Heterogeneous ice nucleation on biological particles: Bacteria and pollen

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Heterogeneous Ice Nucleation on Biological Particles: Bacteria and Pollen

F. Stratmann[a], S. Augustin[a], T. Clauss[a], S. Hartmann[a], H. Grothe[b], D. Niedermeier[a], B. Pummer[b], T. Šantl-Temkiv[c], and H. Wex[a]

[a]*Institute for Tropospheric Research, Permoserstr. 15, 04318 Leipzig, Germany*
[b]*Institute of Material Chemistry, Vienna University of Technology, Vienna, Austria*
[c]*Aarhus University, Stellar Astrophysics Centre, , 120 NyMunkegade, 8000 Aarhus, Denmark*

Abstract. In the atmosphere the importance of biological ice nuclei is still not well understood. Therefore we investigated the ice nucleation behavior of Snomax^{TM}, used as a model for bacterial ice nucleation, and birch pollen washing water, used as a model for pollen induced ice nucleation. Thereby we quantified the ice nucleation behavior of the INA protein complexes controlling the ice nucleation ability of *Pseudomonas syringae*, and that of sugar-like macromolecules controlling the ice nucleation ability of birch pollen. The given parameterizations can be used to describe the ice nucleation behavior of the respective ice active bacteria and pollen in atmospheric models.

Keywords: Ice nucleation, biological particles, nucleation rates, bacteria, pollen
PACS: 42.68.G

INTRODUCTION

In the atmosphere, heterogeneous ice nucleation is often found to occur at temperatures above -20°C (e.g. Seifert et al., 2010). But the majority of atmospheric ice nuclei (IN) are mineral dust particles (Twohy & Poellot, 2005, Kamphus et al., 2010), which in laboratory studies often were found to be ice active only at lower temperatures (e.g. Hoose & Möhler, 2012, Murray et al., 2012). One possible explanation for this discrepancy might be the presence of biological particles (e.g., bacteria or pollen) in the atmosphere, which can act as IN already at higher temperatures (see e.g. Maki et al., 1974 and Morris et al., 2004 for bacteria, Pummer et al., 2012 for pollen). However, the actual importance of biological IN in atmospheric ice nucleation remains unclear. To achieve a better understanding, investigations concerning the fundamental processes underlying biological ice nucleation and their quantification are important.

MEASUREMENTS

We investigated the immersion freezing behavior of droplets grown on size segregated, quasi monodisperse, particles generated from a) Snomax^{TM} (a commercially available product used in artificial snow production) containing *Pseudomonas syringae*, which has been used as model substance when investigating

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bacteria induced ice nucleation in the past (e.g. Wood et al., 2002, Morris et al., 2004), and b) from birch pollen washing water (which was found to contain ice active sugar-like macromolecules, Pummer et al., 2012).

The measurements were performed at LACIS (Leipzig Aerosol Cloud Interaction Simulator, Hartmann et al., 2011).

Particles were generated by atomization of aqueous solutions/suspensions of either Snomax^{TM} or birch pollen washing water. For Snomax^{TM}, generated particles contain bacteria cells, fragments of cell walls, which may or may not carry an INA protein complex, remnants of the nutrients the bacteria were grown in, and material leeching from the inner parts of the bacteria. For birch pollen washing water, particles consisted of proteins, sugars, polysaccharides, fats and volatile organic compounds, i.e., the various substances from the pollen.

The generated solution/suspension droplets were dried with a diffusion dryer and size selected using a Differential Mobility Analyzer (DMA), and were then fed into LACIS. Examined particle diameters varied between 100nm to 800nm.

At the LACIS outlet, ice fractions were measured as a function of temperature.

RESULTS

Fig. 1 depicts ice fractions (f_{ice}) as function of temperature as measured for particles generated from a Snomax^{TM} solution/suspension (left panel) and birch pollen washing water (right panel).

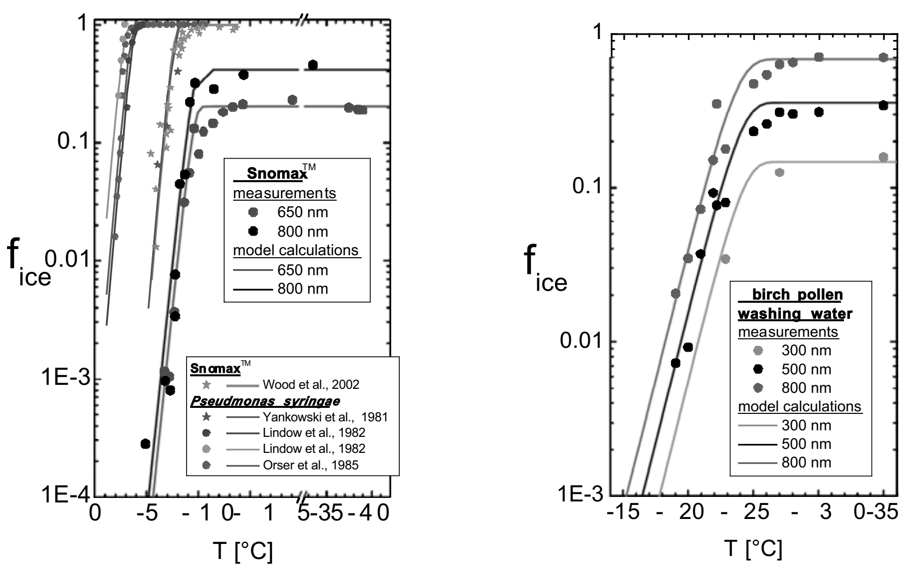

FIGURE 1. Ice fractions as function of temperature for different particle size for Snomax^{TM} (left panel) and birch pollen washing water (right panel)

Looking at Fig. 1, it can be seen that ice fractions feature a steep increase at higher temperatures and a particle size dependent saturation behavior at lower temperatures. From these curves, both the average number of ice nucleating entities (INA protein complexes for Snomax^{TM}, and sugar-like INA macromolecules for birch pollen washing water), being present in the droplet ensemble, and the ice nucleating entity's ice nucleation rate can be determined.

