

Chapter 3

Climatic Variations in the East European Plain During the Last Millennium: State of the Art

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3.1 Introduction: Climate of the East European Plain

East European (Russian) Plain is located in the high to mid latitudes between the Arctic Ocean in the north, Black and Caspian Seas in the south, and from the Polish/Ukraine frontier in the west and the western slope of to the Urals Mountains in the east (Fig. 3.1). The radiation balance in winter is negative at the whole East European Plain except for the most southern territories, while in summer it is positive everywhere. The climate is mostly influenced by the Westerlies. The air masses from the Atlantic in winter bring warmth and precipitation, in summer they are responsible for the cool and wet weather conditions. Moving to the east the air masses become drier – warmer in summer and colder in winter (Shahgedanova 2002).

Because the warm weather in winter is caused by the Atlantic cyclones coming from the west, the spatial contrasts in winter climate is smaller in the north-south comparatively to the east-west direction. In the northern part of the East European Plain the mean January temperature varies from -10°C to -20°C from west to east, in the southern part – from $+5^{\circ}\text{C}$ to -15°C changing in the same direction. The summer temperature depends mainly on solar radiation, therefore the summer isotherms almost correspond to the parallels. Mean July temperature is $+8^{\circ}\text{C}$ at the far north and $+24^{\circ}\text{C}$ in near Caspian region.

Precipitation distribution depends mainly on the atmospheric circulation patterns. The Westerlies bringing high cloudiness and precipitation are complimented by the high frequency of cyclones of the Arctic and the Polar Fronts. The cyclones are most frequent between 55°N and 60°N where the annual precipitation is up to 600–700 mm in the west and 500–600 mm in the east of the Plain. To the east the frequency of anticyclones increases. The air masses are losing their humidity here

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Fig. 3.1 East European Plain. The sites indicated are mentioned in the text. The numbers are: (1) Polovetsko-Kupanskoye peat bog, Yaroslavskaia oblast'; (2) Polistovo, Pskovskaia oblast'; (3) Panfilovo, Vladimirskaya oblast'; (4) Karelia; (5) Belorus'; (6) Nigula, SW Estonia; (7) Usvitsky Mokh, Tverskaya oblast'; (8) Saki Lake, Crimea; (9) Pertozero, S. Karelia

and the precipitation in the southern part of the East European Plain is lower (500–300 mm, down to 200 mm per year). Precipitation in summer is caused by the circulation at the Arctic and temperate fronts while only 10% of precipitation are associated with the inner mass processes. The precipitation/evaporation ratio is positive (+200 mm) in the north, close to zero in the area of the issues of the Don and Dniester rivers, and negative to the south (the deficit is up to 700 mm).

Alisov (1969) subdivided the territory of the East European Plain into three climatic areas. This division is still valid despite of the half century time passed since Alisov's work. The regions are: (1) Northern Atlantic-Arctic area (southern boundary located between the Ladoga and Pechora river issues). (2) Middle Atlantic-continental area (southern boundary from the mid flow of the Dniester to the mid Volga) (3) Southern continental area. The areas are also subdivided into the western and eastern sub-areas with the boundary running from the Severnaya Dvina to the Volga issues and Dnieper mouth. The climate is mirrored by the vegetation and soil zones. The major zones represented at the East European Plain are tundra, forest-tundra, forest, forest-steppe, semi desert and desert.

In this paper we briefly overview the data on long instrumental series of meteorological records, historical, tree ring, palynological records and the results of multi proxy reconstructions of the mean annual, summer, winter temperatures and annual precipitation in the European Plain for the last millennium published in the scientific literature both international and Russian.

3.2 Materials and Methods

The details on the methodology of proxy-based reconstructions can be find elsewhere (e.g. Bradley 1999; Jones and Mann 2004), therefore we do not describe it here unless these details are necessary to explain the discrepancies between the results obtained by different researchers or the methodology of the reconstructions substantially differs from the standard one.

Longest instrumental records in the Eastern Europe go back to the mid eighteenth century (Table 3.1). The long instrumental meteorological series provided here are from the data bank VNIIGMI-MTSD (<http://www.meteo.ru/data/mdata.htm>) as well as from the earlier records revised and summarized by Gazina and Klimenko (2008). The long term trends of temperature and precipitation variations in the East European Plain were revised from time to time (e.g. Veyeikov 1892, 1907; Gruza et al. 1977; Gazina and Klimenko 2008) using the long instrumental time series and taking into account the new portions of records. In the most recent comprehensive summary of climatic variations in the Russian Federation the basic period used is 1936–2006 (Meleshko 2008).

Various types of historical records are available in the East European Plain for the last millennium, including historical chronicles, letters, notes of travelers, merchants etc. The oldest historical chronicle was initiated during the time of Prince Yaroslav the Wise in Kiev in AD 1037–1038 (Likhachev 1947) though the earliest record of unusual climatic events dates back to the earlier time (year AD 867) (Rybakov 1963). The registration of climatic events in the Russian Plain became systematic from the fourteenth century. Climatically significant data was extracted from these records and analysed by a number of researchers such as Bogolepov (1907, 1912), Berg (1911), Buchinsky (1957), Betin and Preobrazhensky (1962) and many others. The most comprehensive compilations belong to Borisenkov

Table 3.1 List of the longest meteorological records (stations) at the East European Plain

No	Meteorological station	Latitude (N)	Longitude (E)	Beginning of records
1	St-Petersburg	59.97	30.30	1743
2	Vilnius	54.63	25.28	1777
3	Moscow	55.75	37.57	1779
4	Riga	56.97	24.70	1795
5	Tallinn	59.42	24.80	1811
6	Kiev	50.40	30.45	1811
7	Kazan	55.78	49.18	1812
8	Arkhangel'sk	64.58	40.50	1813
9	Petrozavodsk	61.82	34.27	1816
10	Syktvykar	61.67	50.85	1817
11	Odessa	46.48	30.63	1821
12	Simferopol'	45.02	33.98	1821
13	L'vov	49.82	23.95	1824
14	Kishinev	47.02	28.87	1825
15	Orenburg	51.75	55.10	1832
16	Saratov	51.57	46.03	1836
17	Astrakhan'	46.27	48.03	1837
18	Tambov	52.73	41.47	1845
19	Fort Shevchenko	44.55	50.25	1848
20	Minsk	53.87	27.53	1849
21	Kaliningrad	54.70	20.62	1851

and Pasetsky (1988, 2003). They are based on the 37 volumes of “Complete Selection of Russian Chronicles” and also include the data from other historical sources. In Section 3.4 we summarize the results of these studies.

Several researchers attempted to quantify the historical information on climatic changes in the East European Plain in the last millennium (Lyakhov 1984; Zolotokrilin et al. 1986; Zolotokrilin and Popova 1988; Voronov 1992; Klige et al. 1993; Krenke and Chernavskaya 1998). Lyakhov (1984) qualified as temperature and precipitation anomalies as those which exceed the half of the amplitude of the observed fluctuations. The correlation of the number of these cases and the mean values of temperature averaged for 30 years periods allowed the quantification of the historical records for 30-years mean periods.

Voronov (1992) and Klige et al. (1993) used a similar approach. However instead of the absolute numbers of anomalies these authors used their normalized values (i.e. the number of extreme events divided to the total number of the recorded events). They also made corrections for the decrease of the density of historical data back in time suggesting that the total number of events should be constant through the time. According to Klige et al. (1993) the coefficients of correlation of the 30-year averaged extremes with the mean monthly temperatures and sum of precipitation for the longest meteorological records (Sankt-Petersburg, Moscow, Kiev, Riga) for four regions (respectively NW, Central, SW, W) are high enough ($r = 0.80-0.85$) to allow the reconstructions. The mean statistical error of the

reconstructions is estimated as $\pm 0.2^{\circ}\text{C}$ for the temperature and ± 20 mm for precipitation. However Klige et al. (1993) warned that a degree of uncertainty of these reconstructions related to the specific data source as well as to the approach itself based on several assumptions is still rather high.

High resolution reconstructions based on the tree-ring data are not sufficiently long in the East European Plain to cover the whole millennium. Most tree-ring time series constructed for the East European Plain before 1990s were not quality controlled. The common practice to apply the running means for the detrending eliminating the long-term trends does not allow the use of most of old series for the climatic analyses. The archeological wood covering the last millennium in the Arkhangelskaya, Tverskaya, Novgorodskaya oblast' and some other regions although successfully cross-dated within individual archeological sites (basing on the historical dates of churches) was not aggregated into chronologies and used for the climatic reconstructions except for some rare cases (Chernikh 1996; Pushin et al. 2004).

In the last decades new high quality tree-ring based reconstructions 300–400 years long for the East European Plain were published (Schweingruber and Briffa 1996; Vaganov et al. 1996; Briffa et al. 2001) Schweingruber and Briffa (1996) analysed the coherency of ring width and density records along the northern tree line and found out that the spruce and larch chronologies in the Sub-Arctic of North Eurasia react similarly to the environmental factors. Both ring width and maximum density chronologies represent well the fluctuations of several decades, but the density chronologies show better the high frequency fluctuations. There is a clear coherency between all chronologies from 42°E to 152°E , although a certain growth (density) patterns vary in different regions. The general coherency of the records allowed Briffa et al. (2001) to average the individual chronologies in three sectors in the Northern Eurasia North of Europe (NEUR), North of Siberia and East of Siberia. All these series were correlated against the instrumental data (mean monthly temperature for April–September, anomalies from 1961–1990) produced from the grid box instrumental surface anomalies. The correlation of the series with the temperature is generally very high ($r = 0.76$ for the NEUR series). However the Northern European regional chronology includes as well the chronologies from Sweden, Finland and other northern territories outside the East European Plain, therefore it is not fully applicable here. In general tree-ring based reconstructions represent one of the best source of climatic information at the northern tree line of the East European Plain for the last four to five centuries due to their high resolution, good replication of chronologies, and high correlation of tree-ring parameters to the climatic variations. The records are available at <http://www.ncdc.noaa.gov/paleo/treering.html>.

