Retrieval of the aerosol optical thickness from UV global irradiance measurements

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Abstract. The UV irradiance is measured at Évora since several years, where a CIMEL sunphotometer integrated in AERONET is also installed. In the present work, measurements of UVA (315 - 400 nm) irradiances taken with Kipp&Zonen radiometers, as well as satellite data of ozone total column values, are used in combination with radiative transfer calculations, to estimate the aerosol optical thickness (AOT) in the UV. The retrieved UV AOT in Évora is compared with AERONET AOT (at 340 and 380 nm) and a fairly good agreement is found with a root mean square error of 0.05 (normalized root mean square error of 8.3%) and a mean absolute error of 0.04 (mean percentage error of 2.9 %). The methodology is then used to estimate the UV AOT in Sines, an industrialized site on the Atlantic western coast, where the UV irradiance is monitored since 2013 but no aerosol information is available.

1. Introduction

The strong influence of aerosols in atmospheric processes and consequently in climate makes their quantification in terms of the aerosol optical thickness (AOT) to be extremely important [1]. The AERONET (AErosol RObotic NETwork) program [2-3] represents an important step towards a long-term database of aerosol optical, microphysical and radiative properties, providing globally distributed observations of these quantities in diverse aerosol regimes.

Although ultraviolet (UV) radiation accounts for less than 10 % of the solar radiation, the UV irradiance reaching the surface has particular significance within the solar spectrum due to its potential harmful effects, constituting a hazard for several life forms on Earth. For this reason UV radiation is being monitored since several years in regions with high insolation values [4]. In the absence of clouds, aerosols are the major regulators of the Earth radiation budget and play a central role in modulating UV radiation. Therefore, UV irradiance measurements may be used to estimate the atmospheric aerosol load under cloud-free conditions, constituting a useful tool to estimate AOT values in regions where only the UV radiation is monitored but no aerosol information is available, as was already proposed for pyranometer data [5].

In this work, the UV irradiance measured at Évora since several years is combined with radiative transfer calculations to retrieve the AOT in the UVA spectral region. The simultaneous existence of a CIMEL sunphotometer integrated in AERONET allows for checking the validity of the methodology

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applied, enabling its application to different sites. This work is organized as follows: after the introduction, a brief description of the sites and instrumentation used is presented in section 2; the methodology is presented in section 3 followed by the results and discussion in section 4. Finally, the conclusions are summarized in section 5.

2. Sampling sites and instrumentation

Simultaneous measurements of the UV radiation and aerosol characteristics are taken in Évora, at the Atmospheric Physics Observatory of the University of Évora (Institute of Earth Sciences - ICT) (38°34' N, 7°54' W, 293 m a.s.l). The site is located about 100 km eastward from the Atlantic western coast and it is in the pathway of different air masses, experiencing the influence of long-range transport of anthropogenic aerosols emitted in northern Europe, and by desert dust plumes advected from Africa. Desert dust and smoke from forest fires (often in summer), account for a significant amount of the suspended particle mass [6-9]. The UV irradiance is also monitored at the University of Évora pole in Sines, a small town located on the Portuguese western Atlantic coast, about 150 km south of Lisbon (37º57' N, 8º51' W, 15 m a.s.l), characterized by the existence of a fairly large industrial complex, one of the largest in the country. It is therefore of great interest the monitoring of the AOT at this site where air pollution is a major problem for the local population.

Measurements of the UVA (315 - 400 nm) irradiances are being taken with Kipp & Zonen radiometers at Évora (since 2011) and Sines (since 2013). The broadband radiometers are periodically calibrated at the Atmospheric Sounding Station "El Arenosillo" of the National Institute for Aerospace Technology in South-Western Spain, similarly to the erythemal broadband radiometers [10-11]. The Évora site has also a CIMEL CE-318 sunphotometer and is integrated in AERONET [2]. This sunphotometer provides measurements of the direct solar radiation with a 1.2º full field of view at 340, 380, 440, 500, 675, 870, 940 and 1020 nm. In addition, measurements of sky radiances in the almucantar and principal planes geometries, at 440, 675, 870 and 1020 nm, are also performed by the instrument. The AERONET AOT at 340 and 380 nm are used here to evaluate the accuracy of the AOT retrieved from the UVA irradiance measurements.

