Anonymous Referee #3

First we would like to thank Referee #3 for the time dedicated to provide the comments and suggestions for the interactive discussion. We made all efforts to follow all recommendations provided by the referee. We hope that the updated version is satisfactory. Below you will find a point by point description of how each comment and suggestion was addressed.

The paper explains calibration procedures for lidar depolarization measurements and compares and contrasts various methods used in EARLINET. This will be a very useful reference for EARLINET operators and for those wishing to understand the data quality of EARLINET depolarization measurements. I would like to see it published. However, the manuscript suffers somewhat from a sub-optimal organization related (perhaps) to a confusion about its primary purpose.

Thank you for pointing this limitation. All updates performed on the manuscript tried to overcome this issue. One extra paragraph was also included in the introduction to better explain the purpose of the manuscript.

New text:

"This study will be a useful reference for EARLINET operators and for those wishing to understand the data quality of EARLINET depolarization measurements. The reader has the opportunity to follow the current calibration procedures used in EARLINET, starting from the theory and then following all required steps to reach the final calibrated data products. Several new techniques used to optimize the lidar instrumentation are presented through the manuscript."

I have two major concerns. First, I spent hours just trying to understand the paper. This included a lot of time paging back and forth to find variable definitions. There are 16 variables in the first equation which are explained in a somewhat scattered way in the following paragraph, and ultimately the final equation of the theory section includes 25 variables, only some of which are the same as in Eq. (1). This is many more variables than I can keep in my head at once. Later sections refer to quantities only by variable name without any verbal description or reminder of what the variable means as if we have everything memorized. It was good to see the list of variables at the end, but this is not sufficient. If this paper is going to be useful for its recommendations or as a reference for data quality, it should be written clearly and consicely for a target audience who will probably want to use it practically, not theoretically. While it's admirable to see the theory treated in such a thorough way, I'm not sure there is anything new in the theory section.

The theory is presented at the beginning of the manuscript to provide the theoretical background used further on. The aim of the theoretical section is to meet the requirements of a reference paper for new operators. After many discussions between the contributors at the beginning of this study, we decided to keep the theoretical section in the manuscript. If the reviewer is convinced that this section is somehow redundant we will try to reduce it during the following iteration. Still we feel that is important to have this section.

Rather, I think the purpose of this section should be to lay the foundation for understanding the calibration procedures and results that will be discussed in later sections. To that end, is it possible to streamline the derivations and to present the equations in a simplified way such that they clarify the relationships between the quantity you would like to assess (a or delta), the quantities that are more directly measured (Stokes vectors) and the calibration parameters that are going to be discussed (diattenuation parameters and offset angles), without every detail of scattering theory being included? I have to admit that ultimately I failed to thoroughly understand the theory section although I am familiar with these concepts using different equations and different variable names and symbols. So possibly I'm wrong and all this really is indeed needed. In that case, it is even more important to make this section pedagogically clear. Describe in words the purpose of each part of the derivation, end sections with the most simplified useful version of the equations (like the equations that undergraduate textbooks enclose in a box), and restate the variable meaning and not just the symbol each time a variable is reintroduced in a later section. You'll need to write it as if you are teaching it, not just demonstrating that you know it well yourself.
Thank you for this comment. This is the reason why each calibration technique is described in different sections with information and descriptions on how the procedure could be applied. The additional details provided also for the theoretical section were removed from manuscript's length considerations as indications provided by referees and contributors (feedback). Also some simplifications were left out from the same considerations (reader feedback). Since the theory is quite extended, the authors tried to make a compromise between the amount of information and the level of details. This is the reason why this paper aims to be used together with the theoretical manuscript provided by Freudenthaler 2016. In the updated version of the manuscript much consideration was given to make each section as clear as possible.

My other concern is about the results section. You have stated two purposes, given at the start of section 4.4: to present the importance of calibrated depolarization products and to assess the accuracy of the calibrated depolarization products. I suggest that the first purpose is misplaced here. Except for the brief discussion in the introduction that can be seen as motivation, this paper doesn't need to show the importance of calibrated products.
Thank you for this comment. We had made the suggested updates to the text.

The second objective, to assess them, is of far more importance and there is room for improvement in how this objective is addressed. It's good that you have examples to show that the measured depolarization is close to the expected value, especially for the aerosol-free molecular depolarization which is known independently. This should be expanded. Is there any other simultaneous data available for independent assessment or inter-comparison? Other than these comparisons, you also have error bars which can give an idea of the precision of the depolarization measurements. Please be more thorough in explaining how the error bars are calculated and make sure they are consistent in the various comparisons, because these are a large part of the rather small set of information available to assess the results of the calibrations presented.

In most cases inter-comparison data is unavailable. The error calculation is a complex topic that could not be fully discussed in this paper. To cover the error calculation, a depolarization paper on the assessment of lidar depolarization uncertainty by means of a polarimetric lidar simulator was published in this special issue.

