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Aerosols in the Atmosphere

Comparison between an independently retrieved aerosol optical depth and AERONET estimations

Comparación entre el espesor óptico de aerosoles obtenido independientemente y las estimaciones de AERONET

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ABSTRACT:

Aerosol optical depth is the main primary parameter to quantify the load of atmospheric aerosols. It can be estimated from radiometric measurements performed at ground level. This study is aimed at developing and validating an alternative algorithm for the retrieval of aerosol optical depths at different wavelengths from original measurements of the sun photometer CIMEL #341 installed in Cáceres (Spain). The estimations resulting from this alternative algorithm have been validated by comparison to spectral aerosol optical depth retrieved by AERONET (AErosol RObotic NETwork) version 2 direct sun algorithm. A good agreement between the aerosol optical depths calculated by the two algorithms is obtained for all channels, being the differences lower than the uncertainty of the measurements.

Keywords: Aerosol, Optical Depth, Retrieval.

RESUMEN:

El espesor óptico de aerosoles es el principal parámetro primario de aerosoles. Este parámetro puede ser estimado a partir de medidas radiométricas. La obtención de estimaciones precisas de este parámetro es la clave para lograr una descripción radiométrica fiable de los aerosoles. El objetivo de este estudio es desarrollar y validar un algoritmo alternativo que permita obtener valores de espesor óptico de aerosoles en diferentes longitudes de onda a partir de medidas originales realizadas por el fotómetro solar CIMEL #341 instalado en Cáceres (España). Las estimaciones obtenidas con este algoritmo han sido validadas mediante comparación con los valores espectrales de espesor óptico de aerosoles calculados por la versión 2 del algoritmo de AERONET (AErosol RObotic NETwork). Se obtiene un buen acuerdo entre los valores de espesor óptico calculados por los dos algoritmos para los diferentes canales, siendo las diferencias menores que la incertidumbre de las medidas.

Palabras clave: Aerosol, Espesor Óptico, Cálculo.

REFERENCIAS Y ENLACES / REFERENCES AND LINKS

[1]. H. Horvath, "Estimation of the average visibility in Central Europe", *Atmos. Environ.* **29**, 241-246 (1995).

[2]. B. N. Holben, T. F. Eck, I. Slutsker, D. Tanre, J. P. Buis, K. A. Setzer, E. Vermote, J. A. Reagan, Y. J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, A. Smirnov, "AERONET - A federated instrument network and data archive for aerosol characterization", *Remote Sens. Environ.* **66**, 1–16 (1998).

[3]. C. Toledano, *Climatología de los Aerosoles mediante la Caracterización de Propiedades Ópticas y Masas de Aire en la Estación El Arenosillo de la Red AERONET*, PhD Thesis, Universidad de Valladolid, Spain (2005).

[4]. V. Estellés Leal, Caracterización de los Aerosoles Atmosféricos en Valencia mediante Fotometría Solar, PhD Tesis, Universidad de Valencia, Spain (2006).

[5]. V. Cachorro, C. Toledano, M. Sorribas, A. Berjón, A. M. de Frutos, N. Laulainen, "An "in situ" calibration-correction procedure (KCICLO) based on AOD diurnal cycle: comparative results between AERONET and reprocessed (KCICLO method) AOD-Alpha data series at El Arenosillo, Spain", *J. Geophys. Res.* **113**, D02207 (2008).

[6]. http://aeronet.gsfc.nasa.gov/

[7]. A. Ångström, "The parameters of atmospheric turbidity", *Tellus* **16**, 64–76 (1964).

[8]. F. Kasten, A. T. Young, "Revised optical air mass tables and approximation formula", *Appl. Opt.* **28**, 4735-4738 (1989).

[9]. D. Komhyr, K. D. Grass, R. K. Leonard, "Dobson spectrophotometer 83: a standard for total ozone measurements, 1962-1987", *J. Geophys. Res.* **94**, 9847-9861 (1989).

