Editor Comment and Authors’ Answer.

#1 Editor Comment:

Do you feel that there are no particles smaller than what is measured in the smallest 2DS size bin ? Or if you feel that there are, what is an estimate of the contribution of these missed particles to integrated quantities as N, beta, and CWC ?

Authors’ Answer:

The PSD in this study start with smallest hydrometeors of 50µm in diameter. Despite the fact that particles with smaller diameters down to 1 pixel (10µm) are also recorded with the 2DS, these particles within the size range 10µm to 50µm are not taken into account in the composite PSD spectra. The reason is that we think that there are signifificant uncertainties in retrieving concentrations related to the measurement of smallest particles of only a few pixel in diameter. The uncertainties are particularly due to the shattering impact, depth of field issues (out of focus particles).

The total concentration of ice crystals is of low interest for this study, since we don’t discuss ice nucleation or ice multiplication issues. With respect to this study, particles of 10-50 µm would not impact the σ parameter (and likewise not the subsequent best guess of β depending on σ), because σ calculation starts for Dmax beyond 250µm (figure 5 of the actual version of the paper).

Test: To estimate the contribution of the small particles to CWC, composite PSDs have been build (new PSDs in order to reply to above editor’s comment) for particles larger than 10µm, while in the manuscript the composite PSD start with particles larger than 50µm (old PSD). Subsequently, the new composite PSD are used to calculate new CWC values (hereafter $CWC_{10}(\alpha_\sigma, \beta_\sigma)$), thereby using the previous α_σ and β_σ coefficients of the m(D) relationships, which were retrieved with the old composite PSD. Then the new calculation of $CWC_{10}(\alpha_\sigma, \beta_\sigma)$ is confronted with the old CWC values presented in the manuscript ($CWC(\alpha_\sigma, \beta_\sigma)$ in the manuscript, here denoted $CWC_{50}(\alpha_\sigma, \beta_\sigma)$). The additional mass related to 10-50µm particles is estimated by the following formula :

$$\frac{\Delta CWC}{CWC} = 100 \cdot \frac{CWC_{10}(\alpha_\sigma, \beta_\sigma) - CWC_{50}(\alpha_\sigma, \beta_\sigma)}{CWC_{50}(\alpha_\sigma, \beta_\sigma)}$$

Figure 1 then shows the Probability Distribution Function of $\frac{\Delta CWC}{CWC}$, *where the maximum probability close to 1 is found for 0%<*$\frac{\Delta CWC}{CWC}$*<1%.*

95% of the data reveal $\frac{\Delta CWC}{CWC}$ *uncertainties smaller than 1%*

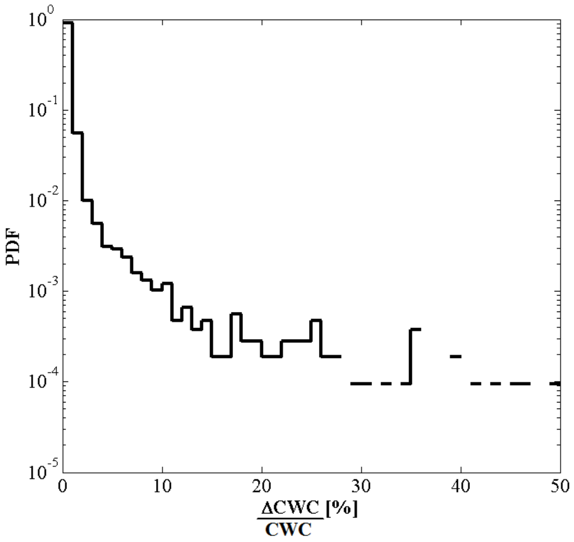

Figure 1: Probability Distribution Function of the added mass, when concentrations of hydrometeors in the size range 10-50µm are added to the PSD composite.

In the revised version of the manuscript the following paragraph is added to comment on the small particle issue not taken into account in the PSD in the manuscript ((section 3.4, page 16 line 8-17 ff.)

"PSD used in this study solely take into account hydrometeors of D_{max} larger than 50µm, even though the 2D-S starts recording particles at 10µm. However, due to significant measurement uncertainties (shattering effects, out of focus particle sizes and related sampling volume) of the concentration of small particles of only a few pixels in size the composite PSD used and presented in this study do not take into account particle diameters below 50µm. The impact on CWC of 10-50µm size particles (not taken into account in this study) has been estimated, comparing CWC values calculated in parallel for PSD starting at 10 µm and starting at 50 µm. These comparisons illustrate that for more than 95% of the overall dataset, the small hydrometeors with diameters below 50µm would have increased CWC values presented in this study by less than 1%."

#2 Editor Comment:

I would like to caution as well that it strikes me as dangerous to apply a Shattering algorithm that assumes a priori what nature should look like. Poisson distributions are unnatural since they presume that the positions of particles are uncorrelated in space. A lack of any correlation violates the second law which forbids any system (e.g. a particle) from being isolated through space and time from its environment.

Authors answer:

First, we would like to notify a mistake in the "answers to the reviewer". We have written in the 5th answer to the first reviewer that the shattering is calculated on a sample of 20000 of particles inter-arrival time, but in fact the number of particles is 2000. The inter-arrival time based shattering analysis is performed continuously to packages of 2000 particles along the flight track and 2D image data are corrected as a function of time, accordingly.

We agree with the fact that particles are not uncorrelated in time and space in their respective environment. This is also explained in Field et al., 2003. The inter-arrival time expresses the distance between 2 hydrometeors in the sampling volume. This distribution here is fitted with a Gaussian Probability Distribution Function (or Poisson distribution). Since the shattering may create a non-natural mode in spacing between two neighboring particles, their inter-arrival time (which translates into particle distance) is described with a Poisson distribution mode which often is rather different from inter-arrival time modal distributions of natural particles. We are aware of the limitations of the method, whenever shattering and natural inter-arrival time modes cannot be clearly dissociated, particularly in cloud regions showing high hydrometeor concentrations.

We propose to add the more detailed reference of Field et al. (2003) discussing the subject of inter-arrival times modeled with Poisson distributions. In addition to this reference, the above yellow underlined sentence is added in the manuscript (page 7, line 9-12).

Field, P. R., R. Wood, P. R. A. Brown, P. H. Kaye, E. Hirst, R. Greenaway, and J. A. Smith, 2003: Ice Particle Interarrival Times Measured with a Fast FSSP. *J. Atmospheric Ocean. Technol.*, **20**, 249–261, doi:10.1175/1520-0426(2003)020<0249:IPITMW>2.0.CO;2.