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

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Pickler et al (2015) presents an analysis of thirteen temperature-depth profiles of deep boreholes (depths ≥1500 m), located in eastern and central Canada, with the purpose of determining the ground-surface temperature histories during and after the last glacial cycle. It gives a detailed account of the procedures employed in analysis of residual temperature profiles and extraction of thermal signals generated by past changes in surface temperatures. The theoretical basis of the work and the inversion techniques used for this purpose are well known in the geothermal literature (Shen and Beck, 1991; Beltrami and Mareschal, 1995; Dorofeeva et al, 2002; Hamza and Vieira, 2010). The main conclusion is that ground surface temperatures throughout the last glacial cycle fall in the range of -1.4 to 3.0°C, in the region covered by Laurentide Ice Sheet.

However, the parts on data analysis of this paper appears to have problems, not only in obtaining first order estimates of variations in heat flow and long-term surface temperatures but also in deriving robust estimates of ground surface temperature history (GSTH). Consider for example the characteristics of transient signals identified in the thermal profiles of shallow and deep-seated sections. The upper parts of profiles (generally for depths less than 1000 meters) seem to be characterized by relatively smooth variations in heat flow (see figure 2 of the discussion paper) and long-term surface temperature changes (see figure 3 of the discussion paper). On the other hand, the lower parts of profiles (generally for depths greater than 1500 meters) are characterized by the presence of unrealistically large (spike-like) variations in vertical heat flow. It is curious that such high frequency variations in vertical heat flow are present mainly in the depth intervals where post-glacial warming trends are absent. Such fluctuations in heat flow are unlikely to have sound physical basis. These appear to be artifacts arising from erroneous procedures employed in obtaining first order estimates.

I have taken liberty in indicating in figure (1) approximate spatial domains of low and high frequency fluctuations in profiles of wells at Pipe, Oql, Balmertown and Val d' Or. The domains were selected by visual examination, though statistical criteria may be employed for a more rigorous identification.

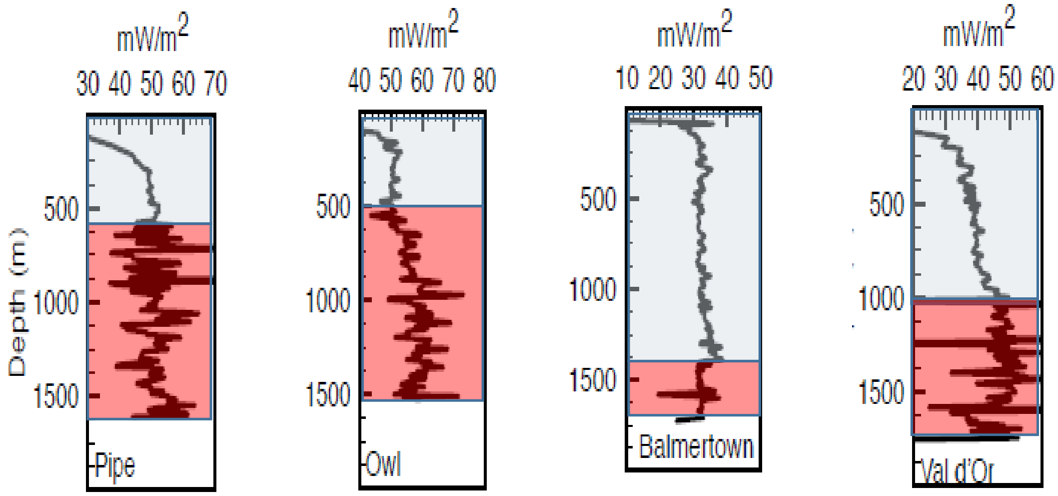

Figure 1. Simplified representation of domains in vertical variation of heat flux with depth at four sites. The domains, marked in in light blue, indicate depth intervals where post-glacial warming trends have been identified. The domains, marked in in light red, indicate depth intervals where unrealistic fluctuations in vertical heat flow are present.

Estimates of ground surface temperature (GST) histories derived using inversion techniques also seem to be incorrect. Consider for example the GST history reported for Flin Flon (Manitoba). It indicates temperatures less than 2ºC for the period of last glacial maximum (around 10000 to 20000 years BP), which is followed by temperatures in excess of 6ºC at times greater than approximately 50000 years BP (see upper panel in Figure 4 of the discussion paper). Such high temperatures are in sharp contrast with values of 0 to 1ºC reported for two nearby sites (Pipe and Owl) in Manitoba (see lower panels in Figure 4 of the discussion paper). In addition, unpublished results of inversions (carried out using the same primary data set for Flin Flon) indicate GST less than 1ºC for the time interval of 20000 to 100000 years and values of about 3ºC for the time interval of 200000 to 1000000 years. A comparison of the two inversion results for Flin Flon is presented in Figure (2).

