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Supplement of

Assessing the robustness of Antarctic temperature reconstructions over the past 2 millennia using pseudoproxy and data assimilation experiments

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S1 Supplementary figures

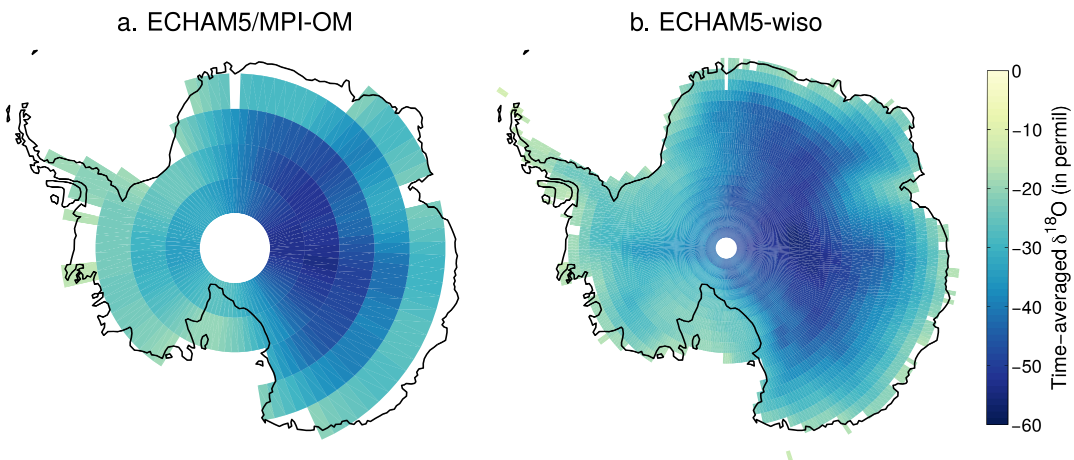

Figure S1. Time-averaged δ^{18}O in precipitation in a. ECHAM5/MPI-OM over the period 800-1999 CE and in b. ECHAM5-wiso over the period 1871-2011 CE.

S2 Sensitivity to data uncertainty

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 observations. 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 δ^{18}O. However, we have shown here that the temperature-δ^{18}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 δ^{18}O data (Stenni et al., 2017), often missing the recent past, is very short. Given the 5-year temporal resolution of the δ^{18}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. S3). 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.

