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Supplement of

Climatic information archived in ice cores: impact of intermittency and diffusion on the recorded isotopic signal in Antarctica

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S1. Climatic parameters

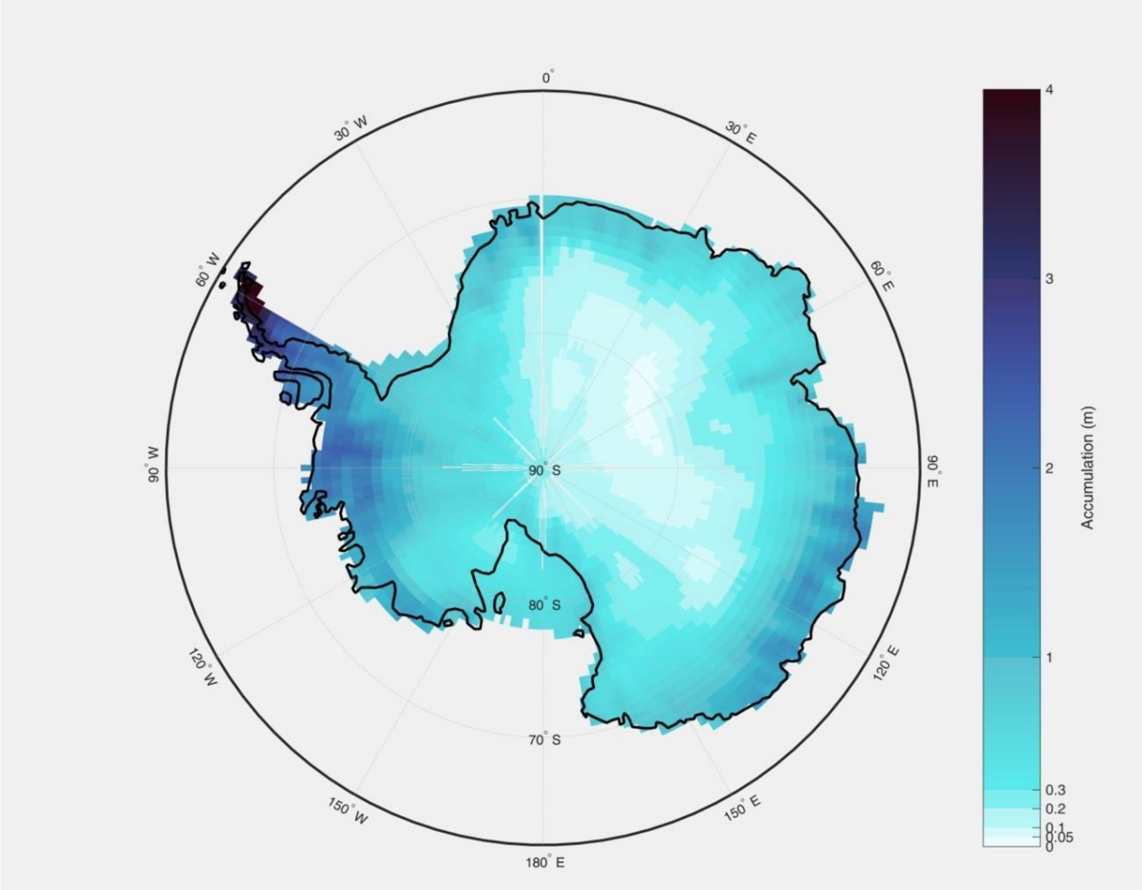

Figure S1: *Maps of the accumulation rate (m w.e.) produced by correcting ERA-interim precipitation amounts with satellite data and ice core estimates*

S2. Impact of the accumulation correction

To test the sensitivity of our results on the accuracy of the accumulation rate correction, we run the model at EDML without including the accumulation amount correction. This only has a small effect on effect of precipitation intermittency; The noise level added by precipitation intermittency, without the accumulation amount correction is 0.60‰^{2}m, vs. 0.59‰^{2}m when including the correction.

