

Answer to referee 1

The referee's comments are shown in black and our answers in blue :

This is an interesting paper that explores important issues (stability of oxygen isotope-temperature relationships) in a novel, thorough and systematic way. Given the challenges of reconstructing temperatures (and climate in general) over the Antarctic, this paper is a valuable step towards better reconstructions, and importantly understanding issues in developing these reconstructions and their uncertainties. The paper is well-written, in particular the conclusions as well as providing a strong summary of what has been found, points well to the implications of the findings, and what is needed to address some of the issues found.

I therefore recommend acceptance subject to minor revisions, which I list below.

We would like to thank the reviewer for the positive evaluation of our manuscript and for the useful comments that will be addressed in the revised version as specified here :

1) Abstract, line 3. Consider changing to 'short and spatially sparse' (or something like this) to reflect the issue that the instrumental records are limited in spatial coverage as well as temporal.

This will be modified accordingly.

2) Page 8 line 33. You discuss that the choice of error has an impact on the results. Some more information on this would be useful (perhaps in supplementary information).

We agree with the reviewer that this is an important point. We thus plan to change this sentence (p8|32) :

Those different estimates of the data uncertainty have an impact on the results, but no best choice could be determined based on our experiments.

by:

Those different estimates of the data uncertainty have an impact on the results, but, as shown in the supplementary Section B, this impact is limited in our experiments.

and to add a new supplementary section (including a new figure) discussing the choice of the data error:

Appendix B: Data uncertainty sensitivity

Specifying the error on the data is a key element of the data assimilation process. The smaller it is, the stronger the constraint provided by the data will be. In paleoclimatology, obtaining the right estimate of this error is challenging as there is often no quantitative uncertainty provided with data series derived

from observation. This implies that we have to make a choice that will inherently be associated with strong hypotheses or subjective considerations.

As mentioned in Section 2.4, several distributions of data error have been considered here. First, the uncertainty has been assumed spatially homogeneous, meaning that each data series has the same error (either 0.15‰, 0.25‰ or 0.50‰). While this strategy is likely unrealistic, it has the advantage to be very simple. The data error has also been considered proportional to the variance of the data series. It implies the same signal to noise ratio in all the series but there is no obvious reason to justify this hypothesis. Finally, the data error has been defined as proportional to the regression error term between observed temperature and $\delta^{18}\text{O}$. However, we have shown here that the temperature- $\delta^{18}\text{O}$ link is weak and temporally and spatially varying. Furthermore, the time overlap between the temperature observations (Nicolas and Bromwich, 2014), covering the past 50 years, and the $\delta^{18}\text{O}$ data (Stenni et al., 2017), often missing the recent past, is very short. Given the 5-year temporal resolution of the $\delta^{18}\text{O}$ series (see Section 2.2 for more information), the regression is computed using maximum 10 points, hampering its reliability.

To limit as much as possible choices that may be hard to justify, the data assimilation-based reconstructions analyzed in this paper have used a spatially homogeneous uncertainty of 0.25‰. Fortunately, it appears that the different strategies used to estimate the uncertainty of the data give regional temperature reconstructions that are relatively consistent (Fig. B1). Although there are some weak differences in variance, the different reconstructions show similar patterns over the last two millennia. This relatively limited impact on the results of the way the data error is estimated adds robustness to the reconstructions based on data assimilation.

