Clim. Past Discuss., 3, S397–S405, 2007
www.clim-past-discuss.net/3/S397/2007/

Climate of the Past Discussions

CPD

3, S397–S405, 2007

Interactive Comment

Interactive comment on "Spatial distribution of Pleistocene/Holocene warming amplitudes in Northern Eurasia inferred from geothermal data" *by* D. Yu. Demezhko et al.

D. Yu. Demezhko et al.

Received and published: 22 June 2007

We are thankful to Jan Safanda (Referee), Anonymous Referees #1 and #2 for their useful comment and interesting discussion.

Reply to J.Safanda comments

As J. Safanda justly noted, *"the main problem is a small number of data, which do not cover the crucial areas of Western Europe and Scandinavia"*. And then: *"Contrary to the authors, I would be very careful in using the spatial distribution of the PHW amplitude shown in Fig.4 as a basis for the terrestrial heat flow paleoclimatic corrections, especially in Scandinavia and Western Europe"*

We agree with this statement. Extrapolation of the obtained dependence to these areas should be considered as unreliable. We will add corresponding changes to the final paper. Due to a small number of data we also cannot exploit more physically based models. For example, we cannot use the model that accounts for the principal air mass (and heat) transfer from West to East: our experience shows that such a model demands at least one addition free parameter, but leads to statistically insignificant improvement (minimum of M-functional). The application of such models will become available with new data, especially in Western Europe and North America (at the opposite side of temperature anomaly).

"I suggest to omit two sentences on page 616, lines 14-17 "The only possible such source.. ..redistribution of solar energy" and to begin the following sentence like "One such a source could be provided by hypothesis of Karnaukhov (1994)"

We will follow this suggestion.

Technical corrections *"Table 2 lacks explanation of the last column, which definitely does not contain the references."*

We apologize for this mistake. Certainly, the last column does not contain the references, but the mean rate of temperature increasing since the Last Glacial Maximum (18000 years ago). This parameter is unnecessary in the paper and we'll omit it in the final version.

"The sentence on p.609, l.13 would make more sense, if instead of expression "..separate qualitative.." contained "..separate high quality.." "I suggest to change it (the sentence on p.613, l.19) *"like This warming influence increases with the snow cover height and with the amplitude of the seasonal air temperature variation, and decreases with the increasing mean annual air temperature"*

We will follow these suggestions.

Reply to Anonimous Referee #1 comments

We agree with the referee that the process of ground surface temperature is established through a number of complex processes. However, our main purpose is to infer very general characteristics of the PHW spatial distribution in Northern Eurasia. Obviously, these characteristics may be disturbed at coastal regions or in ice covered areas. We have found similar disturbances in Western Siberia and Yakutia north of the 68-th parallel. In order to establish the general characteristics we used practically all available and reliable geothermal estimates of PHW amplitudes. The recent estimate for the Kola Peninsula (20 K, Glaznev, Kukkonen et al., 2004) was inferred because of the necessity to correct the measured heat flow.

"Inversion results from the immediate vicinity of the Kola super-deep borehole, and the borehole itself show only moderate Weichselian temperatures which are 4 K - 7 K lower than today (Rath and Mottaghy, 2006)". "Kukkonen & Johelet (2003) find a postglacial warming of 8±4.5 K for the Fennoscandian Shield, using an extensive data set".

It is hard to judge the reliability of the obtained estimate by the abstract (Rath & Mottaghy, 2005). The amplitudes of reconstructed climatic events essentially depend on the choice of the value of the Tikhonov's regularization parameter. Joint inversion of a number of temperature profiles may also lead to an underestimate of PHW amplitude.

"Results from Outokumpu, Finland (Kukkonen & Safanda, 1996) show only about 7 K lower temperatures than today."

Unfortunately, we did not know the result from Outokumpu, Finland (Kukkonen & Safanda, 1996). Though this result was obtained for shallow boreholes (790-1100m) and under 2D heat transfer conditions it should to be mentioned. Comparatively low PHW amplitudes estimates for Outokumpu probably reflect the spatial temperature variations on the base of Scandinavian Ice Sheet.

In our opinion, the high PHW amplitude estimates in Northern Europe are quite viable and reflect the "normal" Late Pleistocene temperatures rather than the low ones. This statement is confirmed by the latitudinal reconstruction of Late Pleistocene air surface temperature distributions. The temperatures of the Late Pleistocene have been calculated by subtracting the geothermal estimates of warming amplitudes from the contemporary mean annual temperatures. Both the contemporary and Late Pleistocene latitudinal dependences were approximated by linear low. The latitude dependence in the Pleistocene has a higher temperature gradient than today (-1.1 and -0.9 K/grad N correspondently), and (it is more sufficient) a four times smaller deviation from linearity (0.05 and 0.23 K^2). Hence, the North Atlantic temperature anomaly was significantly suppressed at that time and the mean annual temperatures changed with a strong dependence on latitude (common for Europe and Siberia).

