Response to Reviewer 1 by B. J. Elash et al.

We would like to thank the referee for their helpful comments and suggestions. Below are the referee's comments in italics followed by our reply.

Abstract: The abstract is good, but provides a summary that is not detailed enough. Please add specifically what was studied: aerosol signal fraction, retrieval bias and precision. Apart from the fact that linear polarization can be used as effectively as total radiance, also add the finding that horizontal polarization seems to be more promising in terms of signal magnitude.

Reply: This is noted and brief details have been added to the abstract on specific methods and results.

Sections 1:Third paragraph: A recent paper on the ALTIUS mission should be cited. Fussen, D., Dekemper, E., Errera, Q., Franssens, G., Mateshvili, N., Pieroux, D., and Vanhellemont, F.: The ALTIUS mission, Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2016-213, in review, 2016.

Reply: Reference added.

Sections 1:Third paragraph: please explain briefly the technical reason why the use of an AOTF filter necessarily means that the obtained signals are linearly polarized.

Reply: A brief comment on the measured polarized signal due to the phonon-phonon interaction within the AOTF was added.

Section 2.1, third paragraph: please explain briefly (for general readability) how the Solar Scattering Angle (SSA) is defined.

Reply: A definition of the SSA has been added to this section.

Section 2.1, third paragraph: "… angles of 0 and 180 degrees assuming horizontal atmospheric unity". I don't understand what is atmospheric unity. Do you mean homogeneity? Please clarify.

Reply: Agreed this was a confusing term. It is not necessary to the discussion and has been removed.

Section 2.1, third paragraph: Fig. 1, caption: please indicated that these data were simulated with Sasktran, including multiple scattering.

Reply: Corrected.

Section 2.2: please mention the reason for the pseudo-polarized approximation (likely processing speed).

Reply: The following sentence has been added into the text: This pseudo-polarized approximation was used for quicker processing times.

Section 2.3, Fig. 2: Please check the units of the aerosol extinction profiles. To me the values seem to be quite large. Shouldn't this be km^-1 instead of cm^-1?

Reply: Corrected.

Section 3: Sixth paragraph: The authors mention that no normalization is applied with respect to a shorter wavelength. I just want to comment that spectral normalization is one possible way to remove or minimize polarization effects since these vary less with wavelength than the spectral signature of atmospheric species.

Reply: Yes this is true, and this specific normalization was only mentioned since it differed from the Bourassa et al. (2012) retrieval method that was followed within this study.

Section 3: Seventh paragraph: The authors mention that ozone, NO2 and albedo are fixed to the values used to simulate the measurements. This is of course legitimate in a study that focuses on aerosols, but it is necessary to take them into account in actual retrievals. Also, as I mentioned in the General Comments, the retrieval quality of these species depends on polarization as well. I would suggest to include an extra sentence here, to clarify that in actual operational retrieval schemes the need for fitting of the other species will induce extra retrieval uncertainty for aerosols.

Reply: The following sentence has been added: It should be noted that actual retrieval schemes would need to account for ozone, NO_2, and albedo which will induce additional uncertainties in the retrieved aerosol extinction profiles.

Section 3: "The assumption of a fixed particle size distribution …" etc. This sentence is too complicated. Please rephrase. Basically what the authors want to say is that they want to test the sensitivity of retrievals from polarized measurements to assumed particle size distributions. That should be enough.

Reply: This sentence has been changed to the following for clarity: The assumption of a fixed particle size distribution is common in limb scatter retrieval algorithms. The difference between the assumed particle size distribution and the true state is used to explore the sensitivity of the retrievals from polarized measurements to the assumed particle size distribution.

Section 4.1: Fig. 3: indicate in the caption what the different grey curves represent. It's explained in the text, but a figure caption should clarify as much as possible by itself.

Reply: The following has been added: The grey lines are the differences for each individual case and the black line is the mean of the bias.

Section 4.1: Last sentence of the section suggests that in the rest of the paper total radiance refers to the radiance I from the vector model, which is not true (if I understand well). Please change to "For the other cases presented, any …" or something similar.

Reply: Corrected.

