Review of “Retrieval of aerosol optical depth over land based on a time series technique using MSG/SEVIRI data” by L. Mei et al.

Thanks so much for your constructive comments. We have revised our manuscript and the responses are listed in-situ below.

This article describes a new algorithm for the joint retrieval of surface reflectance and aerosol optical depth (and “aerosol type”), which utilizes the high temporal sampling of the geostationary MSG SEVIRI instrument. I am somewhat surprised that it is being considered for Atmos. Chem. Phys., as it is manifestly a algorithm paper, and as such I would have expected to be directed towards ACP’s sister journal, Atmos. Mes. Tech.

Responses: We have searched the ACP issues. Here is the short list of papers published on ACP recently.

Yu, F., Luo, G., and Ma, X.: Regional and global modeling of aerosol optical properties with a size, composition, and mixing state resolved particle microphysics model, Atmos. Chem. Phys., 12, 5719-5736, doi:10.5194/acp-12-5719-2012, 2012.

Huneeus, N., Chevallier, F., and Boucher, O.: Estimating aerosol emissions by assimilating observed aerosol optical depth in a global aerosol model, Atmos. Chem. Phys., 12, 4585-4606, doi:10.5194/acp-12-4585-2012, 2012.

Redemann, J., Vaughan, M. A., Zhang, Q., Shinozuka, Y., Russell, P. B., Livingston, J. M., Kacenelenbogen, M., and Remer, L. A.: The comparison of MODIS-Aqua (C5) and CALIOP (V2 & V3) aerosol optical depth, Atmos. Chem. Phys., 12, 3025-3043, doi:10.5194/acp-12-3025-2012, 2012.

Ma, N., Zhao, C. S., Müller, T., Cheng, Y. F., Liu, P. F., Deng, Z. Z., Xu, W. Y., Ran, L., Nekat, B., van Pinxteren, D., Gnauk, T., Müller, K., Herrmann, H., Yan, P., Zhou, X. J., and Wiedensohler, A.: A new method to determine the mixing state of light absorbing carbonaceous using the measured aerosol optical properties and number size distributions, Atmos. Chem. Phys., 12, 2381-2397, doi:10.5194/acp-12-2381-2012, 2012

Zhang, H., Lyapustin, A., Wang, Y., Kondragunta, S., Laszlo, I., Ciren, P., and Hoff, R. M.: A multi-angle aerosol optical depth retrieval algorithm for geostationary satellite data over the United States, Atmos. Chem. Phys., 11, 11977-11991, doi:10.5194/acp-11-11977-2011, 2011

Liu, Y., Huang, J., Shi, G., Takamura, T., Khatri, P., Bi, J., Shi, J., Wang, T., Wang, X., and Zhang, B.: Aerosol optical properties and radiative effect determined from sky-radiometer over Loess Plateau of Northwest China, Atmos. Chem. Phys., 11, 11455-11463, doi:10.5194/acp-11-11455-2011, 2011

Kiliyanpilakkil, V. P. and Meskhidze, N.: Deriving the effect of wind speed on clean marine aerosol optical properties using the A-Train satellites, Atmos. Chem. Phys., 11, 11401-11413, doi:10.5194/acp-11-11401-2011, 2011.

Lehahn, Y., Koren, I., Boss, E., Ben-Ami, Y., and Altaratz, O.: Estimating the maritime component of aerosol optical depth and its dependency on surface wind speed using satellite data, Atmos. Chem. Phys., 10, 6711-6720, doi:10.5194/acp-10-6711-2010, 2010

Paton-Walsh, C., Emmons, L. K., and Wilson, S. R.: Estimated total emissions of trace gases from the Canberra Wildfires of 2003: a new method using satellite measurements of aerosol optical depth & the MOZART chemical transport model, Atmos. Chem. Phys., 10, 5739-5748, doi:10.5194/acp-10-5739-2010, 2010

