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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Characteristics of immersion freezing nuclei at the south pole station in Antarctica" *by* K. Ardon-Dryer et al.

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We would like to thank Reviewer 2 for his comments and questions which helped us improve the paper. All the points raised by the reviewer have been answered below and in the revised manuscript. We also acknowledged the reviewer's contribution at the end of the manuscript.

Reviewer 2: p. 93, line 8: Today, most scientists agree that particles need a minimum size of 100 nm to be active as IN. Could you comment on that and discuss this where you refer to the old studies where IN are reported to be mostly around only 10 nm?

Reply: We agree that the most effective ice nuclei are those with size larger than 0.1 μm. In the introduction of the paper and as part of the literature survey, we simply quoted from the work of Bigg and Hopwood (1963), not stating if we agree or not. Reviewer 2: p. 94, line 14: How do you define wind directions at the South Pole? Is it appropriate to refer to them with cardinal points at the South Pole? Wouldn't all winds come from north there anyway?

Wind direction is defined based on the deviation in degrees from longitude 00 as can be seen in Table 3 and Fig. 1. In the revised version we explained it better. Reviewer 2: p. 95, line 9: To assess the quality of the data in this study it would be very helpful to know details about the dimensions and shape of the filter holder and the sampling inlet and how it was placed with respect to wind direction. When sampling aerosols in a non-isokinetic way (which is definitely the case when the wind is "in the back" one has to take under- and oversampling of certain sizes of aerosols into account. This also depends on the wind speed and the pump speed with which air is drawn through the filter. Please provide information about the details and discuss possible sampling artifacts. It is possible that the current setup leads to an undersampling of larger particles which are known to be the better IN than smaller particles!

This point was also raised by Review 1. Sampling was carried out at 8 LPM through an inlet in a standard Millipore sampler with an opening of 5.5 mm diameter. The air speed at the inlet is therefore 5.6 m s-1. The wind speed varied between 2-10 m s-1 (see Table 3). Since the wind direction and speed were never constant, it is difficult to estimate the size cutoff of the sampled particles. However, based on the orientation of the inlet and based on the above wind and air sampling speeds it is clear that we under-sampled large particles. This implies that the dependence of ice nuclei concentrations on wind speed (Figure 7a) should be steeper. However, we cannot give a good estimate for this difference. Since we under-sampled large particles, the chances for collecting ice crystals were also low. Even if we did collect a few ice crystals they would have evaporated soon after sampling leaving an ice nucleus that had nucleated the crystal in addition to a few other aerosols which had impacted it. In that case the number of measured ice nuclei would have increased a little. In the text we expanded the

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explanation about the possibility of collection of ice crystals.

Reviewer 2: p. 95, line 13 (and introduction): I am wondering why this study focuses on immersion freezing nuclei. In Antarctica I would assume that the likelihood of finding liquid or mixed-phase clouds is rather low, which is a prerequisite for immersion freezing to take place. Under the given conditions I would assume that deposition and condensation freezing would be much more important. Can you please add (in the introduction) references about the importance and relevance of immersion freezing in Antarctica and why you focus on this mechanism?

Reply: During this campaign Lawson (private communication) and Lawson et al. (2011) observed liquid and solid particles on two days. Their preliminary investigation of the Lidar data shows that the mixed-phase signature observed is not an anomaly, and that the signature is even found in clouds aloft when the surface temperature is -500 C during the Austral winter. Furthermore, one of the objectives of this study is to obtain the freezing nuclei concentrations at a remote and pristine area such as Antarctica that could be compared with previous similar measurements near the coast of this continent and with measurements at other more polluted areas.

A note about this rational is included in the revised version of the paper

Reviewer 2: p. 95, line 24 and p.96 line10: The influence of the Vaseline layer and the background found on the blank filters should be discussed more in-depth. Especially the treatment of the blank filters is of relevance as the measurements show that they contain a significant amount of background IN. How were the blank filters treated? Were they shipped to and from Antarctica as well, and undergone the same procedure as the sample filters (including mounting them into the filter holder just without sampling air through them) or were they directly measured from the original packaging.

