Response to comments by Anonymous Referee 1

October 28, 2016

We are grateful for the reviewer's thoughtful and constructive commentary.

[1] The methodological section seems to me too long. The methods to derive temperature histories from borehole temperate profiles are well known and I think that this section can be reduced, supported by citation of existing literature. In my understanding, the present study is not introducing any methological novelty so that this section should just present a summary of the methods for the sake of completeness.

We understand the reviewer's concerns about the repetition of the methodology. However, this paper expands the borehole climatology analysis to all North America within the framework of the PAGES2k project. Our results will be integrated with a variety of paleoclimatic records of this continent. This work, is intended for paleoclimatic specialists working in areas outside borehole climatology who will benefit from having the theory laid out in a self contained paper. The methodology of borehole climatology often suffers from a lack of details; its exposition, with advantages and limitations, remains accessible only to those working directly in the field. Therefore, we prefer to include a thorough overview of the methodology.

[2] On the other hand, I found the comparison to dendro and pollen reconstructions a bit too short.

We agree that extending the discussion with other proxy reconstructions would enrich the results section. Therefore, we intend to present Figure* 1, a revised version of Figure 6 in the paper where we have added two pollen reconstructions from Viau et al. (2006) and Viau et al. (2012). With this, we expect to show a better comparison of long-term temperature variations from different proxy approaches.

There are clear agreements between all tree, but also some discrepancies that may be worth noting (the manuscripts succinctly acknowledge some of these differences) and discussing. For instance, it seems clear that the temperature difference between the long-term pre-industrial mean and present are larger in the borehole reconstructions than in the other two. What could be the reason? It seems to me that this is a systematic result when comparing the reconstructions of the Northern Hemisphere mean by Huang, Pollack and others and the multy-proxy reconstructions. Is this a seasonal bias of the proxies? is this due to the different spatial coverage?

Differences can be attributed to a combination of factors as discussed in Pollack and Smerdon (2004). For instance, while a significant part of boreholes are located in higher latitudes (Eastern & Central Canada), tree-ring data are mainly obtained in lower latitudes (Western US). Therefore, the spatial distribution of proxies could explain colder temperatures. Other possible reasons for those disparities are the seasonal bias of the proxies and the limitation of borehole climatology in resolving short-term variability. Furthermore, we decided to truncate the geothermal profiles to 300 meters which could explain the absence of the Little Ice Age in some reconstructions (as discussed in the paper). On the other hand, we were able to extend the spatial coverage over North America by increasing the number of borehole temperature profiles from 245 in Huang, Pollack and Shen (2000) to 510 in the present manuscript. We will add an extended discussion on these points in the revised version of the article.

I would suggest to compare all three reconstructions together with the observed temperature trends in the 20th century, spatially resolved over North America. This is partly shown in Figure 8, so what I would find interesting is to have three maps of the long term trends over North America: boreholes, tree-rings and HadCRUT4) or any other observational data set). This can shed some light on the origin of the pre-industrial minus present differences, for instance if one of the reconstruction under or overestimates the observed trends.

We agree that it would be interesting to extend the comparison with other proxies. However, we present this article as an independent contribution to study past temperature changes using the basis of heat transport in geophysics. Nevertheless, we will include Figure* 1 to compare different multiproxy reconstructions as mentioned in the first response of paragraph [2].

[3] As a more minor note, the readability of the abstract could be improved, specially the first half, maybe having in mind a non-expert reader.

We take good note of the comment and we have rewritten the abstract accordingly: Within the framework of the PAGES NAm2k project, 510 North American borehole temperature-depth profiles were analyzed to infer recent climate changes. To facilitate comparisons and to study the same time period, the profiles were truncated at 300 meters. Ground surface temperature histories for the past 500 years were obtained for a model describing past temperature changes at the surface for several climate-differentiated regions in North America. The evaluation of the model is done by inversion of temperature perturbations using singular value decomposition and its solutions are assessed using a Monte-Carlo approach. The long-term surface temperature and thermal gradient were retrieved by linear regression for the bottommost 100 meters. The results within 95% confidence interval suggest a warming between 1.0°C to 2.5°C during the last two centuries. A regional analysis of mean temperature changes over the last 500 years shows that all regions experienced warming, but this warming is not spatially uniform and is more marked in northern regions.

[4] All of them presented as departures from the 1904-1980 temperature mean (Figure 6). However, the reconstructed GST warming signal for the past 200 years is greater than results from pollen reconstructions, coinciding with the findings of PAGES 2k-PMIP3 group (2015).

