

Interactive comment on “Heterogeneous ice nucleation activity of bacteria: new laboratory experiments at simulated cloud conditions” by O. Möhler et al.

O. Möhler et al.

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We acknowledge the valuable comments from the three referees of our paper. Based on these comments, a revised and improved version of the manuscript will be prepared and submitted for publication in BG. Here we respond to the referee comment by Gabor Vali.

General points: Following the referee comments we will modify the structure of the paper. The section title ‘Cloud simulation experiments’ will be changed to ‘Cloud chamber experiments’. This section will be structured into further subsections entitled ‘The AIDA cloud chamber facility’, ‘Aerosol formation and characterisation’, ‘Spray experiments’ and ‘Cloud expansion experiments’. For the subsection ‘Spray experiments’

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we will include two more figures with time series from two selected spray experiments. These figures and also the former Figures 4 and 5 will include an additional panel with the optical diameters of all individual particles detected by the Welas2 optical particle counter. These plots will clearly show the distinct groups of droplets and ice particles that formed during the spray and expansion experiments. Care will be taken to separate the method description and results into the respective sections and to avoid repetitions of method descriptions.

The droplet freezing experiments were mainly done because the results were used to determine the optimum starting temperature and aerosol cell concentrations for the cloud chamber experiments. The main focus of the present study was not to compare the droplet freezing method to the cloud chamber method. This will be more clearly stated in the revised manuscript. We would not like to remove this piece of information from the paper. We agree to the referee that more comprehensive and systematic measurements would be required to compare both methods on a quantitative basis.

Answer to specific comments:

page/line(s)

1448/1-2 This part has been rearranged. See also answer to Paul DeMott's comments.

1448/8-9 Done.

1448/12-19 The cell concentration in the aerosol phase depends on the cell concentration of the suspension and the amount of suspension sprayed into the chamber. Please note that the latter was different in the two experiments. The concentration estimates are consistent and well explained. Because this is only an estimate of the cell concentration in the Snomax pellets we agree that there is no need to refer to minor losses. This paragraph has therefore been changed to: 'The SM1 sample was prepared for the Bio02 experiments with a Snomax™ mass concentration of 1 mg ml⁻¹. From the amount of suspension sprayed into the 84 m³ large aerosol vessel (see Sect. 4.2)

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and the resulting cell number concentration obtained from respective aerosol measurements (see Sect. 4.2 and Tab. 2) we estimated the cell concentration in the suspension and in the Snomax™ pellets. Dispersion of 20 ml of SM1 resulted in an aerosol cell concentration of about 160 cm^{-3} , a total number of 1.34×10^{10} cells in the aerosol vessel, a cell concentration of $6.7 \times 10^8 \text{ ml}^{-1}$ in the SM1 sample, and a cell concentration of $6.7 \times 10^8 \text{ mg}^{-1}$ in the Snomax™ pellets used to prepare SM1. The SM2 sample prepared for Bio03 had a mass concentration of 0.1 mg ml^{-1} , 10 times lower than that of SM1. Dispersion of 50 ml resulted in a cell concentration of 40 cm^{-3} in the aerosol phase, a total number of 3.36×10^9 cells in the aerosol vessel, a cell concentration of $6.7 \times 10^7 \text{ ml}^{-1}$ in the SM1 sample, and a cell concentration of $6.7 \times 10^8 \text{ mg}^{-1}$ in the Snomax™ pellets, which agrees with the cell concentration obtained from SM1.'

1448/21 Changed to 'at temperatures between 0 and -10 C '.

1448/22 OK.

1448/26 OK.

1449/1 OK.

1449/8-9 Change 'We have observed that storage of the cells ...' to 'Storage of the cells ...'.

1449/11 OK.

1449/12-13 Not necessarily. This is standard microbiological procedure.

1449/15-16 OK. In the revised version of the manuscript we will use the acronym INA only for the noun 'Ice Nucleation Activity', 'ice nucleation active' will be abbreviated with 'IN active'.

1449/21 We wait 30 sec because not all drops freeze at time 0. The number progressively increases, and at 30 seconds we see no further change. This is an empirical observation and a standard way of doing this test. We referred to a paper by Lindow

who reported more experimental details about it.

1450/11-12 OK.

1450/17 Changed to 'operated at homogeneous temperature control'.

1450/27 Split into several sentences.

1451/17-20 Also according to a comment by Paul DeMott, lines 18 to 20 have been changed to 'Further details of the spray process and measurements of ice nucleation during spray experiments will be discussed in Sect. 4.3'. This is the new section we have added to the manuscript. We do not see inconsistent statements about droplet evaporation or a lack of clarity with that. It is clearly stated that the spray droplets evaporate inside the cloud chamber before the expansion experiments are started. What we do not know is the actual evaporation time period for the individual droplets. We estimated the evaporation time to be not more than 10 minutes.

