Replies to the Reviewer 1 comments.
Manuscript: "Assessment of performance of the inter-particle spacing algorithm to identify ice shattering artifacts in cloud particle probes measurements" by A. Korolev and P. Field

The authors appreciate the detailed and thoughtful comments by the reviewer and time spent to perform this work.

Comment: 1) The relevant metric that is calculated and used in the statistical analysis is the interparticle spacing, or distance. I acknowledge that the community that processes these measurements is accustomed to referring to the "interarrival time", since that is the parameter measured in the instrument; however, in order to underscore that it is the physical spacing of the crystals that is important here, I think that the title of the paper should be changed to "Assessment of performance of the inter-particle spacing algorithm to identify ice shattering artifacts in cloud particle probes measurements".
Reply: The title of the manuscript has been modified following the reviewer's comment.

Comment: 2) I think the authors should actually state how many particles should be sampled in order to generate the inter-spacing distributions. This is a non-trivial question since it depends on the width of the spacing intervals and it will also determine how well separated the two modes are, when there is a shattering mode in addition to the normal mode.
Reply: A brief discussion of the number of counts required for statistical significant description of $\varphi(\Delta x)$ was added at the end of section 4.1

Comment: 3) Related to recommendation (2), the authors have presented three, very distinct cases that illustrate the good (no shattering), the bad (shattering indistinguishable from good particles) and the ugly (two modes with some separation). The reader is left with no quantitative method to assess the how many babies are being thrown out with the bathwater. Put in a different way, are there cases where the inter-spacing method should NOT be applied, or should it always be applied but accompanied by a quantitative estimate of how many good particles have been removed?
Reply: The interarrival time algorithm (ITA) should be always applied. The good particles rejected by the ITA could be reaccepted with the help of special image recognition algorithms. However, we feel that a discussion of those types of algorithms goes beyond the scope of this study. One of the objectives of this work was to demonstrate that blindly applying ITA will not filter out all shattered aggregates. To mitigate against the effects of shattering, ITA should be used together with other means, such as antishattering tips and potentially specially designed algorithms for improving the performance of the ITA.

Additional comments listed in the auxiliary file

Page 10254, lines 20-25: "In cases when only one mode was present, τ^* was forced to be equal to minimum interarrival time found in this averaging interval. "
Comment: Is there a way to determine the conditions under which only a single mode is found? A single mode can mean that there is no shattering or it could mean the concentrations are so high that the interarrival times between shattered particles are indistinguishable from real particles.
Reply: This question can be reformulated in the following way: Is it possible to identify cases when the concentration of natural particles is comparable to the concentration of particles in the shattered

clusters? In other words when the spatial separation between intact (natural) particles Δx_i becomes comparable with the spatial separation between shattered fragments Δx_s.

We would need to produce a climatology of environmental and microphysical conditions as function of the degree of bimodality and determine whether the conditions for monomodality are constrained or not. This has been done to a certain extent in Field et al. 2006 where the variable describing the relative weighting between the two modes is plotted as a function of the characteristic (or mean) size of the PSD. That plot shows that the short interarrival time mode increases in magnitude as the PSD mean size increases. Presumably when the distribution is broad enough this parameter will approach 1.0 and the interarrival time distribution will again be monomodal.

Page 10254, lines 10-15: "This gives another reason to recalculate τ^* at each averaging time interval."
Comment: But the averaging interval can't be too short or the statistics are bad. I assume further down that this is addressed.
Reply: The statistical significance is discussed in section 4.1

Page 10255, lines 1-5: "Any shattered particles are deflected into the sample area of the probe after the impact with the inlet."
Comment: I don't think that you really mean this. Not all shattered particles end up in the sample area.
Reply: This statement was reworded: "Shattered particles detected by the probe were deflected into the sample area after the impact with the inlet."

Page 10255, lines 1-5: "Therefore, the shattered particles have external origin, are intermittent and their distribution can be considered as independent, but still Poissonian, with respect to the intact particles."
Comment: Isn't it a fairly large assumption to say that the shattered particles have a Poissonian distribution? Given that the particles are being produced in an unnatural event, it would indicate that they likely are not distributed uniformly and randomly. How does this impact the analysis?
Reply: "Poissonian" was removed from this statement. However, inspection of the short interarrival time mode does indicate that these particles also appear to be characterized quite well with a Poisson distribution (e.g. Field et al. 2003,2006).

