Reply to General comments:

1. *When the authors introduce the SRON multimode retrieval algorithm in section 2.1, no aerosol size distribution parameters are included in the state vector. However, in the retrieval results, effective radius of fine and coarse mode particles are shown. Although the calculation of fine and coarse mode effective radius is presented in section 2.2, the retrieved aerosol parameters related to size parameters are not clear.*

   Response:

   Thanks. We added a description of the multimode retrieval algorithm to the paper in Sect. 2.1:

   " In principle, the idea of the multimode approach is that instead of fitting the size distribution parameters (the effective radius r_{eff} and the effective variance v_{eff}) of two modes, one aims to fit the size distribution with a larger number of modes for which r_{eff} and v_{eff} are fixed. The advantage of this approach is that it makes the inversion problem more linear since r_{eff} and v_{eff} tend to make the inversion highly nonlinear. Another advantage is that the multimode approach has more freedom in fitting different shapes of size distribution if the number of chosen modes is sufficiently large. In this paper, multimode retrievals based on 5 modes are used and the aerosol size distribution are described in Table 3 (Fu and Hasekamp, 2018). "

   In the retrieval, we don't retrieve r_{eff} and v_{eff} for the 5 modes. The fine and coarse effective radius are calculated after retrievals based on Sect. 2.2. The sensitivities of the retrieved aerosol parameters related to different particle size parameters (parametric 2-mode, 3 to 10 multimode) have been extensively studied in Fu and Hasekamp (2018).

2. *As defined in the manuscript, the* χ^2 *used to decide retrieval convergence is different for different instruments. For example, for AirMSPI, observed intensities in 8 bands and DoLP in 3 bands are used in the retrieval, while radiance and DoLP at 16 wavelengths for SPEX are used. Although* χ^2 *is defined as a mean value of total number of measurements, the ratios* ($\frac{F_i - y_i}{S_y(i,i)}$) *in Eq. 3 for radiance and DoLP may have different scales. Therefore, if different numbers of radiances and DoLP are used even though two instruments have the same total number of measurements, the* χ^2 *may differ a lot. Does this problem affect the retrieval results between different instruments? Do they use the same threshold* χ^2_{max}*?*

   Response:

   In this paper, for different instruments we use the same threshold $\chi^2_{\mathrm{max}} = 1.5$. It is true that for the different instruments there are different contributions to the χ^2. This would only pose a problem if the assumed errors in S_y are a poor representation of the true measurement errors. We believe we have used reasonable error estimates in our S_y for the differnt instruments so this should not pose a problem.

3. *The retrieval results of 3 different instruments are compared in this manuscript, but only some statistical parameters, such as MAE, bias and STD are presented. Are there any conclusions or suggestions about the measurements (radiance or DoLP) at which wavelengths are combined better for aerosol retrieval? Or are different numbers of multi-angle measurements affect aerosol retrievals a lot? I think more similar common summaries could attract audiences.*

   Response:
   Our study confirms earlier studies that different combinations of spectral and angular measurements yield a very similar retrieval capability for aerosol properties (Hasekamp and Landgraf, 2007; Wu et al., 2015; Hasekamp et al., 2019). We have highlighted this in the conclusion of the revised manuscript.

4. *In the state vector, aerosol column numbers and microphysical properties are included, thus the AOD in the retrieval at different wavelengths are calculated from retrieved column numbers and other parameters. I'm a little confused that why the authors use different wavelengths when compare total AOD and fine and coarse modes AOD (Figure 1 and Figure 3). If the same wavelengths are used, the retrieval performance of fine, coarse mode AOD and total AOD can also be evaluated.*

   Response:
   Only measurements at 500 nm have been used to compare the fine and coarse mode AOD because the measurements (fine and coarse mode AOD) at other wavelengths are not available in the SDA product.