It is not clear whether this discrepancy was also found by the Pages2K, or that the borehole reconstructions now agree better with the Pages2K results than the pollen reconstructions.

The sentence will be rewritten to clarify that this discrepancy was found in previous literature where it was mentioned that simulations and dendrochronological reconstructions had a stronger warming trend than pollen for the recent past. Concretely we referred to the regional analysis of PAGES 2k-PMIP3 group (2015) page 1679 where it is stated that a warming signal is stronger in the tree-ring based reconstruction than in the pollen-based reconstruction.

[5] Figure 8 indicates a warming trend of ∼1-2°C in most parts of North America during the last 200 years. This is consistent with previous studies (Huang et al., 2000; Harris and Chapman, 2001; Beltrami et al., 2003). A cooling trend is observed in central California. Stevens et al. (2008) shows how this differs from the output of the ECHO-G model and postulates that it is the result of intensive irrigation in California's central valley, which could drive a regional cooling signal (Kueppers et al., 2007). A similar cooling signal is observed in British Columbia which might be associated with irrigation in the Fraser Valley.

This point is related to my previous point 2. What are the observed trends in California?

In Figure* 2, California's annual mean temperature history obtained from weather stations shows a weak warming trend between 1895 and 1970 not clearly seen by geothermal reconstructions of the region. Furthermore, the limited amount of useful borehole temperature profiles for Western US (9) were logged in the 1960's, the most recent of them was measured in 1970. Thus, we are not able to reconstruct the past 40 years where the increasing in temperature is more marked.

The referee's comment drew our attention to the fact that the regional mean temperatures and maps (Figure 7 and Figure 8 in the manuscript) should be averaged over the same time period (50 years). Because of the lack of recent measurements, our reconstructions for California and the Western US are restricted to the period before

1970 (i.e. we are missing the most recent warming shown in red in Figure* 2). Therefore, we had to compromise the reconstruction of recent past changes in order to obtain mean temperatures over the same time periods. Thus, Figures 7 and 8 in the manuscript will be replaced by Figure* 3 and Figure* 4 in the present document.

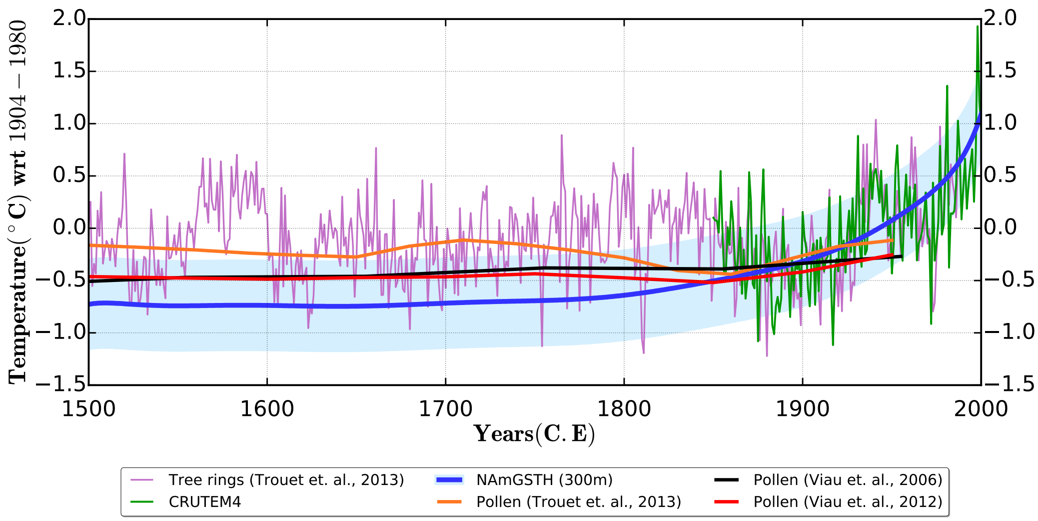

Figure* 1: Mean North American ground surface temperature history (blue) and maximum temperature range of accepted models ($\sim$0.44°C) obtained from the Monte Carlo method (blue shade). Also shown are proxy-based surface air temperature reconstruction for North America from 1500 to 2000 CE. Anomalies are displayed as departures from 1904-1980 mean and Pollen reconstructions are shifted to match the tree ring data at 1955 CE.