Table S1: *Time scales τ_a for which $SNR = 1$ for averaged samples for precipitation intermittency at EDML without any correction of the ERA interim accumulation rate*

β	0	0.2	0.4	0.6	0.8	1
$\tau_a(a)$	/	/	143	22	8.9	4.6

This results in small increase of the time scales at which a meaningful signal can be retrieved, for instance, for $\beta = 0.6$, we obtain $\tau_a = 22\,a$ (with the correction 17 a, see Table S1 without accumulation correction, versus Table 1 with correction). The small difference comes mainly from numerical approximation when both the intermittent and the climate virtual cores were block averaged to 1cm resolution (see the small differences between figure S2 and Figure 4).

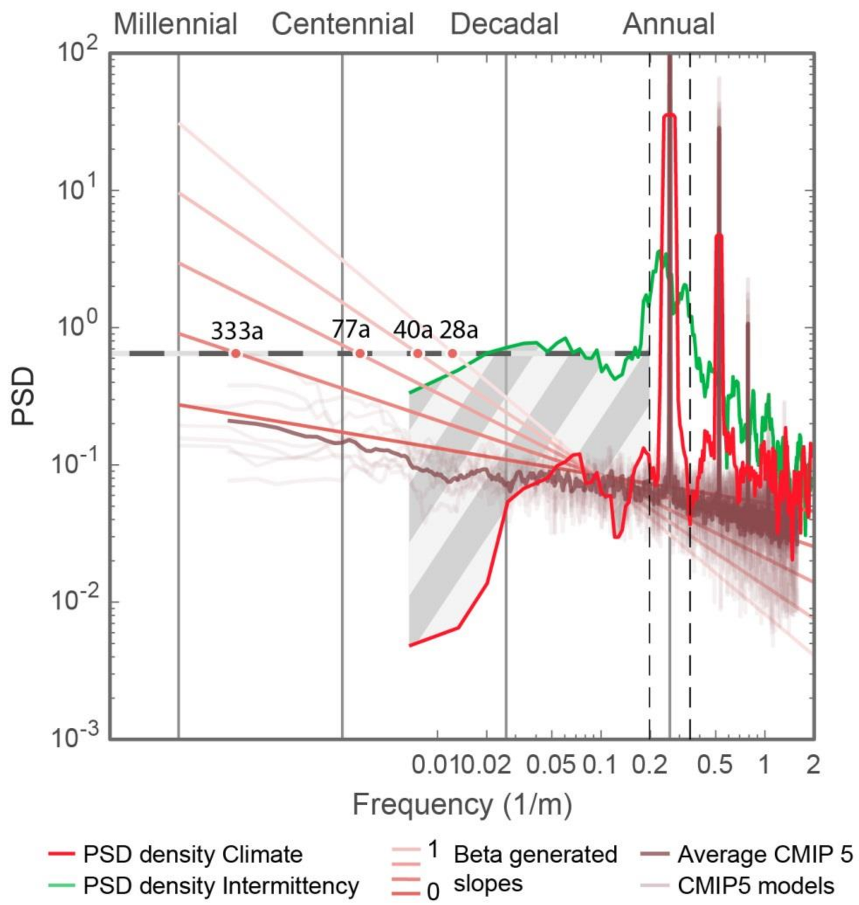

Figure S2: *Same as Figure 4 without the correction of the accumulation.*

When including diffusion, we obtain values for τ_a of 30 a and 11 a for values of β of 0.6 and 0.8, respectively (versus 23 a and 9.2 a with the accumulation correction). While these values are larger than the ones obtained when the accumulation is corrected to be matching observations, they remain of the same order of magnitude, even though the accumulation rate is 12 to 15 times stronger than the observations (Thomas et al., 2017). We expect that lower accumulation sites will be more sensitive to the accumulation correction than EDML. On the other hand, the uncertainty of the accumulation correction is expected to be much smaller than the extreme case tested here.

S3. Impact of dating on the precipitation intermittency

We now evaluate the impact of the dating on the power spectral estimates, and as a result, on the amount of noise created by precipitation intermittency. In the manuscript, we describe mainly the impact of the archival processes in a "realistic" case for which the ice core relies on only a few dating tie points, resulting in the depth series being converted into time series based on the average accumulation rate. Typically, in our case, the accumulation rate is calculated from the sum of the precipitation amount for the entire ERA-interim time series, lasting 39 years. This is equivalent to cores for which one tie point is available at the bottom of the core.
As shown in the manuscript, the correlation between the virtual cores and the climatic signal is strongly improved when using the perfect dating assumption, which consists of tagging each layer of snow with its date, mainly because the phase shift

between the records are limited, removing a large of the impact of precipitation intermittency. Yet, this assumption is in practice unrealistic, as it involves dating snow layers at a resolution of 16 days, far beyond precision of any dating methods for ice core records.

