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Climatic changes in the Urals over the past millennium. An analysis of geothermal and meteorological data

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Abstract

This investigation is based on a study of two paleoclimatic curves obtained in the Urals (51–59° N, 58–61° E): i) a ground surface temperature history (GSTH) reconstruction since 800 AD and ii) meteorological data for the last 170 years. Temperature anomalies measured in 49 boreholes were used for the GSTH reconstruction. It is shown that a traditional averaging of the histories leads to the lowest estimates of amplitude of past temperature fluctuations. The interval estimates method, accounting separately for the rock's thermal diffusivity variations and the influence of a number of non-climatic causes, was used for obtaining the average GSTH.

Joint analysis of GSTH and meteorological data bring us to the following conclusions. First, ground surface temperatures in the Medieval maximum during 1100–1200 was 0.38 K higher than the 20th century mean temperature (1900–1960). The Little Ice Age cooling was culminated in 1720 when surface mean temperature was 1.58 K below than the 20th century mean temperature. Secondly, contemporary warming began approximately one century prior to the first instrumental measurements in the Urals. The rate of warming was +0.25K/100years in the 18th century, +1.15 K/100years in the 19th and +0.75 K/100years in the first 80 years of the 20th. Finally, the mean rate of temperature warming increased in final decades of 20th century. An analysis of linear regression coefficients in running intervals of 11, 21 and 31 years, shows that there were periods of warming with almost the same rates in the past, including the 19th century.

1 Introduction

One of the attribution approaches of recent climatic changes is based on studying instrumental climate records over periods of minimum anthropogenic impact and comparing them with modern climatic changes (Hansen and Lebedeff, 1987). However, the time-limitedness of meteorological records makes it impossible to assess normal

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climate characteristics and long-term variability (for several hundreds years). Temperature measurements in boreholes allow reconstruction of the ground surface temperature history (GSTH) over periods of several hundred to several thousand years. The purpose of our investigation is to reconstruct climatic history of the past 1000 years in the Middle and South Urals and to compare climate characteristics of the pre-industrial period (the 9th–19th centuries), when anthropogenic impact was almost insignificant, with those of the second half or the last quarter of the 20th century.

2 Geothermal data and reconstruction

More than two hundred temperature logs in ore-prospecting boreholes of the Urals have been logged since the 1970s. From these, we have selected 49 borehole temperature logs in compliance with the following criteria: (a) depth of recording is not less than 700 m; (b) no evidence of ground water flow; (c) no sharp contrasts of rock thermal properties; and (d) location within a region characterized by a single geological structure and common climatic history. Temperature logs included in the final sample were obtained from the boreholes drilled mainly on the eastern slope of the Middle and Southern Urals (51–59° N, 58–61° E – Fig. 1), where Paleozoic crystalline rocks crop out at the surface.

The left panel in Fig. 2 gives examples of borehole temperature logs included in the final sample. As the figure shows, the temperatures increase with depth almost linearly. Such temperature behaviour agrees with conductive heat transfer in thermally homogeneous media. Variations from the linear law are considered as temperature anomalies associated with climatically dependent variations of surface temperatures. A clearer understanding of the nature of these anomalies can be gained by reducing the measured borehole temperature logs (Fig. 2-right). The reducing procedure involves linear approximation of the lower section of a borehole temperature log (bearing interval) by the least-squares method, linear trend extrapolation to the earth surface, and by computing the difference between measured and extrapolated temperatures.

To standardise the interpretation procedure we used an identical bearing interval of 720–900 m for all the borehole temperature logs.

