PRACE GEOGRAFICZNE, zeszyt 107
Instytut Geografii UJ
Kraków 2000

Gabriel Wójcik, Jacek Majorowicz, Kazimierz Marciniak, Rajmund Przybylak, Jan Šafanda, Andrzej Zielski

THE LAST MILLENNIUM CLIMATE CHANGE IN NORTHERN POLAND DERIVED FROM WELL TEMPERATURE PROFILES, TREE-RINGS AND INSTRUMENTAL DATA

Abstract: In order to reconstruct the air temperature variations in Northern Poland for the last millennium observational and proxy (tree-ring widths) data were used. For the first time the ground surface temperature (GST) for Northern Poland was reconstructed based on geothermal data (well temperature profiles). A general warming trend is observed for both the GSTH (GST Histories) derived from geothermal data and instrumental data, in particular, for the last 200 years.

Key words: climate change, tree-rings, well temperature profiles, Northern Poland.

1. Introduction

The purpose of this paper is the reconstruction of the air temperature variations in Northern Poland for the last millennium. This will involve the use of observational, proxy (tree-ring widths) and geothermal data. For the first time an attempt will be made to reconstruct the ground surface temperature (GST) for Northern Poland based on geothermal data (well temperature profiles). Northern Poland lacks long-term temperature histories (i.e. histories dating back more than a couple of centuries). Geothermal methods and dendrochronology provide such an opportunity, though such approximations of past climatic change are not of an accuracy and resolution comparable to instrumental series. However, they do provide us with some very rare tools to look back into the past. Each of these methods has its advantages and weaknesses. Cross-checking and verification of the proxy results, geothermal reconstruction and comparison against the instrumental records (for the available part of the time scale) is needed. We also need to compare northern Polish climatic history with other available time series in the neighbouring areas.

Past climatic reconstruction (1600-1996 AD) has been already carried out for south-western Poland from well temperature profiles (Wójcik et al. 1999). The geophysical inversion technique was applied to high precision thermal logs measured in 10 wells in Lower Silesia and the Sudetian Mountains. The analysis of the data showed warming trends with a magnitude of 1°C starting at the end of the last century comparable with the results of the instrumental data in Prague, Berlin, Wrocław and also with European and Northern Hemisphere temperature anomalies. These were compared with tree-ring data constructed for the Scots pine from Northern Poland starting since 1600 AD (Zielski 1997) and for the Norway spruce from Southern Poland since 1641 AD (Szychowska-Krąpiec 1998). Several existing tree-ring chronologies, or temperature reconstructions, were also used (Schweingruber 1983; Briffa, Schweingruber 1992; Brazdil et al. 1997). A reasonable correlation between direct and proxy data has been observed (Wójcik et al. 1999).

2. Area of Investigation

The history of the air temperature for the last millennium is presented for Northern Poland and, to a certain extent, for neighbouring areas also. Only five well temperature profiles out of the available twenty were selected for the study area of Northern Poland based on the analysis of the data quality and well thermal equilibrium (Fig.1). The majority of wells are located in deforested and open areas. These data were compared with data from western Belarus and eastern Czech Republic for the comparable time intervals.

Only limited tree-ring data and instrumental data were available for our study area. Therefore, we have also used data from the neighbouring (north-eastern Germany /Brandenburg region/, southern Sweden /Gotland Island/, Lithuania and Latvia) (see Fig. 1).

3. Data and Methods

a. Climatological

Long-term (since the early 18th century) mean annual air temperature series from the study area were chosen. The data for five stations - Berlin (1701-1990), Warsaw (1779-1990), Vilnius (1778-1963), Riga (1851-1989) and Stockholm (1757-1988) - were taken from the Global Historical Climatology Network which is produced by the National Climatic Data Center/ NOAA, the office of Climatology at Arizona State University, and the Carbon Dioxide Analysis Center. Gaps in the temperature series were filled using standard climatological methods. The curves were smoothed using 11-year running means.

b. Dendrochronological

An absolute chronology of Scots pine tree-ring growth has been compiled for the Lower Vistula region for the period from 1168 to 1994 AD. Compilation included measurements of tree-ring growths from living trees (since 1767) and historical data (wooden roof constructions and wooden frames from old churches and residential

Fig. 1. Location of source data used in the present paper:

1 - long-term series of air temperature, 2 - anomalies of ground surface temperature, 3 - tree-ring width indices.

buildings) (Zielski 1997). The above is compared with tree-ring data of pines from Gotland (Bartholin 1987), Brandenburg (Heussner 1986; pers. comm.) and Lithuania (Karpavicius 1997; pers. comm.).

