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Interactive comment on "A Microphysics Guide to Cirrus – Part II: Climatologies of Clouds and Humidity from Observations" *by* Martina Krämer et al.

Anonymous Referee #2

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This article reports findings of cirrus microphysical properties (IWC, Nice, Rice) and humidity from a climatology constructed from a large amount of airborne measurements, covering latitudes from 20S to 75N. This impressive data archive has been carefully quality checked and includes 150 flights from 24 campaigns. This effort is a huge contribution to our field. It is extremely difficult to build an unbiased climatology from airborne measurements as they often exist only for specific regions and at specific seasons. Results are presented as function of altitude and temperature, also stratified by tropics and NH midlatitudes (Sections 3 and 4). The supplement presents separate results for each of the 15 campaigns added to the ones of an earlier publication. Special attention has been given to the TTL of the Asian monsoon, using recent

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measurements of the StratoClim campaign (Section 5). A second important part of this article consists of using these measurements to rescale ice crystal number concentration retrieved from global satellite radar-lidar observations, which then allows to compare Nice of different latitude bands (Section 6), in the case that this scaling factor of 1.73 is valid over the whole IWC-T range and over the whole globe.

This is a highly important article and should be published after revision. The abstract, introduction and conclusions are well written. It is really not an easy task to synthesize so much information. The present form of the article, though already quite well synthesized, is long, with a multitude of figures. The article could gain in clarity by taking into account the following suggestions. In particular, as already in Part I the cirrus clouds have been classified as in-situ and liquid origin and here are further distinguished according to updraft strength, a presentation of the in-cloud properties Nice, Rice and RHice in the IWC-T space, instead of only in the T space, would be very helpful.

Major comments:

Sections 3 and 4 both present results of the airborne climatology, with many figures. In general 6 variables, 3 corresponding to cirrus microphysical properties (IWC, Nice, Rice) and 3 corresponding to humidity (in-cloud RHice, clear sky RHice and clear sky water vapour mixing ratio) are presented stratified by altitude, latitude and temperature in these two sections. I would merge these sections into one section (3. In-situ climatologies), with for example subsections 3.1 Latitude – altitude distributions (including description of Figure 2), 3.2 In-cloud properties stratified by T and by (IWC, T), 3.3 In-situ and liquid origin cirrus. There are long descriptions, and as the title includes the word 'Guide', the behaviour of Nice, Rice and RHice in the IWC-T space, instead of or in addition to in the T space alone, would probably be clearer in respect to the cirrus classification. Therefore this new section 3.3 should show IWC as function of T (as already in Figs. 6-10), but then the other in-cloud properties as function of IWC and T (median or mean in IWC/T intervals and also variability in IWC/T intervals). The presentation in the (IWC-T) space has several advantages: 1) one can probably better distinguish the different types of cirrus and their the properties Nice, Rice and RHice, leading to a more quantitative Table 1, and 2) this would be a very useful synthesis for testing parameterizations in climate models, as recent bulk ice cloud schemes rely on both of these parameters, IWC and T (see for example Field et al., 2007; Furtado et al., 2015; Baran et al. 2016 or Figs. 4f-h of Stubenrauch et al., 2019). Merging some of the figures as follows:

1) Figure 2 should only show 3 of the 4 sub-figures which links altitude and temperature for different latitude bands (one could imagine to separate summer and winter midlatitudes). What are the different colors within one latitude band? The right panel seems to be only an example from one field campaign (perhaps one could move this to section 5 where the TTL is discussed, or as it is published one can just resume the conclusion in the text).

2) Figure 3 presents scatter plots of these 6 variables deduced from all measurements, as function of altitude and latitude. The information could be presented in a more quantitative way by building intervals in altitude (for example per km) and per 10° in latitude and plot then the averages or medians in these intervals (and in addition the variability within the intervals in a separate plot), instead of superposing each of the measurement which indeed shows the scatter but also leads to confusion as some of the points are below others. It looks to me that the most rare measurement values are plotted above so that one can see them (in blue). The comments on the figures are very interesting, but the color blue should only be used if they correspond to the color of the variable value.

3) Then in Section 4, these 6 variables are shown as function of T in Figures 6 to 9. Take out Figure 7 (earlier results, already in supplement as Figure 1), and build two figures, 6 and 7: new Figure 6 could present IWC as fct of T, and Nice, Rice and RHice in IWC-T space, for all, NH midlatitudes and tropics, and new Figure 7 H2O clear sky as fct of T and perhaps RHice clear sky in H2O-T space, for all, NH midlatitudes and tropics. One motivation of this analysis is certainly to verify that there

is a coherent relationship between the microphysical values and T, even if the tropics and midlatitudes include cirrus with a different range of these values. Therefore a joint discussion of all, NH midlatitudes and tropics will be easier to follow.

Section 3.1.1: As already in Part I, the authors classify cirrus according to their origin: in-situ or liquid origin; and they nicely summarize their characteristics by further distinguishing those meteorological situations with slow and fast updrafts. However, it is not clear to me from where the authors have the information on the updraft speed. Is this based on simultaneous measurements or on intuition? As this classification is one of the core findings, it is important to explain from where this information is obtained.

I would place Table 1 at the end of Section 3, so that the words 'low', 'few', 'large', etc. can be replaced by ranges (probably separately for tropics and midlatitudes). The authors show ranges in Figure 5, but these are only for midlatitudes, (probably at equinox conditions, as they were used for a specific simulation).

