

Interactive comment on “Climatic changes in the Urals over the past millennium. An analysis of geothermal and meteorological data” by D. Yu. Demezhko and I. V. Golovanova

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In their interactive comments J. Majorowicz (Referee), Anonymous Referee #1, Anonymous Referee #2 and R. Donner raised some points, which partially overlapped. We have classified these points in 4 blocks. Additionally, some items were raised individually, which we have also responded to.

1. The Interval estimate method realization.

R. Donner: *“How is the uncertainty of the LIA and MWP positions within the reconstructed data taken into account?”*.

Anonymous Ref #2: *“In particular, how optimum curve GSTH is determined?”*.

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According to the method (Demezhko et al., 2005) in order to obtain the maximal estimate of the mean amplitude of the LIA temperature minimum, which takes into account variations in thermal diffusivity and ignores nonclimatic noise, it is enough to calculate the difference between the temperatures of the 20th century (first 60 years) and the temperatures in the minima identified as LIA for all GSTH curves. The mean difference is then attributed to the mean date. This procedure should also be performed with the MWP maximum.

The optimal temperature history takes into account different statistical properties of the distortions that are introduced by nonclimatic noise and variations in thermal diffusivity. It is based on statistical analysis of the distribution of the LIA and MWP dates. This analysis allows an evaluation of the contribution of nonclimatic causes in the total variance of the dates identified as LIA or MWP. Evaluation of variance caused by nonclimatic noise is the basis for numerical modeling using the Monte Carlo method. The original (“real”) GSTH curve including the MWP and LIA is superimposed with low-frequency noise, which operates in the same frequency range as the “real” curve. The amplitude of the noise (signal to noise ratio) was adjusted so that the standard deviation of dates was equal to the standard deviation of the dates caused by nonclimatic factors. The knowledge of signal to noise ratio allows a correction of the overestimated maximum temperature history.

2. Reliability of the reconstruction.

J Majorowicz: *“how accurate well temperature reconstructions are when it comes to depiction of the Middle Ages Optimum”. “For a typical log GST is estimated as an average over about $0.5-0.7\tau$ ”. “to show error bars on the reconstruction shown in Fig. 4. - upper panel”*

R.Donner: *“Statements about the absolute temperature during the MWP and LIA should be accompanied by error bars in Fig. 4, which should involve not only the variations of the estimated values between the different boreholes, but also the uncer-*

tainties of the single reconstructions which are probably largest in the older part of the record”.

Anonymous Ref #2: “the statement “no evidence of water flow” needs more argumentation, like heat flow data versus depth, resistivity (salinity) logs, geochemical composition of ground water with depth, radiogenic heat generation , elevation amplitude of well head, etc”. “how much ground surface temperature changes repeats change of air surface temperature on time scales from century-long and more?”. “it has been shown, that the major factors determining mean annual soil-air temperature difference in Ural are: the snow cover depth, the annual amplitude of air temperature and the mean annual air temperature. There is no reliable evidence on how these factors varied during last millennium”.

Reliability of geothermal GSTH reconstruction is limited by two factors: physical limitations (resolution power, maximal duration) and uncertainty caused by nonclimatic noise, thermophysical heterogeneity, and water filtration. The problem of ground/air temperature interaction is not the method's problem, but the problem of paleoclimatic interpretation of reconstructed GST histories. We principally cannot evaluate the reliability of past air temperature change using geothermal method alone. We can only propose that air/surface temperature difference was relatively stable in preinstrumental period as it was in the 19-20th centuries.

According to our analysis (Demezhko, 2001, Demezhko, Shchapov, 2001) the resolution power of the paleoclimatic signal in the contemporary temperature field can be described by the parameter “relative duration” of a paleoclimatic episode (warm or cold period). “Relative duration” is the ratio of the duration of climatic episode to the time that passed from the beginning of the episode till the moment of a temperature record. Only episodes with “relative duration” > 0.5 can be resolved from the temperature field. Among them are the Wurm stage (relative duration = 0.88) and the Little Ice Age (0,82). The Medieval Warm Period cannot be resolved alone (relative duration = 0.33), but we can evaluate the average temperature conditions for the period including the Medieval

Warm Period and the Roman Optimum (200 BC - 1200 AD, relative duration = 0.64). These two periods are separated by the short Vandal Minimum (relative duration = 0.25). Our experience testing different inversion algorithms, including FSI (Golovanova et. al., 2002) shows that in order to reliably reconstruct the maximum of the Medieval Warm Period one should perform an inversion for the period not less than 3000 years ago, which demands at least 800 m temperature-depth profiles.

