Author’s response to Interactive comments of Anonymous Referee #3 on “An Aerosol Optical Depth time series 1982–2014 for atmospheric correction based on OMI and TOMS Aerosol Index” by E. Jääskeläinen et al.

We thank the referee for careful reading of our manuscript and for the helpful comments. We will incorporate these comments to the revised manuscript. Below, we list referees’ comments followed by our answers (in blue). The pages and lines included in our answers refer to the revised manuscript.

Summary

This paper describes a procedure to create a climatological representation of aerosol optical depth over the continents for the period 1982-2014 using the OMI and TOMS aerosol index (AI), via an AI-to-AOD conversion procedure that involves the use of MODIS and OMI AOD satellite products. The main purpose of the analysis is to replace a constant AOD value of 0.1 currently used in the CLARA-A2-SAL project with an estimate derived from the analysis in this paper, which, in the opinion of the authors, is a more realistic value.

Review

Although the authors have made an effort to develop a sound methodological approach, I do not believe they have achieved their proposed goal of deriving a realistic quantitative representation of the background atmospheric aerosol load over land which over most of the world is associated with sulfate-based industrial aerosols and biological particles, which is precisely what the AI is not. Since the AI represents only a partial description of the global aerosol load, I do not believe their goal of deriving a realistic product is actually achievable. For that reason, I do not think this work is publishable in its current form. In the review below I offer a few recommendations mostly on the correct interpretation of the AI data to arrive at more realistic representation of the AI in terms of AOD only in the regions where the AI may indeed be used as proxy of most of the atmospheric aerosol load.

Main comments

My main criticism of this work is this work has to do with the over-interpretation of the AI as a proxy of the total column AOD, as well as its miss-interpretation in conditions where the residual quantity is associated with other non-aerosol related effects. As it has been well documented the AI is only sensitive to elevated aerosol layers (about 2km and higher above the surface) of smoke, desert dust, and volcanic ash. Thus, the AI cannot be interpreted as a proxy of the total AOD column everywhere, and neither can it be interpreted as being representative of aerosol types other than optically thick layers of dust and smoke. As the residual quantity it is, the AI is a representation of any wavelength dependent process unaccounted for by a simple radiative model representation of the Earth’s atmosphere where molecular scattering and ozone absorption are the only radiative transfer processes explicitly included. Positive AI values larger than about 1.0 are generally associated with the absorption effects of layers of smoke, dust or volcanic ash located at least 2.0 km above the surface. AI values less than 1.0 over land are undistinguishable from those associated with non-aerosol related effects such as wavelength dependent surface reflection effects (especially over the arid and semi-arid regions of the world) and scattering effects of clouds. Thus, in the analysis carried out in this manuscript AI values lower than 1.0 should not be used.

We were aware of this issue (the over-interpretation of the AI as a proxy of the total column AOD) when constructing the AOD time series. The motivation for the AOD time series is the need for daily AOD information for the years 1982-2014. As there is no such data set available, we have to construct it to avoid using a climatological solution in varying climate. The only existing homogenous aerosol related data set for the whole needed time period, from which to calculate this AOD time series, is AI data from TOMS and OMI instruments. It is true, that there are issues in using the AI data as a proxy for AOD information and the issues should have been described better in the manuscript. There is now a remark of this issue in the manuscript, P. 2/ L. 23-27, and also information of where the relation between AI and AOD is most reliable and where it is not.
We have also now clarified in the manuscript (i.e. P. 4/L. 8-10 and P. 10/L. 28-30), that the use of the land use classification information in the calculations provides some information about the nonabsorbing aerosols.
The demarcation of limits of the data used is always difficult, and we decided to use AI values below 1.0 even though it produces possible problems by weakening the overall quality. For us, the atmospheric correction is the main interest, and the results obtained by using the constructed AOD as aerosol information in the atmospheric correction algorithm are quite promising. The use of AI values below 1.0 is also a conscious risk, but we will take this matter into account in the future versions of the AOD time series.
Estimating AOD of scattering aerosols at 550 nm using the UV information is justified, because the wavelength difference is relatively small to allow using the Ångström exponent relation. For absorbing aerosols one cannot expect to get a direct relationship between two wavelengths. In that case the statistical relationship between the amounts of scattering and absorbing aerosols seems to be typically strong enough to provide good enough results.

