Chapter 6
Documentary Evidence

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6.1 Introduction

Historical climatology is a scientific discipline which has been developing rapidly in recent years (Brázdil et al. 2005). Learning about the climate's natural changeability is of key importance and it can be done in the most precise and reliable manner by analyzing the last millennium. At present we have many climate reconstructions based on documentary and natural proxy data for selected regions of the world (e.g. Pfister 1999; Rácz 1999; Proctor et al. 2000; Glaser 2001, 2008; Brázdil 2002; Briffa et al. 2002a, b; Luterbacher et al. 2004; Xoplaki et al. 2005; Büntgen et al. 2006; Pauling et al. 2006; Dobrovolný et al. 2008), as well as for the Northern Hemisphere and the earth as a whole (e.g. Mann et al. 1998, 1999; Jones et al. 2001; McIntyre and McKitrick 2003; Moberg et al. 2005; Juckes et al. 2007; Mann et al. 2008). Our knowledge of the climate of Poland in the last millennium has increased considerably (see for instance Michalczewski 1981; Maruszczak 1988, 1991; Sadowski 1991; Paczos 1993; Wójcik et al. 1999, 2000; Bokwa et al. 2001; Limanówka 2001; Majorowicz et al. 2001, 2004; Przybylak et al. 2001, 2003, 2004, 2005, 2008; Oliński 2002; Kotarba 2004; Nowosad et al. 2007).

The first study of the climatic conditions of Poland in the Middle Ages was conducted by Polaczkówna (1925). Unfortunately, the results of this work were affected by the fact that the sources used were not completely reliable. Another drawback was the uncritical acceptance of Brückner's theory of 35-year climatic cycles, which in the light of subsequent research proved to be false. Semkowicz (1922) pointed out the imperfections of the written sources used during the work on the reconstruction of the climate in the Middle Ages.

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Prior to the Second World War, apart from the research dealing directly with the climate there appeared studies concerning natural disasters, including various meteorological phenomena. Franciszek Bujak started research in this area in 1918, putting forward a research project in the area of economic history (Hoszowski 1960; Bujak 1976). The team he organised collected a considerable amount of data. This information was inconsistent, however, and the usefulness of some of it (for example, concerning famine, plagues, high prices and fires) is limited as far as research on climate change is concerned. Another drawback of this study was that the information about the weather was derived mainly from published sources. Excerpts were published for what was then the area of Poland from sources for the following years: 1450–1586 (Walawender 1932), 1648–1696 (Namaczyńska 1937) and (for Galicia) for the years 1772–1848 (Szewczuk 1937, 1939). The results of the research for the period 1587–1647 were shown only in Werchracki's preliminary report (1938). After the Second World War the material was analysed by Hoszowski, though he failed to publish his findings. The materials for the years 1697–1750 were destroyed during the war (Hoszowski 1960).

After 1945 research on the history of Poland's climate was begun again by both climatologists and historians. On the initiative of the State Institute of Hydrology and Meteorology a catalogue of weather records from the tenth to the sixteenth centuries was created on the basis of sources published and their translations into Polish (Rojecki 1965). Nevertheless, the translation is not perfect, and has recently been criticised by the historian Wnęk (1999). After a heavy drought in Silesia in 1959 an interdisciplinary team was established consisting of the staff of the Higher School of Agriculture in Wrocław and the Chair of Economic and Social History of the University of Wrocław. The team's supervisor was the historian Stefan Inglot and their main aim was to examine the effects of drought on agriculture in Poland. To this end, the historians collected not only materials connected with droughts in Silesia from the sixteenth to the mid-nineteenth centuries, but also all the available information about extreme hydrological and meteorological phenomena (such as rainy years and floods, severe winters, hot summers, etc.). The catalogue of weather information was not published, and the outcomes of the historians' work are known only from Inglot's short reports (Inglot 1962, 1966, 1968).

Malewicz's dissertation (1980) on natural phenomena in Polish medieval historiography is more comprehensive. It comprises not only information about the weather included in the sources analysed, but also questions from the history of science. In the appendix the author included source extracts on the subject of meteorological and astronomical phenomena. Malewicz's research was heavily criticised by the historian Derwich (1984), who reproached him for numerous mistakes in the chronology of records and the incompleteness of preliminary source research.

Within the scope of this brief review, it is worth mentioning the work of Górski (1965), who emphasised the usefulness of historical sources for examining climatic changes in Poland, and the study by Dunin-Wąsowicz (1974) which analysed the relationship between afforestation, water relations and settlements in the Middle Ages. There were also many studies devoted to the research into elemental disasters, in which the climate was not always present (see for example Stamirski 1962;

Kwak 1987; Ratajczak 1987, 1991; Motylewicz 1993). Yet all these studies referring to the reconstruction of Poland's climate on the basis of historical sources fail to include conclusions of a climatological nature or detailed analyses of climatic fluctuations.

This research direction becomes visible in the works of Maruszczak (1988, 1991), who presented a thorough description of temperature and humidity conditions in Poland in the last millennium. He estimated the average temperature of the subsequent 50-year periods on the basis of changes in temperature in the higher latitudes of the Northern Hemisphere and of palynological data, taking into account the correction resulting from the analysis of the prices of vegetable groceries. It must be noted however that in this hemisphere there was considerable regional diversity of tendencies relating to climate change in the periods from 50–100 years. Thus drawing conclusions about the value of elements of Poland's climate on the basis of data from places which are quite distant from each other (Great Britain, California, Greenland) may be misleading. One of the few Polish attempts to deal with the climatological interpretation of records exclusively from historical sources are studies by Sadowski (1986, 1991). They include among others the list of famine disasters in Poland in relation to climatic phenomena (rainy, dry and cold summers) from the period 1351–1750 as well as the frequency of severe winters and hot summers in individual decades starting from the thirteenth century.