Concerning the uncertainty (errors) of GSTH reconstructions, our study shows that this uncertainty may be larger than commonly thought: although individual reconstructions differ substantially, the standard error of the mean does not exceed 0.12 K (We will add in the revised version a new Figure that shows individual reconstructions, minimum estimate curve with standard error bars, maximum estimate, and optimum estimate.). Differences between minimum and maximum estimates are larger (0.5K for LIA and 0.35 for MWP), and determine the main interval of uncertainty. The optimum curve presents the most probable history within the main interval of uncertainty.

3. Other (proxy) evidences of paleoclimate change.

J. Majorowicz: *"The GSTH shown from well temperatures is an obvious challenge to the so called 'hockey stick' proxy reconstructions for the Northern Hemisphere".*

Anonymous Ref #2: *"It was necessary to present and other evidences of paleoclimate change in Ural region".*

R.Donner: *"it would be interesting to systematically compare not only temperature estimates from different borehole studies, but also some complementary reconstructions based on other palaeoclimatic proxies".*

First of all, it was not our intention to challenge to anybody. But if so, we would like to introduce a new term "naildrawer" as a description of a reconstruction that looks like ours. For example, such a "naildrawer" multi-proxy reconstruction for the Northern Hemisphere was obtained by Moberg et al. 2005 (thanks to Jacek Majorowicz

for this reference). They combined tree-ring data with low-resolution proxies. The averaged low-resolution proxies curve (including ice records, borehole temperature records, pollen and diatoms in lake sediments, foraminifers and stalagmites - Moberg et al. 2005) reveals higher temperature conditions during 700-1100 A.D. as compared with the 20th century.

Paleoclimatic records from the former Soviet Union territory were summarized by (Solomina and Alverson, 2004). According to this analysis, there are two paleorecords in the Ural region besides the GST reconstructions: tree-ring based summer temperature anomalies (Briffa et al., 1995) and reconstruction of upper treeline limit variations in the Polar Urals (Shiyatov, 2003). The tree-ring summer temperature reconstruction reproduces well the high-frequency temperature variations and suppresses multicentennial variations. Our borehole temperature reconstruction is in good agreement with tree-line variations in the Northern Urals (Shiyatov, 2003). Though, treeline curve is shifted by 50-100 years (to the recent times) relative to the geothermal one. We hypothesize that it is caused by delayed responses of trees to climate change.

4. Surface air temperature data.

Anonymous Ref #1: *“ authors do not refer to any paper, so my impression is that the data are published in the present form for the first time. The number of local meteorological stations used in compiling the 170 year time series varies large. The first 40 years is based on 1-2 stations only, but the authors claim that “the reliability of instrumentally measured data is beyond doubt”.*

R.Donner: *“[Stulc et al., 1997, Golovanova et al., 2001] have already studied some time series from the region taken from the Global Historical Climatology Network. In the presented work, a corresponding reference is missing, which does not allow to evaluate the homogeneity and reliability of the considered records”. “if the authors claim “the reliability of instrumentally measured data is beyond doubt”, this statement should be accompanied by an appropriate reference”. “The averaging procedure firstly applied*

to the meteorological data involves the subtraction of an individual temperature value. The authors should mention how these values have exactly been derived.

First, we agree with the statement that “the reliability of instrumentally measured data is beyond doubt” is not an apt turn of phrase in this context. We will exclude this phrase from final text. The meteorological data are indeed published in the present form for the first time. Here we used only 5 records (of total 43) coinciding with the same in the referred papers (Stulc et al., 1997, Golovanova et al., 2001). All the records were taken from the Russian “Meteorological Bulletins”. As compared with previous studies, this sample of meteorological records is spatially more compact and the weather stations are located closer to the boreholes. The individual records were combined according to the method described in (Hansen and Lebedeff, 1987). No homogeneity tests were performed.