Bravo-Aranda, J. A., Belegante, L., Freudenthaler, V., Alados-Arboledas, L., Nicolae, D., Granados-Muñoz, M. J., Guerrero-Rascado, J. L., Amodeo, A., D'Amico, G., Engelmann, R., Pappalardo, G., Kokkalis, P., Mamouri, R., Papayannis, A., Navas-Guzmán, F., Olmo, F. J., Wandinger, U., Amato, F. and Haeffelin, M.: Assessment of lidar depolarization uncertainty by means of a polarimetric lidar simulator, Atmos. Meas. Tech., 9(10), 4935–4953, doi:10.5194/amt-9-4935-2016, 2016.

Specific comments:

Page 1, line 4. Which "derived parameters". Please be specific in the abstract.

Thank you for pointing this out. The text was updated accordingly.

Old text:

"The uncertainties related to the retrieval of particle depolarization ratios are the main factor in determining the accuracy of the derived parameters in such studies."

New text:

"The accuracy related to the retrieval of particle depolarization ratios is the driving factor for assessing and improving the uncertainties of the depolarization products."

Page 2, line 18. What are "all relevant parameters". I think "all relevant parameters are shape dependent" might be a bit of an overstatement, but the rest of the paragraph does a good job of explaining when depolarization measurements need to be highly accurate and when they are used just in a relative sense.

Thank you for pointing this out. The text has been modified.

New text:

"Recent atmospheric studies based on remote sensing data have been dedicated to aerosol typing, microphysical inversion and aerosol mass concentration retrievals. Since for these studies the most reliable optical parameters should be sensitive to the aerosol un-isotropy (e.g. shape), the depolarization products obtained from lidar measurements proved to be essential…."

Page 2, lines 25-30. These two sentences should be rewritten to make your point more clear. What do you mean by "ranges around close values", that the depolarization values are clustered well so that different types are distinguished easily, or the opposite, that different types have similar values and can't be distinguished unless the depolarization is very accurate? What does "The same issue" refer to?

Old text:

"According to Petzold et al., 2010; Gross et al., 2013; Burton et al., 2012, the particle linear depolarization values characterizing several aerosol species (or mixtures of aerosols) ranges around close values: for pure dust, the particle depolarization value at 532nm ranges from 0.30 to 0.39 and for dust mixtures from 0.1 to 0.30. The same issue emerges when discriminating between biomass burning aerosol mixed with mineral dust and industrial pollution aerosol, with values around 0.1 to 0.2 for the first and 0.04 to 30 0.1 for the second."

New text:

"According to (Petzold et al., 2010; Gross et al., 2013; Burton et al., 2012), the particle linear depolarization values characterizing several aerosol species (or mixtures of aerosols) overlaps for some ranges: for pure dust, the particle depolarization value at 532nm ranges from 0.30 to 0.39 and for dust mixtures from 0.1 to 0.30. Same overlap issue emerges when discriminating between biomass burning aerosol mixed with mineral dust and industrial pollution aerosol, with values around 0.1 to 0.2 for the first and 0.04 to 30 0.1 for the second. Therefore, in order to discriminate between different types of particle, the uncertainty of the depolarization products must be reduced."

Page 3, line 27 - Page 4, line 11. With so many variables, it would be helpful to organize the descriptions more predictably. Please either describe all the variables left to right, including the dependent variables, or else describe all the dependent variables and then all the independent variables. Or simplify as discussed in the general comments above, and then maybe fewer variables will be needed.

Thank you for this comment. This will really help to organize this section. The section was reorganized

page 4, line 22. A new variable ε is introduced without being explained.

Thank you for pointing this out. This parameter was described later on. The text was updated to solve this issue.

page 7, lines 2-9. "For most cases we consider" suggests there is a much simpler version of the equation that is being used for the rest of the paper. Please give this simpler version explicitly.

The updated equation proves not to be simpler. Only one parameter is removed. If the referee agrees, we would like to keep the current format of the equations.

page 7, Eqn 20. Is the variable the same as the sub-scripted variable ηs from Eqn 1?

The variable η can be retrieved from eq 19 and 20. ηs is included in eq 19 when performing the x45 degrees calibration. ηs is the electronic amplification of individual transmitted/reflected channels, η is the calibration factor including only the electronic amplification and the optical diattenuation of the polarizing beam splitter and η* is the measured calibration factor of the polarization channels, the calibration factor including the cross talk from optics before the polarizing beam splitter and from system alignment errors.

page 9, line 11. Spell out acronyms, Half Wave Plate
Thank you

page 13, line 11. Reintroduction of variable Y after 4 pages. Here is an example where it would be easier to follow if you remind readers what variable Y means and where it was introduced, something like "Y, which was introduced in Eq. (24) and is mathematically related to the error angle". Or better yet, since the error angle is a more familiar variable than Y, maybe consider recasting the plots in Fig 5 to use error angle instead of Y.
Thank you for pointing out this aspect. A short introduction of the variable to remind the readers what a particular variable means will ease the reader's effort. The manuscript was modified accordingly for all sections presenting reintroduced parameters.