At the end of this review one must mention the most recent research (Limanówka 2001; Bokwa et al. 2001; Nowosad et al. 2007; Przybylak et al. 2008), which analyzes climatic conditions in Poland in selected short periods from the sixteenth century (1502–1540) and seventeenth century (1656–1685) on the basis of records of weather conditions written by professors of the Academy of Cracow (in particular by Marcin Biem) and the voivode Jan Antoni Chrapowicki.

Studies describing the history of the development of meteorology, including the oldest meteorological observations in Poland, constitute a separate category (see for example Parczewski 1948a, b; Rojecki 1956, 1965; Staszewski 1966; Hanik 1972; Michalczewski 1979, 1988; Marciniak 1990; Miętus et al. 1994; Lorenc 1996, 2000; Wnęk 1999; Limanówka 2001).

As can be concluded from the survey, research on the modern climate in the historical area of Poland, based on documentary evidence, was not very common in the twentieth century, unlike in other parts of Europe and the world (for more details see Brázdil et al. 2005). Lack of interest in such research was the result of skepticism about the possibility of using historical sources in climate research, the final outcome of which, it was thought, should be clear-cut statistical results, enabling easy comparison between regions. This concerned mainly the Middle Ages and the early modern period (Semkowicz 1922). Undoubtedly, the skepticism was excessive, though its positive effect was that it showed limitations connected with obtaining data from historical sources.

It was not until the end of the twentieth century that research on the climate in Poland in the last millennium began to flourish. Earlier statements on this subject were quite general. Historians and geographers claimed that in from the medieval times on the climate was more humid and cooler on account of substantial forestation

and a bigger amount of precipitation (Smolka 1881). There were opponents of this thesis who maintained that the humidity of the climate was rising as it had been much drier earlier, while others believed that the climate had not changed in Poland in historical times except some temporary fluctuations (Semkowicz 1922). Obviously statements of this kind were not based on extensive source research and analytical examination. The popularity of the research of Edward Brückner conducted at the beginning of the twentieth century and proving the existence of 35 year periods of climate fluctuations was continued in research on the Polish climate (Polaczkówna 1925).

The growing popularity of climate research in Poland is a reaction to the many gaps in our knowledge on the subject in this part of Europe, particularly with reference to the Middle Ages and modern times. Research is facilitated by methods which enable at least partial check of information included in historical sources. The check is possible thanks to the instrumental data provided by other fields of research, in particular in biology and geography, and better methods of evaluating the usefulness of historical sources in climate research. Also of major importance is the creation of various marking scales which enable comparison of data based on historical sources for different regions (Pfister 1999; Brázdil et al. 2005). Nevertheless, the basic problem was and is the precise transformation of source information into numerical data based on historical narratives. The methods used here are still not perfect, though they allow us to obtain relatively precise data and, more importantly, they help to define the existing research possibilities and limitations which cannot be ignored. A growing number of written sources, including both climate records as well as similar studies concerning other regions of Europe, facilitate climate research and enable us to make comparisons and to draw conclusions.

6.2 Documentary Sources – Kinds and Quality

Polish sources from the fifteenth century to the end of the eighteenth century are specific. Unlike in many other regions, data concerning the viticulture (such as in France, Guyot and Godet 1935; Lachiver 1991) did not survive. Economic data concerning corn crops are imperfect too. Taxes paid by villages and individual farms are recorded, though these reflect neither the time nor the amounts harvested – factors which in many regions enabled the examination of climatic fluctuations (see for example Pejml 1966; Pfister 1979; Brázdil and Kotyza 2000). Some information can be provided by data concerning fluctuations in the prices of corn in comparison with data referring to the amounts of corn which were harvested (e.g. for Gdańsk, the most important harbor for corn exports from Poland, see Pelc 1937). Changes in prices may result from different factors, not always connected with the amount of crop (e.g. Brázdil and Durďáková 2000). Hence, the price index cannot be conclusive for the evaluation of conditions of corn growth and weather conditions. While such research will certainly be useful in climate reconstruction, this field still requires much work in the future. At present, narrative sources prove to be the most

useful, such as chronicles, diaries, individual records, records including daily comments on the weather, and correspondence. Their major drawback is their subjective character, which makes it more difficult to transform them into numerical data. Moreover, instrumental data based on permanent observations and expressed numerically were preserved for periods in the eighteenth century (cf. Chapter 5).

Sources including systematic information for longer chronological periods are particularly important. They allow us to learn more about the language employed by the author, to define the magnitude of the meteorological phenomena which they describe and to provide a comparative description of the weather during a longer period of time.

The following kinds of sources were analysed:

1. Narrative sources – yearbooks, chronicles (political, monastic, parish, home, and school chronicles), diaries and memoirs, descriptions of journeys and trips, military expeditions and diplomatic missions. Such sources frequently included general descriptions of seasons of the year and were quite reliable. They were created either directly after the events they described or some time later. In the second case they were written from memory or were based on earlier records. In each case, critical source research was conducted in order to specify such questions as the period of time which passed from a given weather phenomenon to the moment of recording it, the location of a given weather phenomenon in relation to the place where the phenomenon was recorded, the source of information of the author, the reliability of the source, etc.
2. Daily weather records. The overwhelming number of weather records in some sources allow us to regard them as "weather chronicles" (excerpts from historical sources). The best known source of this kind is the diary of the Voivode of Vitebsk Province Jan Antoni Chrapowicki written in the second half of the seventeenth century (Nowosad et al. 2007). Other examples are notes of professors from Cracow from the sixteenth century, particularly those of Marcin Biem (Limanówka 2001). Apart from diaries, calendars were also taken into consideration. Their owners used to write in empty spaces their comments about interesting events, many of which were meteorological. The value of sources of this type is high, provided the owner of the calendar or his address can be indisputably identified and that we have long and complete descriptions for one particular place.
3. Correspondence. The problem which the use of correspondence raises is the selection of collections of letters to research. Sensitivity to weather conditions was a personal feature of individual writers. Having found a writer who met the requirements, researchers began seeking out collections of his letters. Appropriate letter writers were found among numerous sources – agents of the royal courts and clients of powerful dignitaries, or co-workers of special agencies established in Europe with the aim of providing information. Another group constituted letters of farm officials to their superiors or farm owners. One example of correspondence which includes weather data are the letters of Michał Dorengowski to the Radziwiłł family kept in the Central Archives of Historical Records in Warsaw, or the letters of Anzelm-Piarist, officer of Sapieha, starost of Merkinė to his

principal in the Library of the Lithuanian Academy of Sciences in Vilnius. Longer series of correspondence can be found for the eighteenth century, when writing skills and, in particular, the habit of writing down one's emotions, stopped being the privilege of the rich.

