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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Circular depolarization ratios of single water droplets and finite ice circular cylinders: a modeling study" *by* M. Nicolet et al.

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We would like to thank the referee for his comments and suggestions. We corrected all minor and technical issues according to the referees suggestions which are not explicitly mentioned below with a more detailed answer. The corresponding questions and comments from the referee are cited with bold italics. Our detailed answers are:

"The paper will benefit from much more careful subediting. There are numerous stylistic, grammatical and typographical errors. They affect the clarity of the paper. Some are listed below."

We have re-edited the paper for clarity in addition to the comments as the referee suggested.

"The Abstract should mention the somewhat negative conclusion concerning the use of circular polarization included at the end of Discussion."

We have added the following sentence to the abstract:

Instruments exploiting the difference in the P_{44}/P_{11} ratio at a scattering angle around 115° are significantly constrained in distinguishing between water and ice because small droplets with size parameters between 5 and 10 do cause very high circular depolarizations at this angle.

"On page 30127 line 29 why is "Right-handed" circular polarization singled out? For non-chiral particles there should be no (statistical) difference between left and right. The first paragraph in the "Theory" section belongs more properly somewhere in the Introduction."

This is true for particle ensembles and for single particles with small elements Z14 and Z41. Since at this point in the introduction we are discussing circular depolarization in the context of randomly oriented particles, "right-handed" indeed can be omitted. We also have mode the first paragraph here to the introduction as suggested.

"Why does the fact that $\delta_L < \delta_C \leq 2\delta_L$ make the circular depolarization method attractive (page 30131)? Surely the numerical value itself is of little importance; rather, it is the relative strength of the depolarization signal with respect to error sources (multiple or molecular scattering, orientation effects etc.) that determine any advantage.

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The Authors cite Baran et al. 2001 in support of the assertion that circular cylinders are an acceptable approximation for hexagonal ones. However, in the cited study randomly oriented crystals were considered, unlike in the present one. Lack of axial symmetry adds a further degree of variability to depolarization, so we can expect a greater spread of values for hexagonal cylinders than for circular ones. Moreover, Baran et al. 2001 were concerned with linear depolarization, not circular. So it would be more appropriate to say that the Authors assume acceptability of this approximation for circular polarization. Another approach to this justification is to say that the approximation is valid as far as the relative comparison of circular and linear depolarization is concerned (i.e. the results are likely to be valid when considered together with the earlier study of linear depolarization). These caveats must be clearly spelled out here and/or in the Discussion."

According to Mishchenko and Hovenier (1995), the unequation for LIDAR depolarization measurements is $2 * \delta_L < \delta_C < \infty$ (we misquoted this in the manuscript). Therefore, the use of circular depolarization is likely be more sensitive at least for LIDAR backscattering on particle ensembles (by several factors depending on the depolarization property of the particles). Thus, the numerical value is by far not of little importance. We use this fact as a logical motivation for our analysis. However, the referee is right in saying that the more complex set up for circular depolarization measurement introduces further uncertainties. We have changed the relevant sentence into:

According to Mishchenko (1995), the circular depolarization ratio for randomly oriented particles is always greater than or equal to twice the linear depolarization ratio: $2 * \delta_L < \delta_C < \infty$ This fact makes the circular depolarization method attractive for LIDAR applications.

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We also changed the beginning of the second paragraph of section 3 (p. 30131) as follows:

Ice crystals are assumed to be circular cylinders, which is an acceptable approximation at least for randomly oriented hexagonal columns (Baran et al., 2001). This approximation is acceptable also for the present single particle study, since the intention of this paper is to asses the quality of the circular depolarization measurement method for discriminating water droplets from ice crystals relative to to the linear depolarization method which was investigated in the previous work by Nicolet et al. (2007).

"The second paragraph on page 30133 needs rewriting to improve clarity, it requires too much effort to decode the meaning. For example, what does "The occurrence also indicates a decreasing trend with rising..." mean? What does "more regular and stable" mean, etc?

