Reply to Referee #1

First of all authors would like to thank the reviewer for his/her constructive suggestions and general efforts in improving this paper. All suggested revisions were addressed and responded. Please, find the details in the document below.

Review of paper:

Positives - photometer inversion ability to separate fine and coarse mode composition with added lidar data - well explained inversions method - very helpful demonstrations (sensitivity studies and test-cases) - honesty about the limitation

Concerns - efforts to analyze and comment on test cases including to inversions with- out lidar - more discussions to the use over std AeroCom inversions and outlook what we need to improve

General comments

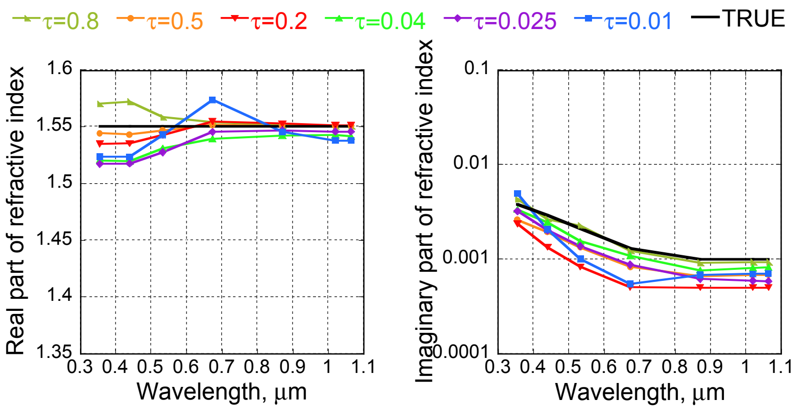
The paper introduces a generalized algorithm to invert from simultaneous sun-/sky- photometer data and lidar data aerosol microphysical properties. With the addition of lidar data (which have been already deployed at many AERONET sites) not only the aerosol vertical distribution but also the compositional detail (e.g. refractive index and single scattering albedo) can be addressed separately for sub-micron and super- micron diameter aerosol particles. This extra aerosol detail is important for aerosol (satellite retrieval) validation and (global model) evaluation efforts. The capabilities of the new "GARRLiC" algorithm are demonstrated with synergetically prescribed scenarios and two observed aerosol events over Minsk, one smoke event and one dust event. The overall method and concept is nicely outlined. And since I am a potential data-user I prefer to focus on the presentation of the results, which also demonstrate differences to standard AERONET inversion products, when no extra lidar-data are available. I was very excited to hear that the coarse and fine mode compositional contributions can be distinguished with this new inversion only to learn later in the text that the sensitivity to the fine mode properties is rather limited, as "lidar measurements do not provide sig- nificant new info about refractive indices of the fine mode" (does this alternately mean that in case of the significant coarse mode the fine mode-mode can be alternately retrievals from [total] minus [coarse-mode]?). Aside from the sensitivity studies (where the figure(s) should be more clear, as to which investigated case(s) are displayed) also some real cases are investigated. There is a lot of material and comparison provided in almost 10 Figures and often inadequately "covered" in two sentences. Therefore I recommend to cut figures or to add explanations (I prefer the ladder). The paper (de- spite a few minor grammar /spelling issues – suggest careful re-reading) is well written (with a strong focus on describing the algorithm). The innovative new aspect is the (somewhat limited) capability to separate fine-mode composition from coarse mode composition via the lidar (-ratio) data, and in applications (sensitivity and cases) there should be a focus on that element. Otherwise this is a great contribution, especially as the number of

co-located lidar and photometer sites are increasing and more detail on aerosol below clouds are needed to understand aerosol-cloud interactions.
Generally we agreed with above overall evaluation of the paper. At the same, we would like to note in our opinion the separations of the complex refractive indices of two modes is certainly new important feature of the retrieval but it is not the major innovative aspect. From our view point the main innovative aspect is the more accurate retrieval of two vertical profiles. Actually our analysis show that though using lidar attenuated backscatter measurements in addition to AERONET data helps to separate properties of two modes; it is difficult to achieve high accuracy in separation. On the other hand using lidar attenuation measurements in joint inversion provide constraints necessary to achieve more accurate resulting lidar ratios of both fine and coarse than if only AERONET data were used (compare to how it is done in LiRIC). We have corrected the text to make this aspect more clear.