Longer chronologies exist only in the mountain areas surrounding the East European Plain. Those from the Polar Urals and Khibiny Mts are temperature sensitive. For the Polar Urals Mountains Shiyatov (1986) reconstructed the May–September temperature from AD 914 to 1990. The reconstruction accounts for 66–70% of summer temperature variance (Briffa et al. 1995). The millennium long reconstructions based on ring width, density and stable isotopes in the Khibiny Mts are under way (Boettger et al. 2004). MacDonald et al. (2007) used tree rings chronologies and Palmer Drought Sensitivity Index for the river discharge reconstructions for the period

AD 1800–1990 for the S.Dvina, Pechora, Ob', Yenisey, Lena and Kolyma Rivers. The dendrohydrologic models explain up to 55% (the Pechora) of the observed variability of flow. The drought sensitive chronology in the Crimea was used for the reconstruction of the spring-early summer precipitation by Solomina et al. (2005).

The wood macrofossils can be useful to estimate the long-term temperature trends, which are not preserved in the ring properties alone. This kind of data is available for the Polar Urals (Shiyatov 2000) and the Khibiny Mountains (Hiller et al. 2001).

Another way to estimate the low frequency temperature variability is the borehole temperature measurements. More than 1,400 sites of heat flux measurements in the Former Soviet Union were catalogued, although most of the sites are located in the Urals and Siberia. After a quality control of these data Pollack et al. (2003) included only four sites from the European Russia in their reconstruction of the surface temperature trends based on borehole data <http://www.ncdc.noaa.gov/paleo/borehole/core.html>. The Urals' data set is much more comprehensive and suitable for the regional reconstructions (Demezhko et al. 2003).

Palynological records are numerous in the Russian Plain, though they normally are poorly constrained by the radiocarbon dates, which precludes the possibility of high resolution reconstructions. However they are suitable to estimate the multidecadal variations of the last one to two millennia. Detailed palynological reconstructions in the East European Plain used in this paper are listed in Table 3.2.

In palynological reconstructions, cited in this paper, a statistical approach, which allows the transformation of the palynological parameters into the numerical climatological format developed by Klimanov (1989) was used. This approach takes into account the relation between subfossil spectra and modern climatic conditions. The resolution of these reconstructions is limited by the accuracy of the radiocarbon dates and is sometimes less than a century. However in case of high and regular peat accumulation the reconstructions can reach a multidecadal resolution and therefore these reconstructions can be compatible with the long instrumental data (Klimanov and Nikiforova 1982; Klimenko et al. 2001). Summer, annual and winter temperature and annual precipitation can be reconstructed this way though with different degree of reliability which is higher in case of parameters related to the growth season. The mean error estimate for the mean annual temperature reconstruction and for the mean July temperature is $\pm 0.6^{\circ}\text{C}$, for mean January temperature is $\pm 1^{\circ}\text{C}$, and for annual precipitation is ± 25 mm (Klimanov 1989).

One of the most detailed palaeoclimatic reconstruction is based on the Usviatsky Mokh (UM) site (Klimenko et al. 2001) (see Fig. 3.1). The peat sediments were recovered from the section up to 80 cm depth with the resolution of 1 cm, and further down to 2 m depth cored using a TBO borer and sampled each 2.5 cm. Thus 128 samples in total were collected and palynologically analysed. The age of sediments was constrained by 20 radiocarbon dates (from 170 to 4630 ^{14}C years). Due to the detailed sampling Klimenko et al. (2001) were able to distinguish in these records 35 periods of warming/cooling during the last ca 600 years. The high resolution of the palynological records in the last 600 years and very high rate of peat accumulation (1.3 mm per year) in UM allows a direct comparison and calibration of palynological data with temperature records which are more than 200 years long in this area. The deeper layers (older than 600 years) allow only a lower resolution (see Section 3.7).

Table 3.2 Most detailed palynological records in the European part of the FSU

Region	Period	Climatic parameter reconstructed	Reference
NW of Russia (Leningradskaya and Novgorodskaya oblast' (58–61°N, 30–31°E)	Last 13,000 years	Mean annual temperature	Arslanov et al. (1999)
Polovetsko-Kupanskoye peat bog, Yaroslavskaia oblast' (57°N, 39°E)	AD 250–1950	Mean annual, summer, winter temperatures and mean annual precipitation	Klimanov et al. (1995)
Polistovo (Pskovskaya oblast') (56.8° N, 30.1°E)	AD 500–1950	Mean annual temperature	Chernavskaya (1995)
Panfilovo (Vladimirskaia oblast') (55.7°N, 40.5°E)	AD 500–1950	Mean annual temperature	Chernavskaya (1995)
Karelia (63°N, 34°E)	Last 11,000 years	Mean annual, summer, winter temperatures and mean annual precipitation	Klimanov (1994)
Belorus' (54°N, 27°E)	Last 13,000 years	Mean annual, summer, winter temperatures and mean annual precipitation	Klimanov (1994)
Nigula, SW Estonia, юго-запад (59°N, 26°E)	Last 2,000 years	Mean annual and summer temperatures and mean annual precipitation	Klimanov et al. (1985)
Northern Near Black Sea Region	Last 8,000 years	Temperature of January, July and annual precipitation	Kremenetsky (1991)

There were several attempts to compare the results of different proxies, but most of them were qualitative and descriptive (e.g. Krenke 1995). Slepsov (2002) and Klimenko and Slepsov (2003) produced the first quantitative multi-proxy temperature and precipitation reconstructions for the East European Plain for the last one to two millennia. The temperature reconstruction is based on eleven time series of palynological, historical and dendrochronological data mostly from the central and northern parts of the East European Plain (Table 3.3). As soon as the borehole data are of too low resolution this type of records was not included in the reconstruction. In total for the annual temperature reconstruction Klimenko and Slepsov (2003) possess a data set consisting of 374 points unevenly distributed in time from AD 15 to 1995. For the mean annual precipitation reconstruction they selected six most relevant sources (284 points for the period from AD 305 to 1995 (Table 3.4). Data sets for summer and winter temperatures consist of 388 and 293 points respectively from AD 350 to 1995.

The authors of this reconstruction used two approaches to deal with the initial data sets (see details in Klimenko et al. 2001): (1) Methods of correlations and spectral analyses and the algorithm of numerical filtration, taking into account the stochastic

Table 3.3 Time series used for the multi-proxy mean annual temperature reconstruction

	Site	Type of data	Weight	Reference
1	Usviatsky Mokh, Tverskaya oblast' (56°N, 32°E)	Palynology	1.0	Klimenko et al. (2001)
2	NW of Russia (58–61°N, 30–31°E)	Palynology	1.0	Arslanov et al. (1999)
3	Polovetsko-Kupanskoye, Yaroslavskaya Oblast' (57°N, 39°E)	Palynology	0.5	Klimanov et al. (1995)
4	Panfilovo (55.7°N, 40.5°E)	Palynology	0.5	Chernavskaya (1995)
5	Polystovo (56.8°N, 30.1°E)	Palynology	0.5	Chernavskaya (1995)
6	Center of East European Plain	Historical	1.0	Klige et al. (1993)
7	Center of East European Plain	Historical	1.0	Lyakhov (1984)
8	NW of East European Plain	Historical	0.25	Klige et al. (1993)
9	W of East European Plain	Historical	0.25	Klige et al. (1993)
10	SW of East European Plain	Historical	0.25	Klige et al. (1993)
11	Northern Eurasia	Dendrochronology	0.5	Lovelius (1979)

Table 3.4 Time series used for the multi-proxy of annual precipitation reconstruction

No	Site	Type of data	Weight	Reference
1	Usviatsky Mokh (56°N, 32°E)	Palynology	1.0	Klimenko et al. (2001)
2	Polovetsko-Kupanskoye, Yaroslavskaya Oblast' (57°N, 39°E)	Palynology	0.5	Klimanov et al. (1995)
3	Center of East European Plain	Historical	1.0	Klige et al. (1993)
4	NW of East European Plain	Historical	0.25	Klige et al. (1993)
5	W of East European Plain	Historical	0.25	Klige et al. (1993)
6	Pertozero	Hydrological	0.5	Schostakovich (1934)

nature of discretisation. (2) The program of nonparametric regression using the expert estimates of the weight of each record. These estimates are based on the detalization, accuracy, potential biases of the series which were estimated by the disagreement of each record with other series. The series reconstructed using the two approaches agrees well and also are significantly correlated with the long instrumental data (average for Sankt-Petersburg, Moscow, Riga, and Vilnius) ($r = 0.79$). The method 1 is however resulted in a less detailed curve losing the high frequency variations. Therefore the final reconstruction is based on the method 2 (see also Section 3.9). The accuracy of the reconstruction is estimated as $\pm 0.2^\circ\text{C}$. The same approach was used to reconstruct annual precipitation (see Table 3.4). The correlation coefficient between the instrumental data of precipitation and the reconstructed values is 0.57.

3.3 Instrumental Data

In this section we discuss the long-term trends of annual temperature and precipitation and their spatial coherency within the East European Plain recorded at the meteorological stations with the longest records.

