.10). The next periods with above normal annual precipitation totals occurred from 1960 to 1972 and from 1996 onwards (Twardosz 2007; see also Fig. 5.9). The linear trends calculated for different sub-periods of the Cracow series are insignificant and unstable with respect to sign. For example, Kaczorowska (1962) obtained a positive trend in annual precipitation totals for the period 1851–1958 (20 mm/100 years), while Kożuchowski (1985a) noted a negative trend for the period 1881–1980 (−11 mm/100 years). For the whole series (1812–2007) the trend is slightly positive (23 mm/100 years) and is also statistically insignificant. Year-to-year (and long-term mean) changes in seasonal precipitation totals are markedly greatest in summer and lowest in winter (see Fig. 23.7 in Twardosz and Cebulska 2009, this volume, and Fig. 5.10). In the period 1876–2007 (Fig. 5.10), summer and autumn precipitation totals show downward trends, while trends are positive for winter and spring. However, all trends are small and, with the exception of winter, are not statistically significant.

Analysis of the other precipitation series presented in Figs. 5.9 and 5.10 reveals generally the same pattern of changes as in the Cracow series. This is particularly true for the series representing the Baltic coast and the whole of Poland. The correlation coefficients vary from 0.6 to 0.8 between the areally averaged precipitation series shown in Fig. 5.9 and the series from Polish stations calculated on the basis of data from the period 1951–2000 (see Fig. 3 in Kożuchowski and Żmudzka 2003). Seasonal and annual precipitation series in Poland are mainly characterised by short-term oscillations of between 2 and 4 years (Kożuchowski 1985a; Miętus 1996; Kożuchowski and Żmudzka 2003). The results presented in Figs. 5.9 and 5.10 and in the cited papers show that long-term trends in precipitation in Poland have so far been insignificant.

5.3.3 Other Variables

The long-term history of cloudiness changes in Poland can best be described using data from the Astronomical Observatory in Cracow. Żmudzka (2003) found that the series of areally averaged cloudiness for Poland in period 1951–2000 correlates strongly with data from particular stations located in lowland parts of the country (correlation coefficients vary from 0.7 in north-east Poland to more than 0.9 in central Poland). As was mentioned earlier, the Cracow series is the longest, and has recently been reconstructed and homogenised back to 1826 (Lewik et al. 2009, this volume). Many papers have provided various long-term analyses of different aspects of cloudiness in Cracow (e.g. Morawska 1963; Morawska-Horawska 1984, 1985, 2002; Matuszko 2001, 2003, 2007a, b; Lewik et al. 2009, this volume). The paper by Lewik et al. also provides a detailed description of the series and thus, only the main findings will be given here. The authors found a small increase in cloudiness for the entire series (see their Fig. 15.1), which, however, is statistically significant at a confidence level of 0.05. On the other hand, in the last 50 years there has been a dramatic statistically significant decrease in cloudiness. This decrease is also significant throughout the whole of the twentieth century (Matuszko 2007b). The highest values of cloudiness occurred in the periods 1826–1846 and 1926–1966, while the lowest were in the periods 1846–1858 and 1983–1995. The course of cloudiness in the twentieth century (and especially from around 1950 onwards) exhibits a significantly greater variability than in the nineteenth century. In two long-term observation sites located in mountainous areas of Poland (Śnieżka 1885–1995; Zakopane 1906–1990) the trends of both seasonal and annual values are upward and are statistically significant (Dubicka 1999; Limanówka and Ustrnul 2002). The greatest upward trends were noted in autumn in Śnieżka, and in summer in Zakopane. Recently, Żmudzka (2003) calculated monthly, seasonal, and annual areally averaged values of cloudiness for Poland (excluding mountainous regions) for the period 1951–2000. In all seasons (with the exception of autumn), and for the year as a whole, trends in cloudiness are downward and are not statistically significant. Positive trends, also not statistically significant, occurred only in three months: March, June, and September (see Table 1 in Żmudzka 2003). Thus, the Polish mountain areas reveal an opposite tendency in long-term cloudiness to that exhibited by lowland parts of Poland.

