Answer to Referee#1 (RC1)

The comments of the referee are in black,
responses by the authors in blue,
changes in the manuscript text in light blue.

Review of a Technical note: Bimodal Parameterizations of in situ Ice Cloud Particle Size Distributions, by Irene Bartolomé Garcia and coauthors, submitted to EGUSphere.

This study uses a massive set of in-situ aircraft observations collected from high latitude to equatorial ice clouds and collected in the Julia data base to investigate the size distributions of the ice and mixed-phase clouds over a wide range of conditions. Figure 1 and the cloud descriptions nicely shows the locations of the sampling, which clearly shows where the clouds were sampled. The particle probes included the CDP, FCDP, and the NIXE-CAPS, which is a CAS and grey scale CIP. The acronyms for these probes are identified in the text. Normalized size distributions, derived as a function of the melted equivalent diameter are evaluated. The interpretation of bimodality draws heavily on the data from the small particle probes. It is shown that bimodal particle size distributions (PSD) fit the observations much better than a single mode.

I have several major comments that I would like the authors to consider. A few are as follows.

1. Are the actual size distributions bimodal?

   Not every single PSD is bimodal. Our idea that a combination of two PSDs might lead to a better representation of cirrus clouds retrieved from satellite observations bases on the comparison between means of numerous measured PSDs and those retrieved from satellite observations shown by Sourdeval et al. (2018) (see Fig. 2). The observed PSDs are from a part of the campaigns which are also now included in the PSD database.
   From the two panels in Fig. 2 the bimodality of the mean observed PSDs can be seen, the more the warmer the temperatures are (especially for T $>$ - 50°C). This is in agreement with other studies that analyzed in situ data, for example Jackson et al. (2015). In Fig. 2 it is also visible that the PSDs from the unimodal satellite retrievals deviate the more pronounced the bimodality of the observations is.

   Your assumed mass dimensional (m(D)) relationship is poorly constrained for small particles. This could affect your interpretation.

   In Afchine et al. (2018), we have tested the mass dimensional (m(D))relation versus a number of others (see Fig. 8 here) and also compared the resulting IWCs to IWCs from total water instruments. The agreement of the IWCs was satisfactory, therefore, we are confident that the mass dimension relationship reproduces the IWC as well as possible within the given range of uncertainties.
   For the smaller ice particles $\leq$ 100 μm), the mass dimension relation is increasingly close to spheres, which corresponds to all other m(D) relations summarized in Afchine et al. (2018) and also the newly proposed by Lawson et al. (2019), i.e. we use the best available knowledge.

2. I have attached a figure showing PSD measured with balloon-borne ice crystal replicators, with very high resolution, no particle breakup, and unequivocal detection of small particles. There is little evidence of bimodality. It would be interesting to see if your

assumed mass dimensional relationship (based on Mitchell et al., 2010) could change this result.

Please see the answers to points 1. and 3., we think that the explanations given there also answer this point.

3. I'm very uneasy about your use of the small particle probe data. Shattering is a serious concern. The CAS is known to yield PSD that have major contributions from shattering. This issue could certainly create the bimodality you find. This issue needs to be discussed in more detail, not just in the references cited.

   We agree that ice particle shattering played a role in earlier studies. However, the efforts made in the development and use of antishatter probe tips and particle interarrival time algorithms to minimize ice particle fragmentation have resulted in this effect no longer heavily distorting the microphysical properties of the PSDs. There are a number of publications on this issue, some of which we have cited in our manuscript. We do not feel that it is necessary to discuss the problem again in more detail, since it is 'state of the art' that shattering has been minimized as much as possible in advanced cloud probes. The following has been added to the manuscript (lines 116-120):
   As mentioned in Sect. 1, shattering of the ice particles during the measurements would increase the number of small particles and cause an artificial bimodality in the PSDs. However, as presented in the above references, major efforts were made in the development of antishatter probe tips and particle interarrival time algorithms that have resulted in a successful minimization of the shattering of ice particles. Therefore, we are confident that the bimodality present in the JULIA database is not due to distorted microphysical properties of the PSDs.

4. Lines. 122-124. Mass dimensional relationship. Some of your measurements are at temperatures considerably warmer than for cirrus. Is there some reason to think that you can apply the modified m(D) relationship of Mitchell to the warmer emperatures?

   The reason that we used the same m(D) relation at warmer temperatures is from the comparison of various m(D) relations in Afchine et al. (2018). There it can be seen that the difference between all relations is small, even when looking at relations derived for warmer temperatures. However, we are aware that the uncertainties of the derived IWCs are larger than at colder temperatures. This explanation is now included in the manuscript in Section 2.2.:
   The used m - D relation was compared in Afchine et al. (2018) with other m - D relations from the literature and also with the measurements from total water instruments showing good agreement for cirrus clouds. For temperatures warmer than the cirrus range, we are aware that the uncertainties of the derived IWC are larger than at colder temperatures. However, we use the same m - D, since as shown in Afchine et al. (2018), the differences between the compared m - D relations is small, even when considering those derived for warmer temperatures.

5. Line 131 and Eq. (3). What is the advantage of using the melted equivalent diameter (from the measured PSD) versus the physical diameter. The former uses an assumed mass diameter relationship which may not be valid under certain conditions.

   The normalization method followed in our study and developed by Delanoe et al. (2005, 2014) (hereafter D05 and D14, respectively) is based on the normalization method presented by Testud et al. (2001) (hereafter T01) for raindrop spectra. We also followed this approach. Because of the high complexity of ice particles types and shapes compared to rain, D05 and D14 chose the equivalent melted diameter instead of the physical diameter of the ice particles to adapt the mathematical formulation of the method of T01 to ice PSDs. It can also be noted that m-D relations would be necessary to relate the PSD to properties like the IWC regardless of the definition of the diameter. Please see answers to points 1 and 2 considering the chosen mass diameter relationship and its adequacy to the analyzed clouds.

6. Eqs. (3) and (4). Is it valid to assume that the PSD extends from 0 to infinity, rather than a partial gamma? Does this affect the IWC?

   To compute the moments of the distributions we do not use the general continuous form, but the discrete form summing from the minimum observed diameter to the maximum (third term in Eq. (3)).

7. Normalizing as a function of N_{ICE}. The value of N_{NICE} is subject to considerable uncertainty and potential error.

   To normalize the PSD it is necessary to find a parameter to scale the size space and the concentration space. As shown by Lee et al. (2004), a PSD can be normalized by using combinations of moments, therefore the question is, which moments to choose. For the normalization we are not using the total ice number concentration, which corresponds to the zeroth moment, but a concentration metric that corresponds to the third and fourth moment. This parameter was selected as adequate (and less uncertain than N_{ice}) for the normalization process in D05 and D14 (in our manuscript Eq. (4)). These moments were carefully selected to make normalized PSDs independent of the ice content and the mean volume-weighted diameter.

8. Line 199. D05 and D14 use the Brown and Francis m(D) relationship. How will this affect your comparison with their normalized PSD.

   In Fig. 8, we plotted in addition to the m(D) relations shown in Afchine et al. (2018) that of Brown and Francis (1995). It can be seen that the mass around 100 μm is higher than those from the other m(D) relations. We suspect that in the more recent relations the underlying measurement techniques have improved. Furthermore, in D14, it is argued that the Brown and Francis m(D) was obtain primarily at temperatures between - 20 °C and - 30 °C and dominated by particles between 200 and 800 μm, so they update the study of D05 and use m(D) relationships derived from direct IWC measurements. Therefore, we consider that the Francis and Brown m(D) might not be the most suitable one for our study since we cover colder temperatures and smaller particles.

9. Lines 265-267. ‘minimize the impact of shattering effects’. Down to 3 microns? This is difficult to agree with.

   In Fig. 4, we show exemplary the mean PSD of Flight#6 of the StratoClim aircraft campaign. The inlets of the CAS probe is modified and the CIP probe is equipped with antishatter tips (see Krämer et al., 2016). In the left panel, the PSD without IAT correction to exclude shattering is shown, the right panel presents the same data set but with IAT correction applied. Comparing the two PSDs it is visible that they are nearly identical. From our analyses, ice particle shattering is generally not very frequent in cirrus clouds, because often the ice crystal sizes are not large enough to cause severe fragmentation of ice crystals. Only liquid origin cirrus sometimes carry ice crystals large enough so that an IAT correction reduces notably the number of ice crystals. In our measurements, we found only very few such events.