Swartz, W. H., Yee, J.-H., Shetter, R. E., Hall, S. R., Lefer, B. L., Livingston, J. M., Russell, P. B., Browell, E. V., and Avery, M. A.: Column ozone and aerosol optical properties retrieved from direct solar irradiance measurements during SOLVE II, Atmos. Chem. Phys., 5, 611-622, doi:10.5194/acp-5-611-2005, 2005

The paper is generally poorly written and shows many signs of being a sloppy, rushed job. The standard of English is rather variable and the paper lacks a clear structure; the reader is often left searching for the relevance and reason behind various passages of text. Furthermore, some sentences don't make sense and appear incomplete. Indeed the spelling and grammatical errors are so numerous that I am surprised this paper was allowed to reach the open discussion phase. Particular grips regarding the style and presentation of the paper include:

Responses: We are revised the manuscript with contributions from all co-authors. We also use the Elsevier language editing service to polish our manuscript.

- Introduction doesn't describe why a new AOD retrieval method for SEVIRI is needed, or what the new method provides that is not already provided by the existing approaches.

Responses: Up-to-date geostationary instruments like the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) on-board Meteosat-8 and GOES 8 imager offer considerable prospects to enhance the frequency of aerosol mapping due to their high temporal resolution. Wang et al. (2003) used 30 days of half-hourly, high temporal resolution GOES 8 imager data and radiative transfer calculations to retrieve dust aerosol optical thickness (AOT) over the Atlantic Ocean (14°N ~ 26°N, 73°W–63°W) during the Puerto Rico Dust Experiment (PRIDE). The GOES 8 imager with high temporal resolutions also captures aerosol diurnal variation in this study that can further reduce the uncertainties in the current aerosol forcing estimations caused by the high temporal variations of AOT, thereby playing a complementary role with global AOT retrievals from polar orbiting satellites.

Aerosol products from polar-orbiting satellite sensors, such as MODIS, represent a significant improvement over those from other satellite imagers, which are generally only based on single or dual channel reflectances. However, polar-orbiting satellites are restricted to overpasses at a fixed local time, and thus cannot resolve the diurnal cycle and temporal evolution of aerosols (Spörl and Deneke 2011).

To address this shortcoming from polar-orbit satellites, we utilize the geostationary METEOSAT Spinning Enhanced Visible and Infrared Imager (SEVIRI) data to obtain an aerosol product at SEVIRI's 15 minute temporal resolution. The MSG/SEVIRI, which has three narrow spectral bands in the solar spectrum (at 0.63, 0.81 and 1.64 μm) provides a chance to obtain high-temporary AOD products (Thieuleux, 2005). As what was mentioned by the first reviewer, for such a good satellite dataset, there are not many AOD retrieval methods, especially for high temporal resolution AOD products over land, although there definitely already exits several algorithms as described in the paper. Several algorithms focus on daily or hourly average AOD product (Bernard et al., 2009; Bernard et al., 2011; Govaerts et al., 2010). Of course, all existing approaches, including those were transplanted from other mature algorithm, has its own advantages. For instant, the method presented by Brindley and Ignatov (2006) can provide both AOD and size information, only for mineral aerosol. Govaerts et al. (2010) shows a retrieval method providing both AOD and surface reflectance, only for mean daily product, and so on.

While the Time Series (TS) algorithm described in the paper derived high temporal resolution product. On the other hand, the paper also provides some high-temporary information about aerosol type (at least signal scattering albedo and asymmetry factor) while existing approaches need fixed aerosol type information for establishing Look-Up-Table (LUT).

- Not all symbols are defined (μ_0 and r_0 for example), some definitions are self contradictory (τ is defined as aerosol optical depth in the appendix and then as $\tau=\tau_{molecular}+\tau_{aerosol}$ at 4040-106), and some values are defined with more than one symbol. The authors are particularly guilty of the last error with equation 23, where radiance is redefined (I to L), Earth-Sun distance is redefined (r to d(t)) and what was radiance is redefined as irradiance.

