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Supplement of

Inter-annual snow accumulation and meter-scale variability from trench measurements at Dome C, Antarctica

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S1 Details on SSA analysis

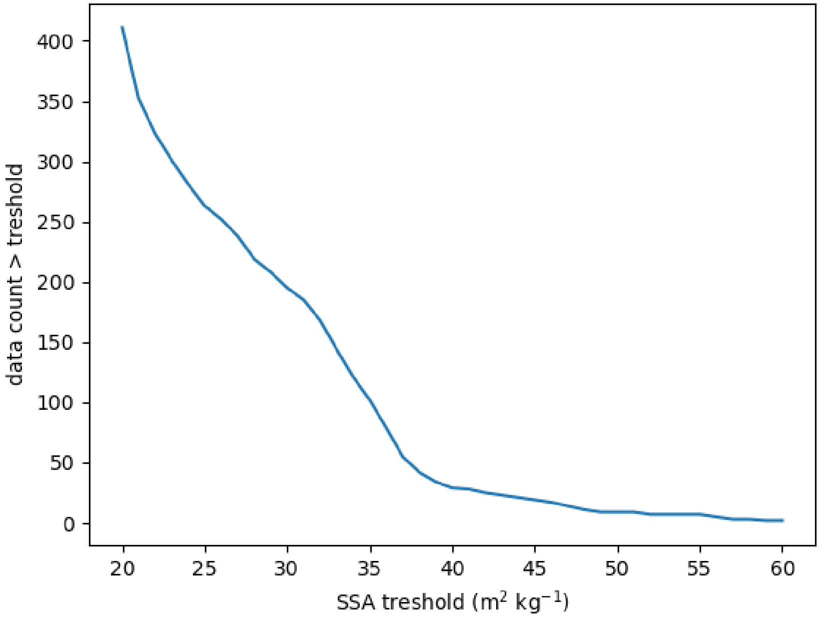


Figure S1. We have performed a sensitivity test to ensure that this was also an appropriate threshold for the trench dataset. We counted all SSA values in the trench dataset (26 envenly distributed profiles) above a certain threshold, for threshold values ranging from 20 $\mathrm{m^2kg^{-1}}$ to 60 $\mathrm{m^2kg^{-1}}$. We see a clear transition around 38-42 $\mathrm{m^2kg^{-1}}$, where the datapoint count increases sharply under 38 $\mathrm{m^2kg^{-1}}$, indicating a longer persistence of such SSA values during grain coarsening. This confirms that 40 $\mathrm{m^2kg^{-1}}$ is a sweet spot to identify fresher snow.

SSA. In our alignment protocole, we have only used SSA to get the topmost tie point for each profile in the upper section of the trench. SSA values exhibit a steady decrease in the first 40 cm just under the surface. Surface SSA can be as high as 70 $\mathrm{m^2kg^{-1}}$ in the surface layers and drop consistently below 20 $\mathrm{m^2kg^{-1}}$ at 40 cm depth and beyond.

It has been already documented that SSA values of 60 $\mathrm{m^2kg^{-1}}$ and above correspond to snow from the winter season (Picard et al., 2016b). In our case, high SSA value can only correspond to snow from the 2019 winter season. It is not expected for SSA slopes to align as a direct result of the sulfate isochrone alignment. Indeed, grain size growth depends on the burial history of the snow. Snow that has been exposed for a longer time will be subject to metamorphism for an extended period, resulting in a sharper gradient of SSA.