Minor Comments.

I feel that the comments above and the few minor comments below are the ones that need to be addressed in the revised article. I'll identify more minor comments after I see the revised manuscript.

1. Line 3. based on aircraft in situ
   Modified
2. 8. consists of
   Modified
3. 71. What is the averaging time as that is the relevant time.
   We are not averaging, we use the PSDs for every second.
4. Eq. (2) what is the [m]
   It indicates that the units of the equivalent melted diameter are meters. To avoid confusion, [m] is deleted and it is explicitly indicated in line 139.
5. 149: remove studied
   Done
6. 176: "fast" to "strong"
   We would like to keep "fast" to use the same terminology as in Krämer et al. (2016, 2020) referring to updrafts.
7. 255. Parameterization
   Modified

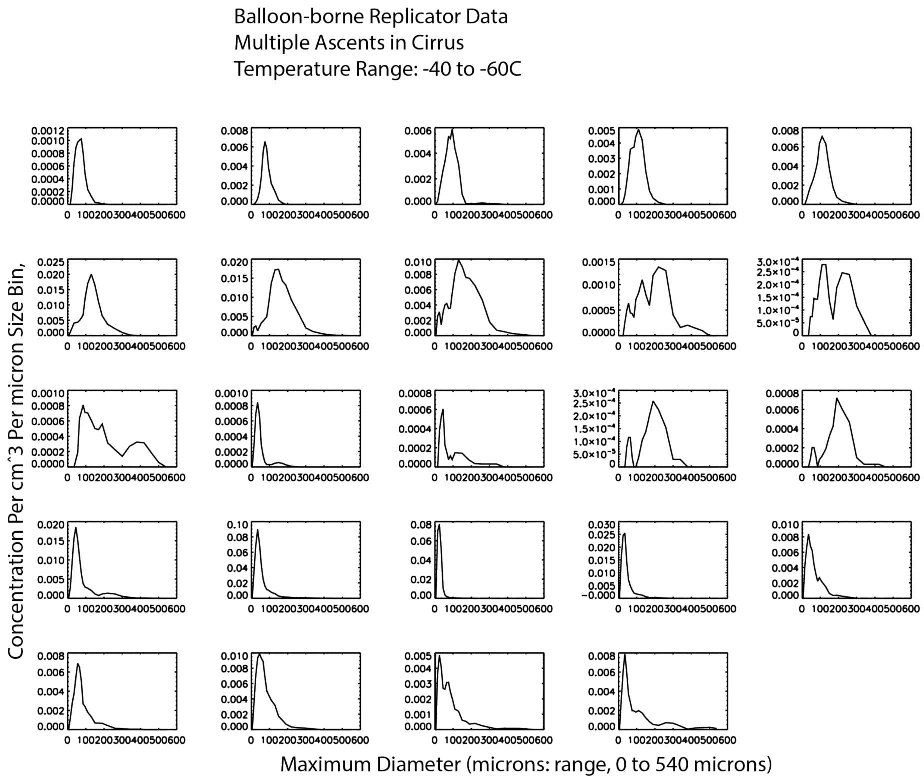

Figure 1:

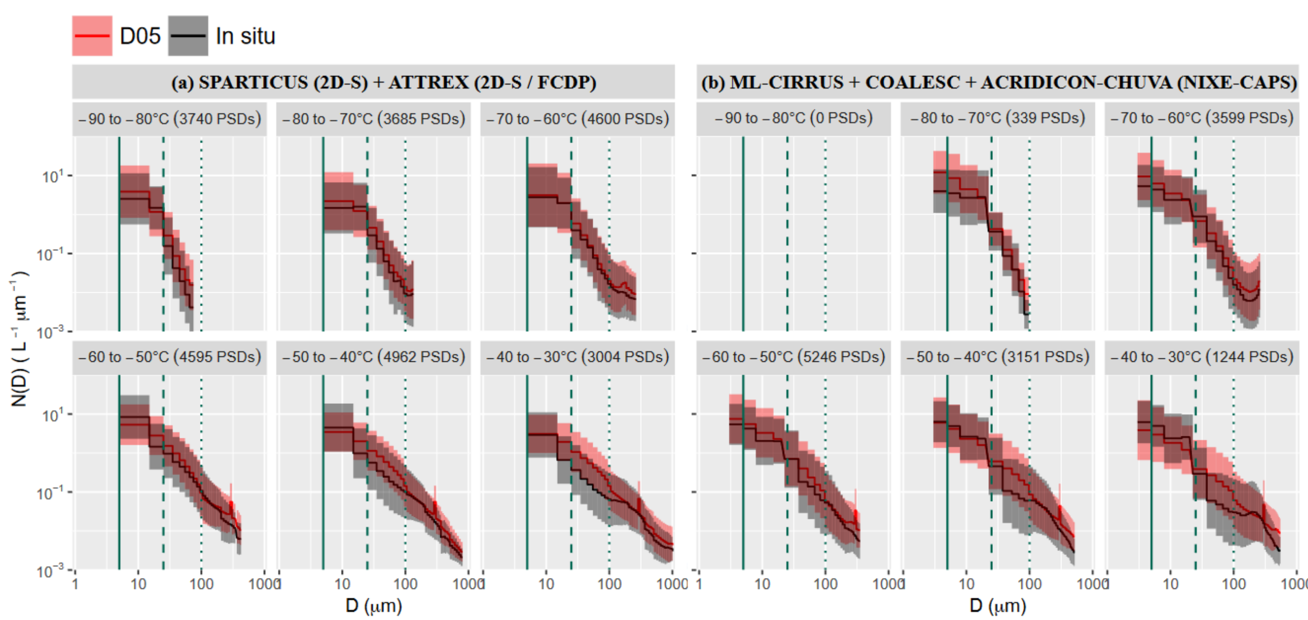

Figure 1. **(a)** Mean PSDs measured (black lines) during SPARTICUS and ATTREX, averaged per 10 °C temperature bin (from −90 to −30 °C). Black contours indicate one standard deviation around the mean. The mean and spread of one-to-one predictions by the D05 parameterization are similarly indicated in red. The total number of PSDs in each T_c bin is indicated in the panel heading and the relative contributions from each campaign can be deduced from Fig. S1. Vertical plain, dashed and dotted green lines indicate $D = 5$, 25 and 100 µm, respectively. The SPARTICUS data with $T_c < -60$ °C are ignored here to avoid contaminating FCDP measurements with uncertainties arising from the first size bins of 2D-S. **(b)** Similar to **(a)** but for the ML-CIRRUS, COALESC and ACRIDICON-CHUVA campaigns.

Figure 2: Figure 1 from Sourdeval et al., 2018, ACP

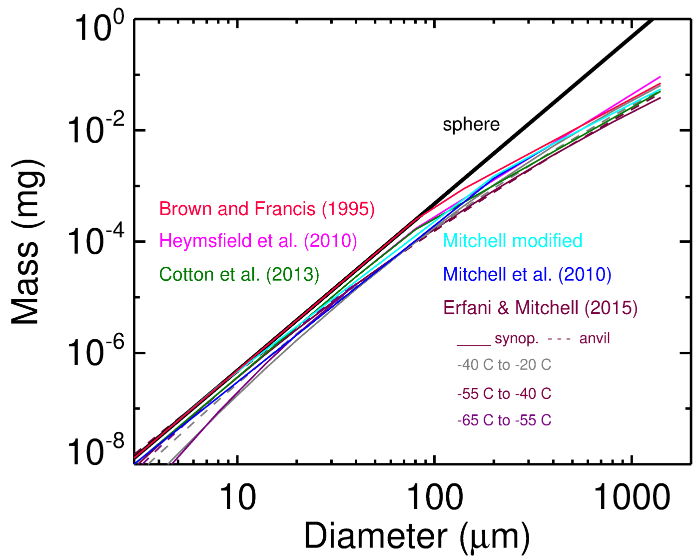

Figure 3: Afchine et al. (2018), Figure 8 (left panel) with the m(D) relation of Brown and Francis (1995) added.