Page 10257, lines 10-15: "Such situation may occur, when most of the shattered fragments travel outside of the sample volume, but a single fragment passes through the sample volume."
Comment: This contradicts the next to the last sentence before 3.1.
Reply: The aforementioned text in section 3.1 (page 10256) is referred to two natural (intact) particles arriving through the sample volume within the time interval Δt. The text on page 10257 describes shattered artifacts. So, the authors do not see any contradictions.

Text on page 10260, lines 10-15: "For most clouds sampled during the AIIE project such averaging provided statistically significant particle numbers to estimate the function $\varphi(\Delta x)$ and cut-off-distance χ^*."
Comment: What is that number?
Reply: For this study the number of bins in $\varphi(\Delta x)$ was selected to be 25. This yields a reasonable compromise between the statistical significance of number of counts in each bin and the accuracy of

finding χ^*. Usually for a typical shape of $\varphi(\Delta x)$ a number of particle counts over 100 yielded an acceptable estimate of χ^*.

Text on page 10261, lines 5-10: "Whereas, the uncorrected concentration measured by the standard 2DC varied from 300 to 1600 L−1. "
Comment: Shouldn't you be comparing with the ITA corrected standard probe here?
Reply: A new sentence addressing the reviewer's comment is added: "After applying corrections to the standard 2DC data the concentration varied in the range 150l^{-1} to 700l^{-1}."

Page 10261, lines 15-20: "It is possible to attempt to correct for the removal of intact particles by using Poisson statistics to estimate the fraction of intact particles rejected and then scale the 20 remaining intact size distribution (e.g. Field et al., 2006)."
Comment (Page 10261): This seems out of place and should be moved to the section where you discuss ways to compensate for Type II errors, i.e. incorrectly removed good particles.
Reply: This paragraph was moved to Section 3.2 as per reviewer's comment

Page 10262, lines 1-5: The number of rejected images for the standard probe (Fig. 5a) appears to be higher than that for the modified probe (Fig. 5b).
Comment: "Appears" seems very subjective. Isn't this quantifiable?
Reply: The difference is quantified as suggested by the reviewer's comment.

Page 10262, lines 5-10: Shattered artifacts usually appear and elongated along the flight direction images due to the slower speed that they enter the sample volume.
Comment: This would be hard to distinguish in an ice cloud. We know this happens in all water clouds.
Reply: Out-of-focus compact ice particles appear as circular donut-looking images. They look very similar to out-of-focus droplets.

Page 10262, lines 5-10: Figure 6 shows the distributions of particle counts, concentration and mass calculated for all images before corrections, after corrections.
Comment: (*Page 10262*): How is size defined here?
Reply: The following sentence was added to address the reviewer's comment: "These distributions were calculated for the image sizes measured along the photodiode array direction (i.e. perpendicular to the flight direction)".

Page 10263, lines 20-25: "Integration of the mass distributions for standard and modified probes shows that IWC corrected standard and modified OAP-2DCs for this particular case agree to within approximately 20%, and the mean IWC values averaged over entire time interval agree within 4%."
Comment: Well within the expected uncertainty due to assumption about density and size.
Reply: This is a systematic bias. The relevant text was modified to clarify the statement about the difference in IWC more clear: "Integration of the mass distributions for standard and modified probes shows that IWC corrected standard is systematically lower than that for the modified OAP-2DCs. For

this particular case IWC corrected standard is approximately 20% lower , and the mean IWC values averaged over entire time interval is approximately 4% lower than the modified OAP-2DC."

Page 10263, lines 20-25: "The ITA corrected concentration measured by the modified OAP- 2DC varied from 0.5 to 5 L^{-1}, whereas the uncorrected concentration measured by the standard probe varied from 100 to 300 L^{-1}."
Comment: Again, why are you not also comparing corrected to corrected?
Reply: A new sentence was added to address the reviewer's comment: "After applying corrections to the standard 2DC data its concentration varied in the range 1l^{-1} to 10l^{-1}."

Page 10263, lines 20-25: "In contrast, for the modified probe the distribution $\varphi(\Delta x)$ the number of counts in the short distance mode is smaller than for the long distance mode."
Comment: What does it mean that the modes of the inter-particle distances for the shattered particles are different? Does this say something about how particles shatter off of the modified probe compared to the standard probe?
Reply: This is typical difference between $\varphi(\Delta x)$ calculated for standard and modified 2DCs observed during the AIIE project. Basically it says that the modified probe with antishattering tips shatters less than the standard one.