3. Methodology

The UVA irradiance is simulated using the 1D radiative transfer package LibRadtran (Library for Radiative Transfer) [12] considering the spectral response function of the radiometer (see figure 1), for varying conditions of solar zenith angle, total ozone column and AOT as shown in table 1 and a fixed surface albedo of 0.035. This allows for obtaining LookUp Tables (LUTs) that will subsequently be used to obtain the AOT from UVA irradiance measurements.

Table 1. Solar zenith angle, total ozone columns and aerosol optical thickness used in the radiative transfer simulations.

Quantity	Values
Solar zenith angle (º)	0 to 70, step of 1
Total ozone column (DU)	200 to 500, step of 5
Aerosol optical thickness	0.00001 0.01 0.03 0.06 0.1 0.15 0.2 0.25 0.3 0.4 0.5 0.6 0.8 1.0

A mid-latitude type of atmospheric vertical profile for winter or summer is considered in the calculations, according to the season [12]; aerosols are assumed to be described by the default properties [12], with rural aerosol type in the boundary layer, background aerosols above 2 km, spring-summer or fall-winter conditions (according to the season) and 50 km visibility. The use of a fixed

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aerosol type may introduce some bias under situations of African dust advection or smoke from forest fires, when the particle load is high, nevertheless, in the majority of the situations the approximation proposed is quantitatively accurate [13].

The radiative transfer equation is numerically solved using the discrete ordinates method with 16 quadrature angles. The extraterrestrial solar spectral irradiance is taken from the SORCE satellite mission that provides measurements of incoming x-ray, UV, VIS, NIR, and total solar radiation, available online at http://lasp.colorado.edu/home/sorce/data/ssi-data/ (last accessed 07/06/2015). The SORCE Solar Spectral Irradiance (SSI) composite data used here is constructed using measurements from the SOLSTICE (115-310 nm; spectral resolution: 1 nm) and SIM (310-2400 nm; spectral resolution: 1 to 27 nm) instruments, for 2013. The use of SORCE SSI is justified by the comparisons shown in Figure 1, between the SORCE SSI used here and one of the SSI contained in LibRadtran. Radiative transfer calculations in the UV spectral region are especially sensitive to the solar irradiance considered, since the smaller values with respect to the visible would translate into more substantial errors in the AOTs. Considerable differences between both can be distinguished in the graph of figure 1, which would lead to significant differences in the LUTs and consequently also in the derived AOTs.

