Point-by-point reply to the comments

Ref. No.: amt-2011-105

Title: Aerosol optical depth and fine-mode fraction retrieval over East Asia using multi-angular total and polarized remote sensing

We are grateful to the anonymous referee for useful comments! According with your advice, we amended the relevant part in manuscript. The point-by-point report on how I addressed each of the comments is below:

Anonymous Referee #3:

MAIN ISSUE:

This paper offers an alternative algorithm to retrieve total aerosol optical depth and fine mode fraction from POLDER measurements over land in East Asia. The operational POLDER algorithm, over land, provides only fine mode AOD and not TOTAL AOD and definitely fine mode fraction, which would require an additional piece of information. Thus, if successful the algorithm described in the current paper would provide an important new tool for aerosol studies in East Asia.

There is hope that more information can be attained from the POLDER instrument. With its multi-channel, multi-wavelength and polarization signal, previous studies investigating information content suggest that such an instrument is actually currently under utilized. Dubovik et al.(2011), Hasekamp et al. (2011), both referenced in current paper, are suggesting optimization and inversion techniques, applied to POLDER that may advance the original operation algorithm, significantly more than the important though modest in comparison advance proposed here.

There is always room for a regionally-specific algorithm, like the one presented here, to fine tune assumptions for a specific region and improve upon a generic global retrieval. Such a regional algorithm must be presented in context with the standard operational one. How do the two differ? What makes the regional one better? The new algorithm must be presented with sufficient detail for a reader to be able evaluate the principles and assumptions in the algorithm. There should be sensitivity studies and understanding of WHY the new algorithm works better, not just that it does.

In my opinion this paper fails to meet this standard. I find it very interesting that the results look so good against AERONET. I would like to understand why it works so well. The authors owe the community a more comprehensive description of the physical reasoning or strong empricial support behind every decision. While as a reviewer I was grateful to have to read only 6 pages of text, this is insufficient to introduce a new algorithm. It is not as though this is a short summary paper of a long history of papers describing the different components of the algorithm creation. The authors only self-reference two papers and neither sufficiently fills in the holes missing here.

For this reason and for the specific reason I describe below, I would recommend rejection of this paper at this time and encourage the authors to resubmit a more comprehensive description of their algorithm that explains how they overcame the challenges of the operational POLDER algorithm.

Answer:

Thanks for these constructive suggestions which would make the manuscript more consistent and easier to follow. In order to make our regional algorithm be presented in context with the standard operational one, the detailed information of the regional algorithm has been added in the revised manuscript, including difference of the regional algorithm and operational algorithm, the improvement of the regional algorithm to make the regional one better, the sensitivity study and the comparison between the products of regional algorithm and operational algorithm.

- **a.** A sub-section (2.1) was added to present the operational algorithm of PARASOL over land. In this sub section, the basic principles of operational algorithm, the aerosol model assumptions, the surface polarized reflectance model assumptions, and the shortcomings of the operational algorithm were added.
- **b.** Based on the description of the operational algorithm, in sub-section 2.2, the detailed basic principles of the regional algorithm was added to present where

the new POLDER algorithm start. The key point of the paper was also added in this sub-section 2.2 “This study is focusing on an improvement of the aerosol model to reflect local characteristics and its integration within the retrieval procedure. The two main aerosol parameters (AOD and FMF) were simultaneously retrieved using POLDER measurements to study the aerosol effect on climate change.”

c. In order to discuss why this particular design of the algorithm was chosen, what are limitations and accuracy, and what are the alternatives and perspectives, the sensitivity study was added as sub-section 2.3.

d. In order to show the difference of the regional and operational algorithm, the products (fine AOD) of these algorithms were compared with the products of AERONET. The fig. 7 (the spatial distributions of the Fine AOD of regional and operational algorithm), fig.8 (comparison of Fine AOD retrieved regional algorithm with those of operational algorithm at Beijing AERONET station), and fig.9(comparison at Xianghe AERONET station) were added to show the difference of the two algorithms.

