Chapter 8
Geophysical Data

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8.1 Introduction

The thermal "memory" of the Earth under its surface permits the reconstruction of a long-term ground surface temperature history (GST). Data comes from temperature profiles measured in fluid-filled deep wells. In recent decades the Functional Space Inversion (FSI) technique has mostly been used (Shen and Beck 1991; Shen et al. 1995) for this purpose in variety of regional, continental and global studies (e.g. Čermak 1971; Lachenbruch and Marshall 1986; Harris and Chapman 1998, 2001; Pollack and Huang 2000; Majorowicz et al. 2004a; Bodri and Čermak 2007).

Reconstructions of GST histories using the FSI method usually have a low time resolution, which gradually deteriorates as the elapsed time increases. Such behaviour is a result of the diffusive propagation of the surface temperature changes causing the decrease of the temperature signal with increasing depth. As a result, the reconstructed GST using inversion techniques is averaged for longer and longer periods the further back we go. Harris and Chapman (1998) have proposed a different approach to the method. According to them, the most realistic application of the geothermal method is its use in determining average GST prior to the period of instrumental observation. They called their method "Pre-observational Mean Temperature" (POM). In the accepted model it is assumed that annual GST variations in the period of instrumental observation are the same as air temperature variations measured in a standard meteorological station. The pre-instrumental air

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temperature mean and its offset from the GST is determined by the best fit between the measured and synthetic anomalies of rock temperature with depth, when the POM is used together with measured air temperature series in calculating the synthetic profile.

Recently, reconstructions of the GST history for Poland using well temperature profiles in equilibrium wells have been constructed and compared with proxy and instrumental records of recent centuries climatic change (Majorowicz et al. 2001, 2004b, 2008; Šafanda et al. 2004). First results were based on precise temperature logs in south western Poland in the Sudets region The results came from well temperature logs taken in an observational well, sufficiently old to be in thermal equilibrium, of the Polish Geological Institute by the Geothermal group of the Geophysical Institute of the Czech Academy of Sciences. These logs followed earlier work on GST history from temperature logs taken south of the border in Czech Republic where GST warming signatures were derived using inversion techniques (Šafanda et al. 1997).

In this paper, we present a summary of the results of the borehole temperature logs across Poland (Fig. 8.1) derived GST history for the last 500 years. We compare it with the longest homogenised Surface Air Temperature (SAT) series of Warsaw (Lorenc 2000) station, where the observations started in 1779.

8.2 Review of GST Reconstruction in Poland Using Geothermal Data

Majorowicz et al. (2001, 2004b, 2008) and Šafanda et al. (2004) analysed available temperature logs for Poland, deriving the amplitude of the temperature change in recent centuries (Majorowicz et al. 2001, 2004b), as well as the long term climatic change of the Pleistocene-Holocene transition and the recent climatic changes of the last 100 years (Šafanda et al. 2004; Majorowicz et al. 2008). The FSI technique was used. It permitted reconstruction of the GST for the last 500 years (Majorowicz et al. 2001, 2004b). Comparison of the GST with the recently homogenised annual air temperature records from Warsaw (Lorenc 2000) and a summary of other proxy and instrumental records through Poland (Przybylak et al. 2005; Wójcik et al. 1999, 2000) showed that the all temperature profiles during the last 200 years were very similar. The amplitude of GST warming deduced from the individual inversions of well temperature data using the FSI method was (0.9°C ± 0.3°C). The inversions of the deep continuous logs and of the deep accurate temperature depth profiles showed excellent agreement with the homogenised Warsaw temperature time series (Majorowicz et al. 2004b). However, when shallow accurate temperature logs from the upper 150 m were inverted, the minimum GST shifted towards the beginning of the twentieth century in comparison with GST histories from the deep logs and the Warsaw temperature time series. The spurious minimum of the GST history was interpreted as being created artificially by the use of the inversion procedure on a temperature profile of restricted depth.