3.3.1 Mean Annual Temperature

Gazina and Klimenko (2008) analysed the winter, summer and annual temperature variations (Fig. 3.2) at four longest meteorological stations in the Eastern Europe which possess minimum or no gaps (St-Petersburg, Vilnius, Moscow and Riga). The upward trend in the annual temperature can be seen in Moscow records since 1870s. At the three other stations the warming began much later – only in 1960s–1970s.

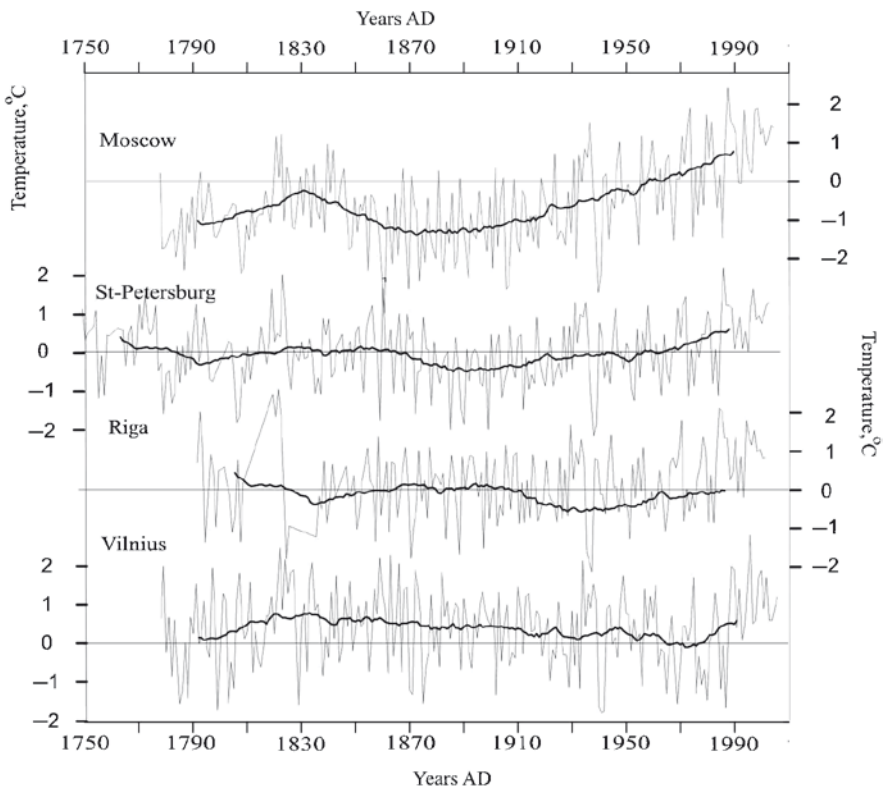


Fig. 3.2 Mean annual temperature anomalies from 1951 to 1980 mean at St-Petersburg, Moscow, Vilnius and Riga (annual and 30-year running means)

Gazina and Klimenko (2008) found out that during the last two centuries the winter temperature significantly increased (up to 3°C) at all four stations, while the summer temperature slightly decreased. This finding contrasts with the Western Europe, where the warming both in winter and summer are recorded (IPCC 2007).

The temperature records from all four meteorological stations are significantly correlated (r from 0.64 to 0.86). According to this data the major coolings in the northern and central regions of the East European Plain occurred in 1760s, 1780s, 1810s, 1940s; warmings date back to 1770s, 1820s, 1930s and 1990s. The mean annual temperature in the 1990s and 2000s only slightly exceeded the thermal maximum of the 1820s.

A century long records (1890–1990) provide an opportunity to assess the agreement between the temperature changes in the different regions of the East European Plain (Fig. 3.3). Generally interannual to decadal variations occur simultaneously in these regions, though the similarity of the southern curve with the two others is lower ($r = 0.66$). Gruza et al. (1977) analysed the spatial variability of temperature and precipitation in the Former Soviet Union and concluded that the temperature anomalies in the center and the periphery of the East European Plain correlate for all months. Instrumental data show that in general the temperature variations in the East European Plain are similar to those in Central Europe (Gazina and Klimenko 2008).

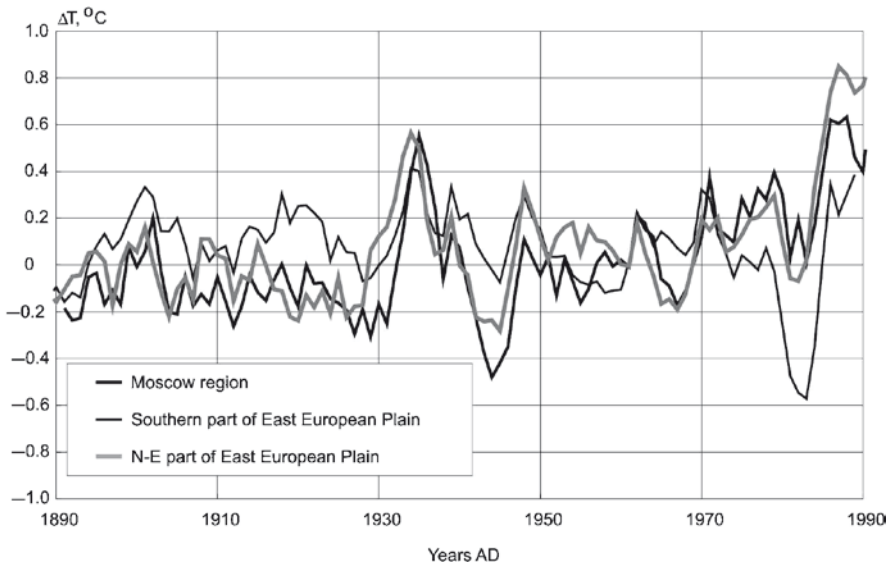


Fig. 3.3 11-years running mean of instrumental annual temperature anomalies from 1951 to 1980 mean for Moscow, NW part of the East European Plain (St-Petersburg, Riga, Vilnius), and SW part of the East European Plain (Kiev, Simferopol', Odessa)

3.3.2 *Annual Precipitation*

In general precipitation is much more variable in different regions in the East European Plain, however some anomalies occur simultaneously in the whole region. The annual precipitation in northern (St-Petersburg) and central (Moscow) parts of the Plain on one hand and southern stations (Kiev and Odessa) on the other are poorly correlated ($r = 0.21$). The difference between the north and south is quite large for both interannual variability and long-term trends. The increase in annual precipitation over the last 150 years is significant both in Moscow and St-Petersburg, but the trend is insignificant in the southern regions. The most prominent increase of annual precipitation in the East European Plain begun in the last decades (1976–2006) (Meleshko 2008).

3.4 Historical Data

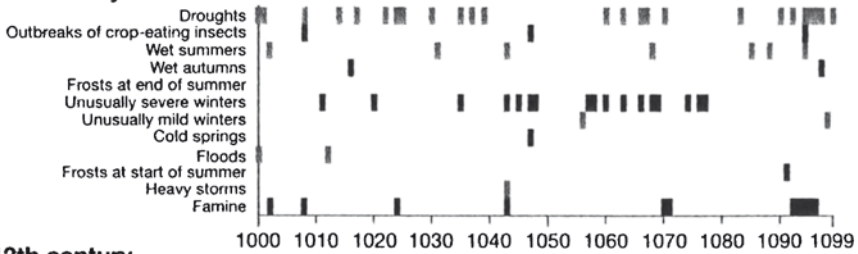
3.4.1 *Documentary Evidence of Climate Changes in the East European Plain*

Figure 3.4 compiled by Shahgedanova (2002) from the data of Borisenkov and Pasetsky (1988) presents the occurrence of extreme droughts, outbreaks of crop-eating insects, wet summers and autumns, frosts in the early and late summers, unusually wet and dry winters, cold springs, floods, heavy storms and famines. The number of extremes is gradually increased from the second half of twelfth century. The tendency continued into the early thirteenth century: in 1200–1220s the highest number (seven) of cold winters were recorded, whereas in the next 20 years, in contrast, the unusually warm winters (five) prevailed. Such conditions led to the severe famine recorded in the chronicles (Bozheryanov 1907; Likhachev 1947). In AD 1230 there was a total crop failure at the whole Russian territory – one of about ten events of the same magnitude recorded in the whole historical period (Slovtsov 1858).

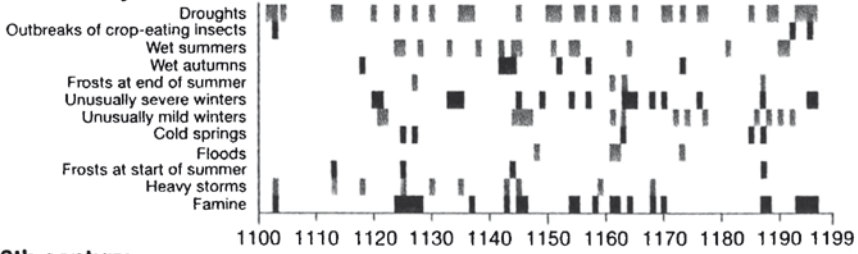
The decades of the 1230s and 1240s were mild and no extreme weather events were recorded. In the last quarter of the thirteenth and the early fourteenth centuries the chronicles mention more often the “great storms” and unusual floods, dry summers would follow the rainy warm seasons. The decades of the 1340s and 1350s were relatively stable in terms of climate: except for four “great storms” no other extreme are mentioned at that time. The last 40 years of this century were very dry: 11 dry years were recorded which resulted in the fully dried rivers, forest and peat bogs fires. At the same time the number of cold winters, early frosts and late springs increased. In total in the fourteenth century the chronicles recorded more than 100 extreme events and 30 years of famine.

