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Effects on surface meteorological parameters and radiation levels of a heavy dust storm occurred in Central Arabian Peninsula

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ABSTRACT

On 24 April 2015 a severe dust storm event arrived at Riyadh causing various problems. The quantitative impact of this dusty event on solar ultraviolet radiation UVA and UVB, global solar radiation component, downward and outgoing long-wave radiation, and some meteorological variables, was investigated and presented. The results showed significant changes in all of these parameters due to this event. Shortly after the storm arrived, UVA, UVB, global radiation, and air temperature rapidly decrease by 83%, 86%, 57.5%, and 9.4%, respectively. Atmospheric pressure increased by 4 mbar, relative humidly increased from 8% to 16%, and wind direction became northerly with wind speed increasing to a maximum of 6.3 m/s. Outgoing long-wave radiation decreased by 19 W/m^2 and downward long-wave radiation increased by 41 W/m^2. The dust storm caused the atmosphere to emit radiation that resembled that of a black body. The daily average of the atmospheric pressure showed no changes compared to a non-dusty day. Apart from the relative humidity (which increased by about 32%), the remainder of the variables have shown significant reduction, with different magnitudes, in their daily values due to the dust event compared to the values of a non-disturbed reference day. For instance, the daily mean values of the UVA radiation, air temperature, and outgoing long-wave radiation, decreased in the dusty day by 15.6%, 30.8% and 11.4%, respectively, as compared to the clear day.

1. Introduction

Dust storms are the major source of atmospheric aerosols and are considered as a serious natural hazard that can cause a variety of problems. They have social and economic effects and can severely affect air quality and human health (Ozer et al., 2006; Bennion et al., 2007; Andrew, 2009). Dust storms cause damage to agricultural crops and a reduction in soil fertility (Xu, 2006). They produce atmospheric instabilities and affect chemical and biological ecosystems (Donaghay et al., 1991; Satheesh and Krishna Moorthy, 2005) which results in a great impact on the biogeochemical cycles. Dust storms play a significant, direct and indirect, role in radiation balance and climate by modulating solar and terrestrial radiation (Jayaraman et al., 1998; Haywood and Boucher, 2000; Hara et al., 2006; Helmert et al., 2007; Bryant et al., 2007). They bring pollution that increases atmospheric turbidity, causing extinction of solar and atmospheric radiation by scattering and absorption (Kaskaoutis et al., 2006). Dust aerosols can affect cloud formation, thereby causing an indirect radiative forcing associated with these changes in cloud properties. Furthermore, dust can modify the amount of ultraviolet (UV), which significantly affects living beings and the environment (Krzyscin and Puchalsky, 1998; Zerefos et al., 2002; Balis et al., 2004).

Due to the substantial effect of dust storms on various activities, numerous studies have been conducted using a variety of instrumentation and techniques to analyze their impact on solar radiation, air quality, aerosols, climate, and human health (Barkan et al., 2004; Yang et al., 2008; Maghrabi, 2012).

Saudi Arabia is surrounded by some of the sources of global dust such as the Empty Quarter (21° 30′N; 48° 50′E). This makes dust storm events a common phenomenon in Saudi Arabia, particularly during the pre-Monsoon season when dust aerosols are brought by southwesterly winds from the arid regions (e.g. Ackerman and Cox, 1989; Pease et al., 1998; Prasad et al., 2007; Miller et al., 2008; Alharbi, 2009). The characterization of large-scale dust loads using surface and/or satellite data was the main focus for most previous studies conducted in this region (e.g. Kutiel and Furman, 2003; Alharbi et al., 2013). However, few studies have been carried out to characterize the effect of these events on the radiative properties of solar and atmospheric radiation (Maghrabi et al., 2011).

On 24 April 2015, a strong dust storm moved over Riyadh (24° 43′N; 46° 40′E), causing heavy dust deposition, which affected visibility and air quality. In this study we quantify the influence of this event on solar ultraviolet radiation, UVA and UVB, global solar radiation

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component, downward and outgoing long-wave radiation, and some meteorological variables.

2. Experimental data

The observational dataset analysed here consists of Global solar radiation (G), Ultraviolet A (UVA), and B radiation (UVB), Outgoing (OLR) and Downward (DLR) long-wave radiation, and surface meteorological data.

The measurements are taken using a radiometric and weather station installed on January 2014 on the rooftop of the radiation detector laboratory building at King Abdulaziz City for Science and Technology (KACST) campus.

The Global radiation was measured with the Skye Pyranometer model SKS 1110 sensor that has a spectral response between 400 and 1100 nm and 180° field of view FOV. The SKU 421 sensor was used to measure UV-A radiation between 315 and 400 nm. The SKU 430 sensor measures UV-B radiation between 280 and 315 nm (Skye instrument, 2015).

The three sensors measure the radiation from the entire hemisphere after the cosine effect is corrected. The incident radiation perpendicular to the sensor is fully measured, whereas that at angles greater than 87° is rejected. Incoming radiation at other angles is calculated according to the cosine of its angle to the perpendicular. According to the manufacturer, the cosine errors up to angles of 70° are minimal and errors are less than 5% between 70 and 80°. Detail descriptions about this topic are explained in the instruments handbook provided by the manufacturer (Skye instrument, 2015).