4. Manuscript and printed materials recording meteorological phenomena in chronicles of events, where special coverage was given to extreme cases (for example data for the years 1760–1767 in *Thornische Wöchentliche Nachrichten* and separate articles about some meteorological phenomena in this magazine).
5. Official files: documents (for example tax exemptions due to floods), inspection and inventory protocols, tax registers, official books (informing for example the closing down of offices during a flood or plague, but also including testimonies of witnesses), resolutions of parliament and regional assemblies, reports and protocols from meetings of collegial bodies, official statistics, directives and official reports. These provide some data, though the information is scattered and scarce. Moreover, they inform us about events which took place in the time which is hard to define. In cases where the basic sources of information are derived from reports of eye-witnesses, it must also be remembered that these individuals' accounts should not necessarily be taken at face value; it is always possible that such reports may have exaggerated the magnitude of the phenomena for the personal ends of those reporting them. Research done by Fr. Józef Nowacki is of particular value. He collected historical records from the archives of the Poznań diocese, many of which are of considerable climatological interest.
6. Economic sources, particularly bills.
7. Epigraphic sources (for example records about the flooding of the river at the Bridge Gate (*Brama Mostowa*) of the Old Town in Toruń).

6.2.1 The Middle Ages

The medieval period seems the most difficult with regard to doing such research due to the smaller number of sources available. Estimates as to how many extant sources are available for climate reconstruction vary between 200 to nearly 300 (Walawender 1932, though only from the second half of the fifteenth century; Rojecki 1965; Malewicz 1980). Excerpts referring to weather in Poland, particularly Silesia, found in foreign literature, are not numerous (Alexander 1987). The number of references collected by Polish researchers is incomplete, and it remains highly probably that new sources of data from the Middle Ages and later periods will emerge (Derwich 1984). It seems that potentially there may be up to a 1,000 notes concerning the weather, covering 70–80% of the period of the Middle Ages. Needless to say, the quality and information value of the source data will vary. They are very often dependent on each other and represent different interpretations of the same event. The characteristic feature of medieval records is that they comment on weather phenomena as if these phenomena had concerned the whole kingdom.

As a result, it is hard to draw more precise conclusions about the weather conditions in different regions. On the other hand, individual regional records do not allow us to make generalizations on the subject of the weather over a larger area. Descriptions of individual extreme events such as storms or hails, which led to destruction, are less important – naturally they concentrate on the particular place where the record was being made.

Roczniki written by Jan Długosz must be considered one of the most essential sources. It was the subject of a study by Polaczkówna (1925), who used records for almost 200 individual years from the period from the tenth century to the end of the fifteenth century, which she presented statistically. However, the study was based on the theory of Brückner, accepted *a priori*, and referred to the cyclical repetition of climatic periods, which affected the results and conclusions (Polaczkówna 1925). Gaps in data for many years resulted in imprecise conclusions. Undoubtedly, the source data needs to be reinterpreted, taking into account information from other sources. More attention should be paid to the analysis of the sources of individual records (Semkowicz 1922). Długosz used many other sources, in particular with reference to earlier centuries and many of these sources have survived (Semkowicz 1887; Zonenberg 2000). Historians' efforts should now be directed at the critical evaluation of the information acquired. Meanwhile, Długosz's records should be interpreted taking into consideration events in his life. Perhaps it might be useful to consider some differences resulting from his age: at different stages in his life he displayed varying degrees of sensitivity to temperature and humidity. Nevertheless, research of this kind remains a task for the future.

6.2.2 The Sixteenth Century

The last two decades of the fifteenth century and the sixteenth century as a whole brought a change in the quality of the sources. Academics at the University of Cracow began to keep systematic records of general meteorological phenomena, (not only extreme events). The significance of this development is even greater when one takes into account the fact that the sixteenth century was a period of substantial climatic changes (Pfister and Brázdil 1999). The records are written very straightforwardly and can easily be transformed into numerical data. However, their drawback is their lack of accuracy. The observations made by Marcin Biem (died 1540) for the years 1499–1531 and 1534–1540, included in *Almanach nova* by Johannes Stöffler and *Ephemerides* by Lucas Gaurricus, are of major significance. A number of writers kept records of this kind for longer periods, including Bernard of Biskupie for the years 1515–1531, Mikołaj Sokolnicki for the years 1521–1531, Michał of Wiślica for the years 1534–1550, and many others. The records were made on pages of different copies of Stöffler's *Almanach nova*, and on pages of another book by the same author, *Ephemeridum opus*. These are very often daily records, and altogether there are almost 13,000 of them. They have been studied in detail by Limanówka (2001). Outside Cracow it is difficult to find such

rich meteorological information for the sixteenth century. Records referring to the weather in the sixteenth century are included in chronicles of Miechowita, Wapowski, and the diaries of Heinrich Wolff (for the times of Henry of Valois). Later sources describing the sixteenth century also deserve to be mentioned, such as the chronicle of Łochowski Mayor of Bydgoszcz, which was written up to 1637, and the Lvov and Ostrów yearbooks covering the same period and describing the eastern part of Poland (Bewzo 1970). In total, apart from the Cracow sources approximately 800 other records have been found.