Special care should be exercised to avoid anomalous positive AI values (often larger than unity) that are commonly observed at high latitudes in the late fall and winter seasons in both hemispheres. The nature of these anomalous AI values is not well understood, but it appears to be related to a breakdown at high solar and satellite zenith angles of the Lambertian approximation used in the AI calculation.

The Solar zenith angle is over 70° at high latitudes in both hemispheres in the late fall and winter seasons, and the CLARA-A2 SAL product is not calculated over those high SZA values. So these anomalous AI values do not affect calculation of the AOD time series in question

Based on the above stated considerations the AI signal can be considered a reasonable proxy of the total columns aerosol load only over regions where either dust, smoke or a dust-smoke combination account for most of columnar aerosol content yielding AI values larger than 1.0. Those regions include the well-known tropical and sub-tropical regions of Africa and both South and Central America where the AI signal is associated with the presence of optically thick smoke layers as well as the so-called dust belt that contains the world's major dust sources.

We added and improved text to emphasize, that the constructed AOD works well in certain areas (i.e. Sahara), but might fail in others (i.e. Amazon): P. 2/L. 26-27, P. 6/L. 12-14, P. 12/L. 11-18..

The description of the different data sets presented in Table 2 is confusing and misleading. The authors seem very unfamiliar with the AI data sets they are using. The TOMS v8 algorithm using the 331 and 360 nm channels is applied uniformly to both Nimbus-7 and Earth Probe observations. The earlier version (v7)made use of 340-380 nm for Nimbus7 and 331-360 nm for Earth Probe.

According to the tabulated information the authors may actually be using v7 data for both sensors. The v8 data sets should be used. Otherwise, a scaling factor should be applied to the 331-360 AI which is about 25% lower than the 340-380 nm AI definition due to the wavelength separation.

We apologize, there were error in Table 2, the used version was indeed v8 and the wavelength range for AI calculation in Nimbus-7 is also 331-360 nm, the same as it is in Earth Probe. It is now corrected in the manuscript Table 2.

Earth-Probe TOMS AI data after 2001 should not be used. A serious degradation issue affecting the sensor diffuser produces anomalously high AI values that must be ignored in any kind of trend analysis [Kiss et al., 2007].

Yes, the TOMS-AI data 2002 onwards are omitted from the calculations, P. 9/L. 14-17.

Other comments

The reported wavelength-pair (342.5-388 nm) used for the calculation of the OMAERO AI parameter is at odds with the 354-388 nm pair reported in the literature [Torres et al., 2007].

We apologize, there was an error in Table 2, the wavelength range for the calculation of the OMI-AI is indeed 354-388nm. It is now corrected in the manuscript Table 2.