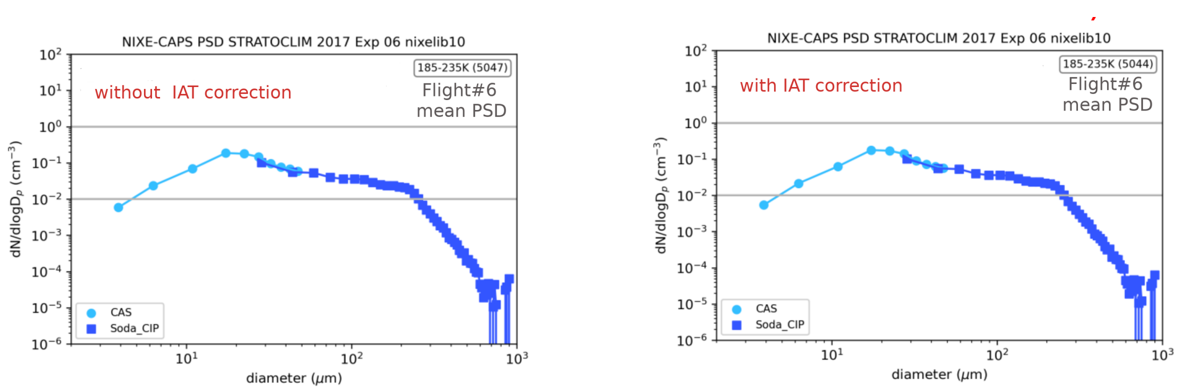

Figure 4: Mean PSD of Flight#6 of the StratoClim campaign. Left: without IAT correction, Right: with IAT correction.

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Testud, J., Oury, S., Black, R. A., Amayenc, P., and Dou, X. K.: The concept of "normalized" distribution to describe raindrop spectra: A tool for cloud physics and cloud remote sensing. J. Appl. Meteor., 40, 1118–1140, 2001.

Answer to Referee#2 (RC2)

The comments of the referee are in black,
responses by the authors in blue,
changes in the manuscript text in lightblue.

Review of Tecnical note: Bimodal Parameterizations of in-situ Ice Clouds Particle Size Distributions Authors: Irene Bartolomé Garcia et al.

The authors are proposing a new technic for the parameterization of ice particle size distributions with gamma normalized size distributions as in Delanoë et al 2014. But, they are using two normalized distributions, one for Diameters smaller than 50 µm and one for Diameters larger than 50 µm, instead of one for all spectrum of size of measured ice crystals. They are comparing their retrieved ice PSD with the ones of retrieved with the former methods i.e Delanoë et al., (2014 and 2005) and applied to their dataset. Globally, overall their dataset (Figure 4 and 6) the new method seems to be more accurate to retrieve small ice crystals concentration. They motivate their study, on the fact that concentrations of small ice crystals are too often neglected or not considered, impacting accuracy of retrieval methods for clouds properties. The main reason being the measurment uncertainty of small ice crystals.
This is not the first study that offers a parameterization of ice PSD with two modes (two gamma distributions cf. Field et al., 2007). However, this is the first in my knowledge that includes ice particles since 3 μm.

Major Comments:

1. **Bimodality:**
   (a) Are you assuming that all ice PSD in your ice clouds are bimodal?
   No, we do not assume that all PSDs are bimodal, but that bimodality can be observed in ice crystal PSDs. Futhermore, Sourdeval et al., (2018) showed using mean PSD from in situ aircraft observations compared with the retrieved mean PSD from satellite measurement that the occurence of bimodality impacts the capability of single-mode parameterization to predict the PSD shape and leads to major retrieval issues in these warmer clouds. The deviation between the mean of the PSDs is indeed clear for temperatures $T > -50°C$ where the bimodality is present (Fig. 1, where aggregation and possibly secondary ice production processes can occur. This is in agreement with other studies that analyzed in situ data, for example Jackson et al. (2015)
   (b) Line 53: You are introducing frequencies of bimodality in the discussion, would it be consistent to divide the distribution in two modes if there is only one mode?
   Since the modes of the distribution correspond one to the small particles and the other one to the large ones, even if the PSD is monomodal, it would be covered by one of the two modes or by both. In Fig.3, the rmse (root mean squared error) of the correlation between the parameterized and the observed N_{ice} is compared for each of the parameterizations. It is shown, that for the monomodal ones the warmer the temperature interval, the larger the rmse is, whereas for the bimodal parameterization it remains approximately constant. Therefore, the impact of using one mode when bimodality is present (warmer temperatures) seems stronger than the use of two modes when one mode is present (colder temperatures).

(c) Hu et al 2022 have developed a method to estimate the number of modes in ice PSD. They, showed that at coldest temperature (-50° C to -40° C) ice PSD are 60% of the time one mode; except for IWC$>1.5\ gm^{-3}$. Why there should be bimodality?

Please, see answers to (a) and (b).

(d) In the introduction you are linking the shape of the ice PSD and the growth process. Then, it is shortly discussed in section 4.3. You are assuming that it is the difference of newly formed ice particle against sedimenting sizes. I encourage you to improve the discussion on this topic. Because, if the evolution of the size of the hydrometeors is linked to the growth rate: vapor diffusion, aggregation and riming. Then, If there is more than one growth process (without counting secondary ice production) there should be more than one mode in ice PSD !?

The following has been added to the manuscript in Sect. 4.3:

In cirrus clouds, riming and secondary ice production play no role and aggregation is nearly negligible. These processes are of importance for mixed-phase clouds, which, as mentioned in Sect. 4.1 entail 9.8 % of the analyzed data. In Jackson et al. (2015) it was discussed that at temperatures lower than $-45\,°C$ **the growth of the ice crystalls is likely due to depositional growth and sedimentation and aggregation are less significant. For warmer temperatures, smaller particles grow by vapor deposition and aggregation, being sedimention from above another possible source for the large particles, which together with heterogenous nucleation taking place at the same time would explain the bimodality (Zhao et al., 2018).**

(e) Then, you choose a cutting diameter of 50 μm, do you mean that the division of the growth processes such growth by vapor diffusion against growth by aggregation (or sedimentation) is here. Can you give a reference or an argument, assumption maybe, for this cutting diameter? If I observe one column of few hundreds of micron wasn't it a monocrystal of few microns in its past?

The diameter of 50 μm was first tested because it is the smallest diameter in D14, but also because it seems to agree well with the division between two modes when computing the median PSD (Fig. 2).The following has been added in Sect. 4.3:

This cutting diameter agrees well with the division between the small and large modes when plotting the median PSD of all data (not shown).

A diameter of 20 μm and 100 μm have been tested to see if there are major differences with the current results. 20 μm was chosen as a division between smaller particles being mainly dominated by nucleation / evaporation and larger by growth / coalescence / aggregation processess (Krämer et al., 2022). 100 μm was selected as one of the cutting diameters from Hu et al. (2022). Figure 4 compares the rmse of the correlation between retrieved N_{ice} and the observed N_{ice} for 20, 50 and 100 μm using the parameters specified in the manuscript (obtained using a diameter of 50 μm). There is a slight decrease for the coldest temperatures and a slight increase for the warmer ones when using a cutting diameter of 20 μm with respect 50 μm. For 100 μm there is a slight increase for all temperature intervals.

Additionally, the alpha and beta pairs have been computed using 20 μm and 100 μm. Figure 5 shows the comparison of the rmse of the correlation of parameterized and observed N_{ice}. It is shown that for colder temperatures the results for 20 and 50 μm are close, but the warmer the temperature, the greater the difference, being the rmse for 20 μm higher. For 100 μm, the rmse is for all temperature intervals above the rmse for 50 μm. Considering the results shown inf Fig. 4 and Fig. 5, we consider a cutting diameter of 50 μm is an adequate choice.

