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 #1:

This paper discusses a new aerosol retrieval algorithm from multi-angular total and polarized measurements. This algorithm uses the lookup tables (LUT), calculated for bi-modal log-normal mixtures of 6 fine and 6 coarse aerosol models. The algorithm fits total and polarized radiance at 3 wavelengths and retrieves aerosol optical depth (AOD) and fine-mode fraction (FMF). The algorithm is tuned for applying to PARASOL data over East Asia. With that purpose the aerosol models are chosen by applying the cluster analysis to AERONET retrievals over East Asia. The algorithm has been applied to PARASOL data and the results were successfully validated by comparisons with AERONET observations. The paper is clear and well written. The results are well explained and illustrated. At the same time, the paper seems to be too descriptive. In depth discussion of the method accuracy, potential limitation and possible perspective future improvements is missing. Therefore, I recommend the publication of this paper in Atmospheric Measurement Techniques "after a minor revision". I have outlined below the comments for the authors consideration.

Comments:

MAIN ISSUE:

The authors provide clear technical description of the algorithm, however they do not any discussion why this particular design of the algorithm was chosen, what are limitations and accuracy, what are the alternatives and perspectives. I suggest including such discussion.

Answer:

Thanks for these constructive suggestions of the reviewer which make the manuscript more consistent. In order to test the ability of the inversion algorithm, to discuss why this particular design of the algorithm was chosen, what are limitations and accuracy, and what are the alternatives and perspectives, we added a section “sensitivity study”:

“In order to test the ability of the inversion algorithm, we have studied the relationship between the polarized reflectance at 0.675μm, 0.870μm, based on the numerical simulation (LUT) as a function of aerosol optical depth and FMF (Fig. 2). The solar zenith angle is 50°; the satellite viewing angle is 30°; and the azimuth relative angle is 180°. The solid lines represent constant FMF (from 0.0 to 1.0) while the symbols on the solid lines represent different AOD (from 0.0 to 2.0).

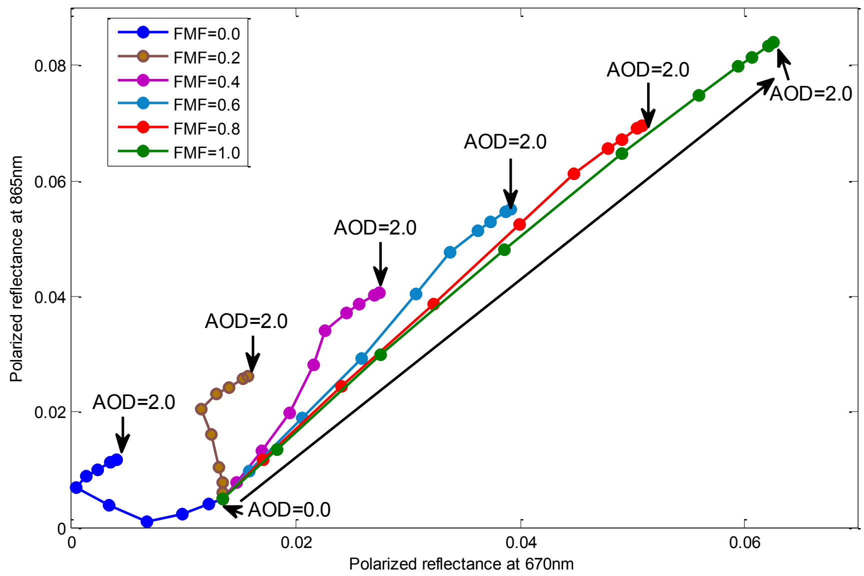

Fig.. Two-dimensional polarized reflectance correlation diagram in terms of the FMF (0.0, 0.2, 0.4, 0.6, 0.8, 1.0) and AOD (0.0, 0.1, 0.2, 0.3, 0.5, 0.8, 1.0, 1.2, 1.5, 2.0) for two wavelengths of 0.675μm, 0.870μm in the calculation for a solar zenith angle is 50°, a satellite viewing angle is 30°, and the azimuth relative angle is 180° .

From the 2-dimensional diagram, for a given geometry, it is noted that there is a strong sensitivity of the combination of polarized reflectance at 0.675μm, 0.870μm to FMF when the AOD is confirmed. The sensitivity to FMF decrease with the AOD decrease, and the accuracy of retrieved FMF is very low when the AOD is smaller than 0.1 at 0.870µm. There is also a strong sensitivity of the combination of polarized reflectance at 0.675µm, 0.870µm to AOD when the FMF is confirmed, especially for higher FMF (fine aerosol mode), and the sensitivity to AOD decrease with the AOD increase which means it's very hard to accurately detect the AOD with AOD lager than 1.5 at 0.870µm. The sensitivity to FMF is larger than that of AOD, so the FMF can be retrieved using the initial total AOD from radiance measurements, and then the adjusted Total AOD can be retrieved using the FMF. The accuracy of the FMF can be accepted when the AOD is larger than 0.1 at 0.870µm, and the AOD cannot be detected when the AOD lager than 1.5 at 0.870µm."

Specific Comments:

--Eq.(1) is based on an approximation. It is fully valid in single scattering approximation only. Wang and Gordon (1994) showed that this approximation introduces an error that does not exceed 4% for optically thin situation (optical thickness is up to 0.4). However, over East Asia high aerosol loading events are frequent with TAU=1.0 and even much higher. Evidently, this approximation may introduce much quite significant error. Ref: Wang, M., and H.R.Gordon, Radiance reflected from the ocean-atmosphere system: Synthesis from individual components of the aerosols size distribution, Appl. Opt., 33. 7088-7095, 1994

Answer:

Wang and Gordon (1994) described a 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.

