Aerosol Optical Properties Retrieval from Surface Radiation Measurements

G. Kosmopoulos and A. Kazantzidis

Abstract Multiannual measurements of solar irradiance at various locations were used to conduct an inverse study of aerosol properties under cloudless conditions. Solar direct irradiance (I) data at 6 stations of the Baseline Surface Radiation Network of the World Radiation Monitoring Center with collocated aerosol optical depth (AOD) measurements from the Aerosol Robotic Network were used. A method was developed to estimate AOD at different wavelengths from I values. The expected dependency of I values and AOD as a function of solar zenith angle (SZA) was revealed. The results demonstrate a fair agreement between the estimated and the measured AOD data. The differences were examined as a function of water vapor column (wv). Minor dependency was shown and further investigation is needed to improve the method performance in different atmospheric conditions. The method is expected to provide an extra tool to acquire in-depth knowledge of aerosol optical properties for dates and areas in absence of aerosol measurements.

1 Introduction

Aerosol particles affect Earth's climate and the radiation budget of the Earth-atmosphere system. This influence occurs in two ways: directly by scattering and absorbing of radiation and indirectly by modifying optical properties and cloud lifetimes (Ramanathan et al. 2001). Despite the significant interest and the continuous studies on this field, several uncertainties remain on aerosol radiative forcing, mainly due to the aerosols spatial and temporal variability (Kazadzis et al. 2009) as well as changes at longer time scales (Nikitidou et al. 2014). Remote sensing of aerosols is a useful tool to understand and characterize aerosol optical properties. Despite the simplicity of such methods and instruments, the absence of global coverage forces us to use alternative methods to retrieve aerosols optical

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properties. One of these methods is based on ground based solar radiation measurements (Lindfors et al. 2013; Foyo-Moreno et al. 2014).

In this study, a method to evaluate aerosol optical depth (AOD) through the direct solar radiation (I) component was developed. For this reason, I and AOD measurements were used from stations of the Baseline Surface Radiation Network (BSRN) of World Radiation Monitoring Center (WRMC).

2 Data and Methodology

One minute averaged measurements of I at 6 stations (Xianghe, Izana, Bondville, Carpentras, Tamanrasset and Sede Boquer) with at least 4 years of measurements, in contrasting climatic zones derived from BSRN. AODs at 380, 440, 500, 675, 870 and 1020 nm and water vapor column (wv) measurements were provided by collocated Cimel sun photometers that belong to the Aerosol Robotic Network (AERONET). Synchronized, cloud screened and quality assured (level 2.0) data were used from all instruments. To avoid possible cloud contamination in the 1-min averaged irradiances, only cases with standard deviation values lower than 1 % of the average were taken into account.

At each station, a Beer-Lambert like empirical relation between the measured I and AOD (AOD_{aer}) values ($I = a * e^{-b*AODaer}$,) was used. The statistical parameters a and b as well as the coefficients of determination (R^2) were computed for classified datasets according to the solar zenith angle (SZA). By keeping I as the only known measurement, the theoretical values of AOD (AOD_{th}) were computed from the empirical fits. The differences between the theoretical and measured AODs (AOD_{th}-AOD_{aer}) were examined as a function of AOD_{aer} and wv.

3 Results

The statistical parameters a and b as well as the coefficients of determination (R^2) at selected AOD wavelengths (380, 675 and 1020 nm) and two solar zenith angles (30° and 60°) at the selected BSRN stations are presented in Table 1. The best fits were found at Xianghe, Tamansrasset and Izana ($R^2 > 0.91$) while for Sede Boquer, Carpentras and Bondville the performance of the empirical relation is lower ($0.7 < R^2 < 0.9$). The agreement between measured and estimates AOD values is similar to the ones presented in previous studies (Lindfors et al. 2013; Foyo-Moreno et al. 2014). At all sites, the performance of the empirical relation is lower at 1020 nm. AOD is generally decreased with wavelength and the irradiance is not equally distributed across the solar spectrum. The combination of these factors is revealed in the “a” and “b” values of the Beer-Lambert like empirical relation between the measured I and AOD. According to the results presented in Table 1, the “a” values are higher at 380 nm, while the “b” values are higher at

