Response to Reviewer 1's comments on “The GRAPE aerosol retrieval algorithm” by Thomas et al.

The authors thank the reviewer for their comments and recommendation, which we believe we have addressed, as detailed below. The reviewers comments are included in italic text, with our responses in regular font.

Note that I have reviewed this manuscript already for another journal. Unfortunately, the authors have not changed the manuscript based on the comments that I provided.

Overall recommendation

The manuscript presents an algorithm and its theoretical sensitivities. Several papers have been published on this subject over the last decade and I did not find new insights in this manuscript. However, if a large dataset is going to be produced with the algorithm as described in this manuscript, the information could be valuable for the user community. In that case major revision of the manuscript is needed, as indicated in the general and specific point below.

We believe this is one of the first applications of optimal estimation to retrieve aerosol (and cloud) information from nadir imagery. This approach has become established as best practice for the interpretation of remotely sensed data. The quantification of aerosol properties are recognised as a high priority in IPCC (2007) and this work address how well an aerosol retrieval works. Without this insight the use of retrieved data is fraught with the danger of generating spurious results from poorly characterised retrievals.

General

This manuscript describes the GRAPE aerosol retrieval algorithm and provides a theoretical sensitivity analysis. The algorithm is based on optimal estimation and focuses on the retrieval of the aerosol optical depth, the effective radius and the surface albedo. Critical a priori information includes the aerosol composition and size distribution, the surface albedo and the spectral behavior of the surface albedo. The sensitivity analysis shows that the expected precision of the retrieved optical depth is of the order 0.1, and for the effective radius approximately 50%.

This manuscript is one of many papers that have been written on aerosol retrieval algorithms and their theoretical sensitivities. Although many papers have been published, the authors fail to include their results with these publications. At least comparisons to the standard algorithms of MODIS, MISR, MERIS should be made, as well as other studies related to ATSR-2 and AATSR. This is one of the main shortcomings of the manuscript.

The introduction has been expanded to give an overview of the more common retrieval techniques employed by other instruments, as well as other techniques applied to (A)ATSR, and to compare the ORAC approach to these.

From an algorithm point of view I was disappointed to see that only the nadir view of the ATSR-2 and AATSR instruments were used in the GRAPE algorithm. The two-views is the most important part of the instrument concept and very interesting for aerosol retrieval. The reasons for leaving out the forward view should be discussed in the manuscript.

This is a sensible question which can is answered by the following points:

i) The objective of the GRAPE algorithm was to produce cloud and aerosol products from nadir imagery. Our objective was to attempt to avoid biased aerosol and cloud statistics due to sampling. For example an aerosol algorithm could be applied with a very strict cloud flagging procedure so that regions of aerosol optical depth are removed as cloud. The algorithm may work very well but will show a low bias. We have changed the text to point out the algorithm retrieves cloud first then does an aerosol retrieval on the pixels that have been identified as ‘clear’.

ii) The GRAPE algorithm was developed so that it could be applied to a number of imaging sensors (ATSR-2, AATSR, SEVIRI, MERIS, MODIS) to retrieve aerosol properties on clear scenes and cloud properties on cloudy scenes. So far it has been applied to ATSR-2, AATSR and SEVIRI. Using this approach we are able to compare results from different sensors with the same algorithm.

The section discussing why only nadir view was used has been expanded in the text.

Although sensitivity analyses are essential for algorithm development, I prefer papers that combine such analysis with real data, for example by presenting validation results. The current manuscript gives the impression of a purely theoretical exercise, with little connection to the real world. Given the fact that there is lots of ATSR-2 data available, including or discussion of validation data will give more meaning to the theoretical results.

The description of satellite products is achieved by publishing papers describing the instrument calibration, the retrieval algorithm and product validation before publishing science results. This best practice approach is taken by many instrument teams (e.g. those on the UARS and AURA platforms such as MLS and ISAMS). An advantage of this approach is to decouple the analysis of the algorithm from real data — a sensitivity analysis is not possible with real remote sensing data, since it isn't possible to know the true state of the atmosphere. However, we do agree that the only way to assess the real world performance of an algorithm is to perform validation studies on retrievals of real data. As is mentioned in this paper, the algorithm described has all ready been applied to the global ATSR-2 data from 1995 – 2001. The validation of this dataset is the subject of a separate paper submitted to Atmos. Chem. Phys. Note that at the time of submission of this AMT paper, the ACP paper was still in preparation and could not be referenced. This has now been rectified.

The results of a precision of 0.1 for the aerosol depth are rather disappointing. The reason for such low precision should be addressed in the manuscript. Is this the result of the instrument signal-to-noise ratio or due to large a prior errors, or something else?

The precision of the algorithm represents the projection of the instrument signal-to-noise combined with the forward model error into state space. It is a fundamental strength of the optimal estimation approach that the approximations implicit in the radiative transfer are included in the reported uncertainty.

Validation data of MODIS show considerable better results than a precision of 0.1. Would applying the MODIS algorithm to ATSR-2 data give much better results than the GRAPE algorithm?