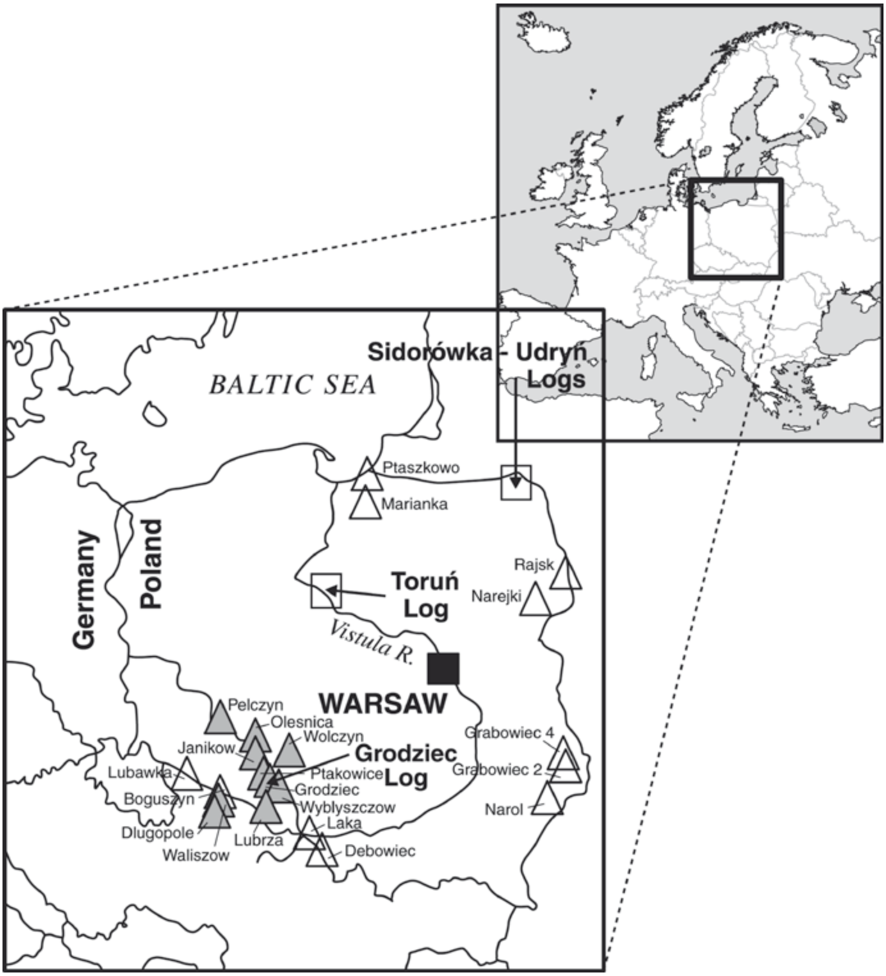

Fig. 8.1 Location of source data used in the present paper: *unfilled triangles* – boreholes with continuous temperature logs (11 deep wells with continuous industrial temperature logs done in 1970th); *filled triangles* – high precision point temperature logs taken in equilibrium observational wells in 1996; *open squares* – deep temperature logs taken after 2000 (Toruń 1 in 2005 -continuous log and 2006 precise point logs and Sidorówka in 2003); *black square* – long-term series of air temperature from Warsaw. All wells were used for the reconstructions presented in Fig. 8.3

Vertical distribution of transient mean anomaly of rock temperatures for Poland from continuous temperature profiles from deep >0.5 km wells allowed GST- POM reconstructions, using the method of Harris and Chapman (Harris and Chapman 1998). These were used for comparison with other proxy and instrumental records of change (Przybylak et al. 2005). The history of annual air temperature in Warsaw (Lorenc 2000) and the most probable long-term mean of the pre-observational GST history (i.e. that which best fits the observable temperature anomalies with the depth) compared well (Przybylak et al. 2005, see their Fig. 7B). The difference calculated between the mean temperature for the period 1951–1981 and the mean temperature for the pre-observational period (prior to 1779) was found to be 1.53°C. The modelling studies indicated that the contemporary long-term mean of the annual air/ground temperature in Poland is significantly higher (>1.5°C) than the long-term mean from the period 1500–1778. This difference is about two times greater than its analogous value calculated from borehole temperatures located in the Northern Hemisphere (0.7°C; Harris and Chapman 2001). It is also greater than the GST increase for SW Poland calculated using the FSI technique (some 1°C; Majorowicz et al. 2001, 2004b).

