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Interactive comment on "Uncertainty characterization of AOD for the AATSR dual and single view retrieval algorithms" *by* P. Kolmonen et al.

Anonymous Referee #2

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This paper gives an overview of the ADV and ASV algorithms for retrieving aerosol parameters from the AATSR instrument over land (ADV) and sea (ASV), and then presents a methodology for propagating measurement uncertainty into the retrieved parameters. The paper also gives an overview of cloud screening and quality control used by the two algorithms, as well as the reflectance averaging techniques used to scale-up the ADV/ASV algorithms for processing of extensive global datasets. The paper then presents an AERONET validation of both the retrieved AOD and uncertainties.

The paper is well written, on the whole and is certainly of scientific interest. However, there are three facets of the analysis presented in this paper that require attention by

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the authors before I could recommend the paper for publication. Once these issues have been addressed by the authors, I would be happy to re-review the revised paper.

Issue 1

The first is, relatively speaking, a minor issue. Both the ADV and ASV algorithms discussed in the paper are essentially unweighted linear-least-squares fits, which do not take measurement, or modelling, uncertainties into account. This paper presents posteriori propagation of uncertainties from the measurements onto this unweighted estimate of the retrieval parameters (commonly referred to as the retrieved state). This is not incorrect, but the authors should be aware, and make it clear in the paper, that the unweighted state will be different from that which would be obtained if the measurement errors were taken into account in the least-squares fit. Essentially, the authors approach produces a PDF of the retrieved state using one set of assumptions, but an expectation value using different assumptions.

Issue 2

More pressingly however, I am rather concerned about the derivation of the error propagation presented by the authors on Pg 4049/4050. The approach taken is to write the square root retrieval cost function, and given in Eq.(11) & Eq.(14), in vector form and then propagate the measurement errors into the retrieved state using a Jacobian matrix. The basic mistake here is the use of Eq.(14) for this analysis. Essentially error propagation involves mapping the measurement uncertainty from the manifold containing the measurements to the one containing the state parameters, which is done using a forward model relating the retrieved parameters to the measurements. The derivation as it stands makes no sense - the measurements, $\mathbf{r}$ appear in the independent argument vector of the function $\mathbf{f}(\mathbf{x})$, and this function does indeed depend on them. However, they are mysteriously missing from the derivation of the Jacobian, which the

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authors themselves correctly define as: $\mathrm{F}_n = \left(\frac{\partial \mathbf{f}}{\partial \mathbf{x}}\right)_{\mathbf{x}_n}$ although the Jacobian written down in Eq.(18) is that for retrieved parameters only. The authors then define a "measurement covariance" $\mathbf{C}_T$, which contains the uncertainties on three out of six of the measurement values and treat it as though it refers to the left-hand side of Eq.(14). The authors then use the partial Jacobian given in Eq.(18) to map the partial measurement covariance into state space.

There are three things wrong with this derivation:

1. The measurement covariance matrix should be a 6×6 element matrix, with row/column for each of the measurements (forward and nadir TOA reflectance in three channels).

2. $\mathbf{f}(\mathbf{x})$ is a function of the measurements, rather than describing the measurements themselves (i.e. it is not a forward model). The measurement covariance does not describe the PDF of $\mathbf{f}(\mathbf{x})$ and thus cannot be used as shown in Eq.(15). In fact, as $\mathbf{f}(\mathbf{x})$ is a function of both the retrieved parameters and the measurements, the $\mathbf{C}_{\mathrm{X}}$ matrix in this equation should describe both the "model defining parameters" and the measurements.

3. The calculated Jacobian does not map from the retrieved state manifold to the measurement, but to the $\mathbf{f}(\mathbf{x})$ function. Hence it cannot be used to map the measurement errors onto the retrieved parameters.

In order to perform the error propagation correctly, the authors require a forward model expression which maps the retrieval parameters into the measurement manifold. In the ADV case, this is actually Eq.(1): $\rho(\mu_0, \mu, \phi, \lambda) = \rho_a(\mu_0, \mu, \phi, \lambda) + \frac{T(\mu_0,\mu,\phi,\lambda)\rho_g(\mu_0,\mu,\phi,\lambda)}{1-s(\lambda)R_s(\lambda)}$. Of course, the retrieval technique employed by the ADV algorithm removes the dependence on R_s and ρ_g, so that no knowledge of the surface reflectance is required. However, the resulting expression is then a function of both the forward and nadir radiances in each channel, which makes the linear error propagation the authors are

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attempting impossible. This creates something of a conundrum, as propagation of the uncertainty requires knowledge of two parameters which have been deliberately made unknown in the retrieval problem.

Thus, it is not immediately clear to me what approach should be taken to propagate the errors in ADV. It is possible that the complete Jacobian of Eq.(14) might be used to propagate the measurement uncertainty (assuming zero values for the covariance of the state parameters) to provide a PDF of the f(x) function. The same Jacobian could then be used to propagate this back into a full covariance of the x, including the state parameters. It also should be possible to gain some information on the surface reflectance from the retrieval, although not enough to provide all the information required for the forward model expression above, as retrieval of the b_{fine}, b_{naf}, L & k parameters mean the four values have already be extracted from 6 measurements. This is for the authors to investigate.

As the same approach to uncertainty propagation is taken with the ASV algorithm in section 3.4, the same problems described above apply. Things are a little easier to rectify in this case however, as all terms of the forward model – Eq.(22) – are known.

Issue 3

Finally, I have some problems with the validation of the uncertainties discussed in section 5.2. Firstly, the authors do not mention the uncertainty or possible biases in AERONET. These are certainly smaller than would be expected in a satellite data-set, but they should be discussed.

In addition to discussing the per-pixel uncertainty, Fig.(5) also shows level 3 uncertainty as a function of AOD. How is level 3 uncertainty derived? Is this just the average of the per-pixel level 2 uncertainty, or is the error on the mean AOD?

Fig.(6) presents the actual validation of the uncertainty. The authors have done this by taking the difference between the predicted uncertainty, derived by the methods described above, and the actual discrepancy between the ADV/ASV retrieval and AERONET measurements for 2012 AATSR-AERONET pairs. This is not the correct way of validating the uncertainty. There are two possible approaches for validating the retrieval uncertainties against AERONET:

1. The discrepancy between the retrieval and AERONET can be divided by the retrieved error, and a histogram built up of these normalised errors. If the uncertainty budget is correct, and the retrieval is close to linear over the scale of the uncertainty, this should result in a normal distribution with a mean of zero and a standard deviation of one.

2. A χ^2 test can be carried out between the retrieved AOD and the AERONET values, taking the uncertainties in both measurements into account. This essentially provides a probability that the two data sets are consistent within their errors, and thus provides a validation of both the retrieved state and its uncertainty.

Furthermore, there are some important questions relating to the validation of uncertainty that the authors have not addressed. Are the calculated uncertainties internally consistent? I.e. in a region of low AOD variability (the remote ocean for instance) the standard deviation of the retrieved AOD should be close to the reported uncertainty.

Given the uncertainties, what is the sensitivity of the measurement system? In other words, what is the minimum AOD that can be measured before the measurement noise dominates?

What is the dependence, if there is any, of the uncertainty on surface reflectance, viewing geometry, aerosol type etc?

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