6.2.3 The Seventeenth Century

The first half of the seventeenth century was not as prolific in weather records as was the sixteenth century and the second half of the seventeenth century. Apart from the above mentioned chronicles of Łochowski and the Lvov and Ostrów yearbooks, the following constitute important sources: diaries of Albrycht Stanisław Radziwiłł from the years 1632–1656 (Przyboś and Żelewski 1980), the chronicle of Joachim Jerlicz from the years 1612–1668 (Wójcicki ed. 1853) and the diary of Stanisław Oświęcim from the years 1643–1651 (Czermak ed. 1907). The number of records included in those sources does not exceed several dozen. The remaining diaries from the first half of the seventeenth century included even less information. In the second half of the seventeenth century numerous records can be found in Chrapowicki's diaries, written in the period 1656–1685. These are daily records, sometimes made even a few times a day. Rarely did he give weather information for longer periods. Usually they refer to temperatures, precipitation and winds and, in total, there are about between ten and 20,000 of them. Their drawback is that they refer to different and sometimes remote areas which happened to be on the journeys made by Chrapowicki. The records deal with Polish regions – Masovia, the Białystok region, and Podlasie – as well as with Lithuania, Belarus and even Russian areas such as the regions of Vitebsk and Smolensk. Another problem is that the second part of Chrapowicki's original manuscript is missing, and the diary is known exclusively from copies. Transcriptions made in the eighteenth and nineteenth centuries were not precise as copyists tended to omit weather records or to reduce them, concentrating on other areas of life described by the author (Nowosad et al. 2007).

Besides Chrapowicki's diary other sources known for this period include the printed calendars of Fryderyk Buethner, professor of mathematics in the Gdańsk gymnasium. Despite the fact that they fail to provide actual weather information (they are a printed forecast of the weather for subsequent days of the year based on astronomical research) short notes about actual weather conditions are included in the marginalia (Miętus 2007). A modest complement to the notes of Chrapowicki are other memoirs and diaries from the second half of the seventeenth century written by Werdum (Liske 1876), Łoś (Śreniawa-Szypiowski 2000), Niezabitowski (Sajkowski 1998), and the collection of memoirs of Sarnecki from the end of the seventeenth century (Woliński 1958). The end of the seventeenth century and

the first years of the eighteenth century were described thoroughly, on a daily basis, in relation to south-western areas of Poland and south-eastern parts of Germany for the years 1692–1712 by David von Grebner (Grebner 1714). Aside from memoirs, a range of other sources was used where several 100 references of various kinds were found. Some of them such as *The Pelplin Chronicle* or other monastery chronicles included relatively homogeneous data referring to the vegetation periods of plants, times of harvest and weather conditions. The kind of source determined the type and quality of the record. Memoirs, diaries and occasional correspondence provided daily records and were kept systematically. Chronicles recorded complete seasons or years, which might have generated a coincidental picture and led to faulty judgment.

The attempt to gather and compile information about natural disasters for the seventeenth century was undertaken before the Second World War as the continuation of Walawander's research (Namaczyńska 1937). The effect of the research was the compilation of a few hundred records from printed memoirs, taking into consideration information about fires and plagues. Still, there were relatively few weather records, and further verification of the sources used in the project showed that many had been omitted as they had not been in the scope of the project concerning weather disasters. As a result of the research of the last few years (aside from Chrapowicki's records) over 700 weather records of various significance and character have been found. It must be emphasised that their number in the first and second half of the seventeenth century was almost the same. More than 300 records were found for the period from 1600 to 1649, while almost 400 were found for the period 1650–1699. As a consequence of further research we can expect a considerable increase in the number of weather records for this period. As historical sources (including memoirs) have been published with greater intensity lately, there is some hope that access to new historical data will be easier. Nevertheless, sources such as correspondence, calendars or newspapers will not be printed in the immediate future. Consequently, further research in archives and libraries in Poland and elsewhere is indispensable.

6.2.4 The Eighteenth Century

In the eighteenth century instrumental observations were becoming more and more common, and thus this allows us to compare older non-instrumental data against the new more reliable data which allows us to check references to the weather of a non-instrumental nature. In the eighteenth century weather records appeared more and more frequently in memoirs and private chronicles. The sources are characterised by a greater degree of regionalization. References relate mainly to the town or region where a source was created. Two sources from Toruń are typical examples of this kind: the chronicles of Johann Richtsteig, referring to Toruń in the years 1704–1730, and the memoirs of Dawid Brauer for the years 1719–1750. The amount of weather information included in private and official correspondence rose considerably in comparison with

earlier periods, though it is largely unpublished and thus mainly to be found in manuscripts. Examples of such sources are the letters of Dorengowski from the years 1740–1741, and the letters of Anzelm-Piarist from the years 1729–1738.

6.2.5 *A Concise Typology of Sources for the Period from the Sixteenth to Eighteenth Centuries*

In the case of collected sources the biggest problem was the evaluation of the usefulness of information for purposes of climate reconstruction. Reliability was not the only element taken into account. Sometimes, due to the omission of details of some periods or territories, the research was based on data of poorer quality. Data coming from neighboring countries was also used for comparative purposes (e.g. Brázdil and Kotyza 2000; Munzar 2004). Further research in libraries and archives will certainly allow us to check and correct the data for these periods and territories. As was noticed in relation to the Middle Ages, records concern either one-off events, limited to a small territory and a short time period, or descriptions of weather conditions for a larger area and a longer period (a month, season or year). In various periods the proportions between those two basic types of phenomena were different. The usefulness of sources recording one-off events depends on their quantity, while sources recording weather conditions more broadly over a longer period are valuable when there is a scarcity of other data.