Table 1 Statistical parameters, a (W/m^2), b, and R^2 of the empirical fit applied to direct irradiance I and AOD_{aer} at 1020, 675 and 380 nm for solar zenith angles 30° and 60°

	380 nm a, b, R^2	675 nm a, b, R^2	1020 nm a, b, R^2
	Solar zenith angle = 30°		
Xianghe	986, 0.56, 0.95	975, 1.01, 0.97	957, 1.56, 0.91
Tamanraset	1108, 1.15, 0.94	1066, 1.18 0.92	1033, 1.21, 0.93
Sede Boquer	1043, 0.81, 0.82	995, 1.06, 0.85	952, 1.04, 0.74
Izana	1115, 1.11, 0.93	1092, 1.18, 0.94	1087, 1.30, 0.94
Carpentras	990, 0.57, 0.87	985, 1.24, 0.90	–
Bondville	989, 0.50, 0.91	991, 1.21, 0.85	980, 2.06, 0.71
	Solar zenith angle = 60°		
Xianghe	924, 0.86, 0.95	931, 1.64, 0.97	942, 2.63, 0.93
Tamanraset	1049, 1.86, 0.96	1011, 2.04, 0.97	991, 2.25, 0.97
Sede Boquer	1001, 1.40, 0.85	959, 2.09, 0.90	912, 2.23, 0.79
Izana	1073, 1.99, 0.93	1037, 2.12, 0.93	1033, 2.35, 0.92
Carpentras	924, 0.89, 0.79	914, 1.9, 0.84	891, 2.92, 0.76
Bondville	956, 0.93, 0.88	956, 2.17, 0.84	–

1020 nm. The "optical path" of DNI is increasing with SZA. As a result, lower "a" values are revealed for 60° at each station, since even for no aerosols the DNI at the surface will be lower when compared to the one for 30°. In addition, the increase of AOD affects more the "optical path" of DNI for 60°: For this reason, the empirical relations for this SZA are accompanied by higher "b" values.

Figure 1 shows the difference AOD_{th}-AOD_{aer} at the selected wavelengths as a function of AOD_{aer} for SZAs 30° and 60°. At all sites, there is no similar dependence of the difference with AOD_{aer} while the scattering is higher for 60° due to the increasing effect of molecular scattering on surface DNI. At all stations, the high AOD measurements are underestimated for the vast majority of cases. The magnitude of underestimation is around −0.1/unit of AOD and the higher discrepancies are found for the AOD value at 380 nm.

For cloud-free conditions, wv is considered the second most important atmospheric constituent (after AOD) affecting DNI. WV values, provided by AERONET, are used in this study and the difference AOD_{th}-AOD_{aer} versus wv is presented in Fig. 2. At all sites, there is a clear dependency of the AOD differences with wv. Since the empirical relations represent the average effect of wv on DNI, the calculated AOD_{th} values are generally underestimated (by almost ~0.1) for the lowest wv values. On the contrary and due to the exponential relation between DNI and wv, small overestimations of AOD are found for atmospheric conditions with high wv values.

