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Interactive comment on "Late Weichselian thermal state at the base of the Scandinavian Ice Sheet" *by* Dmitry Y. Demezhko et al.

Anonymous Referee #2

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The main goal of this manuscript by Demezhko et al., as clearly stated in the introduction, is an evaluation of the basal thermal state and extension of the Scandinavian ice sheet in the Late Weichselian (25 – 12 kyr BP) using ground surface temperatures and heat flux histories as derived from deep-borehole geothermal data. Data from 11 boreholes from the region of study are applied.

The core results consist of a compilation of published/reported results with the extraction of Late Weichselian (LW) ground surface temperature (GST), either from original author's model results or supplemented with new modelling results by the authors. Unfortunately, it is not always clear to the reader, when new modelling results are included.

The main idea of the study is very good, however, the borehole data and resulting temperature histories are mostly of insufficient quality for the conclusions. The extraction

of long-term past GST history from deep-borehole geothermal data is possible only if high-quality temperature-depth data are applied (undisturbed by the drilling process, ground-water movement etc.) and from boreholes of sufficient depth and sufficient information on rock thermal conductivity and heat production. Apparently, so far, only rather few such good results are available, such as that of Kukkonen et al. (2011; Physics of the Earth and Planetary Interiors, 188, 9–25) and Dahl-Jensen et al. (1998; Science, 282, 268–271) from a different environment - the Greenland ice sheet.

In addition to using data of generally insufficient quality, there is not much information on the methodology applied and no discussion on uncertainties of the extracted main temperature parameter, the Late Weichselian ground surface temperature. As an illustration of the apparent lack of sufficient emphasis (and understanding) of potential uncertainty, the authors indicate an uncertainly of the time of an extracted level of GST as t +- t/3. This is illustrate with the example of a t-value of 21 kyr BP where the "reconstructed GST history represents an average over a period of 14 – 28 kyr BP" (p. 7). This is clearly too simple. There is also uncertainty on the amplitude of temperature variations and a tradeoff between time and amplitude.

Still, the main problem here is the quality of the applied GST histories. The data from Kukkonen et al. (2011) from the Outokumpu deep borehole in SE Finland, mentioned above, are used and seem of good quality. Most other results are of far less quality. This is apparent from Fig. 2, which shows the applied GST reconstructions.

Starting from the top, with SG-3, we see an almost linear trend of increasing temperature (from c. -3°C to positive) from between 10 and 5 kyr BP and up to 1 kyr BP (present GST is +1.5°C). Similar unrealistic long trends of temperature increase up to recent times are seen also in the data from Forsmark, Laxemar and Ullrik. These 'reconstructions' are clearly inconsistent with the general knowledge of past climate in these areas as well as inconsistent with the applied data from boreholes of better quality.

Among the sites with very low LW GST estimates are the Kola (C-1), Krl and Onega boreholes. For Onega, we see an 'unexpected' drop in temperatures by more than 5°C from c. 5 to 2.5 kyr BP. Looking into details of original borehole temperature data (in Demezhko et al. 2013), we observe too high near surface temperatures (c. 11°C significantly above present day GST of c. 5.5°C). The applied borehole temperature data are clearly disturbed by the drilling process. A correction is attempted resulting in an unrealistic 'warming period' and the above 'unrealistic' temperature drop. This results in too large amplitude of the temperature rise from c. 20 to 10 kyr BP and significant uncertainty on the Late Weichselian temperature estimate of - 14.5°C.

For the Kola (C-1) site, a LW GST estimate of -18°C is indicated. The problem here is a 'deep narrow cooling' between c. 35 and 20 kyr BP. Such a narrow time interval of low temperature is very unlikely to be resolved from borehole data and imposes significant uncertainty on the GST estimate. For borehole Krl, no GST history is given, and the low LW value of -15°C is obtain by 'selecting' an estimated 'unperturbed' heat flow of 40 mW/m2 without any mention of modelling procedure, nor information on deep background heat flow (why 40?). Again, significant uncertainty. It is likely, that this last group of boreholes may show quite low LW GST estimates, but there is a lack of critical evaluation and no discussion of uncertainty levels.

Without a more detailed analysis of original borehole geothermal information, it is difficult to point to general or specific reasons for obtaining often unrealistic GST histories or GST histories with great uncertainty. As indicated above, main sources include insufficient depth of borehole temperature data, lack of representative information on rock thermal properties (variability of conductivity) and temperature disturbances from ground water migration. In addition, modelling procedures often seem to underestimate uncertainty limits and the possibility of applying independent prior information.

There are also other aspects of this manuscript, which point in a clearly negative direction. Two examples are given:

The 'mathematical/numerical' contouring of data in Fig. 3 and the extrapolation into the Scandinavian region (with "a center of warming" located in the North Atlantic) has so large uncertainties in the region of study, that it should not be used for a detailed treatment as in Table 2 and Fig. 4 and associated discussion.

The notion of a potential correlation between the region of very low modern seismicity (Fig. 6) and very low LW temperatures seems highly speculative. Most of Finland has very little seismicity, also in areas of significant ice thickness towards Gulf of Bothnia. The highest current seismicity is in southwester Norway in areas along the ice sheet margin.

Among the positive elements of this study is the compiled data of "basal thermal state" of the Greenland ice sheet (Fig. 7), shown for a comparison and the discussion.

The main problem with this study is that, if such information on Late Weichselian temperatures is published without a critical selection of data and clear indications of uncertainty limits, readers without much knowledge of the field in question and a detailed information on background data, may take statements and numbers indicated on maps and in tables as valid proxy data. Unfortunately, this is not the case for several of the borehole data applied here. This is a pity, since the topic of this study is clearly of significant interest.

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