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Aerosols in the Atmosphere

Improving aerosol optical depth estimations including temperature correction

Mejora en las estimaciones del espesor óptico de aerosoles mediante corrección por temperatura

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ABSTRACT:

This study is aimed at investigating and correcting the dependence with temperature of the aerosol optical depth at 870 nm of the CIMEL #341 sunphotometer. This instrument is installed in the station of Cáceres (Spain) and belongs to the AErosol RObotic NETwork (AERONET). The aerosol optical depths at this channel, as derived by AERONET algorithm, have been compared with those estimated using a new algorithm proposed and validated by our group. A temperature correction was applied to the original voltage signal in order to quantify the magnitude of the mentioned dependence. For this goal, different coefficients were tested, obtaining the value 0.25%/ºC as the most appropriate to correct the influence of the sensor temperature on the aerosol optical depth values at 870 nm.

Keywords: Aerosol, AERONET, Correction, Temperature.

RESUMEN:

Este estudio tiene como objetivo corregir la dependencia con la temperatura del espesor óptico de aerosoles para el canal de 870 nm del fotómetro solar CIMEL #341. Este instrumento está instalado en la estación de Cáceres (España) y pertenece a la red AErosol Robotic NETwork (AERONET). Los valores de espesores ópticos correspondientes a dicho canal, obtenidos mediante el algoritmo de AERONET, se han comparado con los estimados a partir de un algoritmo propuesto y validado por nosotros. Se ha aplicado una corrección a la señal del voltaje original con el fin de cuantificar la magnitud de la dependencia del espesor óptico en 870 nm con la temperatura. Para este objetivo, se han probado diferentes coeficientes, obteniéndose finalmente el valor de 0.25%/ºC como el más adecuado para corregir la influencia de la temperatura en el espesor óptico de aerosoles de 870 nm.

Palabras clave: Aeronet, AERONET, Corrección, Temperatura.

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1. Introduction

The study of atmospheric aerosols is of great interest because of their important effects at short term on Earth's radiative budget, environment and human health, and at long-term on radiative balance and climate. The anthropogenic aerosol emissions are a potential contribution to climate change.

The high heterogeneity in aerosol composition as well as their temporal and spatial variability make their study very complex and difficult, and demand global-scale initiatives aimed at improving their characterization. In this framework, it is worth to note the efforts to develop observational networks such as AErosol RObotic NETwork (AERONET) [1,2]. This network coordinates measuring stations around the world and applies strict measurement and calibration protocols in order to guarantee the quality of measurements and the inter-comparison of results from different sites. All the stations of this network use the same type of instrument, the multichannel CIMEL sun-photometer and AERONET processes raw radiation data from these instruments according to a standardized procedure for retrieving optical and microphysical properties of atmospheric aerosols.

Despite using strict protocols, sometimes inconsistent results may occur than can lead to incorrect conclusions when analyzing the data. An example of such problems is the artificial diurnal cycle detected in the aerosol optical depth (τ_a) at 870 nm. This cycle was observed specially during the warm season, suggesting a likely relationship with the temperature. The dependence of CIMEL measurements with temperature is widely known for the 1020 nm channel [1], but only recently has been reported for the 870 nm channel [3,4].

The objective of this study is analyzing the dependence with temperature of the aerosol optical depths at 870 nm. For this purpose, temperature corrections have been included in the algorithm used to retrieve aerosol optical depths (τ_a) [5] and the resulting effect is analyzed by the comparison with AERONET retrieved aerosol optical depth at 870 nm.

2. Site description and instrumentation

Data for this work were obtained in a measurement station located in the vicinity of Cáceres town, in the Extremadura region (South Western Spain).

The region of study is bounded by two mountain ranges, the Sistema Central to the north, and Sierra Morena to the south and it is an interesting location representative of the aerosol over this region, predominantly rural, with no industry and where local pollution is mainly due to moderate road traffic.

