Reply to general comments:

1. *Although the paper focuses on aerosol retrievals, surface is an important component in the retrieval process and is included in the state vector. A good characterization of surface reflectance can significantly affect the retrieval accuracy of aerosol properties, which is especially true when aerosol loading is small (such as of the most ACEPOL cases). So, as a reader I would like to see some retrieval results for surface BRDF/BPDF properties and how the retrievals behave between different polarimeters.*

   Response:
   Thanks. We included a figure (Figure 6) showing the dependence of AOD difference between MAP and HSRL2 as function of the surface reflection (A) at 532 nm in the revised manuscript.

2. *The retrieval algorithm needs some more clarification in a few aspects of the radiative transfer calculations and the inversion configurations. These include: (i) which radiative transfer model and what are the relevant assumptions (such gas absorptions, Rayleigh scatterings, etc) in the radiative transfer assumptions? (ii) How the first guess of the state vector is defined? While the first guesses for aerosol parameters are mostly given, the paper mentions nothing about prior values for surface BRDF/BPDF parameters. (iii) It is not clear how the aerosol refractive index are treated, although it is mentioned to use the D'Almeida et al (1991) database. (iv) It is also not clear about how the weighting matrix (W) in the cost function is defined, as well as the threshold for the goodness of fit. Please refer to the relevant specific comments below for more details.*

   Response:
   - (i) We use the SRON radiative transfer mode LINTRAN (Hasekamp and Landgraf, 2005; Schepers et al., 2014). Rayleigh scattering cross sections are from Bucholtz (1995). Values for O3, NO2, and H2O columns are taken from MERRA-2 and AFGL as mentioned on page 11.
   -(ii) The first guess is obtained using a LUT approach. We extended the description. The LUT retrieval provides first guess values for aerosol and surface properties. The LUT retrieval itself starts with fixed values for all surface properties, i.e., 0.05, -0.09, 0.80, 1.0 for A, g, k, B, respectively. The prior values are listed in Table 2 of the revised manuscript.
   -(iii) The treatment of the refractive index is explained end page 4 and start page 5. The coefficients are included in the state vector.
   -(iv) We include the values for the weighting matrix in Table 2 of the revise manuscript.

3. *By reading the title of the article (Aerosol retrievals from the ACEPOL campaign), I would expect to see aerosol retrievals from different polarimeters and from their respective*

aerosol products. Are there any aerosol products available from the ACEPOL campaign with other existing retrieval algorithms? If yes, it would be more helpful to compare the aerosol retrievals from different algorithms. Such a comparison may also explain the consistent biases in the retrieved aerosol size (Figure 2), depolarization ratio and lidar ratio (Figure 7). Otherwise, I would suggest to make the article title more specific, for instance, by adding "using the SRON algorithm".

Response:

We agree maybe the title is too general, and we have changed the title to:

" Aerosol retrievals from different polarimeters during the ACEPOL campaign using a common retrieval algorithm "

Reply to specific comments:

1. *Page 4, first paragraph of section 2.1. Description about aerosol refractive index is too brief. Please clarify: (i) at which relative humidity (RH) is assumed for the D'Almeida et (1991) database, or a dynamic RH relationship is considered with ancillary meteorological data? This is important as the inorganic aerosols are strongly hygroscopic. (ii) How the coefficients are defined for combining the aerosol species? In terms of volume concentrations? (iii) Are the different aerosol species internally or externally mixed in the calculation of modal refractive index? In addition, it would be helpful if the refractive indices used in this study being provided in a supplemental document.*

Response:

(i) We only use the refractive index spectra from d'Almeida for the spectral dependendence of the refractive index. So. no assumtions are needed on RH.