We evaluate the impact of the perfect dating assumption on the estimates of the amount of noise added by precipitation intermittency by reproducing the calculation with PSD of time series, comparing the PSD of the intermittent virtual core in the case of a perfectly dated core (ideal case), a core dated only once at the bottom (case described in the manuscript, one tie point 40 years before the surface point), and intermediate cases with tie points every 1, 3 and 10 years.

We show that the noise created by precipitation intermittency does not vary when the dating intervals are longer than 3 years (noise level of 1.3, 1.3 and 1.1 ‰^{2} a for the spectrum with a constant accumulation, tie points every 10 years, and tie points every 3 years, respectively). When the dating intervals get close to 1 year, or when every layer is dated, the amount of noise created by precipitation intermittency significantly decreases (noise level of 0.9 and 0.1‰^{2} a, for 1 year and perfectly dated, roughly every 16 days, respectively).

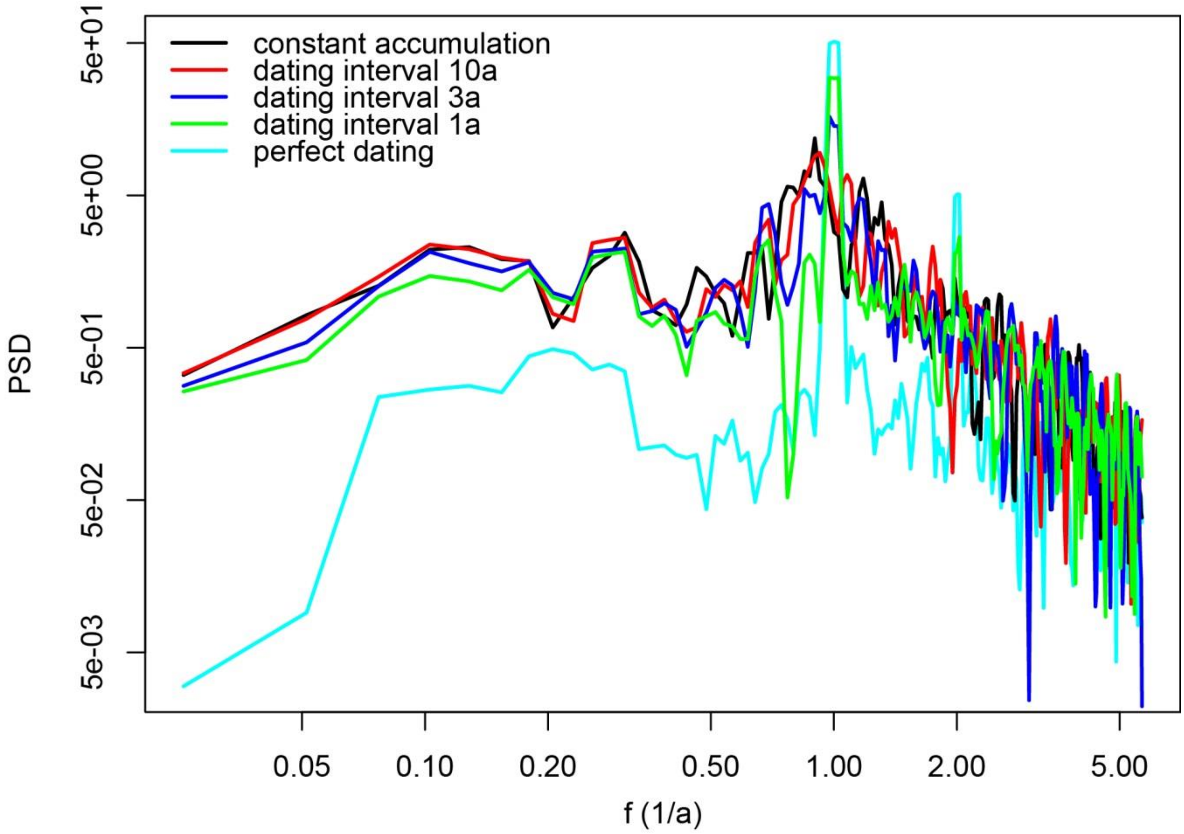

Figure S3: *Power spectral density of the intermittent virtual core calculated from time series for different dating interval (with constant accumulation in between dating tie points): black, constant accumulation over 39 years (version of the manuscript), red, dating interval of 10 years, blue, dating interval of 3 years, green, dating interval of 1 year, teal, perfect dating, for which each layer is dating (on average every 16 days).*