We have re-written this paragraph which now reads as follows:

Background measurements with the SIMONE detector show depolarization ratios around 0.04 (Wagner et al., 2009, Schnaiter et al., 2012). We therefore have chosen 0.05 as a lower limit to identify an ice crystal by depolarization and distinguish it from water droplets. For linear depolarization, the fraction of ice crystals having depolarization ratios below this threshold, due to their size and orientation lies within a range of 27.9% and 44.1% and gets smaller with increasing particle size. In contrast, for circular depolarization, this fraction with $\delta_C < 0.05$ remains between 4.5% and 13.8%. Circular depolarization ratios also seem to fluctuate less with changing orientation, except for a diameter of 1 μm where two peaks occur at $[0.1-0.15]$ and $[0.55-0.6]$.

We also have removed the following sentence because it is a repetition of what has already been discussed before: "The occurrence also indicates a decreasing trend

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with rising $\delta_{||}$."

In both linear and circular cases, ice plates ($\Gamma = 2$) have better chances to be detected as ice crystals than isometrical particles with volume-equivalent spherical diameters of 2 μm. These results confirm that the circular depolarization ratio of single ice particles is in general higher and less sensitive to the actual particle orientation than the linear depolarization ratio. However, it has a non-negligible interference with liquid droplets as discussed in the next section.

"Further along, what are "mineral dust polydispersed spheres"?!

We have re-writen the sentence as follows:

Scattering matrix elements F_{ij} for a hypothetical spherical particle ensemble using the refractive index of mineral dust were also investigated and the ratio F_{44}/F_{11} calculated as a function of scattering angle and size parameter.

"In Discussion, the authors seem to be suggesting that circular depolarization is used by CALIPSO. This is not so.

We agree. There were numerical studies conducted in advance of the CALIPSO design. But the instrument now uses linear depolarization. We therefore have removed the reference to CALIPSO in the discussion.

"Page 30131 lines 21-23: the sentence needs correcting; and what is "nominal 405 nm"?

We have re-written the sentence to be:

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In this simulation, particles with diameters d between 0 and 5 μm were simulated. This corresponds to size parameters $x = \pi d/\lambda$ between 0 and 38.6 with a IODE laser beam wavelength λ of 407 nm.

We have also removed the mentioned nominal diameter as it is of no importance here.

"Page 30133 lines 18-20: In the following one does "countervail if not exceed" mean "counteract or even exceed"?

We have re-phrased the beginning of this paragraph to be:

It has been shown that spheres may depolarize light if the incident laser source is circularly polarized. The ratio Z_{44}/Z_{11} differs from –1 if the scattering angle is not close to $180°$. Depolarization caused by water droplets at specific detection geometries and sizes may be as high or even higher than depolarization ratios for ice crystals of similar sizes.

"Page 30134 Lines 14-15 should be rewritten (what is "intervals discontinuity"?!).

We have re-written this sentence to be:

The discontinuity steps at low size parameters at side scattering regions reflect the finite steps in Θ and x in which we did our calculations.

"Line 18-19: why mention here how δ_C is determined?

We have deleted this sentence.

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"In line 21 is "This is still the case for a 1° departure from exact backscattering" meant?

We have rewritten the beginning of this paragraph to be:

As expected, discrimination between ice and water particles is not a problem in LIDAR applications (i.e. at $\Theta = 180°$). This is still the case for a 1° deviation from exact backscattering, except for size parameters between 30 and 35.

"Page 30135: the meaning of the second sentence in the second paragraph ("They assume...") is unclear.

We have re-phrased the paragraph as follows:

The principle for this detector is based on the difference in the P_{44}/P_{11} ratio. The detection of this ratio at side-scattering angles around 115° has been suggested to be more sensitive in distinguishing between a collection of spheres and a collection of non-spherical particles each following a gamma distribution (Hu et al., 2003). Bundke et al. (2008) assume that this method is also applicable for single particle detection. However, single water droplets can cause depolarization at this angle already from x larger than 2.

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