There are a few stations which have a long-term and homogeneous series of sunshine duration in Poland (Cracow, Wrocław, Warsaw, and Puławy). As was mentioned earlier, the longest series is available for Cracow, consisting of a reconstructed part (1826–1883) and of an observed part (1883-present). The changes in this variable for the period in question are described in detail in the paper referred to earlier by Lewik et al. (2009, this volume). From their Fig. 15.5 it is evident that in the nineteenth century the changes in sunshine duration were very small and there was no trend. On the other hand, in the twentieth century a downward trend is well expressed and is statistically significant at the level of 0.05 (Matuszko 2007c). The downward trend is also seen for the whole series, though it is not statistically significant. In the other stations discussed the trends are similar to those in Cracow. In each series a downward trend is observed up to about 1980 and then a small increase in sunshine duration is seen (Górski and Górska 2000; Podogrocki 2002; Bryś and Bryś 2007). There is only one long-term series of global solar radiation dating back to the nineteenth century (Wrocław) (Bryś and Bryś 2007). This series shows a statistically significant negative trend in the incoming solar radiation in the period 1875–2004. After 1980 an increased trend in global solar radiation is observable. For the period 1961–1995 similar tendencies were also observed in other Polish stations (Gdynia, Kołobrzeg, Suwałki, Mikołajki, Warsaw, Zakopane, and Kasprowy Wierch), that is decreasing to 1980 and then increasing (Bogdańska and Podogrocki 2000).

In addition to incoming solar radiation data, information about atmospheric pressure is also very important in climatic change research, particularly for the description of atmospheric circulation. While there are long series of observations of this variable available for Poland, the only homogeneous series available are for Warsaw (Ustrnul and Czekierda 2000) and Cracow (Trepińska 1988, 1997c, 2007). The Cracow series has been analysed in detail by Janina Trepińska in several papers. For example, figures presenting average monthly and annual changes in air pressure in the period 1792–1995 can be found in Trepińska (1997c), and for the period 1901–2000 in Trepińska (2007). For the earlier period, in all months (except June) and for the year as a whole, upward trends were observed, though they were not statistically significant. On the other hand, throughout the twentieth century a decreasing tendency was noted (except for March) (Trepińska 2007). According to Trepińska (2007), this means that in the nineteenth century anticyclones prevailed, while in the twentieth century cyclones were more frequent, although anticyclonic pressure patterns still dominated. In Polish conditions, such changes in circulation result in a decreasing degree of climatic continentality from the nineteenth century to the twentieth century. Ustrnul and Czekierda (2000) present an analysis of long-term air pressure series (1826–1999) for Warsaw. For the entire period, a slight positive trend in the mean annual values was observed (almost the same as for Cracow). The authors do not give information about monthly and seasonal changes but, based on the similarity of both of the described series (determination coefficients r^2 varying usually from 0.6 to 0.9, see Figs. 3–14 in Trepińska 1988), we can assume that in Warsaw changes were also insignificant in the majority of months and seasons.

For Poland we have two long-term continuous series of air humidity (for Wrocław and Cracow) dating back to the nineteenth century. However, at present the only reliable homogeneous series of this variable available is for Cracow for the period 1901–2000 (Wypych 2007). Three periods within the twentieth century can be distinguished in the series presenting average annual values of relative humidity (Fig. 5.11): 1901–1930 (slight rising tendency), 1931–1955 (no trend), and 1956–2000 (significant downward tendency). During the period as a whole a statistically significant downward trend is observed. Roughly speaking, seasonal patterns of changes are similar to those described for the annual values (Fig. 5.11). The negative trends in spring and summer are half those for autumn and winter. However, all these trends are statistically significant. On the other hand, saturation deficit shows a positive trend, in particular in the last four decades (Wypych 2007).