Specific Comments:

1. Comparison with operational POLDER retrievals over land

The operational POLDER algorithm avoids the challenge of characterizing the INTENSITY surface reflectance over land and relies only on the multi-angle, multispectral POLARIZED reflectance to retrieve aerosol properties. Because most of the polarization signal results from small spherical particles, the operational algorithm ignores coarse mode in the retrieval and returns only fine mode AOD, not total AOD and definitely not fine mode fraction. The POLDER LUT consists of only fine mode lognormals.

This has to be where any description of a new POLDER algorithm must start. None of what I wrote in the above paragraph makes it into the current paper. Referencing POLDER papers without describing them is not enough. The current paper must clearly explain how they will extract more information from POLDER.

Then, they should show by sensitivity study or reference previous work explicitly the source of the new information. Where does the sensitivity to coarse mode particles come from?

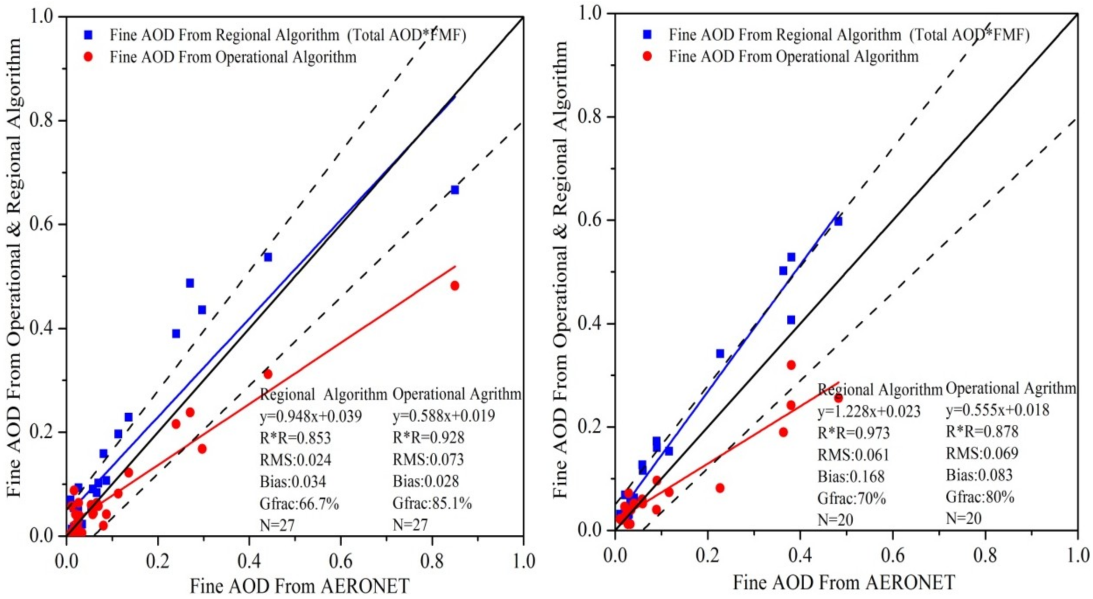
Finally, at the end there should be comparison with standard algorithm retrieved fine mode AOD, as well as AERONET. The new algorithm retrieves AOD in both dust and pollution. The old algorithm should severely underestimate AOD when compared with the new algorithm. Is this so?

Answer:

In order to compare the regional algorithm with the operational algorithm, the basic principles, the aerosol model assumptions, the surface polarized reflectance model assumptions, and the shortcomings of the operational algorithm were added in sub-section 2.1.

The detailed information of the regional algorithm has been also added in the revised manuscript, including difference of the regional algorithm and operational algorithm, the improvement of the regional algorithm to make the regional one better, to present where the new POLDER algorithm start. And the sensitivity study was added as sub-section 2.3 to discuss why this particular design of the algorithm was chosen, what are limitations and accuracy, and what are the alternatives and perspectives.

In order to show the difference of the regional and operational algorithm, the products (fine AOD) of these algorithms were compared with the products of AERONET. The fig. 7 (the spatial distributions of the Fine AOD of regional and operational algorithm), fig.8 (comparison of Fine AOD retrieved regional algorithm with those of operational algorithm at Beijing AERONET station), and fig.9(comparison at Xianghe AERONET station) were added to show the difference of the two algorithms.