Responses: We rewrite the equation (19) as $\tau=\tau_{molecular}+\tau_{aerosol}$ under the assumption that atmospheric optical depth (τ) consists of two parts: the molecular Rayleigh scattering ($\tau_{molecular}$), and the aerosol optical depth ($\tau_{aerosol}$).

We rewrite equation (23) as following;

$$A'(i)=\frac{\pi\times \mathrm{I}(i)\times r^2(t)}{L\times\cos(\theta(t,x))}$$

where I(i) is the measured radiance in $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$,

r(t) is the Sun-Earth distance in astronomical units (AU) at time t,

L is the band solar irradiance at 1 AU in $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$ (shown in Table 2),

Θ(t,x) is the solar zenith angle in radians at time t and location x and

i is the channel number.

We make all signs in the paper unanimous and update the Appendix.

- Figure 1 and especially Figure 2 are not of publication quality and the figures are sloppy in general (figure panels aren't aligned, the font size of figure labels and legends are often too small to be legible ect)

Responses: We improve all the figure quality in the paper. All figures are submitted separately as JPG or TIF files.

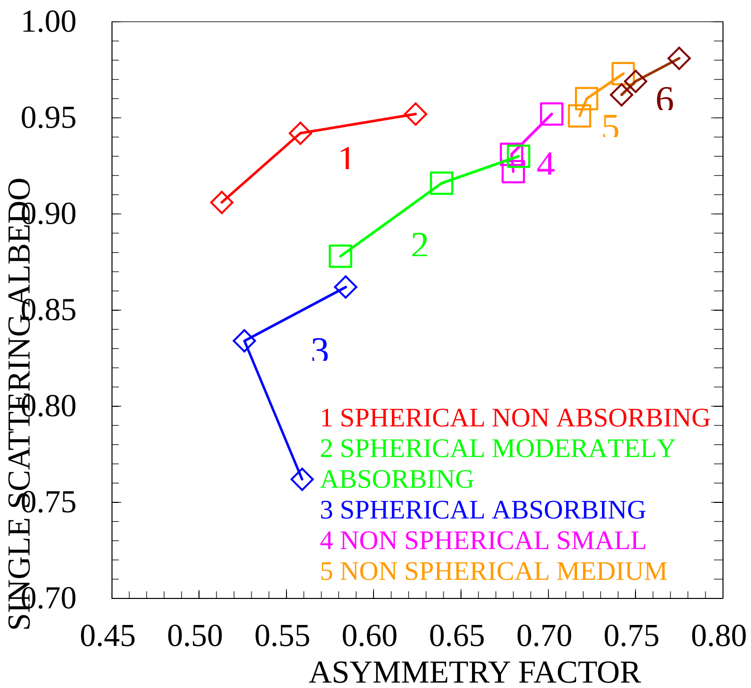


Figure 1. Aerosol classes in the (g, ω) space derived from the analysis of AERONET observations at the SEVIRI solar channel wavelengths (Adapted from Govaerts et al., 2010).

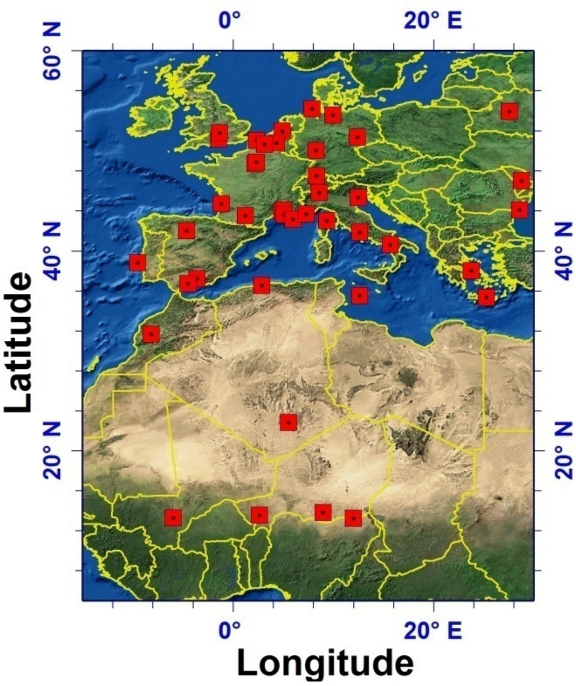


Figure 2. AERONET chosen for validation in study area (red squares stand for AERONET) (-15° - 30°E, 5° - 60°N). Here red squares with black point in the central stand for the AERONET sites.