[10]. O. Dubovik, M. King, "A flexible inversion algorithm for retrieval of aerosol optical properties from Sun and sky radiance measurements", *J. Geophys. Res.* **105**, 20673-20696 (2000).

1. Introduction

Atmospheric aerosols play a substantial role in the Earth's radiation balance and their influence extends from regional to global scales, by directly interacting with solar radiation through scattering, absorption or emission processes, or indirectly by acting upon cloud formation. Additionally, their high concentration at low levels can highly reduce the visibility [1] and also be very detrimental for the human health favoring allergies and respiratory diseases.

Despite the high interest of the study of aerosols and the significant progress performed in recent years, its current knowledge is still insufficient due to their intrinsic great complexity. A first difficulty in their study derives from their short lifetime, being removed from the atmosphere by the action of gravity, coagulation, condensation and precipitation. A thorough description of atmospheric aerosols must also consider their heterogeneous spatial distribution driven by the existence of a large variety of sources both natural and anthropogenic, whose effects are usually very difficult to separate. Due to their high temporal variability, atmospheric aerosols must be continuously monitored at short time scales.

Therefore, nowadays there are several networks aimed at the monitoring of aerosols at different scales. A valuable global initiative is the AERONET radiometric network, operated by NASA. This network is based on a standard instrument: the CIMEL multi-wavelength sun/sky photometer. All measurements performed by the instruments within the network follow the same standard processing protocol [2]. Since this protocol routinely applies to all measurements performed at stations belonging to the AERONET network, it is not opened to include additional corrections specific for each instrument, such as those related to the appearance of false diurnal cycles due to an erroneous calibration [3], and certain temperature dependence possibly shown by some channels [2,4], that could result in improved aerosol optical depths. According to Toledano *et al* [3], KCICLO method corrects errors of 2-8% in the data, which result in differences in the aerosol optical depth between 2% and 12% depending on the channel, as shown in a study using data from El Arenosillo (Huelva, Spain) [5]. These corrected values will there after contribute to the obtaining of improved subsequent primary and secondary aerosol parameters. Consequently, the availability of an alternative reliable algorithm is of great interest in order to address the effect of additional corrections which can not be assimilated by a concluded and locked algorithm such as the one used by AERONET.

Before considering any additional improvements, the first step for an alternative algorithm is to prove the reliability of its results and its skill to reproduce the values obtained by AERONET. Therefore, the objective of the paper is to develop a algorithm for the retrieval of aerosol optical depths at different wavelengths from measurements of a sun photometer CIMEL and to validate it by comparison to AERONET estimations.

2. Site description and instrumentation

The data used for validating the proposed algorithm correspond to original measurements performed by the sun-photometer CIMEL #341 at the radiometric station of Cáceres, Spain. This station is located at Western Spain, being the only one existing in Extremadura and, therefore, being representative for a wide region in the Iberian Peninsula. It is installed at the Campus of Cáceres (39.47°N, 6.34°W, 397 m a.s.l.) of the University of Extremadura, on the terrace of the Polytechnic School building, guaranteeing an open horizon free of obstacles. It belongs to AERONET and RIMA aerosols monitoring networks and has been operatively working since July 2005. The global network AERONET consists of a federation of ground-based remote sensing aerosol networks promoted by NASA and LOA-PHOTONS [2].

This network uses the CIMEL Electronique 318A multi-wavelength Sun/sky photometer as standard instrument. It performs direct sun measurements using filters at 340, 380, 440, 500, 675, 870, 940 and 1020 nm wavelengths, and sky measurements at 440, 675, 870 and 1020 nm wavelengths. The CIMEL radiometer is designed to perform series of automatic measurements throughout the day according to a certain schedule. It is important to note that the instrument avoids measuring under rainy conditions. The solar direct radiance at the above mentioned wavelengths measured by the sun-photometer CIMEL allows to retrieve radiation parameters of the aerosols related to their nature and size. AERONET processes the original measurements resulting in datasets of different quality levels (1.0, 1.5 and 2.0), depending on the processing stage completed [2]. The final uncertainty of the aerosol optical depth is estimated to be between 0.01 and 0.02 [2]. The processed parameters are freely available at the AERONET website [6]. In this study 1.5 level aerosol optical depth data and original raw data of radiance measured by the CIMEL #341 photometer have been used.