Comparison of Fine AOD retrieved present algorithm with those of operational algorithm at Beijing and Xianghe from September to December in 2010.

2. The aerosol models

The authors describe a set of 12 aerosol models, six fine and six coarse mode, obtained from AERONET clustering, and reference a paper by Lee and Kim. The modes presented in Table 2 are not very distinctive, and it is hard to see how a retrieval algorithm is going to find unique solutions.

Most importantly the current work misuses the results from the Lee and Kim paper. In that study, AERONET inversions were clustered into six bimodal models. Two look like dust, and four look line various stages of pollution or cleaner background conditions. Lee and Kim make no attempt to separate their 6 bimodal models into independent monomodal models. They cannot because the AERONET inversions allow independent size bins to make the size bins to make the size retrieval, but require that there be only one set of refractive indices retrieved for the aerosol as a whole. They cannot assign different refractive indices to the different modes. I would expect the values of refractive index in the current paper's Table 2 to be the same for pairs of fine and coarse mode coming from the Lee and Kim analysis. Indeed, Fine 1 and Coarse 1 have the same refractive indices. However, something changes for the pairs representing Lee and Kim's dust models. I do not see where the dust refractive indices come from. Dividing the bimodal clustered models into mono-modal models is ill=posed because of the partitioning of the refractive indices.

This splitting of the Lee and Kim bimodal models into monomodal models and allowing all of them equal weighting in an inversion scheme is just wrong, even if the refractive indices were understandable. There needs to be subsequent analysis of the Lee and Kim results showing that the optical properties (spectral single scattering albedo, asymmetry parameter, phase matrix) are sufficiently different for each entry in the table to justify their remaining in the table. There is a statement saying that these properties were studied, but the results of that study have to be shown. Size distributions should be shown also.

Answer:

The properties of aerosol are complicated and immense diversity, not only aerosol size, composition, and origin, but also in spatial and temporal distribution. Until now, all available aerosol models are unable to characterize the complexity of the real properties of aerosol. The properties of aerosol based on shape, size distribution, refractive indices etc.

The main motivation for this research stems from the need to develop the conceptual approach to accurately retrieve the AOD and FMF over East Asia land for studying the impact of aerosol of East Asia on climate change with the priori assumptions. The assumption is that one fine and one coarse lognormal aerosol modes can be combined with proper weightings to represent the ambient aerosol properties.

Wang and Gordon (1994) described the method by which the aerosol component of the radiance at TOA can be synthesized from the radiances generated by individual components of the aerosol size-refractive-index distribution. The method is exact in the single-scattering approximation and usually reproduces the aerosol contribution with an error < 2-3% (and only rarely >3-4%) for aerosol optical thickness as large as 0.5 at 865nm. Only when the aerosol is strongly absorbing, the method can fail. They concluded that the method can provide a basis for the estimation of aerosol properties with Earth-orbiting sensors. This method has already been successfully used for interpretation of MODIS and POLDER aerosol retrieval over ocean.

From the AERONET observations at Beijing and Xianghe from September to December in 2010, we found that the aerosol optical depth over Beijing and Xianghe are smaller than 0.8 at 870nm, so we believed that the method used in this paper will not introduce much quite significant error. In this paper, we used the Wang and Gordon's method to calculate the aerosol component of the radiance at TOA by synthesizing the radiances generated by individual components of the fine mode and coarse mode. The aerosol size distribution used in this study for fine and coarse model is the mono-modal lognormal size distribution. The inversion is based on determining which of the 36 combinations of fine and coarse aerosol models and their relative optical contributions best mimics the TOA spectral polarized measurements.