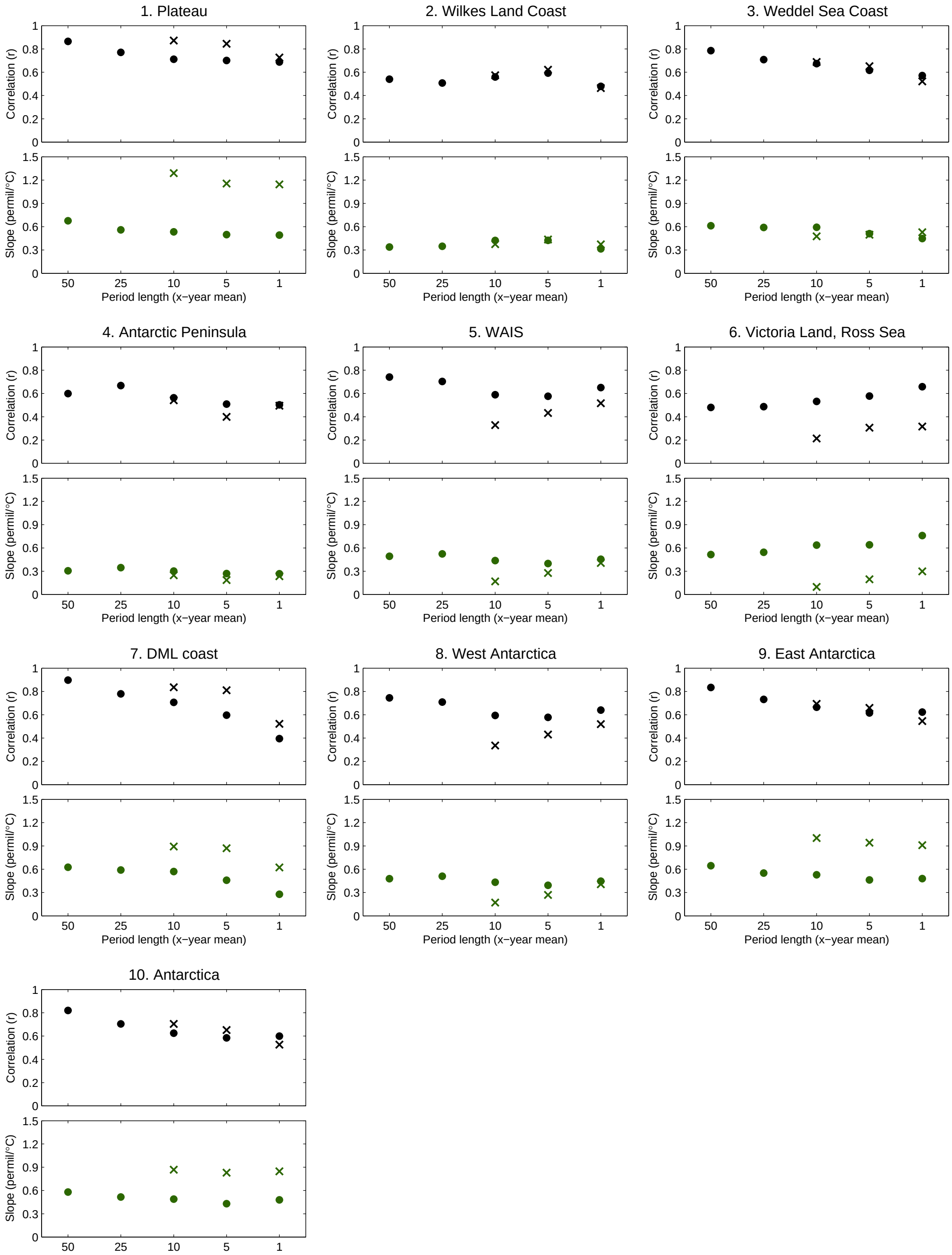

Figure S2. Pearson correlation coefficients (black) and slope (in $^{\circ}C‰^{-1}$) between surface temperature and $\delta^{18}O$ in ECHAM5/MPI-OM (points) and in ECHAM5-wiso (crosses) over the full period covered by the simulations (800-1999 CE for ECHAM5/MPI-OM and 1871-2011 CE for ECHAM5-wiso), as a function of the bin length over which the data are averaged.

