Radiative Effects and Optical Properties of Aerosol during Two Dust Events in 2013 over Zanjan, Iran

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ABSTRACT

Aerosol optical properties like Aerosol Optical Depth (AOD), Angstrom Exponent (AE), ASYmmetry parameter (ASY), Single Scattering Albedo (SSA), and Aerosol Volume Size Distribution (AVSD) have been analyzed for the atmosphere of Zanjan, a city in Northwest Iran. These properties have been studied using the ground-based AErosol RObotic NETwork (AERONET) during the periods from 8 to 18 May and 8 to 14 June, 2013. During the study period, 14th May and 10th June are identified as dusty days, and AOD at 500 nm reached a peak value of 0.64 and 0.80, on these days. The high values of AOD and low values of AE during dusty days illustrate that coarse mode particles like dust are dominant. In the visible spectrum ASY usually decreases and then somewhat increases in the near infrared region. Both SSA and AVSD suggest predominance of coarse particles on the dusty days. The Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) model is utilized to simulate the solar irradiance values for the above-mentioned periods at the earth's surface, within the atmosphere, and at the Top of the Atmosphere (TOA). The results show that dominant aerosol types are dust particles which have a cooling effect on the earth's surface during the study periods, especially on two dusty days, 14 May, and 10 June. The correlation coefficient shows a very good agreement between the ARF values retrieved from AERONET and SBDART simulation results.

Keywords: SBDART; AERONET; Aerosol Optical Depth; Aerosol Radiative Forcing; Zanjan.

INTRODUCTION

A colloidal system of solid or liquid particles in the atmosphere is defined as aerosols. Dust, sea salt, urban-industrial aerosols, and biomass burning are different types of aerosols, which are classified according to their physical forms and the ways they are generated (Kokhanovsky, 2013). Aerosols have a noticeable effect on radiative forcing, cloud properties, air quality, visibility reduction, and human health (Jacob, 1999).

The aerosols are the main sources of uncertainties in climate assessments due to various distributions and insufficient understanding of their properties (Hansen et al., 1997; Choobari et al., 2014; Bhaskar et al., 2015). Aerosols have an influence on radiative processes and climate: Directly by backscattering and absorbing shortwave solar radiation (McCormick and Ludwig, 1967), Semi-directly by changing the structure of atmospheric temperature and altering the rate of cloud droplet evaporation (Koren et al., 2004) and indirectly, by affecting the cloud microphysics (Liou and Ou, 1989; Kumar et al., 2011). Both incident solar radiation into the atmosphere and Earth’s thermal radiation are absorbed and scattered by aerosols. The mechanism causes to change the atmospheric radiative fluxes and is known as the aerosol direct radiative forcing. Depending on the aerosol types and physical and optical properties, the direct aerosol radiative forcing may show negative/positive values and have cooling/heating effects on climate (Feng and Christopher, 2013; Bhaskar et al., 2015). The average direct aerosol radiative forcing for all types aerosols is found to be $-0.5 \pm 0.4 \text{ W m}^{-2}$ at the Top Of Atmosphere (TOA) with a medium-low level of scientific understanding (IPCC, 2007). The study of aerosol optical characteristics like Aerosol Optical Depth (AOD), Angstrom Exponent (AE), ASYmmetry parameter (ASY), Single Scattering Albedo (SSA) and Aerosol Volume Size Distribution (AVSD) can give important information.

Very few studies have been done on retrieval of aerosol optical and physical properties for the atmosphere of Iran plateau using ground-based measurements (Bayat et al., 2013; Masoumi et al., 2013; Khoshisma et al., 2014). Bayat
et al. (2013) investigated the polarized phase function of atmospheric aerosols and SSA over Zanjan during 2010–2012. Masoumi et al. (2013) used ground-based measurements to study aerosol properties like AOD, AE, SSA, AVSD and refractive index over Zanjan during 2006–2008. Khoshshima et al. (2014) studied AOD, AE and Angstrom turbidity coefficient during 2009–2010 over Zanjan. In this paper for the first time, we computed the aerosol direct radiative forcing at the earth's surface, within the atmosphere, and at the TOA of atmosphere over Zanjan using Santa Barbara Discrete-ordinate Atmospheric Radiative Transfer (SBDART) model (Ricchiazzi et al., 1998). Since ARF calculations have not been previously reported in Iran, therefore, the present study will fill a geographic gap in our present knowledge about the importance of atmospheric aerosols in different climate processes. Aerosol properties retrieved from the Aerrosol RObotic NETwork (AERONET) station in Zanjan city. AERONET and space-borne meteorological satellite data are used as inputs to SBDART model. We also used the radiative forcing values obtained directly from AERONET inversion product to validate the SBDART model results. The paper context is organized as follows. The next section is a description of the instrumentation and methodology. Radiative transfer simulation results and their discussion have been explained in the later section, and finally, the work is concluded in the last section.