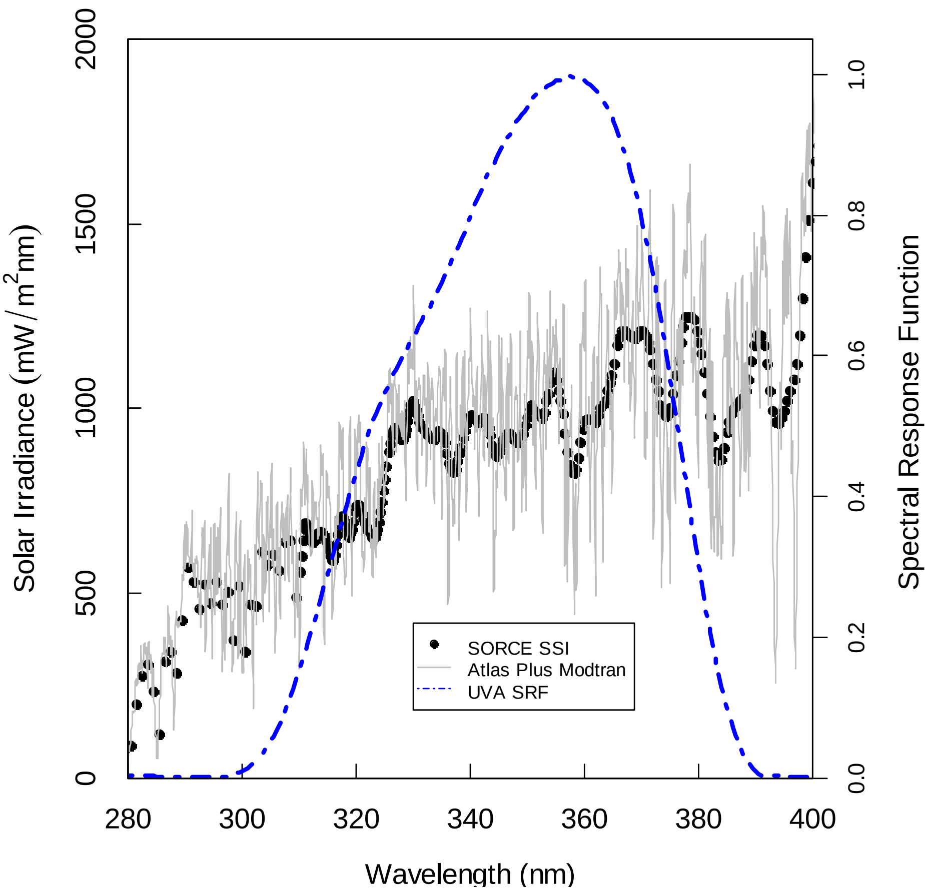

Figure 1. Spectral solar irradiance (SSI) in the UV region. Black dots represent the SORCE satellite data, whereas the gray line shows one of the SSI data contained in LibRadtran (Atlas Plus Modtran). The blue dash-dotted line represents the spectral response function of the UVA radiometer used.

The AOT values are then obtained by simple interpolation of the measured UVA irradiance, with a temporal resolution of 2 minutes, using the modelled irradiances contained in the LUTs. For each UVA measurement, the corresponding LUT (matching solar zenith angle and total ozone columns) is used, yielding the corresponding interpolated AOT value. The daily total ozone column is obtained from the Ozone Monitoring Instrument (OMI) flying onboard Aura satellite (ftp://toms.gsfc.nasa.gov/pub/omi/data/overpass/; last accessed 07/06/2015). Cloud screening is done through the inspection of the daily global UVA irradiance. Comparisons between the retrieved AOT results and corresponding AERONET AOT level 2.0 data, at 340 and 380 nm, are then carried out.

4. Results and discussion

The evolution of the AOT values retrieved from the UVA irradiance measurements in Évora is presented for each month of 2013 in the graphs of figure 2. From January to March, as well as from October to December the AOT values are in general lower than during spring and summer. The absence of data during June is connected to the participation of the UVA radiometer in a calibration campaign. In general the UVA derived AOT agree quite well with AERONET data, accompanying their behavior during background and event situations.