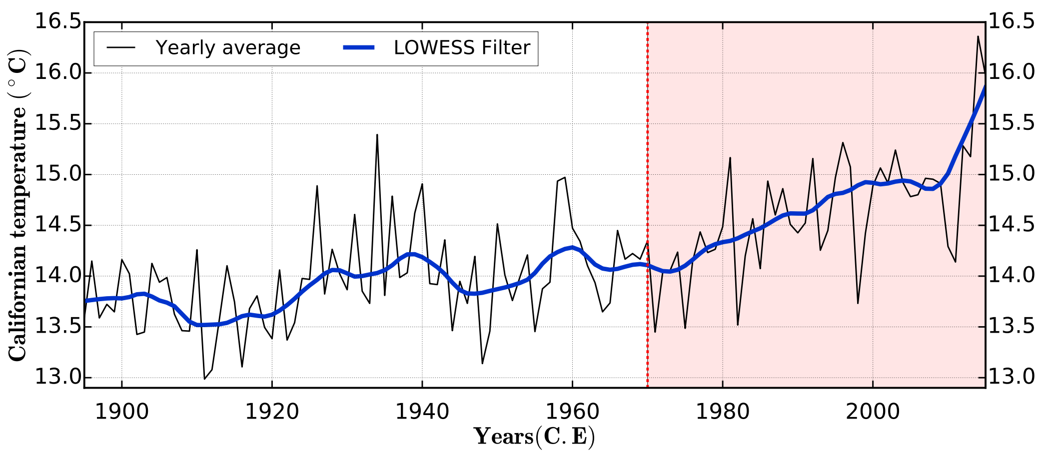

Figure* 2: NOAA's annual mean temperature of California since 1895 (ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/). The red zone covers past temperature changes that we are unable to resolve because the thermal profiles in the region were measured before 1970.

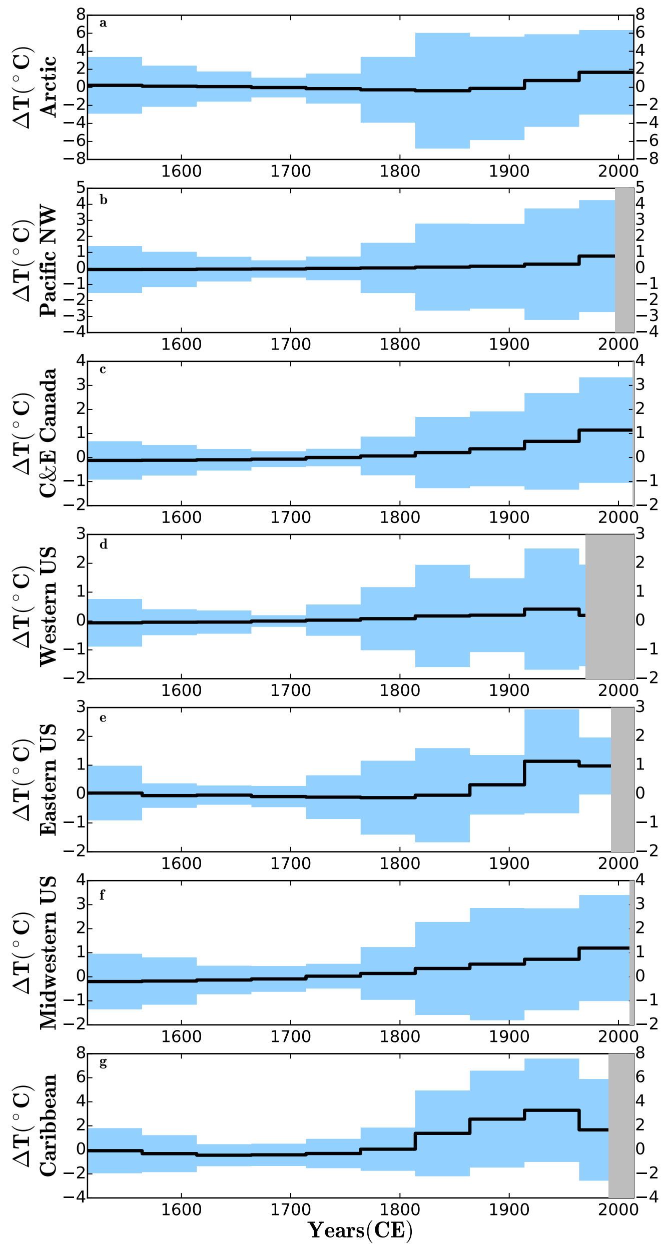

Figure* 3: Mean ground surface temperature histories (black), the shaded areas represent the 95% confidence interval associated with the climate variability of each area. a: Artic (78 sites), b: Pacific Northwest (78 sites), c: Central & Eastern Canada (220 sites), d: Western US (21 sites), e: Eastern US (9 sites), f: Midwestern US (100 sites), g: Caribbean (4 sites). Mean temperatures are shifted with respect to the most recent logging date in each region (grey)