(f) You are citing Field et al., (2007) that also proposed a bimodal normalized parameterization, but as function of optical maximum length and effective radius. However, they did not use concentrations of small ice under 100 microns. What would be the impact by taking the concentration from 3 μm (this would be maybe to consider for a second part publication).

The parameterization by Field et al (2007), hereafter F07, is technically bimodal but only one mode was constrained with in-situ observations. The second mode, for crystals with sizes smaller than 100 μm, correspond to an exponential extrapolation. Following the Sourdeval et al (2018) study, the authors performed a similar investigation of the performance of the F07 parameterization as part of an internal evaluation for the MetOffice. Fig. 11 shows one such comparison done for the SPARTICUS campaign. It can be seen that F07 (in green; here their mid-latitude parameterization) does not perform as well as D05 for the colder temperature bins but especially that D05 and F07 perform equally poorly when bi-modality occurs. This makes the present study relevant for even parameterizations such as F07. If the study of Field et al., (2007) was updated using a database that includes ice particle size down to 3 μm (like the JULIA database used in our study), we consider that the resulting parameterization could deliver better results.

2. **Melting diameter and mass-size relations**:

(a) To retrieve the melting diameter you are using a mass-dimension relationship used in Krämer et al., (2016). In this later study, it is justified for temperature less than -38° C (235.15K) in cirrus cloud and based on former studies. Is it consistent to use it for T $>$ 235K, knowing that few studies with direct measurment of IWC have shown an impact of the temperature on the m(D) coefficients in ice clouds.

The reason that we used the same m(D) relation at warmer temperatures is from the comparison of various m(D) relations in Afchine et al. (2018) (see Figure 8 here). There it can be seen that the difference between all relations is small, even when looking at relations derived for warmer temperatures. However, we are aware that the uncertainties of the derived IWCs are larger at warmer than at colder temperatures. This explanation is now included in the manuscript in Section 2.2.

(b) I would like to see IWC retrieved with this m(D) and original ice PSD, compared with the measured IWC available in your dataset; and also as function of temperature. Why not use, your own retrieved m(D) from the dataset you are using and see the impact on the Nice. And also with Brown and Francis as in the original version (see first review comment).

Figure 6 shows correlation plots between the retrieved IWC using the modified m(D) of Mitchell et al. (2010) together with the bimodal parameterization and the same m(D) but with the observed PSDs. Each correlation plot corresponds to a temperature range of 10 °C. The agreement between parameterized IWC and observed IWC is overall high, especially for temperatures between -90°C and -60°C.

A comparison between measured IWC (with a hygrometer) and IWC from the observed PSDs and the modified m(D) of Mitchell et al. (2010) was done by Afchine et al. (2018) for two campaings (Fig. 7) showing satisfactory results. However, the comparison was made only for the colder temperature range, since the measured IWC was only available in this range. Direct measurements of IWC together with measurements of PSD are only available for one campaign, therefore it is not possible to derive our own m(D) for each single campaign as in Delanoë et al. (2014).

Regarding Brown and Francis m(D), Afchine et al. (2018) did a comparison between several m(D) relations (Fig.8). The differences were not significant, except for diameters around 100 μm where the Brown and Francis m(D) presents a higher mass. Additionally, in Delanoë et al. (2014), it is argued that it was obtain primarily at temperatures between - 20 °C and - 30 °C and dominated by particles between 200 and 800 μm. Therefore, we consider that the Francis and Brown m(D) might not be the most suitable one for our study since we cover colder temperatures and smaller particles.

(c) Figure 4 and 5, I would consider plotting the error in percent regarding original concentrations instead of pure concentration, with a recall of your measurement uncertainties especially for smaller size. Small crystals and large ones do not have the same order of concentrations ; this is important.
Figure 9 and Fig. 10 in this response show the median percentage error of the PSD for each size bin for each parameterization. The shadowed region correspond to the range between the percentile 25 and the percentile 75. Inside the panels it is indicated the median percentage error when considering all size bins. These figures have been added to the manuscript replacing the previous figures.

(d) Figure 5 only, AS your study is questioning the retrieval of small ice concentration, I would summarize it, for small and large ice particles i.e. below and above the cutting diameter, instead of showing it as function of size bins.
In the new version of Fig. 5 (Fig. 10) for each temperature interval it is included the median error for diameters smaller and larger than 50 μm and for the complete range of diameters.)

(e) Line 243 : I do not think that IWC and ice PSD can be dissociated. Can you be more clear on your description of the error of IWC, dimension you are using instead of log, , rate of underestimation and overestimation. It does not talk for someone who is not a specialist.
The units of the IWC are gm^{-3} and the parameterized and observed IWC are compared in correlation plots similar as the ones for N_{ice}. Line 243 has been modified in the manuscript: **There is a slight underestimation (about 2 %) of the IWC for values between about $1 \times 10^{-7}\,gm^{-3}$ and $1 \times 10^{-5}\,gm^{-3}$ and an overestimation (about 7 %) between about $1 \times 10^{-3}\,gm^{-3}$ and $1\,gm^{-3}$.**

(f) 'IWC is sensitive to large particles': it is more complicated than that. Where do you define large ice particles hundred of microns, millimeter ... The spectrum of all ice crystals goes from few microns to centimeter in some case. Then, C, S and X band radars would be enougth to retrieve IWC in cloud. For a fact, W band and Ka band do a better job i.e Delanoë et al., (2005 & 2014) which are less sensitive to very

large ice crystals.
We have modified the the sentence to: **Since all parameterizations have a similar behaviour for the large particles and IWC is sensitive to large particles ($\gtrsim$ 300 µm), this result was to be expected.**

3. **Remarks on the conclusion** ;

   (a) The methods of Delanoë et al., is developed for all ice clouds, while I understand that the dataset used in this study is mainly made with sampling in cirrus clouds (except for ACRIDION campaign). What about the temperature below -20° C? Can we generalize your conclusions to all ice clouds and to all range of temperature ? If yes Why ?
   In our study we focus on the retrieval of ice PSDs and for temperatures lower than about -20° C. Therefore, we wouldn't generalize the results of our parameterization for warmer temperatures and we would suggest a specific study.

   (b) Maybe you can recall the definition of cirrus clouds you are using, does it agree with the one in Heymsfield et al., (2017) and the AMS glossary for example?
   We consider all clouds colder than -38°C to be cirrus (see Krämer et al., 2016), because at warmer temperatures clouds can also be in the mixed-phase state. This physical definition is based on the ice formation mechanism and includes in-situ origin cirrus that form directly as ice, and liquid origin cirrus, which forms at lower altitude as liquid clouds which completely galciate latest at -38°C (included now in the manuscript in Sect. 4.1). This is not entirely in line with Heymsfield et al. (2017) or the AMS glossary, however, as discussed by Heymsfield et al. (2017): 'Classifying cirrus by means of the formation mechanisms leads to cirrus types characterized by physical parameters, besides those embedded in the terminology of the WMO (1956) for all cloud types (see section 2a), which are defined based on morphology derived from observations of visual appearance.'
   We are aware that these two cirrus definitions currently exist side by side and a discussion is ongoing which one should be accpeted in the future.