Determination of Nucleation Rates

Based on the stochastic nature of the ice nucleation process, we developed the CHESS-model (stoCHastic modEl of similar poiSSon distributed ice nuclei, eq. 1) for determining ice nucleation rates J_{het} from the measured ice fraction curves.

$$f_{ice}(T) = 1 - \exp(-\lambda(1 - \exp(-J_{het}(T)t))) \qquad (1)$$

Here λ corresponds to the average number of ice nucleation active entities per droplet, is a function of initial particle volume, and can be calculated from the ice fractions in the saturation range f_{ice}^{*} (see Fig. 1) by $\lambda = -\ln(1 - f_{ice}^{*})$, assuming the ice nucleating entities to be Poisson distributed over the droplet population.

Resulting values for the heterogeneous ice nucleation rate J_{het} are show in Figure 2 as function of temperature for Snomax^{TM} (left panel), and birch pollen washing water (right panel).

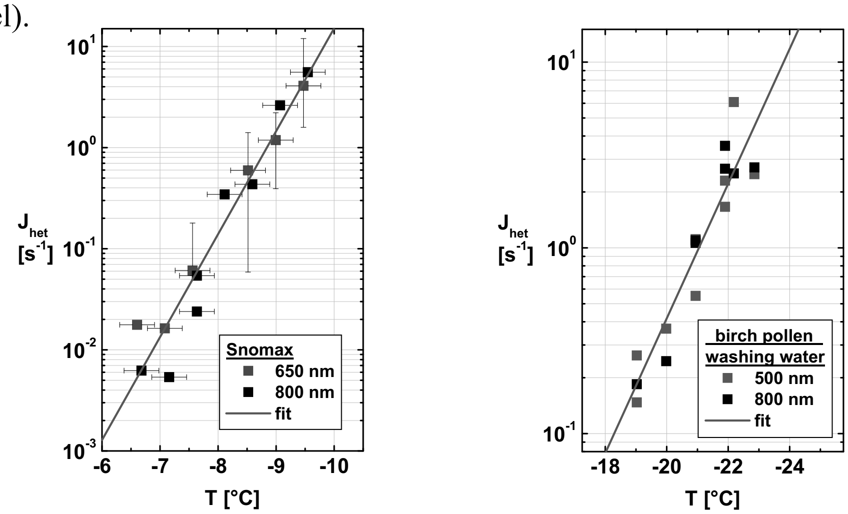

FIGURE 2. Heterogeneous ice nucleation rates as function of temperature and different particle diameters for Snomax^{TM} (left panel) and birch pollen washing water (right panel)

As to be expected, for both examined substances the resulting heterogeneous nucleation rates are independent of particle size. The fact that nucleation rates are no function of size suggests that we are really quantifying the ice nucleation behavior of the smallest ice nucleation active entities, i.e., *P. syringae's* INA protein complex in case of Snomax^{TM}, and the sugar-like INA macromolecule in the case of birch pollen washing water. Consequently, the solid lines in Fig. 2 represent parameterizations quantifying these entities' ice nucleation behavior, based on Eq. 2 and featuring values of A = $1.55 \cdot 10^{-8}$ s^{-1} and B = -2.032 °C^{-1} for INA active protein complex, and A = $2.24 \cdot 10^{-8}$ s^{-1} and B = -0.831 °C^{-1} for the macromolecule.

$$J_{het}(T) = A \bullet \exp(B \bullet T) \qquad (2)$$

Utilizing these nucleation rates, together with the CHESS model, ice fractions were calculated/predicted for the experiments, which are also shown in Fig. 1 (left panel, Snomax^{TM}/ *P. syringae*, right panel, pollen washing water). In all cases the comparison between measured (symbols in Fig. 1) and predicted (lines in Fig. 1) ice fractions is very good, underlining the applicability of both nucleation rates and CHESS model for describing and quantifying the ice nucleation behavior observed in the different experiments. It is worth mentioning, that the suggested nucleation rate is also applicable when intact *P. syringae* are considered as done in Yankofsky et al. (1981), Lindow et al. (1982), and Orser et al. (1985).

For a more detailed description and further results please see Hartmann et al. (2012) (ACPD) and Augustin et al. (2012) (ACPD).

SUMMARY

Investigating the ice nucleation behavior of particles generated from a Snomax^{TM} suspension/solution and birch pollen washing water, we quantified the ice nucleation behavior of the INA protein complexes controlling the ice nucleation ability of *P. syringae*, and that of sugar-like INA macromolecules controlling the ice nucleation ability of birch pollen. The given parameterizations can be used to describe the ice nucleation behavior of the respective ice active INA bacteria and pollen in atmospheric models, provided that the number concentrations of INA protein complexes or INA macromolecules being present in the atmosphere is known.

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