**Atmospheric
Measurement
Techniques
Discussions**

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Interactive comment on "Remote sensing of ice crystal asymmetry parameter using multi-directional polarization measurements – Part 1: Methodology and evaluation with simulated measurements" *by* B. van Diedenhoven et al.

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We would like to thank the reviewer for his very helpful and constructive comments. Below the comments are repeated before the responses. The exact changes to the final version will be listed in a separate online comment once the final version is submitted.

COMMENT 1: (Page 4,325 and Fig 1) The authors provide a nice summary of previous measurements of asymmetry parameter. I note the range of values in the quoted liter-

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ature is 0.65 to above 0.95. The corresponding limits of Fig 1 are narrower: the colour scale goes from 0.71 to 0.93, and these edge values are only found in quite extreme roughnesses/aspect ratios. Do the authors have some comment on their LUT being narrower in range than the literature–would extending the roughness or aspect ratio range help, or would that result in unphysical particles? Do you think these extreme values in the literature are a result of instrumental problems, unusual situations, or just different shapes (i.e. not plates/columns)? Is there some other factor which is limiting the range of asymmetry parameter going into your LUT? This would be nice to note in the paper.

REPLY 1: The quoted values (0.65 to above 0.95) are results of modeling, not measurements. The high asymmetry parameters found in the literature are mainly obtained by assumption of extreme aspect ratios such as for thin plates. The low asymmetry parameters in the literature are obtained by either assuming roughness values higher than 0.7 (e.g., Macke et al., 1996) or including air bubbles within the particle (e.g., C.-Labonette et al., 2000). Indeed our LUT could be extended with more extreme aspect ratios and greater roughness parameters. As mentioned in the paper, roughness parameters exceeding 0.7 are not considered because for these values the probability of unphysical scattering events strongly increases, resulting in progressively larger loss of accuracy of the GO calculations. Similarly, accuracy decreases as aspect ratios become increasingly extreme. The accuracy for such particles can be improved by increasing the number of 'photons' in the Monte Carlo computations. The computational effort was the limiting factor in the present calculations, and roughness parameters beyond 0.7 and/or more extreme aspect ratios could be included in the future if deemed necessary. We will add a sentence in the revised paper stating that our LUT could be extended with more extreme aspect ratios and greater roughness parameters.

COMMENT 2: (Page 4,330, lines 7-8) In this notation the DOLP is just Equation 3 (Rp) divided by the total reflectance I, correct? Or am I misunderstanding? I suggest stating this explicitly, for clarity.

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REPLY 2: The definition of DoLP here is P12/P11 where P11 and P12 are the corresponding elements of the scattering phase matrix (see e.g., Macke et al., 1996). Under the assumption of single scattering and by omitting the sign, this definition is equivalent to Rp/I. We will add the definition of DoLP used here for clarity, as suggested.

COMMENT 3: (Page 4,330, Section 3.4, and associated figures) You show quite nicely the uncertainties on your retrieval from simulated data and how these are affected by noise, sampling and so on. You are only using the polarised reflectance. Can you comment on whether or not considering the total reflectance as well would be likely to decrease these uncertainties significantly, or does it not add much extra information? I would imagine the biases might not change much but wonder whether the standard deviation envelopes would get a bit thinner. Alternatively, would much be gained from also considering polarised reflectance at a second channel in the retrieval? What I find particularly interesting from Fig 10 (b) is that it seems that using only 5 or so measurements gives similar uncertainties on asymmetry parameter to using 80 measurements (i.e. there must be some degeneracy in the information content), suggesting to me that to further shrink this envelope, a different type of information is needed: perhaps either total reflectance or a second wavelength. Or perhaps the remaining uncertainty is more linked to the ice crystal shape/size distribution assumptions. Some brief discussion would be welcome.

REPLY 3: Retrieval results do not significantly improve by using Rp/I instead of Rp. For instance using Rp/I for the retrieval on simulated measurements assuming complex habits as presented in Fig. 5, results in a mean bias of 0.006 versus 0.004 when using Rp, while the standard deviation is 0.016 versus 0.018. The use of Rp is preferred because for thick clouds it is independent of cloud optical thickness. Moreover, for thin clouds, Rp/I can be highly sensitive to the total bidirectional reflectance function of the surface, which is not always known well. Furthermore, since scattering in ice clouds is relatively independent of wavelength, addition of another wavelength is not expected to improve the results. We will discuss this in the revised version. As noted by one of

the other reviewers, improving the LUT by a better treatment of particles outside of the Geometric Optics range might help to reduce the uncertainty, and we will also add a discussion about this in the revised version.

COMMENT 4: As a final suggestion: for completeness, I think there are a few more points which could be discussed briefly and perhaps quantified. These simulations were performed for ice clouds above a black surface. What happens if the surface is different, e.g. a land surface or an ice cloud above a water cloud? Can you say anything about vertical inhomogeneity of clouds; I guess the algorithm would retrieve some average asymmetry parameter, weighted towards the ice cloud properties near the top of the cloud? Perhaps these aspects will become more apparent in Part 2 where real measurements are used, but it would be nice to have an idea of what we might expect from the simulations.

REPLY 4: For thin cirrus (about OT<1) the influence of polarized surface reflectance at 864 nm is expected to be significant and should be included in the forward model. Accurate models exist for ocean reflectances (e.g., Chowdhary et al.; Remote Sensing of Environment, 118:284–308, 2012) and land surface reflectances (e.g., Litvinov et al., J. Quant. Spectrosc. Radiat. Transfer, 111:529–539, 2010). Furthermore, for certain observation geometries, ocean sunglint may be significant at greater cloud optical thicknesses, as will be addressed in part 2 of the paper. In the case of optically thin ice clouds overlying liquid clouds, the method is not expected to be applicable to measurements in the solar channels since the strong polarization by the liquid clouds would overwhelm the signal (e.g., van Diedenhoven et al., 2012). However, as briefly mentioned in the paper (page 4340, line 10), "application of the method to polarization measurements in wavelength bands that include strong water vapor absorption, such as the 1.88 μm and 1.39 μm bands in the RSP and APS designs, respectively, allow the retrieval of ice crystal asymmetry parameters of subvisual cirrus, as demonstrated by Ottaviani et al. (2012a)." As we clarify in the revised version, this is because these measurements are virtually unaffected by the underlying surface or lower liquid clouds.

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Also the vertical weighting and possible issues attributable to vertical inhomogeneities are discussed in part 2 and will be addressed in future studies using realistic cloud permitting model simulations. We will add brief discussions about these issues and the references to part 2 and future work in the revised paper.

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