The uncertainty of averaged air surface mean annual temperatures can be evaluated by the standard error of mean (We will include corresponding curve in the revised version). For the period 1890-1930, the mean value of standard error is about 0.2 K, then it decreases to 0.05 K (1935-1990), and increases again in the last decade of the century.

Anonymous Ref #1 comments

Technical corrections

“With respect to the standard deviations of the reconstructed minimum and maximum amplitudes of the little ice age and the medieval warm period, I suggest to give the optimal estimates not as 1.58 K and 0.38 K, but 1.6 K and 0.4 K.

On page 8, line 24, it should be instead of “1863 - 1983” a different date, probably “1963 - 1983”.

In the revised manuscript we will account for these remarks.

J. Majorowicz advises

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1. to show a stack of their individual well inversions.

We will add a new Figure with the stack of individual reconstructions.

2. to reject some of the noisy data which they show in Fig. 2 (an example - the most right temperature depth anomaly in Fig. 2 - right panel). There are at least couple more of these which I can see at the scale provided by the figure .

All the data (including “noisy” ones) satisfy the formal criteria: depth of recording; no evidence of ground water flow; no sharp contrasts of rock thermal properties. Concerning the last two points, we accounted for only the presence of low frequency noise, because the high-frequency noise is effectively suppressed by the inversion algorithm.

Anonymous Ref #2 comments

According authors, selected for analysis temperature logs have “no evidence of water flow” - this statement needs more argumentation, like heat flow data versus depth, resistivity (salinity) logs, geochemical composition of ground water with depth, radiogenic heat generation , elevation amplitude of well head, etc. On fig. 1 I recommend to give generalized relief contour.

It is a usual practice to reject from geothermal paleoclimatic analyses the data that reveal obvious evidence temperatures disturbed by water flow. Unfortunately, there is no existing suitable technique of simultaneous hydro and paleoclimatic analyses of temperature-depth profiles (except, perhaps, in the simplest of cases - see Parkhomov and Zui, 1999, Taniguchi et al., 1999, Verdoya et al., 2007). In our analysis we suppose the absence of preferred direction of water flow. In this case the influences of upward and downward water movement are eliminated. An analysis of generalized relief cannot give the appropriate information, because the features of water filtration are determined by microrelief, and mainly by geological structure. A proxy evidence of negligible influence of ground water flow is close to zero correlation between reconstructed GSTH parameters (e.g. amplitude and date of LIA minimum) and borehole

elevation.

2. Of course black and white limitation for pictures (fig.3 and 4 for example) looks like “hand-to-scan document

We will try to account for this recommendation.

R. Donner comments

“The authors state that for their selected boreholes, the temperatures increase almost linearly with depth. In general, however, the heat induction equation involves an additional quadratic term”.

Exactly. But we have in mind an obvious deviation from linear dependence due to ground water flow and thermal properties variation. Influence of heat production in depth interval under consideration is negligible - about 0.04 K. This issue was considered in detail for the Urals rocks in (Demezhko, 2001).

“the authors claim that the depth of recordings was less than 700 m (page 3, line 12), whereas Fig. 2 shows data up to a depth of 900 m.”

We wrote: “depth of recording is not less than 700 m”

“It is not clear how the inversion algorithm of [4] copes with the fact that in the presence of non-climatic influences and measurement noise, the GSTH reconstruction is an ill-posed inverse problem. In particular, I expect that a proper reconstruction requires a suitable regularization.”

The “suitable regularization” is not entirely clear. The inversion algorithm we used does not imply any suppression based on a priori information. Regularization is based only on the feature of time intervals discretization: the duration of intervals increases while moving into the past (because a natural resolution power decreases). This is enough for suppressing high-frequency noise. The reconstructions obtained by this algorithm contain higher false climatic signal (than obtained by FSI method, for example) but they

are more comparable and suitable for further statistical analysis (see Demezhko et al., 2002, Golovanova et al., 2002).

“it is thus inappropriate to derive a trend “per 100 years” from an 11-years subsample”

Why not? We can evaluate a speed of a car as “km per hour” for a few minutes interval.

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