In a good approximation, the optical properties of a particle are determined by the refractive index and size distribution. The refractive index depends on the chemical composition of the particles. In order to improve the aerosol model of retrieval algorithm to reflect local characteristics, the detailed parameters of fine model and coarse model size distribution of this study are retrieved from the regional aerosol modes of East Asia based on the AERONET measurements. Lee and Kim have studied (2010) the aerosol models using the cluster analysis technique (Omar et al., 2005) based on the AERONET sun-photometer observation over the East Asia. They defined six aerosol optical modes with the bimodal lognormal size distribution. The six cluster aerosol models of East Asia can represent realistic possibilities of the aerosol properties. The detailed parameters of fine and coarse model of this study are retrieved from the six cluster aerosol models of East Asia. The effects of splitting of the Lee and Kim bimodal models into monomodal models have been ignored in this paper. In future work, we will update the aerosol models with escalation ground-based measurements of aerosol properties over East Asia and the theory of aerosol models developed.

3. Surface intensity reflectance

The current paper makes its most major departure from operational POLDER retrievals in characterizing surface intensity reflectance in order to make use of POLDER measured intensity reflectance in the aerosol retrieval. The procedure employs a technique described by von Hoyningen-Huene. The procedure uses average surface reflectance measured by aircraft instrument at three wavelengths in Germany near Berlin and divided into vegetated and bare soil categories. Then the method uses NDVI to weight the categories.

The problem with using NDVI is that NDVI calculated from top of atmosphere radiances is affected by aerosol. In heavy aerosol loading, NDVI decreases and the fraction of bare soil will be artificially increased.

The more important problem is the use of surface reflectance characterization based on vegetation and soils in Germany, now applied to East Asia. It defeats the whole advantage of creating regional aerosol retrieval.

Answer:

A precise estimate of the radiation (including polarization of radiation) reflected by the surface is crucial for remote sensing of aerosol properties over land. The brightness of the surface and its angular variability, as well as its spatial heterogeneity, make the differentiation of aerosol and surface contributions in the upwelling total radiance a challenging problem.

It's very hard to simulate the surface reflectance using BRDF to characterize the complexity of the real properties of surface reflectance, because the surface reflectance is known to change and depend on various parameters not all of which depends on the vegetation cycle, and on the ground humidity etc. Contrary to the total radiances, polarized reflectance of surfaces is small and fairly spectrally independent, and the atmospheric contribution is larger than the surface polarized reflectance. Utilization of only polarized observations allows one to derive aerosol properties and to avoid challenging issue of separation of surface and aerosol contributions into the total reflectance. So in this paper, the TOA reflectance was only used to retrieve the initial total AOD, and the adjusted Total AOD and FMF were retrieved using TOA polarized reflectance at 0.675μm, 0.870μm.

In order to retrieve the initial total AOD accurately, the effects of directionality of land surface reflectance are accounted for by a liner mixing model of vegetation and bare soil spectra (von Hoyningen et al., 2003) using NDVI to weight the categories. It should be noted, however, that the von Hoyningen et al. (2003) formulations, chosen as primary models for BRDF in the present algorithm, have limited accuracy (e.g. see Litvinov et al., 2010, 2011). We agreed the comments that NDVI calculated from top of atmosphere radiances is affected by aerosol, especially in heavy aerosol loading, NDVI decreases and the fraction of bare soil will be artificially increased. In order to improve the accuracy of the von Hoyningen et al. (2003) method, the NDVI were derived from the PARASOl measurements on the clear-sky conditions in this paper.

The von Hoyningen et al. (2003) method has already been successfully used for simulating the surface reflectance over East Asia land by K. H. Lee and Y. J. Kim, 2010 (K. H. Lee and Y. J. Kim: A case study of clean, polluted, and Asian dust storm days, Atmos. Meas. Tech., 3, 1771–1784, 2010).

4. Presentation and results

Why false color images? True color would be much easier to understand. Lee and Kim used true color and the aerosol plumes are much easier to see in their paper. At the very least, the channels used to mix the false color must be stated.

More information needs to be given with each case study. What are the distributions of the residual term (chi value) in each case? Which modes are chosen? How unique is each choice? These hard diagnostics are as important as the AERONET scatter plots in proving a new algorithm.

Answer:

We agreed the comments of the reviewer that true color would be much easier to understand, so the all false color images of the paper have been changed into the true color images (RGB 0.44, 0.565, 0.675μm).