Tree-ring width chronologies were transformed using computer code CRONOL (Dendrochronology Program Library - DPL, routine CRN, Holmes 1994). The procedure of detrending was applied to each of the series. Further, computing of the chronologies was carried out with the aim of obtaining maximum common signal and minimum amount of noise. Application of the auto-regressive procedure (modelling) to the detrended tree-ring series produced the residual version of the chronologies.

Polish, German, Swedish and Lithuanian chronologies were compared; (due to a lack of data, the Lithuanian chronology covers only the past two centuries). From this comparison it appears that their correlation is historically variable. The highest correlation and the closest “Gleichläufigkeit” factor is achieved by Polish and German chronologies for the Middle Ages.

The relationship between residual chronology from Poland and mean monthly temperatures and monthly sums of precipitation was investigated using the response function model (Fritts 1976). This model takes into account both data from the present year and data for the last few months from the previous vegetation period. Response functions were calculated using data from 1861-1991 (Zielski 1997).

c. Geophysical

Changes in GST propagate into the subsurface, exponentially decreasing in amplitude with increasing time and depth. The solid earth acts like a low-pass filter, filtering out daily and seasonal changes in GSTs while maintaining a running record of the long-term mean and departures from it. Functional space inversion (FSI) techniques (Shen, Beck 1991; Shen et al. 1995) have been applied to selected industrial temperature logs in Northern Poland (Fig. 1). These were logged continuously with depth using various types of commercial resistance thermometers in wells approaching thermal equilibrium. Data were obtained from the archives of the Polish Geological Institute. The relative temperature change accuracy is assessed to be in the proximity of 0.1°C for the best cases chosen for this analysis. An example of equilibrium versus non-equilibrium temperature well logs is shown in Fig. 2. (Bytów and Nidzica temperature profiles). Analysis of these two logs shows quite clearly that the Nidzica temperature profile is not in equilibrium with the surrounding rock temperature and surface temperature regime. Extrapolation to the surface suggests a ground surface temperature in the vicinity of 15°C which is quite unrealistic (the mean annual ground

Fig. 2. Example of temperature-depth profile for two wells: Bytów (Byt 1) (in thermal equilibrium) and Nidzica (Nid 1) (non-equilibrium state).

surface temperature in Poland varies between 7°C and 10°C). On the contrary the temperature well log in well Bytów is in thermal equilibrium. The temperature log shows a characteristic curvature in the upper parts of the profile, probably related to the surface warming in the last couple centuries. The individual GSTHs (GST Histories) were obtained by applying the functional space inversion technique. This technique assumes that heat transfer is by conduction alone through a one-dimensional, possibly heterogeneous medium. With Shen's et al. (1995), FSI inversion method, a GSTH reconstruction is sensitive to relative constraints on the *a priori* conductivity model, physical properties, and temperature measurements. A GSTH reconstruction is the goal of inversion. The temperature profiles were subjected to a „loose" inversion described by Shen et al. (1995).

4. Results and Conclusions

Composite ground surface temperature histories

An averaging procedure was applied to obtain combined standardised GSTH curves representing the study area. Figure 3a shows a composite GSTH curve as well as individual GSTH curves for all 5 wells. The average magnitude of warming is 1.5°C. The major increase occurs in the last three centuries and is especially high in the last 150 years. The extended minimum at the turn of the 19th and 20th centuries, observed on the basis of more precise south–western Polish geothermal data (Wójcik et al. 1999), is not visible here. It is also not observed from the Belorussian GSTH reconstruction, where recovery after the cooling period of the 15th-18th centuries occurs earlier (around 1800 AD) (Fig. 3b). Warming magnitude is 1°C and lower than in Poland and eastern Bohemia (Czech Republic) (Fig. 4). The Czech and northern Polish GSTH curves are remarkably close considering the data uncertainties and the large distance between groups of wells analysed. Analysis of the average GSTH curves shown in Fig.4 requires understanding that the resolution of the GSTH rapidly decreases with time as a result of the diffusive character of the heat conduction process. It is such that an event, to be resolved, has to have been of a duration of at least 60% of the time since its occurrence (i.e. the minimum we observe at AD 1900 is really at approximately 1870-1930 AD).