5.4 Conclusions

Results presented in this chapter show that the instrumental history of observations in Poland is one of the longest in the world and that some of the available sources of data have either not been analysed at all or only partially. Thus, the improvement of our knowledge about climate changes in Poland in recent centuries is still possible. The mean annual temperatures for the periods 1779–1998 (Warsaw) and 1792–1995 (Cracow) show upward statistically significant trends reaching 0.55°C and 0.52°C per 100 years, respectively. The areally averaged annual temperature for Poland as a whole reveals a statistically significant increase (by 0.89°C) from 1901 to 2000. On the other hand, long-term trends in precipitation and atmospheric pressure in Poland have been insignificant. In the twentieth century decreasing statistically significant trends were observed in Poland for relative air humidity, cloudiness, sunshine duration and incoming solar radiation.

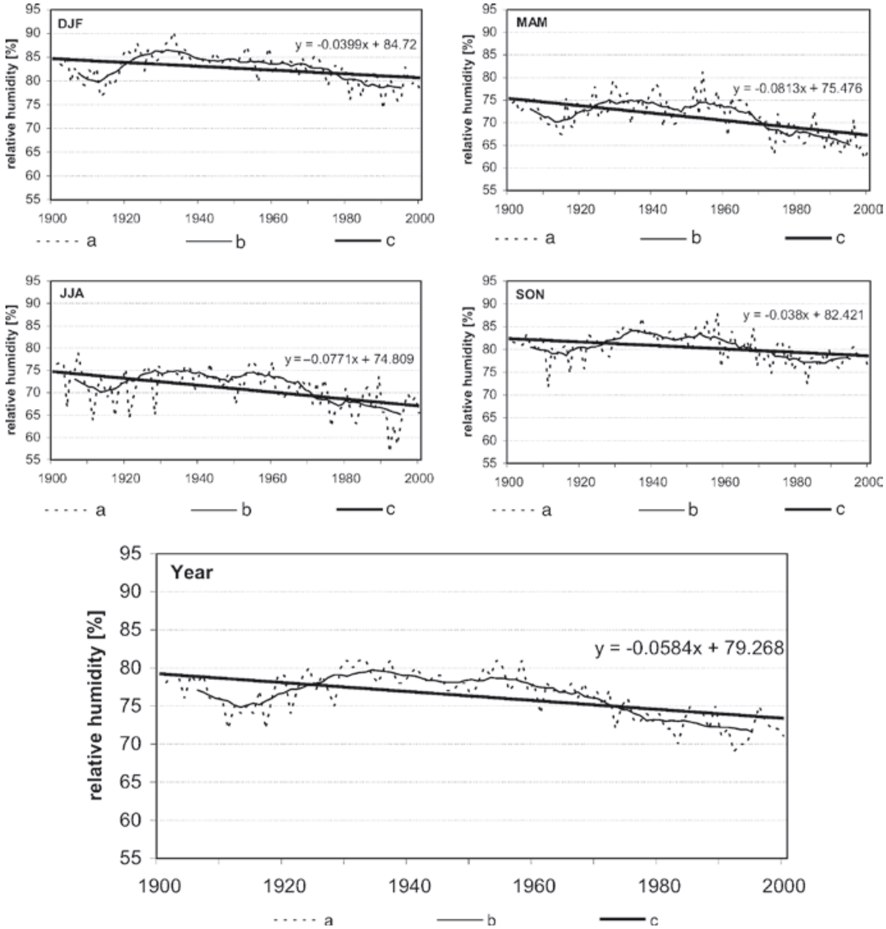


Fig. 5.11 Long-term courses of mean annual and seasonal relative air humidity in Cracow, 1901–2000 (based on data published in Wypych 2007). Key: DJF – winter, MAM- spring, etc.; a – year-to-year course, b – 11-year running mean, c – linear trend

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