In the fifteenth century the number of extremes further increased up to 150 events, though most of them were regional. Heavy rains and severe droughts, cold winters and cool summers resulted in more than 40 years of famine, 15 of them were

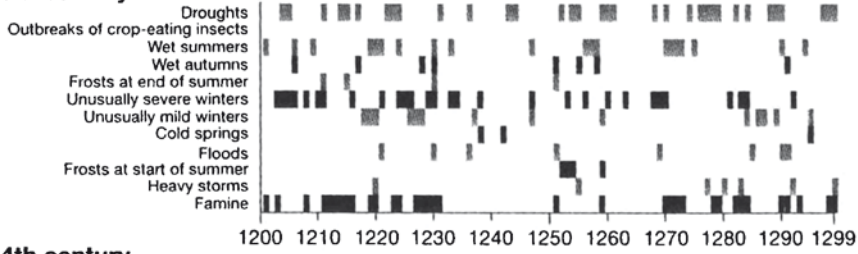
11th century



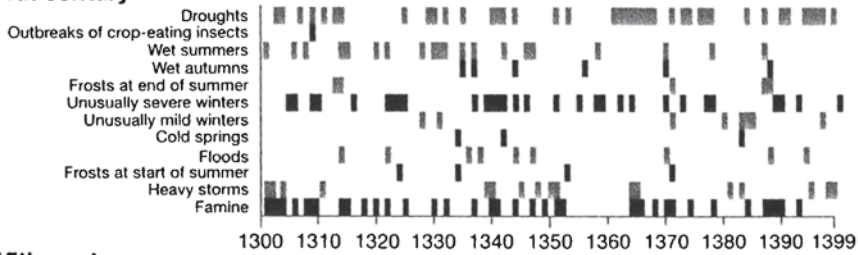
12th century



13th century



14th century



15th century

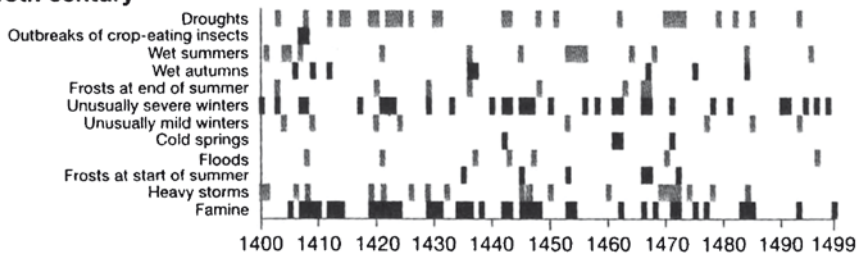


Fig. 3.4 Number of climatic extremes (occurrence of extreme droughts, outbreaks of crop-eating insects, wet summers and autumns, frosts at the beginning and ends of summers, unusually wet and dry winters, cold springs, floods, heavy storms and famines) in the East European Plain compiled by Shahgedanova using the data of Borisenkov and Pasetsky (1988, 2003) (From Shahgedanova 2002)

extremely hard. The decades of the 1440s and 1450s were extreme in terms of frequency of severe winters.

In the second half of the sixteenth century and in the early seventeenth century the climate in the East European Plain was very variable: the number of severe winters increased as well as the occurrence of cold summers. The frosts and long heavy rains in summer 1601 in combination with the winter conditions unfavorable for agriculture resulted in a very severe famine in 1601–1603. The early eighteenth century in general was rather mild – the extremes were not numerous. This information agrees with the data on favorable conditions for the marine travels in the Arctic seas. In the second quarter of the seventeenth century the Russian seafarers reached Chukotka and passed through Bering Strait.

The climate in the second half of the seventeenth century was very variable. Between years 1640 and 1659 eleven summers were extremely dry. On the other hand the anomalously rainy summers with frosts in the early and late summers were also recorded.

In the eighteenth century 39 years were extremely dry, 19 years extremely rainy, 36 had very severe winters, 22 – mild winters, 33 – high floods and 22 – “great storms”; more often than before the frosts were recorded in the late summers and cold springs. These climatic conditions led to 68 extremely famine years in the eighteenth century (including those of the very poor crops in the whole Russia in 1716 and 1722).

In the beginning of the nineteenth century the severity of winters was still high and mild winters were rare. The droughts were still often, but they occurred mostly locally. The lowest number of extremes were recorded between 1800 and 1820 and between 1860 and 1900.

3.4.2 Quantitative Estimate of Climate Changes in the East European Plain Using Historical Data

Figures 3.5, 3.6, 3.7, and 3.8 display the results of the reconstructions of 30-years anomalies of annual, summer, winter temperatures and annual precipitation for various regions of the East European Plain from Voronov (1992), Klige et al. (1993), and Lyakhov (1984). According to historical data (Borisenkov and Pasetky 1988; Voronov 1992; Klige et al. 1993) the annual temperature was changing relatively synchronously in the western, south-western, north-western and central regions of the East European Plain (see Fig. 3.5). This conclusion corresponds to the results obtained from the long instrumental records in the nineteenth to twentieth centuries (see Section 3.3, Fig. 3.3). The late twelfth and late fourteenth centuries were the warmest within the twelfth to nineteenth century period, whereas the early fifteenth and the whole nineteenth centuries were the coldest. The precipitation variations are more regionally variable with the most humid conditions in all regions in the fifteenth to the early sixteenth centuries (see Fig. 3.6). Some discrepancies noticeable in different reconstructions are discussed in Section 3.10.

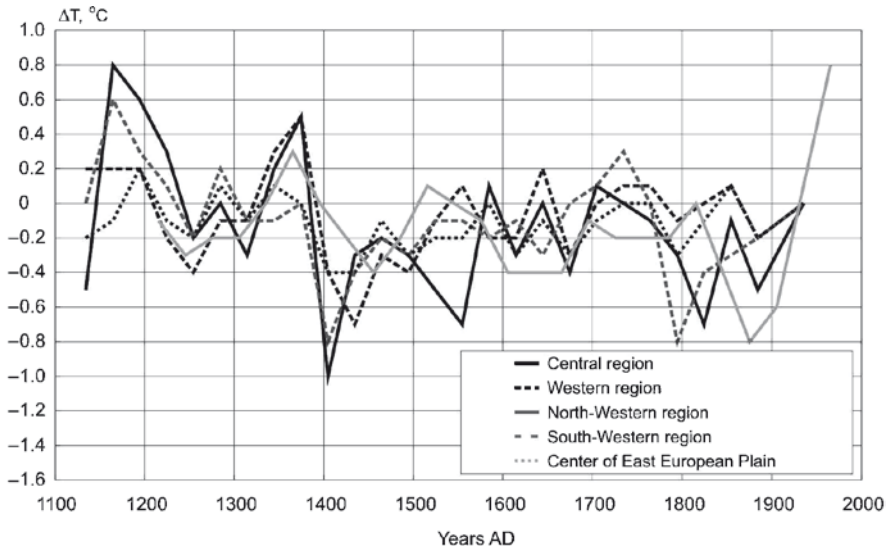


Fig. 3.5 Mean annual temperature anomalies in the center of the East European Plain (deviations from 1890 to 1950 mean) based on historical records (Lyakhov 1984; Klige et al. 1993)

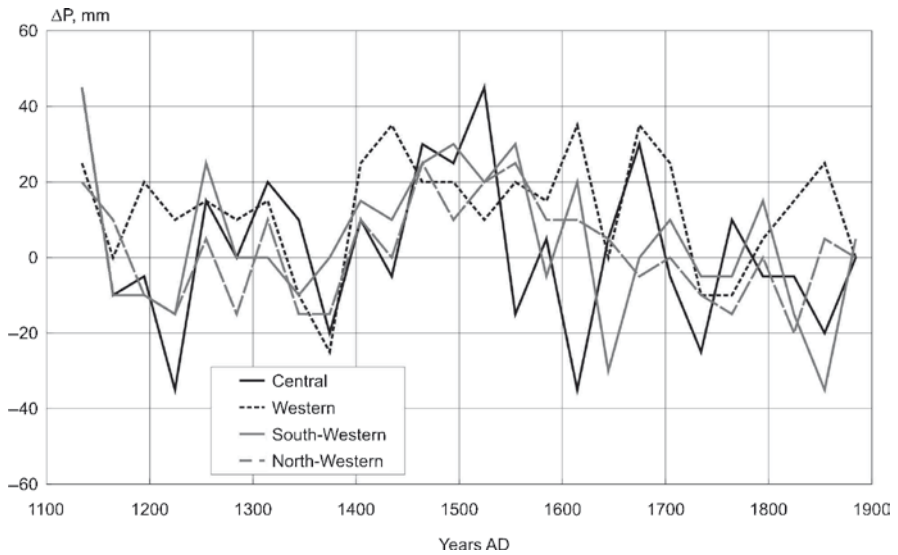


Fig. 3.6 Mean annual precipitation anomalies (deviations from 1890–1950 mean) based on historical records (Klige et al. 1993)