Comparison of GSTH with other direct and proxy data

Generally there is a good correlation between the GSTH derived from geothermal data and instrumental data, in particular, for the last 200 years (see Fig. 3a,b, 4 and Fig.5). A general warming trend is observed by both sets of data. Air temperatures measured at individual stations have increased in this time span by about 1°C or more (Warsaw, Berlin, Stockholm), except for Riga and especially for Vilnius. Generally, similar results reveal temperature series calculated from 57 European stations (Balling Jr et al. 1998). The magnitude of average GST warming derived from geothermal data is close (>1°C). It is worth noting, however, that the

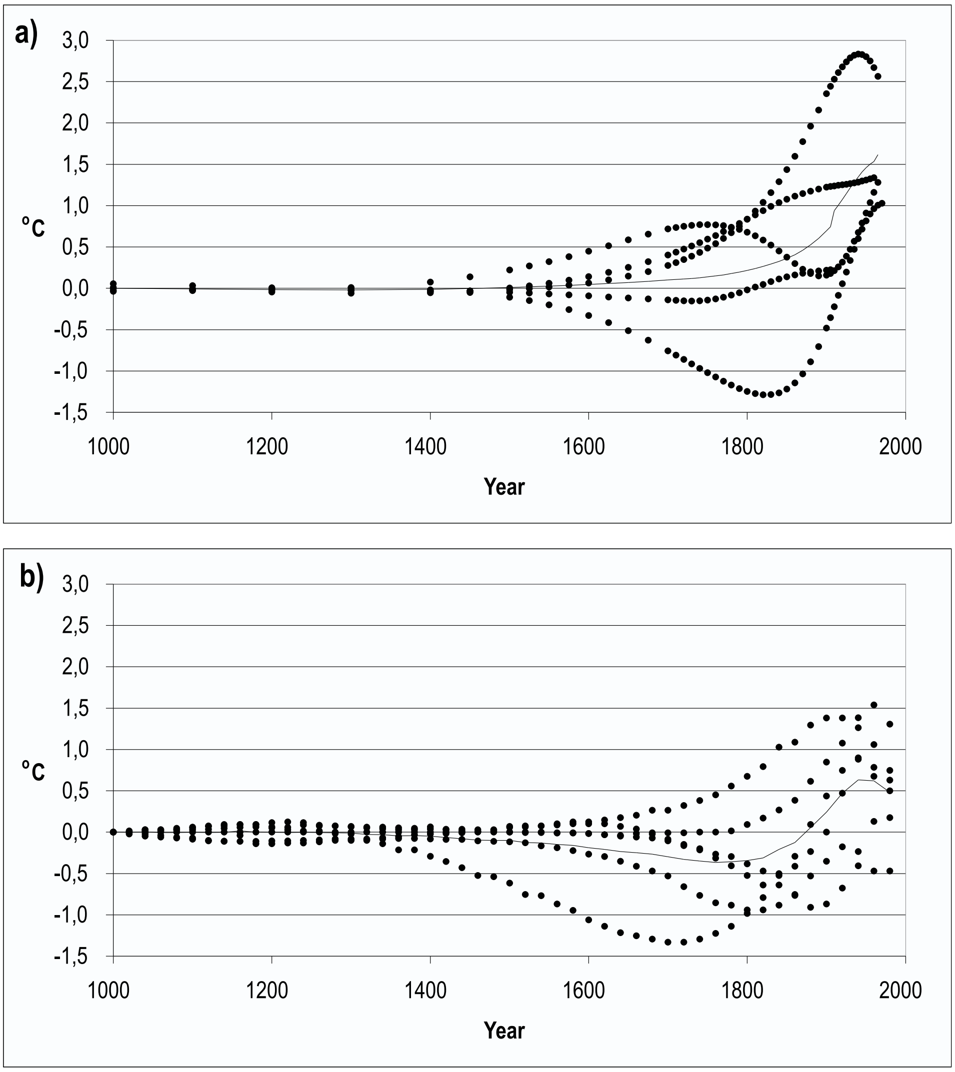

Fig. 3. Anomalies of GST histories (GSTHs) for northern Polish wells (a) and for wells from western Belarus (b) according to Zui (1999) (dotted lines - individual well's GSTH; continuous line - average GSTHs).

start of this warming is as early as the 17th century for the northern Polish data. The most significant increase occurs in the 19th and 20th centuries. It compares well with the Czech GSTH. In the case of Belarus, the onset of recent GST warming follows a broad minimum at the end of the 18th century. The magnitude of warming is also close to 1°C (see Fig. 4 for the comparison).