The more information is added in the revised manuscript. In section 4 (Analysis and validation), the more information about the accuracy of the regional algorithm are added in the fig.6.

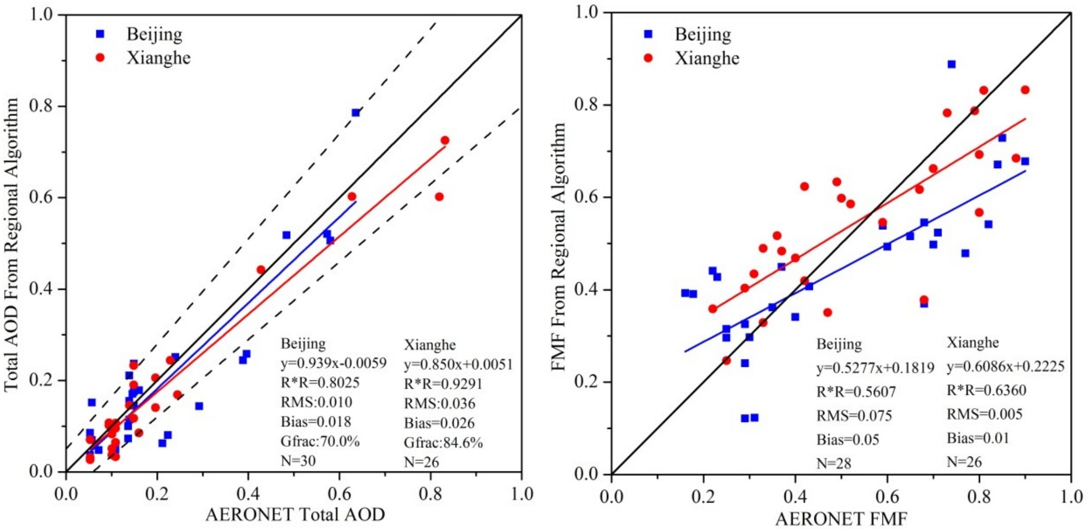
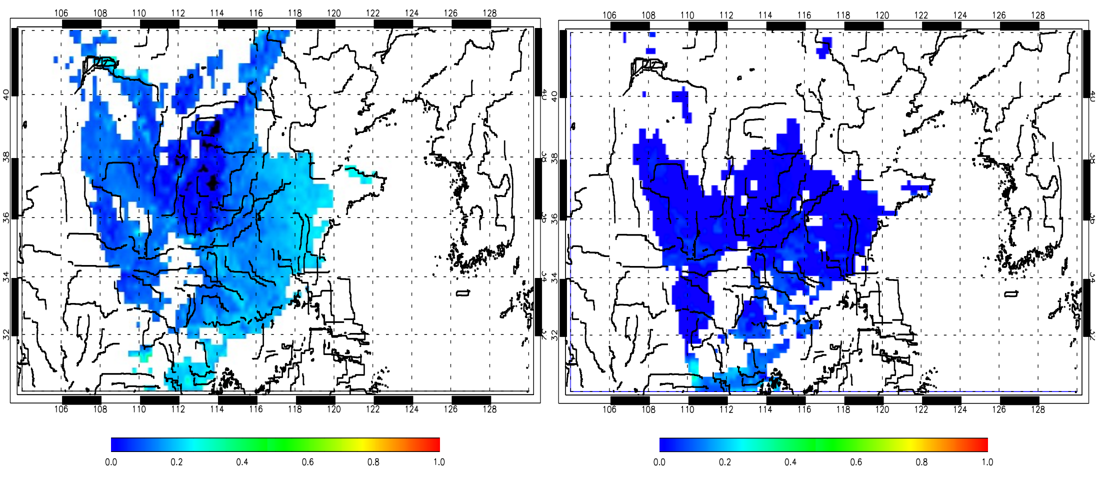
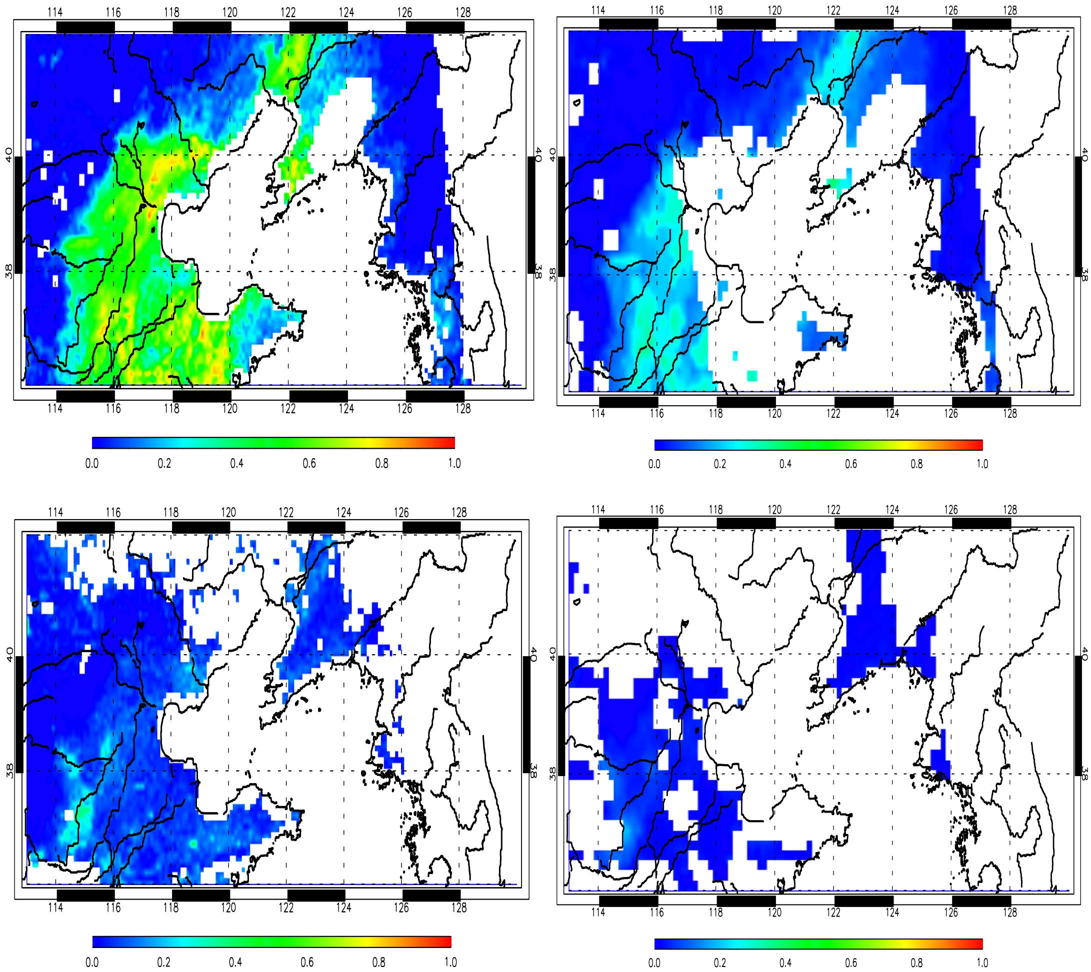


Fig.6. Comparison of Total AOD and FMF retrieved present regional algorithm with those of AERONET observations at Beijing and Xianghe from September to December in 2010.

In order to compare the products from regional algorithm with the products (fine mode AOD) from operational algorithm of PARASOL, the fine mode AOD of regional algorithm were retrieved from Total AOD and FMF. Fig.7 shows the spatial distributions of the Fine AOD from regional algorithm (left-hand side column) and operational algorithm (right-hand side column) for the three aerosol cases (clean, polluted, and dusty cases), respectively.





Fine AOD from regional algorithm Fine AOD from operational algorithm

Fig.7. Fine AOD from regional algorithm (Left) and operational algorithm (Right) for an Asian dust case (Upper) on March 20, 2010, a polluted case (Middle) on October 06, 2010, and a clean case (Lower) on October 25, 2010, respectively.