- Section 4.1, and its overlap with the end of section 3, is particularly poorly written. At no point do the authors state that the purpose of this section: ie. To use AOD time series from SEVIRI, collocated with AERONET stations, to validate their retrieval.

Responses: Section 4.1 is a validation part use AERONET ground-based measurements, which is different from section 3. In short, section 3 is the data description part while section 4 is the validation part that used the data described in section 3. The end of section 3 gives a simple description about how we convert AEERONET measurements to the specific wavelength that are corresponded to satellite channels. We added several sentences as following at the beginning of section 4.1:

In section 4, we mainly focus on the comparisons between satellite-derived AOD results using TS algorithm and AERONET ground-based measurements in two aspects: One is the statistical analysis using scattering plot between satellite-derived AOD products and AERONET AOD measurements (AERONET measurements have been interpolated to the same wavelengths as satellite using the method described in section 3). The other is the time series analysis to see the variability of AODs during the day.

Concentrating on the science content of the paper, I believe the algorithm presented in the paper shows some merit and is definitely worth of publication. The authors have come up with a new approach (as far as I am aware) and done a reasonable initial validation. However, there is a great deal of scope for improving the clarity of the presentation:

- The authors need to state up front why they feel new aerosol retrieval for SEVIRI is necessary and what makes their algorithm special.

Responses: Current Earth observing sensors provide operational aerosol maps over ocean and land but most polar orbiting systems are limited to maximum cover a region once/twice a day. Up-to-date geostationary instruments like the SEVIRI on-board Meteosat-8 offer considerable prospects to enhance the frequency of aerosol mapping due to their high temporal resolution. The MSG/SEVIRI with high temporal resolutions could capture aerosol diurnal variation that can further reduce the uncertainties in the current aerosol forcing estimations caused by the high temporal variations of AOT, thereby playing a complementary role with global AOT retrievals from polar orbiting satellites.

On the other hand, the paper also provides some high-temporary information about aerosol type (at least signal scattering albedo and asymmetry factor) while existing approaches need fixed aerosol type information for establishing Look-Up-Table (LUT). Of course, each existing approach, including those were transplanted from other mature algorithm, has its own advantages.

- The discussion of the aerosol model used in the retrieval algorithm needs expanding. Why did the authors choose those particular models?

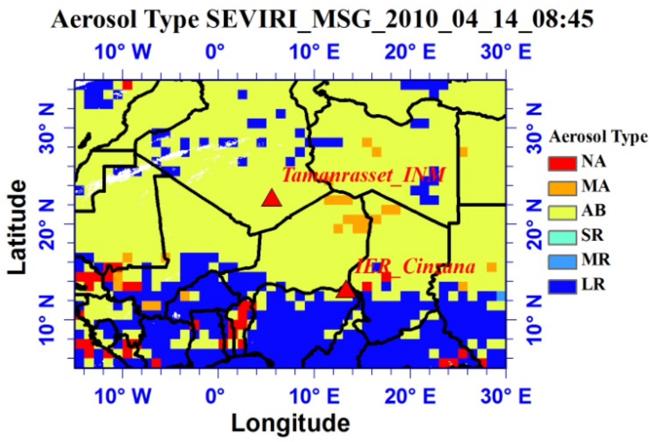
Responses: The use of aerosol models results from the need to provide some prior information on the aerosol physical and chemical which determine their radiative properties (Govaerts et al., 2010). One absorption parameter (single scattering albedo, or SSA) and one size parameter (g) are sufficient for representing the entire aerosol parameter space (Levy et al., 2007). Other parameters used are e.g. size information (such as mean radius) and optical properties (such as extinction/backscatter ration) (Omar et al., 2005), fine-mode fractions (FMF) (Kim et al., 2010). Govaerts et al. (2010) suggested six aerosol types (spherical non-absorbing, spherical moderately absorbing, spherical absorbing, non-spherical small, non-spherical medium and non-spherical large) that can be used in MSG/SEVIRI AOD retrieval. The aerosol models proposed by Govaerts et al. (2010) and the values of parameters describing each of them are presented in Table 1 and in Fig. 1.