Outgoing and Downward long-wave radiation was measured using two Kipp & Zonen CGR pyrgeometers, model CGR3 (Kipp and Zonen, 2015). The two instruments were mounted base-to-base and fitted with the mounting rod one looking up and one looking down. They both have a 150° field of view and spectral range between 4.5 and 42 μm.

Meteorological data such as atmospheric pressure, relative humidity, wind speed and directions, air temperature were measured using the Skye Mini Metstation (Skye instrument, 2015) that incorporates different meteorological sensors.

Additionally, Aerosol Optical Depth at 500 nm (AOD_{500}) and Angstrom Exponent ($\alpha_{380-500\ nm}$) data from the AERONET solar village site located 15 km North West of KACST; were used to characterize this event. In this study, the hourly-averaged Level 1.5 products were used, which are cloud-screened and quality assured (Holben et al., 2001). The instrumentation, data acquisition, retrieval algorithms and calibration procedure for the used instruments are described in detail in several studies (e.g., Kambezidis and Kaskaoutis, 2008; Maghrabi et al., 2011).

The evolution of the AOD and $\alpha_{380-500\ nm}$ from 23 to 27 April 2015 is shown in Fig. 1. On the early morning of the 24 April, the AOD was around 0.50 and $\alpha_{380-500\ nm}$ was about 0.22. On that day at 12:30 UT, AOD sharply increased to 1.5 and $\alpha_{380-500\ nm}$ dropped to 0.07 indicating the start of the atmospheric disturbances associated with the arrival of the dust storm. Since that time, the AOD continued to increase and $\alpha_{380-500\ nm}$ continued to decrease until AOD reached a maximum of 1.78 and $\alpha_{380-500\ nm}$ dropped to −0.19 by 14:30 of the same day. Unfortunately due to technical problems, no data were available for the rest of the 24 April. For the rest of the period both the AOD and the $\alpha_{380-500\ \mu m}$ resume their diurnal variation.

The AOD values during this dust storm event were higher than those reported in other locations around the world, for example in Arabian Sea (Badarinath et al., 2010) and Osaka, Japan (Yu et al., 2006). On the other hand, AOD values of this event were similar to the dust storm recorded in, for instance, southeastern Spain (Antón et al., 2014). Contrary, other locations have shown higher AOD values during dust events higher than those reached during this event (Badarinath et al., 2007);

The Direct Dust Effect (DDE) was calculated to quantify the impact of the dust event on the considered variables. This parameter calculates the difference between the measured variables immediately after the onset of the dust event and those of undisturbed values before the dust storm.

The normalized dust effect factor (NDE) represents the impact of the dust storm on the considered variables as a percentage and was obtained using the following equation:

$$NDE = \frac{x - x_0}{x_0} \times 100 \qquad (1)$$

where x and x_0 are the measured values of the variable(s) pre-and post-the event, respectively.

3. Results and discussion

3.1. Ultraviolet, global solar, and long wave radiation

Fig. 2 shows the daily variations of the ultraviolet radiation (UVA-UVB), global solar radiation component, and long wave radiation from the 23 to 27 April 2015. The mean values of the above mentioned variables, before and after the dust storm and the corresponding DDE and NDE, are given in Table 1. Diurnal variations are evident for all the

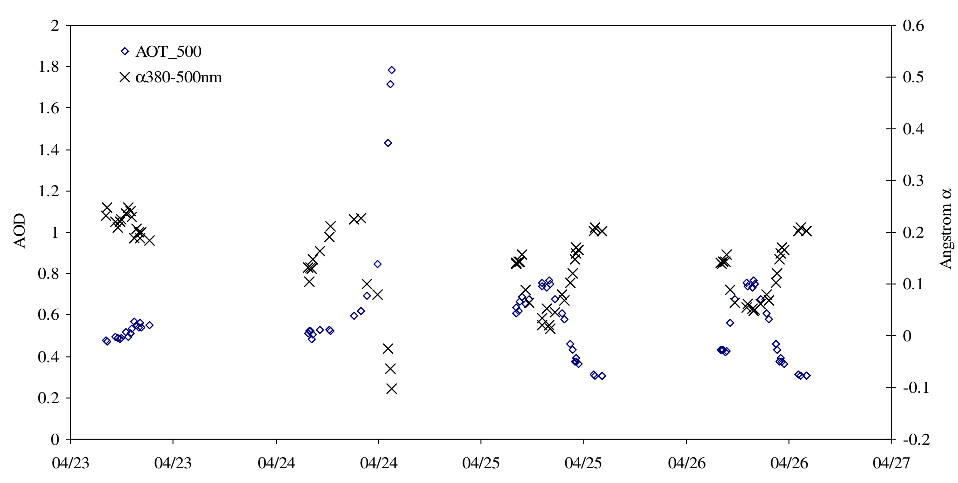

Fig. 1. Day-to-day variability of AERONET (1.5 quality level) AOD at 500 nm and Angstrom α for the wavelength range 380–500 nm from 23 to 27 April 2015. The time is Local Time.