In (Fig. S2), SSA data show a sharp decrease across the 2020 to 2018 isochrones. The maximum value of SSA at the 2019 level is 37 $\mathrm{m^2\ kg^{-1}}$, and the 90% quantile is 35 $\mathrm{m^2kg^{-1}}$. So values of SSA under 37 $\mathrm{m^2\ kg^{-1}}$ at the time of the trench sampling on the East Antarctic plateau can be attributed to snow older than a year. Another argument for chosing this threshold comes from the distribution of SSA values accross the trench (Fig. S1). It shows a clear transition around 38-42 $\mathrm{m^2kg^{-1}}$, showing a longer persistence of SSA values under 38 $\mathrm{m^2kg^{-1}}$ during grain coarsening, confirming that 40 $\mathrm{m^2kg^{-1}}$ is a sweet spot for identifying fresh snowfall at Dome C. Based on the distribution of SSA in surface snow (2019 level), with a mean value of 37 $\mathrm{m^2kg^{-1}}$ (and a 90% quantile of 35 $\mathrm{m^2kg^{-1}}$), we interpret the fraction of profiles with SSA under the threshold value of 37 $\mathrm{m^2kg^{-1}}$ (indicator of snow older than a year) as the annual hiatus probability at the surface at the time of sampling. We identify about 20% of the profiles (6 out of 26) with surface SSA under this threshold. When using the 90% quantile threshold (35 $\mathrm{m^2kg^{-1}}$), the annual hiatus estimate for year 2019 is reduced to about 10% (three out of 26 profiles), giving a 10-20% estimate of annual hiatus for the year 2019.