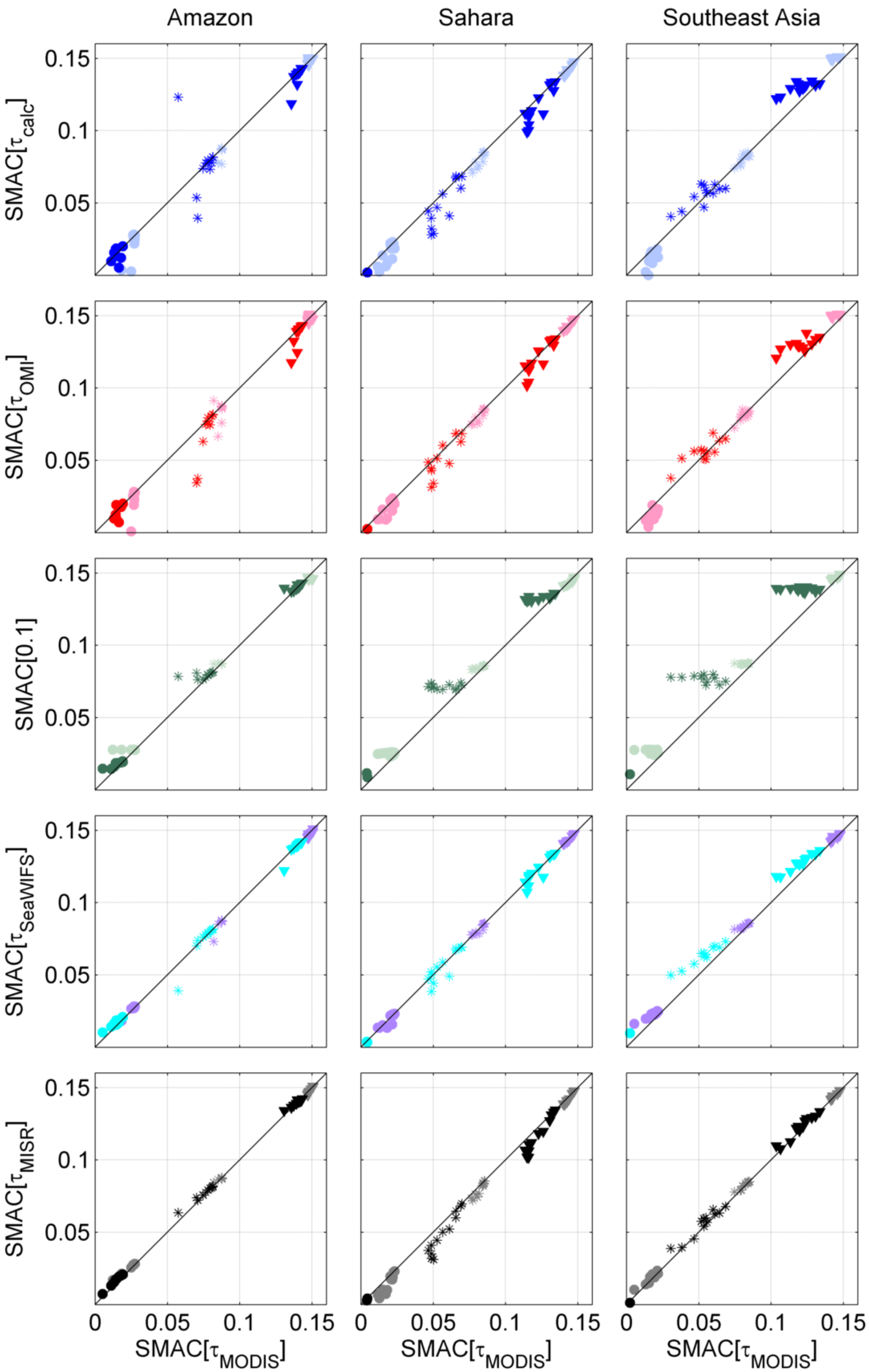
It is not clear why the authors have chosen to work with the OMAERO AI. The obvious choice should be the OMTO3 AI product that uses the same wavelengths and the same algorithm as the TOMS V8 products. The V8 AI algorithm applied to Nimbus7 TOMS, Earth-Probe TOMS and Aura OMI (OMTO3) uses an algorithm that accounts for the presence of clouds at realistic location above the surface (MLER model). OMAERO AI uses a simple approximation (LER model), in which clouds are placed at surface level. These algorithmic differences produce significant AI difference in the presence of clouds and cloud-aerosol mixtures (Penning de Vries and Wagner, 2010).

Yes, this is true, we should have used OMTO3 data. In the future versions we will use the OMTO3 data. Note of this is in the new section in the manuscript, section 7 titled as Discussion and conclusions. See next answer for more information.