Section 4.2: Please state exactly (equations) what are the quantities that are being calculated (δ, $δ_{tot}$, $δ_{pol}$, Δδ). The discussion very rapidly becomes confusing if this is not known.

Reply: These variables have been clarified and the changes are noted in the revised document.

Section 4.2: Spell out the abbreviation BRDF (bidirectional reflectance distribution).

Reply: Corrected.

Section 4.2: Fig. 6: what is exactly shown? Is it the ratio of linearly polarized radiance to total radiance (as is written in the caption), or is it the ratio of linearly polarized aerosol signal to total radiance, as is written in the x-label of the figure? This is important, please clarify.

Reply: This has been corrected and is the ratio of linearly polarized radiance to total radiance.

Section 4.3: "The radiance calculations in the iterations of the retrieval were set to match …" etc. I really don't understand this sentence. Please rephrase.

Reply: As been reworded to the following: The retrieval algorithm was set to match the polarization state of the input radiance, note that total radiance is used from the vector SASKRAN-HR model for the total radiance case.

Section 4.3: "There is no substantial difference between the results for the background and volcanic extinction profiles". This is not correct, the sign of the bias is different (which, by the way, isn't surprising).

Reply: Noted and has been rewritten to: There is no substantial difference between the absolute magnitude of the bias for the background and volcanic extinction profiles, but the difference in sign of the bias is expected.

Section 4.3: "This large bias is very sensitive to scattering angle and is nearly eliminated for even 85° or 95°". Please make the sentence more clear by saying that farther away from 90° (below 85°, above 95°), the bias rapidly disappears.

Reply: Has been rewritten for clarity to the following: This large bias rapidly disappears for SSA farther away from 90° and is almost gone by SSA of 85° or 95°

Section 5: Third paragraph: the authors describe the results for a compensated instrument, not for an uncompensated instrument. Please also include them.

Reply: The conclusion for the uncompensated instrument has been added.

Abstract: … that are encountered in typical low earth orbit(s) …

Reply: Corrected.

Abstract: (Taking into account instrument signal to noise capabilities, it) is found that in general, the linear polarization can be used as effectively as the total radiance measurement.

Reply: Corrected.

Section 1: Stratospheric aerosols, which are (sub)micron-sized spherical …

Reply: Corrected.

Section 1: … over the last decade was primarily caused by a series of (REMOVE somewhat) minor, mostly tropical …

Reply: Corrected.

Section 1: The solar occultation technique has provided a robust and reliable method to retrieve aerosol (extinction) by directly measuring the atmospheric (transmittance). However, the (measurement frequency) of occultation measurements is somewhat limited … NOTE: 'sampling rate' is better reserved for the number of acquisitions per second during one occultation.

Reply: Corrected.

Section 1: … and most recently (from) OMPS …

Reply: Corrected.

Section 1: … using limb scattering including the (Belgian) instrument Atmospheric Limb Tracker …

Reply: Corrected.

Section 2: … and the SASKTRAN-HR model … : please give abbreviation here, not further down in the text.

Reply: Corrected.

Section 2: … where the (coefficients) of the Stokes vector, defined in …

Reply: Corrected.

Section 2: The (4 x 4) scattering matrix is represented by …

Reply: Corrected.

Section 2: … that is determined from the (Rayleigh-Gans) approximation …

Reply: Corrected.

Section 2: The strong polarized nature can be (noticed) around (the) SSA of 90 degrees where the radiance is almost (completely) horizontally polarized.

Reply: Corrected.

Section 2: … both Rayleigh and Mie scattering occur in a weighted fraction (determined by) the optical depth of air and aerosol.

Reply: Corrected.

Section 2: … two panels of Figure 1 show the difference in the ratio of the polarized over the total radiance for the atmosphere with aerosol and (the) one without, (demonstrating that) this effect has a weak dependence on …

Reply: Corrected.

Section 2: … but it obviously varies depending on (the) aerosol loading and …

Reply: Corrected.

Section 2: The SASKTRAN framework … and number density profiles, and (assumes) a fully 3D …

Reply: Corrected.

