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Atmospheric Measurement Techniques Discussions

Interactive comment on "The portable ice nucleation experiment PINE: a new online instrument for laboratory studies and automated long-term field observations of ice-nucleating particles" *by* Ottmar Möhler et al.

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Author comment in response to the comments provided by Referee # 1

We thank referee # 1 for her/his effort in reading and commenting our manuscript. In the following, we report the referee's comments (in italics), give point-by-point answers, and suggest manuscript revisions based on the referee's comments and our answers. Respective reference will be given to the line numbers of manuscript version 1.

Referee comment: This manuscript details the design and performance of a new ice

nucleation chamber. This instrument is based on an expansion principle, much like the AIDA chamber at KIT (location of several of the co-authors). In this regard the chamber is different than the continuous flow principle used on almost all current ice nucleation chambers. PINE therefore represents an important addition to the field. The design and performance is important and the use of a long term (in this case 45 days) makes this a solid paper and very appropriate for AMT. The paper is well written and only minor revisions are needed. There are a few points I'd like to ask the authors to consider: Starting in the Abstract but running through paper there are several unquantified terms : "... extensive ...", "... good ...", "... high time resolution ...". These are all subjective and need to be removed.

Answer: We scanned the manuscript for such unquantified terms and removed most of them (see lines 9, 15, 61, 297, 493) or replaced them with more quantitative statements (see lines 11, 371).

Referee comment: The Introduction, although highly comprehensive, is also very long for an instrumental paper (3 pages). It seems like it could be considerably shortened.

Answer: The third referee (Paul DeMott) also mentioned the introduction to be overly comprehensive. We agree and suggest removing or shortening the following parts:

Remove section about cirrus clouds (lines 37 to 43) which are not further subject of this paper. We had included this short paragraph in the first manuscript version because PINE is also capable of measuring INPs in the cirrus cloud temperature regime. This is subject of ongoing activities and the further development of the PINE instrument.

Reformulate lines 56 to 61: "Existing parameterizations are applied in models to calculate and predict primary ice formation in clouds, however, the atmospheric INP data that we can compare with global fields of model predicted INP concentrations are limited in spatial, ...

Remove lines 69 to 76 ("While high temperature INPs ... may dominate high tempera-

ture INPs in many regions (. . .).”

Modify line 77 to “Most of previous INP measurements were only sensitive to immersion freezing . . . ”.

Modify lines 103/104 to “. . . in a wide temperature range. In this paper, PINE′s ability is demonstrated to measure in the mixed-phase cloud temperature regime from $-10\,^{\circ}\mathrm{C}$ to $-40\,^{\circ}\mathrm{C}$. PINE is also able to measure ice nucleation at cirrus cloud temperatures to about $-65\,^{\circ}\mathrm{C}$, which is the topic of ongoing studies.”

Referee comment: The ‘milestone’ portion of the 2. Basic Principles section should be removed. It does not seem relevant to outline the timeline / dates (i.e. 20 years, first test 2016, etc.) since they don’t impact the instrument performance. Please eliminate this part of the paper.

Answer: We believe that the experience in operating the AIDA cloud expansion chamber was indeed an important contribution to the PINE development. Referring to AIDA operation as a well-known and well-cited cloud simulation chamber also introduces the reader to the basic operating principles of PINE. Moreover, PINE was developed during relative short time, as e.g. compared to the development of continuous flow diffusion chambers. Thus, we believe that it is interesting to the reader to be informed about the development steps. Therefore, we like to keep this part, but have made the following modifications:

Change first sentence of section 2 (lines 111/112) to “The idea for PINE resulted from the experience in operating the AIDA facility for cloud experiments at simulated conditions of up-drafting atmospheric air parcels.”

Modify the last two sentences of first paragraph of this section (lines 122 to 124) to: “Large aerosol particles, droplets and ice crystals are measured and counted with an optical particle counter (OPC). Placing the OPC in the vertically oriented pump tube below the cloud chamber was one of the critical development ideas for PINE (see

patent applications DE 10 2018 210 643 A1 and US2020/0003671 A1). PINE can be operated both for ice nucleation research in the laboratory, and for INP measurements in field campaigns or long term monitoring activities.

