# Review of 'Joint retrieval of surface reflectance and aerosol properties with continuous variations of the state variables in the solution space: Part 1: theoretical concept'

This paper outlines an algorithm to retrieve surface reflectance and optical properties of atmospheric aerosol from visible and infrared satellite imagery. The vast majority of equivalent algorithms (including previous iterations of this technique) assume the optical properties of the aerosol particles observed (known as the aerosol type). The paper proposes considering multiple types simultaneously, such that the retrieval can freely explore a continuous space in single scattering albedo and asymmetry factor. A theoretical demonstration of the algorithm is presented using idealised data.

I wish to clearly state that I quite like the idea behind this algorithm. Single-scattering albedo and the asymmetry parameter provide a theoretically superior state space in which to evaluate aerosol retrievals and I would love to see (and do) more research around this idea. I am always pleased to see a discussion of information theory in an atmospheric science paper and more validation papers should discuss uncertainty. I want to see this pair of papers eventually published.

My issue is that I see no evidence that this algorithm currently produces acceptable results. Even in the idealised circumstances presented here, the retrieval exhibits biases in AOD of up to 0.04 and the reported uncertainties of 0.1 - 0.3 are well in excess of any method I'm familiar with. Even looking in the SSA-$g$ space used by most of the figures, the uncertainty on each term is substantial. For example, the 440 µm point in Fig. 11 occupies about a third of the area defined by Fig. 3. I know retrieving SSA is difficult, and the uncertainties should therefore be large, but the tone of this paper is entirely unjustified by the results presented. The introduction and conclusions need to be toned down to represent the quality of the results.

The revisions to the manuscript are an improvement, but the authors seem to have disagreed with the majority of my original comments. My apologies for being unclear — I shall try again. I leave it to the discretion of the editor which, if any, of the following should be addressed in a further revision.

- I still think you should have applied the retrieval to noisy data. I'm not asking for a perfect satellite simulation that replicates real viewing conditions and different spectral response function. Merely adding 3 % random perturbations to the observations underlying experiment F12 and F22 would be sufficient. There needs to be some evidence that the algorithm can deal with unavoidable noise to be of practical use. Such an analysis might also demonstrate that your predicted uncertainties are justified, improving the reader's confidence in your technique. (I'd actually prefer to see a thorough sensitivity study of bias as a function of the various parameters rather than the simple 1 - 3 % uncertainty you've added, but that can be in a third paper.)

- I remain unhappy that a joint retrieval of aerosol and the surface is promised but only aerosol is discussed. There's a hint of a quite good surface retrieval at the end of Part 2 (and it's supplement). Yes, this paper is describing how the aerosol retrieval has been improved but your previous paper was from 2010. You can't have left the surface retrieval completely unaltered over almost a decade of research and, even if you did, I'd be rather surprised if all the changes you made to the aerosol scheme didn't impact the response of the surface scheme in some way. As you point out in your first sentence, the two are non-linearly coupled. Why decouple the papers when there's only one forward model?

- On L118, I don't think LUTs should be mentioned. The problems your describe aren't caused by the use of LUTs, but rather the use of LUTs that are either too coarse or are tabulated for insufficiently general variables. It is possible to build LUTs that have SSA and $g$ as their axes. (As a side note, the GRASP algorithm of Dubovik's group was demonstrated on PARASOL data but can be, and has been, adapted to any sensor. As the information content decreases, the reliance on the prior increases.)

- You're entitled to use whatever terminology you like, but why not call the terms 'surface' and 'atmosphere' as you did in Govaerts et al. (2010)? 'Single' scattering could describe both single scattering by the surface and single scattering by an aerosol.

- You missed my point about the beginning of your conclusions (now L425) for the example I gave. The third sentence of the conclusions implies you provided evidence of a fundamental flaw in retrievals that assume an aerosol type. You did no such thing and this statement should either be removed or edited to be accurately represented as an opinion.

- Apologies for my unclear remark on the title. Throughout the paper, you argue that assuming aerosol type is inconsistent with the assumptions of OE. I agree with that technical point. It is conceptually preferable to define state space in terms of the microphysical properties, as you have done. However, 'continuous variations of the state variables in solution space' will not convey that point to most readers as 'state variables' is not specific and all OE involves continuous variation of variables. Your enhancement is to select different variables to retrieve and constrain them through a choice of aerosol type (a.k.a. vertices).

  Your paper proposes something between Dubovik's direct retrieval of SSA-phase function and the assumed type of your previous algorithm. Aerosol types are still assumed (presumably to get around the highly non-Gaussian nature of the SSA-$g$ prior distribution) but the retrieval may freely combine them to produce continuous variations in SSA and $g$. Hence, I would recommend a title along the lines of 'Retrieval of surface reflectance and aerosol microphysical properties through the mixture of representative aerosol types' but better worded. That emphasises the variation of aerosol mixture rather than the variables themselves.

  To be pedantic, the techniques you critique are completely valid when evaluating only one type as they are effectively claiming to have perfect prior information about certain variables. That's obviously an inaccurate claim but it's statistically consistent. The inconsistency arises from the manner in which different types are combined.

- I recommended deleting the sentence now starting on L354 as it is obvious that the uncertainty in SSA is larger than that in $g$ since your retrieval could not vary $g$. As it stands, a reader unfamiliar with retrieval theory may not appreciate that your precise retrieval of $g$ derives from having given it no other option (as the aerosol types provided demonstrate no variation in $g$.)

A few more comments that occurred during my most recent read of the work,

- Reading through Part 2, it became evident that Part 1 demonstrates retrievals using only one observation while Part 2 combines observations from 5-16 days. Why didn't you demonstrate the retrieval you actually intend to use? Presumably the additional data would improve the retrieval and provide better agreement? You spent several pages introducing the **H** matrices but it doesn't seem they played that much of a role in this paper. And, anticipating your response, a reader will be no more distracted by a few additional plots than they already are by Figs. 6-12. The retrievals could be plotted on the same axes, hopefully showing a reduction in uncertainty and bias as more overpasses are included.

- If not doing that, I agree with the other reviewer's comments that Fig. 6-9 and 10-12 could be merged into single figures to facilitate comparison of the retrievals as a function of the vertices used.

L18 I'd prefer to say "can be modelled as" rather than "is equivalent to" as there are various possible models for this particular problem.

L309 Could you be more specific than 'small' about this threshold?

L379 I disagree that $\omega_0$ is well retrieved; at 870 nm it's off by 0.03. The retrieved values are *consistent* with the truth, but so is half of the available range. If you insist that getting the range right is noteworthy, you need to provide an idea of how good these sorts of retrievals normally are and my memory is that AERONET is more accurate than 0.03 in these conditions. If I remember incorrectly, my apologies.

L382 This uncertainty isn't underestimated — it is merely wrong. The retrieval wasn't given the ability to change $g$ and so it considers it's retrieval to be very accurate.

- In the conclusions, it would be more honest to mention the significant uncertainties in your retrievals at the end of L444 and to remove the word 'major' on L454.

And some grammatical recommendations,

L21 the amount of sky incident radiation

L33 improve to allow permit the processing

L71 Finally, the possibility ability to

L127 be applied on to the entire

L172 similar approach as to the one

L182 way. In the case of When processing of actual satellite data

L254 often assumed being to be acquired

L255 Such a situation

Eq.11 Plus signs are missing between the terms.

L355 retrieved values match exactly exactly match the true

L367 correlated with the amount of atmospheric

L369 the observations are taking place

L436 is radiatively coupled with the a surface, represented with by the RPV