DATA AND METHODOLOGY

Site Description

Iran Plateau is the central part of the semi-arid to arid area that is named as the “dust belt” and is spreading from west (North Africa) to east (China) (Prospero et al., 2002). Zanjan is in the northwest part of the Iran plateau (36.70N, 48.50E, and 1800 m above sea surface). Zagros Mountains separate the city from the Mesopotamian low-altitude area. The climate of Zanjan is cold semi-arid. The area has hot and dry summers, cold winters and moist springs and winters. In the last 33 years, the annual mean precipitation, temperature and relative humidity were reported to be 295 mm, 10.7°C, and 53%, respectively (Khoshshima et al., 2014). The atmosphere of Zanjan is frequently affected by dust particles. During the dry months, especially from May to July, dust is abundant in the atmosphere. Strong and active dust sources like Tigris-Euphrates basin, and the Arabian Peninsula and weak local dust sources such as dried seasonal lakes or rivers are the origin of the dust aerosols in the atmosphere of the city (Bayat et al., 2011; Masoumi et al., 2013).

Aerosol Data

The AERONET program is the international ground-based aerosol remote sensing networks. The Institute for Advanced Studies in Basic Sciences (IASBS) is a research institute in the city of Zanjan and is equipped with a CIMEL CE318-2 sun-photometer from 2006 till now. The sun-photometer is linked to AERONET network since 2009 and is named as “IASBS site”. An important database of aerosol physical, optical, and radiative properties like AOD, AE, AVSD, ASY, SSA, and complex refraction index is accessible via the IASBS site. AOD data are made available by AEROENT at three levels: Level 1.0 (unscreened), Level 1.5 (cloud-screened) and Level 2.0 (cloud screened and quality-assured). Level 1.5 data were used in this work. Under cloudless conditions, the uncertainty in retrieval AOD for the wavelengths longer than 0.44 nm is lower than ± 0.01 and for shorter wavelengths is less than ± 0.02. In addition, the uncertainty is less than ± 0.05 for the retrieval of sky radiance measurements (Dubovik et al., 2000).

SBDART Model

The SBDART model is used in a wide range of radiation and atmospheric energy budget analyses. The SBDART is able to solve the plane-parallel radiative transfer equations to calculate the radiative effects of several atmospheric boundary layers. In the boundary layer section of the model, the user can choose between rural, urban, or maritime aerosols. It should be mentioned that such options differ from each other in terms of their scattering efficiency. For example, SSA and ASY are different due to their selected wavelengths. In the upper atmosphere, at most, five different aerosol layers with particular radiative characteristics can be recognized (Ricchiazzi et al., 1998).

Meteorological Conditions

The variation of meteorological parameters over the site were first analyzed. Fig. 1 illustrates variations in average values of air temperature, daily columnar water vapor, and mean synoptic wind vector.

The daily mean temperature and the relative humidity were acquired from the Iranian Meteorological Organization for the studied periods, May and June. That surface meteorological data monitored from an earth's surface station, with an elevation of 1805 m above sea level in Zanjan. The maximum and minimum air temperatures were recorded 25.3°C and 10.5°C on 17th June and 16th May (Fig. 1(a)). There is an inverse relation between the temperatures and the relative humidity. The corresponding columnar water vapor data were obtained from AERONET for the months of May and June. The maximum columnar water vapor was 1.56 cm on 23rd June while minimum value of 0.34 cm was observed on 7th May as shown in Fig. 1(b). The near surface wind flow patterns at 850 mb were attained from NCEP/NCAR reanalysis daily data over west of Iran (Fig. 1(c)). The arrows show wind directions and the colors represent the wind speeds. As it can be seen, in June the region experienced stronger winds than May. Wind directions were predominantly from the west and southwest.