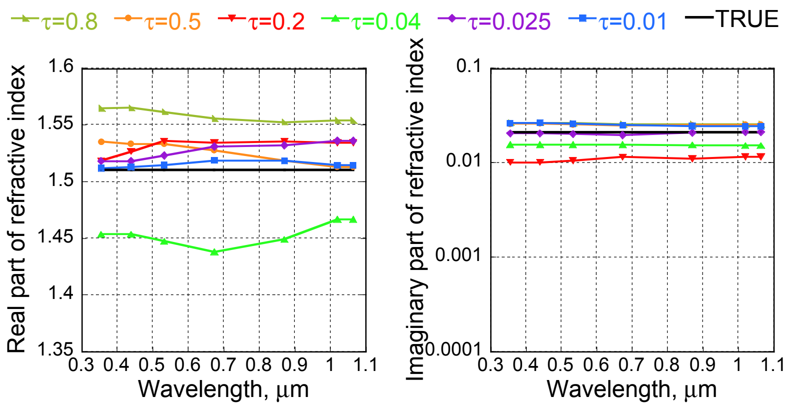
Minor comments

2275 when introducing the 6 scenarios you may want to explicitly mention the associated fine and coarse AOD, since these are displayed in the plots
As suggested the associated AOT of fine and coarse modes were mentioned in the text.

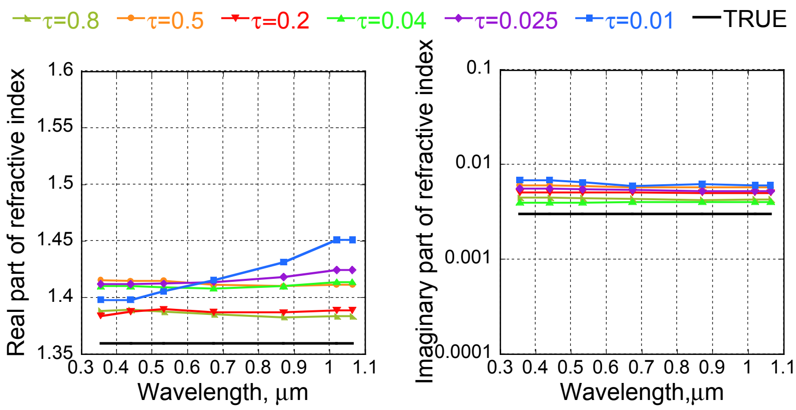
Figs 3/4 for uneven AOD contributions (by fine and coarse mode) underestimates for dust absorption are displayed and for lower fine-mode AOD overestimates for fine- mode absorption are displayed. These errors appear significant (as later also illustrated for associated SSA values) and I am not sure if the entire blame should go to the introduced noise.
The analysis of the retrievals with no noise did not show any significant errors and no clear bias. As can be seen from below figures all errors are much lower in cases without noise. As results of these observations we concluded that observed retrievals were caused mainly by introduced random errors. Some minor clarification of this added in the text.



Retrievals of the refractive index of “Dust” aerosol model in noise free conditions.



Retrievals of the refractive index of "Smoke" aerosol model in noise free conditions.



Retrievals of the refractive index of "Urban" aerosol model in noise free conditions.

2277 There are two major tendencies specifically mentioned, but based on what I see for the RFimag in **Figures 3 and 4**, this is not clear. I really would focus on RFimag, since mode absorption is the most interesting addition. It certainly is true that when AOD is low (as expected) error are larger, but for (larger) dust only when they are uneven.

As suggested, more detailed explanation of the **figures 3-6** was added:

"…First, the higher relative contribution of the aerosol mode into the total optical thickness the better is the accuracy in the retrieval of the optical properties of this aerosol mode. Second …"

2278 and Fig7 The retrieved vertical distribution is much better captured by the coarse mode than by the fine-mode. Is this related to available depolarization information by the lidar?

We would like to clarify that depolarization information wasn't used in this study. In order to avoid any misunderstanding **Figure 1**, describing inputs of the algorithm was added. The analysis suggests that the vertical distributions are retrieved better due to better sensitivity to the properties of coarse mode. This point is additionally discussed later in the same section:

"Another tendency observed in the sensitivity study is lower sensitivity of the retrieval to the fine mode properties, especially to the complex refractive index. …".

Fig 8 It is not quite clear that this figure relates to the orange case of the previous figures. Still I also wonder, what is the point of showing this graph? And why is the retrieved UV SSA profile so different?
After detailed revision of the text the **Figure 8** was deleted.

2278 and Fig 9 the fine-mode lidar ratio shows relatively little RFimag dependence for the near-IR but there is some dependence for the VIS and especially the UV. Are there some other properties (e.g. involving the color ratio) considered that may help bring out more sensitivity?
The following explanation was added to the text in the paragraph describing **figure 3** and **4**:
" Such behaviour could be explained by the fact that the efficiency of scattering by small particles reaches the maximum values when the size parameter is comparable with the wavelength, thus scattering of small particles is more pronounced at the short wavelengths, and scattering of the big particles is more pronounced at long ones."