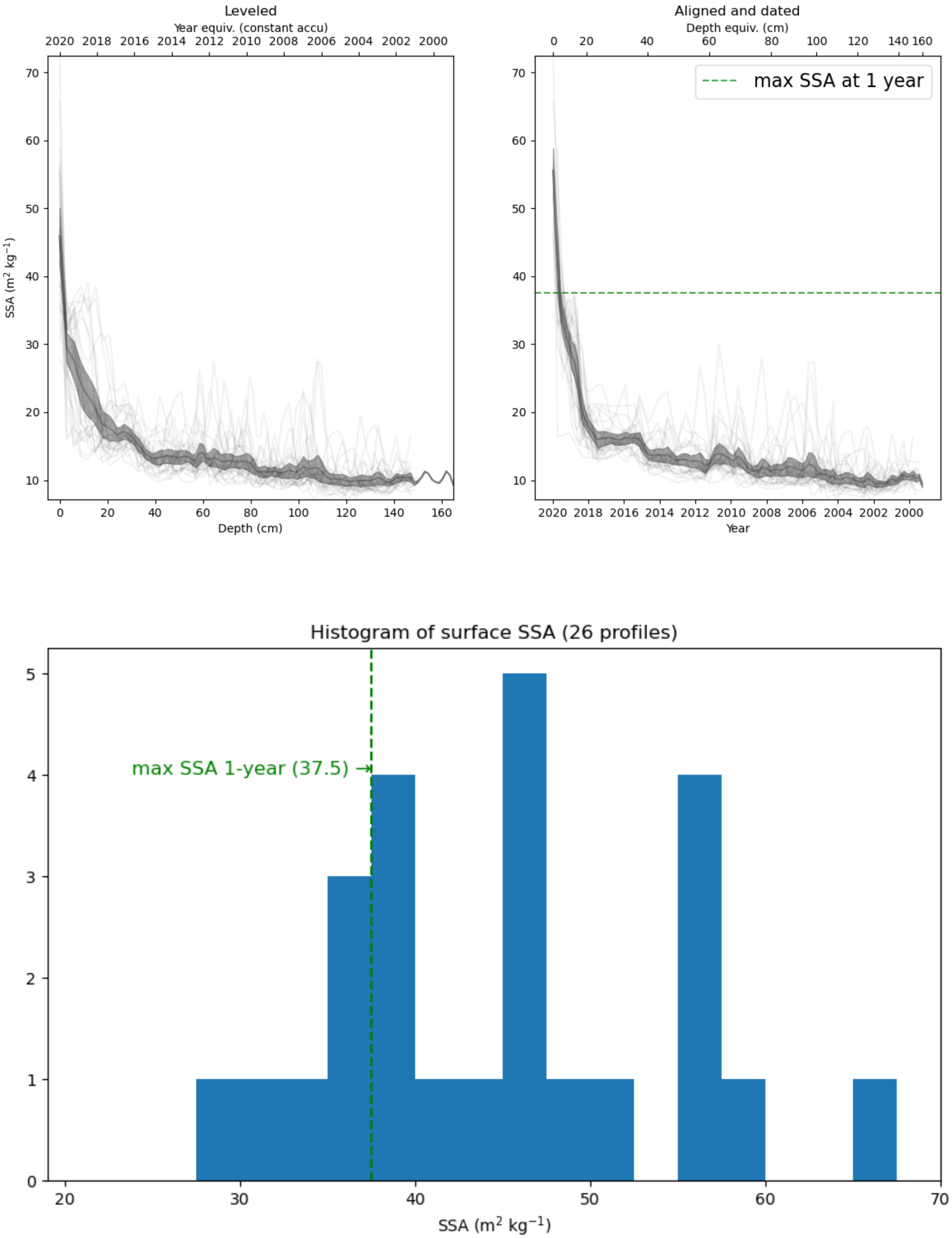


Figure S2. Decreasing behaviour with depth. 1 year SSA corresponds to the 35 unit threshold.

S2 Effect of the alignment on correlation patterns

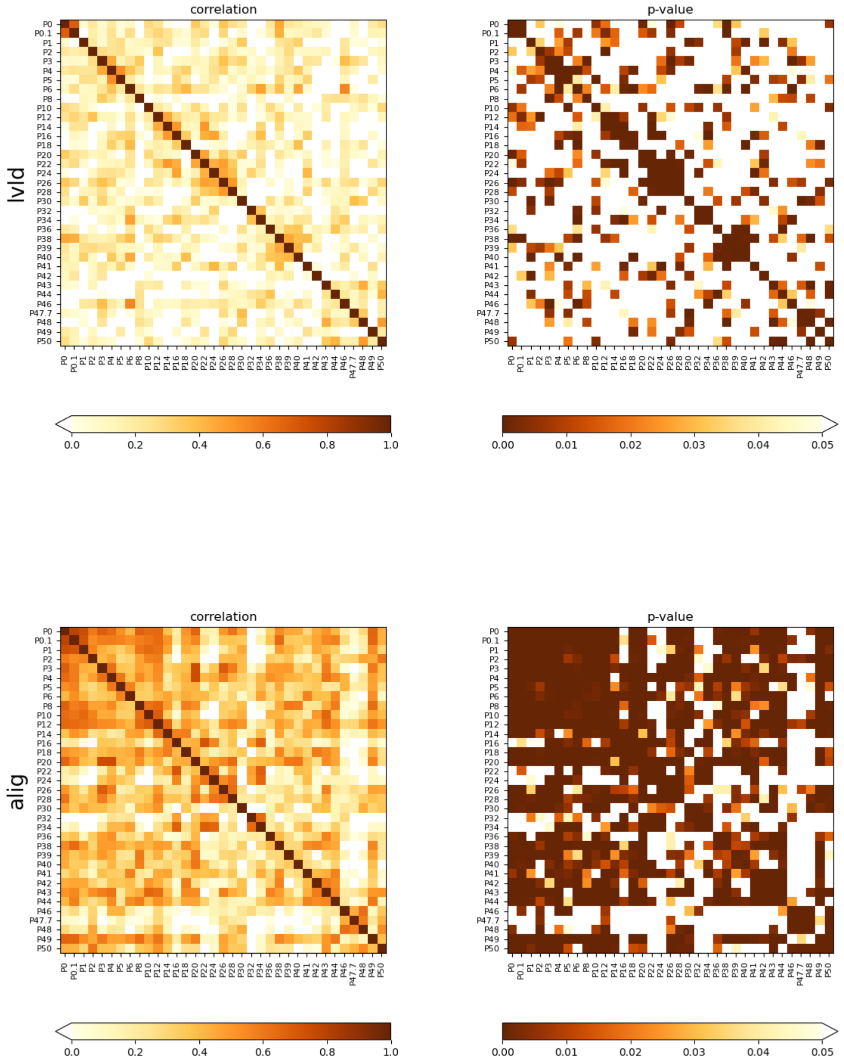


Figure S3. Quantitative diagnosis of the chemistry alignment described in section A3, showing a sharp increase in interprofile correlation accross the entire trench after alignment. Only pits distant by $2\ \mathrm{m}$ have been used for mean correlation computation presented in the text.