The station is installed on the terrace of the Polytechnic School building (39.47º*N*, 6.34º*W*, 397 m a.s.l.) of the University of Extremadura and it is operative since July 2005, moreover, it is included in AERONET (AErosol RObotic NETwork) and RIMA (Red Ibérica de Medida fotométrica de Aerosoles) monitoring networks.

The standard instrument of these networks is the CIMEL Electronique 318A automatic sun tracking photometer that is composed of an optical head, an electronic box and a robot with two step-by-step motors that control zenithal and azimuthal movements. The sensor head is equipped with a filter wheel with eight filters and a temperature sensor. The instrument performs direct sun measurements at eight wavelengths between 340 and 1020 nm, and sky measurements at wavelengths 440, 675, 870 and 1020 nm.

CIMEL instrument performs a programmed measurement sequence throughout the day at an approximate rate of 15 minutes. The instrument measures only during daylight hours and under non-rainy conditions. A complete description of this instrument and the data acquisition procedure can be found in Holben *et al* [1].

Raw measurements processed by AERONET result in radiative parameters related to the nature and size of aerosols. These products are accessible at AERONET website [2] in three different quality levels: 1.0, 1.5 and 2.0. In this study, aerosol optical depth values from level 1.5 have been used, with an uncertainty estimated between 0.01 and 0.02 [1].

3. Methodology

The AERONET protocol to derive aerosol optical depth includes only a temperature correction for the 1020 nm channel values using a coefficient of 0.25%/ºC±0.05%/ºC [1]. However, certain temperature dependence has also been recently reported for the 870 nm channel [3,4]. In the case of the CIMEL installed at the Cáceres station, a diurnal cycle at 870 nm compatible with a temperature dependence was detected. This anomalous behaviour results in 870 nm values inconsistent with measurements performed at other wavelengths being, for instance, higher than aerosol optical depths at 675 nm during some hours in the day and a different diurnal pattern than the rest of the channels (Fig. 1). This fact is in disagreement with the Ångström law (Eq. (1)), which states that the higher the wavelength, the smaller the optical depth obtained [6]:

$$\tau = \beta\lambda^{-\alpha}. \quad (1)$$

In this expression, λ is the wavelength (μm), α the Ångström alpha parameter and β the Ångström turbidity parameter, which represents the optical depth at a wavelength of 1 μm.

The diurnal cycle observed can be associated with temperature dependence and, therefore, aerosol optical depths at 870 nm have been calculated including certain adjustments in order to correct this temperature effect. The use of a linear dependence is justified by its good performance in previous studies [3,4,7]. Additionally, this dependence has been verified by Estellés [3] after laboratory studies. This proposed expression is also similar to the temperature correction applied by Holben [1] for the 1020 nm channel. It is applied to the original voltage signal $V_{\lambda T}$ and depends on the difference of instrument temperature with respect to a reference temperature of 25ºC, as follows:

$$V_{\lambda,corrected} = V_{\lambda,T}\left(1 + C_{\lambda,T_{ref}}\left(T - T_{ref}\right)\right), \quad (2)$$

where $C_{\lambda,T_{ref}}$ represents the characteristic thermal coefficient for a particular spectral channel λ, and a reference temperature T_{ref} expressed as a percentage variation of the signal per ºC.

In order to find the most suitable coefficient in Eq. (2), various values were tested and their results analysed. The values tested were from 0.10 to 0.50%/ºC.

4. Results and discussion

When analyzing the behavior of the aerosol optical depth along the day, we found a diurnal cycle at the 870 nm channel which has not been detected in the other channels. This cycle was not centered around noon but presents its maximum at a later time in the day. Also it was particularly noticeable during the warm season, suggesting a likely relationship with the diurnal temperature change. These facts make also very unlikely a diurnal cycle due to calibration problem (e.g. by filter degradation). Therefore, to explore this dependence, the behaviour of aerosol optical depth was studied along particular days with a wide range of temperature values.