Very often the historical records which were collected concerned extreme situations as it was these which diarists and letter-writers thought most worthy of comment. Weather conditions were described in relation to vegetation periods and the influence of the weather on harvests. If a particular meteorological phenomenon took place in a month when it did not affect the vegetation of plants and harvest, there was little chance of it being recorded. The incidental nature of records and the noting down of only extreme phenomena are two dominant features in the data taken from source materials. It also presents us with certain methodological difficulties. If we assume, on the basis of the content analysis of sources, that during periods when no regular weather observations were made only abnormal phenomena were recorded, can we assume that in times and periods not mentioned in a source the weather conditions were average? Such an assumption is justified only in the case of sources for which it is quite probable that extreme phenomena were recorded comprehensively. It reflects the view expressed in the literature that a successful harvest was not recorded as a normal phenomenon because it did not attract attention. A lack of data thus leads us to assume that there was a good or average harvest in a given year (Hoszowski 1960).

A major drawback of the Polish source base is the paucity of sources presenting long-term series for one place. Most of the information we have is scattered among other sources. Hence, the selection of research sources plays a major role. Our experience leads us to opt for collections of daily records (frequently updated diaries and calendars, which we have just started to explore), chronicles and sets of correspondence made by individuals particularly interested in natural phenomena.

6.2.6 Territorial Distribution of Records

As far as the territorial distribution of weather records is concerned, we have about 150 records which cover the whole country, over 1,300 records for Pomerania, 35 records for the Warmia, Masuria and Suwałki region, about 200 for Greater Poland, 5,430 for Masovia, about 500 for Silesia, about 350 for Lesser Poland, 30 for the neighboring countries from the West, and about 5,000 for territories situated beyond the eastern border of Poland (used mainly to reconstruct the weather conditions in Masovia). Chrapowicki's diary results in a disproportionately high number of records for Masovia (with Podlasie) and the regions adjacent to Poland in the vicinity of Podlasie.

6.2.7 Chronological Distribution of Records

Altogether about 13,000 records were collected from over 200 different sources. The chronological distribution of references which were collected is as follows: the sixteenth century – about 750 records (not including the study by Limanówka [2001] which was also used and which comprised over 12,000 pieces of data for Cracow), the seventeenth century – about 11,000 records; the eighteenth century – 1,200 records; the nineteenth century – 35 records. The disproportionately high number of records in the seventeenth century results from the wealth of references to the weather in the diary of Jan Antoni Chrapowicki. This source has already been the subject of climatological analyses, though these studies have only used those parts of the diary which have been published – about 40% of the diary as a whole. We are now also working on including data derived from the diary manuscript. The information was first taken into consideration during the reconstruction of the climate of modern Poland. Poorer quality research from the nineteenth century resulted from the fact that the range and number of sources had not at that stage been analysed. The material collected is of a synthesizing nature (i.e. concerning opinions about seasons of the year), which increases its value.

Almost 300 records refer to the year as a whole; winter and spring get about 3,400 records each; 3,100 records deal with summer; and about 2,800 are related to autumn. Thus a fair distribution of sources between seasons has been achieved.

6.3 History of Poland's Climate in the Last Millennium

Climatic conditions are usually characterised by the use of data from instrumental observations (during last 200–300 years) and from so-called proxy data, which exploit the dependence of various natural phenomena on the climate. For the pre-instrumental period of the last millennium the best sources of information

(in terms of precision and trustworthiness) for area of Poland are dendrochronological, documentary and borehole data. The use of research results from other branches of science (e.g. geology, geomorphology, pedology, archaeology, botany etc.) is limited, mainly due to restricted time resolution.

Before discussing the characteristics of the climate of the past millennium, readers should be aware of the fact that proxy data do not enable the reconstruction of all the meteorological variables which are generally used to describe the climate of a given region. In principle, for the greater part of a particular period, only three variables can be reconstructed in a virtually continuous way, though luckily these are the three most important variables: air temperature, ground surface temperature and precipitation. Information about other elements (e.g. wind, cloud cover, atmospheric phenomena) is only contained in historical sources, usually only those that contain daily records. Sources of this type are scarce and cover only a small fragment of the past millennium.

The methods for the reconstruction of these variables are described in detail in a number of recent studies (Przybylak et al. 2001, 2004, 2005; Majorowicz et al. 2001, 2004), and thus they will not be discussed here.

6.3.1 Air Temperature

As was mentioned earlier, air temperature is the meteorological variable for which the most information on changes has been collected in the past several hundred years. It is a well-known fact that it is connected with the very tight interdependency of natural phenomena with air temperature in our geographical latitude. Moreover, there is no doubt that this variable is highly important to life and human activity. Therefore most documentary records which have survived feature examples of extreme air-temperature values. Nevertheless we lack a sufficient volume of information for the credible reconstruction of the air temperatures for the first half of the past millennium (see Rojecki 1965). Furthermore, the credibility of historical records from that period is limited, a problem which was raised as early as 1922 by Semkowicz and which has been confirmed by modern historians (P. Oliński 2008, personal communication). Dendrochronological data available go only as far back as the year 1170 (Zielski 1997; see also Chapter 7). Practically speaking there are virtually no proxy data available on the climate for the first two centuries of the last millennium. Certainly it is possible to attempt to reconstruct the history of air temperature changes for that period on the basis of the data available from other regions, as has been proposed by Maruszczak (1991). However the credibility of such reconstructions is very limited, particularly when data from distant regions such as Great Britain, Greenland and California, are taken into consideration, which, when compared to Poland, often show a different rhythm of air temperature changes (see for instance Fig. 34.2 in Bradley and Jones 1995, where air temperature reconstructions for Europe and North America are presented). The opposition of air temperatures in Europe (including in Poland) and in Greenland (Kosiba 1949) has been known for a long time, particularly for winter; this phenomenon can be