1451/22 OK.

1451/27 Changed to 'These diameters'.

1452/6 OK.

1452/10 OK.

1452/12-14 Actually, we cannot completely rule out the possibility that the 'residual particles' also contain ice nucleation active cell fragments. However, this seems to be unlikely for the experiments with living cells, but could contribute to the ice formation during the experiments with Snomax™. Any ice formation by the smaller residual particles would lower the IN active fraction of the intact cells. On page 1457 of the manuscript we already commented on the possible contribution of residual particles.

1452/16 Part of the difference can be measurement uncertainty. However, considering the fact that Snomax™ is a manufactured product whereas the 31R1 cells are freshly grown, one may even expect different sizes or even shapes of the cells in the two sam-

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ples. The 31R1 cells show a larger back scattering depolarisation ratio (see Figs. 4 and 5) and therefore have a more a-spherical shape than the Snomax™ cells. This shape difference can also partly explain the difference in the equivalent-sphere diameter.

1452/24 OK.

1453/1-4 Yes. The number of cells in the chamber aerosol was consistent with the number of cells in the suspensions sprayed into the aerosol chamber.

1453/4 Because of the new subsection structure of this whole experimental section we leave this sentence as is. No reason to remove it.

1453/16 OK.

1453/19 OK.

1453/19 We see no reason for change here.

1453/23 What we mean here is the ‘temperature change’ with time of pumping.

1453/24 OK.

1453/24-30 In the revised manuscript all instrument details will be moved to the new subsection 4.1 which describes the AIDA chamber facility together with the measurement techniques. The measurements with the MBW chilled mirror instrument are used as an independent calibration standard for the TDL water vapour measurements. Both methods are in excellent agreement as long as no condensed water (liquid or solid) is present in the aerosol chamber.

1454/11 Droplets evaporate in the sampling tube of the CPC which is at room temperature most of its length. The droplet residuals are measured with the CPC.

Section 4 In fact we were not able to clearly differentiate between the condensation and immersion mode, but measured the sum of both modes. It is already stated in the manuscript that ice formation is either by condensation or immersion mode of freezing.

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We will make that more clear in the revised manuscript.

1455/8 'zero volume' is a bad substitute for 'a value of zero in this column of the table'.

1455/8 As mentioned earlier we have modified the structure of section 4 in order to more clearly explain the experimental methods.

1455/10 Sentence removed.

1455/16 The estimated uncertainty is about $\pm 30\%$ for the ice number concentration and about $\pm 50\%$ for the IN active cell fraction. This will be mentioned in the revised manuscript.

1455/21 OK.

1455/24-27 We know from many other AIDA expansion experiments that such a change in the SDR signal is significant and can only be explained by ice crystals formed in the aerosol vessel. The SDR measurement is an in situ technique. The depolarisation signal has nothing at all to do with growth rates or fall speeds of ice crystals.

1456/6-9 No, this has nothing to do with detection limits. After 20 seconds enough ice surface has been formed in the mixed-phase cloud to make the Bergeron-Findeisen mechanism efficient and fast enough to evaporate the droplet phase.

1456/12 OK.

1456/14 OK.

1456/15 OK.

1456/16 OK.

1456/20 Yes. See comment by Paul DeMott.

1456/26 OK.

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1456/28 OK.

1457/1 OK. See earlier comment.

1457/5 We believe this is the right place to mention the experiment with the filtered sample and see no reason for changes.

1457/19 OK.

1457/20-21 As mentioned above we were not able to distinguish between condensation and immersion freezing. We just observe, within experimental uncertainty, the the IN active cell fraction was the same in both experiments at the same temperature. We changed the sentence to 'This example demonstrates that IN active fractions measured in spray and expansion experiments at the same temperature agree to each other.'

1458/3-8 We did not exclude the possibility that ice nucleation could occur at other temperatures and in other modes of freezing.

1458/9 We already mentioned, also in the reply to Paul DeMott's comment, that the main objective of the droplet freezing experiments was to test the temperature range of the IN activity of the bacterial cells for setting the starting temperature of the AIDA cloud chamber experiments. Why should we not mention the results from these tests? This was done very careful and we also mentioned in the manuscript on page 1458 that further studies are needed for comparing the both methods.

1458/19 Change to 'IN active', which is defined in the experimental section of the paper.

1458/23-27 Again, the purpose of this paper was not to systematically compare the droplet freezing and cloud chamber methods. This deserves another study.

1459//5 The deactivation results are carefully explained in the results and discussion section on pages 1458 and 1459. During the first nucleation event means the first activation of the IN active cells either in a spray or an expansion experiments. The deactivation could happen by destruction of the IN active cell membrane structures

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during freezing of the cell.

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