S3 More details on the alignment

S3.1 Correcting for missing snow in the upper section of $\mathrm{P0}$

In the results section, we explained how we chose $\mathrm{P0}$ as reference profile for the alignment. $\mathrm{P0}$ has a low value of SSA close to the surface, compared to most profiles in the trench, indicating a hiatus. A preliminary alignment of the highest SSA values accross the trench indicates that 70% of profiles have 3 cm more snow (one data-point) than $\mathrm{P0}$. If we used the raw depth scale of $\mathrm{P0}$ with our protocole, we would be discarding this top snow layer, which would hinder the accumulation reconstruction for the top section of the trench. Instead, we proceed to extend the reference profile, adding two datapoint (3 cm at 1.5 cm resolution) to the chemistry profiles of $\mathrm{P0}$. We create a new reference profile for all species by filling these two data points with the average top 3 cm data of the other profiles with higher SSA values. This way, we obtain a reference profile on which an accurate alignment of the top section of the trench is possible.

S4 Sensitivity tests

S4.1 Using $\mathrm{P48}$ as a reference profile

We redo the entire alignment and dating procedure starting from another profile $\mathrm{P48}$ (the other 1.5 cm resolution profile in our dataset). The pair P0-P48 is a great example as it illustrates the differences that can exist between two profiles over the same depth range; they are shown in Figure S4: for example, a large peak around 35-40 cm depth in $\mathrm{P0}$, which is also present in several profiles in the trench, is absent from $\mathrm{P48}$. We recall that $\mathrm{P48}$ sits on top of a dune and the other end of the trench, which could explain the differences in signal archival. This raises the question of how much the aligned trenches resulting from one or another choice of reference can differ.

To illustrate this, we show the dated profiles $\mathrm{P0}$ and $\mathrm{P48}$ resulting from both alignments (Fig. S4). We get mismatches of up to a year in the position of the peaks. Here we have two factors at play; one is the way both profiles are aligned onto each other, which ought to be symmetric if our alignment is consistent; the second is the way each profile is dated in their respective alignment, which will depend on the matching features between our set of snow pits and the reference profile. When we look at other profiles, discrepencies can amplify because of different choices in associating peaks to the reference. Comparing both alignments accross the trench, the mean absolute difference in dates for each depth is 300 days for the entire trench, versus 150 days for $\mathrm{P0}$ and $\mathrm{P48}$.