very easily explained by the influence of atmospheric circulation described by means of the North Atlantic Oscillation (NAO) index (Hurrell 1995). Bearing these reservations in mind, one can mention that the eleventh century according to Maruszczak (1991) was probably warmer than the norm, and the twelfth century (particularly its last 50 years) was the warmest on record for the whole millennium. The reconstructed average temperature for the months from January to April in the years 1170–1200 was one of the highest, if not the highest (see Fig. 7.15 in Chapter 7). For the years 1201–1500 slightly more information is available, as there has also been a study by Sadowski (1991) that utilises a small number of not very credible historical sources. According to Maruszczak (1991) average annual air temperatures were above the norm in the thirteenth century and in the first half of the fourteenth century, then a cooling followed for about a 100 years and in the second half of the fifteenth century a warming occurred again. According to studies by Sadowski (1991) there were both fewer severe winters and hot summers in the thirteenth century than there were throughout his 800-year study period, which means that this century was characterised by the highest degree of oceanism on the climate (see his Fig. 6). The average temperatures for the January–April period (as seen in Fig. 7.15 in Chapter 7) were relatively high and changed little during this period. Similar temperatures may be noted in the fourteenth century, during which period Sadowski's research (1991) also does not indicate higher air temperature changes. Thus his work cannot confirm the occurrence of climate cooling in the second half of the fourteenth century, as was described by Maruszczak (1991). According to Sadowski, the fifteenth century was characterised by the highest degree of climatic continentality in the study period. In that period, a sudden rise is noted in the number of severe winters, including as many as six in the decade 1451 to 1460. There were also many hot summers (from two to five per decade). Taking into consideration the fact that it is the winter temperature which exerts the greatest influence on the mean annual temperature, it should be noted that the second half of the fifteenth century was cool. This result thus contradicts the evaluation presented by Maruszczak (1991): the reconstructed average air temperatures for the January–April period indicate a somewhat later occurrence of this cooling (by about 20 years) (Fig. 7.15 in Chapter 7).

In summing up the state of our knowledge of air temperature changes in the period from 1001 to 1500, we should note that it is generally very modest and the existing reconstructions are highly unreliable.

A radical improvement in this respect occurs from the sixteenth century onwards. For this period there exist a few successful attempts at reconstructing the air temperature by means of utilising documentary sources (Sadowski 1991; Maruszczak 1991; Przybylak et al. 2004, 2005). Also air temperature reconstructions were published that were based on historical sources with large resolution (daily), but for shorter periods of several years (e.g. Limanówka 2001; Bokwa et al. 2001; Nowosad et al. 2007).

The frequency of occurrence of all extreme events (Table 6.1) in the period 1501–1840 was greatest in the first 150 years. Later they were noted more rarely, especially in the first half of the eighteenth century. Very severe and severe winters (indices −3 and −2, respectively) in the 10-year periods were most frequent in the last decade of the sixteenth century (six winters) and in the decades 1641–1650 and 1731–1740 (five winters in both cases). The fewest such winters occurred in the

Table 6.1 Frequency of occurrence of exceptionally warm and cold winters (DJF) and summers (JJA) in Poland from 1501 to 1840 (after Przybylak et al. 2005)

Period	DJF		JJA		Extreme seasons	
	2 and 3	−2 and −3	2 and 3	−2 and −3	Total	%
1501–1550	**7**	12	2	0	21	15.9
1551–1600	1	**14**	7	0	22	16.7
1601–1650	0	11	**10**	0	21	15.9
1651–1700	4	11	3	1	19	14.4
1701–1750	2	12	1	**3**	18	13.6
1751–1800	1	10	2	0	13	9.9
1801–1840	0	9	7	2	18	13.6
1501–1840	15	79	32	6	132	
%	11.4	59.8	24.3	4.5		100.0

Explanations of the indices (+3, +2, −2, and −3) are given in the text
The highest frequencies of occurrence of the exceptionally warm and cold seasons in 50-year periods are shown in bold

decades 1621–1630, 1631–1640, 1751–1760, 1831–1840, and probably in the period 1701–1720. From the 50-year periods, the second half of the sixteenth century was the richest in very severe and severe winters (14). A large number of such winters (12) also occurred in the first halves of the sixteenth and eighteenth centuries. Sadowski (1991) also obtained quite similar results.

There are significantly fewer historical sources which describe extremely warm and very warm winters (indices +3 and +2, respectively) in comparison with severe winters. However, the results presented in Table 6.1 show that their maximum frequency was in the first half of the sixteenth century (seven) and in the second half of the seventeenth century (four).

Only a third as many notes have been found for summer thermal conditions in comparison with those for winter (Table 6.1). Significantly more excerpts (32) relate to hot (extremely warm) and very warm (indices +3 and +2, respectively) summers than those referring to extremely cold and very cold summers (indices −3 and −2, respectively). The first group of summers occurred with the greatest frequency in the period 1580–1640 and at the beginning of the nineteenth century. Information about the second group of summers has only been found after 1650, with the highest frequency in the first half of the eighteenth century (Table 6.1).

Average 10-year air temperature values in winter (December to February) in the period from 1501–1840 were in all instances lower than those occurring in the twentieth century, and this is also true in the period from 1851 to 1950 (Fig. 1.2 in Luterbacher et al. Chapter 1). On average, the coldest winters occurred in the decade from 1741 to 1750 (the anomaly was −3.6°C). Major anomalies (app. −2.5°C) were recorded in the following decades: 1541–1550, 1571–1580, 1591–1600, 1641–1650, 1651–1660 and 1771–1780. Within the whole study period two long sub-periods can be distinguished when low temperatures persisted in winter (generally with anomalies lower than −1.5°C): 1540–1600 and 1720–1820. Between those two periods, with the exception of the years from 1641 to 1660, winters were distinctly warmer.