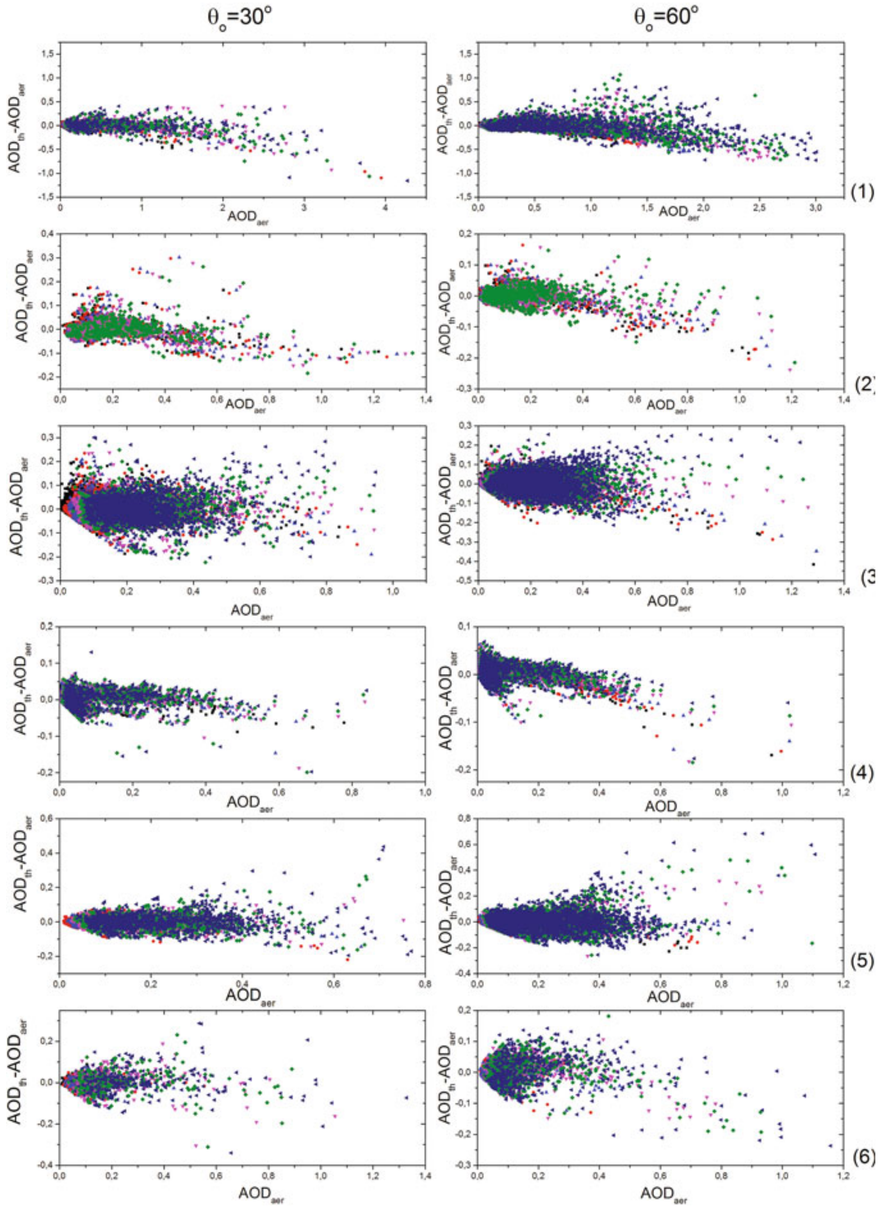

Fig. 1 AOD_{th}-AOD_{aer} versus AODaer at (1) Xianghe, (2) Tamanrasset, (3) Sede Boquer, (4) Izana, (5) Carpentras, (6) Bondville for solar zenith angles 30^{o} and 60^{o} and wavelengths 1020 (*black*), 870 (*red*), 675 (*blue*), 500 (*purple*), 440 (*green*) and 380 nm (*dark blue* symbols)

