Reply to Anonymous Referee #1

The authors would like to thank the referee for his thoughtful and helpful comments and suggestions. His review has made a significant contribution to the improvement of the paper. Comments of the referee are blue and answers are violet. Text in green square are included in the reviewed manuscript. The line numbering in the reviewers' comments refers to the manuscript published in AMTD whereas the line numbering in the responses refers to the new version of the manuscript.

Comment: […] However, as stated in Eq. 2.23, it is the depolarization parameter that is truly a measure of the depolarisation caused by the aerosol independently of the polarization state (linear or circular) of the lidar. I understand depolarisation ratio measurement inherited from strong a legacy; at the minimum a reference to Gimmestad [3] (see at the bottom a list of pertinent references) and a short paragraph explaining how to transform depolarisation ratio to depolarisation parameter is required. Your definition of the Muller matrix for randomly oriented is inconsistent with the one use the references above:

$$\boldsymbol{M_{atm}} = p(180°)\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1-d & 0 & 0 \\ 0 & 0 & d-1 & 0 \\ 0 & 0 & 0 & (2d-1) \end{pmatrix}$$

Unless 'a' the polarisation parameter is define as '1-d', 'd' being the depolarisation parameter. It needs to be clarified.

Answer: We agree that the use of the polarization parameter a instead of the de-polarization parameter d as in Gimmestadt, 2008, can cause confusion. Therefore, we add the following sentence (page 8-9 lines 33-2):

Please note that instead of the polarization parameter *a* different but equivalent expressions are used in other publications as described in more detail in Freudenthaler, 2016a. Probably most known is the de-polarization parameter $d = 1 - a$ used in Gimmestadt, 2008.

Comment: The work and references are highly EARLINET centre: On the effect of mirror on depolarization measurement reference should be made to Bissonnette [4]. On measurements techniques that cancel out most of system depolarisation artefacts, reference to Cao [5] should be of interest.

Answer: Bissonnette et al, 2001, use two scanning mirrors in the emitter optics and show that they indeed have an important influence on the measured depolarization ratio. We thank the reviewer for the hint to this publication and add the following sentence (page 5 lines 22-23):

The possible effect of 45°-tilted scanning mirrors on depolarization measurements was highlighted by Bissonnette et al., 2001.

Cao et al., 2010, employ a rotating half-wave plate and a quarter-wave plate in the emission optics to subsequently change the state of polarization of the emitted laser beam. They show that when measuring the same atmospheric volume with a horizontal and a vertical polarized laser beam, the two measurements together can compensate some errors. This setup is not very common, and it can introduce additional errors (e.g. temporal atmospheric changes) in the determination of the depolarization ratio. No systematic error assessment is presented there. In this manuscript we cannot include all the possibilities to measure the linear depolarization ratio and all the possible errors, but focus on the error calculation for the most commonly used types of lidars. To our opinion, the lidars used in EARLINET and those which are investigated in this manuscript are typical for the majority of lidars used in other networks. However, Cao et al., 2010, is referenced in the compagnion manuscript (Freudenthaler, 2016a), which describes the theoretical basis of this manuscript.

Furthermore, the uncertainties in the compensation of two identical (=> uncertainties) mirrors perpendicularly rotated with respect to each other introduce more error sources, whose treatment is in principle possible with the techniques shown in this and the compagnion manuscript, but we cannot elaborate all possibilities in one paper.

Comment: The figure caption for figure 1 is anemic; identify each component; if I understood correctly, R should be identify as a lambda/2 waveplate in the text and in the figure caption

Answer: The caption has been improved following the suggestion. To avoid misunderstandings, an explicit comment is performed in the caption (caption Figure 1):

Figure 1: Lidar scheme based on functional blocks (adapted from Freudenthaler, 2016a). From right to left, laser ($\boldsymbol{I}_L$), steering optics ($\boldsymbol{M}_E$), atmosphere ($\boldsymbol{F}$), receiving optics ($\boldsymbol{M}_O$), calibrator ($\boldsymbol{C}$), additional rotation of the PBS by 90° (**R**)), polarising beam-splitter cube (transmitted (T) and reflected (R) matrices, M_T and M_R), detectors (η_T and η_R), and the transmitted (T) and reflected (R) signals ($\boldsymbol{I}_T$ and $\boldsymbol{I}_R$).

and in the text (page 7, lines 14-18):

The parallel polarized component of the emitted laser beam can be detected either in the transmitted or in the reflected path behind the PBS. This depends on the orientation $\Psi$of the PBS with respect to the laser polarization. We consider this by means of a rotator, **R**(ψ), (Eq. 2.14) before the PBS (see Fig. 1). For $\Psi = 90°$, the reflected and transmitted signals correspond to the parallel and perpendicular polarized components, respectively, and vice versa for $\Psi = 0°$.

Comment: In eq 2.1, why 2 alpha instead of alpha.

Answer: The Stokes' vector of the laser beam rotated by an angle alpha is calculated by

$$\boldsymbol{I}_L(\alpha) = \boldsymbol{R}(\alpha)\boldsymbol{I}_L(0°) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(2\alpha) & -sin(2\alpha) & 0 \\ 0 & sin(2\alpha) & cos(2\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} I_L \begin{pmatrix} 1 \\ a \\ 0 \\ 0 \end{pmatrix}$$

and thus, the 2α comes from the Müller matrix of a rotation by an angle α.

Comment: In Eq. 2.13, why 2 beta instead of beta.

Answer: See previous comment.

Comment: For Eq. 2.2 a reference is required.

Answer: The references Lu and Chipman, 1996 and Chipman, 2009 have been included (page 3, line 28).

Comment: For Eq 2.23, it should be specify it is the scattering matrix for randomly oriented particle; reference to Michenko [2], Gimmestad [3] and Roy [6] should be made;

Answer: We assume the referee makes reference to the Eq. 2.27 (AMTD version).The references of van de Hulst, 1957 and Mishchenko and Hovenier, 1995 have been included (page 8, line 29).

Comment: Eq. 2.27, how Gs and Hs are obtained?

Answer: We assume the referee makes reference to the Eq. 2.31 (AMTD version). As stated in the manuscript, "the parameters G_T, G_R, H_T and H_R, are determined solving the matrix multiplication of Equation 2.24 and separating the energy measured, $\boldsymbol{I}_S$, by the polarization parameter, a, as $I_S = G_S + aH_S$". We don't explain in detail this part because it is deeply done by Freudenthaler, 2016. Therefore, a comment pointing to the manuscript has been included in this paragraph (page 9, line 19-21).

where the parameters G_T, G_R, H_T and H_R, are determined solving the matrix multiplication of Equation 2.24 and separating the measured energy, I_S,in terms with and without the polarization parameter, a, as follow
(…)
(further details given by Freudenthaler, 2016a)

Comment: The authors should know that the average reader what to have a good idea of the meaning of a graphic by simply reading the caption. So for figure 3, 4, 5, 6, 7 and 8 spell out clearly all the meaning of variables. It is important.

Answer: Captions have been improved including detailed information of each variable (captions from Figure 3 to Figure 8).