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## **Comment on amt-2021-212**

Anonymous Referee #1

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Referee comment on "Optimization of Aeolus' aerosol optical properties by maximum-likelihood estimation" by Frithjof Ehlers et al., Atmos. Meas. Tech. Discuss.,  
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Review of "Optimization of Aeolus Optical Properties Products by Maximum-Likelihood Estimation"

This paper outlines the application of maximum likelihood estimation to the analysis of profiles observed by the high spectral resolution lidar mounted on ESA's Aeolus satellite. To facilitate a bounded optimisation, the lidar equations are cast in terms of layer optical depths and lidar ratios while measurement uncertainties are approximated by the variance of the observations. The method is compared to a more traditional lidar analysis techniques for both real and simulated observations and is shown to produce smoother, more physically consistent fields that are more consistent with other measurements and the truth, respectively. This work, inspired by unexpected limitations in the instrument after launch, hopefully represents the beginning of more routine use of modern retrieval techniques in the analysis of lidar profiles.

I recommend this paper for publication after minor corrections and thank the authors for providing a genuinely enjoyable read on a rainy morning. My only significant comments relate to the discussion of iterations from lines 278 to 292:

■

In Eqn. 15 you say  $L_p > 0$  but on L281 you say you start iteration at  $L_p=0$ , which is then out-of-bounds. Presumably you meant to say  $L_p \geq 0$ . Regardless, I am surprised you chose to start at one end of your solution space. I would have started at some climatological mean value to keep the number of iterations down by giving the method the ability to increase or decrease  $L_p$  in the first step.

■

Forty thousand is a preposterous number of iterations! Are you sure L288 shouldn't say 40? Every optimization routine I've worked with tends to converge in 5 to 10 iterations unless the model is extremely non-linear. If you need more than several dozen iterations to get useable solutions, I would guess you've done something wrong – either a gradient is being miscalculated or an inappropriate optimization method is being used.

■

I don't agree with you at L291 that artificially extending the number of iterations produces a fairer comparison to the SCA. This sounds like an attempt to avoid discussing the method of identifying convergence because those are contentious. I honestly don't care how you do it, but I do think the paper should explain how you intend to produce data outside of the context of this validation and, ideally, give some idea of the magnitude of difference. I suspect it makes very little difference, which is why you ran a set number of iterations, but that should be stated.

■

Something similar comes up again at L357 when you say the first guess "contaminates" your mean. A first guess is not a prior; it should not affect your final solution. Exceptions are where the method fails (and so you throw away the solution) or there are multiple minima (which would require a more advanced minimisation routine). Could you explain what you mean here? Is it just that you aren't doing any quality control and so failed retrievals are present in the output? If so, you should do quality control! You don't need a value from every single pixel.

The following comments are mostly matters of personal curiosity rather than issues that need to be addressed:

■

The text in figures should aim to be approximately the same size as the text in its caption. If it is possible, all the figures in this paper would benefit from being regenerated with a smaller page size, such that the font is larger relative to the image.

■

L68) I would say backscatter is 'measured' rather than 'known' with higher precision.

■

L77) Is there a reason you preferred to constrain L to be positive rather than retrieve its logarithm? I could see this being useful in your proposed future work to produce consistent regularization in variables that span several orders of magnitude. Further, aerosol optical depth (which is what you actually retrieve) is known to be log-normally distributed, such that the log of L is a more natural basis in which to define a regularization.

■

L103) I feel like this paper demonstrates that such a retrieval is possible rather than it being something you need to assert in advance.

■

L204) I've not encountered this use of a backslash before. Did you mean to say "a ratio"?

■

L230) While true, lidar signals are often far from this limit.

■

L261) I think that the two uncertainty ranges shown in Fig. 5 come from the two sources of uncertainty you mention here – a simple Poisson assumption and the variance of the downlinked profiles – but it would be useful for that to be stated clearly somewhere. This sentence currently implies the Poisson approximation is not used in the remainder of the paper, but you go on to mention it several times.

■

The first paragraph of Section 4 unnecessarily repeats the preceding paragraph.

■

I would mention the existence of Appendix D at the end of L343 as that's when I asked "what's the RMS deviation"?

- 

In the caption for Fig. 4, don't you mean the west coast? Also, the description of 4(b) implies that three versions of the feature mask are shown. I think you meant to say that the rows show backscatter, extinction and lidar ratio, with identical features masks shown in each frame of the rightmost column.

- 

L418) I'd argue that the image shows the advantage of forcing  $L > 0$  rather than robustness.

- 

L493) Is there any intention to release this data? Any possibility of funding to process the full record or become an operational product?

- 

Appendix A largely repeats Section 3.1.

- 

L516) ECMWF data would typically be interpolated rather than averaged as the values represent behaviour at a point rather than a grid cell average. What do you mean by "mean" here?