A reconstruction of ground surface temperature histories (GSTH) for each borehole temperature log was obtained by solving the heat conductivity boundary problem for thermally homogeneous media in relation to unknown parameters of the boundary condition at the surface. The algorithm of borehole temperature inversion, used in this study (Demezhko and Shchapov, 2001), allows reconstructions of GSTH as a step function with uneven time intervals: the duration of the intervals increase into the past. The pattern of reconstructed GSTHs looks much the same: all reconstructios have temperature minima between 1600 and 1900 yrs and temperature maxima between 800 and 1700 yrs. The maxima approximately correlate with the Medieval Warm Period (MWP), and the minima with the Little Ice Age (LIA). However, dates of the extremes vary. There are two principal causes for disagreement of the extremes: i) joint influence of a number of non-climatic causes (ground water flow, surface relief, changes in vegetation and snow covers); and ii) variations of mean rock thermal diffusivity from one borehole to another. The coefficient of thermal diffusivity a dictates the rate of thermal wave propagation into rocks. In fact, the history argument is not time but the product of $a \cdot t$, where t is the time interval between the climatic event and the date of thermal logging (years ago). A single value of the coefficient of thermal diffusivity is generally used in the palaeoclimatic analysis of several borehole temperature logs. In our case we took the mean for crystalline rocks of the Urals to be $a = 10^{-6}\ m^2/s$ (Demezhko, 2001). The actual variations of a are equivalent to time-scale extension or reduction from the date of logging. Non-climatic causes reveal themselves as an additional low-frequency noise. Hence the reconstructed temperature history is the sum of the true history over the time scale (extended linearly in an arbitrary manner) and low-frequency noise.

To obtain regional characteristic of GSTH we used the interval estimates method proposed by Demezhko et al., 2005, who showed that traditional averaging of individual GSTHs (minimum estimate) yield significantly underestimated amplitudes. Maximum estimates take into account the real position of minima and maxima identified as LIA and MWP on the time scale. Ignoring the presence of non-climatic noise in the initial data makes maximum estimate too high. The optimum estimate curve lies between minimum and maximum estimates and it's position depends on the signal-to-noise ratio in the initial data. In our case the signal-to-noise ratio is equal to 1.25 and optimal GSTH curve is close to the maximal estimate. Temperature differences between the 20th century (1900–1960), LIA minimum (1720 AD) and MWP maximum (1200 AD) calculated according to interval estimates method are summarized in Table 1.

The optimal GSTH has sufficiently higher amplitude of temperature variation than the same obtained earlier by the partially overlapped sample of geothermal data (Pollack et al., 2003). For example, temperature difference between 1720 and 1960 AD in the Urals according to (Pollack et al., 2003) is about 0.7 K – two times less than the optimal estimate. There are a number of reasons for such disagreement: the mentioned paper used temperature profiles of less depth, the choice of reconstruction parameters, and the traditional averaging of individual GSTHs.

Under usual averaging of the GSTH curves applied by a number of researchers (Tyson et al., 1998; Pollack et al., 2003; Pollack and Smerdon, 2004) non-correlated noise is efficiently eliminated. In doing so the true amplitude is also reduced, i.e. the estimate of the mean temperature history is too low. In such cases an optimum procedure can be employed for deriving interval estimates of temperature amplitudes. Such estimates can be derived, provided that either non-climatic noises or variations in temperature diffusivity are taken into account separately.

3 Meteorological data

One of the basic characteristics representative of global climatic changes is surface-air temperature. Regular air temperature measurements have been taken in the Urals since the 19th century. Between 1930 and 1980 there were more than 150 weather stations in the Ural Region, but in the 1990s their number became considerably less. Our analysis involves data for 43 weather stations situated in the close vicinity of boreholes with geothermal information recorded (Fig. 1).

To evaluate regional variability of mean annual air temperatures we used the averaging procedure that takes into account the differences in the length of records and in the temperature constant – a latitudinal trend (Hansen and Lebedeff, 1987). Before averaging, each record was reduced by subtracting an individual value of temperature, the anomaly records were then averaged in the usual manner (Fig. 3). A synchronous pattern of the reduced records suggests that the eastern slope of the Middle and Southern Urals can be treated as a region of identical climatic history.

