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Interactive comment on "Remote sensing of ice crystal asymmetry parameter using multi-directional polarization measurements – Part 2: Application to the Research Scanning Polarimeter" *by* B. van Diedenhoven et al.

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We thank the reviewer for the kind words and very helpful suggestions. Our replies to the issues raised by the reviewer can be found below.

COMMENT 1) Page 32065, line 6: Consider adding "and aspect ratio" after "radius".

REPLY: In our retrieval concept the asymmetry parameter is physically linked to the aspect ratio of a particle (or its components). A leading question is how the asymmetry parameter is linked (if at all) to other cloud properties or atmospheric conditions that

are independently measured. That is why we chose not to add "aspect ratio" in the list.

COMMENT 2) Page 32067, line 7: Normally g is described as a function of aspect ratio and surface roughness, although the exact physical nature of surface roughness may be difficult to characterize and model. My understanding is that surface distortion refers to the tilting of crystal facets, and that both surface distortion and surface roughness tend to produce a featureless phase function. In this work g is a function of aspect ratio and surface distortion. Is surface distortion used here as a proxy for surface roughness? Please discuss.

REPLY: We have expanded the discussion about the distortion parameter and how it relates to large-scale distortion and microscale roughness. The following was added to section 2.1:

"The ice crystal optical properties are calculated using the standard geometric optics code developed by Macke et al. (1996). This ray tracing code takes distortion of ice crystals into account in a statistical manner by perturbing, for each interaction with a ray, the normal of the crystal surface from its nominal orientation by an angle varied randomly with uniform distribution between 0degree and delta X 90 degree, where delta is referred to as the distortion parameter. Thus, this approach represents the stochastic large-scale distortion of a collection of ice crystals. However, Yang et al. (2008) found that this approach is also an efficient, yet accurate treatment of microscale surface roughness. For a large collection of ice crystals microscale surface roughness and large-scale particle distortion both lead to a similar randomization of the angles between crystal facets, which in turn leads to the diminishing of features in the scattering phase matrix. Increasing the number of impurities within ice crystals also has a similar effect (Hess et al., 1998). Thus, we consider the distortion used here a proxy of randomization of the angles between crystal facets possibly caused by any of these effects."

COMMENT 3) Page 32078, lines 1-7: Ice particle size distributions (PSD) tend to broaden (i.e. ice particle sizes increasing) with decreasing height. Ice crystal observational studies like Auer and Veal (1970, JAS) clearly show that aspect ratios depart further from unity (becoming smaller or larger than 1.0) with increasing size. Therefore, based on the postulates of this study, g should increase with decreasing height. But here the CIN measures a weak decrease in g with decreasing height. Could this be due to shattering? Larger ice particles are more prone to shattering, and shattering may result in irregular geometries with aspect ratios closer to unity, producing smaller g values at lower altitudes. These points need to be discussed.

REPLY: As already noted in section 2.4, the potential effect of shattering on asymmetry parameters measured by the CIN is difficult to estimate. An alternative explanation of the vertical variation is that although aspect ratio might increasingly deviate from unity with decreasing height, at the same time the particle distortion/roughness might be expected to increase with decreasing height. This would lead to competing effects of increasing/decreasing asymmetry parameter with height. We have added the following discussion in section 3.2: "As particle size generally increases with decreasing height (Lawson et al., 2010; van Diedenhoven et al., 2012b) and particle aspect ratio is expected to increase somewhat with size (Auer and Veal, 1970; Korolev and Isaac, 2003), asymmetry parameters might be expected to increase with decreasing height rather than decrease as found here. We speculate that the slight increase of asymmetry parameter with decreasing height might result from an increase of particle distortion or surface roughness. "

COMMENT 4) Page 32079, line 15: There needs to be some basis for equating distorted with roughened ice particles, which should be established earlier in the text.

REPLY: Please see our response to comment 2.

COMMENT 5) Page 32082, text above Section 3.4: Baily and Hallett (2009, JAS) show that plates having aspect ratios near unity (e.g. 0.3) only occur at cirrus temperatures when the supersaturation with respect to ice is relatively low. Do these results (median

aspect ratio of 0.33) imply low supersaturations? a. Whether the retrieval method retrieves the mean aspect ratio of ice crystals actually present is not clear, since a mix of habits or shapes is generally present, some planar and some columnar in structure. Is it possible that scattering contributions from both planar and columnar crystals conspire to produce a scattering signature corresponding to an aspect ratio near unity (as found in this study)? If so, would the scattering contributions combine in a linear fashion. that would allow one to deduce the representative ice particle shape, whether it be individual or combined in aggregates?

REPLY: The following explanation has been added to section 2.1:

"The area-weighted mean aspect ratio of the particles (or their components) (cf. Fu, 2007) is retrieved by this method. In the case of mixtures of plates and columns, the technique is expected to yield aspect ratios approximately equal to the area-weighted mean of AR for plates plus 1/AR for columns (or 1/AR for plates plus AR for columns). For example, for a cloud in which plates with AR=0.1 and columns with AR=2 each contribute half of the total cross-sectional area, we expect the retrieved aspect ratio would be either close to (0.1+1/2)/2=0.3 or (1/0.1+2)/2=6. However, this should be verified in future work."

As noted at the end of section 3.5 "Ambient temperatures and ice supersaturation levels are known to influence the aspect ratios of the ice crystals and whether crystals grow as plate- or column-like habits (e.g., Bailey and Hallett, 2009). For most of the cases studied here, plate-like aspect ratios (< 1) and column-like aspect ratios (> 1) are retrieved over the observed storms, consistent with varying mixtures of cloud- top particle shapes, including aggregates with both column and plate elements (Fig. 5), which could be indicative of varying crystal formation and evolution histories."

It is beyond the scope of this paper to try to piece together the evolution of the studied clouds. One obvious difference between the studied clouds that could influence the crystal shapes is that the 11 July case evolved mainly over land, while the others evolved over ocean, as already noted in section 3.5. In the revised version, we added the information that temperatures and supersaturation levels may also influence the ice aspect ratio in addition to whether crystals grow as plate- or column-like habits.

COMMENT 6) Page 32088, line 3: The g parameterization in Mitchell et al. (1996) depends on what shapes are assumed. When polycrystals (i.e. Koch fractals) are assumed, g is independent of crystal size and at visible wavelengths is 0.74. Thus the range of g produced in the cited g parameterizations should be 0.74 to 0.83 (not 0.78 to 0.83 as stated). Moreover, it may be worth mentioning that the main problem facing the atmospheric science community is defensible constraints on the range of g (which would guide us in what g parameterization to use). This study is very helpful in this respect.

REPLY: The sentence now reads "....typical parameterizations of ice crystal asymmetry parameters yield values from 0.78 to 0.83 (e.g. Fu, 1996; Chou et al., 2002; McFarquhar et al., 2002), which is generally larger than retrieved for the case studies in this paper, although some other parameterizations yield lower asymmetry parameters (e.g., Mitchell et al., 1996; Edwards et al., 2007)." The need for stronger observational constraints for the asymmetry parameter was already noted in the introduction of the paper and is retained in the revised version.

COMMENT 7) Figure 2: The magenta dots indicating ground sites are barely visible. Please enlarge them. The dots have been enlarged.

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