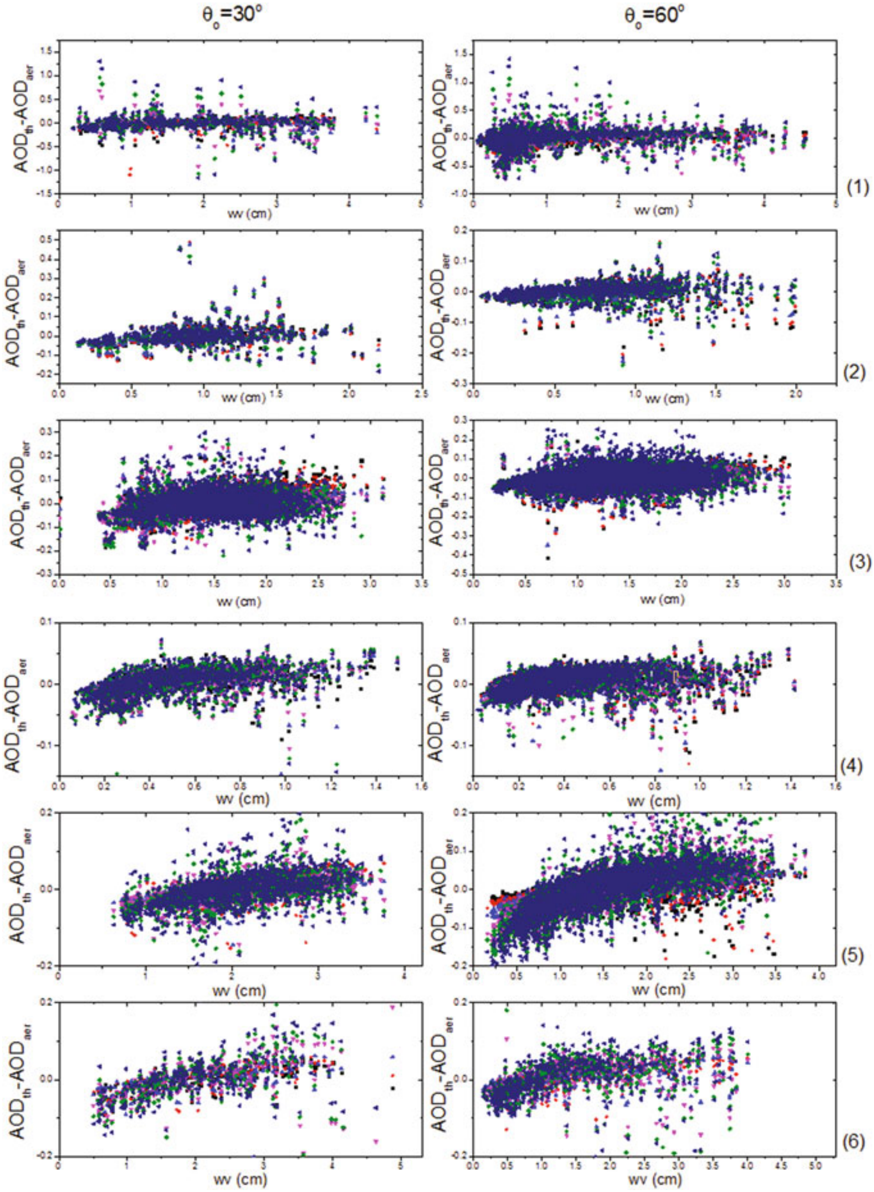

Fig. 2 AOD_{th}-AOD_{aer} versus water vapor (wv). Station numbers and wavelength symbols are the same as in Fig. 1

4 Conclusions

Despite the major influence of aerosols on earth's climate, significant uncertainties remain because of the deficient knowledge of their optical properties. In order to achieve a better understanding, we deployed an inverse method to study AOD through direct solar irradiance ground measurements at selected BSRN stations. The results demonstrate a fair agreement with AOD from AERONET data.

In our efforts to evaluate the sensitivity of our method, we examined the difference AOD_{th}-AOD_{aer} as a function of AOD_{aer} and wv. Minor dependency was shown and further investigation is needed to improve the method performance in different atmospheric conditions. Two important parameters to be examined in future will be: (a) the verification of cloud-free conditions by both AOD and DNI measurements and (b) the calculation of the uncertainty induced in the method by DNI measurements.

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