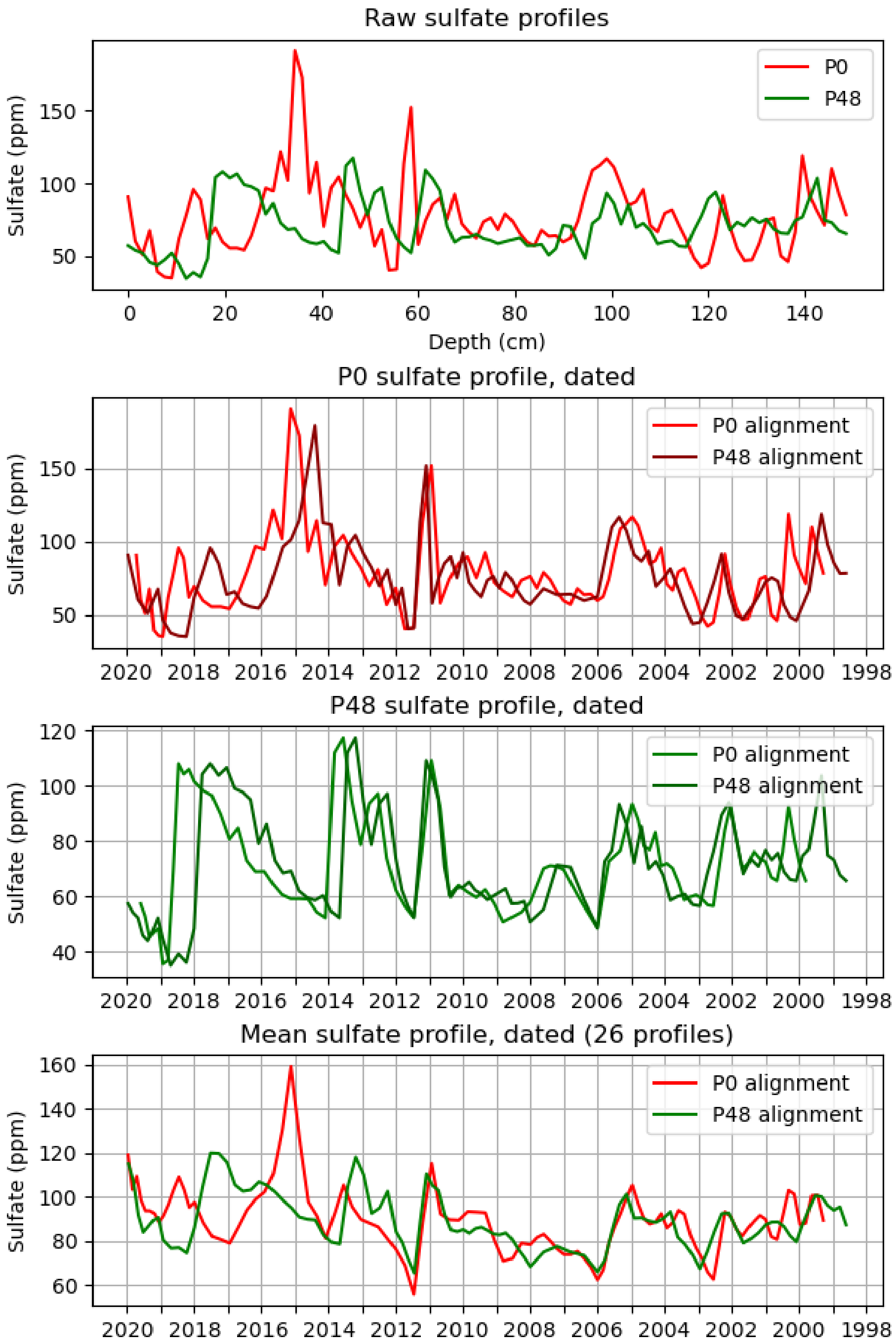


Figure S4. Sulfate profiles for P0 and P48 against depth and against time for alignment and dating procedures based on two different reference profiles.

Despite those differences, the mean accumulation reconstructions are extremely similar, as shown in Figure S5. The mean accumulation over the 20 year period is 23.9 $\pm$ 1.5 $\mathrm{kgm^{-2}}$ for the $\mathrm{P0}$ alignment and 23.1 $\pm$ 1.4 $\mathrm{kgm^{-2}}$ for the $\mathrm{P48}$ alignment ($\pm$ 1 σ spatial envelopes).