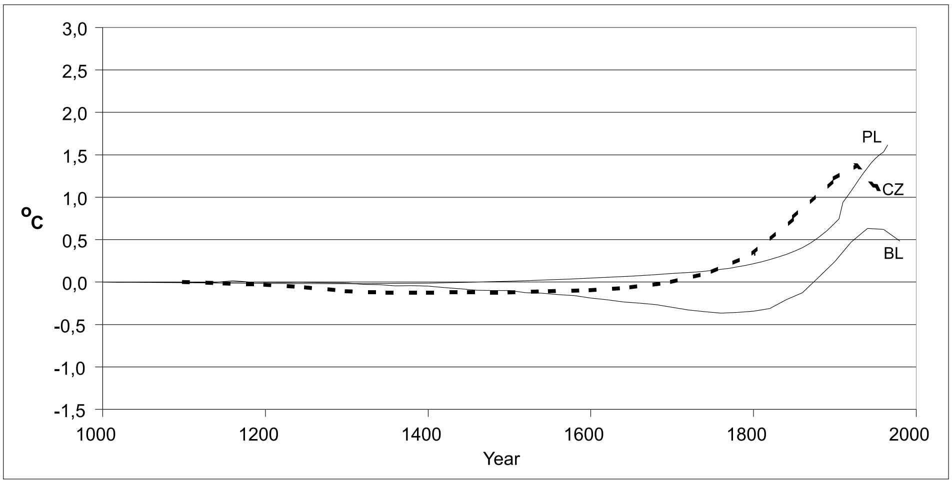

Fig. 4. Averaged GSTH anomalies (northern Poland – PL, western Belarus - BL and Czech eastern Bohemia - CZ) in relationship to 1000 AD level.

Response function calculations conducted for trees growing in Poland (except in mountainous regions) reveal a statistically significant correlation between annual ring widths of the Scots pine on the one hand and, on the other hand, the monthly mean air temperatures, particularly from February and March, but also from January and April. For Northern Poland the following correlation coefficients (r) were computed: 0.47, 0.55, 0.26 and 0.18, respectively (Zielski 1997). A statistically significant correlation with summer precipitation was also found (June – r = 0.28 and July – r = 0.29). The low temperature occurring at the end of winter and at the beginning of spring has a strong negative influence on the width of the tree-rings. A statistical correlation between tree-ring growth indices and temperature exists for the Scots pine in all of the northern-central European Lowland (see e.g. von Lührte 1992; Linderson 1992). The good correlation that was found between dendrochronological and climatological data allows conclusions to be drawn about the variation of late-winter/early-spring air temperature from 1000 to 1995.

Sixty-four-year running averages of tree-ring indices of the Scots pine from the Lower Vistula region reveal relatively a high differentiation of values since the 12th century. It is worth noting, however, that during this time an increase of variability is observed, with the highest values being reached in the last 300 years. This feature occurs in all the dendrochronologies analysed, but is most clear in the areas with a greater degree of climate continentality (see e.g. SE Lithuania in Fig. 6). An increase of variability in the last centuries of the present millennium is observed both in 10-year and 64-year running averages in tree-ring indices.