It seems that one reason for this divergence of the results in Poland might be the differences in the assumptions that are inherent in both methods. Harris and Chapman's method is based on the assumption that the range of GST change in the instrumental period of observation is the same as the range of air temperature change measured at meteorological stations. In the FSI technique, reconstruction of the GST history is obtained using measurement of rock temperature in industrial wells from the surface to 300–500 m depth.

The assumption in Harris and Chapman's method used by Przybylak et al. (2005) – that changes in air temperature are similar to changes in the GST – may not apply to all of the well sites, since changes in land use may have occurred. In such locations and where systematic snow cover has changed, the assumption of Harris and Chapman, that GST changes match SAT changes, may not be valid. It was found (Skinner and Majorowicz 1999) that anthropogenic changes to land surface, like clearing for farming can influence surface temperature change and temperature-depth anomaly. However, in Poland land changes are not as recent as in Western Canada and it was observed (Majorowicz et al. 2004b) that for the range of observed time series FSI reconstructed temperature variations from deep precise well logs agree very well.

8.3 GST History from Joint Inversion

Considering together the two sets of profiles, namely 11 deep profiles measured in the 1970s and 12 shallower profiles measured in the 1996–2006 period, enables us to detect confidently both the long-term and the recent signals of the GST history inherent in the data. The logs are shown graphically in the Appendix part (Fig. 8.2a–d). Their location is shown in Fig. 8.1.

The former set of about 500 m deep temperature logs documents the subsurface temperature field by the end of the 1970s, and they can provide information on the surface temperature variations in the second half of the last millennium, but the signal of the last 30–50 years before present is missing, as some of the temperature profiles start 30–50 m below the surface only. On the contrary, the latter set of mostly 100–300 m deep recent profiles contains signatures of the most recent variations, the reconstructed amplitude and timing of which can be biased due to uncertain estimates of the deeper, steady-state part of the profile (see Fig. 6b in Majorowicz et al. 2004b). In the case of the joint inversion, the steady-state part is provided by the deep profiles.

