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Interactive comment on "Pervasive diffusion of climate signals recorded in ice-vein ionic impurities" *by* Felix S. L. Ng

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Final Author Response to all reviews

Reviewer 1 gave an engaging summary and detailed appraisal of the manuscript. Two key points are that (i) its appeal and accessibility to non-specialists would be improved by adding a figure to exemplify ice-core ionic records, and (ii) the simulated age spans of the signal peaks in Figure 7 can be further discussed, in relation to the observed signal variability deep in the EPICA Dome C core. I plan to implement both recommendations in the revision. The added figure will probably show two records (including one

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for sulphate), with the aim of illustrating the abundance of the peak signals, their form and length scales, and their presence in deep ice; the records won't be examined beyond this, as detailed analysis of them is best left to the original papers. Regarding (ii), I will try to discuss the age span results a little more along the lines suggested by the reviewer; this will be brief, as how much matrix/grain-boundary impurities contribute to the observed variability remains unknown, and some of the apparent variability may derive from the merging of signals (Section 3.3) rather than from single peaks. In the minor comments, Reviewer 1 also provided valuable suggestions of local wording for different parts of the manuscript, and quite a few of them (especially those that improve writing clarity) will be taken up. For my earlier detailed response to Reviewer 1, please see AC1.

Reviewer 2 provided a helpful summary of the manuscript's contribution and a focussed suggestion that during the revision, I should add discussion to contrast the present model against the original model of Rempel et al. (2001), in regard to the possible effect of grain-size variations on the Gibbs-Thomson term in equations (7) and (8), and the consequential effect on signal diffusion. As I responded before in AC2, I am happy to do this, especially as the discussion may invite more research to examine the mechanisms of grain-size evolution.

Reviewer 2 clarified that Rempel el al. (2001) had ignored the Gibbs-Thomson effect by assuming that inverse coupling between grain size and bulk impurity concentration makes the vein face radii uniform, and that those authors invoked the observed anti-correlation between grain size and measured ionic concentrations in ice-core records as evidence to support this assumption. I don't think that the writing in Rempel el al. (2001) conveyed this assumption clearly/completely (that the Gibbs-Thomson term was neglected on the basis of uniform vein radii was not said; and there are more issues about the support for the assumption, as highlighted below), and I find it intriguing that both follow-on papers by Rempel et al. (2002) and Rempel and Wettlaufer (2003) (exploring the ramifications of Rempel theory) had not once referred to that assumption, but instead elaborated upon an entirely different assumption in order to neglect the Gibbs-Thomson term – via its small size compared to other terms. In any case, I am happy to relate this clarification as made by Reviewer 2 by referring to RC2.

My plan is to add the passage discussing grain-size variations to Section 4, using the above as one of the starting ingredients. It will be noted that adding grain-size variations will modify the rate of signal diffusion in the revised theory, and that the model formulated by me in the manuscript (Section 2) allows any grain-size prescription, even though the numerical experiments in Section 3 employed smooth grain-size profiles, for reasons given on Lines 237-240. Then, the possibility that Gibbs-Thomson diffusion would vanish identically *if* grain-size variations (at short length scales) occur in such a way that the bulk vein impurity concentration cB and mean grain size dg are coupled via the highly-specific relation cB \propto dgˆ{-2} will be discussed. This scenario, favoured by Reviewer 2, is what he clarified to be the assumption behind the Rempel et al. (2001) theory. I think its consideration enriches the manuscript by furthering our query of under what circumstances might signals be able to escape diffusion to show migration at depth. However, there are fundamental issues with arguing for this scenario by using the observed anticorrelation between grain size and impurity loading in ice cores; to state them briefly: (i) Inverse coupling between cB and dg does not generally imply suppression of the Gibbs-Thomson diffusion. Depending on the form of the inverse relation, it can enhance or weaken the diffusion (see my writing in AC2 for details); only strict obeying of cB \propto dgˆ{-2} would suppress the diffusion, so this condition is highly specific/restrictive. (ii) In the assumed scenario, it is the bulk *vein* impurity concentration cB that must obey the inverse-square relation with dg. However, the evidence used for support pertains not to cB; instead, the observed anticorrelation concerns the bulk impurity loading measured in ice cores. One cannot simply equate this loading to the vein concentration cB, because the loading contains an unknown contribution of matrix and grain-boundary impurities. (iii) No physical mechanism has been offered for why increasing cB (in the veins) would reduce the grain size; existing

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theories on how impurities impede grain growth consider the effect of impurities at grain boundaries only, and not impurities in the veins. [See AC2 for further details on (i)-(iii).] These issues, which will be described in the new passage, mean that convincing physical arguments and evidence for this special conjecture to hold ("zero Gibbs-Thomson diffusion because cB \propto dg^{-2} is satisfied throughout the ice column") are currently lacking.

From these, the reader can decide whether to regard the original theory (no diffusion, only migration) as describing the predominant behaviour of vein ionic signals in ice sheets. In contrast, in the manuscript I did not claim that the signal diffusion rate being simulated is precisely accurate nor that grain size profiles are always smooth. The point is to show what happens to signals when the Gibb-Thomson term is there – something which had been overlooked.

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