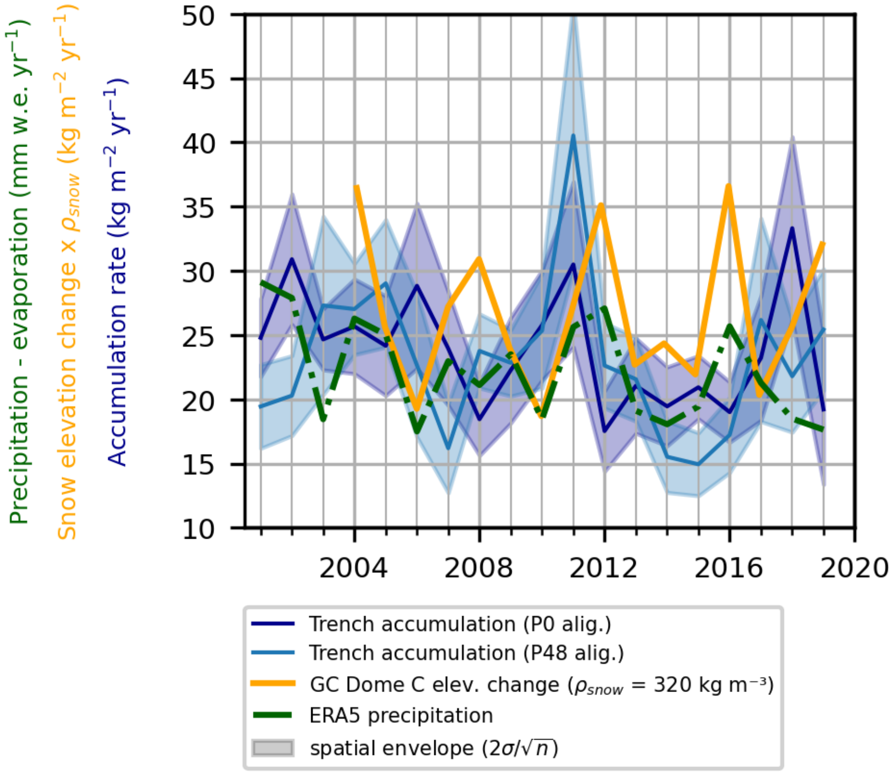
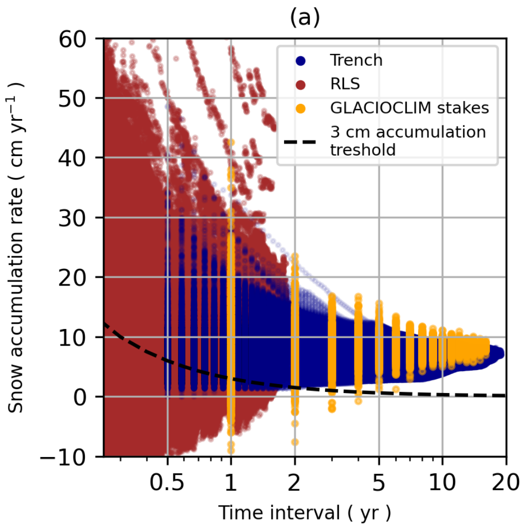


Figure S5. This figure illustrates the uncertainty arising from the choice of the reference profile: $\mathrm{P0}$ as in the main text, or 48. We stress that, despite expected differences, as our method is not resolving annual variations, the two estimates lie within their spatial envelopes (sharded blue and purple curves), and the choice of the reference profile does not explain the differences between the trench and the GLACIOCLIM data.

S5 Snow accumulation distribution

The estimation of accumulation hiatus probability as presented in Section 3.4 relates to the more general question of the distribution of snow elevation change at a given time interval. Here we present two additional figures that illustrate how the trench dataset bridges between the two years of RLS high resolution snow elevation maps and the 14 years of GLACIOCLIM annual snow elevation change measurements. Fig. S6 (a) shows the distribution of snow accumulation rates, and Fig. S6 (b) shows the standard deviation.

(a)



(a)

