Response to Darrell Baumgardner

This study is a logical and complementary follow-up of the Delanoë et al. (2005,2014) evaluations that provided parameterizations of cirrus size distributions based on a large set of measurements taken in both mid-latitude and tropical environments. The author has provided a detailed analysis using more recent measurements with a more modern imaging probe to address an important question: "Given what we now know about the impact of crystal shattering on measurements by cloud particle spectrometers, can historical data sets be trusted"? I think that this study has answered that question, at least with respect to cirrus clouds. In addition, even though the instrument that is used in this study has a faster response time than the earlier 2D-C and 2D-P, and marginally larger sample volume, the results of the current study would suggest that such instrument improvements really have minor impact on the overall statistical robustness of the previous measurements and may also only be marginally more accurate, especially given the many other uncertainties that the new instrument has not overcome. In particular, there remain major uncertainties due to unknown ice density and shape n the third dimension that lead to large error bars in derived bulk parameters. It is only at the very smallest sizes where there is a clear difference between current and previous measurements; however, even when there are several orders of magnitude difference in concentration at these sizes, the propagated error in effective radius, IWC and reflectivity is surprisingly small. What I think would be a useful, and perhaps even necessary, addition to this paper would be to include in Figs. 7&8 the relative errors and standard deviations that are reported in Delanoë et al. (2005,2014) where they compare their data sets against the parameterization. That would then put into context the current comparison with the parameterizations with the original, hence bringing closure. The other very important source of uncertainty that the author side steps is that of oversizing of out-of-focus ice crystals (Korolev, 2007). Although a correction for this issue has not yet been provided, such as has been done for water droplets, measurements in cirrus clearly show crystal images that are out of focus and that should be sizecorrected. These might even be the source of the "bump" in the size distributions, i.e. a certain fraction of the particles in that size interval most certainly are smaller crystals out of focus. This bump is also seen in the Delanoë et al. (2005,2014) studies; however, whereas the bump occurs in the current study at a Deq/DM <1, in Delanoë et al. (2005,2014) the bump is right at 1. How does the author explain this? Lastly, the author refers to three of his papers that have not yet been published. These references should be removed since, as a reviewer, I was unable to access them.

I thank you for your time in providing a thoughtful review. I will attempt to address your remarks (in red) in order.

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I must confess that I entirely misread this comment at first and added error bars to show standard error in the means and standard deviations to those figures. However, now that I have overcome my stupor of thought and understand your comment correctly, I'm not sure that I can read the numbers off those charts accurately enough to replot them.

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I have remarked on the out-of-focus problem in the revamped introduction. However, I have no good explanation for the shifting of the bump. I decided to leave that unaddressed rather than risk proffering a bad explanation. The additional text in the introduction follows.

While it is quite possible for relatively high numbers of small ice crystals to occur naturally (see, e.g., Zhao et al., 2011; and Heymsfield et al., 2017), it is also possible for small ice particle concentrations to be significantly inflated by several measurement artifacts. The various particle size distribution (PSD) probes (also known as single particle detectors) in use employ a handful of different measurement techniques to detect and size particles across a variety of particle size ranges. The units of a PSD are number of particles per unit volume per unit size. Thus, after a PSD probe counts the particles that pass through its sample area, each particle is assigned a size as well as an estimate of the sample volume from which it was drawn (Brenguier et al., 2013). Uncertainty in any of these PSD components results in uncertain PSD estimates.

Leaving aside technologies still under development and test, such as the holographic detector of clouds (HOLODEC; Fugal and Shaw, 2009), PSD probes fall into three basic categories: impactor probes, light scattering probes, and imaging probes. (More thorough discussions on this topic, along with comprehensive bibliographies, may be found in Brenguier et al., 2013, and in Baumgardner et al., 2017.) The earliest cloud and precipitation particle probes were of the impactor type (Brenguier et al., 2013). Modern examples include the Video Ice Particle Sampler (VIPS) (Heymsfield and McFarquhar, 1996), designed to detect particles in the range 5-200 μm. The basic operating principle is thus: cloud and precipitation particles impact upon a substrate, leaving an imprint (or leaving the particle itself) to be replicated (in the case of the VIPS, by digital imaging) and analyzed. This type of probe is particularly useful for imaging the smallest ice crystals (Baumgardner et al., 2011; Brenguier et al., 2013).