RESULTS AND DISCUSSION

Aerosol Optical Depth and Angstrom Exponent

The aerosol properties were analyzed using AERONET data. The AOD and AE spectral variations over Zanjan during the periods from 8th to 18th May and 8th to14th June, 2013 was investigated. The total column extinction of the solar beam by aerosols is called AOD (WMO, 1994). The
amount of the spectral irradiance that reaches the earth's surface can be calculated using a sun-photometer; that is related to a voltage generated by the system. Eq. (1) shows the total optical depth, according to Beer-Lambert-Bouguer law.

\[ V(\lambda) = V_0(\lambda) d e^{-\tau_{tot} m} \]  

(1)

where \( V \) is the digital voltage at \( \lambda \), \( V_0 \) is the extra-terrestrial value for the voltage, \( d \) is the ratio of the average to the actual distance from the sun to the earth, the total optical depth is presented by \( \tau_{tot} \) and the optical air mass is shown by \( m \).

AOD estimations are made only during clear-sky conditions. The maximum AOD values were found to be 0.8 and 0.64 on 10th June and 14th May, 2013 respectively. The spectral variations of AERONET AOD over Zanjan during the periods of 8th to 18th May and 8th to 13th June of 2013 are shown in Figs. 2(a)–2(b). Fig. 2 demonstrates the spectral dependence of AOD, i.e., the longer the wavelengths, the lower the AOD values. Also on dusty days AOD values are higher than those of non-dusty days.

Five days back-trajectory analyses ending on dusty days on 14th May and 10th June were performed to find the origins of air masses that reached the studied area, based on the NOAA HYSPLIT model (http://ready.arl.noaa.gov/HYSPLIT.php) (Stein et al., 2015). These trajectories were plotted at three level 500 m, 1500 m and 2500 m. Fig. 3 presents five days back-trajectories ending in Zanjan, for dusty days on 14th May and 10th June.
Back-trajectory analyses indicated that the aerosols were originated from different sources. The dusty air masses that reached Zanjan on 14th May have originated from the Tigris and Euphrates basins or from near the Mediterranean Sea and Turkey. On the 10th of June, the air masses seem to be coming from three different locations in the north of the African Sahara Desert.

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) measurements have been used to acquire the aerosol subtype profile. In Fig. 3(b) CALIPSO retrieved sub-type profiles are shown on 10th May and 9th June 2013. The aerosol sub-type profiles in the vicinity of Zanjan, illustrate the dominance of dust; however, polluted dust also exist in the area.

AE is indicative of the particle size and can be shown with the Angstrom relationship (Angstrom, 1964) as follows:

$$\tau_{a}(\lambda) = \beta \lambda^{-\alpha}$$

(2)

where $\tau_{a}(\lambda)$ is the AOD at wavelength $\lambda$, $\beta$ is the turbidity coefficient, and $\alpha$ is Angstrom exponent. Lower values of AE indicate smaller concentrations of fine particles, whereas high AE values reveal the domination of fine particles (Alam et al., 2011). Fig. 4 shows AOD at 500 nm, AE (440–870) and visibility variations during the study periods over Zanjan. The figure reveals that AOD has an inverse relationship with AE and visibility. The high values of AOD and low values of AE during dusty days illustrate that coarse mode particles like dust are dominant. High values of AE on non-dusty days show an increase in fine mode particles (mainly caused by anthropogenic processes) in the atmosphere. An inverse relationship between AOD and AE has been reported earlier for a number of locations (e.g., Singh et al., 2005; Alam et al., 2011; Kumar et al., 2013; Srivastava et al., 2014; Kang et al., 2016).

Asymmetry Parameter, Single Scattering Albedo

We also analyzed other optical properties of aerosols, and therefore investigated the variability of ASY and SSA. ASY is a very important component in calculations of radiative transfer and provides useful information about aerosol absorption. ASY is calculated as follows:

$$ASY(\lambda) = \frac{\int \cos \theta P(\lambda, \theta) \sin \theta d\theta}{\frac{\pi}{2}}$$

(3)

where $\theta$ is the angle between the incident and scattered radiation and $P(\lambda, \theta)$ is the phase function. ASY depends on the composition and the size of aerosol. If the scattering is symmetric, ASY becomes zero, for completely forward scattering it is +1 and it is taken to be −1 for completely backward scattering. In cloud free atmosphere, ASY varies from ~0.1 to ~0.75 for very clean conditions to polluted atmospheres (Zege et al., 1991; Ali et al., 2014).