- I am not entirely clear if the authors are claiming that their algorithm can successfully retrieve aerosol type as well as AOD and surface reflectance. Fig. 9 is fairly illegible and section 4.3 doesn't help much. If this is the authors' assertion, they need to perform a validation rather than just plot as series of maps.

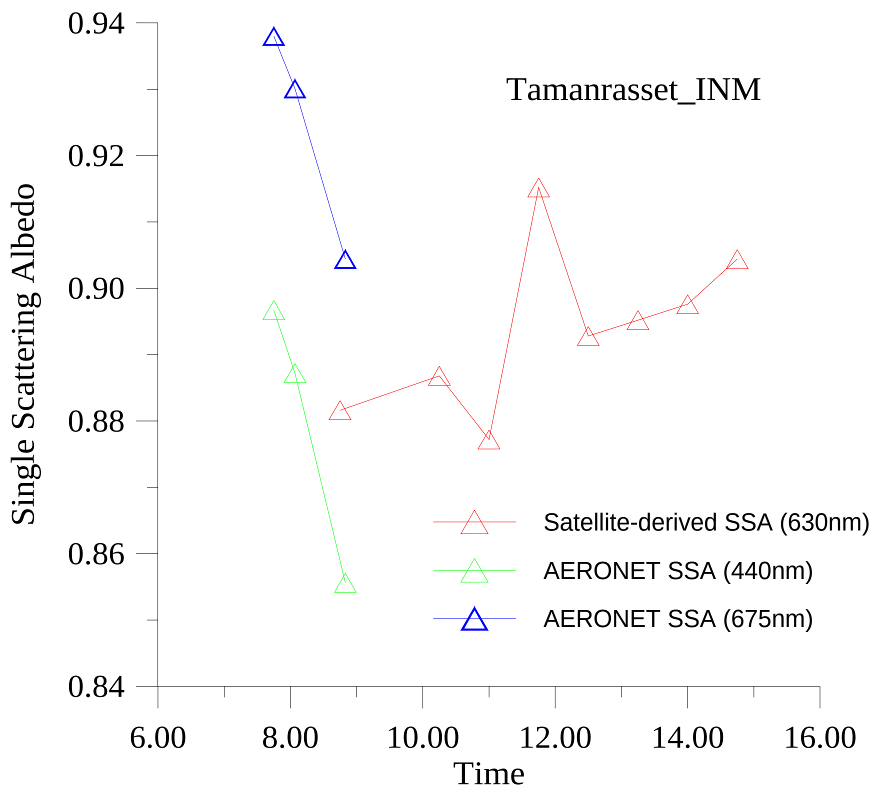
Responses: As we described in the algorithm part, our algorithm show potential for retrieve AOD, aerosol type as well as surface reflectance. The main idea for the retrieval algorithm is that we firstly derived the best suitable aerosol type (ie. g and ω values) from six aerosol types. Then, from the derived analytical solution, we can retrieve AOD, aerosol type and surface reflectance simultaneously. As in this paper, we mainly focus on aerosol properties and we are preparing another paper for extensive validation and reflectance retrieval.

