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Interactive comment on "Ice-nucleating particle versus ice crystal number concentration in altocumulus and cirrus embedded in Saharan dust: A closure study" *by* A. Ansmann et al.

Anonymous Referee #2

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General Comments:

It was a pleasure to review this "first time" closure study on the relationship between ice nucleating particle concentration (INPC) and ice crystal number concentration (ICNC) for two cirrus cloud closure studies and one altocumulus closure study, using state-of-the-science ground based remote sensing. These three successful closure studies validate part of the basic theory of ice cloud formation processes and thus make an important contribution to ice cloud and climate science research. The study was well conceived and executed, clearly relating the dust-enriched aerosol layer containing INPs with the cloud layer in time and space (conditions that strongly favor heterogeneous ice nucleation, or het). The contribution of mineral dust and air pollution (non-dust) aerosol were addressed for deposition and immersion freezing ice nucleation. The paper is well written and organized, showing attention to important details. Sufficient detail and references are given for other investigators to attempt similar studies. This study provides a basis for more advanced field studies on ice nucleation.

The main drawback to this study (as far as this reviewer can see) is the assumption that ICNC can be estimated in the lower part of a cirrus cloud (see Fig. 3). Retrieved vertical ICNC distributions from cirrus (Mitchell et al., 2018, APC, Fig. 10) show N $\sim$ 5 times higher near cloud top relative to the lower half of a cirrus cloud for conditions likely associated with het (e.g. over mid-latitude oceans during summer). Aircraft measurements show ice nucleation is most frequent near cloud top (Diao et al., 2015, JGR). Kanji et al. (2017) show that INPC strongly increases with decreasing temperature for most environmental conditions. Together, these studies indicate ICNC from het is generally much higher near cloud top where ice nucleation prevails, and that relating INPC to ICNC near cloud base is misleading, underestimating ICNC by perhaps a factor of 5.

The modeling work of Spichtinger and Gierens (2009a & b, ACP) for a cirrostratus case study also indicates that ICNC is not quasi-constant throughout the cirrus deck, but is highest near cloud top. This is due to the relative humidity wrt ice (RHi) being highest near cloud top, since freshly nucleated ice crystals grow fast and fall, removing ice surface area from this region, thus allowing RHi (supplied by the constant updraft) to remain relatively high near cloud top. The falling ice crystals deplete RHi lower in the cloud, reducing the rate of ice nucleation there (mostly due to homogeneous ice nucleation in this study, but it may apply to het as well since het also depends on RHi). Although there is a constant supply of new ice crystals near cloud top, these are spread vertically over the whole cloud depth, thus diluting the ICNC near cloud top in the lower cloud.

These concerns are only relevant to the second case study (17-18 March 2015) where

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the cirrus cloud layer can be up to 2 km deep or more. In the first case study (10 April 2017), the cirrus layer was probably too thin for this phenomena to manifest, and for the altocumulus case study, this cloud was quite thin and mixed phase, where the above arguments and observations do not apply.

To summarize, these factors should be considered when evaluating the results from the second INPC-ICNC closure experiment. Even better would be to retrieve ICNC near cloud top during this experiment. Since successful closure is defined as agreement within an order of magnitude regarding INPC and ICNC, successful closure may still be achieved, but the authors may wish to sample ICNC and frame their arguments somewhat differently to accommodate these points.

Finally, the central findings of this study would be more accessible to a casual reader if a table were included (similar to Table 2) that shows the main results (i.e. INPC vs. ICNC) for each of the three closure experiments (i.e. all main closure experiment results in a single table), provided this does not oversimplify the findings too much. In this way, one will not need to search through the text to find these key results.

Major Comments:

1. Page 3, lines 2-4: Please relate this to the above discussion.

2. Page 3, line 14: For completeness, please also cite the satellite retrieval technique of Mitchell et al. (2018, ACP) that retrieves ICNC, De and IWC.

3. Page 3, lines 17-18: This is true for polar orbiting satellites but not for geostationary satellites; please qualify this sentence.

4. Page 7, lines 29-31, and page 8, lines 1-5: Please revise this in accordance with the "General Comments" section.

Minor Comments:

1. Page 1, line 4: "extend" => extent?

2. Page 2, lines 9-10: Because aerosols play a role in the tropospheric water cycle, does this imply that this water cycle is sensitive to aerosols (e.g. their chemistry and concentration)? For example, over the typical range of CCN and INP concentration, is the water cycle sensitive to changes in their concentration? Or are there generally sufficient CCN and INP to accommodate the vertical transport of water?

3. Page 12, line 9: Unbalanced parentheses

4. Page 19, line 30: "extend" => extent?

5. Page 20, line 14: "cloid" => cloud?

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