Page 10264, lines 15-20: "The results of segregation of intact particles and shattered artifacts for standard and 15 modified OAP-2DC performed by the ITA are shown in Fig. 8. The measurements made with the standard probe are dominated by artifacts with very few accepted images (Fig. 8a). "
Comment: How do the shattered particle impact the instrument dead time? Shouldn't that also be mentioned, if not taken into account?
Reply: OAP-2DC was designed to have zero dead time. The same refers to other 2D probes (e.g. CIP, PIP, 2D-S, HVPS). The exception is overload periods. The overload time is different from the commonly accepted definition of the dead time. The dead time follows after each particle measuring event and it does not depend on particle concentration, whereas the overload time depends on particle concentration and it usually disables measurements for a much longer period than the dead time. During the AIIE project the measured particle concentrations were relatively low, so the overload time is not expected to have any significant effect. In case of overloading, the last image before overloading and the first image followed the overloading period may not be identified as a shattering event because of losing information about their neighboring particles.

Page 10266, lines 20-25: "Figure 13 shows distributions of the number of particles Ns within each shattering event (a1–a3), distributions of the length of spatial clusters along the flight direction 25 Ls (b1–b3),…"
Comment: Can you clarify this? Is this adding up all the IAT and multiplying by the airspeed. Wouldn't this contribute to overload and also couldn't this be used to predict the probability of one or more intact particles within this distance? I think I understand these last three statistics but just a little more explanation would be helpful.
Reply: To begin a shattered cluster was identified as a group of images with $\Delta x_i \le \chi^*$. The first image in the group and the first image following this group have $\Delta x_i > \chi^*$. The length of the cluster is determined as $L = \sum_i \Delta x_i$, where *i* is the particle count in the cluster. As seen from the statistics in

Fig.13a1,a2 the number of particles in the shattered clusters is usually less than 40. Taking into account that shattered fragments are usually small (D~100-200um), the shattered fragments from one shattered event fit one 2D buffer (32 X 1024). This reduces the probability of overloading. Triggering probes overloading requires sustained high concentration. This is different from the shattering events, which have high local concentration, and which after averaging becomes low. So, the authors argue that overloading for the cases considered in this study, does not have any significant effect on the results.

Page 10268, lines 10-15: "Secondly, the standard probe χ^*_{st} *has a mode at approximately 10 cm, whereas the modified probe* χ^*_{mdf} *has a mode at approximately 2 cm. And thirdly, for nearly all cases* $\chi^*_{st} > \chi^*_{mdf}$ *."*

Comment: This factor of 10 is significant but it seems to go the wrong direction. If the standard tips produce more shattering and hence higher concentrations of shattered particles, then I would think they would be closer together. I think what is missing here is that the modified probe also has the truncated sample area and that restricts a lot of the particles that are seen by the standard probe. If these two probes do not have the same sample areas, this needs to be explained.

Reply: Analysis of high speed videos of shattering and bouncing from a hemispherical surface showed that during shattering some fragments rebound forward against the airflow (up to 1 cm at P=1000mb and TAS=90m/s), whereas other fragments rebound from the surface at a relatively small angles with respect to the airflow. Such a broad distribution of initial velocities and directions of rebound particles results in enhancing of the spatial dimensions of shattered clusters along the air flow direction. In contrast to the hemispherical tip, a spear shape tip does not rebound particles in forward directions. The shattering is mainly related to impact with the side walls of the arms at small AoA. After impact with the wall at small angles the shattered fragments are closer grouped to each other and we anticipate that those fragments will form smaller clusters. This was confirmed by the results presented in Fig.13.a1,2 &b1,2.

Page 10268, lines 10-15: "However, for the modified probe the correlation coefficient between Nsmax and Dmax is low (0.57) and the Nsmax(Dmax) saturates at Nsmax ~ 15 when Dmax > 5mm (Fig. 15b)."

Comment: 0.57 isn't that low, particularly for the number of events it is still probably significant at the P<.001 level. You should compare the linear functions for each probe.

Reply: The point of this statement is that for the modified probe the number of fragments per shattering event saturates at ~15. At the moment the authors do not see much use for the linear parameterization for the modified tips $N_{smax}(D_{max})$. Apriori it won't work for large D_{max}. For that case a more sophisticated parameterization would need to be used.

Page 10269, lines 1-5: "A relatively high correlation coefficient between Lsmax and Dmax (0.78) for the standard probe allows linear parameterization of Lsmax(Dmax) (Fig. 16a)."

Comment: Why parameterize?

Reply: This parameterization can be used for numerical simulation of shattering, which eventually may help retrieval of historical data. A relevant statement was added in the text.