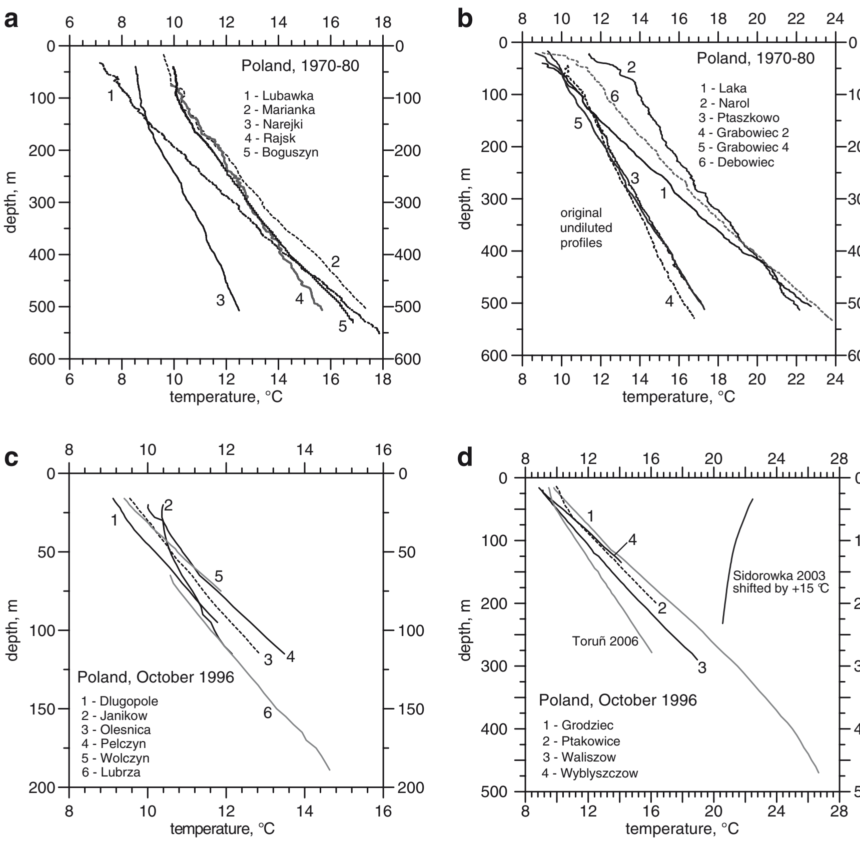

Fig. 8.2 (**a**–**d**) Thermal logs from Poland

The two joint inversions of the all 23 profiles shown in Fig. 8.3 differ in a choice of a priori standard deviations of the logged temperature data. The first choice of 0.5°C reflects a conservative estimate of a measurement precision of the ten profiles from the 1970–1980 period. The second choice distinguishes between these ten low precision logs (SD of 0.4°C) and the remaining high precision, more recent logs (SD of 0.1°C). As can be seen from Fig. 8.3, the corresponding GST histories differ appreciably only in the most recent history of the last 50 years, where considering the small SD of 0.1°C enabled extraction of the warming signal contained in the high precision logs. The inversion results suggest a gradual warming by 0.4°C since the beginning of the nineteenth through the middle of the twentieth centuries, followed by a more rapid warming by another 0.4°C by the end of the twentieth century.

The joint inversion of the whole set of the available profiles guarantees a robustness of the results, but on the other hand it may lead to suppressing amplitudes of the reconstructed GST variations. Therefore, we carried out also a joint inversion of

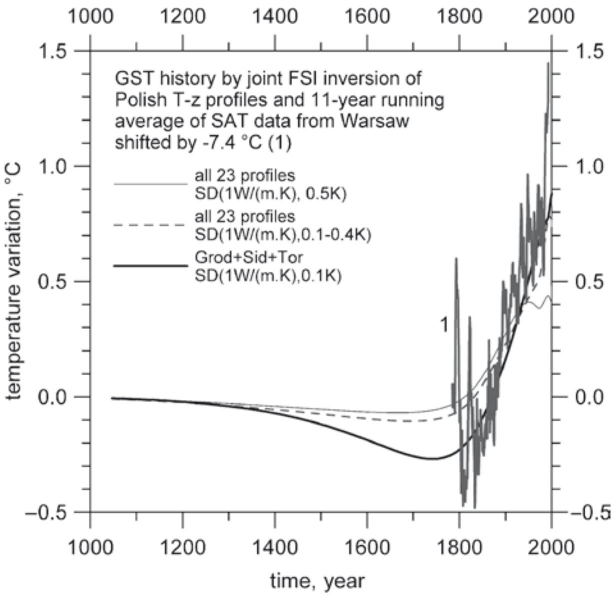

Fig. 8.3 Reconstruction of ground surface temperature (°C) (GST) history for Poland compared with homogenised instrumental temperature series from Warsaw (11-year running average) (Lorenc 2000). Note that Warsaw series is shifted by −7.4°C

three selected high precise temperature logs from wells at least 20 years in rest after drilling, namely that from boreholes Grodziec (16 m–470 m deep), Toruń (16 m–278 m) and Sidorówka (34 m–232 m), which span Poland from SW to NE. The results confirm the warming trend evidenced by the inversion of the all 23 logs. In addition to it, they indicate a GST minimum in the middle of the eighteenth century, followed by a gradual warming, which accelerated in the last decade of the twentieth century. An overall amplitude of the warming is 1.0°C–1.2°C.

Having in mind the decreasing resolution power of the geothermal method when going back in time, we see very good correspondence between the reconstructed history and the homogenised SAT series from Warszawa meteorological station (Lorenc 2000). The 11-year running average of the Warszawa series shifted by −7.4°C is superposed with the reconstructed history in Fig. 8.3.

8.4 Concluding Remarks

A very good correspondence of the results has been found between reconstructed series of annual mean GSTs and mean seasonal air temperatures reconstructed using documentary evidence from the longest series in Poland. Geothermal logs indicate that the ground surface temperature (GST) minimum in the middle of the eighteenth century is followed by a gradual warming, which accelerated in the last decade of the twentieth century. An overall amplitude of the warming is 1.0°C–1.2°C.

Other proxy records (Przybylak et al. 2005) also showed that the twentieth century was exceptionally warm. All mean winter 10-year air temperatures in the period 1501–1840 were colder than in the twentieth century. Anomalies of the majority of mean decadal temperatures oscillated between −2°C and −3°C in comparison with the 1901–1960 mean. On the other hand, summers were generally slightly warmer than in the twentieth century. This would suggest that high warming GST derived from inversion of well temperature logs was mainly non-summer driven.

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