A clear example of this cycle was observed in the day July 23rd, 2006. Diurnal evolution of temperature and aerosol optical depth at 870 nm for this day is shown in Fig. 2, where it can be observed that both variables follow a similar pattern.

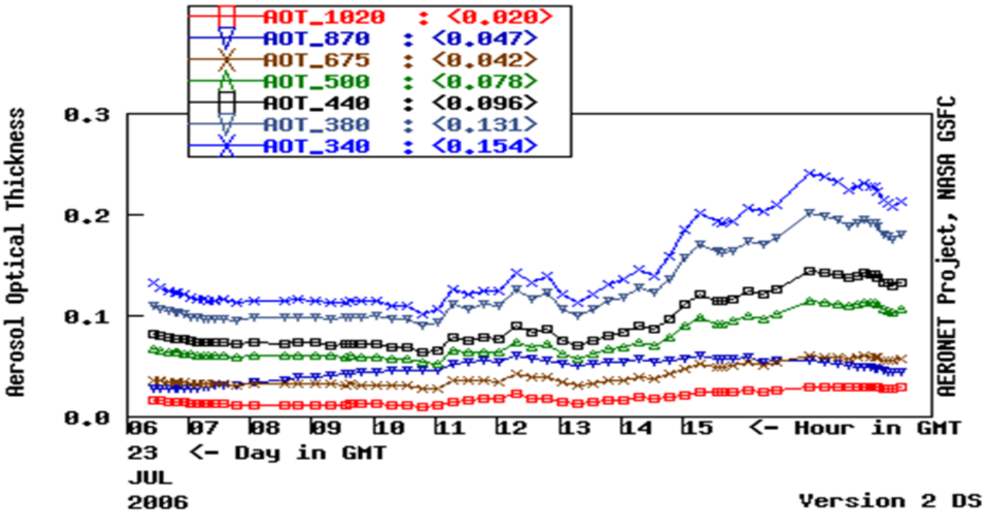

Fig. 1: Aerosol optical depth during the day July 23rd, 2006, in Cáceres station calculated by AERONET.

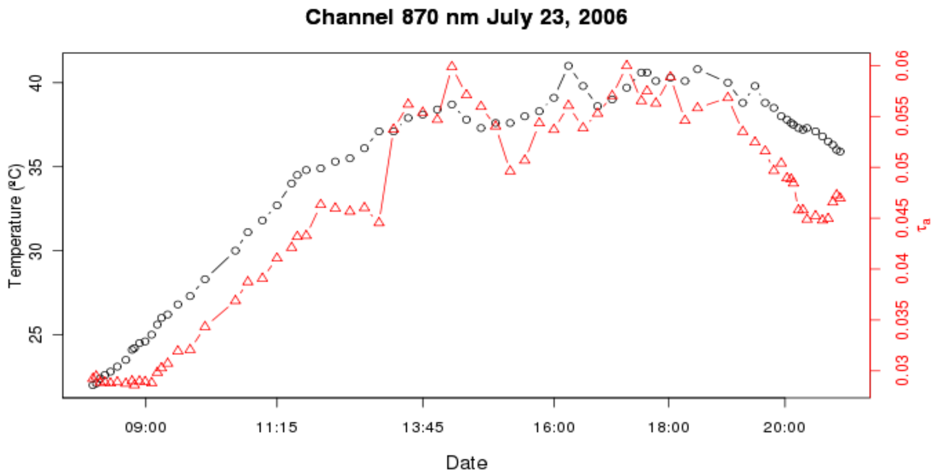

Fig. 2: Aerosol optical depth at 870 nm, calculated by AERONET, and temperature (July 23rd, 2006) in Cáceres.

