Interactive comments on "Laurentide Ice Sheet basal temperatures at the Last Glacial Cycle as inferred from borehole data" by C. Pickler et al.

Reply to Comments by H. Beltrami

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I thank the opportunity to clarify some additional points in the work of Pickler et al (2015), referred to hereafter as PBM. The discussion here is limited to the scientific aspects of the problems identified in the work of PBM, without dragging in questions about familiarity with heat flow measurements and with inversion of borehole temperature profiles.

1 - Much of the variations in temperature gradient (and hence in heat flow), reported in the work of PBM, arise from inaccuracies in the precision with which small temperature differences can be measured at closely spaced depth intervals during log operations. Such variations should be smoothed out over suitable depth intervals that are compatible with the accuracy of the sensor used in temperature logs. The practice of reporting such "noisy" variations in temperature gradient and heat flow has led to erroneous interpretations in the work of PBM. Much of the high frequency variations reported in the work of PBM are "noisy" data. However, it still does not explain why high frequency variations are present only in the bottom parts of the boreholes.

2- Consider now the argument of PBM that minor changes in lithology is responsible for high frequency variations in heat flow. Under steady state conditions, changes in thermal conductivity arising from minor variations in lithology lead to compensating changes in temperature gradients such that vertical heat flow remain unaltered. Local changes in vertical heat flow may occur as a result of 2D/3D thermal refraction effects arising from lateral variations in thermal conductivity and/or perturbation effects of groundwater flow. According to the results reported, high frequency variations in heat flow are present in the deeper parts of all boreholes, not just those in the mining areas, as claimed by PBM. Why such changes occur preferentially in the deeper parts of the thirteen boreholes remain a mystery. The argument that high frequency fluctuations arise from minor changes in lithology, occurring in the bottom parts of boreholes, appears to be ad-hoc. It is more likely that smoothing procedures have been carried out only for data sets of the upper parts of boreholes.

In this context, the reference to repeat measurements in Sept-Isles (in the reply comment of PBM) has only limited validity, in view of absence of data for the deeper parts of the borehole in the log of 1994.

3- It is important to point out that the results illustrated in Figure 2 are inconsistent with those in Figure 3, in which the authors fit straight lines over 100m sections of the T-z data. This procedure has been used in obtaining an extrapolated surface temperature. Why not multiply the temperature gradient so obtained with the corresponding mean thermal conductivity to obtain the mean heat flow density for the 100m section? The resulting Q-z profile would surely have been much smoother. After all, Figure 2 is billed as a first order inverse results and not merely the presentation of raw data.

4- The value of T_o for Flin Flon, as estimated by the authors, is 3.8^{o}C. The calculated GST at 100,000ybp is about 6^{o}C. The significant discrepancy of 2.2K between T_o and the temperature at 100,000ybp suggests that the time period employed in inversion of data for Flin Flon, is too short to obtain a reliable estimate. There is no harm in using a longer time period for inversion because the inversion will simply taper to T_o when the T-z data contain no information about GST variations toward the remote past. On the other hand, using too short a time period is harmful because inversion would be trying to squeeze in temperature variations that do not belong in the time period. I encourage you to redo the inversion for Flin Flon with a longer time span.

By the way, the captions of Figures 4 – 7 indicate that the displayed GSTH has been offset by T_o. Clearly, this is incorrect.

5- Using singular value cutoff for smoothing is adequate when equal time steps are used. However, singular value cutoff alone is not adequate when unequal or logarithmic time steps are used, because unequal time steps carry unequal weights. Let us consider an extreme example in which we have 15 large time steps and one very small time step. Then the temperature for this small time step would likely be associated with small singular values and hence poorly resolved or not resolved at all. An additional smoothing constraint is one way to ensure that the temperature for this small time step falls in line with the neighboring values.

In concluding this reply, my recommendation again is to verify the computational procedures used in the inversion program. It is also advisable to take a second look at the procedures employed in calculating first order estimates of heat flow and long-term surface temperature history.