Remove the sentence “This setup was operated in a cold room . . . attached to the pump line (see patent applications . . .)” (lines 127 to 130).

Referee comment: The dates of the SGP test (Oct 1 -) is found in Section 2 and then repeated 4 times in the paper; please state once.

Answer: Done as suggested (see lines 414, 466).

Referee comment: During HyICE, there are repeated references to CCN activation. Just as PINE is compared to AIDA, wasn’t there a CCNC at HyICE? If so can the PINE droplet data be compared to those data? The topic of drop formation could be more fully developed in the paper and this would help.

Answer: We were using the term CCN activation because aerosol particles sampled into the PINE chamber first act as cloud condensation nuclei to form supercooled droplets which then eventually freeze when they include an ice-active aerosol particle (INP) at the given temperature. In other words, the same particle acts as CCN and INP. However, CCN activation happens in a fast cloud expansion process without independent control of the relative humidity or supersaturation. Therefore, an expansion cloud chamber like PINE or AIDA cannot control or quantify the CCN process as a function of relative humidity, just is then filled with the droplets resulting from the CCN activation and diffusional droplet growth processes, but without quantifying the parameters controlling those processes. The size distribution of the resulting droplet cloud can then well be measured with the OPC and compared for subsequent runs, as demonstrated by first field measurements with the PINE-1A prototype instrument during the HyICE field campaign. To clarify this, we suggest the following changes to the manuscript line 296: “This means that PINE is able to reproduce the formation of the supercooled droplet cloud in repeated runs at constant sampling and operation conditions, . . . ”

Referee comment: Figures Please check f ice and others not in subscript ;

Answer: checked and corrected

Referee comment: Figure 8 : Does “in preparation of the HyICE field campaign” have an impact on the measurement? It seems highly extraneous.

Answer: Yes, agreed and removed.

Referee comment: Figure 11 : Is ‘aerosol, right after the PINE-1A runs were finished.’ the relevant point? Is ‘using the same aerosol’ correct?

Answer: Yes, correct, both chambers are using the same aerosol. Therefore, no modification needed here.

Referee comment: Figure 12 : Does not seem necessary to attribute funding to DOE here since this is typically done in the acknowledgements. Site location seems sufficient. Inset legend seems to mean ‘6 hour averaged data’ (not daily)? And ’45 day average’

Answer: Reference to DOE funding will be removed. The figure indeed shows temperature binned data for both 6 hour averaged data and average over all 45 days. We will change the legend and rephrase the figure caption as follows: “Temperature-binned concentrations data ($\Delta T = 1\,^{\circ}\mathrm{C}$) is shown for 6 hour time averaged data (black markers) and 45 days averaged data (green markers).”

For consistency with the updated Figure 12, we also suggest modifying lines 15/16 of the abstract as follows: “. . . with continuous temperature scans for INP measurements between $-10\,^{\circ}\mathrm{C}$ and $-30\,^{\circ}\mathrm{C}$.”

Referee comment: Figure A1 : ‘setup’ can be removed, it is redundant after ‘Schematic’

Answer: done

Referee comment: Figure A5 : Figure text appears to be of low quality and needs to be increased in resolution.

Answer: Figure with higher quality will be included in the revised version of the manuscript.

Referee comment: Figure A6 : ‘foto’ should be ‘photograph’. Panel (b) appears redundant and can be removed.

Answer: “foto” changed to “photograph”. Because the left shows a photograph of PINE-c at the SGP field site, and the right the 3-D construction of the commercial PINE version as a new instrument, we would like to keep the figure as is, but suggest to change the caption as follows: “Photograph of PINE-c (a) located at the ARM-SGP site in Oklahoma for 45 days of continuous INP measurements from October 1st to November 14th, 2019. Part (b) on the right shows a composite photograph of the same instrument before delivery.”

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