In the revised version we will add the followings:

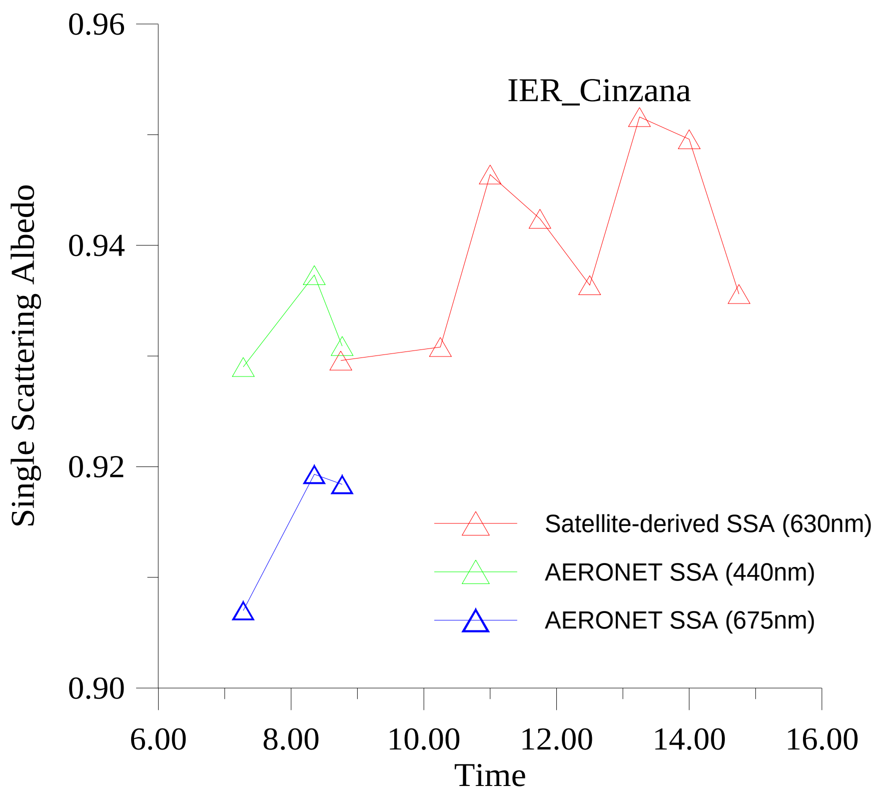
It is very difficult to validate the aerosol type. However, here we try to compare the aerosol type using single scattering albedo, which is the very important factor, provided by AERONET. Due to the fixed constant of single scattering albedo and asymmetry factor for each aerosol type, we should notice that there are surely some differences between satellite-derived aerosol types and AERONET measurements. Also, the wavelengths between satellite-derived data (630nm) and AERONET (440nm, 675nm and 870nm) with different spectral resolution make it hard to compare. We use the 50km×50km averaged values to correspond with measurement at AERONET site. We took two AERONET sites according to the aerosol type distribution in North Africa which may represent the two main aerosol types in this area. One site is Tamanrasset_INM (5.53E, 22.79N), and another is IER_Cinzana (-5.93E, 13.28N). According to the map below (shown as Fig. a), we can see that the site Tamanrasset_INM is much more absorptive comparing with IER_Cinzana according to satellite-derived data, which agrees with AERONET observations, shown in Fig. 10. The satellite-derived SSA at 630nm located between AERONET SSA at 440nm and 675nm, which also agree with the spectral characters of SSA.



(a)



(b)



(c)

Figure 10, The comparison of aerosol types derived from satellite data and measured at two AERONET sites

- The algorithm presented also retrieves surface reflectance, but these data are not discussed at all.

Responses: To avoid extreme long manuscript, in this paper, we mainly focus on aerosol properties and we are preparing another paper for reflectance retrieval.

Over all, given the significant problems with this paper, as well as the fact that it seems out of scope for ACP, I do not believe it should be published in ACP, or any other journal, without significant revision.

Responses: Thanks for the comments from reviewers. We have revised the manuscript extensively.