4 Analysis of geothermal evidence and meteorological data

Our comparative analysis is based upon two averaged datasets: surface air temperature over the past 170 years and optimum estimation of ground surface temperature history over the past 1200 years obtained from geothermal evidence. The reliability of instrumentally measured data is beyond doubt. As to geothermal estimates, their reliability calls for additional independent proofs. Toward such ends, the GSTH reconstruction supports the usual conception of climatic changes during the past 1200 years: according to pollen data the mean annual temperature in the MWP maximum (880-1200) eastwards and westwards of the Urals was 0.7–0.2 K warmer than modern values (Klimenko, Klimanov, 2000). The GSTH curve also may be directly compared with meteorological data (Fig. 4) during their period of overlap (1832–1985). The mean GSTH and air temperature rates of increase are approximately equal and come to 0.8 and 0.9 K per 100 years. A sharper temperature rise spanning the years 1970 to 1985 is also sufficiently reconstructed.

It should be noted that good agreement between ground and air surface temperatures (temperature trends) is not obligatory as a proof of reliable GSTH reconstructions. It is known that mean annual soil-air temperature difference in nothern regions is determined mainly by the insulation effect of snow cover (Beltrami and Marechal, 1991, Bartlet and Chapman, 1998, Demezhko, 2001, Smerdon et al, 2006). Mean annual ground surface temperature may changes due to changing snow characteristics, even if air temperature is stable. Demezhko (2001) demonstrated the warming effect of snow in the Urals rises under conditions in which snow cover depth and annual amplitude of air temperature increased, while the mean annual air temperature decreased. During the last century, mean annual precipitation slowly increased and annual amplitude of air temperature decreased. The amount of snow in the Urals correlates with annual precipitation. Thus, the mean anuual soil-air temperature difference was relatively stable and the rate of GST increase was approximately equal to that of air temperature.

The shape of the optimum GSTH curve over the past 1200 years (Fig. 4) shows that surface temperatures in the MWP maximum (from 1100 to 1200) were 0.38 K warmer than the mean in the 20th century (from 1900 to 1960). Then LIA cooling events followed with a culmination in about 1720 when ground surface temperatures were 1.58 K colder than modern values. It should be noted that the two LIA phases – cooling and warming – were not symmetrical since the rate of cooling was slower. A similar regularity is observed for larger-scale phenomena (close to 100 000 years) such as Quaternary glacial/interglacial succession. Perhaps this is also indicative of the similarity of the physical mechanisms responsible for climatic variations so different in their scale. When analyzing the GSTH curve, one should bear in mind that geothermal information to estimates temperatures averaged over increasingly longer periods back into the past. Any point on the GSTH curve (t, yrs ago) represents a temperature averaged over the period $t \pm t/3$ yrs ago (Demezhko, 2001). Thus, the actual trend of cooling might be more complicated and interrupted repeatedly with occasional warming events. Warming begun after the temperature minimum in 1720 was also irregular. Warming averaged +0.25 K/100 yrs in the 18th century, +1.15 K/100 yrs in the 19th century, and +0.8 K/100 yrs in the first eighty-five years of the 20th century.

It may be concluded that a temperature rise in the 20th century is the final stage of global and natural warming upon termination of the anomalously cold LIA. In the first half of the 21st century, temperatures are identical to those from a thousand years before. Against this background, a sharper temperature rise during the past thirty years, particularly noticeable in the meteorological data, seems to be anomalous. But is it actually so? To answer this question we must consider in greater detail the averaged set of surface-air temperatures.

To estimate the average rates of air surface temperature changes over the periods of different duration we applied the method of linear approximation. The average rate of air temperature changes over the period from 1930 to 2001 appeared to be +1.6 K/100 yrs. Interestingly, the average rate calculated individually for weather stations near the larger cities (Nizhny Tagil, Ekaterinburg, Chelyabinsk, Ufa, Magnitogorsk, Orenburg) is essentially not different from that in the entire data sample. This suggests that urban heat islands, which certainly exist, are rather insignificant and do not affect air surface temperatures recorded at weather stations situated in the suburbs.

One more interesting feature is revealed in the estimates of average rates in different latitudinal zones. From the south to the north the rates of warming decrease: 50–53° N +-2.1 K/100 yrs, 53–56° N -+1.6 K/100 yrs, 56–59° N -+1.4 K/100 yrs. This is contradictory to the wide-spread but insufficiently grounded opinion that amplitudes of the global climatic changes increase with a geographical latitude.