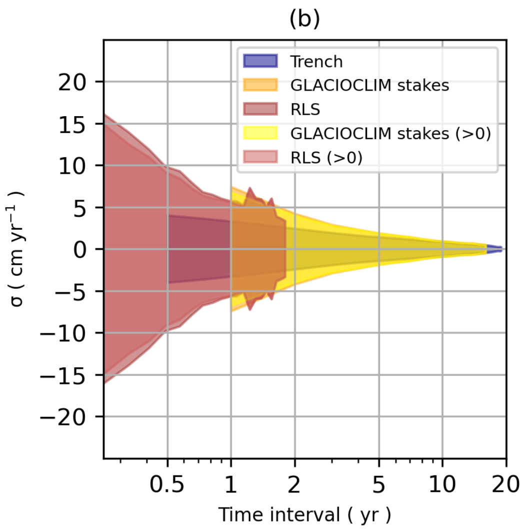


Figure S6. (a) Distribution of snow accumulation rate of single accumulation events according to the trench, RLS and GLACIOCLIM stakes datasets. Accumulation events are obtained from the datasets just as in Section 3.4, using daily elevation maps for RLS, monthly isochrones for the trench and yearly elevation readings for GLACIOCLIM. Time intervals under six months are discarded for the trench as they are under our resolution limit. This is an intermediate figure for the computation of hiatus probability: the black dashed line represents 3 cm total accumulation which is the threshold value for non-negligible snow accumulation. The hiatus probability for a given time period, as computed in Section 3.4, is the fraction of accumulation events under this threshold. (b) Standard deviation of accumulation rates over a given time interval for the trench, RLS and GLACIOCLIM stakes datasets. Same as (a) but centered around mean and given in standard deviation. The accumulation converges around the mean (mean/sigma < 1%) for periods longer than 10 years.

S6 Additional datasets

When comparing our accumulation estimates from the trench to ERA5 reanalysis data, one can ask wether another reanalysis dataset provides a better match, especially in terms of inter-annual variability and dephazing. We tested this we the Modern-Era Retrospective analysis for Research and Applications, version 2 (MERRA2) (Gelaro et al., 2017). We consider the grid-point closest to Dome C (75° 00′ S, 123° 125′ E.). The precipitation time series of MERRA2 along with the datasets of the main text is shown in Figure S7. The precipitation time series is very similar to ERA5, showing the same dephasing of annual precipitation peaks when compared to the trench accumulation time series. Note that we did not check the contribution of sublimation.

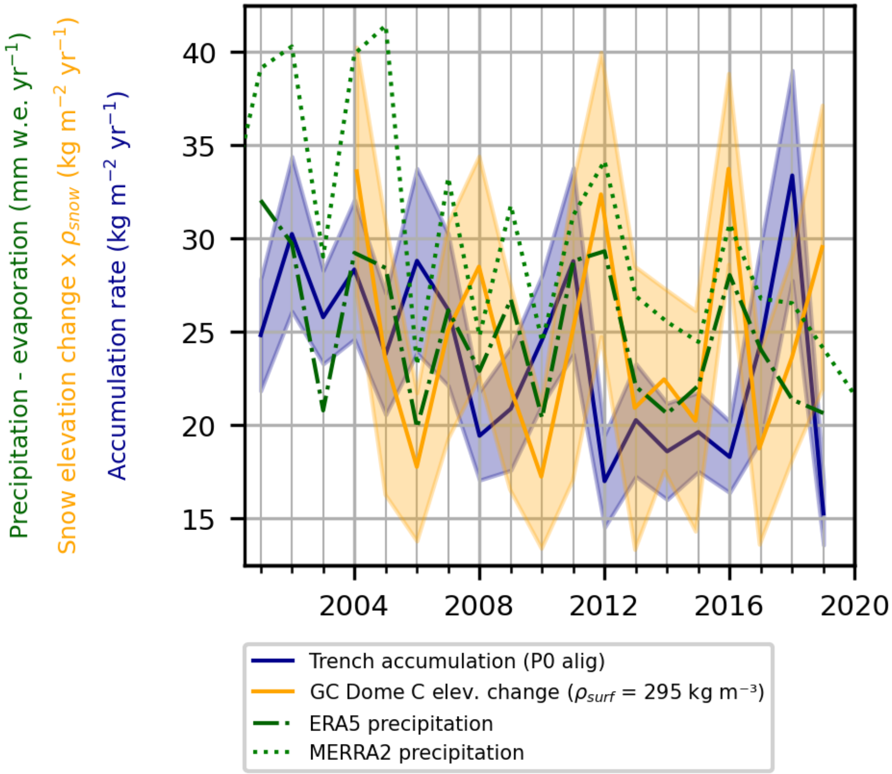


Figure S7. Same as figure 6 using MERRA2 in addition to ERA5 reanalysis precipitation outputs. MERRA2 and ERA5 precipitation dataseots show a systematic offset and a quite close correlation that does not change the results. Note that here we show precipitation (as opposed to precipitation - sublimation in main text).