Light scattering probes also are designed for detecting small, spherical and quasi-spherical particles (a typical measurement range would be 1-50 μm; see Baumgardner et al., 2017). These work by measuring, at various angles, the scatter of the probe's laser due to the presence of a particle within the probe's sample area. Assuming that detected particles are spherical and assuming their index of refraction, Mie theory is then inverted to estimate particle size. Two prominent examples of this type of probe are the Forward Scattering Spectrometer Probe (FSSP; Knollenberg, 1976, 1981) and the Cloud Droplet Probe (CDP; Lance et al., 2010).

Imaging probes, also known as optical array probes (OAPs), use arrays of photodetectors to make two-dimensional images of particles that pass through their sample areas. Unlike the light scattering probes, OAPs make no assumptions regarding particle shape or composition (Baumgardner et al., 2017), and they have broader measurement ranges aimed both at cloud and precipitation particles. Two prominent examples are the Two-Dimensional Stereo (2D-S; Lawson et al., 2006) probe, whose measurement range is 10-1280 μm, and the Two-Dimensional Cloud (2DC; Knollenburg, 1976) probe, whose measurement range is 25-800 μm. OAPs designed for precipitation particle imaging include the Precipitation Imaging Probe (PIP; Baumgardner et al., 2001) and the High Volume Precipitation Spectrometer (HVPS; Lawson et al., 1998), which measure particles ranging from ~100 μm up to several millimeters.

Because an estimate of the sample volume from which a particle is drawn is a function of the particle's size and assumes that the particle is spherical (Brenguier et al., 2013), all PSD probes suffer from sample volume uncertainty. Estimated sample volumes from OAPs perforce suffer from the problem of sizing aspherical particles from 2D images (see Fig 5-40, Brenguier et al., 2013). Nonetheless, impactor and light scattering probes both suffer from much smaller sample volumes than do OAPs (Brenguier et al., 2013; Baumgardner et al., 2017; Heymsfield et al., 2017). Scattering probes, for example, need up to several times the sampling distance in cloud as OAPs to produce a statistically significant PSD estimate (see Fig. 5-3, Brenguier et al, 2013).

The obvious difficulty in sizing small ice crystals with light scattering probes is the application of Mie theory to nonspherical ice crystals. Probes such as the FSSP and CDP are therefore prone to undersizing ice crystals (Baumgardner et al,. 2011; Brenguier et al., 2013; Baumgardner et al., 2017).

Imaging particles using an OAP requires no assumptions regarding particle shape or composition, but sizing algorithms based on two-dimensional images are highly sensitive to particle orientation (Brenguier et al., 2013). Other sizing uncertainties stem from imperfect thresholds for significant occultation of photodiodes, the lack of an effective algorithm for bringing out-of-focus ice particles into focus, and the use of statistical reconstructions of partially imaged ice crystals that graze a probe's sample area (Brenguier et al., 2013; Baumgardner et al., 2017).

Ideally, PSDs estimated using different probes would be stitched together in order to provide a complete picture of the ice particle population, from micron-sized particles through snowflakes (Brenguier et al., 2013). However, while data from VIPS, fast FSSP, and Small Ice Detector-3 (SID-3; Ulanowski et al., 2014) probes are available to complement the OAP data used in this study, none of them are used on account of sizing uncertainties stemming from their small sample volumes and from spherical particle assumptions. The two publications wherewith comparison is made in this paper also restricted their datasets to OAPs.

Lastly, the author refers to three of his papers that have not yet been published. These references should be removed since, as a reviewer, I was unable to access them.

I removed them and replaced them with a simple reference to my dissertation.