Table S2: *White noise amount generated by precipitation intermittency and retrieval time scales for a β of 0.6 (note that the white noise amounts are expressed in ‰²a, hence the difference with the main text).*

Dating interval (a)	Constant accumulation	10	3	1	Perfectly dated
White noise amount (‰² a)	1.32	1.30	1.12	0.92	0.10
τ_a for a β of 0.6	17	17	13	8.3	<1a

Overall, these results account for changes of the calculation of τ_a between 8.3 and 17 a for reasonable dating capabilities. The effect of precipitation is almost removed in the case of a perfect dating.

S4. Addition of clear sky precipitation

Here, we evaluate the impact of clear sky precipitation, a very regular input of precipitation missing from ERA-interim, on our estimation of the limit time scales at which climatic signal can be retrieved. In dry areas of the East Antarctic Plateau, it is often observed that precipitation can occur without any cloud cover. It was proposed that this clear sky precipitation, can account for up to 50% of the total amount and could be equally distributed across the year (Fujita et al, 2006). Such a regular input of small amount of precipitation every day would reduce the impact of precipitation intermittency on the ice core records. This type of precipitation is not included in ERA-interim and thus our main analyses. To test the sensitivity of our results to this potential effect of clear sky precipitation we performed an additional simulation with the forward model assuming that half of the accumulation would originate from clear sky precipitation. To do so, we divided halved the precipitation amount and added a constant precipitation input every day balancing the removed precipitation. Furthermore, we assumed that the link between isotopic composition and temperature was the same for both types of precipitation.

For the EDML site, the noise level added by precipitation intermittency including 50% clear sky precipitation is 0.21‰²m, and thus almost three times below the value obtained assuming no clear sky precipitation (0.59‰²m). As a result, the time scales at which the signal can be retrieved would be reduced by a factor three to ten (Table S2). This is likely the extreme scenario as in most cases, clear sky precipitation will account for less than half of the precipitation and it will not be perfectly equally distributed over the year.

Table S2: Time scales τ_a for which $SNR = 1$ for averaged samples for precipitation intermittency at EDML, including clear sky precipitation with the same isotopic signature than long range precipitation.

β	0	0.2	0.4	0.6	0.8	1
$\tau_a(a)$	/	56	7.1	3.4	2.1	1.4

Finally clear sky precipitation is assumed to follow a different distillation path than the one experienced by long range precipitation, and the associated isotopic sensitivity to temperature is thus also expected to be different (Dittman et al, 2016, Stenni et al, 2016). To test this, we attributed a different relationship for the link between isotopic composition of clear sky precipitation and temperature (0.51‰.C^{-1})

than for the link between isotopic composition of long range precipitation and temperature (0.41‰.C^{-1}). In this case, the amount of noise created by the precipitation intermittency is slightly higher (0.23‰^{2}m) than in the previous case for clear sky precipitation (0.21‰^{2}m), and as a result, the time scales for which the signal is preserved are higher (Table S3). This increase of τ_a is very small compared to the initial decrease due to the inclusion of clear sky precipitation, suggesting that clear sky precipitation would tend in either case to limit the impact of precipitation intermittency on the time scale at which signal is preserved in ice core records.

Table S3: Time scales τ_a for which $SNR = 1$ for averaged samples for precipitation intermittency at EDML, including clear sky precipitation with a different isotopic signature (0.51‰.C^{-1}) than long range precipitation (0.41‰.C^{-1}).

β	0	0.2	0.4	0.6	0.8	1
$\tau_a(a)$	/	91	8.8	3.9	2.4	1.5

S5. Seasonality of temperature and precipitation at EDML

The large amount of precipitation in winter at EDML is associated with warmer conditions than average, leading to the difference between precipitation-weighted temperature and actual temperature being larger in winter than in summer.