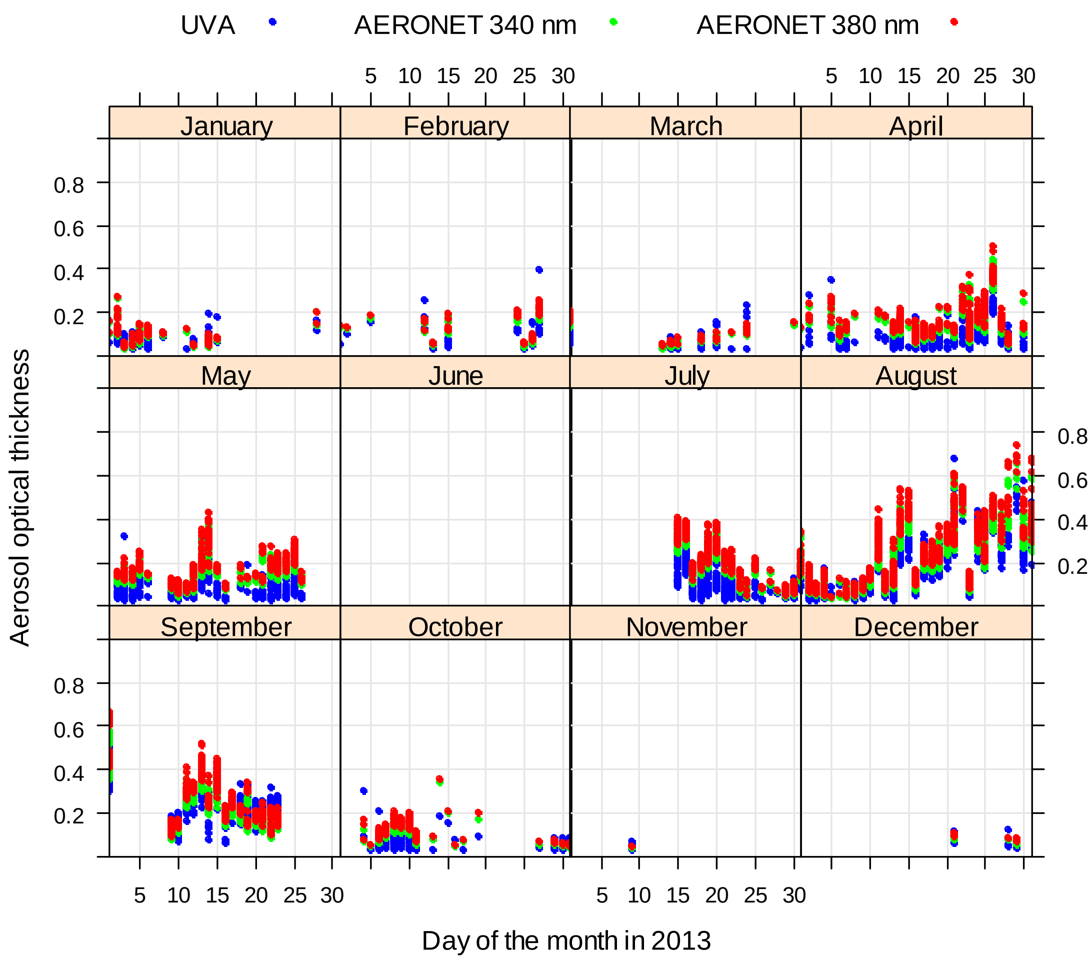

Figure 2. Time series of the AOT in Évora during 2013. Blue dots represent the AOT derived from the UVA irradiance measurements, whereas green and red dots represent the AERONET AOT at 340 and 380 nm, respectively.

The agreement between AERONET AOT and the UVA AOT retrieved for Évora during 2013 is investigated through the scatter plots shown in figure 3. It can be noted that the derived UVA AOT slightly underestimates AERONET AOT, being the agreement with AERONET AOT at 380 nm somewhat better. Curiously the month with the best correlation is August, when the highest AOT values are reached, which seems to show that the method performs better for situations with high aerosol load.