The highest tree-ring increases in the Lower Vistula region were observed in three periods: 1510-1570, 1630-1680 and especially 1780-1860 (Fig. 6). This means

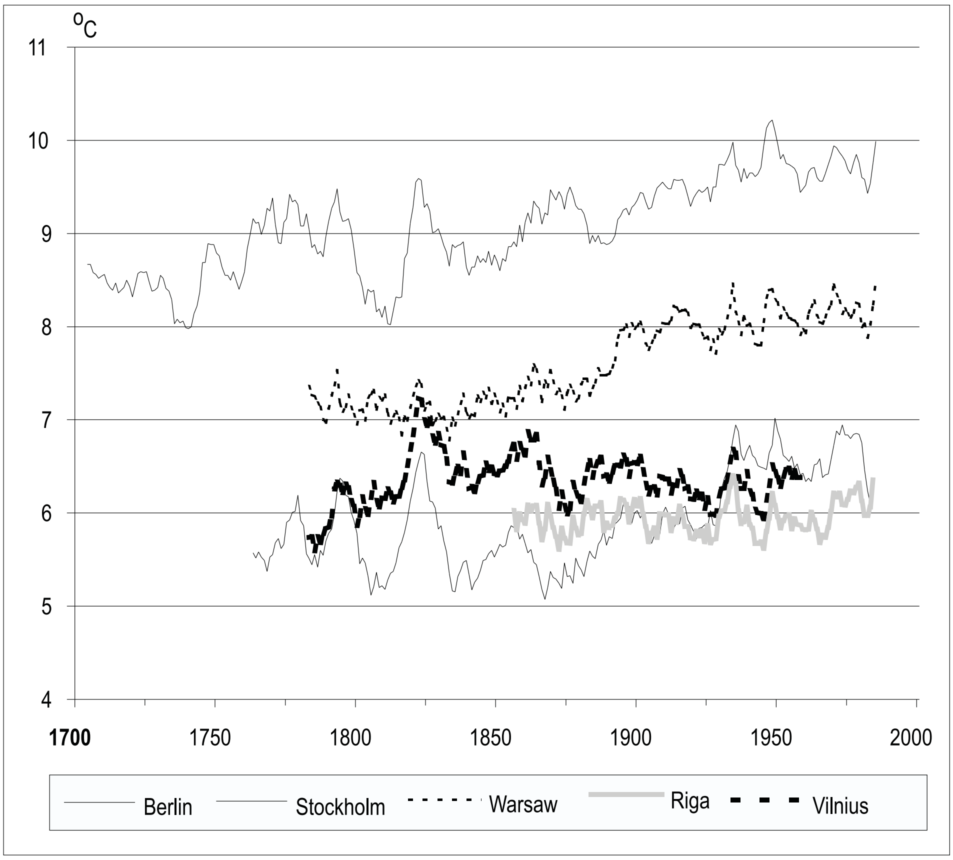

Fig. 5. 11-yr running average of the annual air temperature for central European Lowland stations (Berlin, Warsaw, Vilnius, Riga and Stockholm).

that in these periods the best vegetation and climatic conditions occurred in the study area. The last period mentioned was also clearly seen in other regions, however, with some time delay. In Lithuania and Gotland the maximum tree-ring widths was observed in the second half of the 19th century, while in Germany it was at the turn of the 19th and 20th century. In the mountainous regions of Poland (Schweingruber 1983; Brazdil et al. 1997) and in Central Europe (Briffa, Schweingruber 1992) this maximum lasted from the beginning to the middle of the 20th century. We must add here that the areas taken as Central Europe in Briffa and Schweingruber's paper differ significantly from our Europe regionalisation. A significant portion of western and southern Europe was included in this area. Similar results have also been received by Bednarz (1996) and Wilczyński (1999) based on analyses of Norway spruce in the Beskid Mountains and Scots pine in Kłodzko Basin, respectively. After this maximum in all regions analysed, a steady decrease in tree-ring widths was observed. This tendency, however, stopped in recent decades, when even some small increase is noted. Earlier two periods with good vegetative and climatic conditions were not observed in dendrochronologies from Gotland and Germany, which represent a more oceanic climate.

A long period with low tree-ring widths (i.e. bad vegetative and climatic conditions) in the Lower Vistula region occurred from 1220 to 1500. A similar

