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# *Interactive comment on* "Joint retrieval of surface reflectance and aerosol properties with continuous variations of the state variables in the solution space: Part 1: theoretical concept" *by* Yves Govaerts and Marta Luffarelli

**Anonymous Referee #1**

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This paper outlines an algorithm to retrieve the optical properties of atmospheric aerosol and the surface 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 cannot recommend this paper for publication until Sec. 6 is substantially redrafted.



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Discussion paper

The paper is reasonable as a description of a retrieval method, but it lack a demonstration that the algorithm is *practically* useful. The authors present the evaluation of simulated data, but do so in such idealised circumstances that the exercise provides little insight into the algorithm's overall utility. However, the presentation is decent and the central idea interesting and worth publishing, even if I'm not entirely convinced it is valid.

To be more specific in my critique:

- The paper must demonstrate the algorithm applied to noisy data. As it stands, the results shown are somewhat concerning as the algorithm can only precisely replicate the truth in the simplest case despite perfect input data. This implies significant (if not large) forward model errors that the paper neither discusses, quantifies, nor attempts to alleviate. Considering CISAR has already been applied to real data, this demonstration should be a straightforward matter of adding random noise to the existing experiment's data and adding an additional line to Figs. 5–9 for the retrieval under noise.
- Additionally, your experiments assume that the surface parameters are known a priori. That is unacceptable considering the title of the paper is 'joint retrieval of surface reflectance and aerosol properties'. If you promise a joint retrieval, you need to demonstrate it. If you don't intend to demonstrate it, redraft the paper to de-emphasise the surface terms while explaining why you built a joint retrieval and chose not to use it. Such a demonstration is important as the reader needs to understand how the optimal estimation balances uncertainties in aerosol against the surface. (I would show averaging kernels, but that isn't widely popular.)
- From my experience teaching linear algebra, I would summarise the paper's central idea as, "Rather than assume aerosol optical properties for the retrieval, one should define a basis of aerosol types. The observed properties of any real aerosol are then some linear combination of the properties of those basis types."

From that, I wonder if you could use an objective technique to select your vertices? Given that a large number of aerosol types are currently defined, there are various techniques within linear algebra from which a minimal set of types can be derived (e.g. Gram-Schmidt or one of the eigenfunction analyses). This could give you better fits in the ideal circumstances and would unambiguously resolve the question of how many vertices you should use (which is rather unsatisfying at the moment).

- A central assumption of the paper is that either the surface or the aerosol vary sufficiently slowly as to be effectively constant over the observation period. There needs to be some justification of this. I wouldn't accept a simple citation of existing work as the quality of such assumptions is highly dependent on exactly where and how you evaluate them.

- Various sections of this paper rely on a familiarity with Govaerts et al. (2010). A less brief summary of it's conclusions and how that method differs from this one would be useful to the casual reader.

L95 While it is strictly true that optimal estimation requires state vector variables to be continuous, I feel that your argument here mis-characterises what is going on. As you admit, there are over 100 variables that affect the radiance seen at TOA scattered by aerosols. The prevalent approach is to assume that most of those variables are determined at the aerosol's creation. Diner et al. (2012) demonstrated that superior results can be obtained by assuming less *when additional information is available* (specifically, multi-angular observations).

To me, it seems obvious that attempting to retrieve either more variables or more physically motivated variables will result in a higher quality retrieval. The issue isn't that most retrievals assume an aerosol type. Their issue is that they use too few observations to assume anything better. To put it differently, your retrieval is superior because it uses more data and so can vary more variables, providing the OE algorithm with more freedom to find an accurate solution.

L202 I have a problem with your terminology here. My experience is that in aerosol remote sensing ‘single’ or ‘multiple’ refers to the number of times that the light is scattered by an aerosol particle. Eq. (2) quantifies the reflection from the surface.

Sec. 4.2 I would like to see a justification for this other than ‘it works in Sec. 6.’ Firstly, I’m uncertain if you are only considering single aerosol scattering or not. While I’m quite happy that single-scatting properties combine linearly, I am suspicious of this being true for multiple-scattering. Secondly, I doubt that linearity would hold for large optical depths. I expect that your technique is a reasonable approximation, but you should directly assess the error introduced (i.e. don’t just work it out after-the-fact from the quality of your retrievals).

Tab. 1 Are these values ever used within the retrieval to represent forward model error? If not, they should be.

L314 I have no problem citing grey literature in general, but this is unacceptable. The context implied to me that this referred to a validation study, not an unreviewed conference poster. I assume that application of CISAR to real data is in Part 2 (which really should have been submitted alongside this paper) and this reference should be adjusted accordingly.

Sec. 7 I disagree with many statements here.

L402 This paper contains no analysis of other OE techniques. You cite other studies, but they only comment on specific algorithms. I have no problem with the conclusion that retrieving SSA and phase function provides ‘better’ results than not doing that *when multi-angular observations are available*. Your use of multiple MODIS overpasses to emulate multi-angular observations is fine only in those parts of the world where the aerosol or surface is constant over a period of days. Those of us evaluating plumes or areas that suffer frequent cloud cover can't make that assumption and your rejection of such work is excessive.