5. *The surface reflectance parameters are retrieved simultaneously with aerosol properties in the algorithm. How is the performance of surface reflectance retrieval in the campaign? Are the accuracies of retrieved aerosol properties related to surface reflectance?*

   Response:
   We do not have a good reference to evaluate the accuracy of the retrieved surface parameters. Instead, we have evaluated the difference between MAP and HSRL-2 as function of retrieved surface properties. The results are show in Figure R1 of this response. We do not see clear correlation with surface parameters here.

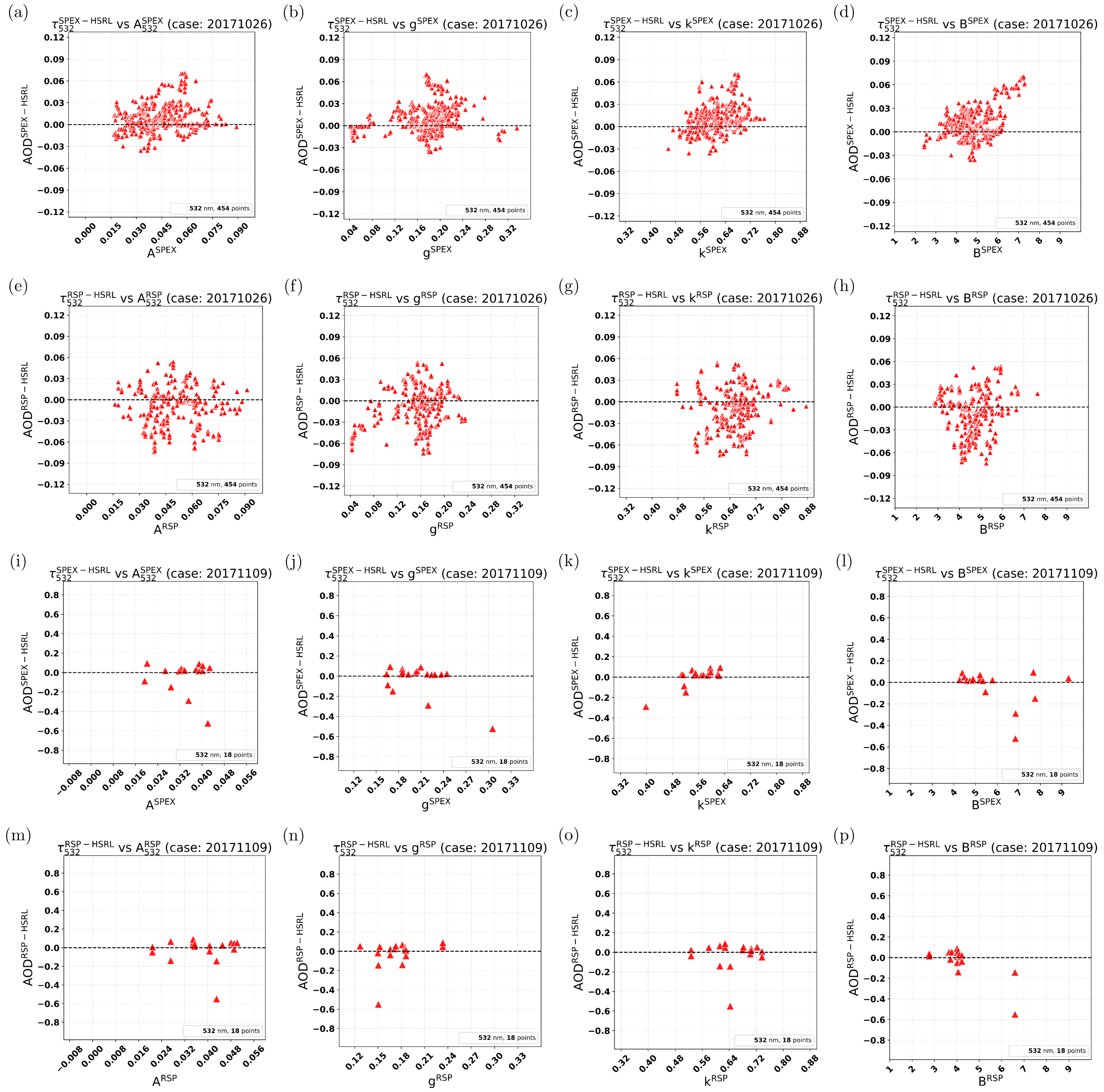

Figure R 1: **Sensitivities between AOD differences (between MAPs and HSRL-2) and surface parameters.** **(a)-(h)** the low AOD case. **(i)-(p)** the high AOD (smoke) case. 1st, 2nd, 3rd, and 4th column respectively represent results with respect to BRDF scaling parameters for wavelength bands (A_{532}), Parameter 1 of RPV model (g), Parameter 2 of RPV model (k), and Scaling parameter for polarized reflectance (B).

6. *The retrieval accuracy of fine and coarse mode AOD depend on the retrieved aerosol microphysical properties. If the dependence of the retrieval bias of τ^f and τ^c on the accuracy of retrieved r_{eff} or refractive index is shown, it will be interesting and beneficial for distinguishing aerosol types.*

   Response:

   We do not see such dependencies in the available data and also we do not really expect it.

Reply to Specific comments:

1. *In the introduction part, the third paragraph in page 2 indicates that combining both intensity and polarization measurements at multiple viewing angles is beneficial for aerosol retrieval. However, this paragraph is too short and simple. This is the most important feature of 3 MAPs used in this manuscript to do retrieval. I think more theoretical foundation and how previous studies use these information could be added.*

   Response:

   We extended the paragraph 3 (in the introduction) in the paper by adding a review of previous studies:

