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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.

**K. Ardon-Dryer et al.**

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We would like to thank Reviewer 1 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. A special acknowledgement to the reviewer's contribution has been added at the end of the manuscript.

Reviewer 1: I am aware that fieldwork at the South Pole station is not an easy task. But the number of 12 samples makes general statements difficult, even if these particle samples are distributed in 1459 individual droplets. For the reader the question remains, why there are no more than three filter samples on the balloon platform and why the time period/sample number is so limited. Especially the balloon results are questionable because of the small data basis (one per case). As a result the authors



limit their findings consequently to a "suggestion".

Reply: The motivation of the field experiment was discussed by Lawson et al. (2011). The sampling of the aerosols for ice nucleation analysis was piggy-backed onto the project and had to be relegated a lower priority. Only one day with three balloon flights with filters was possible due to competing demands presented by other instruments in the project. In spite of that the analysis we conducted both on the ground and on the balloon is an important contribution to the very meager knowledge that is available in this remote and relatively pristine area. It is correct that generalizations based on only three balloon samples is questionable, however, the similarity between the balloon and the ground measurements suggests that they are fairly representative. It should be noted that in the final analysis of the derivation of the best fit line, the balloon results were not included. In the introduction we added an explanation about the part of this sampling effort in the framework of the whole campaign.

Reviewer 1: The cooperation with Paul Lawson "suggests" that the FN measurements are part of a bigger campaign. Please give some hints how your measurements are incorporated.

Reply: As was pointed out above the ice nucleation study was a small piggy-backed project on a larger project which lasted two weeks and was primarily focused on balloon cloud particle measurements. The experiment was unique because it was the first time that a balloon with a 15 kg microphysical package had been flown in clouds at the South Pole. Since the balloon carried many other instruments, the sampling for ice nuclei measurement received lower priority and thus only one day was devoted to this task. In the revised paper we added a few words explaining this point further.

Reviewer 1: Please motivate EQ. 1

Reply: Equation 1 is constructed from the original equation of Vali (1971). Equation 1 is composed of two parts: the first is an integration of the differential probability that a drop will freeze between (Theta) andïĂăïĂĺïĄŤheta- delta ThetaïĂľïĂădue to the

presence of single active nuclei in it over the temperature range from ThetaïĂăto 00C. This integration calculates the cumulative nucleus concentration K'(ïĄś), which gives the number of nuclei active at all temperaures warmer than ThetaïĂőïĂăIn order to obtain the actual concentrations of ice nuclei in the sampled air, consideration must be given to the total air sampled. This is presented in the last part of the equation. An expansion of this point has been introduced into the revised version of the paper.

Reviewer 1: (P95 l7pp Method of analysis) Please add the sample characteristic / schematics of your filter sampler with special emphasis on the upper cut off. Later in the text (P99 5-10) the authors state that it is unlikely that some ice particles have been sampled (due to orientation of the inlet). Sampling ice crystals might also an explanation for the observed strong correlation of FN to wind speed (due to saltation) – and also the "height" dependency - like the authors state on Page 99 line 7) (see also next item)

Reply: 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.

Lawson et al. (2006) reported that at the South Pole Station blowing snow is observed when the wind speed exceeds about 4 m/s. Knuth et al. (2010) measured a threshold of between 6.6 to 7.5 m/s at 10 m height for blowing dry snow at the Ross Ice Shelf. The threshold for blowing wet snow was higher at 8.5 to 9.6 m/s. Threshold for blowing snow on the Ross Ice Shelf is likely to be different than at the South Pole since the type of precipitation is quite different. For our purpose here we took 6 m/s as an average threshold between these two values.



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.

The set up on the balloon could not guaranty that the inlet of the sampler was at a fixed position. Since in all the balloon experiments reported in this paper, the balloon was always in the mixed layer (<200 m) we cannot rule out the collection of ice crystals. As implied by the reviewer, the fact that the concentration of ice nuclei at 40 m was lower than below, may suggest that more ice crystals were collected at lower elevations..

In the text we expanded the explanation about the possibility of collection of ice crystals.

Reviewer 1: (P96 l 12) It not clear which criterion the authors use to eliminate "bad data" points ("contamination") using the blank filter measurements. Why do you have used this criterion on the filter 7-12 but not on filter 1-6. I call this a minor point only, because the correction is of minor importance to the results (like the authors state (P96 l 19)) and might be discarded.

Reply: Following the comment by Reviewer 2 (see our detailed reply to reviewer 2) 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 led to the conclusion that the blank filter sent to Antarctica was possibly contaminated accidentally by exposure to the laboratory air at the South Pole station. Consequently, we modified Fig. 3 to include these new results. The calculated concentrations shown in Fig 4 are now based on the fractional number of drops frozen at each temperature minus the average number of drops frozen at the same temperature on the blank filters. The effect of this change is much smaller than was originally calculated and it appears mostly at the very lowest temperatures. This point has now been added to the manuscript.

New References

Knuth, S. L. Gregory, J. T. Jonathan E. T. and George A. W.: The Influence of Blowing Snow and Precipitation on Snow Depth Change across the Ross Ice Shelf and Ross Sea Regions of Antarctica, J. Appl. Meteor. Climatol., 49, 1306–1321, 2010.

Lawson, R. P. Baker, B. A. Zmarzly, P. O'Connor, D. Mo, Q. Gayet, J. F and Shcherbakov, V.: Microphysical and optical properties of ice crystals at South Pole Station, J. Appl. Meteor., 45, 1505-1524, 2006.

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Interactive comment on Atmos. Chem. Phys. Discuss., 11, 91, 2011.