Response to Anonymous Referee #3

I thank you for your thoughtful and helpful review. I will address your remarks (which are in red) in order.

General Comments:
Overall the paper is suitable for publication with minor changes. The microphysical probe comparisons presented are similar to past work, but the analyses are done in a slightly different and more systematic way. My main comment is that the paper would benefit from a more thorough introductory section, with historical insight into the probes discussed and the characteristics that make them different. This should include not only the ice shattering issue, but a brief summary of other technical differences.

Thank you! The following paragraphs have been added to the introduction.

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.

Minor Comments:
Lines 21-22: Without reading the paper, this sentence in the Abstract is confusing and does not logically follow. Please clarify or simplify abstract.

Lines 21-22 have been changed to "This is done so that measurements of the same cloud volumes from parameterized versions of the 2DC and 2D-S can be compared with one another."

Line 44: Add Garrett et al.: Small, highly reflective ice crystals in low-latitude cirrus, GRL 2003.

Garrett et al. (2003) has been referenced and remarked on as follows. “Garrett et al. (2003) estimated that small ice crystals, with equivalent radii less than 30 microns, contributed in excess of 90% of total shortwave extinction during the NASA Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE).”

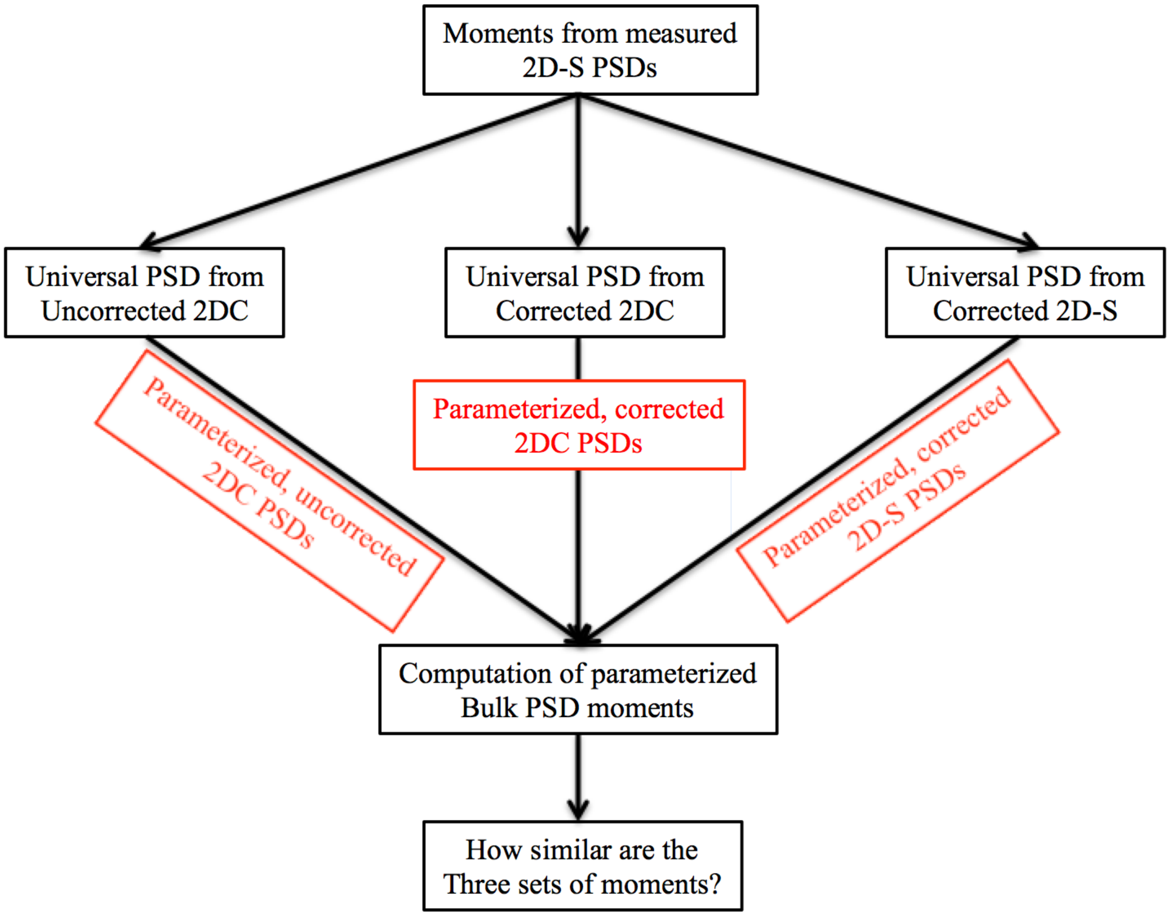
Line 72: “which results jibes” is awkward–please rephrase.

Line 72 rephrased to “in agreement with Lawson (2011)”.

Line 104-108: Perhaps a simple diagram would be helpful here to eludicate the method and steps used?

The text has been changed to the following, and a new Figure 1 has been inserted as shown below.

The comparison strategy, in short is as follows. The D05/D14 parameterizations consist of normalized, “universal” cirrus PSDs to which PSD moments are applied as inputs. The results of so doing are sets of parameterized 2DC PSDs—both shatter-corrected and uncorrected. To make the comparison, the same moments from 2D-S-measured PSDs are applied to the D05/D14 parameterizations in order to simulate what the shatter- and non-shatter-corrected 2DCs would have measured had they flown with the 2D-S. Then, a “universal” PSD derived from the 2D-S itself is computed in order to make a fair comparison. The moments from the 2D-S-measured PSDs are applied to the 2D-S “universal” PSD and it is then seen whether the older datasets differ statistically from the newer in their derived cirrus bulk properties. This procedure is illustrated in Fig. 1.



Line 164: Why not use the actual size distributions?

The idea had been to see how the ~2nd moment of the fit PSD changed with varying degrees of truncation.

Line 166: Please quantify "nominally matches", particularly since the data aren't shown.

The word "nominally" has been replace with "qualitatively".

Line 339: Is it really the "true" value?

No, I suppose not really the true values. The wording is changed to indicate that "true" means derived directly from the measurements.

Line 369: Missing subscript in NT. Corrected.

Line 376: Delete this sentence as it's not really necessary?

Redundant sentence deleted.

Lines 387: A long and wordy sentence. Suggest breaking it up for clarity.

Long sentence split apart.

Line 391: If your other work giving better alternatives to the Gamma distribution is now published, please refer to it here.

Unfortunately, this is still in the submission stage and not yet published. Therefore, a reference to my dissertation is inserted here.

Line 396-398: Redundant with statements in prior paragraph; remove.

Redundant statements have been deleted.

Acknowledgements: No acknowledgements to those scientists who provided the field data?

Thank you for pointing out this oversight. It has been corrected by inclusion of the following text.

The author gratefully acknowledges the SPartICus, MACPEx, and TC^4 science teams for the collection of data used in this study. TC^4 and MACPEx data were obtained from the NASA ESPO archive, which may be accessed online at https://espoarchive.nasa.gov/archive/browse/. The SPartICus data were obtained from DOE ARM archive and may be accessed online at http://www.archive.arm.gov/discovery/#v/results/s/fiop::aaf2009Sparticus. In particular, the author acknowledges Dr. Paul Lawson and SPEC, Inc. for all 2D-S data collected in the field, to Dr. Andrew Heymsfield for the PIP data used from TC^4, and to Dr. Linnea Avallone for CLH data used from MACPEx.