An idea of the temperature behaviour in time is given by the plots of slope coefficient of linear regression calculated in the running intervals of different length (Fig. 5). As the length grows, the amplitudes of the rates show a regular decrease. The sharpest warming took place during the 11-year period between 1860 and 1870 (+15.2 K/100 yrs). A similar period nearest to us fell on 1985 to 1995 (+15.0 K/100 yrs), after which the rate of warming came to be slower, with subsequent cooling. Among the longest periods the most anomalous were 21-year spans 1863–1983 (+6.1 K/100 yrs), 1860–1880 (+5.7 K/100 yrs) and the other six intervals when the rates of warming were somewhat slower. The most anomalous 31-year periods fell on 1968–1998 (+4.5 K/100 yrs) and 1965–1995 (+4.5 K/100 yrs). In this case the difference from previous anomalies, with the rates of warming not more than +2.6-+3.4 K/100 yrs, seems to be wider. However, this does not mean an anomalous trend of climate history during the period nearest to us. One can judge the significance in the differences of the rates of warming from the estimates of confidence intervals. The confidence intervals calculated from the t-distribution (at 95-percent confidence), are shown in Fig. 5 with vertical straight lines. For the most anomalous periods the confidence interval lies within ±3 K/100 yrs; naturally, this makes the difference of 1–1.5 K/100 yrs unimportant.

Thus, the regression analysis of the air surface temperature records gives no grounds to speak about anomalous, presumably anthropogenic, warming in the Urals over the last decades of the 20th century.

5 Conclusions

1. Geothermal evidence (borehole temperature logs) recorded in the Urals and the developed procedure of their interpretation enable the surface temperature history over the last 1200 years to be reliably estimated. According to this estimation, surface temperature in the Medieval Warm Period (MWP) spanning 1100 and 1200 AD was 0.38 K warmer than the mean temperature of the 20th century (1900–1960) and surface temperature in the Little Ice Age in approximately 1720 AD was 1.58 K cooler.

2. A combined analysis of geothermal reconstructions and meteorological data (air surface temperatures) showed that warming observed in the 20th century took place at somewhat less rates than in the 19th century and is presumably the termination of a natural climatic process of warming after the anomalous cold LIA. On retention of the natural rates in the first half of the 21st century the achieved values are to be identical to those we find a thousand years before.

3. In the 20th century the rates of warming are regularly decreasing from the south to the north. This feature is contradictory to the usual notions of global climatic changes dependent on a geographical latitude.

4. During the last decades of the 20th century the average rate of warming was growing. However, the statistical analysis shows that there were the periods of warming with almost the same rates occurred repeatedly in the past, including the 19th century.

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Slight differences among them are statistically unimportant.

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References

Bartlett, M. G. and Chapman D. S.: The timing, depth, and duration of snow events: implication for ground surface temperature histories recovered from boreholes, 1998 AGU Fall Meeteng abstracts, San Fr., F842, 1998.

Beltrami, H. and Mareshal, J.-C.: Recent warming in eastern Canada inferred from geothermal measurements, Geophys. Res. Lett., 18, 4, 605–608, 1991.

Demezhko, D.Yu. and Shchapov, V.A.: 80 000 years ground surface temperature history inferred from the temperature-depth log measured in the superdeep hole SG-4 (the Urals, Russia), Global and Planetary Change, 29 (1–2), 219–230, 2001.

Demezhko, D. Yu.: Geothermal method for palaeoclimate reconstructions (examples from the Urals, Russia), Ekaterinburg, UB RAS, 144 p., (in Russian), 2001.

Demezhko, D. Yu., Utkin, V. I., Shchapov, V. A., and Golovanova, I. V.: Variations in the Earth's Surface Temperature in the Urals during the Last Millennium Based on Borehole Temperature Data, Doklady Earth Sciences, 403, 5, 764–766, 2005.

Hansen, J. and Lebedeff, S.: Global trends of measured Air surface temperature, J. Geophys. Res., 92, 13 345–13 372, 1987.