   " The reason is that the angular dependence of the scattering matrix elements related to linear polarization, depend strongly on the microphysical aerosol properties, like refractive index and particle size (Hansen and Travis, 1974; Mishchenko and Travis, 1997). Furthermore, the polarization signal is mostly dominated by light that has been scattered only once, which means that the characteristics of the scattering matrix remain largely preserved in a top-of-atmosphere polarization measurement. The added value of polarization has been demonstrated by a number of studies on synthetic measurements (Mishchenko and Travis, 1997; Hasekamp and Landgraf, 2007; Hasekamp, 2010; Knobelspiesse et al., 2012), airborne measurements (Chowdhary et al., 2005; Waquet et al., 2009; Xu et al., 2017; Wu et al., 2015, 2016), and spaceborne measurements (Hasekamp et al., 2011; Dubovik et al., 2011; Fu and Hasekamp, 2018). These algorithms can be divided in two main groups: LookUp-Table (LUT) based approaches and full inversion approaches. Generally speaking, LUT approaches are faster but less accurate than full inversion approaches because LUT approaches choose the best fitting aerosol model from a discrete lookup table. Full inversion approaches are more accurate but slower because they require radiative transfer calculations as part of the retrieval procedure. The LUT algorithms are e.g., the LOA LUT algorithm over ocean (Deuzé et al., 2000), the LOA LUT algorithm over land (Deuzé et al., 2001; Herman et al., 1997), and the SSA LUT algorithm (Waquet et al., 2016). The full inversion algorithms are e.g., the GRASP algorithm (Dubovik et al., 2011), the SRON-Aerosol algorithm (Hasekamp and Landgraf, 2007; Hasekamp et al., 2011; Stap et al., 2015;

Wu et al., 2015, 2016; Di Noia et al., 2017; Fu and Hasekamp, 2018), the JPL algorithm (Xu et al., 2017), the GISS algorithm (Waquet et al., 2009) and the MAPP algorithm (Stamnes et al., 2018). Besides, some additional aerosol retrieval approaches can be found in (Sano et al., 2006; Cheng et al., 2011; Masuda et al., 2000; Lebsock et al., 2007). It should be noted that of the full inversion approaches only the SRON-Aerosol algorithm and the GRASP algorithm have been applied at a global scale. "

We also included more theoretical description for the retrieval algorithm in Sect. 2.1 from Eq. (4) to (6).