Specific points and suggestions

The following are labeled with the page number and either the line number of the table/figure number. Note that his is not an exhaustive list of spelling or grammatical errors- such a list would be significantly longer.

Responses: We are working together with all co-authors to improve the English. We also use the Elsevier language editing service to polish our manuscript.

4035-I5: Sentence staring “The relationship of visible…” does not make sense.

Responses: This sentence will be removed in the revised version.

4036-l20: I cannot decipher this sentence

Responses: We have rewritten the paragraph from 4036-l20 to 4037-l16 in the revised version.

Unlike traditional geostationary satellites, MSG/SEVIRI has three narrow spectral bands in the solar spectrum (at 0.63, 0.81 and 1.64 μm), in addition to the wide HRV band. Previous researches have showed varieties of approaches for MSG/SEVIRI AOD retrieval. Some papers tried to retrieve AOD have demonstrated a good AOD results compared with AERONET observation over ocean using MSG/SEVIRI (Thieuleux et al. 2005, Bennouna et al. 2009). As to AOD retrieval over land surface, Popp (2007) used a “background method” which is not suitable for bright surface with absorbing aerosol to retrieve AOD from MSG/SEVIRI and Bernard et al. (2011) did an evaluation of this method, confirming that this method is suitable for most Europe area. Carrer et al. (2010) put forwarded daily estimates of aerosol optical thickness over land surface based on a directional and temporal analysis of MSG/SEVIRI visible observations. Govaerts et al. (2010) developed a joint retrieval method of surface reflectance and aerosol optical depth from MSG/SEVIRI observations with an optimal estimation approach. Meanwhile, Some mature retrieval algorithms were also “transplanted” for MSG/SEVIRI AOD retrieval, such as operational algorithm used to retrieve AOD over ocean for Advanced Very High Resolution Radiometer (AVHRR) (Brindley et al., 2005) and Oxford-RAL Aerosol and Cloud (ORAC) method (Bulgin et al., 2011).

4037-l16: (Claire et al., 2011) should be (Bulgin et al., 2011)

Responses: We have revised this in the new version.

4056-Table 1: Define all symbols used.

Responses: We have revised this in the new version and defined all symbols in Table 1 caption.

Appendix - List of symbols

Standard alphabetical symbol

Symbol	Description
A	Earth’s surface reflectance
A'	Earth’s system reflectance (apparent reflectance observed from space)
$A_{1,\lambda}$	Surface reflectance at λ at the first scan time
$A_{2,\lambda}$	Surface reflectance at λ at the second scan time
$A'(i)$	Apparent reflectance observed by satellite at channel i
$B(\mathrm{T}_e(\tau))$	Planck function at Absolute temperature equal to $\mathrm{T}_e(\tau)$
$\mathbf{C_{vf}}$	Fine-mode volume concentration (μm)
$\mathbf{C_{vc}}$	Coarse -mode volume concentration (μm)
F_{Θ}	Solar flux density at the top of the atmosphere when the instantaneous distance between the earth and sun is r
$F^{\uparrow}(\tau)$	Total upward flux densities with atmosphere optical depth equal to τ

$F^{\downarrow}(\tau)$	Total downward flux densities with atmosphere optical depth equal to τ
g	Asymmetry factor
I	Intensity of the radiation
$I(i)$	The measured radiance in $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$
i	Channel number
k_{λ}	Surface reflectance ratio at λ
L	band solar irradiance at 1 AU in $mWm^{-2}sr^{-1}(cm^{-1})^{-1}$
m	Number of predefined aerosol types
$P(\Omega,-\Omega_0)$	Phase function from direction $-\Omega_0$ to direction Ω
$P(\Omega,\Omega')$	Phase function from direction Ω' to direction Ω
r	Earth-sun distance
r(t)	Sun-Earth distance in astronomical units (AU) at scan time t
r_0	Mean earth-sun distance
$\mathbf{r_{vf}}$	Fine-mode volume median radius (μm)
$\mathbf{r_{vc}}$	Coarse-mode volume median radius (μm)
$\mathbf{r_{ef}}$	Fine-mode effective radius(μm)
$\mathbf{r_{ec}}$	Coarse -mode effective radius(μm)
S	The solar constant (1367 Wm^{-2})
S_0	Percentage of spherical particles
T_e	Absolute temperature
T_{λ}	Transmissivity at λ
t	Satellite scan times