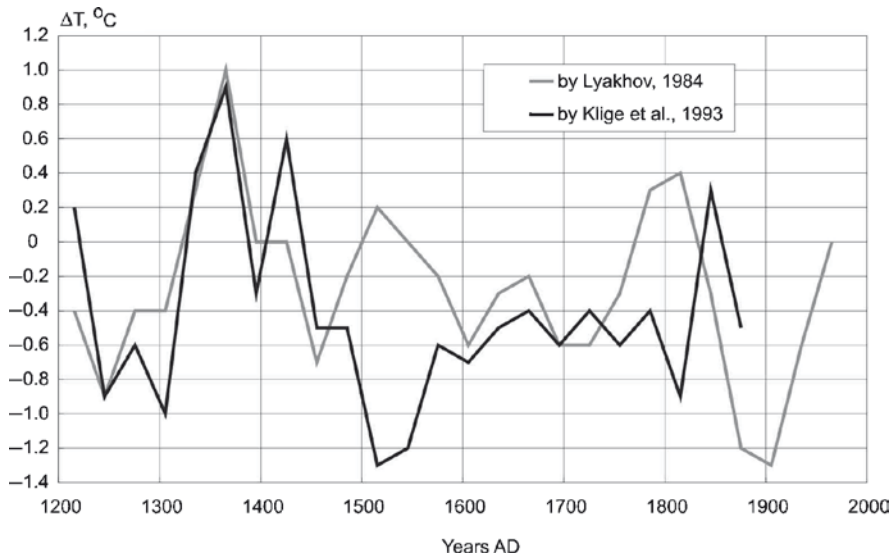


Fig. 3.7 Summer temperature anomalies in the center of the East European Plain (deviations from 1890 to 1950 mean) based on historical records (Lyakhov 1984; Klige et al. 1993)

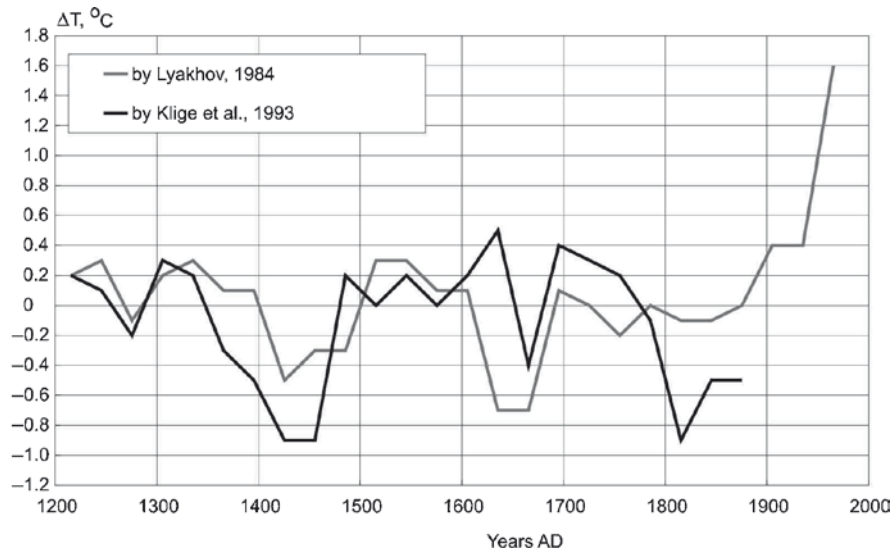


Fig. 3.8 Winter temperature anomalies (deviations from 1890 to 1950 mean) based on historical records (Lyakhov 1984; Klige et al. 1993)

3.5 Tree-Ring Data

3.5.1 Summer Temperature Reconstructions

In the Fig. 3.9 the spatial pattern of maximum density in the Northern part of East European Plain (smoothed by decades) is displayed (Schweingruber and Briffa 1996). Two major large-scale events are evident over the whole profile – the twentieth century warming and extremely cold period in the first half of the seventeenth century. The second decade and the mid nineteenth century were also very cold in the north of the Russian Plain, whereas in the eighteenth century the climate was, on the contrary, rather warm. The short-term coolings in the chronologies – sharp decrease of ring width/density for one to three years (not shown in the Fig. 3.9, where smoothed values are presented) are normally forced by climatically effective volcanic eruptions and they occur simultaneously along the whole profile at the northern tree line (Briffa et al. 2004).

In the mountains of the Urals and Kola Peninsula the reconstructions based on the ring width agrees reasonably well with the upper timberline variations. Both types of records in the Urals show the warming from the ninth to thirteenth centuries (Shiyatov 1986, 2000). At the end of the thirteenth century the degradation of larch forests has begun: this climate deterioration lasted until the early twentieth century. In the Kola Peninsula the warming from ca AD 600 to 1200 was documented by wood macrofossils found beyond the present upper tree limit (Hiller et al. 2001).

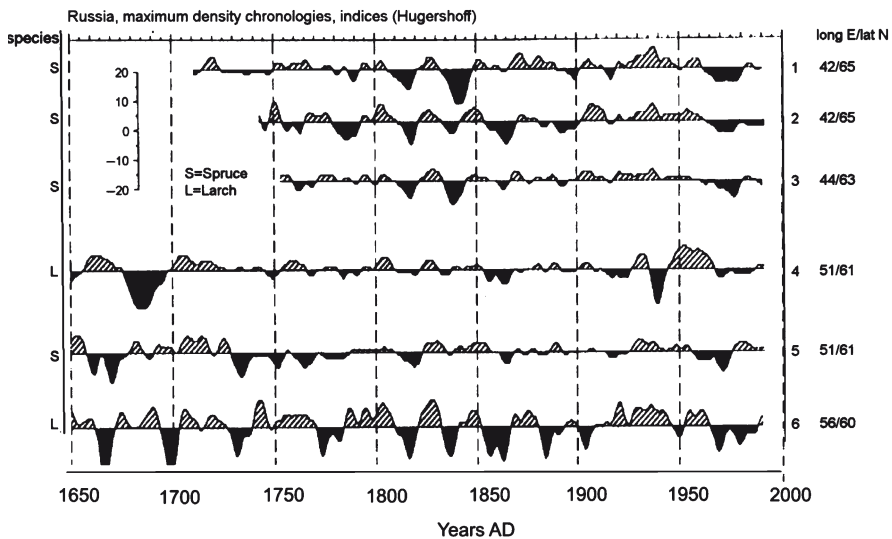


Fig. 3.9 Tree ring maximum density chronologies at the Northern tree line in the East European Plain and adjacent regions (Schweingruber and Briffa 1996). Species: S – spruce, L – larch

3.5.2 Precipitation and Runoff Reconstructions

Due to rare occurrence of trees sensitive to humidity suitable for reconstructions we are not aware of any quantitative tree-ring based reconstructions in the East European Plain. Solomina et al. (2005) reconstructed April–July precipitation using *Pinus hamata* ring width (1620–2002) in the Crimea (Fig. 3.10). Most droughts recorded in historical documents in the seventeenth to nineteenth centuries in the Crimea and Southern Russia (e.g. in 1687, 1833–1834, 1845, 1881–1882) coincide with below-average reconstructed precipitation in the concurrent or following year, however the extremely wet summers recorded in the historical documents are not as well captured by the reconstruction. The reconstruction captures two periods of large variability in April–July precipitation: in the 1650s–1720s and 1820–1920s. The earlier period coincides with the Maunder Minimum period, which was cold over much of Europe (Luterbacher et al. 2001; Luterbacher et al. 2004; Xoplaki et al. 2005). The reconstruction also shows two periods of moderate values during much of the eighteenth and the twentieth centuries (after the 1920s).

Tree-ring based discharge reconstructions of the Northern Dvina and the Pechora Rivers for the period AD 1800–1990 indicate that there is no long-term monotonic trend toward higher discharge over the past 200 years. Reconstructed annual discharge for the individual rivers and the total discharge from all the rivers experienced in the twentieth century are within the bounds of natural variability experienced over the past 200 years. The Northern Dvina and the Pechora reconstructions display significant multidecadal variability in discharge (30–60 years) similar to that observed in the North Atlantic, North Pacific, and Northern Hemisphere climatic parameters (MacDonald et al. 2007).

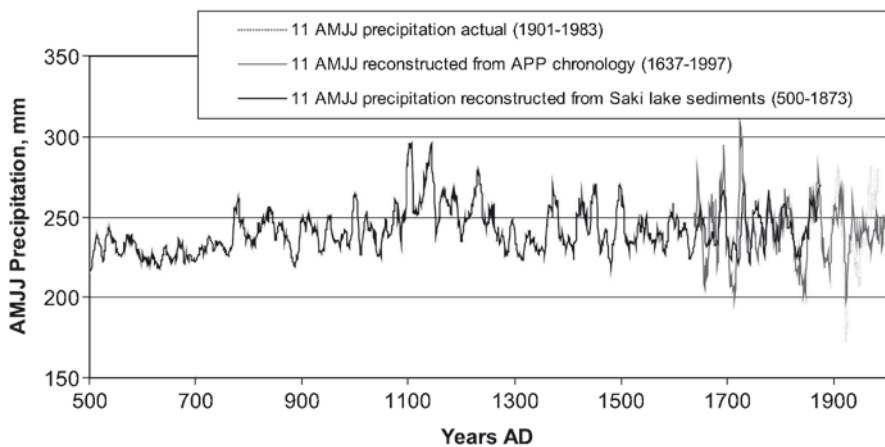


Fig. 3.10 Sum of AMJJ precipitation measured at Aj-Petri meteorological station (a), AMJJ precipitation reconstructed from tree rings (b). Eleven-year running mean of the Saki Lake chronology for the last 1,500 years (c) (Solomina et al. 2005)

3.6 Borehole Temperatures

Most borehole temperature reconstructions of the last millennia in the European Russia come from the Northern and Central Urals (Demezhko and Golovanova 2007). According to this reconstruction the ground surface temperatures in the Medieval Warm Period (approximately between AD 1100 and 1200) were 0.4 K higher than in 1900s–1960s. During the Little Ice Age culmination (approximately AD 1720s) it was 1.6 K cooler than in the twentieth century. The overall pattern of temperature changes in the last millennium reconstructed by borehole data are similar in the Urals and Belgorodskaya oblast', however in the center of the East European Plain the twentieth century mean annual temperature is 0.4 K higher than it was in the warmest period in the first half of the millennium (Duchkov and Sokolova 2000),

3.7 Palynological Data

Chernavskaya (1996) used eleven chronologically controlled sections and calibrated this data with more than 100 recent spectra all over the East European Plain. Chernavskaya (1995) analysed more than a hundred recent pollen spectra and found out that the pollens of broad-leave trees are the best indicators of the warming/cooling trends in the East European Plain. According to this study the maximum warming occurred in the ninth to tenth centuries in the west of the plain and in the tenth to eleventh centuries – in the east. Some spectra display a cooling in the middle of the twelfth century and especially in the late twelfth to early fifteenth centuries, when the temperature decreased by 2–3°C. Coolings also occurred in the late seventeenth and eighteenth centuries and two warmings are recorded in the sixteenth and second half of eighteenth centuries.

