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Climate of the Past Discussions

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Interactive Comment

Interactive comment on "Summer temperature trend over the past two millennia using air content in Himalayan ice" *by* S. Hou et al.

S. Hou et al.

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Referee #1 gives a number of useful suggestions for improving the manuscript. We address his specific comments in the same order as in the review:

1. *It is mentioned briefly that the usually proxy for temperature, d18O and dD are affected not only by temperature but also by other environmental parameters. The ice-core gas-content is proposed as a physically proxy for temperature. Would be very helpful to mention here what are the main advantages of such a temperature proxy relative to d18O and dD. Is the ice-core-gas-content less influenced by other parameters than temperature relative to d18O and dD?*

Water isotopes in mountainous regions have been shown to be a complex mixture of temperature and accumulation rate effects, during transportation of the water vapor

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from its source to the deposition area. In addition, source effects can also alter significantly the temperature interpretation from such proxy. Our gas content record provides an independent dataset which is directly influenced by local climatic parameters. Besides temperature, the ice core gas content might be influenced by other boundary layer parameters including humidity. Furthermore, firnification processes may also affect the eventual gas content. At present, a quantitative evaluation of each mechanism involved at East Rongbuk is impossible, which is also a reason why we focus only on the trend of the gas content record, not on the absolute values.

2. *It is argued that some air is lost by cut-bubbles at the sample surface. For this reason a cut-bubble correction coefficient is calculated. Is this correction introduced here for the first time or this is a common technique to correct gas-content lost due to ice-cutting?*

The cut-bubble correction is a common technique to correct gas-content lost due to ice-cutting. A full description of the method can be found in Martinerie et al., J. Glaciol. 36, n°124, 299-304, 1990.

3. *Dating It is not very clear to me what is the min, max and average time resolution of the temperature reconstruction. A more detailed description of the dating procedure would be very useful when the variability of this reconstruction is investigated with more sophisticated statistical tools for time series analysis.*

The dating procedure involves a combination of ice flow modeling and gas control points. In the new version of the manuscript, we describe in more detail the procedure, in addition to the explanations given in Hou et al. (2004).

The time resolution of our air content record depends on the thickness of the annual layers and of the length of each sample. The larger variability around the mean gas content value in the upper part of the ice cores reflects the thinning of annual layers with depth, as shallower samples partly depict the seasonal variability of air content (Fig. 3a) whereas the deepest samples integrate this variability through multi-annual

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resolution per sample. For that reason, the summer temperature trend reconstruction based on the gas content record makes sense when considering the values averaged over time, not by considering each sample independently.

4. *It is argued that during dry season, the negative latent heat generate strong sublimation which mentain the glacier cold. During wet season, the reduced short-wave radiation does not compensate the increase long-wave radiation and the humidity gradient is reduced. This last process, together with higher temperatures increased the probability of summer melting and therefore of less air content in the ice-core is recorded. A quantitative estimations of the anomalies related to ice-melt process (i.e. radiation flux anomalies, temperature anomalies, etc) would be useful to relate the gas-content-ice-core to specific climate phenomena.*

4.1 Due to lack of field observation at the ice core drilling site, a quantitative estimation of the respective role of changing summer temperature and changing cloudiness and precipitation on the present-day snow structure is impossible. On the other hand, there is an argument which favors our interpretation of the gas content changes as being related to summer temperature and not to cloudiness and precipitation. From detailed chemistry measurements on the East Rongbuk core, and taking into account the thinning of ice layers with a simple ice flow model, Susan Kaspari (University of Maine, personal communication) could estimate changes in accumulation rate along the core. The maximum change reaches about a factor of two over the last 400 years and is not correlated with the trend that we depict in the air content record.

It is unlikely that a possible increase in summer cloudiness over East Rongbuk during the 20^{th} century would have taken place without being accompanied by an increase in accumulation rate. Such increase is absent from the record at times when the air content decreases. Therefore we are left with the most probable explanation that the air content decrease reflects an increase in summer temperature.