For the comment (ii) we have added more description to the paper in Sect. 2.1:

" The coefficients α_k are the real numbers between 0 and 1, and are defined as weighting factors to combine the refractive index spectra for different aerosol components, e.g., DUST, water (H2O), Black Carbon (BC), INORGanic matter (INORG). In this study, we set $n_\alpha = 2$ and assume that spectral dependence of the fine mode and the coarse mode refractive indices can be described respectively by INORG+BC and DUST+INORG. Note that this assumption is flexible and can be updated according to the information content of the measurement. Also spectra based on Principal Component Analysis (PCA) can be used as in Wu et al. (2015). The standard refractive index spectra are only used to describe the spectral dependence as the MAP measurements do not contain sufficient information to retrieve the refractive index for each wavelength separately. "

Comment (iii):

We compute the refractive index given the formula on top of page 5 of the revised manuscript. Given that we perform one Mie/T-matrix computation per mode for one refractive index, this implicitly assumes internal mixing.

2. *Page 5, line 6. Please give the explicit expression for R(G).*

Response:

In the new version, we included $R(G) = \frac{1-A(\lambda)}{1+G}$ in the Sect. 2.1.

3. *Section 2.1. The number of elements in state vector for different sensors would be different because of the different number of spectral bands. I would recommend include a table to list the detailed elements (and numbers) of the retrieved parameters for individual polarimeters. Correspondingly, the selected bands and number of angles for each observation set (as described in section 3.1-3.3) can also be listed in the same table. This will give the reader a clearer picture about the retrieval configuration for different sensors.*

Response:

Thanks. We have included Table 2 as suggested, which lists the viewing angles and wavelengths used in retrievals among SPEX airborne, RSP, and AirMSPI. The state vectors corresponding to these three polarimeters are also listed in the table. For the state vector, the only difference among three instruments is the BRDF scaling parameter $A(\lambda)$ which is wavelength-dependent.

4. *Section 2.1. It is not mentioned in algorithm description about: (i) what radiative transfer model is used and how many layers of atmosphere is assumed; (ii) how the gas absorption are treated; (iii) How the Rayleigh scattering are calculated. Please clarify.*

Response:

We have clarified these aspects in Sect. 2.1: " **F** consists of a radiative transfer model, for which we use the SRON radiative transfer model LINTRAN Landgraf et al. (2001); Hasekamp and Landgraf (2002, 2005); Schepers et al. (2014). All the radiative transfer calculations are performed for a model atmosphere that includes Rayleigh scattering, scattering and absorption by aerosols, and gas absorption. Rayleigh scterring cross sections are used from Bucholtz (1995). The forward model simulates Stokes parameters I, Q, U at the top of the atmosphere (800 km) or the height of the research flight (e.g., ∼20 km for NASA ER-2 in this paper) for given optical properties (scattering and absorption optical thickness and scattering phase matrix for each vertical layer of the model atmosphere (15 layers of atmosphere is assumed). The other part of the forward model computes the optical properties from the aerosol microphysical properties using the tabulated kernels of Dubovik et al. (2006) for a mixture of spheroids and spheres. "

5. *Page 5, Equation (2). Please clarify how the weight matrix (W) is defined to regulate the ranges of individual state parameters.*

   Response:
   Table 2 of the revised manuscript gives the elements of the weighting matrix. It has a comparable role as the prior covariance matrix in Optimal Estimation, except that for our inversion we have an additional regularization parameter that scales the whole matrix.

6. *Page 5, Equation (2). It is not clear how the prior state vector is defined for surface parameters. Please clarify.*

   Response:
   For the comment 5 and 6, we added a phrase to the paper in Sect. 2.1:
   " Table 2 shows the values in $\vec{x}_{\rm a}$ including the prior values for aerosol and surface parameters. **W** is a diagonal matrix and its diagonal values are also shown in Table 2 (in the "weight" column). "
   Table 2 is included in the new version paper.

7. *Page 5, line 15. It is mentioned here "Stokes parameters I, Q, U at the top of the atmosphere" are simulated, but it is not clear what is the TOA altitude as defined. Moreover, the ACEPOL measurements are taken at an altitude of the ER-2 flights. The radiative transfer model should simulate the radiances as observed at the flight level. Please justify.*

   Response:
   Yes. We have added information to avoid confusion in Sect. 2.1:
   " The forward model simulates Stokes parameters I, Q, U at the height of the observation (e.g., ∼20 km for NASA ER-2 in this paper) ... "

8. *Page 5, line 29. Is a constant threshold for Kai-Square used for all retrievals across different instruments? Please clarify.*

   Response:
   Yes, we use 1.5 as the threshold for all instruments and for all retrieval cases in the paper.

