Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2017-48-AC2, 2017

Atmospheric Measurement Techniques
Discussions
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# *Interactive comment on* "A Statistical Comparison of Cirrus Particle Size Distributions Measured Using the 2D Stereo Probe During the TC$^4$, SPartICus, and MACPEx Flight Campaigns with Historical Cirrus Datasets" *by* M. Christian Schwartz

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Received and published: 29 June 2017

My response is included here in plain text. It is also attached as a pdf document, along with a marked up draft, for easier consideration.

xReview: Minor revisions I agree with the previous reviewers in general. This is a pretty clean cut topic for this paper which adds statistical consistency to a long standing problem in ice measurement. Further, looking at the references, this is clearly one paper in a long series originating with the author's days at Utah and beyond. While the topic is clean cut, the paper is nevertheless difficult to follow at times, and the author could do much to improve readability, and hopefully in time, his h-index. Indeed, it is overly terse at times. One previous reviewer noted that the introduction could use a bit of background. I certainly concur with that. Even though this has been reviewed in several other papers, it is good for a paper to be complete. Not only to be tied in more completely with the previous literature base, but also with the author's current lien of thought. I would also say the final results and discussion could also be worked on. For example, the author states to the effect that old data is still usable, provided previously described caveats are respected. Actually going through the paper several times, it was not clear what all of these are. Even though the smaller ice sizes can be mitigated for the bulk moments, what does this mean for say a forward optical model? Perhaps a separate conclusions, or discussion and conclusions as distinct from results, be provided that provides a bulletined list of what are the key take away points-sort of a recipe card. I would also suggest that figure captions be more verbose spelling out variables when convenient. Similarly, laying out in a bulletining form or table the different instruments and processing would help. Other than these comments, my opinion matches those of the previous reviews: the paper oscillates between very formal writing, and conversational vernacular(e.g., jibes, right off the bat, etc); a diagram laying out the steps; . One point that requires emphasis as pointed out by reviewer 3 is the lack of data provider documentation in the acknowledgements. Indeed, by downloading data from the NASA servers not only did the author agree to acknowledge where the data came from, but actually offer coauthor ship to the data providers. Often for this sort of thing they will simply ask for acknowledgement, but the offer does need to be made. Be well.

Response to Referee J. Reid

I am grateful for your thoughtful review. I will attempt to address your remarks (in red) in order.

While the topic is clean cut, the paper is nevertheless difficult to follow at times, and the author could do much to improve readability. . . Indeed, it is overly terse at times.

This point is well taken. I made a number of changes to make notation coherent and consistent both within the text and within the figures, to make the tone more uniform, and to give better explanations. Rather than document all of those changes here, I'll simply put the marked up paper on with this reply.

One previous reviewer noted that the introduction could use a bit of background. I certainly concur with that. Even though this has been reviewed in several other papers, it is good for a paper to be complete. Not only to be tied in more completely with the previous literature base, but also with the author's current lien of thought.

I fleshed out the literature review quite a bit and tried to provide more context. In so doing, hopefully my own current lien of thought is better fleshed out. The following paragraphs were 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 $\mu$m. 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 $\mu$m; 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 $\mu$m, and the Two-Dimensional Cloud (2DC; Knollenburg, 1976) probe, whose measurement range is 25-800 $\mu$m. 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 $\sim$100 $\mu$m 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.

. . . a diagram laying out the steps. . .

I put in improved text (below) about the steps and an accompanying figure (see the marked up draft).

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 PSDsâĂŤboth 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.

I would also say the final results and discussion could also be worked on. For example, the author states to the effect that old data is still usable, provided previously described caveats are respected. Actually going through the paper several times, it was not clear what all of these are. Even though the smaller ice sizes can be mitigated for the bulk moments, what does this mean for say a forward optical model? Perhaps a separate conclusions, or discussion and conclusions as distinct from results, be provided that provides a bulletined list of what are the key take away points-sort of a recipe card.

I’ve cleaned up the last section as well, summarizing the final points in a bulletined list as suggested. I’ll refer you to the attached revision for a discussion on psd shape and optical models.

One point that requires emphasis as pointed out by reviewer 3 is the lack of data provider documentation in the acknowledgements. Indeed, by downloading data from the NASA servers not only did the author agree to acknowledge where the data came from, but actually offer coauthor ship to the data providers. Often for this sort of thing they will simply ask for acknowledgement, but the offer does need to be made.

You are quite correct about the acknowledgements. Co-authorship was offered to the data providers, which was declined. Thank you for pointing out my oversight in not including the data sources in the acknowledgements. References to the data sources are also given.

Please also note the supplement to this comment:
https://www.atmos-meas-tech-discuss.net/amt-2017-48/amt-2017-48-AC2-supplement.pdf

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