We modified the manuscript to take into account this recent work on the accumulation rate at East Rongbuk. This complements the other argument already written on the same subject, that observations on the Xixibangma glacier points toward a very good correlation between snow/ice melt and air temperature (Aizen et al., 2002).

4.2. *The transition from the very detailed description of local physics of ice-core-gascontent to investigation of large-scale climate teleconnections related to the variability in this temperature reconstruction is too abrupt. A discussion of the physics of the gas content in the ice core in one subsection followed by a discussion about the possiblelarge-scale climate teleconnections during the last two millennia as suggested by the variability of this temperature proxy in other subsection will be useful. In this way the the detailed description of the experimental results is separate from the highly speculative discussion about the large-scale climatic teleconnections as suggested by this reconstruction.*

We have divided the previous section “ Results and discussion” into two sections as “ Factors controlling gas content” and “ Summer temperature trend”.

4.3. *The reconstruction of Cobb et al. (2003) supports a cool MWP and a warm LIA which better fit the Himalayan temperature as derived from this gas-contentent ice core temperature proxy. The two time series (Fig 3 b and c) suggest a tendency of the temperature to increase both in central Pacific and Himalayan region. These positive temperature trends seems to be out of phase with the northern Hemisphere temperature trend (Fig. 3c). The out of phase variations of tropics-extratropics temperature trends during the Holocene, as authors suggest here is supported by other temperature reconstruction (e.g. Lorenz et al. 2005 and the reference therein). The fact that temperature pattern during LIA and MWP is not uniform is also discussed in the review paper of Jones and Mann, 2004. However, the time scale of the variations of the reconstructions represented in Figure 3 are very different and a simple visual inspection of them is not enough to conclude about their common or uncommon variations. A separate analysis of the long-term trends and centennial variations will be very useful when compare the variability of these time series.*

We thank the reviewer for citing more references and for reminding the different time scale of temperature variations from these different reconstructions. Though it would be relevant to study the centennial variations of the gas content record to complement its long-term trend, it is currently infeasible due (1) to the coarse resolution of the gas content record, and (2) to the lack of a quantitative estimation of the link between gas content and summer temperature.

4.4 *It is argued that the primary impact of solar activity is to change thermal gradients rather than direct solar heating. The Sun influence the climate via various processes, like the excitation of dominant modes of extratropical variability, modification of the tropical convection and related surface circulation (Waple et al. 2002) or many other mechanisms. The temperature proxies considered here suggest only that the connection between solar forcing and tropical and extratropical climate may be different. While the signature of the solar forcing is evident in the northern Hemisphere temperature reconstruction (Fig. 3d and e) it is not evident in Himalayan temperature reconstruction.*

The impact of solar activity on climate is a complex topic. We do not claim that our summer temperature trend reconstruction bears any common feature, nor direct relationship with the solar irradiance anomalies. The text is thus slightly changed to avoid any possible misunderstanding.

5. *Conclusions*

In my opinion the proxies considered in this study suggest that only the long-term trends of tropical and extratropical temperatures are out of phase. The centennial variations are more complex and seems to be different in the tropics and extratropics.

We agree with the reviewer and again, we do not attempt to discuss short-term trends in our records.

5.Figures

5.1. *While the unusual 20th century warming is evident in the original time series the*

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filtered version (Fig. 3b) does not show clearly this unusual warming. Therefore I suggest to modify a little the filter parameters in order to better emphasize the unusual 20th warming.

The filtered line changed little when employing different filter parameters. As indicated in the paper, the increased "noise" in the shallower part of the gas content record comes from the fact that each sample can then correspond to a single season of accumulation instead of several years for the deeper samples. A better filtering would require that we start from a continuous gas content record, which is currently unavailable.

5.2. *It is difficult to compare the time series of radiative forcing associated to volcanic eruptions with the other time series represented in Figure 3. Therefore I suggest to use a linear plot also for this time series.*

We have revised the figure 3 according to the reviewer's comment.

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