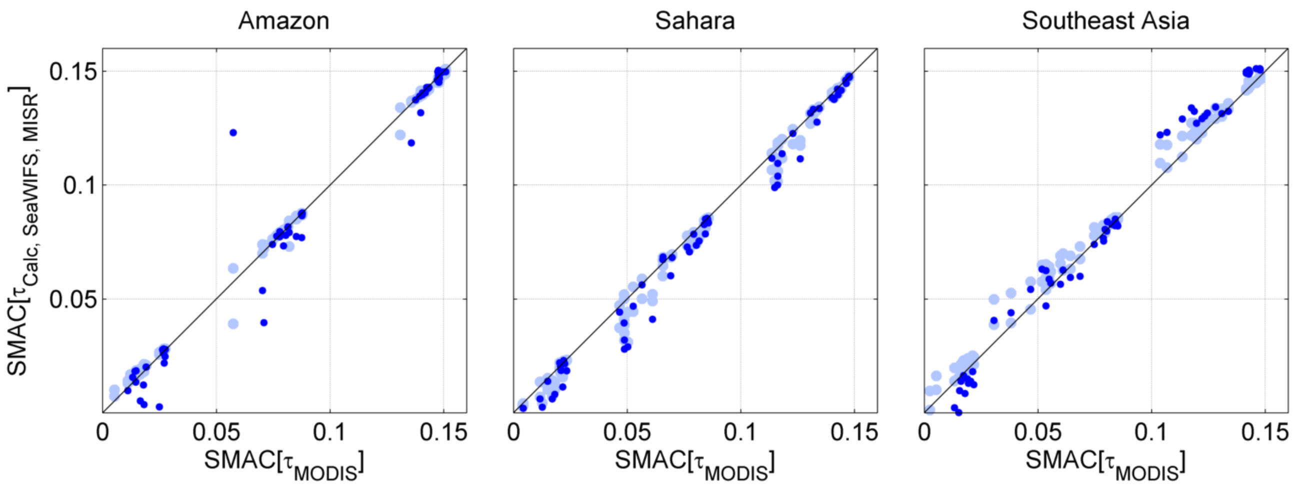
The authors make use of MODIS and OMAERO AOD retrievals to transform the AI into the AOD space. More information on this procedure is needed. Which MODIS data is used? If the Dark Target MODIS (DTM) data is used, how do the authors handle the lack of DTM data over most of the world's arid and semi-arid areas? Please include key references to MODIS AOD validation studies. A justification for the use of the OMAERO product in this analysis should be provided. I am not aware of any comprehensive validation analysis of this product under different of aerosol conditions to support its application in a global product as intended in this analysis. Limited multi-sensor comparisons to AERONET observations [Ahn et al., 2014; Carboni et al., 2014], shows significantly poorer OMAERO statistics relative to other satellite data sets.

The AOD data from Dark Target and Deed Blue aerosol retrieval algorithms are used. This detail is now clarified in the manuscript P. 5/L. 12-13, and we also added the references to the MODIS-AOD validation studies, P. 5/L. 12-13.

The OMAEROe AOD, after calculating to the AOD at 550 nm, are screened with MODIS-AOD (i.e. P. 4/L. 18-19, P. 5/L. 10-13,), so the used AOD are close to the MODIS-AOD values. It is true that we should have used OMTO3 data (see answer above). Below are two figures, where the surface reflectance values calculated by atmospheric correction algorithm SMAC are shown. The used assumptions for constant values for the satellite zenith angle are 0° (light blue, light red, light green, cyan, grey colours) and 40° (dark blue, dark red, dark green, purple, grey colours) and for ToA reflectance 0.05 (circle), 0.1 (asterisk) and 0.15 (triangle). The satellite azimuth angle is a constant 260°, water vapour content 2.5, integrated ozone 0.35 and pressure 1013. The Solar zenith angles, Solar azimuth angles and AOD at 550 nm for each month are chosen to be the most probable value from each subclass of the year 2010 from constructed AOD time series (blue), OMI-AOD (red), MODIS-AOD, SeaWIFS-AOD (cyan and purple) and MISR-AOD data (grey and black). The marker types and colours are used only in the first figure. The individual simulations are in the first figure, and the combined results are in the second one, where the dark blue indicates the surface reflectance values calculated by using constructed AOD as aerosol information and the light blue those values which were calculated by using the SeaWIFS-AOD and MISR-AOD values. The surface reflectance values calculated by using the constructed AOD, OMI-AOD, the constant value 0.1, SeaWIFS-AOD and MISR-AOD are compared to the surface reflectance values calculated by using MODIS-AOD values. From those results can be seen that even though the constructed AOD have some difficulties in the Amazon area, the values it produces for the surface reflectance by applying the SMAC algorithm do not essentially differ from the others. So the use of OMAERO-AOD as the basis data do not seems to cause major problems. Note of this is in the new section in the manuscript, section 7 titled as Discussion and conclusions.