3. Methodology

In this study aerosol optical depths have been retrieved by means of applying an implemented independent algorithm to original measurements taken by the CIMEL #341 sun photometer. This instrument is installed in the radiometric station of Cáceres (Spain). The period of study extends from July 2006 to April 2008, with more than 14000 data. In the proposed independent algorithm, the calculation of the aerosol optical depth for the different channels from the radiation measurements is based on the Lambert-Bouguer-Beer law [7]:

$$I = I_0 e^{-\tau_{TOTAL} m}, \qquad (1)$$

where I is the radiance measured at the ground level, I_0 is the extraterrestrial radiance, τ_{TOTAL} is the total optical depth of the atmosphere, and m is the relative optical mass, i.e., the number of optical depths passed through by the radiation in its travel within the atmosphere due to a particular oblique incidence. Equation (1) can be also expressed as function of the raw voltage signal measured by the CIMEL instrument as follows:

$$\tau_{TOTAL} = \frac{1}{m}\log\left(\frac{V_{TOA}}{V}\right), \qquad (2)$$

where V is the signal measured at the ground level, V_{TOA} the extraterrestrial signal corrected by eccentricity, τ_{TOTAL} the total optical depth of the atmosphere, and m the relative optical mass.

In order to isolate the contribution of aerosols to the total optical depth, the attenuation due to the other atmospheric components has to be calculated. Thus, the optical depths due to Rayleigh scattering by air molecules, and absorption by nitrogen dioxide and ozone have been estimated. Kasten and Young's [8] approximation was used to estimate Rayleigh scattering contribution. Ozone and nitrogen oxide air masses were calculated according to Komhyr's formula [9]. Since our goal is to validate the proposed algorithm against the AERONET methodology, the same values of concentrations of different gases and pressure as those used by AERONET were considered. Finally, the aerosol optical depth was obtained as the residual term according to the following equation:

$$\tau_{aerosol} = \tau_{TOTAL} - \tau_{Rayleigh} - \tau_{nitrogen} - \tau_{ozone}. \quad (3)$$

Once the aerosol optical depth has been estimated for the different wavelengths corresponding to the channels of the CIMEL instrument, they were compared to the level 1.5 AOD values calculated by AERONET version 2 direct sun algorithm [10]. The comparison is summarized by the parameters $rMBE$ (Mean Bias Error) and $rMABE$ (Mean Bias Absolute Error), defined as follows, where N is the number of measurements:

$$rMBE = \frac{1}{N}\sum_{1}^{N} \frac{\tau_{retrieved} - \tau_{AERONET}}{\tau_{AERONET}}, \quad (4)$$

$$rMABE = \frac{1}{N}\sum_{1}^{N} \left|\frac{\tau_{retrieved} - \tau_{AERONET}}{\tau_{AERONET}}\right|. \quad (5)$$

4. Results and discussion

In this section, retrieved aerosol optical depths as estimated by the new independent algorithm have been compared with those calculated by AERONET. For this purpose we have calculated the values of the coefficients $rMBE$ and $rMABE$ and we have represented the evolution of the absolute differences between retrieved aerosol optical depths and the values calculated by AERONET for each channel. Figure 1 shows the evolution of absolute differences for the channel 675 nm, with values of $rMBE$= 0.0232 (±0.0006) and $rMABE$=0.0344 (±0.0005). This figure shows that the most of the values of absolute difference are lower than the uncertainty of the estimations for this channel (0.01) [2]. The same behavior was observed for the other channels, obtaining similar statistics (Table I).