2280 and Fig 10 what cases are these (brown and red with 0.8/0.2 and 0.2/0.8 for mode AODs) I assume the lidar ratios are derived from the retrieved size-distributions. . . so
I conclude that also the size-distribution data of the combined version will be more accurate (if so by how much?) . The results show that lidar ratios are much better for the minor mode . . . but is this also valid for small AOD cases?
The explanatory labels were added in **figure 10**.
In addition, the new figure showing retrievals of size distributions for each of these cases has been added (see **Figure 4**). However it's hard to state that the accuracy of the retrieval of the size distribution of the minor mode is better with inclusion of lidar data. To authors' concerns it's the difference in complex refractive indexes for aerosol modes that have resulted in these improvements.

Table 3 the three cases here are 'olive', 'orange' and 'red' (it is very confusing, what scenarios are displayed. This should be clear from locking at figure and not from detailed reading of the manuscript).
The more detailed description of the used aerosol mixtures was added to **Table 3**.

2282 and Fig 13 there are relatively more large aerosol sizes in the coarse mode. Is there any good explanation for the "size shift"? And from the explanation for the fine-mode difference in the dust case it is not quite clear, which of the two versions is considered more realistic since the GARRLiC sensitivities had problems for such case.
Our analysis and experience suggests that in this case the size distribution of fine more retrieved by GARRLIC is more accurate due to the additional sensitivities to fine particles added by lidar measurements. Indeed, the

considered observation were obtained during the day when AERONET does not observe the radiation at large scattering angles that is more sensitive to fine mode. Therefore, adding the measurements in backscattering make important difference. Adding lidar observations also causes the apparent changes in the coarse mode, however these changes are minor and we consider them insignificant.

Fig 14 Why is the AERONET only absorption for the dust case smaller (and not in between)? And why is the coarse mode absorption for the smoke case basically zero – is this an artifact?

The changes can be explained by the fact that aerosol optical thickness was very low and the retrieval accuracy for the aerosol absorption is generally very low. The explanations were added:

"Such retrievals could be explained by very low optical thickness of the minor modes ($\tau_f = 0.19$ for the dust case and $\tau_c = 0.04$ for the smoke case). As it was demonstrated by the sensitivity study, such low contributions of the minor modes could lead to high estimation errors in their complex refractive index."

2283 and Fig 15/Fig16 Are there real profiles to compare with?

Unfortunately we could not find any independent data that could provide the information on real profiles.

And doesn't a 3&2 RAMAN lidat provide lidar ratios at least at 355 and 532 nm, which could be displayed here?

Unfortunately RAMAN data were unavailable for the selected periods. Also the RAMAN measurements are mostly made during nighttime and, therefore, they are not fully appropriate for the comparison.

Is there any explanation for the high non-sphere contributions in the smoke event and the relatively low contributions in the dust case?

The backscattering measured by lidar always adds some sensitivity to particle shape and, therefore, it is not surprising to see differences between the results of GARRLIC and standard AERONET retrievals for the fraction of non-spherical particles. In addition, in the considered cases the aerosol optical thickness is very low and therefore the accuracy of retrieved information about particle shape is quite limited for both AERONET and GARRLIC retrievals.

2283 and Fig 17 Why is the SSA now lower (absorption stronger) compared to AERONET?

Eventually, this difference was forced by lidar observations necessary for fitting lidiar data in the GARRLiC retrieval in addition to AERONET measurements. At the same time we would like to note that the observed difference is within the error bars of the AERONET-retrieved values of SSA.

2284 and Fig 21/Fig 22 In the end a comparison is given to results of the LiRIC algorithm, an already available sun-/sky photometer/lidar inversion method from the group in Belsk. Except for the different vertical resolution (or integration) the coarse and fine- mode profiles are quite similar. But is this plot needed?

This figure was aimed to demonstrate the consistency between the LIRIC and GARRLIC retrievals in a case where no differences are expected. The appearance of any significant difference in this case would be an indication of some unidentified inconsistencies between the methods or codes.

A paragraph clarifying that was added:

"Figure 22 is aimed to demonstrate the consistency between the LiRIC and GARRLiC retrievals in a case where no differences are expected. Both algorithms provide two distinct vertical concentration profiles for different aerosol components and the comparison of profiles retrieved by GARRLiC and LiRIC was made. The main difference is that GARRLiC modifies the retrieved columnar properties of aerosol. In addition, GARRLiC uses bi-component aerosol model that may have different complex refractive indexes. This assumption affects estimations of lidar ratios for each mode and therefore the retrieved vertical profiles. Therefore the demonstration of LiRIC and GARRLiC codes consistency has been performed1215 suing the case with small difference in complex refractive in- dices of fine and coarse aerosol modes (see fig. 15)."

Similarly I wonder if **Figure 22** is necessary?

After detailed revision of the text **Figure 22** was deleted.