Sleptsov (2002) selected four best constrained palynological series and adjusted these reconstructions to the common reference period (1951–1980) (Fig. 3.11). In all records one can see the absence of the long term trend in the first millennium, the thermal maximum around the turn of the millennium and the clear cooling trend in the last 1,000 years. However the multidecadal variations often differ for individual reconstructions both in terms of timing and amplitude.

Klimanov et al. (1995) provided a quantitative reconstruction of several climatic parameters basing on detailed pollen data of Polovetsko-Kupanskoye peat bog in the center of the East European Plain (see map at Fig. 3.1). They noticed that the negative trends in summer and winter temperature begun in the twelfth century and continued up to the mid twentieth century, while the whole first millennium and the earlier part of the second millennium AD were relatively warm both in summer and in winter. No long term trends are observed in the annual precipitation.

The same approach as used in Klimanov et al. (1995) was applied to reconstruct the temperature and precipitation of the UM pollen site. A very good agreement

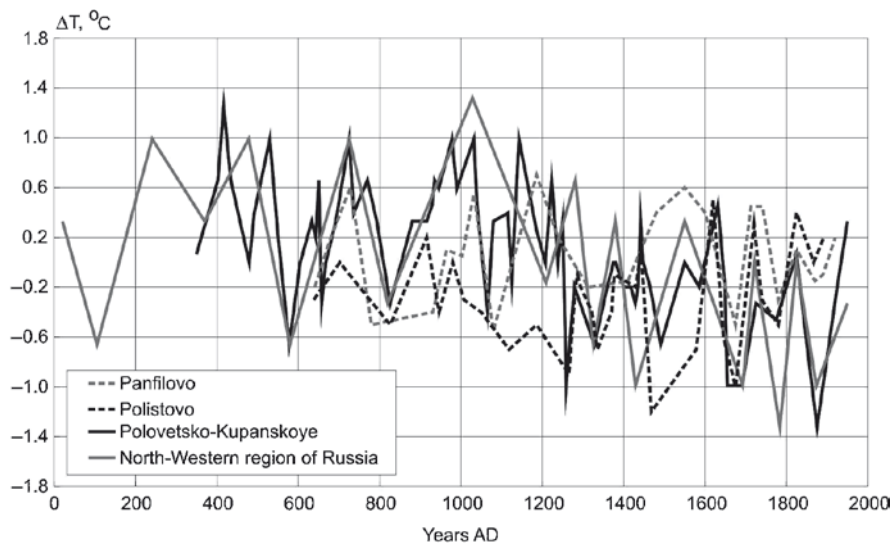


Fig. 3.11 Mean annual temperature anomalies (from 1951 to 1980 mean) according to various palynological reconstructions in the East European Plain

exists between the recorded meteorological parameters (e.g. annual temperature) and the UM pollen-based reconstruction (Fig. 3.12). According to this reconstruction the coldest periods occurred in the first quarter of the fifteenth, end of seventeenth and eighteenth centuries. The warmest periods after the MWP at the decadal and multidecadal levels occurred in the 1820s and in the end of the twelfth century. The coolings were more pronounced than the warmings: the cooling anomalies (from the 1951–1980 mean) were up to 1°C, while the warmest anomalies did not exceed 0.7°C. One can see two thermal maxima when the annual temperature increased by 1°C around AD 2000 and 1100. The first warming was similar to modern conditions in terms of precipitation, while during the MWP the precipitation exceeded the modern values by 25–50 mm. Major coolings date back to around 1700 BP, 1200 BP, 1000 BP, 650 BP, 500 BP. The amplitudes of January temperature fluctuations exceed those in July. No clear relationship between temperature and precipitation is established. A cooling trend is evident in the last millennium, while the annual temperature variations in the first millennium do not show any clear tendency (Klimenko et al. 2001). According to the UM reconstruction the most humid periods occurred in the early fourteenth, end of the fifteenth early sixteenth, mid seventeenth, last quarter of the eighteenth centuries and driest periods in the end of the fourteenth – early fifteenth, last third of the sixteenth, end of seventeenth to early eighteenth, mid nineteenth centuries. There is no clear millennium-long trend in the annual precipitation.

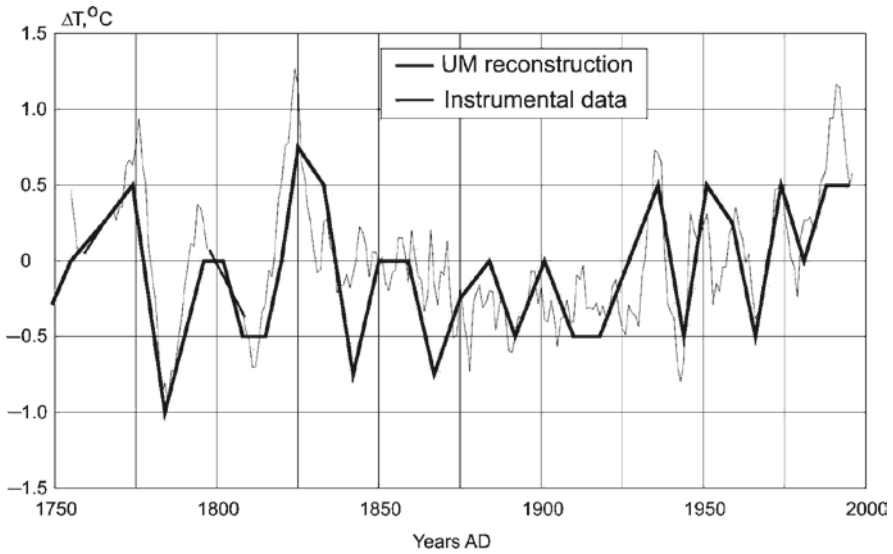


Fig. 3.12 Mean annual temperature anomalies reconstructed by palynological data at Usviatsky Mokh peat bog and average mean annual temperature for meteorological stations Riga, St-Petersburg, Moscow and Vilnius, 7 years running mean (Klimenko et al. 2001)

3.8 Hydrological Data

Schostakovich (1934, 1936) reconstructed mean annual precipitation rate using the thickness of annually laminated sediments in the Saki Lake the Crimea and Pertozero (Karelia) (see Fig. 3.1 and Table 3.5). The sediment layer thickness (mean for 10 and 30 years intervals) were calibrated against the meteorological data, though the Crimean meteorological records at that time were too short to be sure about the relationship between the sediment layers thickness and climatic parameters. Solomina et al. (2005) later on demonstrated that indeed the Saki Lake sediments correlate with spring to early summer precipitation (see Fig. 3.10). An 11-year filtered version of the reconstruction correlates with an annually-laminated sediment-thickness record from the Saki Lake, once this record is shifted backward by 15 years. The offset may be explained by anthropogenic changes at the lake in the late nineteenth century. The correlation allows the extension of the precipitation reconstruction further back in time. The Saki Lake chronology shows that the period between the 1050s and 1250s was extremely wet. The overall humidity level of the region appears higher than at any time of the instrumental records. This interval partly coincides with the MWP (e.g. ~AD 900–1240; Grove and Switzer 1994). Schwets (1978) reconstructed the Dnieper runoff basing on several proxies (see Table 3.5). Rauner (1981) used empirical equation relating the mean precipitation in the Dnieper region and the runoff. This reconstruction explains no more than 50% of variation of precipitation. The three reconstructions of precipitation show that precipitation variations in all three regions were quasi-stationary. In the northern part of the East European Plain (to the North of

Table 3.5 Palaeohydrological series in the East European Plain

Period	Reconstructed parameter	Resolution (years)	Region	Reference
AD 761–1900	Mean annual precipitation	30	Pertozero, South Karelia	Schostakovich (1934)
AD 761–1900	Mean annual precipitation, April–July precipitation	30-years running mean	Saki Lake	Schostakovich (1934)
AD 761–1960	Mean annual precipitation	30	Dnieper basin	Schwets (1978)

55°N) the century-long variations dominate, while in the southern part those of higher frequency (decadal) are more prominent. According to the proxy data the variability of precipitation in the North (60–100 mm) is generally higher than those in the South (30–40 mm). The variations of precipitation in the North and South are not correlated (Klimenko and Sleptsov 2003).

3.9 Multi-proxy Reconstruction

The results of Klimenko and Sleptsov (2003) and Sleptsov (2002) quantitative multi-proxy temperature and precipitation reconstructions are presented in Figs. 3.13, 3.14, 3.15, and 3.16. For all reconstructed parameters the correlation of the proxy time series and the instrumental records (250 years long averaged for decades) are significant at the 95% level.