Reply: The Vaseline was used to prevent ice from forming on the substrate, thus affecting the freezing. This is because without the thin Vaseline layer, a frozen drop becomes a sink for more vapor deposition. As the deposition continues, ice starting

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from the frozen drop's perimeter begins to spreads over the substrate reaching and freezing some neighboring drops. The Vaseline prevents most of these events from occurring. The blank filter was sent to Antarctica together with the other filters that were used for sampling. In the laboratory in Antarctica a blank filter was taken out and placed in a Petri-dish, which was returned to us by mail together with exposed filters. The unexposed filter was not put in the filter holder, because in that case it would have been severely contaminated. The analysis of the blank was done in the same way as the sampled ones. Namely, it was placed in clean water and whatever was on it was removed into the water. Drops from this water were placed on the stage and their freezing with temperature was recorded.

After receiving the reviewer's comment, we decided to analyze a number of additional blank filters from the same batch that had been sent to Antarctica. The results of the freezing spectrum were different and were closer to the spectrum of the pure water. This indicated that the blank filter that was returned from Antarctica had been contaminated accidentally by exposure to the laboratory air at the South Pole station. For lack of more blank filters from Antarctica, we decided to compare the FN measurements with blanks from the same package that remained in our laboratory. Fig. 3 was changed to include these results. The calculated concentrations shown in Fig 4 are now based on the fractional number of drops frozen at each temperature minus the number of drops frozen at the same temperature on the blank filters. The correction was applied to all the relevant figures and the text was changed accordingly.

Reviewer 2: p. 96, line 15-20: Even if the fraction of particles that froze at the same temperature as the blank have been removed from the analysis the current paper neglects the influence of the background counts on the discussed data. I strongly recommend to be more careful here (as already mentioned with my quick review) and include the measurements (M) of the background (BG) in the calculation of the frozen fraction (FF) at a given temperature. e.g. something similar like: FF = (M – BG) / (M_total – BG_total). I also do not understand how the authors assessed the influence of the

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background counts to be 2.4% with formula 2 (line 24). Can you please discuss in detail how this was done? I understand that since the FF increases very steeply with Temperature below a certain Temperature, that the influence of the background quickly decreases. Please also provide error bars for your data, especially in the plots where you discuss differences between different data sets. How significant are the differences taking the error bars into account? At least the statistical error due to Poisson statistics could be reported here.

Reply: See the explanation above. It should be noted that there was an error in the reviewer's equation. It should have been for each given temperature FF= (M-BG)/(M_total-BG). The correction has been made based on the above equation. The reference to the 2.4% was related to the previous calculated difference between the number of FN without and with the correction of the blank. This has been removed from the revised version.

Reviewer 2: p. 98, line 18: Please specify the type of instrument: e.g. : : :.. greater than 0.01 μm as measured with a condensation particle counter (TSI 3760).

Reply: This point has been added in the revised manuscript

Reviewer 2: p 101, line 25: The last sentence is kind of circular logic: Maybe it is better to write: Since the measurements vary strongly with the meteorological conditions, more measurements at different conditions are needed in order to be able to derive reliable parameterizations...or something along these lines.

Reply: This sentence has been modified.

Reviewer 2: Figure 3: As I already mentioned in my quick review, the variability of the curve for different blank samples would be helpful especially when the blank data is used to correct the sample data.

Reply: See our reply above

Reviewer 2: Figure 10 and text referencing it: The temperature scale is named tem-

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perature but the parameter in the fit function -as mentioned in the text- is supercooling. Please be consistent with the scales and terminology.

Reply: Since supercooling is a positive number and the temperature is negative, we kept the caption as temperature and modified the text somewhat.

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