S7 Effect of the alignment on other chemical species

The isochrones presented in the results section are mainly based on the sulfate peak matching. It is interesting to check whether an increase in inter profile correlation of the signal is also visible on other chemical species in the aligned trench, compared to the raw data.

S7.1 MSA

MSA profiles shows a large inter-annual variability in the first 1 m under the surface, with three peaks above 25 $\mathrm{ng\ g^{-1}}$, against a background value of 10-15 $\mathrm{ng\ g^{-1}}$. Beyond 1 m depth, the signal is noticeably damped, with values around 10 $\mathrm{ng\ g^{-1}}$ in the 100-160 cm depth range.

After alignment, which we recall is mainly based on sulfate peak to peak matching, and only secondarilly based on MSA, the common signal in MSA is nevertheless well improved. Inter profile correlation goes from 0.23 to 0.34 compared to the leveled trench, and the number of significant correlations goes from 60% to 70%. The mean signal in the aligned trench, shown on the right in figure S8, is noticeably sharper than in the leveled trench.

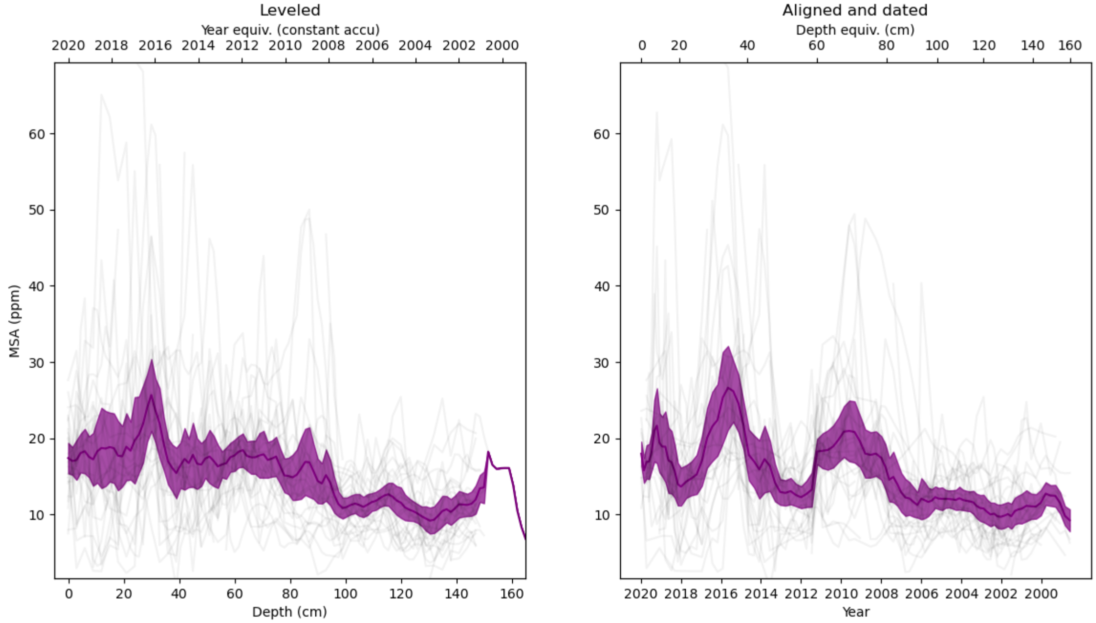


Figure S8. MSA profiles in the leveled and aligned trench, showing a damped signal below 1 m depth. Individual profiles are shown in light grey, and the purple curve represents the mean. The envelope indicates two standard deviation divided by $\sqrt{n}$.