The precision of 0.1 gives an upper bound to how well constrained an individual retrieved AOD is, based on the “shape” of the cost function around the retrieval solution and the measurement errors used. This cannot be directly compared to figures produced by the validation of the MODIS products. The accuracy estimates from MODIS are derived from the PDF of the difference between spatially averaged MODIS and temporally averaged AERONET AOD measurements. For an estimate of the accuracy of the GRAPE product compared to AERONET the reviewer is referred to the validation paper described above.

The manuscript is not clear on the objective of the GRAPE algorithm. Is this algorithm mainly *applied to ocean data, as suggested by the choice of wavelengths described on page 6, or also over land?*

This point has been clarified in the text.

Specific points

A specific section on the state vector, it's a-prior values and the variance co-variance matrix should be added. Currently the elements of the vector is not described specifically. From the context, my guess is that it contains the optical depth (what wavelength??), the effective radius and the surface albedo (at what wavelength??).

The state vector is described in detail section 2.2. However, the authors take the reviewers point that this is probably not entirely obvious. A table giving a description of each state vector element, plus its a priori value and error has been added.

The a-prior over land of the MODIS white sky albedo seems unrealistic to me. The surface contribution to the TOA will be dominated by direct reflection, hence the BRDF function for this sun-satellite geometry should be used. The 0.01 1-sigma error for the albedo is over-optimistic. Given the importance of this error for the retrieval, the choice for this value should be discussed and included in the sensitivity analysis.

The authors freely admit that the treatment of the surface reflectance is the most obvious weakness of the algorithm presented here. The errors introduced by this assumption are discussed in section 3.2. The use of the white sky albedo is a result of the fact that the GRAPE analysis is primarily concerned with retrieving cloud properties, with the aerosol retrieval essentially filling the gaps.

Likewise, we agree that the a priori error of 0.01 on the surface reflectance isn't a true reflection of the accuracy of the MODIS BRDF product or the assumption of a Lambertian surface reflectance. This value was used for more pragmatic reasons, in that it better constrained the retrieval, allowing reasonable AOD retrievals. It should be noted however, that this is not an unreasonable uncertainty for ocean surface reflectance.

The description on the off diagonal elements of the covariance matrix (top of page 12) confused me. I assumed that the state vector contained the albedo at one wavelength and used a fixed spectral shape, however the text on page 12 suggests something else. Pleas explain.

The off-diagonal elements are added to the measurement covariance matrix (not the state vector covariance matrix) to account for the correlation between the measurement channels introduced by assuming the spectral shape of the surface reflectance is fixed at the a priori value (i.e. Increasing the surface reflectance at 550 nm increases proportionally at all other wavelengths). This is the standard way of including forward model error in an optimal estimation retrieval.

A brief description of this technique has been added to page 12 to clarify this point.

A table should be included with the range of effective radii and Angstrom parameters for the different classes.

This table has been added

Include a description or table of the number of nodes in the look-up tables.

This table has been added

On page 10 it is stated that ocean surface reflection can be modeled as Lambertian surface without accounting for the BRDF effects. I would doubt this statement, as developers of other aerosol retrieval algorithms specifically accounted for these effects over the ocean. Analysis is needed to support this statement.

While the authors agree that BRDF effects are important in regions affected by sun glint (and indeed later versions of the ORAC algorithm do include a BRDF surface reflectance model), we don't agree that this is a serious issue away from such areas. Many aerosol retrievals over ocean effectively make a Lambertian surface reflectance assumption and simply flag out regions effected by sun glint, as is done in the GRAPE analysis.

In section 3.3 several sensitivity analyses are performed, however the results are in several places described in a qualitative rather than a quantitative manner. For example in 3.3.1: "..differences are much greater : : :", : in 3.3.3 "The two sets show strong similarities, but are not identical, indicating that the retrieval is somewhat sensitive : : :". All these statements should be made quantitative and the results should be put in one table to be able to compare the results.

As is said at the beginning of section 3.3, these sensitivity analyses are difficult to summarise quantitatively. All of the perturbations investigated have effects that complex functions of AOD and effective radius, and it is safe to say that different (but equally valid) choices of perturbations would result in changes in these dependences. It was for this reason that the descriptions of these results were kept qualitative.

However, the authors do take the reviewers point, and have attempted to be more quantitative where possible.

If there is a data set available produced with the algorithm described, indicate where it can be obtained.

The URL to the website from which data is available is included in the footnote on page 3 of the AMTD paper.

Presentation

The manuscript contains a lot of figures that look almost the same, for example Figure 13 and 14. I would suggest showing to cut back on the number of plots by only describing the results (e.g Figure 11) and/or showing a few (difference) plots. In the current manuscript the reader has look very carefully at the plots to show certain effects. Such effect should be more high-lighted.

The number of figures have been reduced:

Figures 7 and 9 have been removed. Their results are still described in the text.

Figures 11 and 12 have been combined into a difference plot.