Klimenko, V. V., Klimanov, V.A.: Climate of the North Hemisphere in the Medieval Optimum. Doklady Akademii Nauk, 371, 4, 539–543, (in Russian), 2000.

Pollack, H. N., Demezhko, D. Yu., Duchkov, A. D., Golovanova, I. V., Huang, S., Shchapov, V. A., and Smerdon, J. E.: Surface temperature trends in Russia over the past five centuries reconstructed from borehole temperatures, J. Geoph. Res., 108(4), 2180, doi: 10.1029/2002JB002154, 2003.

Pollack, H. N. and Smerdon J. E.: Borehole climate reconstruction: Spatial structure and hemispheric averages, J. Geoph.Res., 109 D11106, doi:10. 1029/2003JD004163, 2004.

Smerdon, J. E., Pollack, H. N., Cermak, V., Enz, J. W., Kresl, M., Safanda, J., and Wehmiller J. F.: Daily, seasonal, and annual relationships between air and subsurface temperatures, J. Geophys. Res., 111, D07101, doi:10.1029/2004JD005578, 2006.

Tyson, P. D., Mason, S. J., Jones, M. Q. W., and Cooper, G. R. J.: Global warming and geothermal profiles: The surface rock-temperature response in South Africa, Geophys. Res. Lett., 25, 14, 2711–2713, 1998.

Table 1. Interval estimates of GST differences.

Estimate	Temperature difference, K	
	XX(1900–1960)-LIA(1720)	XX(1900–1960)-MWP(1200)
Minimum	1.24±0.15	–0.07±0.12
Maximum	1.74±0.13	–0.42±0.14
Optimum	1.58	–0.38

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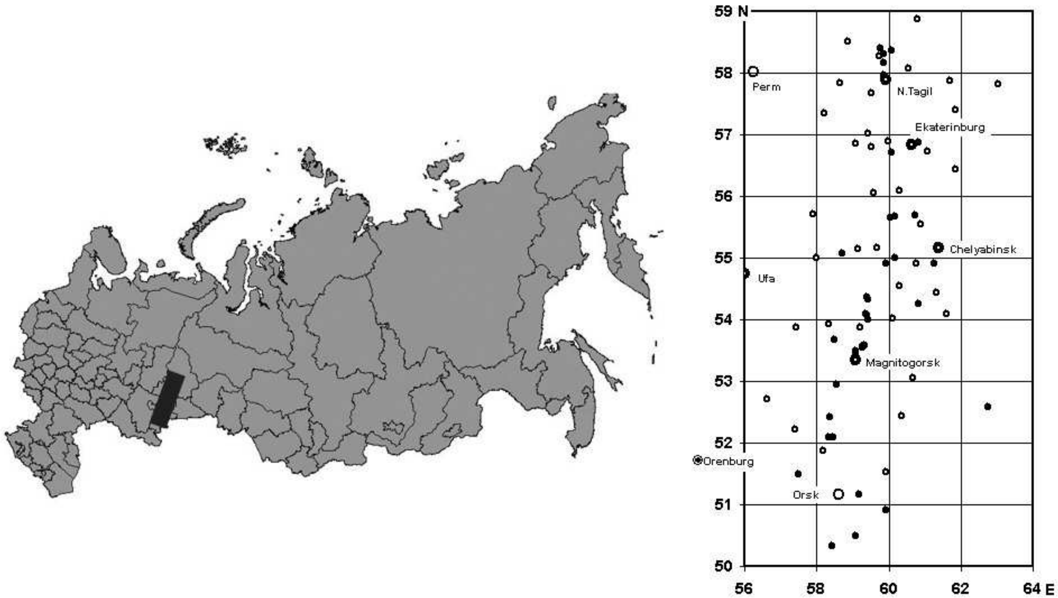

Fig. 1. Location of weather stations (white circles) and boreholes (black circles).