The warmest winters were recorded in the first and third decades of the sixteenth century. Brázdil (1996) obtained roughly similar results for winter air temperature anomaly changes (mostly the same variation, but lower values) for the territory of the Czech Republic. The biggest differences between both reconstructions were recorded for the periods from 1641 to 1660 and from 1721 to 1750. A comparison of these quantitative reconstructions with the results of the frequency of occurrence of severe and very severe winters indicates the existence of considerable differences. For example, according to Sadowski's data (1991) the greatest number of severe winters was recorded in he second half of the sixteenth century and throughout the seventeenth century, while the smallest number were in the eighteenth century. A similar pattern of changes for average annual temperatures is quoted by Maruszczak (1991), who states that the culmination of cooling occurred in the mid-seventeenth century. According to him, this was the coldest period in the whole of the millennium. In Fig. 1.2 in Luterbacher et al. (Chapter 1) one can see that winters were in fact very severe, and summers (see Fig. 6.1) were close to the long-term norm. Yet in the Czech Republic winters (and summers) in that period were not similarly conspicuous Comparing the reconstruction of winter temperature (Fig. 1.2 in Luterbacher et al. Chapter 1) with the reconstruction of the temperature for the period January–April (Fig. 7.15, Chapter 7), the prevalence of their consistent courses (eighteenth–nineteenth centuries) or inconsistent courses (the sixteenth and seventeenth centuries) should be noted. According to Przybylak et al. (2004) probable causes of these discrepancies in the results may include: (1) the use of not fully comparable data (with average temperatures being obtained at various times in the year, only partly overlapping), (2) inaccuracies in the reconstructions which were devised.

The reconstruction of the air temperature for the summer season based on historical data is much less credible and complete than for the winter season as there is less information available. This is clearly visible in Fig. 6.1. Nevertheless the general outline of the changes is clear. There was a dominance of positive or zero anomalies in the whole period under study as compared to the period 1851–1950, with the exception of the eighteenth century, with the maximum reaching 0.5°C–0.6°C in the decades 1551–1560, 1581–1590, 1611–1620, 1631–1640, 1661–1670, 1801–1810 and 1811–1820. The cool summer seasons were recorded mainly in the first half of the eighteenth century with the maximum in the period 1721–1740. In comparison with the territory of the Czech Republic there exists quite a high consistency of anomalies (except for the eighteenth century) although much lower than in the case of winters. It should be noted that due to large deficiencies in the reconstruction of decadal average values for summer temperatures in Poland, a full comparison is not possible. The possibility of the occurrence of hot summer seasons in Poland in the eighteenth century cannot be excluded in the decades for which there is a lack of data, particularly in view of the fact that they were recorded in the Czech Republic (Fig. 6.1).

In conclusion it should be said that our knowledge about the climate of Poland in the past 500 years has increased considerably in the recent years. Nevertheless it is still limited, particularly in relation to the summer season. We may state with some confidence, however, that in the period 1501–1840 the climate of Poland was

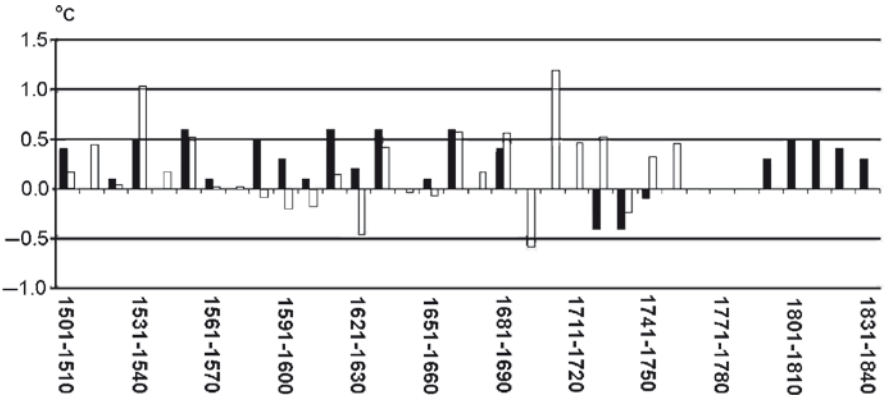

Fig. 6.1 Comparison of summer air temperature reconstructions for Poland (1501–1840, *black bars*) and the Czech Republic (1500–1769, *white bars*; after Brázdil 1996). Anomalies have been calculated relative to 1851–1950 means (modified after Przybylak et al. 2004)

characterised by a higher degree of thermal continentality than prevails at the moment. These results are consistent with the calculations of the values of the continentality index presented in the study by Sadowski (1991).

6.3.2 Precipitation

As was mentioned earlier, the reconstruction of precipitation faces much bigger challenges than the reconstruction of air temperature, mainly due to the lower influence of this variable on natural phenomena (e.g. annual growth of tree rings), and on human life and activity (with, consequently, fewer mentions of precipitation conditions in historical records in comparison with thermal conditions). It is for this reason that there are very few studies describing precipitation in Poland in the pre-instrumental period. Four studies (Maruszczak 1991; Przybylak et al. 2004, 2005; Kotarba 2004) discuss this problem for the period of several centuries, whereas another five (Bokwa et al. 2001; Limanówka 2001; Nowosad et al. 2007; Przybylak et al. 2008; Przybylak and Marciniak 2009, this volume) discuss it only for periods of several decades. Maruszczak (1991) provides very general information about mean annual humidity conditions (in the study the period is not specified), which should be understood as precipitation conditions. In the eleventh century they were average, though the twelfth century was the most humid in the whole millennium. The beginning of the thirteenth century was characterised by a decrease in precipitation, which was below the norm in the second half of the century. In the fourteenth century precipitation was on the increase and, from the second half of that century until the mid-fifteenth century, precipitation conditions were variable but close to the norm. Regarding the next 100 years, Maruszczak only mentions that considerable changes in humidity conditions took place and does not specify what kind of changes these were. It can be inferred, however, from the

context that the climate became more humid, at least in the years 1480–1520. This hypothesis is confirmed by the data published by Przybylak et al. (2004) (see also Fig. 6.2). However Limanówka (2001) states, on the basis of a number of days with precipitation, that in the first half of the sixteenth century there was less precipitation than in the modern period. It seems, however, that the professors of the Wszechnica Krakowska (the precursor to today's Jagiellonian University in Cracow) tended to overlook low levels of precipitation, and these were consequently omitted from records. A similar problem with Chrapowicki's diary for the first 2 years (1656 and 1657) is confirmed by Nowosad et al. (2007). Therefore it seems that the value of the number of days with precipitation presented by Limanówka (2001) should be increased by this probable error. From the mid-sixteenth century to the mid-seventeenth century average precipitation conditions prevailed (Maruszczak 1991). Similar results were obtained by Przybylak et al. (2004) (see among others Fig. 6.2). The second half of the seventeenth century was, according