The reconstruction shows that the tenth century was the warmest in the East European Plain in the last 2000 years. After the tenth century a clear cooling trend is evident up to the early twentieth century. During this period an overall rate of cooling was about an order of magnitude lower than the rate of the recent warming in the course of the twentieth century. On the whole during the past millennium the fifteenth century was the coolest one, while the most pronounced decadal cooling occurred in the late seventeenth century. The winter temperature amplitude of variations is twice as large as those of summer.

Long-term summer coolings are mostly associated with dry periods in the northern regions (to the north of Vilnius–Saratov line, see Fig. 3.1) (The coefficient of correlation between the smoothed summer temperature and precipitation is $r = 0.33$), while in the southern regions the correspondence is opposite (Klimenko 2001). Annual precipitation variations do not show any long-term trend during the last two millennia.

It is of interest that during the last millennium all even centuries were relatively warm, while the odd ones – were cold (Table 3.6). Similar sequence (though with the opposite sign) is evident for the first to seventh centuries AD. This is probably related to the 200-years climatic cycle triggered by solar activity (Mikushina et al. 1997). The reverse of the millennium-long cooling trend in the twentieth century may be caused by anthropogenic influence, but the peak temperature of the tenth century is still to be

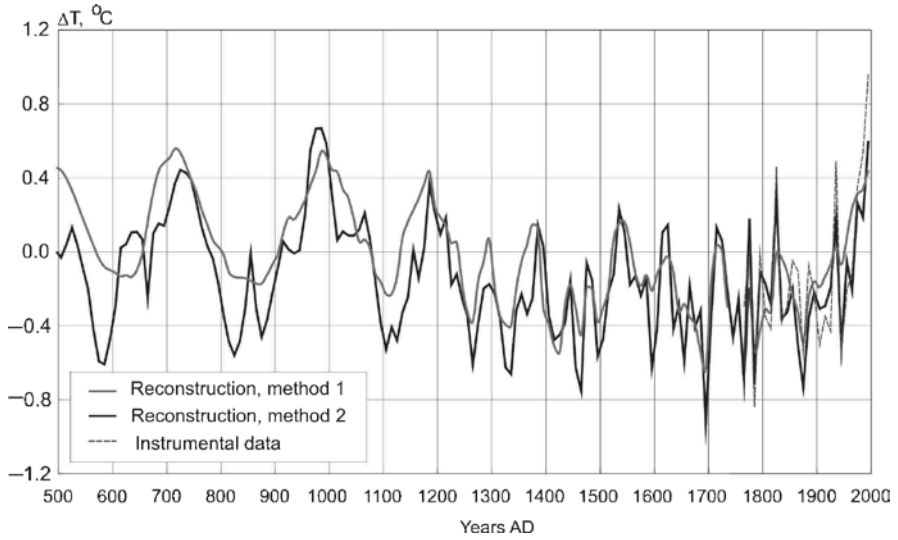


Fig. 3.13 Reconstructed mean annual temperature deviations from 1951 to 1980 mean averaged for decades reconstructed in comparison with the instrumental records (average for St Petersburg, Moscow, Riga, Vilnius)

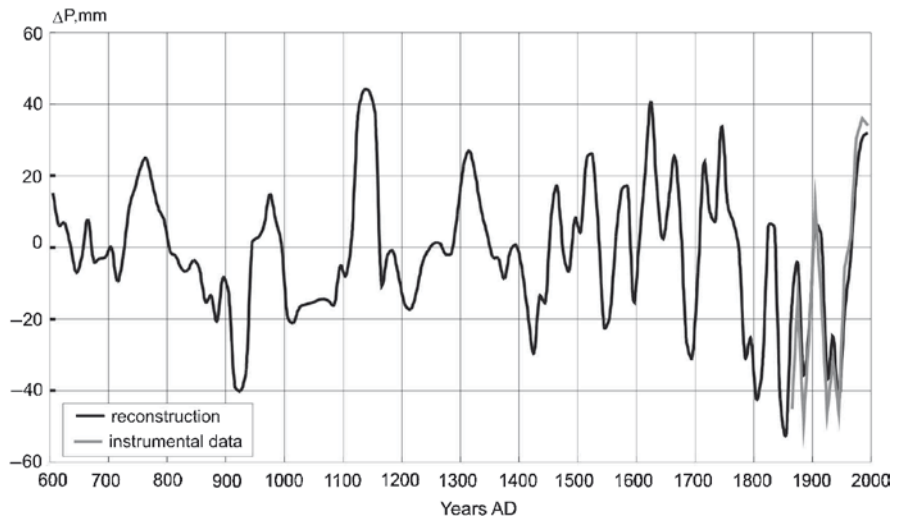


Fig. 3.14 Reconstructed mean annual precipitation deviations from 1951 to 1980 averaged for decades reconstructed in comparison with instrumental data (average for St Petersburg, Moscow, Riga, Vilnius)

reached. The global warming of anthropogenic origin is not manifested in the summer temperature while the winter temperature in the late twentieth century exceeded the peak values of the last two millennia, even those of the MWP.

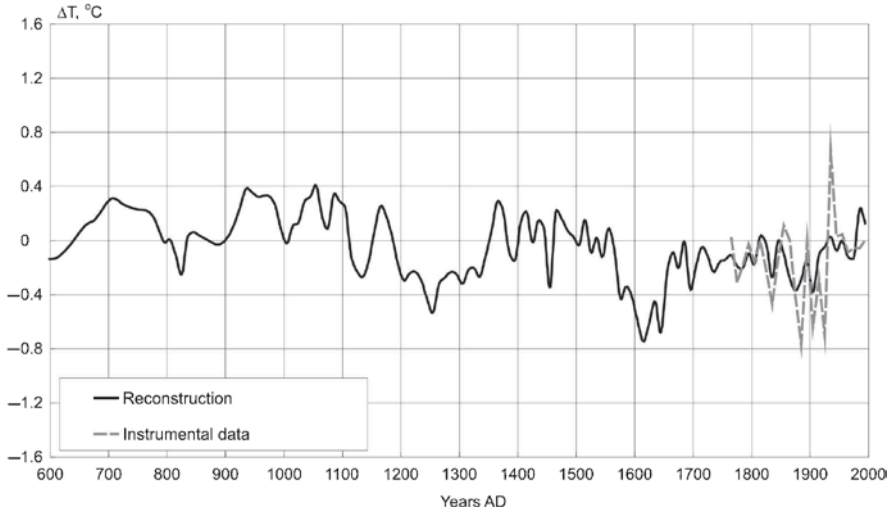


Fig. 3.15 Reconstructed mean summer temperature deviations from 1951 to 1980 averaged for decades in comparison with instrumental data (average for St Petersburg, Moscow, Riga, Vilnius)

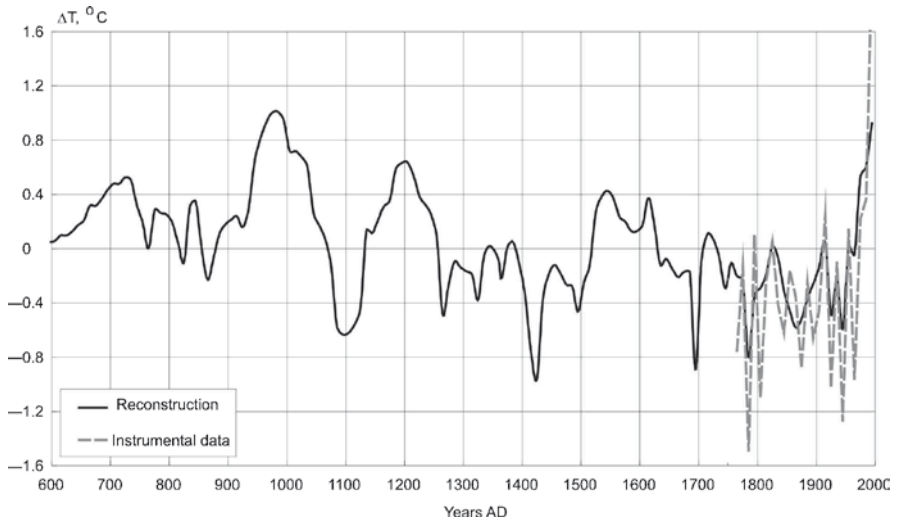


Fig. 3.16 Reconstructed mean winter temperature deviations from 1951 to 1980 averaged for decades in comparison with instrumental data (average for St Petersburg, Moscow, Riga, Vilnius)

Table 3.6 Centennial anomalies of the mean annual temperature (deviations from 1951 to 1980 mean)

Century	Temperature anomaly (°C)
09	-0.34
10	0.30
11	0.07
12	-0.15
13	-0.25
14	-0.20
15	-0.44
16	-0.16
17	-0.33
18	-0.23
19	-0.32
20	-0.02

3.10 Discussion

In this chapter we briefly discuss the possibilities and the gaps in the last millennium climate research in the East European Plain and potential biases and errors in the available reconstructions.

Our overview shows that there are great potentials for the climatic reconstructions in the East European Plain. The instrumental records up to three centuries long can be successfully used to estimate the long term trends in monthly and seasonal temperature and precipitation and to calibrate the proxy records. However the long meteorological records attracted surprisingly low attention of Russian climatologists up till very recent time when the problem of the potential anthropogenic warming had arisen. Still a lot can be and should be done to homogenize the data, fill the gaps in the records, use the historical documents to extend the series back in time and make it available to the public.

The historical information was successfully used by a number of researchers to create the numerical series of almost one millennium long. Still a lot of historical documents including private diaries, notes, documents in local archives etc. are not included in the study. More sophisticated techniques of reconstruction can be also applied in this field, e.g. to derive spatial charts of monthly and seasonal reconstructions of temperature, sea level pressure, 500-hPa geopotential height fields etc. (Brázdil et al. 2005).