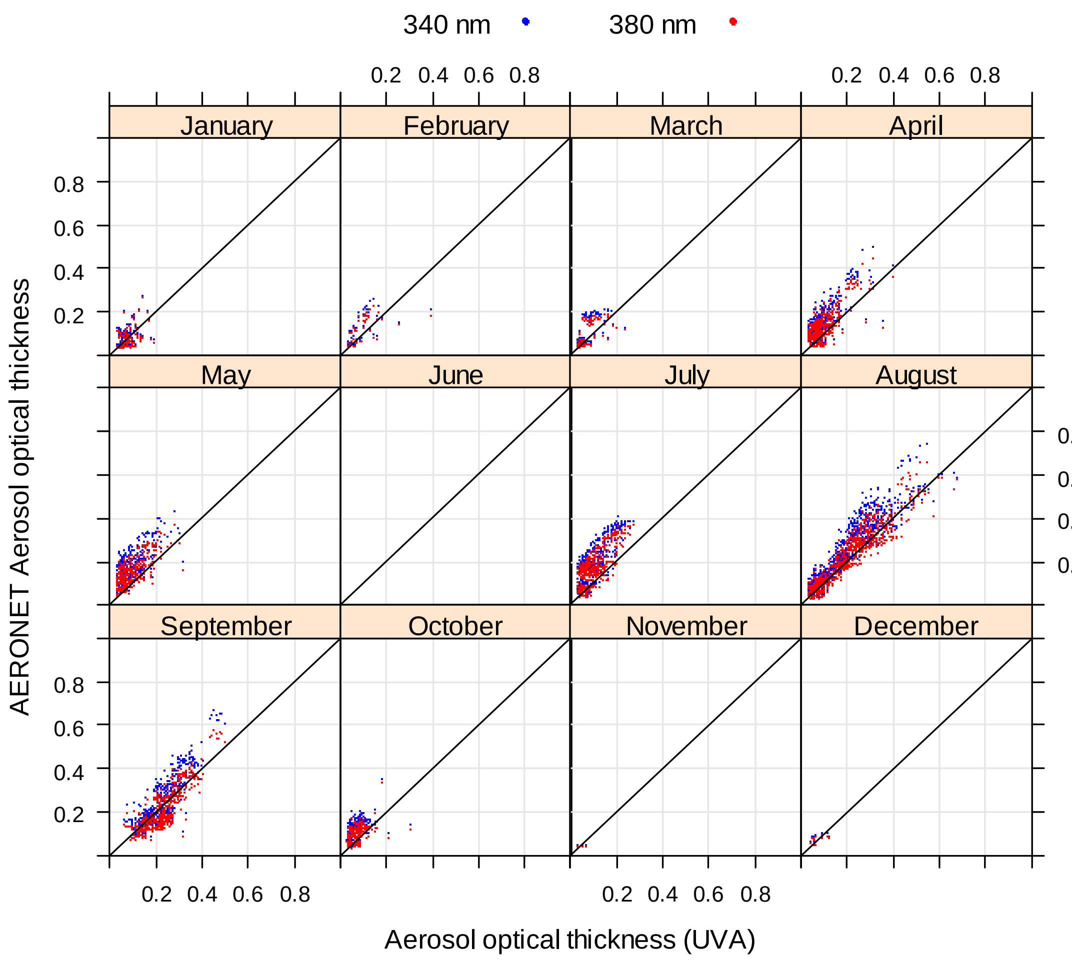

Figure 3. Scatter plots of the AERONET AOT versus the UVA AOT retrieved, for year 2013. The blue and green dots represent the AERONET AOT at 340 and 380 nm, respectively.

Figure 4 shows the smoothed scatter plot of the AERONET AOT at 380 nm versus the UVA AOT retrieved, for year 2013 in Évora. The linear regression confirms the tendency of the retrieved values to slightly underestimate the AOT obtained from AERONET at 380 nm, showing a slope of 0.862.

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The correlation coefficient is rather high (R=0.86) and the root mean square error (RMSE) is found to be 0.05 (NRMSE of 8.3%) and the mean absolute error (MAE) of 0.04 (MPE of 2.9%). Overall results show a fairly good agreement between both AOT datasets, therefore the method may be useful in sites where the UVA irradiance is monitored but no aerosol information is accessible.

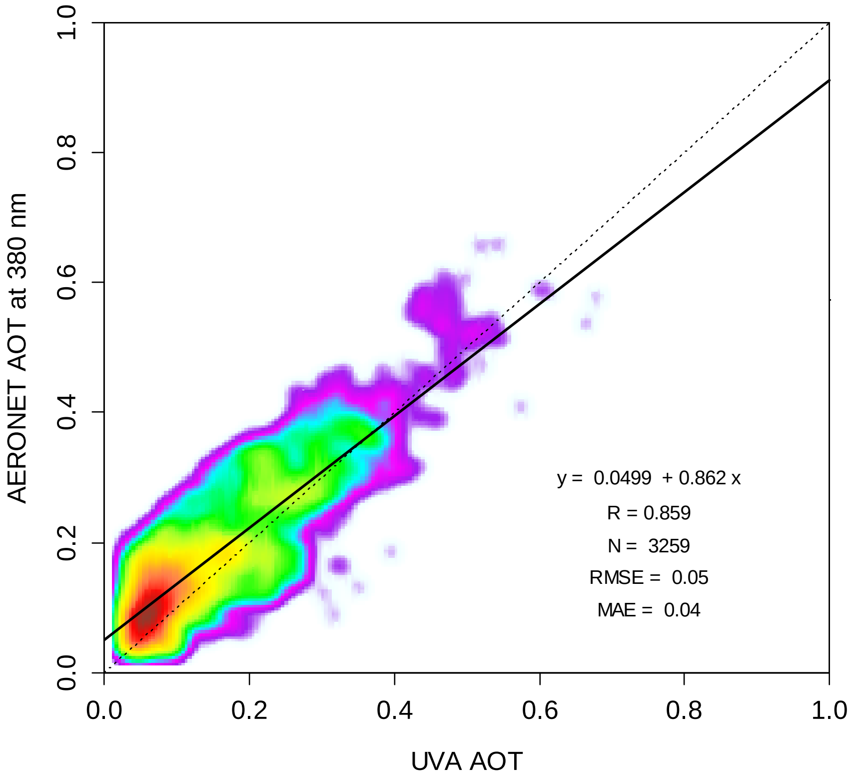

Figure 4. Smoothed scatter plot of the AERONET AOT at 380 nm versus the UVA AOT retrieved, for year 2013 in Évora. Color gradient from magenta to dark redish indicates an increasing density of points. The solid line represents the linear regression performed and the dashed line the 1:1 relation.

