Response to comments

The authors describe an iterative algorithm for the retrieval of aerosol microphysical properties from atmospheric lidar sounding based on damped Gauss-Newton method including Tikhonov-Phillips regularization. They assume a bimodal-log-normal distribution of a mixture of spheroids and spherical particles. First a simulation study is done. Finally a measurement case is evaluated and compared with the SPEX and RSP retrievals.

The results are interesting, although a few limitations, questions and drawbacks are open. List of remarks in random order:

The under-determinedness of the retrieval yields in non-uniqueness. The authors observed the following property:

"A study of the sensitivity of retrievals to the choice of prior and first guess showed that, on average, the retrieval errors increase when the prior deviates too much from the truth value." This is a well-known phenomenon of iterative methods in case of non-uniqueness. Depending on the initial value the algorithm converges to another "solution". This is the main drawback of the presented method. Question: How many iteration steps were made until the algorithm stops?

It is important to distinguish between the effect of prior and the effect of 1st guess. We do not see a large dependence of the retrieval outcome on the first guess, i.e. the algorithm does not converge to another solution depending on the initial values. This means the iteration approach works well and poses no limitation for the retrieval. On the other hand, there is a clear dependence on prior. This is not related to the retrieval scheme but to the ill-posed nature of the problem. It is clear that we need to further emphasise the underdetermined nature of the system, and the ill-posed nature of the inversion. We have changed the text around line 110 as such: "Keeping in mind the results of uncertainty/information content analysis, we apply an iterative retrieval scheme, taking the lidar measurements and investigating where the information in the measurements goes in a retrieval of microphysical parameters. The problem is clearly ill-posed, and the system underdetermined, as the number of microphysical parameters we attempt to retrieve can be around twice the number of measurements, depending on the configuration."

Additionally, we have included the following in the summary and conclusion, in the first paragraph: "For the HSRL-2 configuration, the three measurements of depolarisation ratio yield information on the spherical fraction of the aerosol distribution. This leaves the two *extinction measurements and the three backscatter measurements to provide information on the remaining microphysical properties. The problem is clearly ill-posed, and the system is underdetermined, with the number of unknowns exceeding the number of measurements by almost a factor of two. Thus, it is clear that prior information is needed to provide a constraint on the microphysical properties of the aerosol distribution."*

Finally, added to the second paragraph in the summary and conclusion section: "The majority of information provided by the lidar measurements goes to these microphysical properties, with a preference for the dominant mode, and it appears little-to-no information is provided for the imaginary component of refractive index or the effective variance."

We used a maximum of 30 iteration steps, with the state vector and Jacobian updated in each step.

Please, explain all abbreviations.

We have improved our presentation of abbreviated quantities.

"The coarse-mode contribution to the measurements is negligible, thus only the fine- mode microphysical properties are presented". Why? Please, include the values.

The coarse mode contribution is negligible compared to the smoke-dominated fine mode (fine mode AOD 24 times higher than coarse mode AOD). The AOD of the coarse mode retrieved from the ACEPOL HSRL-2 measurements is 0.021. For such low mode AOD it is virtually impossible to retrieve meaningful information on the microphysical properties of that mode.

Line 145: I am wondering about the variable n which was not introduced before.

Thanks for pointing this out, n is now defined as such: " ...state vector, and $n^{f;c}_{C_m}$ *is the number of coefficients for the fine or coarse mode." Additionally, for clarity, we now use* C_m *to represent the refractive index coefficients instead of* α*, as* α *features as the symbol for extinction coefficient throughout our work.*

(8) and (9): I am wondering that MAE is the same as bias?

For calculating the MAE, we take the absolute value of the difference between truth and retrieval, wheres the bias does not take into consideration the absolute difference, which *allows us to determine whether a parameter is underestimated or overestimated. Equations 8 and 9 in the paper show the MAE and bias, respectively, with the MAE given by:*

$$\mathrm{MAE} = \frac{1}{n_{\mathrm{pass}}} \sum_{i=1}^{n_{\mathrm{pass}}} |x_i^{\mathrm{retr}}[j] - x_i^{\mathrm{truth}}[j]|, \tag{1}$$

and the bias:

$$\mathrm{bias} = \frac{1}{n_{\mathrm{pass}}} \sum_{i=1}^{n_{\mathrm{pass}}} (x_i^{\mathrm{retr}}[j] - x_i^{\mathrm{truth}}[j]), \tag{2}$$

"The correlation between the truth and retrieval for both real and imaginary refractive index components is rather poor, as exemplified by the r values of 0.349 and 0.251, respectively." This was observed even in retrieval techniques for spherical particles, see Mueller et al, AMT 9 (2016) 5007-5035. The authors should compare their simulation studies with those techniques.

