

Interactive comment on “Biological residues define the ice nucleation properties of soil dust” by F. Conen et al.

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We thank Benjamin Murray for his insightful comments and corrections of issues where our understanding has been deficient.

1) Yes, the correct term for what we observed and report should be ‘ice nucleation sites per mass of material’ and we should change this accordingly. Nevertheless, the number of ice nucleation sites per mass of material was probably very similar to the number of ice nuclei per mass of material in our study. Even in the most active soil (D) we found about 40 times less ice nucleation sites active at -12 C than there were particles larger than 0.5 microns (page 16591, line 25 – page 16592, line 1). Therefore, the probability for two or more ice nucleation sites to reside on the same particle will have been very small.

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2) We applied a modified version of Eq. 13 in Vali (1971) for the ‘cumulative nucleus spectra’. The original equation by Vali (1971) provides a number for the cumulative concentration of ice nucleation sites active at a certain temperature or warmer ($K(T)$) per volume of a liquid in which particles with ice nucleation sites are present.

$$K(T) = [\ln(N_{\text{total}}) - \ln(N_{\text{unfrozen}})] / V$$

where N_{total} is the total number of drops of that liquid, N_{unfrozen} is the number of drops still unfrozen (liquid) at temperature T , and V is the drop volume. Our modification is in substituting ‘mass soil dust in one drop’ for ‘drop volume’.

3) Choosing a time independent model is a simplification we think is justified when analysing samples with highly heterogeneous surface properties, such as collections of heterogeneous soil particles. These are likely to carry few sites with a high probability of nucleating ice (e.g. soil D, about 1 site on 400 particles active at -8 and 1 on 40 particles active at -12 C at a cooling rate of 0.3 C/min. Repeated drop freeze tests at cooling rates alternating between 0.7 and 4.0 C/min, also with collections of small soil particles, showed only a minor difference (0.4 C) in mean freezing temperature, although cooling rates differed by about a factor of 6 (Vali (Atmos. Chem. Phys., 8, 5017-5031, 2008). The number of ice nucleation sites in experiments with soil samples is probably less time dependent than in experiments with more uniform samples, carrying a large number of sites with a low probability of freezing ice.

4) Thank you for the correction and the reference.

5) The need to qualify this statement was also pointed out in the review by Paul DeMott.

6) Although we can not rule out completely the possible presence of minerals in soil that are both able to nucleate ice and that change their properties when treated with hydrogen peroxide, to the best of our knowledge and that of our colleagues specialised in mineralogy, we are not aware of any such mineral. Nevertheless, we had already relativised our implicit assumption in the following statement on page 16591, lines 9-

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11: “A loss of IN activity in the mineral phase due to the treatments of the samples seems unlikely, although reactions of the mineral complexes in soil dusts that are not pure phases can not be ruled out.”

7) Montmorillonite and kaolinite have ice nucleation properties that are often used to represent those of mineral dusts in modelling studies and it has been stated that “kaolinite is not freezing as effectively as montmorillonite” (Lohmann and Diehl, 2006). This has led us to think of montmorillonite as the most important clay mineral in heterogeneous ice nucleation in the atmosphere. Yet, re-visiting the literature on this issue has exposed to us that our claim of montmorillonite being the most active mineral is untenable. An more acceptable reference to montmorillonite in this context may be as a “mineral, the nucleation properties of which are often used to represent those of mineral dusts in modelling studies”.

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