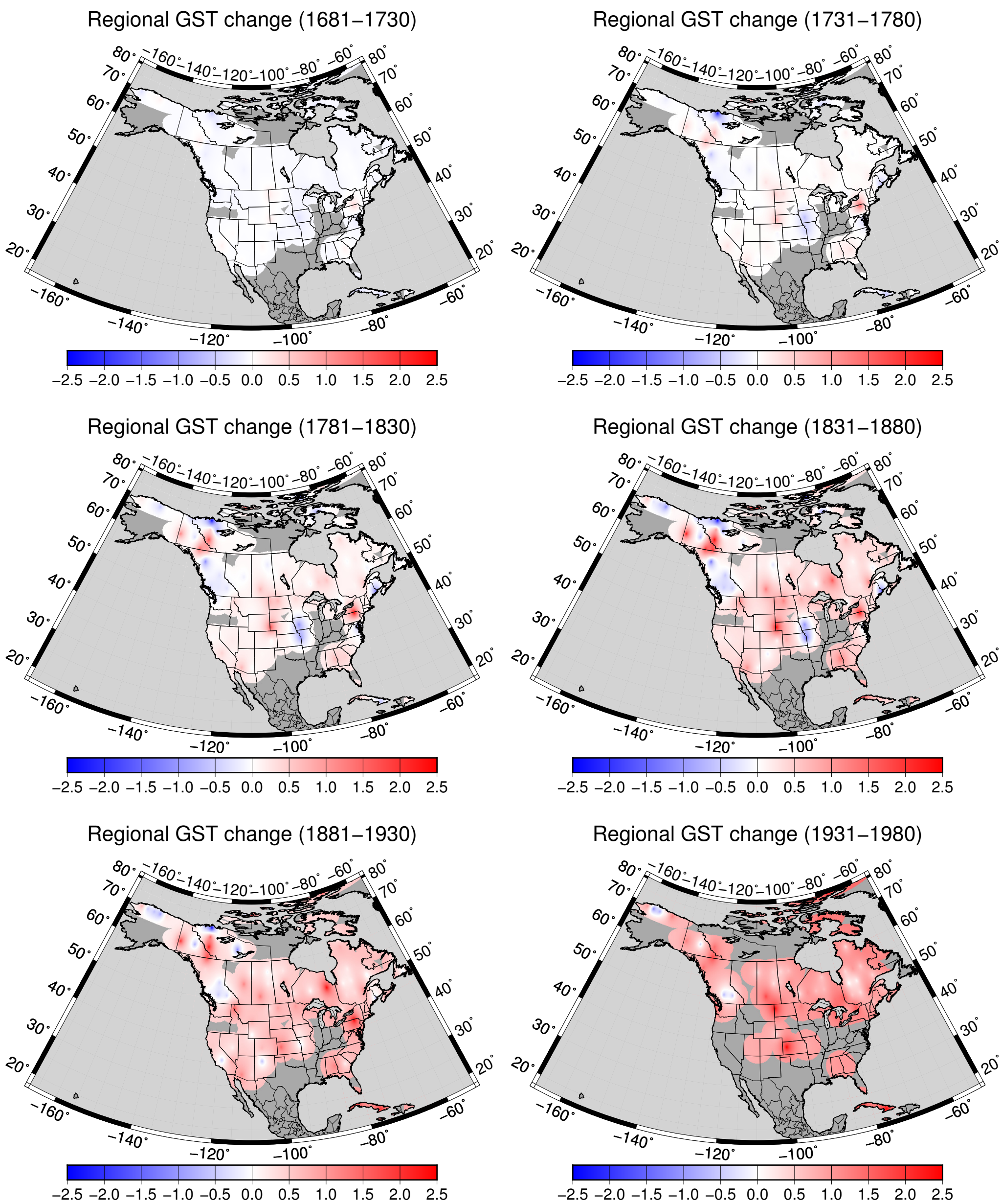

Figure* 4: Spatial variability of the ground surface temperature variation from 1681 to 1980. Each panel shows a regionally interpolated mean ground surface temperature over 50 years. The surface has been masked for zones without at least one datum within a radius of 400 km. Ground surface temperature changes are presented as departures from long-term mean surface temperatures prior to 1500 CE.

References

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