Table I shows very small values of the coefficients $rMBE$ and $rMABE$. The best agreement is obtained for the 870 nm channel, whereas the highest differences correspond to the wavelengths of 1020, 440 and 380 nm.Negative values of $rMBE$ are obtained for the channels 380, 440 and 870 nm, and positive for 340, 500, 675 and 1020 nm, indicating a general behavior around zero and, therefore, no prevalence of underestimation or over-estimation. The most of the values of absolute difference shown in Fig. 1 are lower than the uncertainty of the estimations (between 0.01 and 0.02, depending on the channel) [2].

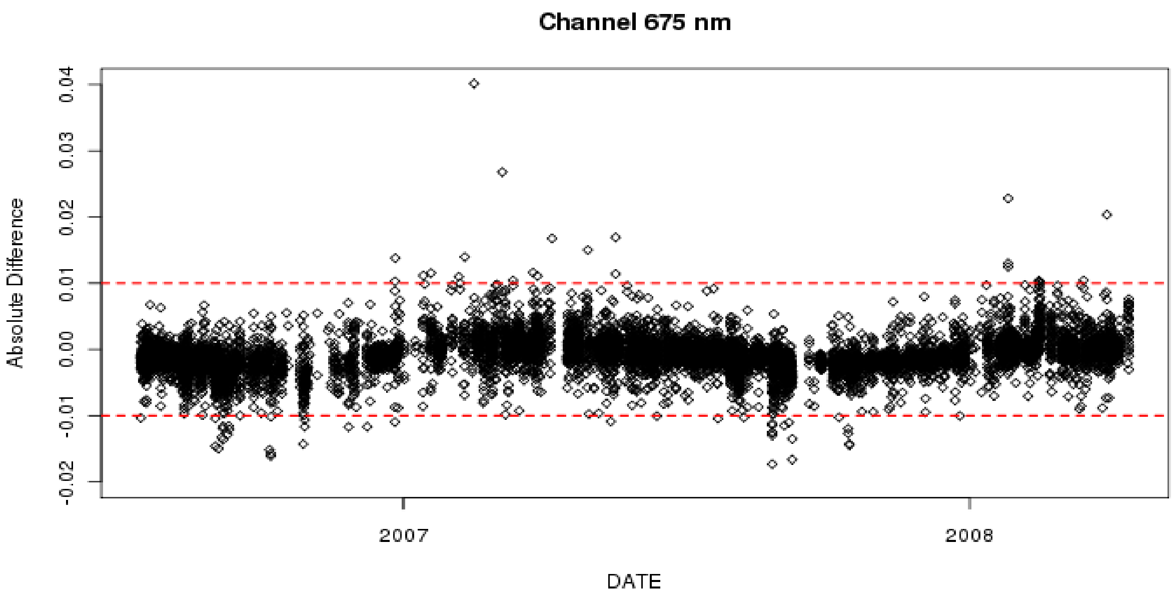

Fig. 1: Comparison between the aerosol optical depth at 675 nm retrieved by the new independent algorithm and the values calculated by AERONET.

TABLE I
Statistics $rMBE$ and $rMABE$ of the comparison of aerosol optical depth values obtained by the two algorithms during the period of study (July 2006-April 2008).

Channel	$rMBE$	$rMABE$
1020 nm	0.1294±0.0207	0.2070±0.0205
870 nm	0.0106±0.0005	0.0249±0.0004
675 nm	0.0232±0.0006	0.0344±0.0005
500 nm	0.0118±0.0006	0.0321±0.0004
440 nm	0.0531±0.0008	0.0567±0.0007
380 nm	0.0319±0.0009	0.0488±0.0008
340 nm	0.0063±0.0092	0.0785±0.0092

4. Conclusions

An alternative algorithm to retrieve aerosol optical depths from CIMEL measurements has been validated by comparison with values calculated by AERONET´s algorithm, obtaining a remarkably good agreement between both algorithms. The low $rMBE$ and $rMABE$ values confirm the skill of the proposed algorithm to reproduce the performance of the AERONET algorithm and, therefore, allow its use in future research to address the effect of additional corrections which are not assimilated by the AERONET methodology.

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