There is a certain disagreement between the historical reconstructions of Lyakhov (1984) and Klige et al. (1993) (Figs. 3.7 and 3.8), especially dramatic for summer temperature in the sixteenth century and winter temperature in the late eighteenth century. The difference was never comprehensively discussed in the literature. It might be explained by some differences in methodology used by the two groups of researchers. Lyakhov and Voronov and Klige et al. used different periods of averaging the data. The documentary base used by Voronov (1992) and

Klige et al.(1993) is larger than the one used by Lyakhov; they also took into account the uneven distribution of the number of records in time. However the comparison of both reconstructions (summer temperature anomalies) with those from Europe (Brázdil et al. 2005) shows that Lyakhov's curve fits much better to the long Prague reconstruction, reproducing most long-term coolings and warmings. One can expect such a similarity, while Klimenko and Sleptsov (2003) demonstrated the close correspondence of the instrumental records of Prague and those of the north of East European Plain. Thus, the problem of reliability of the historical reconstructions of climate on the East European Plain still remains largely unresolved. More scrutinized analyses including the more transparent procedure of selection the data, calibration and verification of the models is necessary to increase the creditability of the reconstructions.

Tree-rings at the northern tree limit provided some well-replicated high quality summer temperature reconstructions up to five centuries long. There are however potentials to extend the series back in time and increase the density of the network using the archeological wood and the material from the wooden houses. Unfortunately no reliable tree-ring based precipitation reconstruction from the southern regions in the East European Plain is available due to the lack of old forests in these agricultural regions. It still might be possible to find some appropriate wood (e.g. oaks) for this purpose in the protected areas. Khasanov (2004) was able to cross-date the oaks buried at the bottom of small rivers in Tverskaya area and create the floating chronology covering the period from the mid tenth to the late thirteenth centuries and demonstrated the possibility to create a millennium-long chronology in the area.

The tree-ring reconstructions in the North of the East European Plain are based on the maximum density rather the ring width (Briffa et al. 2004) therefore the underrepresentation of the long-term trend of the temperature is not critical in this case. However both density and ring width in this area showed a "divergence" problem from the 1960s, when the correlation between the ring width and density from one side, and the instrumental records of temperatures from the other side, weakened considerably. Briffa et al. (2004) cut the calibration series at that point and derived the temperature reconstructions from the shorter meteorological records, although the reason for this "divergence" phenomena, which also happened in many other places, is still unclear (see for details D'Arrigo et al. 2007).

The tree-ring and historical data are sharing to a certain extent their advantages (seasonal resolution, reliable chronologies) and disadvantages. Therefore the comparison of this data both at the annual and decadal (multidecadal) basis is natural. The detailed comparison of this kind was never made for this area and it is also not in the scope of this paper. We can just notice a few cases in this relation. The year 1601 was the coldest in the last 400 years in the Northern Hemisphere (high to mid latitudes) according to the tree-ring data (Briffa et al. 2004).The frosts and long heavy rains in summer 1601 in combination with the winter conditions unfavorable for agriculture resulted in a very severe famine in 1601–1603 and led to dramatic perturbations in the Russian history. The comparisons of the 15 years running means of Briffa et al. (2004) Northern European summer temperature reconstruction

with the two historical reconstructions represented at Fig. 3.7 shows a very good visual agreement with the Klige et al. (1993) curve and much poorer correspondence with the Lyakhov's (1984) reconstruction. In these terms one may conclude that the Klige et al. (1993) reconstruction is more reliable. However this conclusion would contradict the results of our previous comparison of the two reconstructions with the historical data from Prague (see above). This kind of contradictions shows that the problem of the high resolution seasonal reconstructions on the East European Plain is still very far from the final solution.

The lower resolution records, such as borehole temperature and biostratigraphic analyses, can be useful to provide the longer term trends, which are often biased in historical and tree-ring series. Unfortunately most palynological reconstructions in the East European Plain have a very poor chronological control and the lack of the AMS dating facilities in Russia limit the possibilities to improve the reconstructions in terms of resolution and spatial coverage in the future. However Klimenko et al. (2001) showed that pollen reconstruction can also yield a much higher resolution and can be calibrated directly against the meteorological records smoothed by decades if it is well chronologically controlled. The UM reconstruction does not contradict to the earlier palynological reconstructions (see Table 3.3), although due to higher resolution the UM reconstruction provides more detailed chronological information. For instance according to this reconstruction the peak of MWP warming occurred around AD 970 while it was traditionally placed at AD 1000. Other proxies, such as historical data (Borisnikov and Pasetky 1988) and the decrease of sea ice index in the Baltic support this conclusion (Koslowski and Glaser 1999; Tarand and Nordli 2001). A certain agreement exists between the UM reconstruction, historical (Klige et al. 1993) and hydrological data (Schostakovich 1934), though a very clear discrepancy between the records is evident for the periods of the 1450–1550s, the early seventeenth and early eighteenth centuries. The reasons of such disagreement can be related to various biases in proxy records (chronology, seasonality recorded, calibration etc.) as well as they can reflect the real regional variability in precipitation.

The first multi-proxy reconstructions in the East European Plain of the summer, winter, annual temperature and annual precipitation provided by Klimenko and Sleptsov (2003) agrees well with the instrumental data. As soon as almost all reliable millennium-long series were used in this reconstruction there are no many opportunities to check the consistency of these curves comparing them with other independent records in this area. The comparison of the Klimenko and Sleptsov (2003) annual temperature reconstruction with the two well-known reconstructions of the Northern Hemisphere (Fig. 3.17) shows that all three demonstrate a slight negative long-term trend which reverses in the last century (earlier in the case of Crowley and Lowery reconstruction). The amplitude of variations is greatest in the Russian Plain (1.5°C), while the two other curves are much flatter. The decadal variability agrees for some periods, but during the other periods (e.g. the eleventh, fourteenth, sixteenth, nineteenth centuries) there is almost no similarity. The details of this discussion can be found in Sleptsov (2002). It is clear that one cannot expect the identity of these reconstructions which represent different areas. In general it is

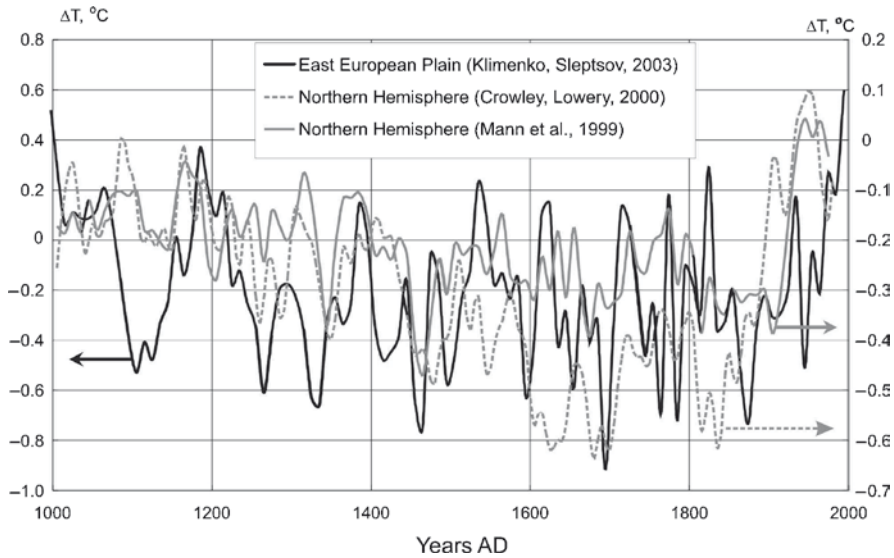


Fig. 3.17 Comparison of the Klimenko et al. (2003) annual temperature reconstruction for the East European Plain with the two Mann et al. (1999) and Crowley and Lowery (2000) annual temperature reconstructions for the Northern Hemisphere

getting more and more clear that reliable regional rather than hemispheric reconstructions for the last two millennia are necessary at the moment in order to increase our understanding of the spatial patterns of natural climatic variability (PAGES Science and Implementation Plan 2009). In case of the East European Plain it means that the north and south of the plain with largely different regimes of temperature and especially precipitation should be considered separately.

Precipitation and humidity reconstructions are generally less reliable in this area. In addition to historical records they are largely based on the Schostakovich (1934, 1936) studies on the lake sediment properties and are not quality controlled. Although Solomina et al. (2005) demonstrated that the thickness of annually laminated sediments in the Saki Lake correlates with the drought sensitive ring width chronology the problem still requires additional studies at the modern technological level.

3.11 Concluding Remarks

Meteorological, historical, tree-ring, palynological, lake sediments records and the first attempts of quantitative multi-proxy reconstructions of temperature and precipitation allow the estimation of major trends in these parameters in the East European Plain for the last millennium. The multi-proxy reconstruction provides most systematic and quantitative estimates. This reconstruction recorded the

long-term negative trends in seasonal and annual temperature over the whole millennium with the exception of the last century. In the twentieth century the winter and annual temperature increased and the trend reversed. The winter temperature exceeded now the level of the peak of the Medieval Warm Period (a turn of the tenth–eleventh centuries), while those of the summer are still within the natural variability of the last millennium. No significant trends are identified in the annual precipitation of the last millennium. In the North of the East European Plain there is a tendency of anticorrelation of decadal variability of annual precipitation and temperature, which was described earlier (Zolotokrilin and Popova 1988). It was noticed that there was a 200-years natural variability in annual temperature during the last millennium (even centuries are relatively warm, while the odd ones were cold), which might be related to the cycles of solar activity (Wanner et al. 2008).

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