Hence, the methodology is subsequently applied to the UVA irradiance data of the Sines site, where no aerosol information is available, providing an estimate of the aerosol load in the atmosphere. The dataset used corresponds to the spring-summer of 2014 (June to September), since in these seasons south-western Iberia is often affected by high atmospheric aerosol loads originated from the transport of desert dust favoured by the meteorological conditions, or from forest fires. In addition, as aforementioned Sines hosts a large industrial area that influences air quality in the area, probably contributing to increase the aerosol load. Marine aerosols also have here an important contribution since this is a costal site. The hourly averaged AOT results obtained when applying the methodology to the UVA irradiance measured in Sines are presented in figure 5. The results obtained for Évora in the same period are also presented for comparisons purposes. The AOT in Sines is systematically higher than in Évora and this is most probably connected with the air pollution issues in the industrialized site of Sines. As for Évora, a background site with no industries around, the main origin of aerosol events is the long range transport of desert dust and smoke from forest fires. The results also suggest that Sines is also affected by long range transport of aerosols, since the events that affect Évora in mid June and in the end of July, are also perceptible in the AOT of Sines. The fact that a fixed aerosol type is considered in this approach may introduce some uncertainties in the retrievals. In this regard, the higher AOT values obtained for Sines should be compared with independent measurements of the AOT, as for example CIMEL CE-318 sunphotometer retrievals, in order to assess the accuracy. This could be done in a near future intensive measurement campaign.

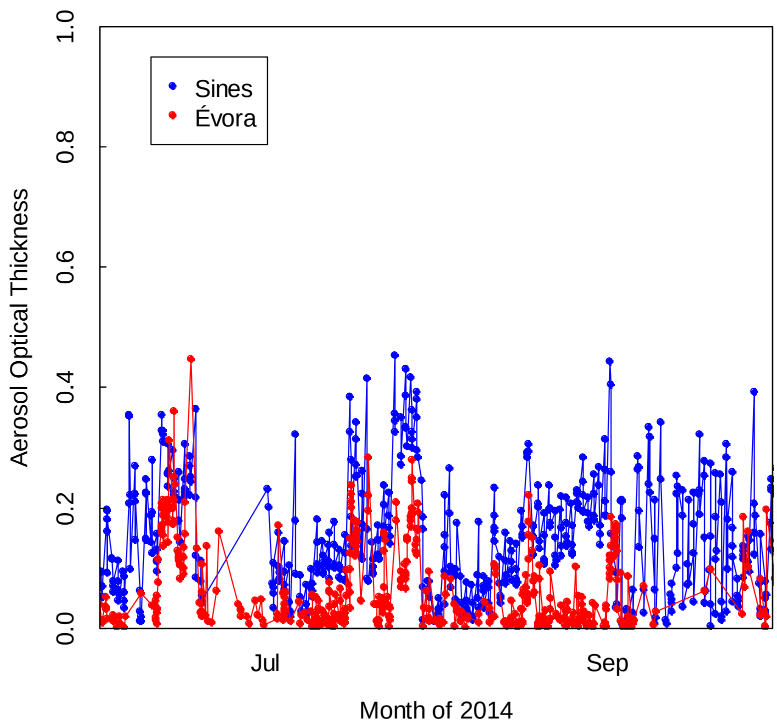

Figure 5. Time series of the hourly AOT derived from the UVA irradiance measurements in Sines and in Évora, during June – September 2014.

5. Conclusions

The work presents a methodology based on the combination of UV global irradiance data with radiative transfer calculations, to retrieve the AOT in the UVA spectral region. It is applied to data measured in Évora and the UVA AOT results are compared with AERONET AOT at 340 and 380 nm. The comparison shows that the derived UVA AOT slightly underestimates AERONET AOT, being the agreement with AERONET AOT at 380 nm slightly better. A high correlation coefficient is obtained for the comparisons (R=0.859). The RMSE is found to be 0.05 (NRMSE=8.3 %) and a MAE of 0.04 (mean percentage error of 2.9 %) is obtained. Overall results show a fairly good agreement between both AOT datasets, therefore the method is considered adequate to apply to different sites, whenever the UVA irradiance is monitored but no aerosol information is available.

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