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Solar and thermal radiative effects during the 2011 extreme desert dust episode over Portugal

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HIGHLIGHTS

- Aerosol thermal capability to offset part of the solar radiative effect.
- Lidar and sun photometer data to initialize a radiative model.
- Aerosol could enhance the response between absorption and re-emission processes.

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ABSTRACT

This paper analyses the influence of the extreme Saharan desert dust (DD) event on shortwave (SW) and longwave (LW) radiation at the EARLINET/AERONET Évora station (Southern Portugal) from 4 up to 7 April 2011. There was also some cloud occurrence in the period. In this context, it is essential to quantify the effect of cloud presence on aerosol radiative forcing. A radiative transfer model was initialized with aerosol optical properties, cloud vertical properties and meteorological atmospheric vertical profiles. The intercomparison between the instantaneous TOA shortwave and longwave fluxes derived using CERES and those calculated using SBDART, which was fed with aerosol extinction coefficients derived from the CALIPSO and lidar-PAOLI observations, varying OPAC dataset parameters, was reasonably acceptable within the standard deviations. The dust aerosol type that yields the best fit was found to be the mineral accumulation mode. Therefore, SBDART model constrained with the CERES observations can be used to reliably determine aerosol radiative forcing and heating rates. Aerosol radiative forcings and heating rates were derived in the SW (ARF_{SW}, AHR_{SW}) and LW (ARF_{LW}, AHR_{LW}) spectral ranges, considering a cloud-aerosol free reference atmosphere. We found that AOD at 440 nm increased by a factor of 5 on 6 April with respect to the lower dust load on 4 April. It was responsible by a strong cooling radiative effect pointed out by the ARF_{SW} value (-99 W/m^2 for a solar zenith angle of 60°) offset by a warming radiative effect according to ARF_{LW} value ($+21.9$ W/m^2) at the surface. Overall, about 24% and 12% of the dust solar radiative cooling effect is compensated by its longwave warming effect at the surface and at the top of the atmosphere, respectively. Hence, larger aerosol loads could enhance the response between the absorption and re-emission processes increasing the ARF_{LW} with respect to those associated with moderate and low aerosol loads. The unprecedented results derived from this work complement the findings in other regions on the modifications of radiative energy budget by the dust aerosols, which could have relevant influences on the regional climate and will be topics for future investigations.

1. Introduction

Desert dust (DD) plays an important role in many atmospheric processes modifying the Earth's energy balance on shortwave (SW) and longwave (LW) spectral ranges through direct effects (scattering and absorption) and indirect effects (cloud formation and

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development) (e.g. Foster et al., 2007; Naeger et al., 2013; Santos et al., 2013). However, nowadays a large uncertainty still remains in the evaluation of total radiative effects, mainly caused by uncertainties on the estimation of dust aerosol properties (IPCC, 2013). Such uncertainties on the dust optical and microphysical properties are due to the high variability in space and time of the particle's size, chemical composition, shape and vertical distribution affecting their light-absorbing and scattering properties. One of reasons for this variability is that dust optical properties at origin, as issued by the sources, are influenced by the potential changes during the path of the air masses as well as by the local aerosol properties at the reception site (e.g. Hand et al., 2010; Bauer et al., 2011; Valenzuela et al., 2014). Close to the source regions, mostly pure dust is found, but after long-range transport the aging of dust and mixing with other aerosol types modify the optical properties of DD (e.g. Bauer et al., 2011).