Figs. 5(a)–5(b) shows the spectral variability of ASY over Zanjan during 8th to 18th May and 8th to 14th June, 2013. ASY values decrease with increasing wavelengths. In the visible spectrum ASY usually decreases and then somewhat increases in the near infrared region. Hence, the decrement of ASY suggests that anthropogenic absorbing aerosol is comparatively abundant, whereas the increase can be caused by an abundance of coarse mode particles (Alam et al., 2012).

SSA is also an important parameter in the calculation of radiative forcing. The magnitude of SSA indicates the relative dominance of scattering type of aerosols as compared to absorbing type of aerosols. Chemical characteristics and composition of aerosol particles can largely control the spectral behaviour of SSA (Srivastava et al., 2014). Fig. 6 shows SSA spectral variations during the study periods. On dusty days in June a significant increase is observed in SSA values for all wavelengths (i.e., 440, 675, 870, and 1020 nm). The maximum SSA value of 0.97 occurred at a wavelength of 1020 nm on 10th of June. With increasing wavelength, SSA increases due to the dominance of desert dust. The low values of AOD and ASY and high values of SSA on non-dusty days indicate the dominance of scattering type aerosols like sea salt and sulfate (Bhaskar et al., 2015).

Table 1 represents the daily values of Extinction Angstrom Exponent (EAE), SSA and ASY for the study period Over Zanjan.

Fig. 2. Spectral variations in AERONET AOD over Zanjan on (a) 8th–18th May 2013 and (b) 8th–14th June 2013.
Fig. 3. (a) NOAA-HYSPLIT model run 5 days backward trajectory analysis of air mass pathways at 500, 1500 and 2500 m altitude over Zanjan on (i) 14<sup>th</sup> May 2013 and (ii) 10<sup>th</sup> June 2013. (b) Aerosol sub-type profiles retrieved from CALIPSO over Zanjan (i) 10<sup>th</sup> May 2013 and (ii) 9<sup>th</sup> June 2013.
Fig. 4. Variations in AOD at 500 nm, AE (440–870) and visibility over Zanjan during (a) 8th–18th May 2013 and (b) 8th–14th June 2013.

Fig. 5. Spectral variation of ASY over Zanjan on (a) 8th–18th May 2013 and (b) 8th–14th June 2013.

Fig. 6. Spectral variations of SSA over Zanjan during (a) 8th–18th May 2013 and (b) 8th–14th June 2013.

Aerosol Volume Size Distribution (AVSD)

The AVSD is another important parameter that has a significant effect on the climate. The AERONET AVSD is retrieved in the size range of 0.05–15 μm using 22 radius size bins. The AVSD can be characterized as follows:

$$\frac{dv(r)}{d\ln(r)} = \sum_{i=1}^{2} c_{i,j} \exp \left[ -\frac{(\ln r - \ln r_{i,j})^2}{2\sigma_{i,j}^2} \right]$$ (4)
where \( c_{v,i} \) is the total volume concentration of fine and coarse modes, \( r_{v,i} \) is the volume median radius and \( \sigma_i \) is the standard deviation (Alam et al., 2011). Using sun-photometer data, it is possible to retrieve AVSD for different size bins. Fig. 7 shows the AERONET retrieved AVSD for Zanjan during the studied period. The figures show that the AVSD exhibits two modes; coarse and fine modes. During the study period significant variations can be found in the coarse mode, while, low variations are noticed in the fine mode. A radius of 0.148 \( \mu m \) in the fine mode has its maximum value on the 10th of May, while a radius of 2.24 \( \mu m \) in the coarse mode has a maximum value on the 10th of June. The AVSD peaks depict prominent distinctions on dusty and non-dusty days. Hence, the AVSD peak indicates the dominance of coarse particles on dusty days. Alam et al. (2012) found a similar variation in aerosol volume size distributions over Lahore and Karachi. Srivastava et al. (2014) reported that, coarse mode particles were dominant over Jodhpur. Sumit et al. (2012) reported that the coarse mode particles were also dominant over Ahmedabad.