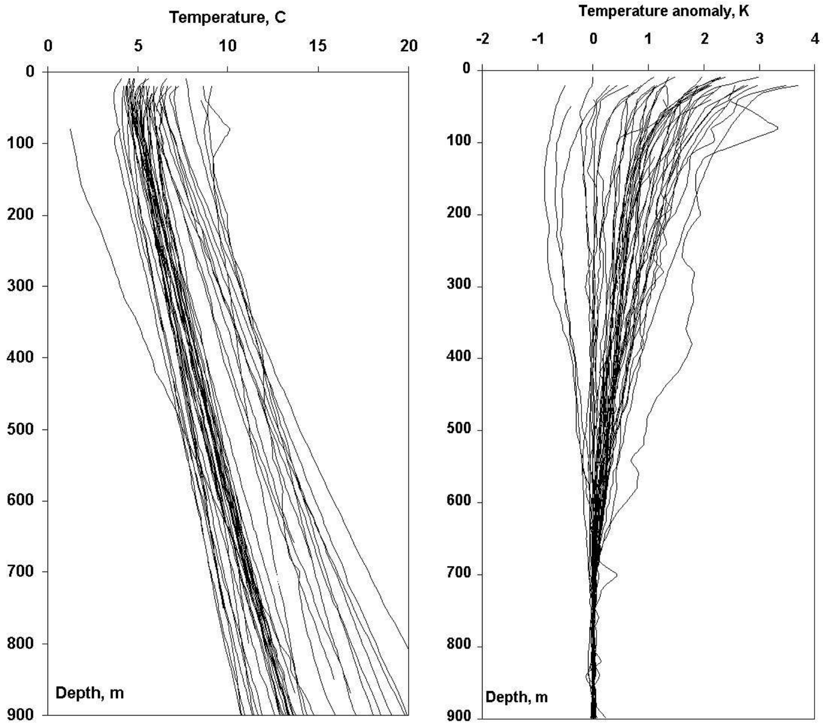

Fig. 2. Borehole temperature logs used in this study (left) and temperature anomalies calculated by reducing borehole temperature logs (right).

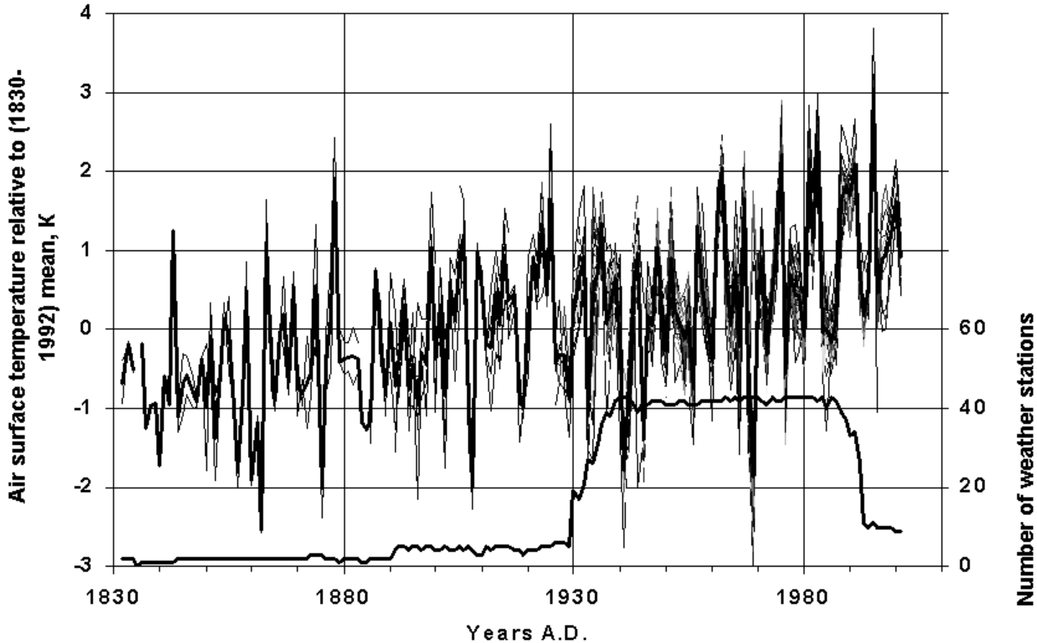

Fig. 3. Reduced air surface mean annual temperatures recorded in weather stations in the Middle and South Urals. The averaged record is shown with a bold solid line. A plot presenting the number of weather stations with the data on each time interval is given at the bottom of the figure.