2. *The paragraph at page 3 line 6-10 has little relationship with this study. I believe the authors could delete or short this paragraph and combine it with last paragraph.*

   Response:
   Thanks. We have shorted this paragraph and combined it with the previous paragraph, as stated in the end of paragraph 4 of introduction:
   " The POLDER design also forms the blueprint for the 3MI instruments (Fougnie et al., 2018), to be flown on METOP-SG in the time frame ∼2020-2035. "

3. *When giving the information of ACEPOL campaign in the introduction, the information about the altitude aircraft flying is suggested to be provided due to the retrieval of ALH, especially at smoke plume case whose ALH is always high.*

   Response:
   We agree. We added the altitude of the NASA ER-2 flight in the introduction: " All 4 airborne MAPs listed above were mounted on the NASA Earth Resources-2 (ER-2) high altitude (∼20 km) aircraft (Navarro, 2007) during the Aerosol Characterization from Polarimeter and Lidar (ACEPOL) campaign, which was performed from October-November 2017, starting from the NASA Armstrong airbase in Palmdale, California. "

4. *At page 4 line 20, the meaning of k in the equation is not explained.*

   Response:
   Thanks. We added it to the paper in Sect. 2.1:
   " where k is a parameter that varies between 0 and 1. This parameter controls the slope of the reflectance with respect to the illumination and view angles (Rahman et al., 1993). "

5. *At page 11 line 18-19, the authors present "the MAE gets smaller with increasing wavelengths, which is mainly caused by the fact that AOD value itself decreases with wavelength". Some other parameters such as mean relative error (MRE) or root mean squire error (RMSE) could remove this effect and are recommended to be compared.*

   Response:

   Thanks. Yes, the MRE can remove this effect, but the RMSE not. We added the MRE to the paper for all the AOD comparisons with AERONET and HSRL-2, and indeed see that the MRE does not decrease with wavelength.

6. *The sentences at line 22-23 and line 30-31 in page 11 present the same thing.*

   Response:

   We re-wrote the latter one (which is especially for the coarse mode effective radius) to the paper in Sect. 4.1:

   " This is in line with synthetic studies (e.g., Hasekamp et al. (2019)) that $r_{\mathrm{eff}}^{\mathrm{c}}$ is a difficult parameter to retrieve, in particular for small AOD values. "

7. *At page 13 line 1-2, "for low AOD the effect of the surface on the measured radiances is larger than for SPEX airborne" is presented. I'm a little confused why.*

   Response:

   We re-wrote this sentence to:

   " A possible explanation is that for low AOD the radiance and polarization measurements have strong influence from the spatially inhomogeneous surface, and therefore errors due to inter-angle mis-registration, which are larger for RSP than for SPEX, may be significant. "

8. *At page 14 line 13-14, the authors explained that the shortest wavelength for SPEX is 450 nm and not suitable for ALH retrieval. Do you mean the shorter wavelengths such as UV band benefit ALH retrieval? More clear and straight forward sentences are suggested to be used. Moreover, this explanation for ALH retrieval is too simple and this may be only one of many reasons. I believe reading more related papers about ALH retrieval could help the authors explain this problem more clearly and deeply.*

   Response:

   To our best knowledge, Wu et al. (2016) is the only paper for ALH retrieval from MAP measurements. We extended the explanation in Sect. 4.2.4 by adding:

“ Here, it should be noted that for SPEX the shortest wavelength that is used in the retrieval is 450 nm, so we do not expect an accurate ALH retrieval because the retrieval of ALH from polarization requires a strong signal from Rayleigh scattering (Wu et al., 2016). ”

9. *Some sentences in this manuscript are a little complex and confused, especially in section 1 and section 4. More concise sentences are recommended.*

Response:

Thanks. We believe both Section 1 and 4 have been improved in the new version paper.

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