### Aerosol Radiative Forcing

Solar radiation is the main forcing of atmospheric circulation; therefore it controls the weather and climate system and is the major factor of the earth-atmosphere system. Accurate and extensive understanding of radiations and their interaction with clouds and aerosols is required for different aspects of climate processes. The radiative effect of atmospheric aerosols can directly cause a decrease in the surface reaching solar radiation flux. The difference in the net solar flux (Wm\(^{-2}\)), with and without aerosols in the atmosphere is defined as Aerosol Radiative Forcing (ARF), as shown in Eq. (5).

\[
\Delta F = (F_{at} - F_{rt}) - (F_{ol} - F_{ot})
\]

where \( \Delta F \) is the irradiance, and \( (F_{at} - F_{rt}) \) is the net irradiance (downwelling minus upwelling) calculated with aerosol \( (F_{at}) \) and without aerosol \( (F_{rt}) \) (Alam et al., 2012).

To calculate the short wave (0.3–4 \( \mu m \)) ARF, the SBDART model (Ricchiazzi et al., 1998) was used. To estimate ARF using the SBDART model, the important parameters such as AOD, SSA, ASY and atmospheric profiles (pressure, humidity, ozone and other gases) were retrieved from the IASBS AERONET site. The Aura OMI, version 3, aerosols level 2 data through the Giovanni online data system were used to obtain the surface albedo values. Fig. 8 shows the ARF at the earth's surface, TOA, and within the atmosphere for the studied days in May and June. 14th May and 10th June of 2013 were dusty days with maximum AOD values of 0.64 and 0.8, respectively.

The difference between ARF of TOA and earth's surface stands for the atmospheric ARF. Its large values for these dusty days show higher radiation absorption that causes a warming effect within the atmosphere. As a result, a considerable cooling was observed at the earth's surface, as has been reported by Miller and Tegen (1998).

The values of ARF at the earth's surface and TOA were found to be –186 W m\(^{-2}\) and –109.64 W m\(^{-2}\), and –119 W m\(^{-2}\) and –40.23 W m\(^{-2}\) on 14th May and 10th June respectively. While the values of ARF within the atmosphere were 186.6 W m\(^{-2}\) and 75.65 W m\(^{-2}\) on 14th May and 11th June respectively, representing considerable heating of the atmosphere over the study site. The heating rate values calculated over Zanjan were 2.16 Kday\(^{-1}\) on 14th May and 0.89 Kday\(^{-1}\) on 11th June. We also used the values of TOA and earth's surface forcing which obtained from the AERONET inversion products and compared them with those of the SBDART model predictions. The AERONET inversion products including the TOA and earth's surface data, present the measured downward and upward fluxes by the sun-photometers at the earth's surface. Fig. 8 also compares ARF obtained from the AERONET data and the SBDART calculations. The magnitude of ARF at the TOA is higher for AERONET than that of the SBDART model, during the study periods; they are almost similar.

A comparison between the AERONET measured and the SBDART calculated ARF over Zanjan was observed. The correlation coefficients between AERONET versus SBDART ARF are greater than 0.99. The comparison reflects a highly acceptable agreement between ARF of these two. The statistical analysis resulted in slopes very close to

### Table 1. The daily values of EAE, ASY and SSA at four wavelengths during the study period over Zanjan.

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<th>Date</th>
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<th>ASY 871</th>
<th>ASY 1020</th>
<th>SSA 440</th>
<th>SSA 676</th>
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Fig. 7. AERONET retrieved AVSD at Zanjan during (a) 8\textsuperscript{th}–18\textsuperscript{th} May 2013 and (b) 8\textsuperscript{th}–14\textsuperscript{th} June 2013.

Fig. 8. ARF at the TOA, earth's surface and within the atmosphere during dusty and non-dusty days on (a) 8\textsuperscript{th}–17\textsuperscript{th} May 2013 and (b) 8\textsuperscript{th}–12\textsuperscript{th} June 2013, over Zanjan.
unity, that supports the validity of the SBDART radiative transfer model calculations in this study.