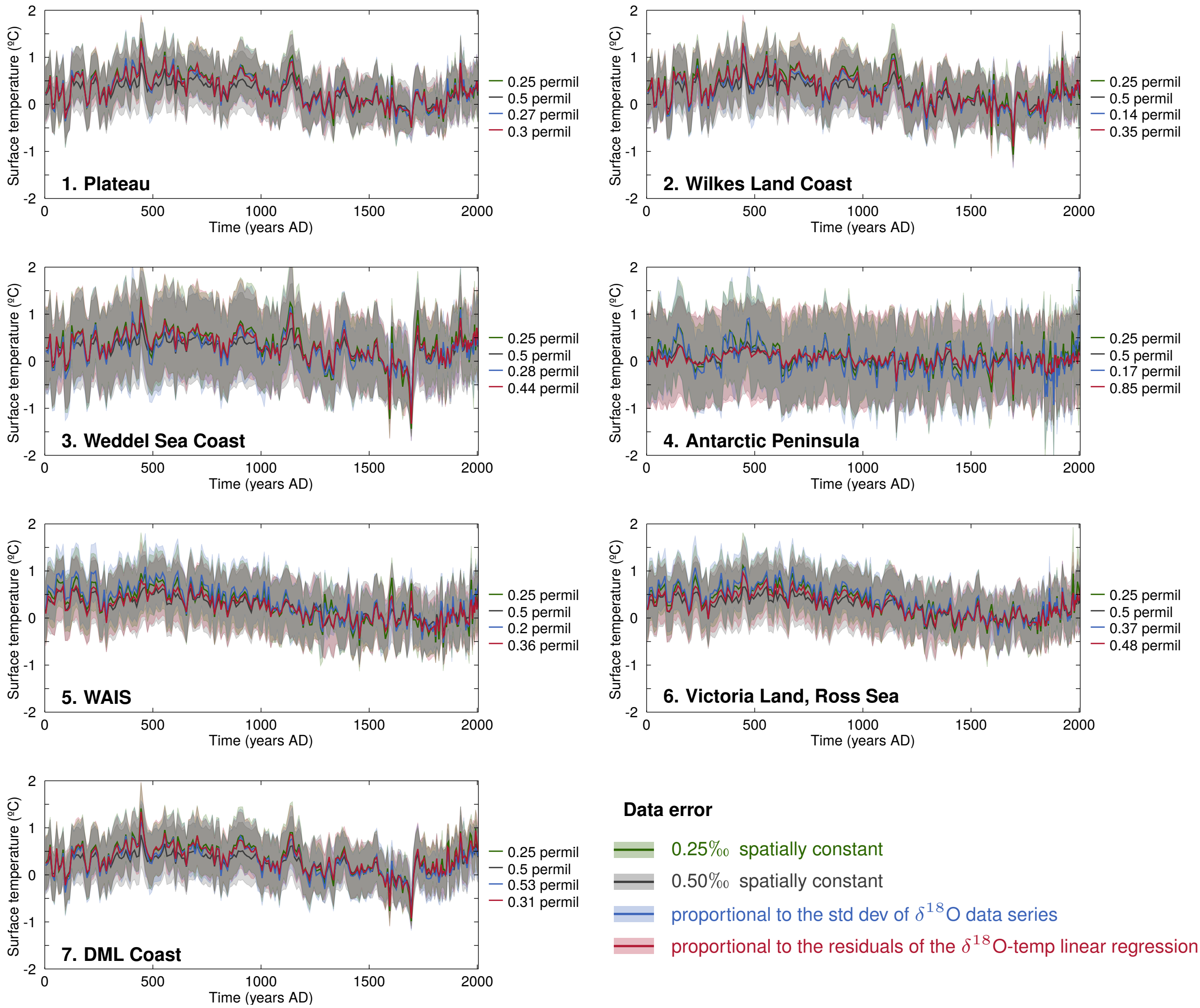

Figure S3. Data assimilation-based temperature reconstructions using the model ensemble ECHAM5/MPI-OM over the period 0-2000 CE over the seven Antarctic subregions. The time series differ by the choice of different data error taken into account in the data assimilation process: 0.25‰ spatially constant (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 δ^{18}O (in red). The uncertainty of the reconstructions is shown in shaded area with the corresponding colors ($\pm$1 standard deviation of the model particles scaled by their weight around the mean). The reference period is 1500-1800 CE.

S3 Information about the data assimilation process

The data assimilation process works well from a technical point of view. The data assimilated constrain strongly the model ensemble, but the constraint is not strong enough to lead to degeneracy, with on average 14% of the particles kept at each data assimilation step, which makes more than 20 particles out of 141 when using the model ECHAM5-wiso and more than 172 out of 1200 when using the model simulations performed by ECHAM5/MPI-OM (Fig. S4). The biggest weight given to a particle reaches in average 11% in the experiment using ECHAM5/MPI-OM and 34% in the experiment using ECHAM5-wiso. The weights are thus distributed over several simulated years, indicating the lack of degeneracy and overfitting (Fig. S5).

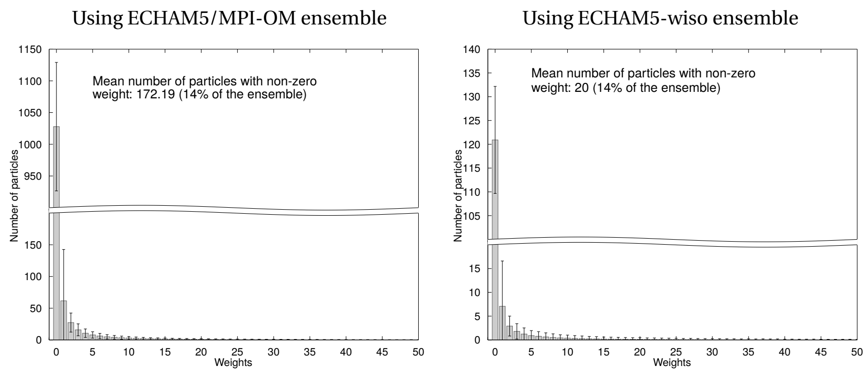

Figure S4. Mean distribution of the relative weights (which have to be divided by the total number of particles to obtain the actual weights) of the particles in the reconstructions achieved by the assimilation of the seven composites of δ^{18}O produced in Stenni et al. (2017) using ECHAM5/MPI-OM ensemble (left panel) and using ECHAM5-wiso ensemble (right panel). The distribution is averaged over the period 0-2015 CE, with the standard deviations showed by the error bars.

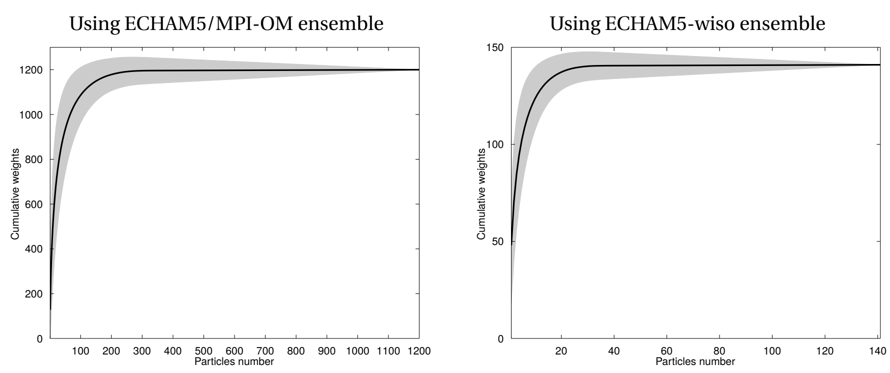

Figure S5. Cumulative relative weights (which have to be divided by the total number of particles to obtain the actual weights) of the particles in the reconstructions achieved by the assimilation of the seven composites of δ^{18}O produced in Stenni et al. (2017) using ECHAM5/MPI-OM ensemble (left panel) and using ECHAM5-wiso ensemble (right panel). The particles are sorted in descending order according to their weight. The weights are averaged over the period 0-2015 CE, the shaded area corresponds to plus and minus one standard deviation around the mean.

References

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