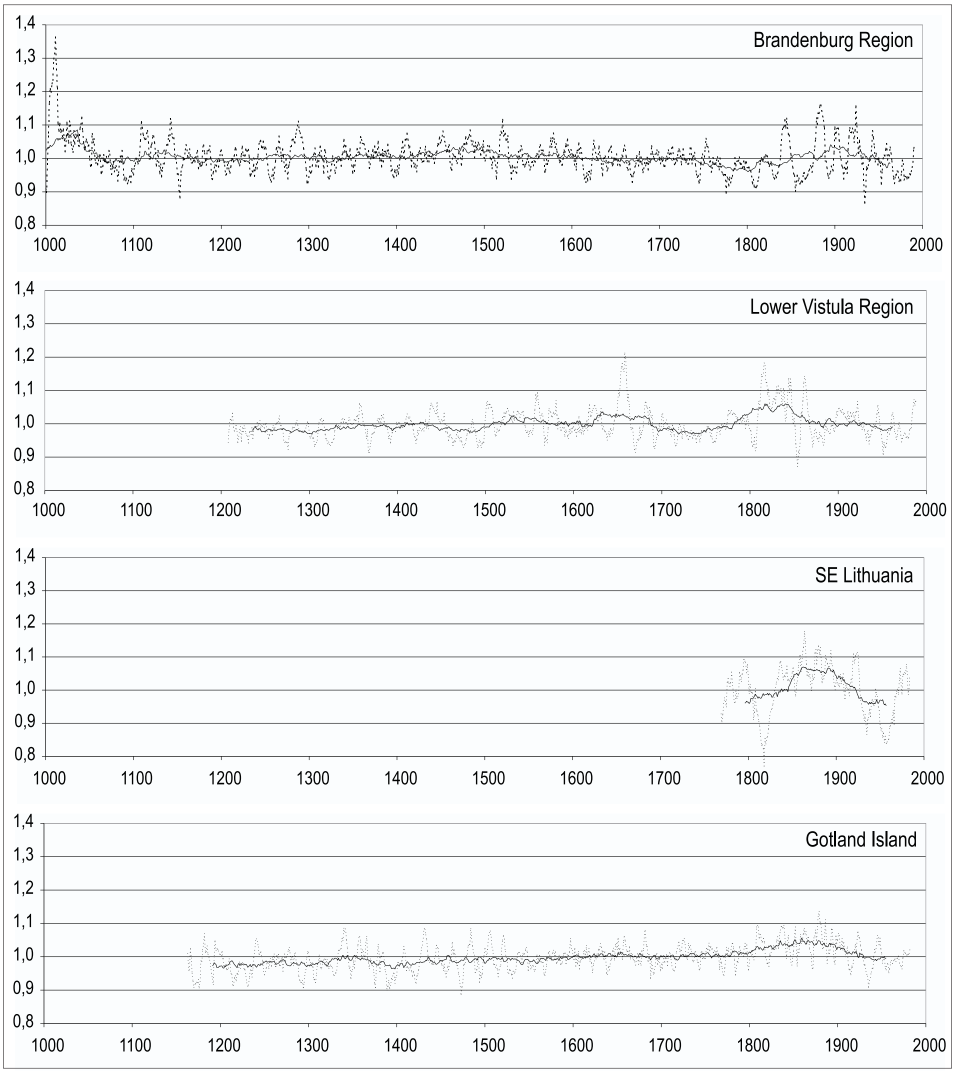

Fig. 6. Tree-ring width indices from Brandenburg region (north-eastern Germany), Lower Vistula region (Northern Poland), south-eastern Lithuania and Gotland Island (Sweden).

deterioration of climate was also observed in Gotland. On the other hand, in Germany the tree-ring widths were near the norm and in the15th century were even above the norm (Fig. 6). Both tree-ring widths and their time variability were lowest from 1690 to 1770 in the last millennium. This period represents the last phase of the "Little Ice Age", which in the Lower Vistula region began probably in the late 13th century. The earlier phases of this cool epoch were not so well seen.

Analysis of tree-ring widths for the last 400 years reveal the existence of 150-year periodicity both in Northern Poland and in Southern Poland, although the maxima and minima were not in the phase (Wójcik et al. 1999). This time pattern is not remarkable prior to 1600 AD (see Fig. 6). Outside Poland this periodicity is not seen at all.

A long-term increasing trend in tree-rings is observed starting in the Middle Ages through the 17th and early to mid 19th century period. This correlates well with the geothermal data trend; however the recent decrease in the tree-ring widths is at odds with temperature increases of some 1°C observed both by the instrumental and geothermal histories. One may ask if industrial epoch pollution has influenced tree-ring growth? The observed decrease in tree-ring indices would suggest so. However other non-temperature related factors may have played their role as well (soil moisture change, environmental factors and others).