This was already mentioned in the Sect. 4.

9. *Page 6, Equation (4). The symbol "G" is already used in equation (1) to denote hot-spot geometry factor. A different symbol should be used to avoid ambiguity.*

Response:
Thanks. We have used "O" to replace "G" here.

10. *Page 6, Equation (7). Are there any references for calculating the columnar depolarization ratio in this way? I recall some studies (sorry I couldn't find the paper) used layer extinction coefficient (rather than backscatter coefficient) as the weighting parameter.*

Response:
Actually, either the extinction coefficient or the backscatter coefficient can be taken as the weighting parameter. The reason why we use backscatter coefficient here is because for ACEPOL, the backscatter profiles from HSRL-2 are more accurate than the extinction profiles from HSRL-2.

11. *Page 9, line 24. Do you meant to "Where the HSRL method is NOT available for the extinction products . . . ."*

Response:
We have changed that part in the new version to avoid confusion:
" For ACEPOL, the extinction products from the HSRL method are reported at 150 m vertical resolution and at temporal resolution of 60 s generally and 10 s. Additionally, the aerosol extinction products at 355 nm and 532 nm are also provided based on the aerosol backscatter and an assumed lidar ratio of 40 sr, and reported at the backscatter resolution. "

12. *Page 11, line 32. It seems the effective radius for coarse modes 4 and 5 are much smaller than the AERONET climatology as reported in Dubovik et al (2002). So why not define a large effective radius values for these two modes.*
Reference: Dubovik, O. et al (2002), Variability of Absorption and Optical Properties of Key Aerosol Types Observed in Worldwide Locations, Journal of the Atmospheric Sciences, 59(3), 590-608.

Response:
Yes, this is also possible. Actually we have other options for multimode retrievals as shown

in Table 2 of Fu and Hasekamp (2018). For example, in the 7-mode retrieval, the largest effective radius is $3.0\,\mu m$. We can also re-define another 5 modes with larger effective radius for coarse modes 4 and 5. But for the 5-mode retrieval used in this paper, given that all the parameters seem to be well retrieved except for the coarse mode AOD (biased with AERONET SDA data) which is very small for the ACEPOL campaign, we think the current 5 modes are still reliable for this study.

13. *Figure 28. Authors may consider to replace the background of Figure 28a with a true color image of the smoke plume. I have seen such a figure from AirHARP gallery. It would be even better if a retrieved AOD map for the smoke plume is presented here.*

Response:

For the true color image of the smoke plume, we don't have it. We included Figure 7a on SPEX spatial sampling, which gives a sense of how variable the smoke plume is. Figure 7a is the retrieved AOD map for the smoke plumn.

14. *Page 13, line 23-24. It is mentioned here the smoke plume has large spatial variability that may contribute to the retrieval uncertainty. The suggestion above (#13) would at least give a visual expression how large the spatial variability is. In addition, the MAP algorithm would have challenge to retrieve AOD as different view angles see different location (thus AOD) of the elevated plume due to the parallax displacement. Can the authors provide some insights on how to addressing this challenge in the retrieval?*

Response:

The different viewing angles see a slightly different location but the difference is on the order of 100 meter. We do not expect the AOD to vary drastically over this distance. The difference in sampling between the MAPs and HSRL-2 however, may be on the order of 1 km, which may affect the comparion, as AOD will show some variation over a distance of 1 km in the smoke plume. So, the variability is not so large that it affects the retrieval uncertainty but rather limits the comparison to HSRL2.

15. *Finally, I would like to see a figure of retrieved particle size distribution for the smoke case, which would help interpreting the retrieval results listed in Table 2.*

Response:

We agree, and have included Figure 9 in the paper for number particle size distribution from SPEX and RSP in the smoke plume.

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