Retrieval of atmospheric optical parameters from ground-based sun-photometer measurements for Zanjan area

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ABSTRACT

We are reporting the results of ground-based spectro-radiometric measurements on aerosols and water vapour in the atmosphere of Zanjan since October 2006 to September 2008 using a CIMEL CE318-2 sun-photometer. Zanjan is a city in Northwest Iran, located at 36.7N, 48.6E and altitude of 1800 m above mean sea level. The spectral aerosol optical depth, Angstrom exponent and columnar water vapour have been calculated using the data recorded by the SPM on direct-beam irradiance measurements of the sunlight. The average value of AOD (at 440 nm) and CWV during the mentioned period are measured as, 0.26 and 0.51 cm respectively. The maximum (minimum) of AOD was recorded in May 2007 (January 2007), and the maximum (minimum) of CWV happened in July 2007 (January 2007). Using the least-squares method, the angstrom exponent, α, was calculated in the spectral interval 440-870 nm along with the coefficients, α_1 and, α_2, of the second order polynomial fit to the plotted logarithm of AOD versus the logarithm of wavelength. The coefficient, α_2, shows that the most part of aerosols in Zanjan area have dimensions lager than 1 micron. The values calculated for, $\alpha_2 - \alpha_1$, show that 70% of the aerosols are in the coarse mode and 30% of them are in the fine mode. Comparison of, $\alpha_2 - \alpha_1$, for Zanjan atmosphere with other regions indicates dust and anthropogenic aerosols are the most dominant aerosols in the region.

1. INTRODUCTION

Iran a country in the Middle East region is located on the global dust belt. Arabian Peninsula in sought and Tigris and Euphrates basin in west are the main sources of dust storms that are frequently observed in the atmosphere of the west and southern regions of this country [1]. Even though our observations show that other sources inside the country like the Qom lake (now days is a salt-covered playa) has some impacts on the existence of the aerosols in the Northwest Iran [2], but outside sources have the dominant role. Zanjan a city in Northwest Iran (36.7^o N, 48.5^o E, 1800m above the sea level), located in a mountain region, subjects to frequent dust storms especially in mid and late spring as well as late summer and early fall.

The Aerosol Optical Depth (AOD), which is the integral of the atmospheric extinction coefficient from the surface to the top of the atmosphere due to the existence of the aerosols, is an important parameter for monitoring the visibility degradation (due to atmospheric pollution), climate changes, and applying tropospheric corrections in remote sensing [3]. The AOD is a unique parameter to remotely assess the aerosol burden in the atmosphere from ground-based equipment, which constitutes the simplest, most accurate, and easy to maintain monitoring system [4].

Here we are reporting the measurements on the atmospheric optical density of the Zanjan atmosphere using an automatic sun-tracker sun-photometer (SPM) CIMEL CE318-2. The measurements carried on the period of October 2006 up to the end of September 2008. Recorded data on the 936 nm wavelength channel of the SPM in combination with the measurements on the 870 nm and 1020 nm wavelength channels provide a measure of the columnar Water Vapour (CWV). This parameter also has been measured for the mentioned period.

The Angstrom exponent, α, is often used as a qualitative indicator of aerosol particle size [5]. In this study, AOD and Angstrom exponent (α) were analyzed to obtain information about the characteristic sizes of the aerosols. Using the least-squares method, the Angstrom-α was calculated in the spectral interval 440–870 nm, along with the coefficients α_1 and α_2 of the second order polynomial fit to the plotted logarithm of AOD versus the logarithm of wavelength.

Results of our measurements show that maximum and minimum values of AOD happen in May 2007 and January 2007 respectively. In July 2007 and January 2007 respectively, maximum and minimum values of CWV were observed. Calculated values for α_1 and, α_2 indicate that about 70% of the aerosols in the Zanjan atmosphere were in coarse mode and the rest 30% in the fine mode.

2. MESUREMENTS AND INSTRUMENTATION

The SPM records the sun and sky irradiance on its photometer surface on eight wavelength channels, 440 nm, 670 nm, 870 nm, 936 nm and 1020 nm when 870 nm channels consists of a non-polarized and three polarized channels to provide four Stock's parameters. The optical absorption of atmospheric gases are minimal at the SPM wavelength channels except at the 936 nm that matches to one of the water vapour absorption lines.