At line 305 we have added: "Previous work considering spherical particles has also shown that it is challenging to retrieve the complex refractive index from lidar measurements (Müller et al., 2016)."

The pt-font in all Fig. is too small.

We have now rectified this.

The main results of Tables 3-6 should be summarized, additionally, in a Figure for the conveniences of the readers. The presentation is boring.

The plots in Fig. 1 of this response have been added to visualise the differences in bias and MAE between the different instrumental setups.

Table 7 caption: The authors should provide more information about:" ...what is to be expected from biomass burning, see for example Nicolae et al. (2013)"

We have added the following to the paper at line 400: As discussed in Fu et al. (2020), the SPEX and RSP values are commensurate with those expected for a smoke plume, specifically that smoke is comprised mainly of fine-mode particles (e.g. Russell et al. (2014)), which is shown by the difference in the retrieved fine-mode and coarse-mode AOD values. The

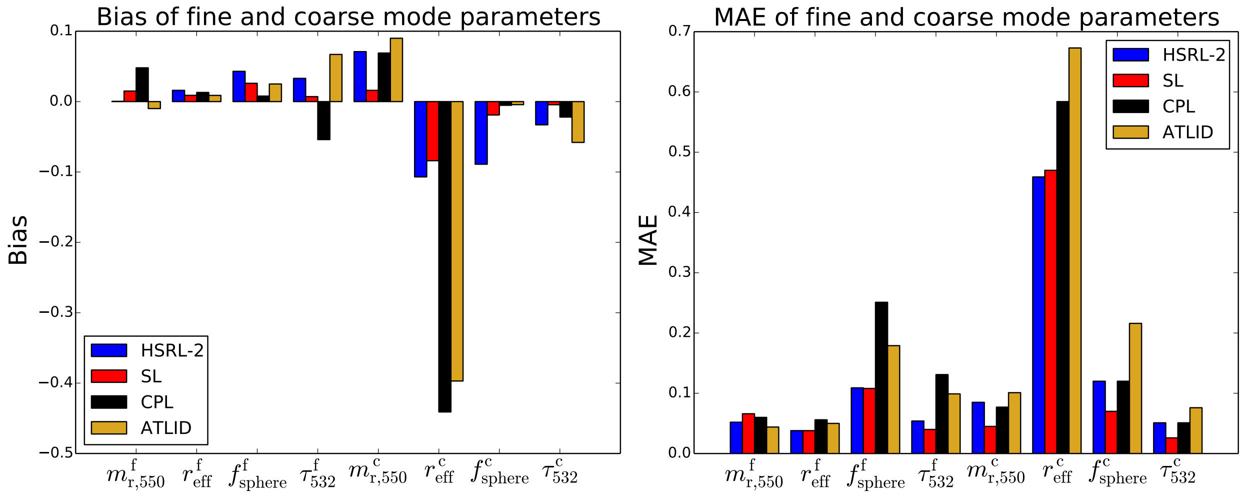

Figure 1: LHS: bias for each of the four instruments, for the various parameters. RHS: corresponding plot of MAE.

clear dominance of the fine mode is also evident from the values of AOD retrieved from the HSRL-2 measurements. The real component of the refractive index retrieved from HSRL-2 is consistent with those reported by Levin et al. (2010), from the Fire Laboratory at Missoula Experiment (FLAME), where the real refractive index value corresponding to biomass burning was found to be mostly in the range 1.55 to 1.60. Additionally, the SSA value for biomass burning was found by Nicolae et al. (2013) to have a value of 0.79 for smoke at 532 nm, with an age of 6 hours, and 0.93 for smoke aged 18 hours. The values retrieved by SPEX and RSP can be considered realistic for smoke, however as mentioned previously we do not expect a better retrieval of absorption properties from HSRL-2 than from MAPs.

It was interesting to learn that using the presented algorithm one gets: "However, the difference between the super-lidar and HSRL-2 configuration is not so clear where measurement noise is included, as overall the results are quite similar in that case." This means in case of measurement errors more input information does not result in a more accurate retrieval. May be this regularization method is not the best one for this retrieval or the regularization parameter was not selected appropriate? Please, regard this point.

The most likely explanation for the fact that the $3\alpha+3\beta$ *yields similar results to* $3\alpha+2\beta$ *is that the information from the extra measurement in the latter case has large overlap with the information already in the other 5 measurements, i.e. it adds only little new information. This small amount of new information seems to 'drown' within the noise for the case where noise is added.*

Given that we allow for a flexible choice of regularisation parameter, it is unlikely that an inappropriate choice is the cause of the similar performance between $3\alpha+3\beta$ and $3\alpha+2\beta$.

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