I suggest these references to help the discussion :

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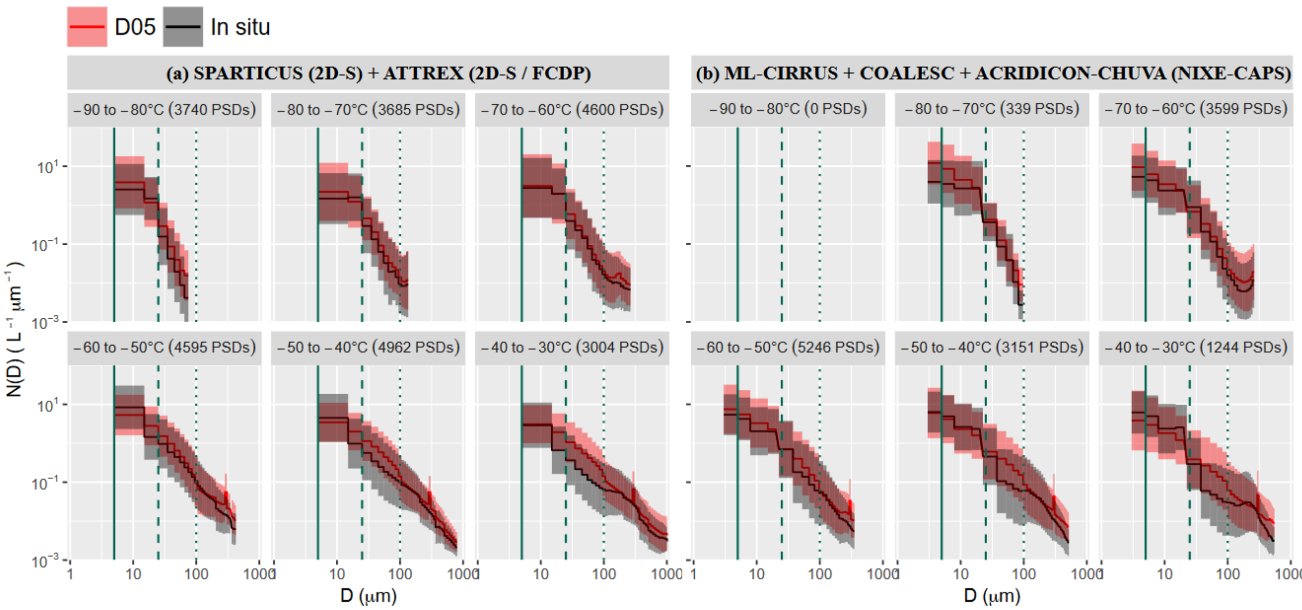

Figure 1. (a) Mean PSDs measured (black lines) during SPARTICUS and ATTREX, averaged per 10 °C temperature bin (from −90 to −30 °C). Black contours indicate one standard deviation around the mean. The mean and spread of one-to-one predictions by the D05 parameterization are similarly indicated in red. The total number of PSDs in each T_c bin is indicated in the panel heading and the relative contributions from each campaign can be deduced from Fig. S1. Vertical plain, dashed and dotted green lines indicate $D = 5$, 25 and 100 µm, respectively. The SPARTICUS data with $T_c < -60$ °C are ignored here to avoid contaminating FCDP measurements with uncertainties arising from the first size bins of 2D-S. **(b)** Similar to **(a)** but for the ML-CIRRUS, COALESC and ACRIDICON-CHUVA campaigns.

Figure 1: Figure 1 from Sourdeval et al., 2018, ACP

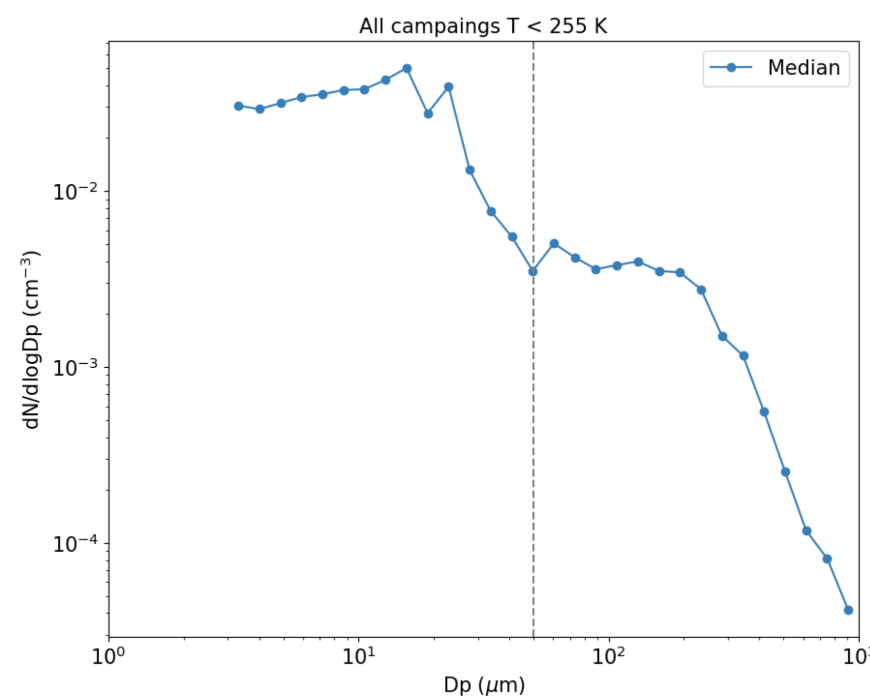

Figure 2: Median PSD of all campaigns considering temperatures lower than 255 K.

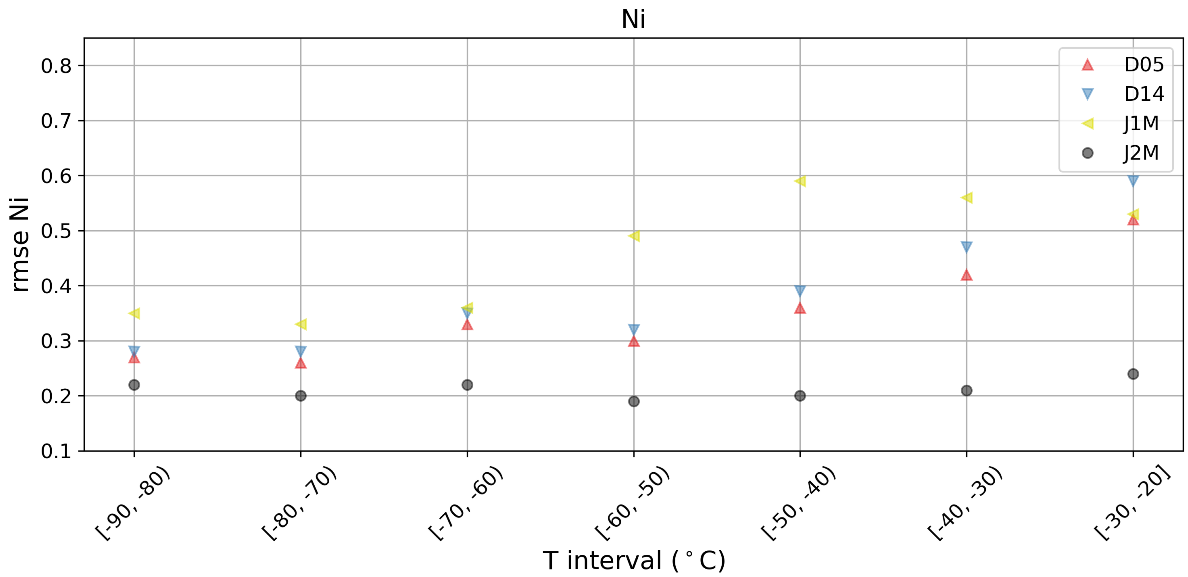

Figure 3: Root mean square error (rmse) of the correlation between the parameterized ice number concentration (N_i) and the observed N_i for several temperature intervals and for each of the parameterizations presented in the study.

