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Interactive comment on "Heterogeneous ice nucleation on atmospheric aerosols: a review of results from laboratory experiments" *by* C. Hoose and O. Möhler

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We thank Dr. Morris for her careful reading and for the important comments on some points which had missed in preparing this manuscript. The comments are included below in italics.

The manuscript by Hoose and Möhler will be a very useful reference both within and outside the area of atmospheric physics. In particular, for biologists interested in the possible role of biological ice nucleators in cloud physics, this work will be an important resource. With this in mind, I would like to suggest three modifications that could en-

hance its interdisciplinary utility. 1) Figure 1 is a very useful summary of the conditions under which the different processes of nucleation take place. Most of us can conceive of examples of conditions under which the processes on the water saturation line occur. However, as a biologist I must admit that I have difficulty to think of examples of real-world conditions that occur at temperatures colder than -40C and below the water saturation curve in their graph. Therefore, I suggest that the introduction might include some examples of how the laboratory experiments concerning this part of the figure are linked to natural conditions – or at least briefly explain the reasons for studying nucleation under these conditions.

These conditions are actually pretty common in the upper troposphere, as demonstrated by the humidity measurements compiled in Krämer et al. (2009). Wiacek and Peter (2009) discuss the frequency of occurrence of different trajectories in the $T - S_i$-space. Very dry air parcels reach water saturation only at temperatures colder than -40C when lifted from the surface. More importantly, air parcel frequently undergo oscillations and cloud cycles during which humidity condenses and falls out as precipitation, such that they can enter this region when lifted a second time. We have added a brief explanation in the introduction section: "Most air parcels rising from the surface reach water saturation at temperatures above -40C (Wiacek and Peter, 2009), but often undergo oscillations and cycling through clouds before reaching the upper troposphere with temperatures below -40C."

2) In section 4 on determining factors of ice nucleation efficiency, I was surprised that there is no mention of the putative mechanisms by which the ice nucleation protein of bacteria nucleates ice nor is there mention of the dependence of the surface area (and overall protein size) on the efficiency of the protein to arrange water molecules into a crystalline structure. There has been some very nice work in this regard and in particular the following. Govindarajan, A. G. and S. E. Lindow. 1988. Size of bacterial ice-nucleation sites measured in situ by radiation inactivation analysis. PNAS USA 85:

1334-1338. Kajava, A. V. and S. E. Lindow 1993. A model of the three-dimensional structure of ice nucleation proteins. J. Mol. Biol. 232: 709-717. Kajava, A. V. 1995. Molecular modeling of the three-dimensional structure of bacterial ina proteins. Biological Ice Nucleation and its Applications. R. E. Lee, Jr., G. J. Warren and L. V. Gusta (eds.). St. Paul, APS Press: 101-114. Garnham CP, Campbell RL, Walker VK, Davies PL. 2011. Novel dimeric helical model of an ice nucleation protein with bridged active sites. BCM Structural Biology 11: 36 (http://www.biomedcentral.com/1472-6807/11/36)

Section 4 is a purely empirical discussion of ice nucleation efficiency, where ice nucleation is not discussed on the molecular level. We feel that an excursion into the extensive literature on INA bacteria would go beyond the scope of this section. However, we have extended and clarified section 3.1.3 by a more accurate description of INA bacteria and have included two of the suggested references.

3) My last remark concerns a misconception about the Snomax product. On pg 12539, lines14-15 the authors state that this product consists of proteins derived from the bacterium P. syringae. This is what is written on the label of the Snomax product. But if you read the description of the manufacturing procedure, there is no step for isolation or separation of the protein. Snomax consists of freeze-dried cells of P. syringae that had been grown in liquid culture. The product consists of dried cells, cell debris and dried culture medium. It has been irradiated to kill the cells, but for the most part they are intact thereby preserving the configuration of the protein that assures the most efficient ice nucleation. This information can be confirmed in a report from a French agency for environmental and workplace security (http://www.afssa.fr/ET/DocumentsET/afssetrapport- snomax-mai08.pdf) and in a peer-reviewed paper from that report: Lagriffoul, A., J. L. Boudenne, R. Absi, J. J. Ballet, J. M. Berjeaud, S. Chevalier, E. Creppy, E. Gilli, J. P. Gadonna, P. Gadonna-Widehem, C. E. Morris, and S. Zini. 2010. Bacterial-based additives for the production of artificial snow: What are the risks to human health? Science of the Total Environ-

ment 408: 1659-1666. The misconception about the composition of Snomax leads the authors to exclude it from this work because "Snomax particles do not occur in the natural atmosphere". Although it is likely that very few Snomax cells per se of P. syringae are floating around in the atmosphere, this form of the bacterium probably represents something rather common – cells that have died but are intact thereby maintaining their ice nucleation activity. Based on the high rates of ice nucleation activity that we reported previously for soils with high organic matter content (Conen et al 2011, cited in their manuscript), it would not be surprising that non-viable forms of ice nucleation active micro-organisms are abundant in the environment. Furthermore, the Snomax product is one of the few "standards" that can be used for biological ice nucleation studies, in the same way that Arizona Test Dust has been used as a reference for mineral nucleators. Therefore, I find it unfortunate that data for Snomax has not been included.

Thanks for the clarification regarding the Snomax product. We have inserted the reference to Lagriffoul et al. (2010) and modified the sentence as follows: "Only for Snomax, an artificial snow inducer consisting of freeze-dried *Pseudomonas syringae* bacteria cells, cell debris and dried culture medium (Lagriffoul et al., 2010), deposition nucleation has been studied extensively (Chernoff and Bertram, 2010; Jones et al., 2011; Kanji et al., 2011; DeMott et al., 2011). "

In addition, this comment has prompted us to revise Figure 3. Figure 3a (nucleation onsets for bioaerosols) is now split up into 3a (bacteria), including Snomax, and 3b (other bioaerosols). The statement "These data are not included ... because Snomax particles do not occur in the natural atmosphere" has been removed.

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