Acknowledgements

The research has been supported by a grant from the Scientific Research Committee (grant no. 6 P04E 022 16).

References

Balling Jr R.C, Vose R.S., Weber G.R., 1998, *Analysis of Long Term European Temperature Records: 1751-1995*, Clim. Res., 10, 193-200.

Bartholin T., 1987, *Dendrochronology in Sweden*, Ann. Acad. Scient. Fennicae, Geologica-Geographica 145, 79-98.

Bednarz Z., 1996, *June-July Temperature Variation for the Babia Góra National Park, Southern Poland, for the Period 1650-1910*, Zesz. Nauk. UJ, 102, 523-529.

Brázdil R., Dobry J., Knycl J., Stepankova P., 1997, *Rekonstrukce teploty vzduchu tepleho pulroku v oblasti krknos na zaklade letokruchu smrku v ordobi 1804–1989*, Geografie - Sbornik ceske geograficke spolecnosti, 102, 3-16.

Briffa K.R., Schweingruber F.H., 1992, *Recent Dendroclimatic Evidence of Northern and Central European Summer Temperatures*, [in:] *Climate since A.D. 1500*, Bradley R.S., Jones P.D. (eds.), Routledge, London and New York, 366-392.

Fritts H.C., 1976, *Tree-Rings and Climate*, Academic Press, London-New York-San Francisco, pp. 567.

Holmes R.L., 1994, *Dendrochronology Program Library Users Manual*, Tucson, Arizona, pp. 51.

Linderson H., 1992, *Dendroclimatological Investigation in Southern Sweden*, Lundqua Report, 34, 198-201.

Lührte, von A., 1992, *Dendroecological Studies on Pine and Oak in the Forests of Berlin (West)*, Lundqua Report, 34, 212-216.

Schweingruber F.H., 1983, *Der Jahrring. Standort, Methodik, Zeit und Klima in der Dendrochronologie*, Bern. Stuttgart, Verl. P. Haupt, pp. 234.

Shen P.Y., Beck A.E., 1991, *Least Squares Inversion of Borehole Temperature Measurements in Funcunal Space*, J. Geophys. Res., 96, 19965-19979.

Shen P.Y., Pollack H.N., Huang S., Wang K., 1995, *Effects of Subsurface Heterogeneity on the Inference of Climatic Change from Borehole Temperature Data: Model Studies and Field Examples from Canada*, J. Geophys. Res., 100 (B4), 6383-6396.

Szychowska-Krąpiec E., 1998, *Spruce Chronology from Mt. Pilsko Area (Żywiec Beskid Range) 1641-1995 AD*, Bull. Pol. Acad. Sci., Earth Sci., 6, 75-86.

Wilczyński S., 1999, *Dendroklimatologia sosny zwyczajnej (Pinus sylvestris L.) z wybranych stanowisk w Polsce*, manuscript of doctoral dissertation, Department of Forest Climatology, Agricultural University, Cracow.

Wójcik G., Majorowicz J., Marciniak K., Przybylak R., Šafanda J., Zielski A., 1999, *Temperatura powietrza w Polsce Południowo-Zachodniej w okresie XVII-XX w. w świetle danych klimatologicznych, geotermicznych i dendroklimatologicznych*, [in:]: *Zmiany i zmienność klimatu Polski: Ich wpływ na gospodarkę, ekosystemy i człowieka*, Łódź, 305-315.

Zielski A., 1997, *Uwarunkowania środowiskowe przyrostów radialnych sosny zwyczajnej (Pinus sylvestris L.) w Polsce Północnej na podstawie wielowiekowej chronologii*, Wydawnictwo UMK, Toruń, pp. 127.

Zui V. I., 1999, *Climate Change in Belarus Derived from Thermograms*, Lithosphere, 10-11, 105-112.

Gabriel Wójcik, Kazimierz Marciniak, Rajmund Przybylak
Department of Climatology
Institute of Geography
Nicholas Copernicus University
Toruń
Poland

Andrzej Zielski
Dendrochronological Laboratory
Institute of Ecology and Environmental Protection
Nicholas Copernicus University
Toruń
Poland

Jacek Majorowicz
Northern Geothermal Consultants
Edmonton
Canada

Jan Šafanda
Geophysical Institute
Czech Academy of Sciences
Praha
Czech Republic