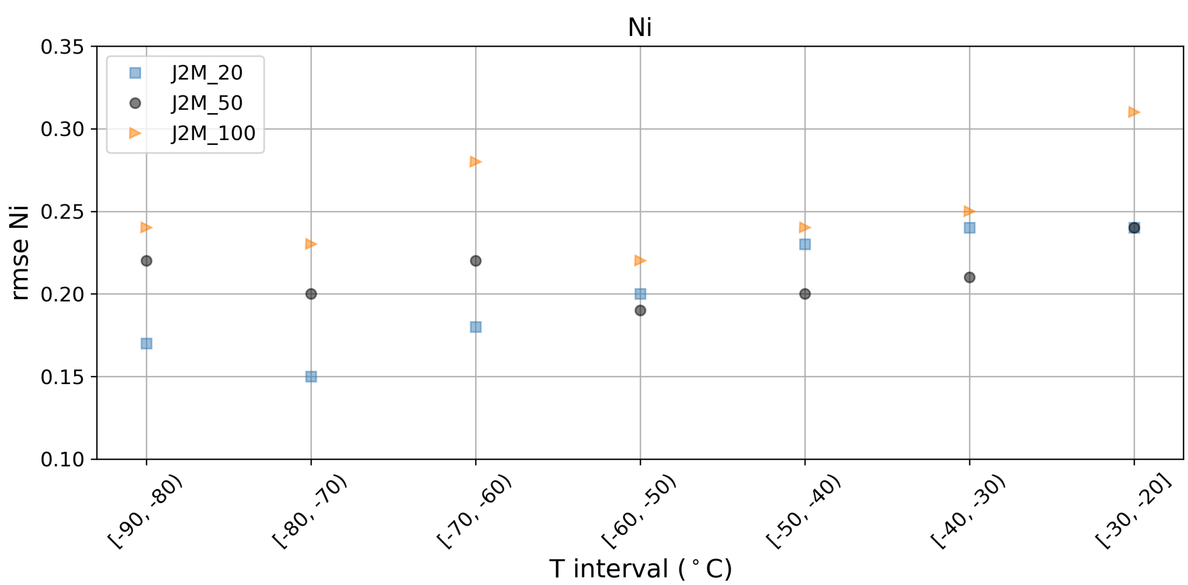

Figure 4: Root mean square error (rmse) of the correlation between the parameterized ice number concentration (N_i) and the observed N_i for several temperature intervals for three cutting diameters. The fitting parameters correspond to the ones specified in the manuscript.

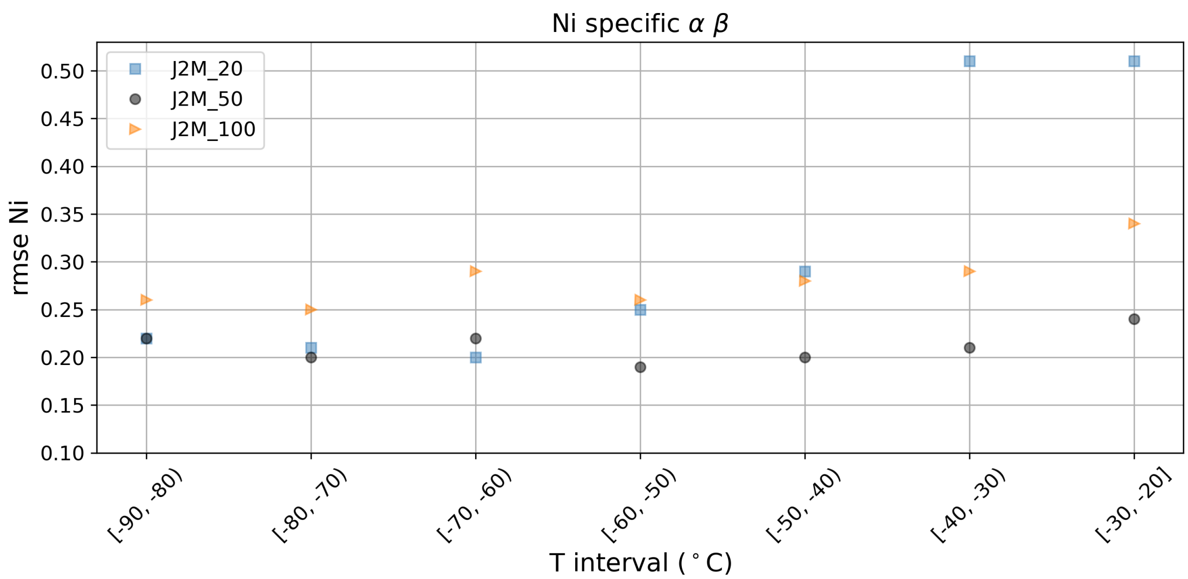

Figure 5: Root mean square error (rmse) of the correlation between the parameterized ice number concentration (N_i) and the observed N_i for several temperature intervals for three cutting diameters. The fitting parameters for the gamma function were computed for each cutting diameter.

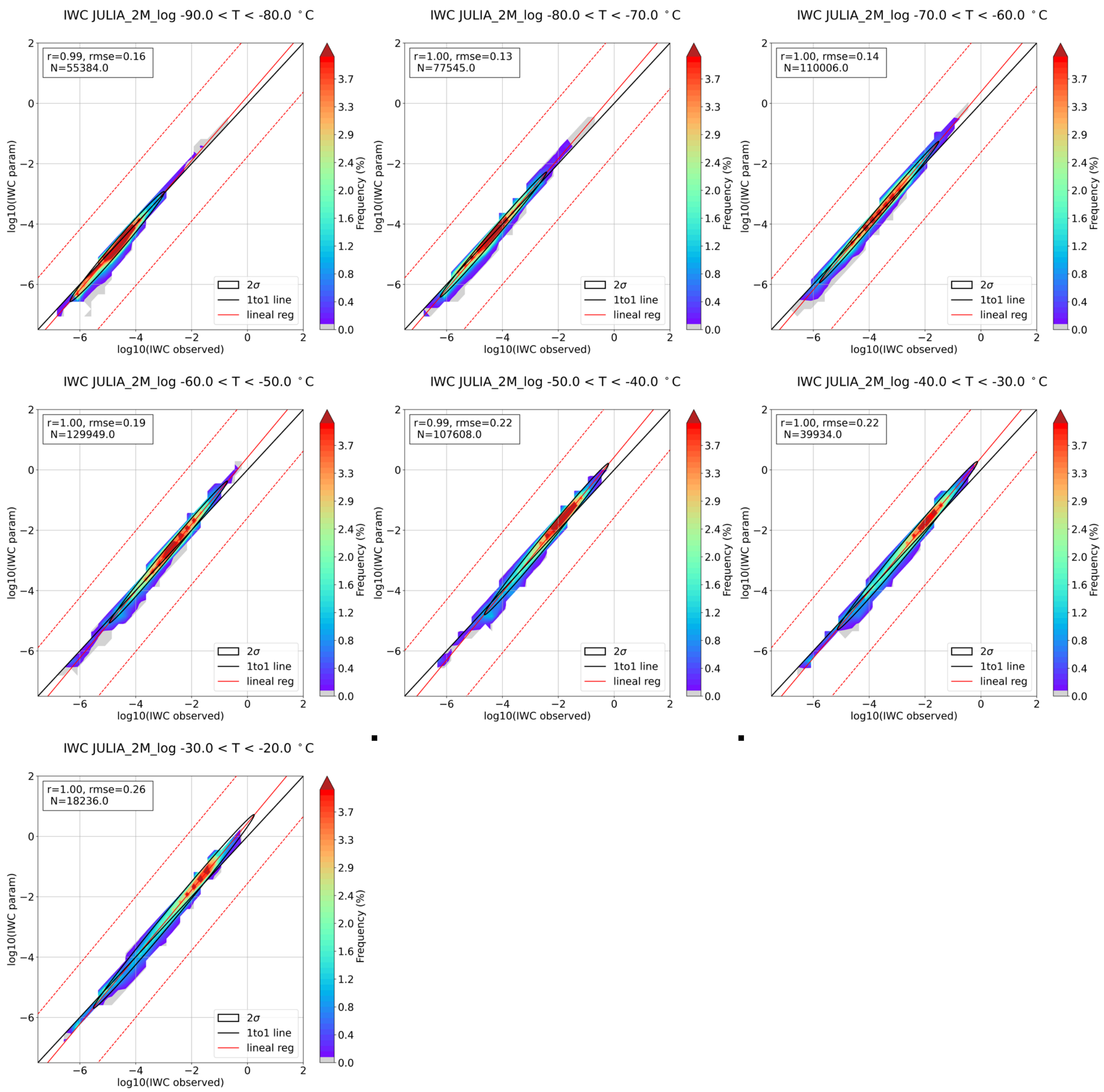

Figure 6: Correlation between the parameterized IWC and the observed IWC for temperatures between -90 °C and -20 °C in intervals of 10 °C, . The parameterized IWC corresponds to the use of the bimodal parameterization. The observed IWC refers to IWC computed using the measured PSDs. The IWC was computed with units of gm^{-3}. Both axis correspond to the logarithm of the IWC.