L425 Experiment F00 did not prove your assumptions are valid. It showed that they might work in one circumstance, and even if you had made a comprehensive evaluation I'd say you only showed that the assumptions were 'useful'. I might accept 'Experiment F00 demonstrated that such assumptions can produce accurate retrievals.' However, my earlier concern that your experiments are insufficient to demonstrate the utility of your method remains.

L433 This statement is far too broad. Replace 'which provide a limited number of independent observations' with something that expresses the limitation of your technique. As it stands, it reads like your algorithm could use any input data and that is plainly false.

L435 I agree that the choice of vertices is critical. Your empirical selection is unsatisfying and this choice needs more thorough consideration.

L440 As outlined above, I disagree with virtually everything in this paragraph.

Some more minor points and comments:

- I have several issues with the title.
  - Though the algorithm can technically retrieve surface properties, this is not demonstrated in the paper nor really discussed other than as a component of an aerosol retrieval. The author's previous paper discussed the surface at great length and, though I don't expect them to replicate that here, a paper on a 'joint retrieval of surface reflectance and aerosol properties' should discuss and demonstrate both.

- The authors rightly wish to highlight the unique consideration of multiple types within their retrieval. However, ‘continuous variations of the state variables in solution space’ fails at that. At first glance, the phrase was virtually meaningless as optimal estimation can only be applied to continuous variables. What the authors have done is define state space differently, such that the retrieval can consider variations along different axes. As an alternatives, I recommend ‘Retrieval of surface reflectance and aerosol optical properties through decomposition into representative types: Part 1: theory’ or ‘Retrieval of surface reflectance and aerosol optical properties by simultaneously considering a representative set of aerosol types: Part 1: theory’.
- Regardless, ‘variations’ should be singular.

L98 Though MISR might not assign uncertainty to aerosol class, that doesn’t mean you can’t and that people haven’t.

L171 Are you sure Liu and Ruprecht (1996) is the most appropriate reference for your radiative transfer solver? That paper assumed spheres and spends a lot of time talking about the microwave.

L207 Why use finite differences to calculate the Jacobian? It’s slow and inaccurate while all the solvers I know provide analytic Jacobians nowadays. If your solver doesn’t provide them, you should explore alternatives. My experience is that the discontinuities produced by finite differences make optimal estimation much more sensitive to the first guess and take longer to converge.

p10L3 Shouldn’t the phase function be a function of angle too?

Eq.(8) Is $\tau_a$ that defined in Eq. (3) or should it be an equivalent definition using $\tau'$?

L220 A superior sentence would be, “The relative RMSE between FASTRE and the reference model is in the range 1 – 3 %.” There’s no need to hide the larger difference in the 0.44 channel.

Eq. (11) The third and fourth terms are common, but they aren't from Rodgers (2000). You'll need another reference for them.

Tab. 2 Why doesn't F0 have a value for $N_f$?

L328 Delete the sentence starting 'The estimated single scattering. . . "

Sec. 6.1 Precisely how many observations are you using and what instrument are you emulating?

Technical corrections and recommendations:

L11 The CISAR algorithm functioning is

L15 surfaces. The Discrimination between

L22 In most of the cases an increase

L23 for an increase of in the fraction

L25 does not allow to full characterisation of the underlying

L35 product generation from archived

L54 Such an approach prevents

L72 demonstrate the possibility of generation of Essential Climate

L74 that time in the EUMETSAT

L77 to 1. It This represents a severe limitation

L78 exceed such a limit.

L83 initiative to generate for a Climate Data Record (CDR) generation of

L91 coupling with the atmospheric scattering

L95 prevents a continuous variation of the

L96 state variables that characterise the aerosol

L97 of such an approach

L98 are defined as a prior knowledge

L105 considerable amount number of observations, such as those

L109 a large amount number of observations

L114 easily applied on to observations

L121 should actually only be applied on to the entire phase function $\Phi$ only. These

L131 Errant space after ‘distribution’

L133 vary essentially mostly as a

L175 computes separately the contributions from single and multiple scattering separately, the

L194 represented by an external

Fig4 radiatively coupled with the

p10L4 These The different vertices, representing fine and coarse mode aerosols, are

L219 As can be seen, in most of the bands the relative

L229 data are often assumed being acquired

L230 where most likely the atmospheric properties likely remain unchanged

L238 which increases the number

L241 thickness $\tau_v$ of for the respective aerosol vertices that are mixed in layer $L_a$ used. Prior information

L242 consists of expected values $\mathbf{x}_b$ of the state variables $\mathbf{x}_b$ characterising

L243 regularization on of the spectral

L247 will be further herein referred to

L279 state variables, such as the

L280 weight, etc, are

L317 showing thereby therefore that the

L321 differs from the ones of these

L323 wavelength is actually limited

L332 as the straight difference

L351 Units shouldn't be italicised.

L377 The errors $\epsilon_\tau$ is in this experiment F12 are further reduced with respect compared to

L378 manages however to

L405 allowing a continuous variation

L406 having the parameters describing the aerosol

L480 This reference is missing the page number. Also, the DOI has a space in it for some reason.

L512 This DOI also has a space.

## References


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