Many researchers have discussed the ARF at the TOA and earth's surface. Alam et al. (2012) reported the values of ARF at the earth's surface for Lahore between –70 and –112 W m\(^{-2}\), and for Karachi between –52 and –73 W m\(^{-2}\). Also the ARF at the TOA was estimated over Lahore between –16 and –31 W m\(^{-2}\) and over Karachi between –14 and –21 W m\(^{-2}\). A good agreement was detected between the SBDART calculation and the AERONET retrieved radiative forcing at the surface. Their results are lower than the ARF values obtained for Zanjan in this work. It is important to note that the humidity in Zanjan is usually much lower than these two cities in Pakistan, and probably with fewer aerosols. Valenzuela et al. (2012) reported the mean daily ARF at the TOA and surface to be –6 ± 5 W m\(^{-2}\) and –20 ± 11 W m\(^{-2}\) over Granada from 2005 to 2010 during dusty days. They observed a good agreement between the global irradiances from AERONET retrieved and SBDART calculated. Sumit et al. (2012) also estimated the radiative forcing over India during December 2006 to April 2007 and found the diurnally averaged surface ARF to be between –18 to –59 W m\(^{-2}\). The values of ARF at the TOA varied from +0.9 to –8 W m\(^{-2}\). In their study a good agreement between the result of SBDART model and AERONET was revealed. Srivastava et al. (2014) also observed a considerable cooling at the earth's surface during the March 2012 over India and Pakistan, i.e., –72.6 W m\(^{-2}\) and –69.0 W m\(^{-2}\) at Lahore and Jodhpur respectively. They observed a significant heating within the atmosphere, with values larger than +71.6 W m\(^{-2}\) at Jodhpur and +68.4 W m\(^{-2}\) at Delhi. Their results are lower than the results obtained in this work for Zanjan, which is an elevated dry city. Vijayakumar et al. (2016) reported that ARF values were –118 W m\(^{-2}\) and +85 W m\(^{-2}\) on dusty days and –67 W m\(^{-2}\) +42 W m\(^{-2}\) on non-dusty days, respectively at the earth's surface and within the atmosphere over an urban station in Western India. Yu et al. (2012) calculated that, ARF values at the TOA and surface lies between –65.88 and –115.65 W m\(^{-2}\) and –166.66 and –236.02 m\(^{-2}\), respectively over Beijing. The uncertainty in the ARF values is due to AOD, SSA and surface albedo. The overall uncertainty was previously calculated around 10–15% over India and Pakistan (Prasad et al., 2007; Alam et al., 2012).

**CONCLUSIONS**

To the best of the author's knowledge, for the first time that a detailed study on aerosol optical properties and ARF values has been performed over Zanjan, Iran. The aerosol physical and optical properties were analyzed using sunphotometer measurements. The AOD and AE spectral variation were investigated over Zanjan during a number of dusty days in 2013. The spectral variations in the AERONET AOD values over Zanjan during 8th–18th May and 8th–14th June 2013 showed the spectral dependence of AOD, i.e., the longer the wavelengths, the lower the AOD values. In addition, AOD increased in dusty days. The AOD high values and AE low values during dusty days revealed that coarse mode particles such as dust are dominant. Back-trajectory analyses indicated that the aerosols were originated from various regions of dust sources. The air masses reached Zanjan on the 14th of May from the Tigris and Euphrates basin, near the Mediterranean Sea and Turkey. While on the 10th of June, the air masses arrived from three other different locations in the north of African deserts.

Spectral variation of the ASY over Zanjan showed a decrease in the ASY values with an increase in the wavelengths. The decrement of the ASY in the visible spectrum suggested abundance of anthropogenic absorbing aerosol, while the increase in the near-IR region illustrated the relative abundance of coarse-size particles. The spectral behavior of the SSA values showed variations during dusty and non-dusty days. The SSA values indicated a prominent increase for all wavelengths on dusty days in June.

The AVSD presented significant fluctuations in coarse mode particles. The maximum value of fine and coarse mode occurred on 10th May and 10th June with a radius of about 0.15 µm and 2.24 µm, respectively. The structure of AVSD showed that aerosol consisted of a mixture of coarse particles.

The SBDART model is utilized to simulate the solar irradiance values over the region. A cooling effect was observed during dusty days at the earth's surface. In this study, the TOA and earth's surface forcing values were acquired directly from the AERONET inversion products and were compared with the SBDART model results. According to our findings, the correlation coefficients of the AERONET versus the SBDART ARF values at the TOA, earth's surface and within the atmosphere were higher than 0.99 that supports the validity of the SBDART radiative transfer model results for the area.

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