I found a number of grammatical corrections:

- 

L2) the Atmospheric Laser

- 

L2) is an Ultra Violet

-

L5) Being an HSRL

▪

L10) demonstrate a predominantly

▪

L11) information by the SCA

▪

L15) due to effective noise

▪

L27) respectively, and the Cloud-Aerosol

▪

L32) addressing high uncertainties in climate change modelling due to the indirect

▪

L46) [commas around 'and similarly Raman lidar observations']

▪

L48) increase the SNR

▪

L68) extinction

▪

L90) Either "revolves around", "orbits", or just "Aeolus is in a Sun-synchronous polar orbit"

▪

L90) seven day repeat

▪

L92) Earth with an off-nadir

▪

L93) Traditionally, "Earth" is the planet and "earth" is dirt so I don't see why you use both versions here.

▪

L93) There should be a space between numbers and their units.

▪

L125) [remove the comma]

▪

L135) scales dependent on

▪

Fig 1) accumulation to observation

▪

L164) [comma after 'following']

▪

L172) into a molecular

▪

L178) [commas around 'in principle']

▪

L181) can be simplified by introducing the range

▪

L209) Appendix A.

▪

L281) consist of an aerosol free

▪

L296)  $y_{\text{obs}}$  are generated

▪

L302 and 563) Moore-Penrose

▪

L312) the real instrument cannot

▪

L334) particularly

▪

L334) by an additional

▪

L336) simulation are shown

▪

L350) but at the

▪

L381) produces very

▪

L409) cloud

▪

L428) the lidar ratio along the plume's horizontal

▪

L439) The ground based

- L450) aerosol
- L457) be located by using extinction coefficients alone due to the fine range
- L484) additional
- L487) [delete comma]
- L514) channels
- Eq A7) [something has gone wrong with the spacing]
- L541) e.g.
- L559) is inverted by
- L561) i.e.

I largely appreciated the relatively conversational tone of this manuscript compared to the average paper, making relatively dry material easier to read. But there are a few places where I would have made a different choice of words. As these are a matter of style, I

leave it to the authors to decide if they agree with me or not.

■

I don't think "Products" is necessary in the title of the paper. Then again, I would have called it "Optimization of Aerosol Optical Properties from Aeolus Profiles by Maximum-Likelihood Estimation" because I'm concerned that someone might think the "Optical Properties" are possessed by Aeolus rather than by particles in the atmosphere.

■

Remove "(partly)" from L8. A problem is either ill posed or it isn't; there is no partly.

■

L52) A white paper under preparation in the UK is hoping to call these "representation errors" rather than worry about 'representivity' vs 'representativeness'. Obviously there's no obligation to agree with us but I think it's a cleaner phrase.

■

L122) "corrected for to obtain" doesn't look strictly wrong but sounds very strange to a native near; I wouldn't say the 'for'.

■

Fig 1) While this image is technically "Exemplary" in that you are using it as an example, English has corrupted the word to typically mean "Outstanding". I'd say "Illustrative" or "Example of" instead.

■

Eq 2-3) I know you're using T for transmission but it hurts slightly to see temperature denoted t. I would have used  $\mathcal{T}$  for transmission.

■

L179) Maybe "extensive" rather than "excessive" as the latter has negative connotations.

■

L312) Perhaps "noise level resembles nominal" as 'resembles' already implies an inexact comparison.

■

L370) "...reacts after the backscatter coefficient, resulting in the attenuation of the first 500 m of the cloud being captured incorrectly with consequences..." I struggled to understand this sentence and have made my best guess at what you were trying to say.

■

L373) "Hence, the same feedback loop is triggered, as described in case I for changes of range bin thickness." I find it difficult to understand long sentences where the verb is at the end, so I moved the verb to the start.

■

L383) "MLE causes extinction" as 'locks' is a rather strong word for what happens.

■

Fig 3) This caption could just say "As Figure 2 for Case II".

■

Fig 4) Is it necessary to use very similar colours for the two lines? If you moved away from a rainbow colour bar, you would have more options so I don't have to strain to see if the line has little dots in it or not.

■

L463) Perhaps "refactored" rather than "rephrased"? The latter usually refers to words rather than actions.

■

L479) Considering you go on to critique the use of a feature mask, you might want to say "it is possible to" rather than "it would be advantageous to".

■

Eq C2) I have never seen the notation  $K^{-T}$  to indicate an inverse transpose. Probably because it's ambiguous if I transpose the inverse or inverse the transpose.  $(K^T S_Y^{-1}) K^{-1}$  is a more traditional way to write this equation.

■

I was taught to put a hyphen between words that together form a single adjective. I provide a non-exhaustive list of places where you could do that: L33 & 439) ground-based; L90) seven-days; L95) Rayleigh-Brillouin; L101) double-edge; L123) time-

gated; L137 & 140) so-called; 281) aerosol-free; L374) noise-induced; L393) polarization-sensitive, dual-wavelength; L541) particle-free.