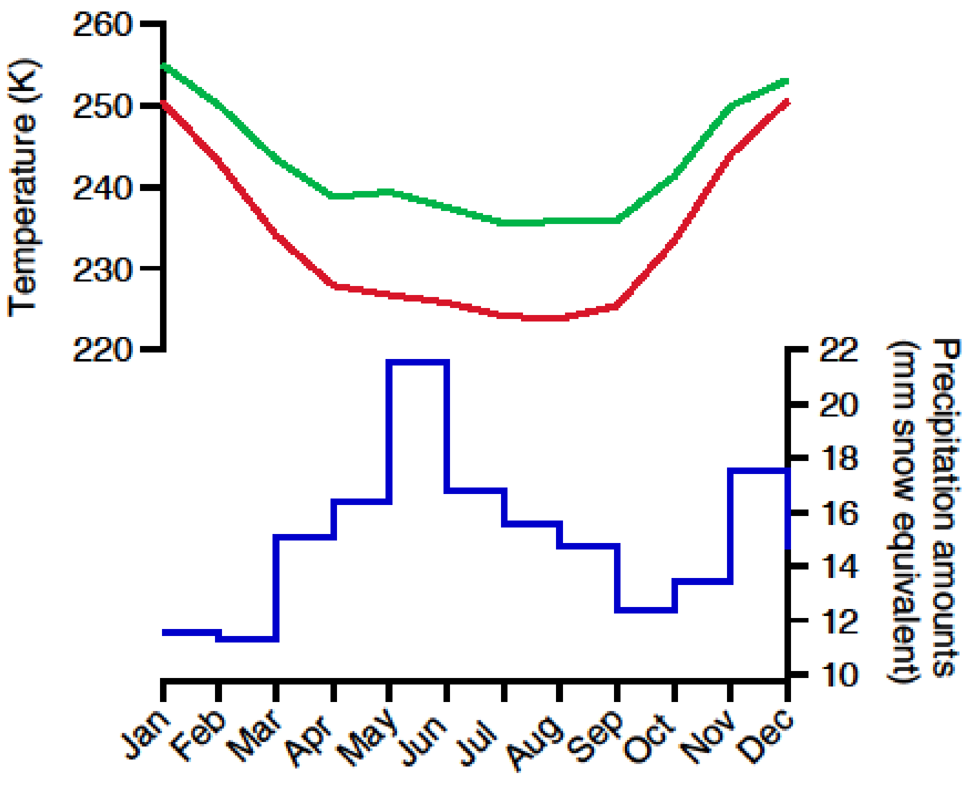

Figure S4: *Seasonality at the EDML site of temperature (red), precipitation-weighted temperature (green), and average precipitation (blue) for each month of the entire ERA-Interim time series.*

S6. Illustration of the forward model on Trace21k temperature time series for Dome C

We use the amount of white noise generated by precipitation intermittency as predicted from the forward modelling approach to simulate the impact of precipitation intermittency on temperature time series from the Trace21k climate model simulation over the last 22000 years (thus neglecting the changes of precipitation patterns due to climate transitions). Specifically, we convert the $\delta^{18}O$ white noise level predicted by the forward model for the site of Dome C (0.48 ‰^{2} m) into a variance amount of the white noise by taking into account the resolution at which the noise is applied on the record (here 3 months, leading to a variance of 20.7‰^{2} of the white noise level). We convert this into a temperature variance using the $\delta^{18}O$-to-temperature conversion we applied in the forward model (0.46 ‰ °C^{-1}). We add this noise to the Trace21k temperature time series extracted from the model grid cell closest to the Dome C site in the temporal domain to match the threshold obtained in the spectral domain. To mimic the impact of only precipitation intermittency on the Dome C ice core, we calculate block-averages at the sampling resolution of the Dome C ice core (55 cm), converted to time using the present-day accumulation (9.5 cm s.e. which yields a time resolution of 5.8 a), and neglect snow densification and thinning, changes in accumulation rate, and dating uncertainty. We add the impact of diffusion to the modelled intermittent Dome C temperature time series before sampling to the ice core resolution. For this, the depth-dependent diffusion transfer function is calculated only within the firn and kept constant below the lock-in depth, which is a good approximation considering the low isotopic diffusivity in solid ice (Pol et al., 2014).