3. THEORETICAL BASIS

3.1 Aerosol Optical Depth

Using the Beer-Bouguer-Lambert law, the total optical thickness of the atmosphere, τ_λ, is obtained from the

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absolute output signal of the SPM, V_λ, when it is working in the sun mode:

$$V_\lambda = \frac{V_{0\lambda}}{R^2}\exp(-m\tau_\lambda)\,, \quad (1)$$

$V_{0\lambda}$ is the considered output signal of the SPM at the top of the atmosphere, corrected for spherical propagation of the sun light by the $1/R^2$ factor. m is known as the relative air mass and it compensates the difference between the geometrical path of the light for the angle that the SPM aimed to the sun and the atmosphere thickness in the zenith direction [6]. AOD or $\tau_{\text{Aerosol},\lambda}$ is obtained from the difference between the total optical depth, τ_λ, and the Rayleigh optical depth, $\tau_{\text{Rayleigh},\lambda}$,

$$\tau_{\text{Aerosol},\lambda} = \tau_\lambda - \tau_{\text{Rayleigh},\lambda}\ . \quad (2)$$

The Langley plot or Long plot method of field calibration is the preferred and most commonly used method to find $V_{0\lambda}$ [7].

3.2 Water Vapour

Extraction of water vapour content of the atmosphere from sun-photometer measurements generally relies on a measurement in the region of water vapour absorption at 936 nm. The aerosol effect is removed by interpolating between two adjacent bands (870 nm and 1020 nm) where molecular absorptions are almost absent. Transmission in the water vapour band T_w can be modelled as,

$$T_w = \exp(-am^b w^b)\ . \quad (3)$$

Where w is vertical column abundance and constants a and b depend on the wavelength, width and shape of the sun-photometer filter transmission function, and the atmospheric conditions (temperature-pressure lapse and the vertical profile of water vapour band). Halthore [8] showed that for a narrow band pass filter (less than 10 nm) a and b parameters are not sensitive to the atmospheric conditions and Eq. (1) can be written as,

$$V_\lambda = \frac{V_{0\lambda}}{R^2}\exp(-m\tau_\lambda)\exp(-am^b w^b) \quad (4)$$

Where τ_λ is the sum of Rayleigh optical depth and AOD. A modified-Langley method is used for deriving calibration values for the water absorption band around 936 nm [9].

3.3 Ångeström exponent

Ångeström (1929) proposed an empirical formula to approximate the spectral dependence of atmospheric extinction (scattering and absorption) caused by aerosols:

$$\tau_{\text{Aerosol},\lambda} = \beta\lambda^{-\alpha} \quad (5)$$

Where β is the Angstrom's turbidity coefficient which is AOD at $\lambda = 1$ μm, and α is the widely known Angstrom exponent [10]. The Angstrom exponent itself varies with wavelength, and a more precise empirical relationship between aerosol extinction and wavelength is obtained with a second-order polynomial fit [11, 12, 13]:

$$\ln\tau_{\text{Aerosol},\lambda} = \alpha_0 + \alpha_1\ln\lambda + \alpha_2(\ln\lambda)^2\,, \quad (6)$$

Where the coefficient α_2 accounts for a curvature often observed in the variations of the SPM measurements versus the wavelength. Negative curvature indicating aerosol size distributions dominated by the fine mode (<1μm) and positive curvature indicating size distributions with a significant contribution by the coarse mode (>1μm) [12, 13, 14].

4. RESULTS AND DISSCUSSION

In this work the measurement only carried on in the sun mode.

4.1 Aerosol optical depth climatology

Fig. 1 shows the AOD monthly average on 870 nm non-polarized channel during the two years. The lowest (highest) value for AOD observed in January 2007 (May 2007). Generally during the winter times (December, January and February) the AOD considerably decreases (down to ~0.1) and during mid to late spring (April and May), AOD increases (up to 0.35). Frequent precipitations not only in the Zanjan area but also even in the Tigris and Euphrates basin can be the main reason for AOD decrease during the winter times.