Section 6: Section 6.1 presents an evaluation of the remote sensing lidar-radar retrieval method, by comparing Nice in the T space from in-situ PSD measurements of 5 campaigns and Nice in the T space, where in a first step N0* and Dm, assuming a modified Gamma function, have been determined from these in-situ PSD data to use them as a constraint in the satellite retrieval (Figure 13). An interesting finding of the comparison between the two Nice results is that the Nice overestimation from satellite retrieval can be partly explained by the fact that the in-situ PSDs often do not contain ice crystals with D < 20 micron, while the retrieval assumes a PSD including all size bins (lines 750-751). This bias should be larger at low T. However, in Section 2.2 it is written that for T > -50°C (220 K), an overestimation in DARDAR Nice is due to the inability of the modified Gamma distribution to match the frequently bi-modal shape of measured PSDs (lines 149-151). This statement means that at warmer T there is also an overestimation, but for a different reason. Should this not be discussed when considering Figure 13? And should then not follow, that a different scaling factor applies for T < 220 K and for T > 220 K? Unfortunately the logarithmic scale and the squeezed y axis do not permit to see if two instead of one scaling factor over the whole T range would be better. Again, I suggest to present Nice also in the IWC-T space, especially since IWC is also available from the DARDAR retrieval. Same for Figures 14 and 15. Then it could be directly seen that the thinnest Ci at cold T are not detected by DARDAR, and perhaps even that different scaling factors would apply in different (IWC-T) intervals. For the analysis in Figure 13, N0* and Dm ware determined from the in-situ data and used as constraint for the satellite retrieval, rather than being constrained from radar-lidar measurements during usual retrievals (line 751). I do not completely understand this sentence: does this mean that for the comparison and the following scaling, results of a special radar-lidar retrieval were used or is the global climatology, presented in sections 6.2 and 6.3, also based on the lidar-radar retrieval with this (N0*, Dm) constraint ? If the usual retrieval is different, then one should also show Nice for the usual retrieval. Perhaps this only needs clarification in the text.

Once Nice adjusted by a constant factor 1.73, Nice is decreasing with increasing T in Figure 14, while Nice is constant with T for in-situ measurements. Again, the presentation of Nice as fct of IWC and T and its variability within the IWC-T intervals will perhaps give additional insight, in particularly if one distinguishes tropics, midlatitudes and polar regions.

Section 7: lines 952-953 (conclusions from Figure 5): The authors should make it very clear that the analysis in Figure 5 only serves as an illustration how this data archive can be used to determine cloud radiative effects. The presented radiative transfer calculations have only been undertaken for a specific situation: at noon, equinox, at 50° latitude, only representative for midlatitude conditions at a specific daytime. This should be clearly written in the conclusions. It is mentioned as a kind of footnote in the legend of Figure 5, but can be easily overseen. Also, there have been many studies on cirrus radiative effects published before, it might be interesting to compare with earlier results (for example Kienast-Sjögren et al., 2016 or Campbell et al., 2016).

Will this data archive be made available? I did not find a section about data availability.

Minor comments:

Abstract, lines 22/ 23: half of the cirrus are located in the lowest warmest cirrus layer; what is the warmest cirrus layer?

Section 2, lines 120 – 124: the data of 4 campaigns out of 24 campaigns are not used, because the data volume is too low or too high. If the data volume is too high, one could imagine to filter out cases randomly. It is a pity that the data are not used at all. Or did I understand something wrong? Are all following results based on the 20 campaigns?

Section 2.2: It was found that the assumption of a modified Gamma distribution for the PSD is only valid for $T < -50°C$, which limits the statistics very much, and which leads to a positive bias of Nice at warmer T, because the assumed PSD shape is not coherent with observed bimodal PSDs. Are there other assumptions in the retrieval which may lead to biases?

Figure 13: It is not clear which satellite retrieval statistics is used: only the regions and seasons of the 5 campaigns? This needs some explanation in the text.

Figure 1: are the airplane schemes necessary? It is nearly impossible to read the name of the campaigns. As there are no flights in the SH higher latitudes, one could use this space to write these names there, which allows to increase the size of the map.

Section 5: Figure 10 is already in the supplement. As this section concentrates on the Asian monsoon, the data of Figure 10 can be analysed in the IWC-T space as proposed above.

Title of Section 6: Global cirrus Nice climatology from satellite remote sensing (the regional data are included in the global)

Table 3: could one add Nice for tropics and NH midlatitudes from in-situ measurements?

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Typo, line 188: distribution of cirrus

Typo, line 409: which can be seen

Typo in Table 2: median for 190K-200K: 0.100 instead of 0.010

References mentioned in 1. Paragraph of major comments:

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Baran, A. J., Hill, P., Walters, D., Hardiman, S.C., Furtado, K., Field, P.R., & Manners, J. (2016). The Impact of Two Coupled Cirrus Microphysics–Radiation Parameterizations on the Temperature and Specific Humidity Biases in the Tropical Tropopause Layer in a Climate Model. J. Climate, 29, 5299–5316, doi: 10.1175/JCLI-D-15-0821.1.

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Campbell, J.R., S. Lolli, J.R. Lewis, Y. Gu, and E.J. Welton, 2016: Daytime Cirrus Cloud Top-of-the-Atmosphere Radiative Forcing Properties at a Midlatitude Site and Their Global Consequences. J. Appl. Meteor. Climatol., 55, 1667–1679, https://doi.org/10.1175/JAMC-D-15-0217.1

Kienast-Sjögren, E., Rolf, C., Seifert, P., Krieger, U. K., Luo, B. P., Krämer, M., and Peter, T.: Climatological and radiative properties of midlatitude cirrus clouds derived by automatic evaluation of lidar measurements, Atmos. Chem. Phys., 16, 7605–7621, https://doi.org/10.5194/acp-16-7605-2016, 2016.

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