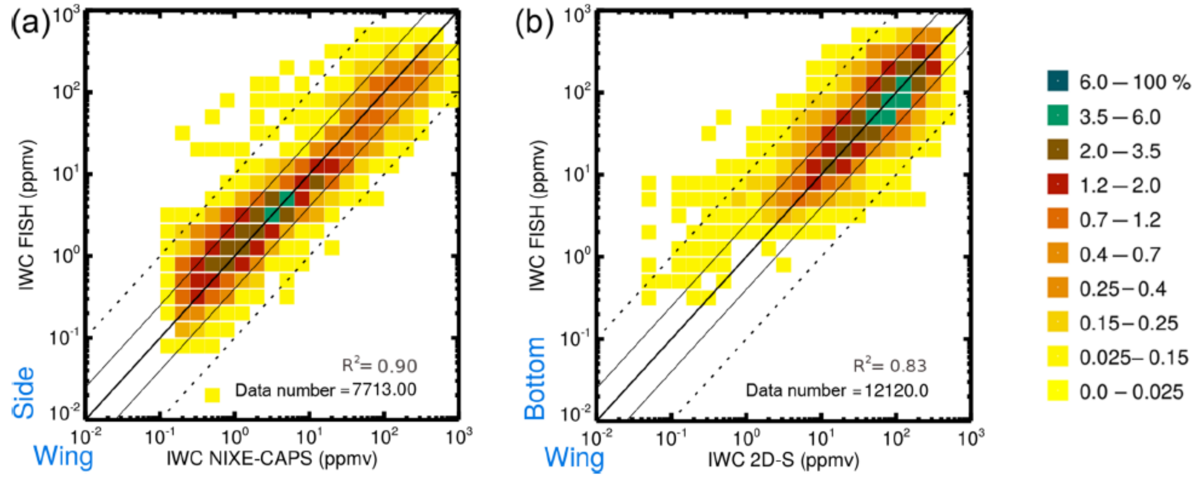

Figure 7: Figure 11 from Afchine et al. (2018). Comparison between IWC measured with a hygrometer (y-axis) and IWC derived from a cloud spectrometer (x-axis).

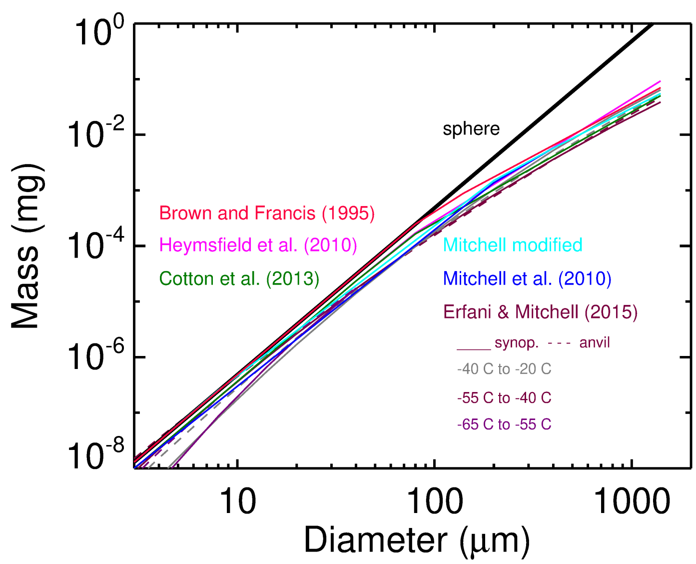

Figure 8: Afchine et al. (2018), Figure 8 (left panel) with the m(D) relation of Brown and Francis (1995) added.

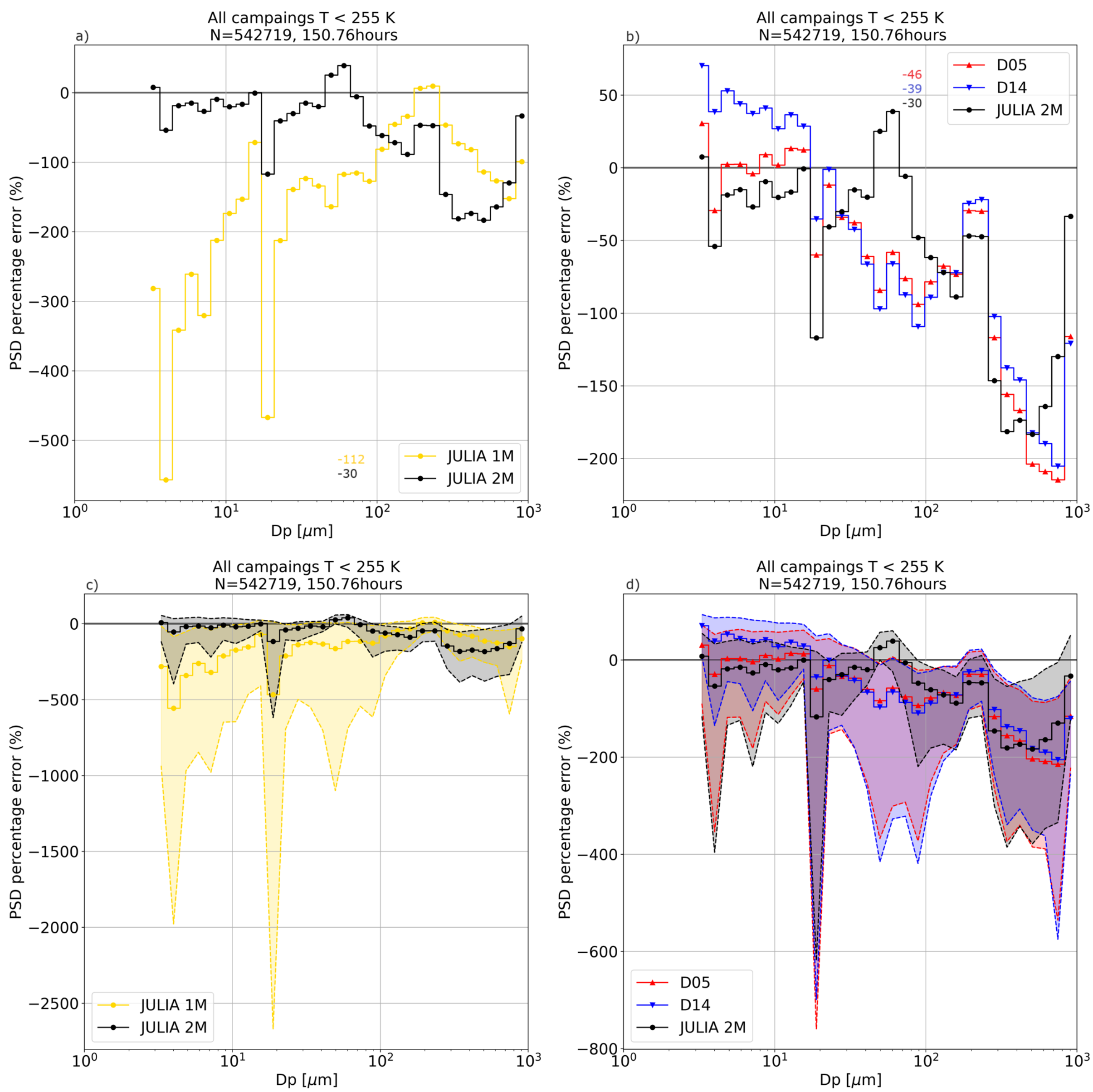

Figure 9: Percentage error of the parameterized PSD. The numbers inside panels (a) and (b) indicate the median error for each parameterization (D05, D14 and bimodal J2M). The shadow region in panels (c) and (d) correspond to the area between percentile 25 and percentile 75.

