Response to Anonymous Referee #1

General Comments:
This study presents a novel approach in estimating ice particle properties from CPI data, and is worthy of publication in ACP after suitable revisions. It is well organized and written, with figures of good quality.

We appreciate the positive assessment and respond to comments below.

A good effort is made to compare the new ice properties with selected properties published 20 or 14 years ago, but no analytical expressions are given for the new ice properties. A table should be added to the paper, similar to Table 1, but showing the mass- and area-dimensional coefficients for the new m-D and A-D relationships (based on CPI data); like results for the new bullet rosettes, bucky-balls, and the polycrystal model. That will allow the community to compare these new results in future studies of ice properties, and promote progress in this field.

Ice properties are supplied as supplementary material (as was already noted in the appendix). Clarification now added more prominently to close of introduction: “Because the derivations here are based on crystal component geometries and do not yield continuous analytic relationships, equations are provided in Appendix A and derived ice properties are provided for download as the Supplement.”

It would also be a service to the community if the recent work of Erfani and Mitchell (ACPD, 2015) were compared against the m-D and A-D results from this study. The Erfani-Mitchell expressions are not for a specific ice crystal habit, but were derived from a mixture of habits (similar to the Cotton et al. m-D results featured in this paper).

We have added Erfani and Mitchell (now ACP, 2016) fits to Figs. 5, 7, 13 and 14, and associated discussion to Sections 1, 4.1, 4.4, 5.1 and 6.

In Lawson et al. (2006, JAS), Sec. 3d, A-D power laws are given for irregulars, bullet rosettes, budding rosettes, and rimed rosettes with slide plane wafers between the branches (similar to the polycrystal model developed in this study). It would be instructive to compare these new results against those A-D expressions since they were also based on CPI data.

We have added the Lawson et al. (2006) m-A relations for budding rosettes and rosettes to Figs. 5 and 7 and associated discussion to Sections 4.1 and 5.1. We have not addressed mixed-phase clouds or riming whatsoever in this study, so we omit rimed rosettes. Because their data set obviously represents a much wider range of particle types, including mixed-phase conditions, we also omit irregulars to guarantee applicability here.

This study apparently applies a single ice crystal model over the entire ice particle size distribution (PSD). However, this assumption is questionable based on CPI observations; see Lawson et al., 2006, JAS, Fig. 5. There you can see that, with increasing size and mass-weighted percent, the smallest crystals tend to be quasi-spherical, then small irregulars, then small irregulars and budding rosettes, then larger rosettes for a single cirrus flight. While this trend may change somewhat from flight-to-flight, it is illustrative of what is typically encountered for cirrus cloud measurements. Similar results are shown in Fig. 13 of Baker and Lawson (2006, JAS). The paper should include some discussion of this, and how such size-dependent habit variation may impact the model results.

We have expanded the discussion intended to address uncertainty in small particle shape in the conclusions (now an independent fifth paragraph of section 6), giving greater emphasis to the concept of habit evolution from quasi-spherical shapes.

Lastly, due to the large number of symbols used in this paper, an appendix for symbol definition is recommended.

We omitted this because various symbols used only in the appendix would require long definitions, and listing the appendix symbols together with those commonly used in the main text would be unnecessarily long for most readers.

Major Comments:
1. Page 8, lines 20-21: Why is arm width W twice the hexagon side length?

This choice is convenient for equations shown in the appendix.

2. Page 9, lines 5-6: Is there vapor competition between homo- and heterogeneous ice nucleation?

Clarification added to model description of homogeneous aerosol freezing: “Heterogeneous freezing is neglected.” And to conclusions: “Unlike the simplified parcel simulations shown here, 3D simulations will consider competition between homogeneous and heterogeneous freezing mechanisms and results can be robustly compared with observed ice size distributions.”

3. Page 9, lines 21-22: Are all ice nuclei composed of $(NH_4)HSO_4$?

All ice crystals are formed from homogeneous aerosol freezing (see response 2).

4. Page 13, lines 14-15: How much difference is there between your Dmax and the Dmax that Mitchell uses? For random orientation, it seems that on average the branches would be oriented at 45 degrees relative to their maximum extension. Taking that maximum length as L = 1.0 (arbitrary units) and true Dmax = 2 L, then the percent error made by Mitchell by underestimating Dmax as 2L cos(45) (randomly

oriented) would be 29%. This seems like too small an error to account for most of the 4-fold difference in mass.

Clarification added in a follow-on sentence: "However, we are unable to quantitatively confirm that [differences in *m* are primarily attributable to differing approaches to defining D_{max}] because randomly oriented maximum dimension cannot be calculated analytically for the idealized geometries derived here nor obtained from CPI images for the natural crystals."

5. Page 17, line 3: Please add temperature information to Fig. 10 so that this sentence makes sense.

Since Fig. 10 is not intended to be statistically representative, we have changed "some rosettes falling from colder temperatures reach a plate growth regime" to "some rosettes exhibit a plate growth regime".

6. Page 19, lines 22-24: No need to wait for future studies; this information already exists (as noted under General Comments) in Lawson et al. (2006, JAS) and Baker and Lawson (2006, JAS).

We added Lawson et al. (2006) relations for budding rosettes and rosettes to Figs. 5 and 7, as discussed above, but omitted Baker and Lawson (2006) owing to their stated conditions, i.e., "The crystal types typical of high-altitude cirrus, that is, bullet rosettes and similar spatial crystals, are not represented in this dataset."

7. Fig. 4. Why not use log-log plots when plotting m-D and A-D since this should be quasi-linear and make the results easier to interpret?

Because of our focus on measurements made over less than one order of magnitude in maximum dimension and our concern with geometric differences, we prefer linear axes when we can use them, as in most panels of Fig. 4. We prefer log axes when emphasizing the small particle size range, where we lack Ice Crystal Ruler measurements, as in Fig. 5.

8. Fig. 15. Is there a super-position of the Mitchell and Heymsfield curves?

Clarification added to caption: "In the absence of specified α_e for some or all crystal sizes, a constant value is taken for Mitchell et al. (1996) and Heymsfield et al. (2002) ice properties (see text)."

Minor Comments:

1. Page 11, line 11: What are "cap vertices"? Please define.

Clarification added: "opposing cap vertices" replaced with "opposing edges of the hexagonal pyramids that cap each branch", and other occurrence of "vertices" replaced with "edges" in the second sentence of Appendix A1.

2. Page 20, line 18: Should < 100 be > 200?

Here < should have been > (correction made), thank you.

3. Page 24, line 11: Does i need defining?

The i was defined in Section 4.1 (bulk density of ice).

4. Page 26, line 13: greater => less? This is a Christiansen band where nr < 1.0 but ni is not > 1.0.

Indeed “greater” should have been “less” and we thank the reviewer for pointing out that this is a Christiansen band. We changed the text to read “At ~2.8 micron, a Christiansen band (Arnott et al. 1995) is present where a combination of strong absorption and refractive indices near or less than unity leads to a decrease in Q_e (cf. Baum et al. 2014).”