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Interactive comment on "Long-term Surface Temperature (LoST) Database as a complement for GCM preindustrial simulations" *by* Francisco José Cuesta-Valero et al.

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We thank the anonymous reviewer for the thoughtful and constructive feedback.

Reviewer comments are shown in plain text, while author responses are shown in bold text.

Anonymous Referee #1

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Review of "Long-term Surface Temperature (LoST) Database as a complement for GCM preindustrial simulations" By: Cuesta-Valero, et al. Corresponding author: Beltrami

This manuscript addresses an important problem – large variation, and therefore uncertainty, in climate sensitivity estimates, that is the change in surface temperature accompanying a doubling of the atmospheric concentration of CO2. Since the 1970s the variation in estimates of ECS has not improved much; still from 1.5 to 4.5 °C.

The paper introduction provides a useful summary of why the existing GCMs have not provided convergence to a narrow band of ECS: differences in model parameterization, in particular radiative transfer and model tuning; feedback mechanisms such as ice-albedo and water vapor effects; and permafrost stability and permafrost carbon feedback. The authors suggest "a constrained preindustrial control simulation may improve the representation of those feedbacks in transient climate experiments, reducing the uncertainty of ECS estimates from model simulations, as well as reducing the spread in projections of future climate change." The proposed constraint for such a preindustrial simulation is a database they have assembled called LoST (LoST = Long Term Surface Temperature). The paleo surface temperature at a given site is estimated by extrapolating a subsurface temperature profile from a depth range of 200 to 300 m, most sensitive to surface temperatures between about 1300 and 1700 CE, to the surface. The database is based on 514 temperature-depth profiles in North America. Creation of a LoST database offers the possibility of a better estimate of a preindustrial reference temperature field and thus an improvement in the ECS estimate. The database is compared with five past millennium and five preindustrial control simulations from the PMIP3/CMIP5 archive to assess the realism of the simulated preindustrial equilibrium state by the current generation of global climate models. The paper is consistent with many previous papers in advocating that borehole temperatures are a robust complement to observational (met data) and model studies of past climate. I recommend publishing the paper after some minor to modest revisions.

Details.

1. Appropriate databases are used. With respect to borehole temperatures, it is safe to neglect heat production (does not introduce appreciable curvature into the temperature-depth profile at the depths considered) but rock heterogeneity can be more of a problem. Extrapolation of a temperature gradient from 200 m to surface to arrive at To has an error that should be discussed.

Rock heterogeneity affects the T_0 estimates via variations in thermal conductivity. In the case of inhomogeneous thermal properties, the ground temperature at a depth z ($T(z)$) is described as

$$T(z) = T_0 + q_0 \cdot R(z) + T_t(t), \tag{1}$$

where T_t is the surface transient perturbation, T_0 is the long-term surface temperature, q_0 is the quasi-equilibrium heat flux and $R(z)$ the thermal resistance (Bullard, 1939). The thermal resistance requires measurements of thermal conductivity through the profile to be estimated. Unfortunately, the majority of borehole temperature profiles (BTPs) do not have conductivity measurements, which hampers the quantification of errors in T_0 estimates arising from variations in thermal conductivity. Additionally, large variations of thermal conductivities can be inferred from the lithological log for each site. Generally, when large variations of thermal properties are indicated from the lithological log descriptions, rock samples are obtained, and if this is not possible, then the temperature log is not used in climate analysis. The BTP database employed in this work has been screened by Jaume-Santero et al. (2016), and only profiles suitable for climate studies were retained for the analysis.

As an example of a borehole site with both temperature and conductivity measurements, we provide here the T_0 estimates using data from the Neil well (Canadian Arctic, see Beltrami and Taylor, 1995 for a full description of the data and the site). We find a T_0 estimate of $-11.6 \pm 0.4\,°C$ assuming a constant thermal conductivity for the linear regression analysis for the depth range from 200 m to

300 m. If we introduce corrections by computing the thermal resistance from the thermal conductivity as a function of depth for the same depth range, we obtain a T_0 estimate of -11.4 ± 0.2 °C. The error due to rock heterogeneity, therefore, is not large for the Neil well site. This result cannot be directly extrapolated to the rest of BTPs, since thermal properties vary from site to site, but it contextualizes the magnitude of the errors in T_0 estimates in a typical borehole site due to variations of thermal conductivity with depth. The new version of the manuscript describes the role of thermal conductivity in the determination of T_0 values and the scarcity of thermal conductivity measurements.

2. Temperatures in the depth range 200 to 300 m are largely affected by surface temperatures from 300 to 700 years prior to the temperature logging as the manuscript points out, corresponding to surface temperatures from about 1300 to 1700 CE. I would like to see a comment on how much of the signal in that depth range comes from surface temperatures outside of that time window.

As the reviewer points out, the depth range of BTPs is fundamental to provide temporal context for the reconstructed surface temperature histories and T_0 temperatures. We identify the depth range of 200-300 m with the temporal period 1300-1700 of the Common Era, but the effect of the Little Ice Age and the Medieval Warm Period may also affect the T_0 estimates. However, the spatial extent of both events is not homogeneous over North America, which implies that not all BTPs employed here are affected by these events. Additionally, their influence should be part of any transient millennial-scale climate simulation and thus, these climate events should be represented within both the transient simulations and the BTPs.

We have added a few lines commenting on the impact of the Little Ice Age and the Medieval Warm Period on the T_0 estimates.

3. Figure 1 is a good illustration of the extrapolation of the borehole temperature profile

to the surface. The term in the caption “linear fit of the last 100 m” is ambiguous. Say, “linear fit of bottom 100 m” or better still, “linear fit of temperatures between 200 and 300 m.” The paper should also say that any thermal conductivity heterogeneity in the depth range 0 to 200 m would affect the zero depth (i.e. Surface) extrapolated temperature and ideally give a bound for how big an error that would introduce.

We have changed the caption of Figure 1 in the new version of the manuscript. Regarding the effect of the thermal conductivity heterogeneity on T_0 estimates, please see our answer to the first comment.

4. Figure 2. Is the temperature scale on Fig 2(b) mislabeled or is it some kind of a non-linear scale? The colored temperature scale for Fig 2(c) and (d) needs a label and units.

Indeed, Fig. 2(b) was mislabeled in the previous version of the manuscript, and the temperature scale of Fig. 2(c, d) should read “Surface Temperature (°C)”. We have corrected all these issues in the new version of the figure.

5. The paper would be improved by a discussion of various kinds of uncertainties in LoST and whether the magnitude of those uncertainties detract significantly from the goal of providing a robust preindustrial surface temperature field. Include: (a) extrapolation uncertainties for a typical borehole site. (b) whether the 514 sites are generally representative of the topography (elevation and site azimuth) of the region being modeled (scatter in extrapolated borehole temperatures in a region can vary by 4 °C). (c) Are the BTT’s in Fig 2(b) corrected for elevation or are elevation differences at particular latitude (considerable in North America) the cause of about 10 oC scatter at constant elevation?

We have included a paragraph in the Discussion section addressing the reviewer’s points.

Overall this is a refreshing new approach of showing how borehole temperature profiles can be used to complement the more conventional meteorological and GCM modeling studies to reveal the long-term evolution of surface temperature on the planet.

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