Section 2: At the end of section 2.2,the authors frequently use the word 'scatter' to indicate a scattering event (ex: the first two scatters in the atmosphere, the final scatter into the instrument). Is this correct? I'm not sure. Perhaps better use 'scatter event'?

Reply: Corrected.

Section 2: … of the scattering matrix (Rieger et al., 2014) [16]. (Aerosols scatter strongly) in the forward direction (resulting) in a weaker relative aerosol …

Reply: Corrected.

Section 2: Caption of Fig. 2: The two aerosol (extinction) profiles used in this study. The blue (profile represents) background aerosol conditions, and …

Reply: Corrected.

Section 2: To probe the range of possible viewing geometries from (a) low earth orbit, a range of …

Reply: Corrected.

Section 2: … 1250 (and) 1500 nm, which approximately cover (REMOVE for) the spectral range …

Reply: Corrected.

Section 3: The polarization states used here are defined as (follows): …

Reply: Corrected.

Section 3: Due to (the non-linear behaviour of) multiple scattering, … at most stratospheric tangent altitudes (the atmosphere is optically quite thin at the considered wavelengths) and this simple percent difference …

Reply: Corrected.

Section 3: … that is essentially similar to (the one) developed by Bourassa et al. …

Reply: Corrected.

Section 3: … is then used to retrieve aerosol extinction profiles using the (technique of) Bourassa et al. …

Reply: Corrected.

Section 3: … which describes the sensitivity of the retrieval to the measurement and the respective noise through the following (equation) (Rodgers, 2000) [31]:

Reply: Corrected.

Section 4: Fig. 4, x-label. Better use "Rel. difference" than "Error". It's not an error, it's a difference between two different retrievals.

Reply: Corrected.

Section 4: Fig. 4, caption: Each (panel) represents a different particle size …

Reply: Corrected.

Section 4: These were used as input measurements (for the retrieval), which was then performed …

Reply: Corrected.

Section 4: A case-by-case comparison … was performed (by calculating) siple percentage differences(s) at each (retrieval) altitude. (These have been shown as) grey lines in Fig. 3.

Reply: Corrected.

Section 4: These results (REMOVE given in Fig. 3) show that across all …

Reply: Corrected.

Section 4: The viewing geometry, which is (typical for a) low earth orbit scenario, is (given by) SZA = 45° and …

Reply: Corrected.

Section 4: Fig. 4, caption: … particle size distribution 1. (Notice that) the red-blue scale is (asymmetric).

Reply: Corrected.

Section 4: Fig. 5, caption: Dependence of the fraction of the limb spectra (at 15 km) due to aerosol on …

Reply: Corrected.

Section 4: … were performed for the full range of SZAs. We found that …

Reply: Corrected.

Section 4: … was found that these two polarization orientations had (a) similar aerosol …

Reply: Corrected.

Section 4: … with very low signal magnitude near (the scattering angle of 90°).

Reply: Corrected.

Section 4: … will cover forward and backward scattering angles, including (the 90° scattering angle), it is ….

Reply: Corrected.

Section 4: … is shown for a series of SSA (and) a tangent altitude of 20 km, …

Reply: Corrected.

Section 4: … total radiance, with the greatest (signal reduction) at the shorter …

Reply: Corrected.

Section 4: Back scatter geometries are (marginally) better with …

Reply: Corrected.

Section 4: In all cases, the retrieval was performed (assuming a fixed log-normal particle size distribution with a) mode radius and width of ….

Reply: Corrected.

Section 4: … the major element of observed bias is simply (due to the) difference between the true …

Reply: Corrected.

Section 4: … various viewing geometries. (None) of the linearly polarized states perform any worse either …

Reply: Corrected.

Section 4: … were calculated for each retrieved state and used (to) determine the gain matrices, …

Reply: Corrected.

Section 4: … due to small sensitivity (at) the lower tangent altitudes … from the data set (approximately 9% of (all) cases). …

Reply: Corrected.

Section 4: For the (compensated) case, (REMOVE where the signal to noise ratio is … for all cases) the measurement …

Reply: Corrected.