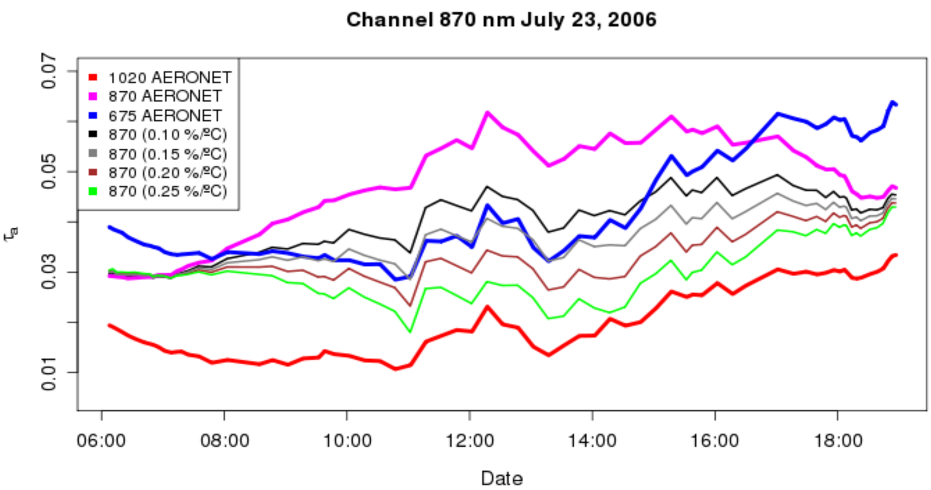

Fig. 3: Aerosol optical depths, calculated by AERONET at different wavelengths and aerosol optical depth at 870 nm estimated by the new algorithm using different coefficients.

Temperature corrected aerosol optical depths at 870 nm were compared with values interpolated from channels without temperature dependence, using the Angstrom law [6]. As mentioned before, different coefficients were tested (from 0.10 to 0.50%/ºC) in order to obtain the best corrected values being consistent with the aerosol optical depths measured at other wavelengths. To compare the AOD values, we have calculated the Mean Absolute Bias Error ($rMABE$) taking into account the interpolated values of AOD at 870 nm (with no temperature dependence) and the values corrected for different coefficients proposed. This parameter is defined as follows, where N is the number of measurements:

$$rMABE = \frac{1}{N}\sum_{1}^{N}\left|\frac{\tau_{retrieved} - \tau_{AERONET}}{\tau_{AERONET}}\right|. \quad (3)$$

The results are shown in the Table I. We obtain that the differences are smaller when we use the coefficient of 0.25%/ºC. This result can also be seen in Fig. 3. As a result of including the temperature correction, the previously observed diurnal cycle in AOD at 870 nm decreases or even disappears, depending on the coefficient used. When applying the coefficients of 0.20 and 0.25, AOD values at 870 nm show a coherent pattern with regard to channels 1020 and 675 nm, the diurnal cycle disappears and the values remain lower than those for 675 nm, as expected according to the Ångström law (Eq. (1)). This desired behavior is not achieved if lower or higher coefficients are used. The highest corrections even yielded to negative AOD's. Because of the fact that the smallest differences are obtained with coefficient of 0.25%/ºC, we believe that this coefficient is the most appropriate to correct the temperature dependence of this photometer channel. This value could change in other days.

TABLE I
$rMABE$ statistics of the comparison of aerosol optical depth values for different temperature corrections.

Coefficient (%/ºC)	$rMABE$ (%)
0.10	0.348
0.15	0.288
0.20	0.211
0.25	0.106
0.35	0.321
0.50	0.775

5. Conclusions

The analysis of AERONET-retrieved aerosol optical depth at 870 nm at Cáceres station shows a diurnal cycle which was in disagreement to the behavior shown by all other channels. This cycle was especially noticeable during the warm season, suggesting a likely relationship with the temperature. This dependence has been successfully accounted for by applying a temperature-based linear correction to the original voltage signal in that channel. The results show that this dependence diminishes and even disappears when applying the correction coefficient 0.25%/ºC. Obtaining this factor in a temperature chamber would be desirable for a correct evaluation of the AOD in this sensitive channel (as well as 1020 nm).

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