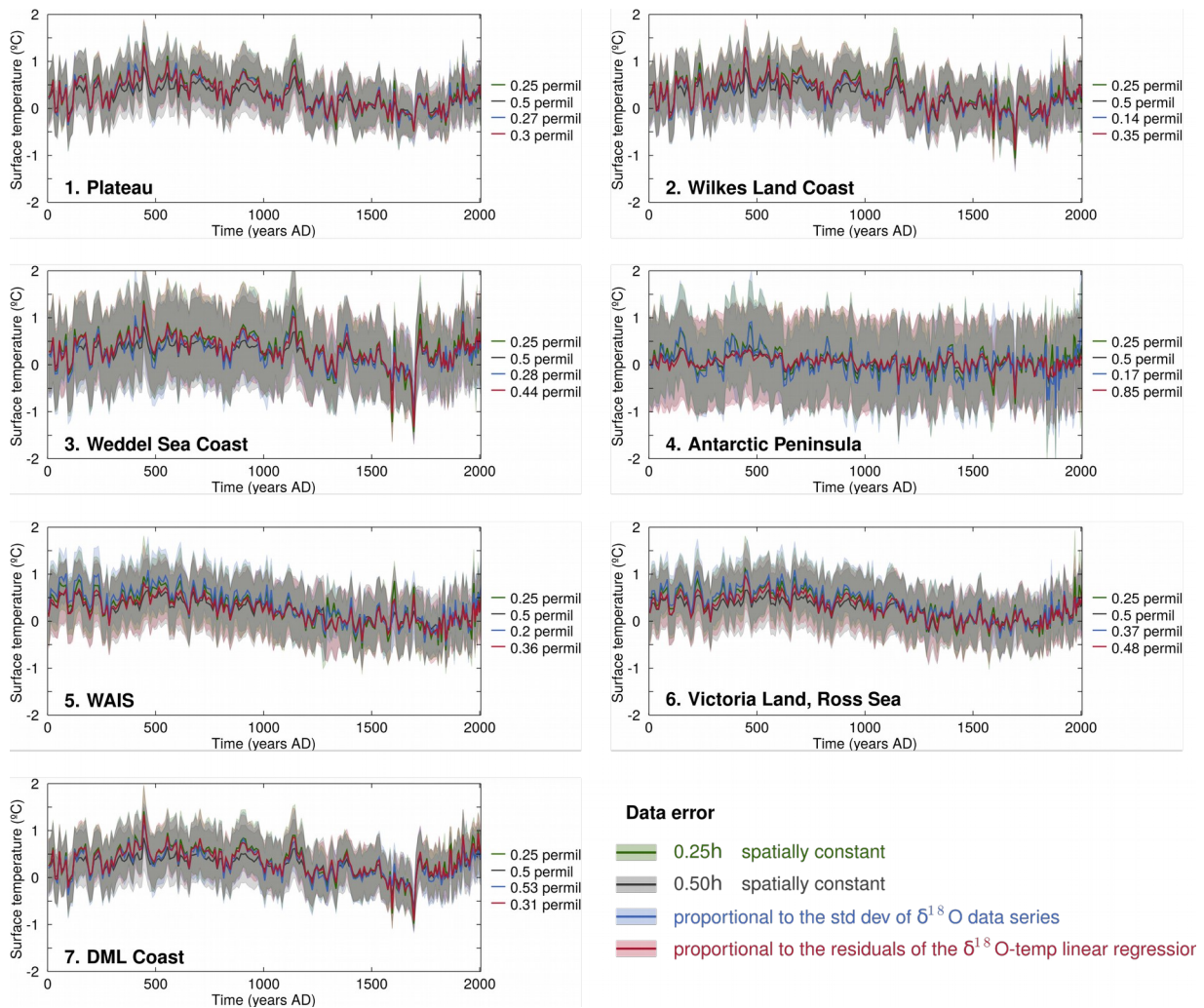


Figure B1: Data assimilation-based temperature reconstructions using the model ensemble ECHAM5/MPI-OM over the period 0-2000 CE over the seven Antarctic subregions. The time series differ due to different data error taking into account in the data assimilation process: 0.25‰ spatially homogeneous (in green), 0.50‰ spatially constant (in gray), $0.5 \times$ the standard deviation of the data series (in blue), and $0.5 \times$ the residual sum of squares from the linear regression predicting observed temperature from reconstructed $\delta^{18}\text{O}$ (in red). The uncertainty of the reconstructions is shown in shaded area with the corresponding colors (± 1 standard deviation of the model particles scaled by their weight around the mean). The reference period is 1500-1800 CE. **Attention, note that the symbols ‘permil’ has been changed to ‘h’ in this document. This will of course not be the case in the revised version of the manuscript.**

3) Page 9 line 20. You state that the CPS method means that more than half of the records are discarded. Giving the exact number here would be useful.

This will be specified (62 out of 112).

4) Page 9, line 33. Here and other places where you discuss trends/warming, consider including whether trends are significant.

We will specify the significance of F tests ($p\text{-value} < 0.05$) testing for a non-zero slope everywhere on the text where numbers of trends are given, as well as in the Figures 1, 8 and 9 where the slope values will be followed by a star (*) when significant.

5) Caption of Figure 1 needs rephrasing. It currently states 'Last millennium 10- (left panels) and 5-year (right panels)', but the right hand panels are not for the last millennium.

It will be modified :

Changes in 10- (left panels) and 5-year averaged (right panels) surface temperature over the period 850-2000 CE ...

6) Caption of Figure 4, line 3, I think should state that the slope values are shown in green.

It will be added in the revised version.

7) At the start of Section 5, a few sentences reminding the reader of the purpose of this analysis in this section would be helpful. Indeed, doing this at the beginning of each section would help the reader, as the analysis involves quite a few different components/data sources.

Thank you for the remark. We will add at the start of Section 5:

In the same way as for the pseudoproxy experiments, we first assess here whether model results can match in the data assimilation experiments the $\delta^{18}\text{O}$ reconstructions of Stenni et al. (2017), which are based on ice core measurements. This is needed to potentially obtain skillful temperature reconstructions. However, given the relatively weak link between $\delta^{18}\text{O}$ and temperature evidenced in Sections 4.1 and 4.2, the skill of those temperature reconstructions is expected to be limited even if the data assimilation process technically works well.

8) Small grammatical errors

We would like to thank the reviewer for noticing all the following typing and spelling errors that will be corrected in the revised version of the manuscript.

- Page 2 final line, change to 'also adds to the challenge of the interpretation of ice core signals '

This will be changed.

- Page 3 line 26, change to something like 'As our study is based on model results ...'

This will be changed as proposed.

- Page 4 line 1, change to 'consist of using climate model ...'

This will be changed as modified accordingly.

- Heading of section 2.2. Change to 'Water stable isotope records'
This will be changed.
- page 9, subheading 2.5, change to 'Statistical reconstruction methods'
This will be changed.
- Page 11 line 16, change 'backyard' to 'backward'
This will be changed.
- Page 17 line 19, change to 'there are no fundamental inconsistencies'.
This will be changed.
- Caption of figure 8: line 8, change to 'measurements of Orsi et al. (2012). Line 11, rephrase to something like 'The reconstructions based on instrumental records by Nicolas and Bromwich (2014)... '
Thank you for noticing. This will be changed accordingly.
- Page 26 line 16, change to 'data assimilation always provides reconstructions'
This will be changed.
- Page 27 line 6, change to 'Consistent with the results of the pseudoproxy experiments'
This will be modified.
- Page 27 line 26, change to 'to help distinguish the forced response from natural variability'.
This will be modified.