The Mediterranean basin is a place of special interest for the study of the atmospheric aerosol due to its strategic geographic location surrounded by continents with different surface characteristics and where local winds, complex coastlines and orography have strong influence on the atmospheric flow. North African dust is injected into the atmosphere through resuspension processes in source areas, and transported at different altitudes (up to 7 km) to different regions of the world (e.g. Tesche et al., 2009). Papayannis et al. (2008) reported more than 130 daily observation of the horizontal and vertical extent of Saharan dust intrusions over Europe in the frame of the European Aerosol Research Lidar Network (EARLINET). They found that Saharan dust source regions play a key role in dust transport to Europe for the height layer between 3 and 5 km. Particularly, the Iberian Peninsula is frequently affected by African dust intrusions with large aerosol loads that modulate the aerosol climatology in different areas of this region (e.g. Toledano et al., 2007; Cachorro et al., 2008; Guerrero-Rascado et al., 2008, 2009; Wagner et al., 2009; Pereira et al., 2011; Preiβler et al. (2011); Valenzuela et al., 2012a; Obregón et al., 2015). Moreover, in many studies the vertical aerosol distribution is assumed to be homogeneous in the entire atmospheric column causing erroneous estimates of the radiative effects both at the surface and at the top of the atmosphere. In fact, most of studies in the Iberian Peninsula performed the evaluation of the DD radiative effects taking into account aerosol properties integrated in the atmospheric column (Santos et al., 2008; Antón et al., 2012; Valenzuela et al., 2012b; Román et al., 2013; Obregón et al., 2015). However, the aerosol layering is a critical point in order to reliably retrieve radiative effects at the surface, top of the atmosphere and within the atmosphere. Gómez-Amo et al. (2014) used a radiative transfer model to simulate SW and LW irradiances under different vertical profiles of the aerosol absorption during a DD event over Rome, Italy on 20 June 2007. Their calculations showed that different LW/all-wave was observed in the boundary layer depending on the boundary layer aerosol absorption. Many authors have provided information about DD radiative effects in SW interval during last years (e.g., Meloni et al., 2005; Derimian et al., 2006; Tafuro et al., 2007; Bergamo et al., 2008; Saha et al., 2008; di Sarra et al., 2008; di Biagio et al., 2010; Sicard et al., 2012; Román et al., 2013; Esteve et al., 2014). However, few studies look into the LW radiative effects associated with DD intrusions over the Mediterranean basin (e.g., di Sarra et al., 2011; Perrone et al., 2012; Sicard et al., 2014; Gómez-Amo et al., 2014; Meloni et al., 2015; Romano et al., 2016). The scarcity of papers related to the DD effects on LW interval in Mediterranean regions against the numerous works about the effects in the SW spectral range is mainly due to the fact that the aerosol LW effect is often small and is within the uncertainties associated with the LW measurements and the model estimates. Most aerosol types, as anthropogenic particles (fine aerosols), have a negligible radiative effect in thermal spectral range compared with the radiative effects in solar interval (Sicard et al., 2014). However aerosols like dust may enhance the greenhouse effect by trapping the outgoing terrestrial radiation through absorption and scattering processes and lead to a positive radiative effect in the LW (Hansell et al., 2010). Some authors point out that, on the daily time scale, the LW effect may compensate for a large fraction (up to 50%) of the substantial decrease of SW irradiance recorded at the surface during DD episodes. Sicard et al. (2014) reported that the scattering process associated with DD particles may notably contribute to the LW radiative effect at surface up to 18%.

Finally, the presence of clouds can noticeably enhance the radiative impact of aerosols, especially when the aerosol layer is above the cloud layer (Podgorny and Ramanathan, 2001). This is one of the most challenging problems due to lack of continuous measurements of aerosols and clouds (IPCC 2013). In this framework, this work aims to determine the aerosol radiative forcing and heating rate profiles in the SW and LW spectral ranges, taking into account sun-photometer and lidar measurements during an extreme DD event over Évora, Portugal that are given as input to a radiative transfer model (SBDART). In addition, in our simulations we always deemed a cloud layer whose optical properties were derived from CALIPSO platform and ECMWF meteorological model. In order to validate the reflected solar radiation measured at the top of the atmosphere (TOA) from the Clouds and Earth's Radiant Energy System (CERES) (Weilicki et al., 1996) Single Satellite Footprint (SSF), vertical distributions of aerosol extinction coefficients derived from the CALIPSO lidar observations together with OPAC dataset parameters were used to constrain the dust aerosol type employed in the radiation model. The main purpose of this study is the assessment of the thermal capability to offset part of the solar radiative effect. The analyzed dust episode took place from 4 up to 7 April 2011 and it has been identified as one of the strongest DD events recorded over the Iberian Peninsula in the last years. This atypical high-aerosol load case was described in detail by Preiβler et al. (2011) using active and passive remote sensing techniques. Therefore, this paper completes the analysis about dust radiative effects, contributing to understand the influence of DD on SW and LW irradiances at the surface, within the atmosphere as well as its top.

2. Experimental site, instrumentation and measurements

2.1. Experimental site description

The instruments used in this study are installed at the Institute of Earth Sciences (ICT) in Évora (38.57°N, 7.91°W and 290 m a.s.l.). Évora, located in the Southern Portugal, is the capital of the Alentejo district, a rural region of Portugal. Although this region covers about one third of the area of Portugal it is only inhabited by less than 10% of its population. Évora is a non-industrialized city situated about 100 km from the Western coast of Portugal and the nearest urban and industrial area is that of Lisbon. The main aerosol sources are traffic and, during the winter season, domestic fuel burning injecting anthropogenic aerosols into the atmosphere. Due to its proximity to the African continent, our study area is often affected by DD intrusions (e.g Elias et al., 2006; Pereira et al., 2008; Wagner et al., 2009; Preißler et al., 2011).

2.2. AERONET data

The aerosol optical depth (AOD (λ)), angstrom exponent (α), single scattering albedo (ω(λ)) and asymmetry parameter (g(λ)) were taken from the sun photometer inversion products. Measurements of total columnar aerosol properties were obtained