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 (Eq. 1). Each components of the Eq.1 are computed individually by solving the RT3 vector radiative transfer mode (Evans and Stephens, 1991). The error of the method is smaller than 2-3%(and only rarely >3-4%) for aerosol optical thickness as large as 0.5 at 865nm.

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.

It's a pity that the reference of Wang and Gordon (1994) is missed in this paper, and in the revised paper, the reference is added:

Wang, M., and Gordon, H.R.: Radiance reflected from the ocean-atmosphere system: Synthesis from individual components of the aerosols size distribution, Appl. Opt., 33. 7088-7095, 1994.

--Eq.(2) defines the residual term. This definition is very simple. It does not account for possible differences in accuracies of observations in different spectral channels and different observation angles. This definition increases the importance of fitting observations with higher magnitudes. Correspondingly, such definition of residual may bias algorithm towards total reflectance, because the magnitudes of total reflectance are generally much higher magnitudes than polarized radiances. Is this definition of the residual is optimal?

Answer:

Yes, we agreed the comments of the reviewer that the residual term is very simple. In this paper, the initial total AOD is retrieved only using the TOA reflectance at 0.490μm based on the least mean squares fitting method. After that, the initial total AOD, LUT of polarized reflectance, TOA polarized reflectance at 0.675μm, 0.870μm, and surface polarized reflectance contribution are used to retrieve the FMF for combination of fine- and coarse-mode, and the adjusted Total AOD.

So the residual term (Eq. 2) has been changed into:

$$\chi_1 = \sum_{n=1}^{16}[R_{comp}^{0.490\mu m}(\lambda, AOD, \mathrm{FMF}, \mu_s, \mu_v, \Delta\phi) - R_{mea}^{0.490\mu m}(\lambda, AOD, \mathrm{FMF}, \mu_s, \mu_v, \Delta\phi)]^2$$
$$\chi_2 = \sum_{w=1}^{2}\sum_{n=1}^{16}[R_{comp}^{p}(\lambda_w, AOD, \mathrm{FMF}, \mu_s, \mu_v, \Delta\phi) - R_{mea}^{p}(\lambda_w, AOD, \mathrm{FMF}, \mu_s, \mu_v, \Delta\phi)]^2 \quad (2)$$

where w is the number of spectral bands, n is the scattering angle observations for each pixel. $R_{comp}^{0.490\mu m}$ and $R_{mea}^{0.490\mu m}$ are computed and measured total reflectance at 0.490μm, R_{comp}^{p} and R_{mea}^{p} are computed and measured polarized reflectance at 0.675μm and 0.870μm, respectably. μ_s is the cosine of solar zenith angle, μ_v is the cosine of view zenith angle, and $\Delta\phi$ is the relative azimuth angle, respectively.

--The algorithm uses only 3 spectral channels of PARASOL, why other spectral channels are not used.

Answer:

The research presented in this paper only aims to retrieve simultaneously the spectral AOD, and fine-mode fraction (FMF) for climate change. The sensitivity study showed that the two parameters (AOD and FMF) can be simultaneously only using the total reflectance at 490nm and polarized reflectance 675nm and 870nm, so in this algorithm only 3 spectral channels of PARASOL are used.

--The authors state that coarse mode aerosol was assumed as mixture of spheroids and the optical properties were calculated T-matrix code. I wonder if the authors really used T-matrix code. If so, it would be useful if they indicate which shape distribution was used for the spheroid mixture and how the optical properties of particles with radii of 2 microns are lager were accounted (T-matrix code may have problems with convergence here). If the authors simply used an approach employed in AERONET retrieval, that should be stated with appropriate reference.

Answer:

We agree with the reviewer that there is sufficient experimental evidence [Volten et al. 2001] that the non-sphericity of coarse mode aerosol (desert dust particles) can cause scattering properties significantly different from those predicted by the standard Mie theory. However, dealing with non-sphericity is not a completely resolved issue, and most aerosol retrieval algorithms are still based on the Mie theory.

Indeed, incorporating non-spherical scattering in remote sensing retrievals is problematic methodologically and technically. As the comments of the anonymous referee, it's very hard to make a realistic choice of a particle shape (or shape mixture) model because the microphoto-graphs of natural aerosols show a great variety of shapes.

The tool to study the optical properties of non-spherical is limited. Even most advanced T-matrix code becomes numerically unstable for elongated and flattened spheroids with size parameters exceeding 40-60. Fortunately, Dubovik et al (2002) have made a great work about nonspherical aerosol retrieval method employing light scattering by spheroids. They proposed a method for the retrieval of the optical properties of non-spherical aerosol based on the model of a shape mixture of randomly oriented poly-disperse spheroids using T-matrix and geometric-optics-integral-equation method.

In this paper, the optical properties of coarse model are not be calculate by ourselves. The database of non-spherical aerosol model constructed by Dubovik is used to study the optical properties of coarse model.

It's pity that the reference of Dubovik et al (2002) and the acknowledgement for the O. Dubovik are missed. So in the revised paper, the reference of Dubovik et al (2002) and the acknowledgement for the O. Dubovik are added.

---Page 5691, paragraph 15. The authors state remaining uncertainties in estimates of DRF. I suggest adding more recent references, for example, the paper by J.Hansen recently appeared in ACPD.

Answer:

The paper J.Hansen et al., 2011 has been added in the references of the paper:

Hansen, J., Sato, M., Kharecha, P., and Schuckmann, K. von: Earth's energy imbalance and implications, Atmos. Chem. Phys. Discuss., 11, 27031–27105, 2011.