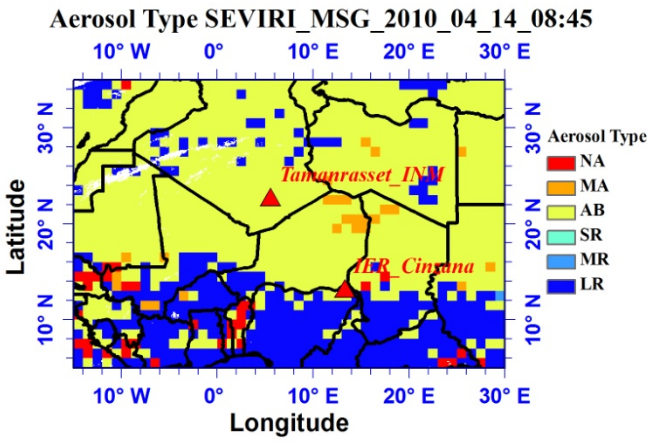
Standard Greek symbols

Symbol	**Description**
α	Wavelength exponent in angstrom’s turbidity formula
β	Angstrom’s turbidity coefficient
ε	the minimal difference between surface reflectance of two orderly observations for each predefined aerosol type
θ	Solar zenith angle
$\theta(t,x)$	Solar zenith angle in radians at scan time t and location x
λ	Wavelength
μ	Consin of satellite zenith angle

μ_0	Consin of solar zenith angle
$\boldsymbol{\sigma_f}$	Fine-mode radius standard deviation (μm)
$\boldsymbol{\sigma_c}$	Coarse -mode radius standard deviation (μm)
τ	Atmosphere optical depth
τ_0	Total atmosphere aerosol optical depth
$\tau_{molecular}$	Rayleigh optical depth
$\tau_{aerosol}$	Aerosol optical depth
$\tau(\lambda)$	AOD at wavelength λ
Ω	Outgoing intensity direction
Ω'	Incoming intensity direction
$-\Omega_0$	Direct solar flux direction
ϖ	Single scattering albedo

4069-Figs. 9&10: A coast outline would make these plots much clearer.

Responses: We have revised this in the new version. For instant,



4041-l19: The fact that an aerosol "type" produces a perfect fit to Eq. (22) does not imply that it is the "true aerosol type", rather, it implies that the model used by in the retrieval is radiatively consistent with the measurements.

Responses: Yes, it is the best estimation from six aerosol models for each pixel.

4043-l10: "TS algorithm" is not defined.

Responses: TS algorithm has been defined in the abstract as "Time Series" algorithm

4045-final paragraph of section 4.1: The authors make a series of conclusion regarding the reasons behind the form of the linear fits shown in Fig.5. The authors need to justify these statements- simply referencing MODIS DDV algorithm validating papers (which is a different algorithm with a different set of assumptions) is not sufficient.

Responses: We compared our AOD data with AERONET AOD measurements as well as NASA MODIS AOD products. We have added more discussions in the revised version.

4047-I15: The statement that Fig. 7&8 show agrees much better with the Deep Blue MODIS product than the DDV is not justified. The two plots actually show rather similar agreement, given the completely different geographical areas and AOD ranges compared.

Responses: We have revised the statement as following. Thanks for the suggestion of the nice presentation.

The correlation between AOD values derived by TS algorithm and DeepBlue method is 0.859 with slope of 0.858 while the correlation between AODs from TS algorithm and DDV method is 0.798 with slope of 0.797. The two plots actually show rather similar agreement, given the completely different geographical areas and AOD ranges compared.