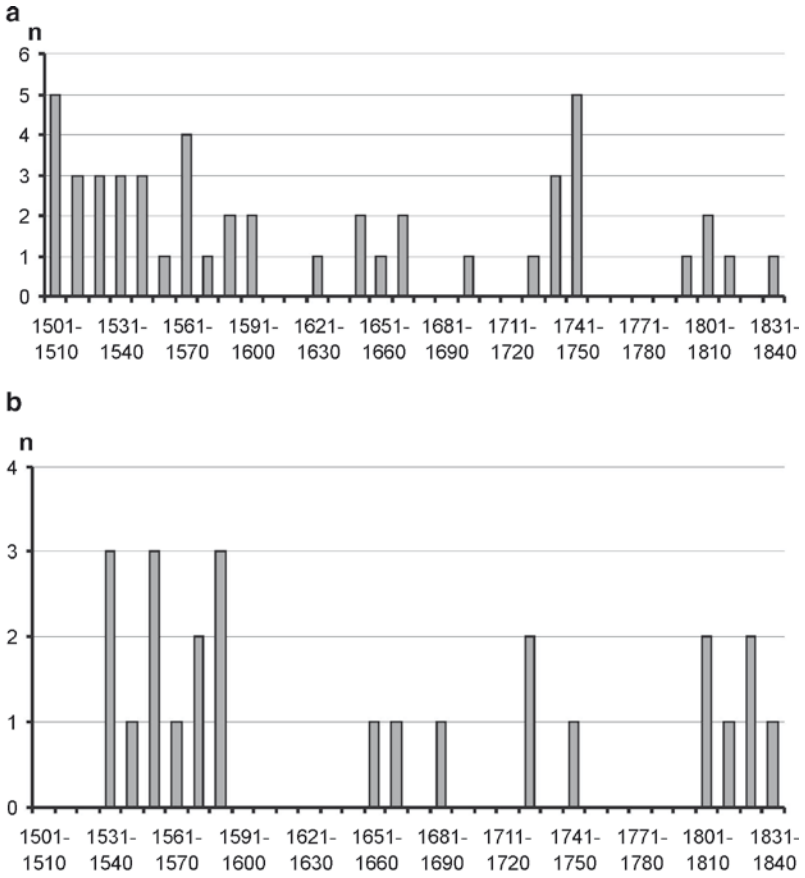

Fig. 6.2 Decadal frequencies (n) of occurrence of summers (Jun–Aug): (**a**) extreme wet and very wet and (**b**) extreme dry and very dry (after Przybylak et al. 2004)

to the reconstruction by Maruszczak (1991), poorer than average in terms of precipitation. However at least the first two decades of that period probably had standard annual precipitation, which was higher in summer and lower in winter than in the modern period (see Fig. 21.14 in Przybylak and Marciniak 2009, this volume). High values of precipitation in June and July in that period were discovered in the precipitation reconstruction carried out on the basis of dendrochronological data (see Fig. 2 in Przybylak et al. 2001). From the eighteenth century precipitation totals were near the norm, except for the turn of the eighteenth and nineteenth centuries, when there was less precipitation (Maruszczak 1991). The results obtained by Przybylak et al. (2004) confirm this in principle, with the exception of the period 1731–1750, which was most probably more wet than the norm (Fig. 6.2). Generally, similar results for the Tatra Mountains (in the southern part of Poland) were found by Kotarba (2004). Reconstructions of the sums of summer and winter precipitation for the Czech Republic (see for instance Fig. 2 in Brázdil 1994) are similar to those obtained for Poland (Table 1 and Fig. 4 in Przybylak et al. 2004).

6.4 Conclusions

1. The existing, incomplete and not fully credible reconstructions of the Polish climate in the last millennium indicate that the first 500 years (and particularly the first 300 years) were warmer than the latter 500 years. Mainly winters were warmer, whereas summers could be even cooler, if we assume the indicator to be the frequency of the occurrence of hot summers (see Fig. 1 in Sadowski 1991). Therefore the first 300–400 years of the millennium was a period of a high (indeed according to Sadowski [1991] the highest) degree of oceanism on the Polish climate. In Polish climate history we can therefore distinguish a so-called Medieval Warm Period, which most probably lasted until the beginning of the fourteenth century (according to Maruszczak 1991) or until the beginning of the fifteenth century (according to Sadowski 1991). Air temperature was then most probably higher on average by about 0.5°C–1.0°C.
2. Beginning from the fifteenth century the degree of continentality of the climate remains at a high level until the beginning of the nineteenth century. As a result winters were colder by about 1.5°C to 3.0°C in comparison with modern conditions, while summers were warmer by an average of about 0.5°C. Mean annual air and ground surface temperatures were probably lower than modern ones by about 0.9°C–1.5°C. A so-called Little Ice Age can be distinguished here, which clearly began around the mid-sixteenth century and probably ended in the second half of the nineteenth century.
3. The reconstruction of precipitation (the most variable meteorological element in time and space) is much more uncertain than is the reconstruction of air temperature. There was probably higher than average precipitation in the twelfth century (and particularly from 1151 to 1200), in the first half of the sixteenth century and also in the first half of the eighteenth century. The second half of thirteenth

century and the first half of nineteenth century were drier than average. In other periods precipitation conditions were close to average.

4. The above brief synthesis of information on the history of the climate of Poland in the last millennium confirms the veracity of the earlier thesis that, despite the advances in research which took place in the past 20 to 30 years, our knowledge of this subject remains both insufficient and uncertain.

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