Section 4: The fainted colours (represent) one standard deviation (around) the mean. Each of the means in … data points(. Values smaller or larger than one respectively indicate retrieval uncertainties smaller or larger than the total radiance retrieval uncertainties).

Reply: Corrected.

Section 4: … Recall, however, that the vertical polarization has significantly lower (REMOVE magnitude) signal levels and …

Reply: Corrected.

Section 4: … SSA for the horizontal and vertical polarizations(. Note that) the SSA of 90° is missing due to the poor signal, (and the associated high retrieval co-variances for this geometry).

Reply: Corrected.

Section 4: … compared to the total radiance case the decreased precision is (larger for the horizontal polarization) at shorter wavelengths.

Reply: Corrected.

Section 5: … of linearly polarized radiance rather than total limb radiance (represents) an advantage or …

Reply: Corrected.

Section 5: The sensitivity of the polarized … is (a complicated function of) many parameters, …

Reply: Corrected.

Section 5: One critical bias … is (caused by the) uncertainty in (the assumed) particle size parameters.

Reply: Corrected.

Section 5: … the magnitude of the signal. (For a compensated instrument, the) polarization can either …

Reply: Corrected.

Section 5: … aerosol products of very similar quality (compared) to an equivalent instrument …

Reply: Corrected.

Response to Reviewer 2 by B. J. Elash et al.

We would like to thank the referee for their helpful comments and suggestions. Below are the referee's comments in italics followed by our reply.

Abstract: Add more information on the findings of this work. All you have is one somewhat vague sentence ("...linear polarization can be used as effectively as the total radiance ..."). Half the abstract is preamble/context as well, which is unnecessary.

Reply: Corrected. See updated abstract in text.

Intro, line 4: aerosol composition is also very important

Reply: Corrected.

Page 2, line 5: "directly measuring the atmospheric optical depth" – the measurement is of slant path extinction.

Reply: Changed to transmittance.

Page 2, line 6: remove "somewhat"

Reply: Corrected.

Page 4, para 3, "easy seen" Add the equation for polarization (or linear polarization)

Reply: The equations have been added.

Section 2.2: provide a sentence or two on how appropriate it is to assume the surface is completely depolarizing.

Reply: The following sentence has been added to the manuscript: The assumption of a Lambertian surface is commonly used even though in many cases a Lambertian surface does not accurately describe surface polarized scattering (Martonchik et al., 1998; Deuzé et al., 2000) [30, 31].

Figure 2: provide the vertical AODs for these extinction profiles

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Reply: Have been added.

General question: Can you comment on how your results might be affected if a different inversion approach is used? I would guess that at the bottom of the retrieval range, different methods would have different sensitivities.

Reply: Two method were used internally within the group for polarized retrieval, the MART algorithm used within this paper and Levenberg-Marquardt technique. Both achieved very similar results. However changing parameters within the algorithm (i.e. normalization height, lower and upper bounds, how the profile is scaled below the lower and upper boundary, etc.) can have a somewhat larger effect on the retrieved results, either larger or smaller than the determined results.

Figure 7: Could it be suggested that based on Figure 7, the vertical component performs better for situations where a single mode might be more representative such as non-volcanic periods?

Reply: There is merit to this statement that the vertical polarization on average has a smaller bias than the other two cases. However it should be noted that only two non-volcanic particle size distributions were used and other similar non-volcanic distributions may be better with the horizontal polarization than the vertical polarization.

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[30] Deuzé, J. L., P. Goloub, M. Herman, A. Marchand, G. Perry, S. Susana, and D. Tanré (2000), Estimate of the aerosol properties over the ocean with POLDER, Journal Geophysical Research, 105(D12), 15329–15346, doi:10.1029/2000JD900148.

[31] Martonchik J. V., D. J. Diner, R. A. Kahn, T. P. Ackerman, M. M. Verstraete, B. Pinty, and H. R. Gordon, Techniques for the retrieval of aerosol properties over land and ocean using multiangle imaging, IEEE Transactions on Geoscience and Remote Sensing, 36- 4, 1212-1227, doi: 10.1109/36.701027.