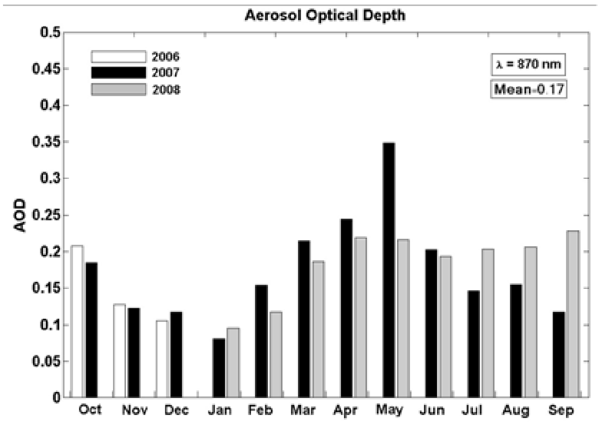

Figure 1. *Temporal evolution of AOD monthly average for Zanjan atmosphere, October 2006 to September 2008. 870 nm wavelength channel.*

The turbidity of the atmosphere increases because of the characteristic spring and summer dry season of Zanjan when the for most of the times westward winds transports the dust from Iraq areas to this regions and for some times northern winds after passing the Alborz mountains, takes the dust from the Iran central desert (Dasht-e-Kavir), to this area. Other observations of our team [2] showed that the Qom lake, a salt covered playa, is the main dust resource in this desert that affect the Zanjan atmosphere. The described behavior is analogous for all other AOD channels.

4.2 Columnar water vapour climatology

Fig. 2 shows that the CWV (936 nm wavelength channel) variation along the two years for the cloud-free available data. The results show that the maximum (minimum) CWV occurred in July (January). Increase of CWV during summer is quite clear when its value is close to 1 cm.

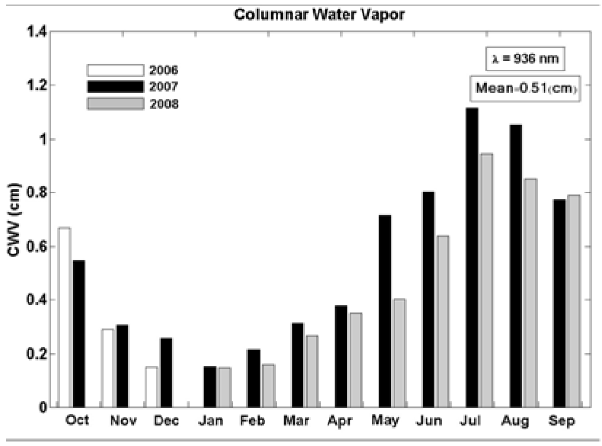

Figure 2.*Temporal evolution of CWV monthly average at Zanjan, October 2006 to September 2008, 936 nm wavelength cahnnel.*

4.3 Aerosol classification, Ångeström exponent

The Ångeström exponent is commonly used as an indicator of predominant aerosol shape, because the spectral shape of the extinction is related to the particle size [12, 14]. The second-order polynomial fit Eq. (6) was also applied to the AOD values at three wavelengths (440 nm, 670 nm and 870 nm). AODs at 1020 nm are not included in the linear and second-order polynomial fits in this work because of possible water-vapour absorption effects at this wavelength, resulting in inaccuracies in the computations of the second order polynomial fit and the estimations of the parameters α_1 and α_2 [12].The α_2 and $\alpha_2 - \alpha_1$ scatter plot respect to AOD, is a common tool to classify aerosol types. While the AOD gives information about the aerosol loading, and the α_2 and $\alpha_2 - \alpha_1$ is the related to the aerosol size (type). The joint analysis of both parameters makes possible an interpretation of the data [5].

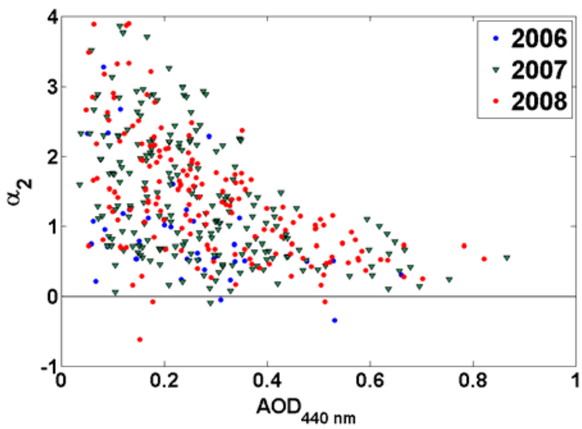

Figure 3.*Correlation between the coefficient $\alpha_2$computed in the spectral interval 440-870 nm and AOD 440 nm for the Zanjan area, October 2006 to September 2008.*

