

Author Reply to the Short Comment by **Zoltán Kern & István Hatvani**

on the manuscript

**How precipitation intermittency sets an optimal sampling distance for temperature reconstructions from Antarctic ice cores**

by Thomas Münch, Martin Werner, and Thomas Laepple,  
submitted to *Climate of the Past* (<https://doi.org/10.5194/cp-2020-128>).

Dear Zoltán Kern and István Hatvani,

thank you very much for posting a short comment on our manuscript, to which we include a reply below. For this, we repeat your original comment, set in normal black font, and add our replies in [blue](#).

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Dear Authors,

First of all let us congratulate you on this very concise and precisely documented study which was highly interesting to read.

[Thank you very much.](#)

In the following we would like to comment on two key results.

We agree that ambient temperature of precipitation events should be expected to show a stronger correlation to precipitation  $\delta^{18}\text{O}$  than annual mean temperature due to the intermittency of precipitation. We also agree that the data calculated from the simulation results reflect this theoretical relationship, however we would like to note that in a more experimental approach (<http://journals.pan.pl/dlibra/publication/116059/edition/100870/content>) we tested this idea and an opposite result was obtained. We found that amount weighting is incapable of ameliorating the signal replication between the stations and the ice cores, while arithmetic means gave the stronger linear relationships. The explanation is thought to be isotopic exchange between vapor and surface snow. In the present paper this may open an additional perspective from which the contrast seen in Figure 3 and Sects. 3.1 and 4 can be viewed from.

[Thank you for pointing us to this study, which constitutes an important test of the effect of precipitation intermittency on the correlation between ice-core derived isotopic composition and temperature based on real world data.](#)

[However, we do not fully agree with your interpretation. In fact, when only data from weather stations is concerned, the study shows the expected result that, firstly, the precipitation-weighted temperature shows a higher degree of correlation with the temporal variations of the precipitation isotopic composition \(which you do acknowledge in the study\), and, secondly, that this effect is more pronounced at a more continental site, where precipitation is more intermittent, as compared to a maritime site on the Antarctic Peninsula with a rather regular seasonal precipitation distribution. These results are thus in line with our results from the climate model that in general the precipitation-weighted temperature correlates to a higher degree with the isotopic composition \(see our Fig. 3\), but not so much for coastal sites \(see the respective map for the difference in correlation in our reply to reviewer #1\).](#)

[The problem arises when the real ice core data is concerned, which in your study may actually exhibit a lower correlation with the weighted than with the unweighted station temperature records. You interpret this finding in terms of a possible surface–atmosphere exchange of vapour, which might lead to a more regular isotopic temperature signal imprinted into the ice core record. However, we think that also other factors might explain the observed lower correlation. Firstly, the significance of the correlation values is unclear, especially given the small temporal overlap of the data \(e.g. Fig. 3 in the study\). Secondly, there is quite some distance between the sites of the used ice cores and weather](#)

stations, and it remains unclear whether these sites really exhibit similar vapour sources and trajectories, etc. Thirdly, and probably most important in our opinion, you do not take into account stratigraphic noise, which can strongly influence the isotopic variability and thus the correlation values, especially for the lower accumulation sites. A comparison with the correlation values between the ice cores could help here to estimate the signal-to-noise ratio.

Overall, we do agree that surface–atmosphere vapour exchange might partially counteract the impact of precipitation intermittency on the recorded temperature signal, if it constitutes a significant contribution to the snow isotopic composition<sup>(\*)</sup>. However, as long as the *atmospheric* isotope signal is concerned, this does not affect the notion that ice core sites should be combined in a way as shown in our manuscript in order to optimally avoid the impact of precipitation intermittency.

<sup>(\*)</sup> The same applies actually to diamond dust (clear sky) precipitation, which is also more regular than convective-type precipitation and which is likely under-represented in General Circulation Models.

We also agree with the concept that the signal can be enhanced by averaging isotope records across space, however it is quite strange that “. . .the optimal sampling strategy is to combine a local ice core with a more distant core 500–1000km away. A similarly large distance between cores is also optimal for reconstructions that average more than two isotope records.” In this paper <http://dx.doi.org/10.1016/j.polar.2017.04.001> we performed geostatistical analysis of 60 ice core derived d18O time series in Antarctica to determine their spatial autocorrelation structure and to find the area yet unrepresented by the assessed set of records. The spatial autocorrelation (variography; Matheron 1963) is not equivalent to decorrelation (Appendix B1-2) but also measures the spatial similarity of the studied parameter. For instance, we obtained a 350km spatial "influence" range of the assessed ice core d18O records via semivariogram analysis, which would be interesting to be compared with your results regarding the question: Why are the original ice core d18O data spatially correlated within 250km and the modeled ones in your study above 500 km to simplify the question...

The variogram technique is indeed an interesting alternative means to study the spatial similarity in the data – thank you for pointing us to this. Again we think that the respective results in your study do not conflict with our findings. To conduct the variogram analysis on the ice core data, you first remove by a multivariate regression the influence of elevation, coastal distance and longitude. Since the first two terms are also the main driving variables on the temperature field, the resulting  $\delta^{18}\text{O}$  residuals exhibit variations which should not be related to the large-scale temperature variations. Thus, the spatial range of influence of 350 km, which you find in the variogram, could be the result of isotopic variability driven by spatially coherent precipitation variations, in line with the same-order-of-magnitude precipitation decorrelation scales that we find in model data (see our Appendix B5) and which we use as decorrelation scale (500 km) to model the intermittency noise. As you mention in your study, an alternative interpretation for the 350 km scale could be regional-scale temperature variations imprinted into the isotopic composition of surface snow by vapour exchange processes. However, in both the climate model and our conceptual model, vapour exchange is not taken into account, so that the regional-scale coherence of the residual isotopic variations is only driven by precipitation variability. Then, it makes perfect sense to place ice cores farther apart than this scale (but below the decorrelation scale of the temperature field), since this optimally averages out the noise by precipitation variability and thereby maximises the correlation with temperature.

We note, however, that in the real world the observed spatial range of influence in the ice core data could be a combined result of both coherent precipitation variability and vapour exchange. Then, the relevance of our results for actual ice core studies would depend on the relative contributions of both processes. To make progress here, we ultimately need solid quantitative estimates of the importance of vapour exchange processes across temporal scales, at least for the main ice coring regions.

These experimental findings based on real life data might worth consideration when your model results are evaluated and may also serve as a good addition to the discussion.

Overall, we agree that the effect of potential vapour exchange between the atmosphere and the surface snow might influence the relevance of our results for real world applications, but this heavily depends on the actual strength of the effect. We will consider adding a paragraph about these issues to the revised discussion section of the manuscript.