page 13, line 22-27. Here is the first time where you make it explicit that correcting errors in the angle with hardware is better than post-processing. I found it very confusing before this part of the paper. While I understand that this paper aims to treat all methods of calibration used in the various EARLINET instruments, the earlier discussion of the two methods (that is, hardware correction and analytical correction in post-processing) did not make a clear distinction between them and I was left wondering if for some strange reason the authors were only considering the post-processing solution, which is the less desireable one. Please do everything you can do to make all options clear from the start and to be certain to distinguish clearly between calibration methods that change (and therefore correct) the angle errors from methods that do not change them (and therefore have to mathematically adjust the results in post-processing) at every stage of the discussion. Don't leave any mysteries to be solved at the end of the paper.
The text was modified to better explain the correction methods at an earlier stage of the introduction (Section 3.4). Thank you for pointing this out.
Updated text:
"This dependency alters the experimental retrieval of the measured calibration factor whenever is considerable large (>5. A good practice would be to assess and correct for 350 the angle before performing the depolarization calibration. Since the correction of alpha can be realized either by experimental techniques or by post processing analytical corrections, the latter statement only applies to the experimental solutions."

Page 18, line 20. "Proper corrections". Please make this sentence more specific. Are you talking about only the diattenuation correction here, or also about the angle corrections?

The text was modified to better explain what the corrections refer to. Thank you for this comment

Old text:

"The study also shows how the associated systematic errors are reduced by one order of magnitude when proper corrections are applied to the polarization profiles."

New text:

"The study also shows how the associated systematic errors are reduced by one order of magnitude when proper procedures (corrections and calibration) are applied to the polarization profiles."

Page 18, lines 22-30. This discussion is critical to your assessment of the calibration results. It is out of place appearing for the first time in the conclusions. This should be part of the results and discussion, and it should be expanded.

Thank you for pointing this issue. The text was modified accordingly.

Updates in section 4.4

"All cases were selected in order to highlight different atmospheric layers and environmental conditions (mineral dust, volcanic ash, ice crystals). The cases presented above emphasize the importance of calibrated depolarization lidar products in aerosol typing and are used to estimate the depolarization accuracy at 532nm for the considered lidar instruments. In the low aerosol height ranges, where the impact of the calibration procedures is more obvious, the volume linear depolarization ratio shows values close to the molecular level: δ = (0:01-0:03) ±0:015 for all lidar instruments (Behrendt and Nakamura, 2002).

Considering that for most cases presented in the study, the low aerosol height ranges are not aerosol free - small amounts of highly depolarizing aerosol could affect the profiles (e.g. ice particles) - it is safe to conclude that based on the low aerosol height range values, the depolarization accuracy estimate at 532nm is better than ± 0.03 for all presented case studies"

Updated text in the conclusions:

"All presented case studies show calibrated and corrected depolarization lidar products for selected lidar stations. The calibrated depolarization profiles at 532 nm show values that fall within a range of values that are generally accepted in the literature. The study shows that the depolarization accuracy estimate at 532nm is better than 0.03 for all presented case studies."

References: the last 3 references are out of order.

All references have been revised. Thank you

Figure 4b. I'm confused about why the true and measured depolarization values don't agree even at an angle error of zero. Is this because there are other calibrations that have not been applied? Given that the point is to show the effect of angle error on the depolarization, then I think the angle error should be the only uncorrected error in the simulation.

For this specific case the diattenuation of the receiving optics is considered to be 0.23 (simulation based on the real parameters determined for the Bucharest instrument). Since the diattenuation contribution will always be present during the assessment of the alpha parameter, we considered that the simulation should follow the real instrument behaviour. The simulation will also be used as a reference for further studies. If the reviewer agrees with these considerations, we would like to keep Figure 4b in the current format.

Figure 4 caption. There is a typo. The range of alpha is 0 to 10 degrees, not -10 to 10.

Text was updated

Figures 8,9,10,11. What do the error bars represent (systematic or random, empirically calculated from data variability or theoretically calculated)? Please explain in the figure caption and in the text.

The error estimation is explained at the end of section 4.4. If the reviewer considers that these details should also be included in the caption, we will perform the required modifications during the next iteration.

Figure 9. Why is there no depolarization data below 2000 m?

The volume depolarization ratio profile is available from several hundred meters but the particle depolarization ratio seems to be limited down to 1.5 km. This constrain could be caused by a higher overlap function affecting the backscatter profile up to that height (1.5 km). In the updated version of the manuscript, the lowest height range is 1 km.

Figures 8,9,10,11. Please make all the y-axis lower limits the same for all the subpanels in a given figure.

All figures have been updated to meet this requirement.