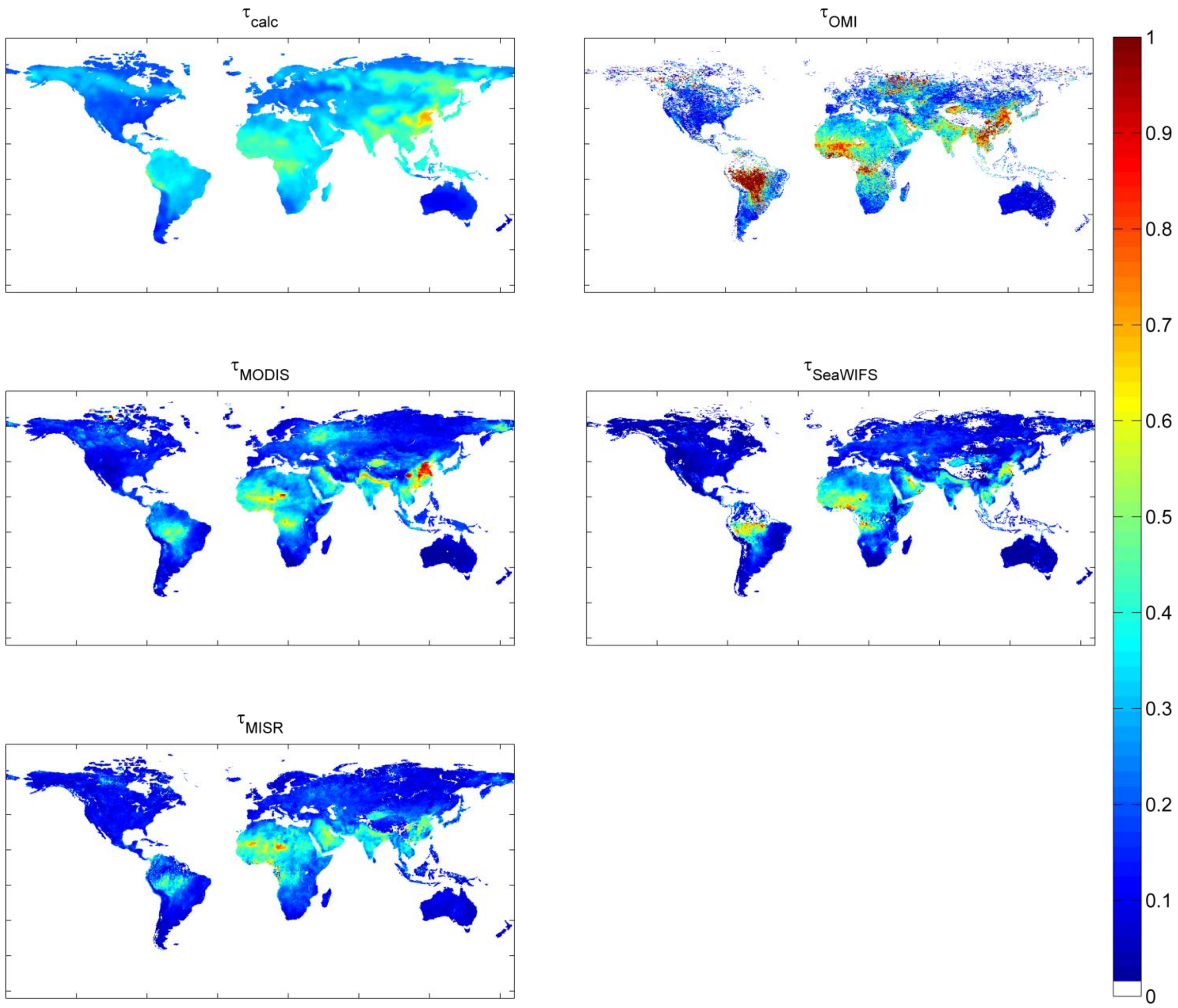


Amazon
Sahara
Southeast Asia
SMAC[τ_{calc}]
SMAC[τ_{OMI}]
SMAC[0.1]
SMAC[$\tau_{SeaWIFS}$]
SMAC[τ_{MISR}]
SMAC[τ_{MODIS}]
0
0.05
0.1
0.15



The representativity of the resulting monthly long-term AOD record should be evaluated by comparison to other available multiyear records such as MODIS and MiSR (2000-present), SeaWIFS (1997-2010) and TOMS (1979-2001).

The annual means of different AOD data (the constructed AOD, OMI, MODIS, SeaWIFS and MISR) from the year 2010 are shown in figure below. The constructed AOD have higher values (around 0.25) compared to the MODIS, SeaWIFS and MISR AOD values in the North-America Taiga area, in the Savanna area in South-America, in the northern Europe, in the Siberia, in the central and eastern Asia area, in the east and southern Africa, and in the islands in the southeast Asia. On the other hand, the constructed AOD do not reach the level of the highest AOD values in the MODIS, SeaWIFS and MISR AOD maps in the Sahara, in the Savanna area in Africa and in the eastern China. In other areas the constructed AOD is close with the other AOD data. Overall the calculated AOD values have the similar behaviour as the MODIS, SeaWIFS and MISR AOD data, but are in some areas too high.



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