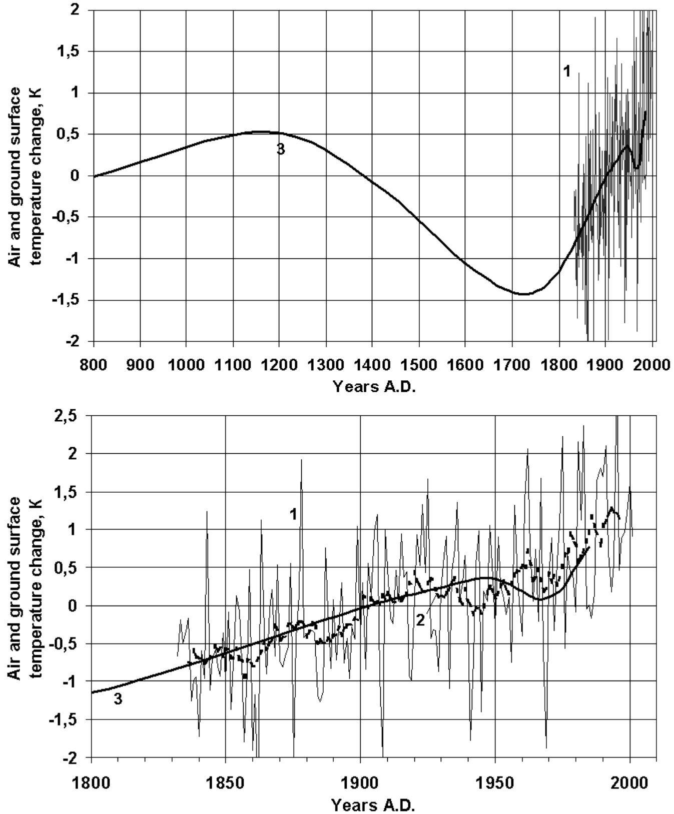

Fig. 4. Comparison of geothermal and meteorological data. 1 – the reduced averaged record of air surface mean annual temperatures; 2 – the same record smoothed out in the running 11-year interval; 3 – reconstructed ground surface temperatures (GSTH). The GSTH curve is slightly shifted along the temperature axis to enable an easier comparison.

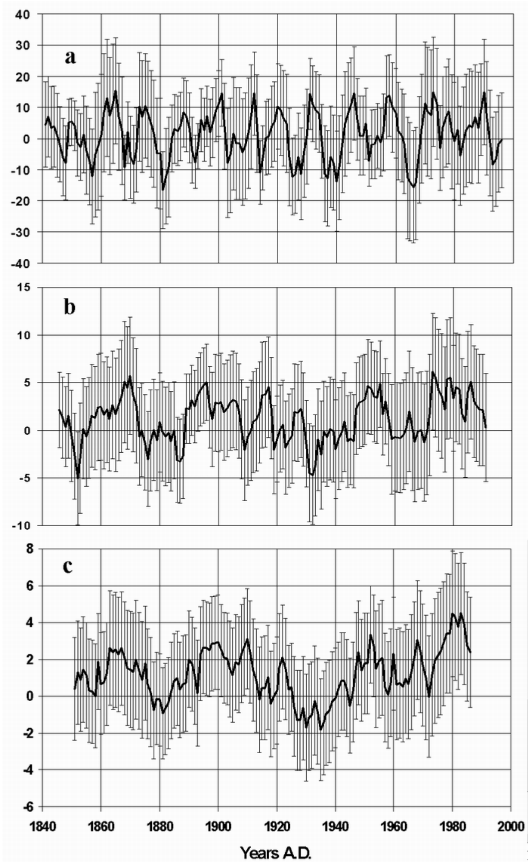

Fig. 5. Slope coefficients of linear regression (average rates of air surface temperature variations) calculated in 11-year (top), 21-year (middle) and 31-year (bottom) running intervals. Vertical lines show 95-percent confidence intervals.