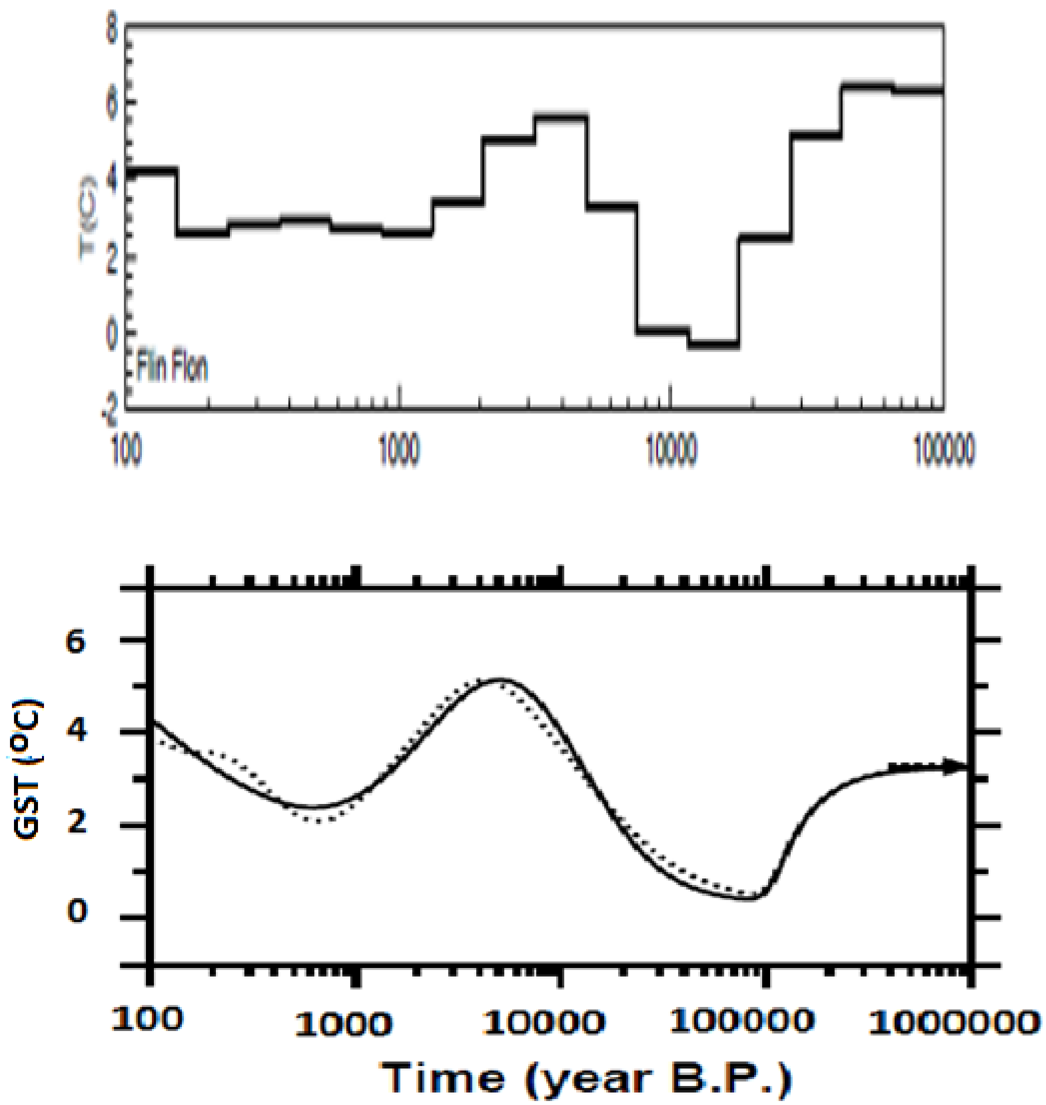

Figure 2. Comparison of the two sets of results of inversions for GST history, using the same data set for Flin Flon (Manitoba). The upper panel illustrates the GST history reported in the discussion paper, for time interval of 100 to 100000 years. The lower panel is the GST history obtained in an unpublished work, using the same data set, for the time interval of 100 to 1000000 years. Note the differences in time scales.

At this point, it is useful to comment on the differences between the inversions used in obtaining results displayed in the two panels of Figure 2. The SVD code used in the discussion paper does not make use of smoothing constraints. That works fine when the GSTH is divided into steps of equal time duration. However, when dealing with GSTH of over 100,000 years, it becomes necessary to use steps of unequal duration. This is when a smoothing constraint, which requires the GSTH to become increasingly smoother into the past, becomes essential. I suspect that the lack of smoothing is probably the cause of poor result obtained for Flin Flon.

In this context, it is convenient for the authors of the discussion paper to verify the computational procedures and data set 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.

Technical Corrections

Table 3 is not referred to in the text.

Missing references: Fahnestock et al., 2001; Pritchard et al., 2012.

References

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