"Page 609, line 8-15: there are works which consider the variation of thermal properties, as well as their temperature dependence (Mottaghy & Rath, 2006; Rath & Mottaghy, 2005). In particular, neglecting latent heat effects may result in an overestimation of PHW". "Page 613, line 24: Assuming constant thermal properties of ice and rock should be discussed and justified. What is the influence of P-T variations?"

Rath & Mottaghy (2005) noted that the influence of latent heat effects can be neglected in the Kola area due to the low porosity of the crystalline bedrock ($<$ 1%).

We have used a very simplified model. It was proposed for the qualitative estimation of the possible temperature effects at the glacier basin. However, by means of the model we have shown that, depending on the relationship between the heat flow and the vertical ice advection velocity, the base of the glacier can either warm up or cool down. Accounting for the real distribution of ice heat properties cannot abolish this inference. For example, according to the dependence of the ice heat conductivity on the temperature (Tarasov and Peltier, 2003).

$$\lambda = 9.828e^{-0.0057T}$$

while the ice temperature increases from -25°C to -1°C, the ice heat conductivity decreases from 2.39 to 2.09 $Wm^{-1}K^{-1}$, i.e. by 12% only.

"On the same page, the authors mention that they consider these effects (regarding the second survey area) - but no further explanation/discussion is given. This could be extended."

The slowness of heat transfer processes in permafrost during PHW allows us to neglect the time derivative term in the non-steady one-dimensional heat equation. As a result, the Stefan's condition at the lower boundary of the permafrost may be considered an ordinary differential equation with respect to permafrost thickness

$$\lambda \frac{\partial T}{\partial z} - q_0 = Q \frac{dH}{dT}$$

Here, q_0 denotes heat flow in the bedrock; Q is the melting heat per unit volume; H(t) is the permafrost thickness at t moment; λ denotes thermal conductivity, which is considered equal for permafrost and bedrock. The solution of the equation allows calculation of the permafrost thickness change during PHW: ΔH and amplitude ΔT_s (Balobaev, 1991, Duchkov and Balobaev, 2001). These parameters are shown in Table 2 of the paper.

"Page 613, line 2: there is not enough data presented to support this conclusion" (no glacial trace in Scandinavian estimates)

Here we establish the absence of PHW anomalies in Fennoscandian Shield. The low PHW estimate for Outokumpu probably presents an example of such an anomaly.

"Ice sheet model: the authors mention a comparison with data from Greenland. It would be nice to see this in a plot"

We will show in the revised paper the comparison between measured and calculated (according to the model) temperature-depth profiles in the Greenland Ice Sheet. Here we used the following initial conditions: The accumulation rate (equal to the ice flow velocity) at the glacier surface 0.23 (GRIP) and 0.49 (Dye) m/year (Dahl-Jensen et al, 1998); thermal conductivity of the ice 2.17-2.23 $Wm^{-1}K^{-1}$; vertical air temperature

CPD

3, S397–S405, 2007

Interactive Comment

gradient 0.0065 K/m. Our calculations show that near GRIP the glacier warms up the rock by 8.5 K, while near Dye-3 it cools the rock down by 5.1 K due to a higher ice flow velocity. As a result, the basal temperature near GRIP is 4.8 K higher than that near Dye-3, though GRIP is situated 800 km north.

Reply to Anonimous Referee #2 comments

The main problem discussed in the review - influence of small number of data and their uneven spatial distribution on paleoclimate conclusions - is indeed one of the most important problems. But Referee #2 had made some inaccuracy - he wrote: *"If the single point in Greenland is eliminated from the dataset, how does this change the interpolation of PHW anomaly contours?"* We wrote (page 610, line 19-20): *"The isoanomalies in Fig. 2 are very imprecise: for the small sample of data used, their shape depends considerably on the interpolation method.* For this reason, we refused from interpolation and proposed another approach - physical model. In this case the influence of the small sample and uneven distribution has less importance, but certainly not negligible. As the referee has justly noted, the Greenland point has is most crucial in the dataset, which is spatially isolated from other estimates. If this point is eliminated from the dataset, the center of warming is shifted by 19 degrees east. The statistical robustness of the warming center position can be tested by means of a bootstrap technique. We generated 600 subsamples with random replacement of PHW estimates (so that any data point can be sampled multiple times or not sampled at all) and calculated the warming center position for each daughter subsample. Most of the centers (90%) are located in the submeridional zone, which coincides with M-functional minimum. We will include correspondent figure in the revised paper.