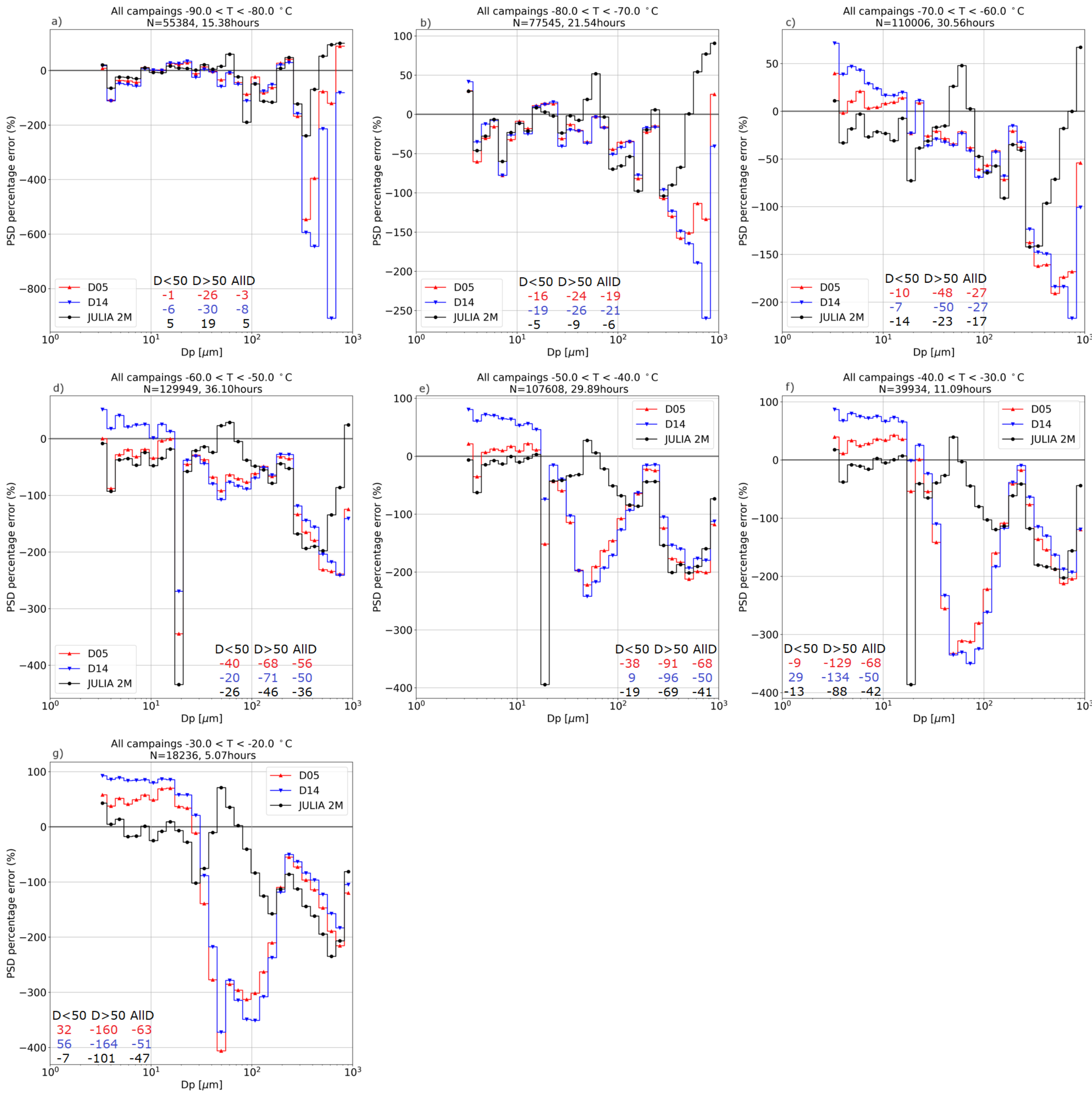

Figure 10: Percentage error of the parameterized PSD in 10 °C temperature intervals. Inside each panel the median error for diameters smaller than 50 μm, larger than 50 μm and the complete range of diameters is indicated for each parameterization (D05, D14 and bimodal J2M).

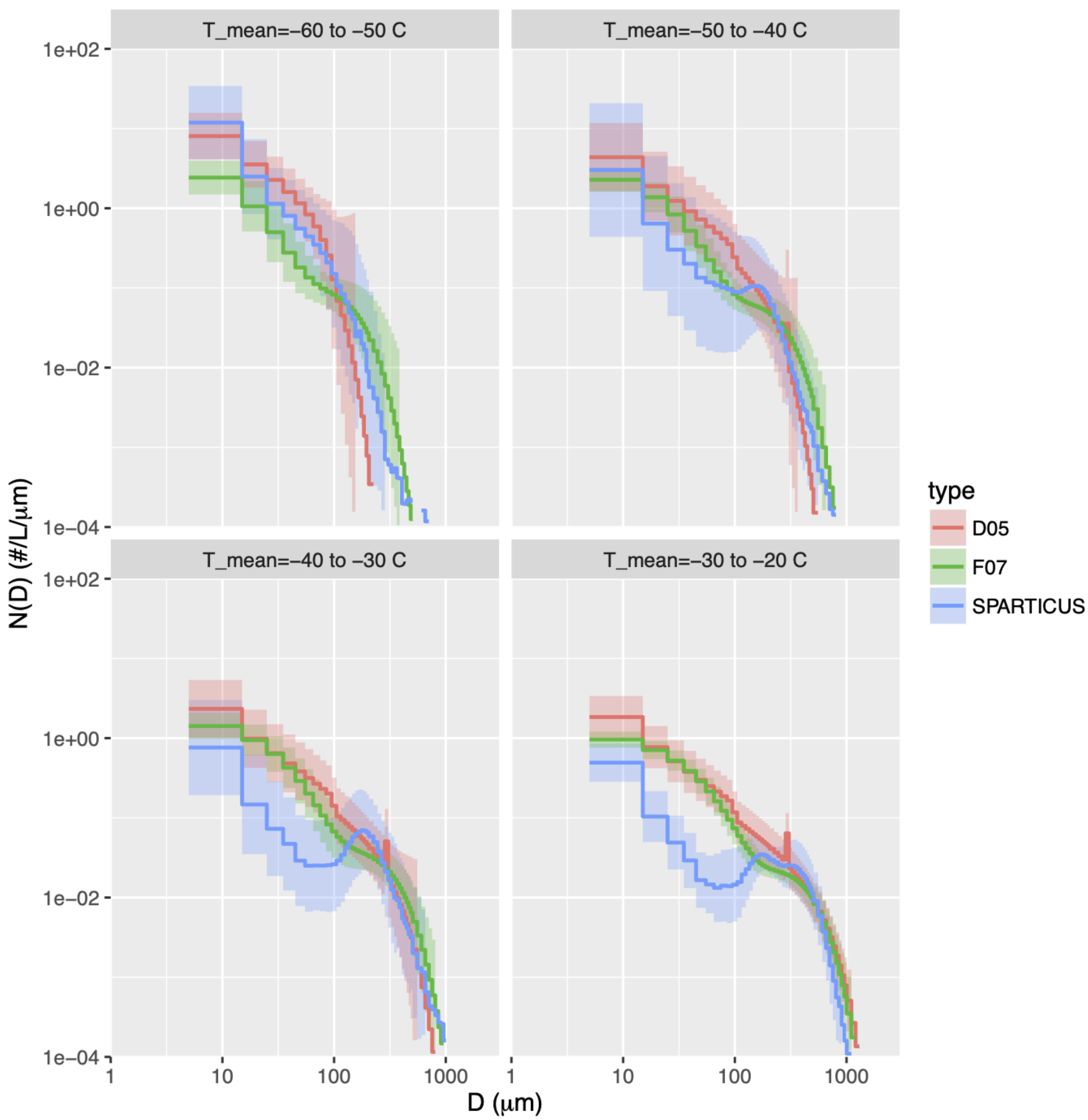

Figure 11: Predictions of D05 and F07 corresponding to observations during the SPARTICUS campaign.

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