The correlation between α_2 and AOD (440 nm) provides information on the atmospheric conditions under which the spectral variation of α is negligible, so the spectral variation of AOD can be accurately described by the simple Ångeström formula. It is interesting to note the existence of negative curvatures in sites characterized by aerosol size distributions dominated by the coarse mode and also the occurrence of positive curvatures in sites characterized by aerosol size distributions dominated by fine mode particles [12].

Both cases occur mainly for low atmospheric turbidity. There is a decreasing trend of α_2 with increasing AOD 440 nm, in line with the results of Fig. 3. Angstrom exponent and α_2 coefficient, show that most aerosols in the Zanjan area are in the coarse mode.

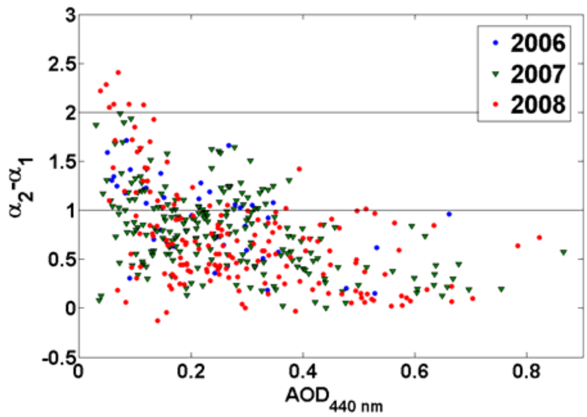

Figure 4.*Correlation between the coefficient $\alpha_2 - \alpha_1$ computed in the spectral interval 440-870 nm and AOD 440 nm for the Zanjan area from October 2006 to September 2008.*

In Fig. 4, the difference, $\alpha_2 - \alpha_1$ is plotted versus AOD 440 nm for Zanjan. In Figure 4, two boundary lines $\alpha_2 - \alpha_1 = 1$ and $\alpha_2 - \alpha_1 = 2$, represent the traditional guidelines for the Angstrom exponent. $\alpha_2 - \alpha_1 < 1$ characterized by aerosol size distributions dominated by the coarse mode and occurrence of $\alpha_2 - \alpha_1 > 2$, by aerosol size distributions dominated by the fine-mode particles. When $1 < \alpha_2 - \alpha_1 < 2$, most of the aerosols are in the fine mode. Refering to Fig. 4, we can find about 70% of the aerosols during the measurements were in the coarse mode and 30% in the fine mode. Comparing $\alpha_2 - \alpha_1$ with other regions we deduce that aerosols of Zanjan come from both industrial/urban pollution and dust [5]. Also that natural dust is the dominant source of atmospheric aerosols in this city. For clean conditions, i.e. small AOD 440 nm, there is a wide range of $\alpha_2 - \alpha_1$ values for all aerosol types. For small AODs at 440 nm there is a large range of values (from -0.1 to 2.5). This is an indication of the existence of bimodal–size distributions at relatively low optical depths, with fine mode particles determining the wavelength dependence of AOD at the shorter wavelengths, and coarse mode particles similarly the wavelength dependence at larger wavelength [15].

CONCLUSIONS

For the first time a SPM has been installed in the IASBS in the city of Zanjan. The 2-year data series presented here allows a climatological approach in the study of AOD, CWV and Ångeström exponent. The average of AOD (870 nm) and CWV during the period of measurements were 0.17 and 0.51 cm respectively. In spite of the reported AOD variability, a seasonal pattern was found with two AOD peaks along the year in April-June and August-October, and a decrease during autumn and winter months. The maximum (minimum) of CWV happened in summer (winter).

A classification for the different aerosol types in Zanjan has been proposed based in the analysis of the AOD and Ångeström exponent features. Angstrom exponent and α_2 coefficient shows that most aerosols in the Zanjan area are in the coarse mode.

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