"An effort should be made to include geothermal data in an even distribution across the study area".

We used practically all existent and most reliable geothermal estimates of PHW amplitudes (for more detail - see Referee #1 comments and authors reply).

“· · · what is recorded by DELTA T values from geothermal data in northern Eurasia? · · · What effect does cover by a thick ice sheet have on DELTA T values and is this taken into account prior to comparing all of the data equally?”

In both of cases (GRIP and Northern Eurasia) DELTA T values mean “solid” surface temperature changes. Ice surface temperature change in GRIP case (not air) and rock (ground) surface temperature change in other cases. There exists a positive difference between mean annual ground and air surface temperatures due to seasonal insulation of snow cover. We discussed this question in our CP first paper (Demezhko D.Yu. and I.V. Golovanova. Climatic changes in the Urals over the past millennium. An analysis of geothermal and meteorological data. Clim. Past, 3, 1-6, 2007, www.clim-past.net/3/1/2007/). Influence of ice sheets is more complicated. Using a simple model of the temperature regime underneath the ice sheet we show that, depending on the relationship between the heat flow and the vertical ice advection velocity, the base of the glacier can either warm up or cool down. Because estimates of the ice sheet margins, timing, and other characteristics are unreliable, it is hard to account for their influence on DELTA T values. We will show the areas with unreliable geothermal estimates.

“The citation of Balobaev (1991) is not helpful for me because it is in Russian. I also suggest for the authors to plot the locations of geothermal data sites on a map which also shows the margins of the former Fennoscandian, Barents and Kara Ice Sheets.”

We will describe shortly Balobayev’s method of modeling (see above) and show the margins of ice sheets.

“I question whether the variations in geothermal data in western Siberia and Yakutia, which are interpreted to show a derivation from the regular pattern, in fact show differences between ice-sheet basal conditions between these locations and those covered by the Fennoscandian Ice Sheet (line 1-3, p. 614).”

We propose the PHW anomaly in Western Siberia and Yakutia north of the 68-th parallel could be attributed to the warming influence of warm-water lakes formed in the

Late Pleistocene by the damming of the Ob, Yenisei and Lena Rivers rather than to influence of ice sheets - especially because the Kara's Ice Sheet was most developed during the earlier and middle Weichsellian (90-60 thousand years ago). There was no glaciation in the lower Lena River region.

"However, no reference is made to the vast numbers of studies on thermohaline circulation during the last glacial-interglacial transition. The first conclusion of the manuscript is not a new idea and thus previous studies should be discussed and cited."

We do not discuss the mechanism of thermohaline circulation in the paper. Our intention is to show new data and an interpretation, which suggest this idea. Suitable references will be included.

"I think more data are needed to obtain a better spatial distribution of data in the study area."

We hope the obtained result will be estimated by paleoclimatologists as a useful one. This will stimulate new geothermal reconstructions and allow evaluations of a spatial pattern of the PHW that is more exact.

References

Tarasov, L., and W. R. Peltier: Greenland glacial history, borehole constraints, and Eemian extent, J. Geophys. Res., 108(B3), 2143, doi:10.1029/2001JB001731, 2003.

Balobaev, V. T.: Geothermics of permafrost zone of the lithosphere of Northern Asia, Novosibirsk, Nauka, 194 pp. (in Russian), 1991.

Glaznev, V. N., Kukkonen, I. T., Raevskii, A. B., and Jokinen, J.: New Data on Thermal Flow in the Central Part of the Kola Peninsula, Transactions (Doklady) of the Russian Academy of Sciences/Earth Science Section, 396(4), 512-514, 2004.

Kukkonen, I. T. Safanda, J.: 'Palaeoclimate and structure: the smost important factors controlling subsurface temperatures in crystalline rocks. A case study from Out-

CPD

3, S397–S405, 2007

Interactive Comment

okumpu, eastern Finland', Geophys. J. Int 1996, 126, 101-112.

Duchkov A.D., Balobaev V.T.: Evolution of a thermal and phase condition of Siberian permafrost / In: E.L. Dobretsov and V.I. Kovalenko (Editors). Global changes of the natural environment - 2001. Novosibirsk: Publishing house SB RAS, Branch "GEO". 2001. P. 79-104 (In Russian)

Interactive comment on Clim. Past Discuss., 3, 607, 2007.