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Short communication

Sensitivity of the atmospheric temperature profile to the aerosol absorption in the presence of dust

J.L. Gómez-Amo [a, b, *], A. di Sarra [a], D. Meloni [a]

[a] Laboratory for Earth Observations and Analyses, ENEA, S. Maria di Galeria, Rome, Italy
[b] Departament de Física de la Terra y Termodinàmica, Universitat de València, Spain

HIGHLIGHTS

- We use radiative transfer simulations in the shortwave and longwave spectral regions.
- We investigate the role of changing vertically the aerosol absorption on atmospheric heating rates.
- We estimate its effect on time evolution on the temperature profile.
- The temperature variation within the boundary layer depends strongly on the aerosol type.

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ABSTRACT

Radiative transfer simulations in the shortwave (SW) and longwave (LW) spectral regions have been carried out to investigate the time evolution of the atmospheric heating/cooling rates and their influence on the temperature profiles under different vertical distributions of the aerosol absorption. The case study is based on measurements made at Rome, Italy, on 20 June 2007, when a dust layer was present above the urban boundary layer (BL) and the column aerosol optical depth at 550 nm was about 0.37. Column-integrated aerosol optical depth and single scattering albedo, as well as vertical profiles of aerosol extinction and meteorological variables have been derived from observations and used in the simulations. Different profiles of the aerosol absorption are considered by varying the absorption of the BL aerosols and of the desert dust, without changing the overall columnar properties. Three scenarios have been considered, with absorbing (ABL) or scattering (SBL) particles in the BL, and with a vertically homogeneous case (HL), which is taken as the reference.

Calculations show that, for the selected case, about 25% of the SW heating is offset by the LW cooling within the dust layer. Different longwave/all-wave contributions are observed in the BL, depending on the BL aerosol absorption. Changes of atmospheric temperature induced by aerosol-radiation interactions only, have been investigated, while interactions with the surface through changes of the latent and sensible heat flux have been neglected. The evolution of temperature is similar for the three scenarios within the dust layer, with a daytime increase and a smaller nighttime decrease. After 24 h, the increase of the atmospheric temperature due to the aerosol radiative processes is about 1 K. In the BL, the increase of temperature is strongly dependent on the aerosol absorption capability. The oscillatory behaviour of the temperature with time in the dust layer, and the different evolution in the BL are expected to affect the temperature vertical gradient and may influence related processes.

1. Introduction

Aerosols play a significant role in many atmospheric processes. They produce a direct effect on the atmospheric radiative budget by absorbing and scattering shortwave (SW) radiation, and may also have a significant impact in the longwave (LW) range, especially when large particles are involved (e.g. Naeger et al., 2013) or when

* Corresponding author. Laboratory for Earth Observations and Analyses, ENEA, S. Maria di Galeria, Rome, Italy.
E-mail addresses: joseluis.gomezamo@enea.it, jlgomeza@uv.es (J.L. Gómez-Amo).

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extreme aerosol events with high loading occur (e.g. Stone et al., 2011; di Sarra et al., 2011).

The aerosol effect on the radiative budget is usually quantified by the aerosol radiative forcing (ARF), which is defined as the difference in the net irradiance between aerosol-laden and aerosol-free atmospheres. The total ARF is the sum of the SW and LW effects. Largest uncertainties in the determination of the SW aerosol effects are associated with uncertainties in the aerosol absorption (McComiskey et al., 2008) and the aerosol vertical profile (Zarzycki and Bond, 2010). In addition, the lack of direct observations of the LW aerosol effect contributes to the overall ARF uncertainties (Bharmal et al., 2009). The aerosol absorption plays a key role in determining the interaction with the SW and LW radiation, and the effects on atmospheric temperature. A complex aerosol stratification composed by layers with different absorption properties may affect locally the thermal profile of the atmosphere, indirectly influencing the vertical stability, dynamics, boundary layer (BL) structure, and cloud formation (Ackerman, 1977; Ackerman et al., 2000; Feingold et al., 2005; Barbaro et al., 2013).

Errors in atmospheric temperature model predictions have been related to the occurrence of absorbing aerosols (Alpert et al., 1998; Carmona et al., 2008). Therefore, the inclusion of an accurate characterization of the aerosol vertical distribution in the meteorological models may help improving the capability of representing feedback mechanisms that may enhance or limit the response of the atmospheric temperature to such forcing (Alpert et al., 2000; Pérez et al., 2006).

The role of the vertical distribution of the aerosol absorption in the SW range has been studied using modelling and observations (Guan et al., 2010; Gómez-Amo et al., 2010, 2011). As shown by Gómez-Amo et al. (2010), changes in the vertical distribution of the aerosol absorption may largely influence the SW instantaneous ARF, by up to 15% at the surface, and up to 63% at TOA.

This work is aimed at determining the sensitivity of the heating rate profiles to the vertical variation of the aerosol absorption. The sensitivity is investigated by means of radiative transfer model simulations initialized with observed data. The observations are relative to a case with presence of dust particles above the planetary BL. This type of atmospheric vertical structure is quite common over the Mediterranean and in Southern Europe, where dust very often travels above the marine or urban BL, particularly in spring and summer (Di Iorio et al., 2009; Ciardini et al., 2012; Israelevich et al., 2012; Marconi et al., 2014). A combination of column-integrated (aerosol optical depth, AOD, and single scattering albedo, SSA), and vertically resolved measurements of aerosol extinction and meteorological parameters, with prescribed aerosol models are used to describe the aerosol properties in the radiative transfer model. The methodology used in this study is similar to that used by Gómez-Amo et al. (2010, 2011) to derive the SW radiative perturbation produced by aerosols of different absorption capabilities. However in this case, both SW and LW effects are taken into account. Based on radiative transfer calculations of the heating rates, and assuming that only the aerosol radiative effect leads to changes in the atmospheric temperature, the temporal evolution of the temperature profiles is also discussed.

The description of the case study, the measurements and the used methodology are given in Section 2. The results are presented in Section 3.

2. Case study: observations and modelling

The case study is based on the atmospheric conditions observed at Rome (41.9°N, 12.5°E) on 20 June 2007. Details on the instrumental setup, calibration and data retrieval are given by Ciardini et al. (2012). The AOD is derived from the Multifilter Rotating Shadowband Radiometer (MFRSR) measurements at 415, 500, 615, 671, and 863 nm. The aerosol Ångström exponent (AE) is calculated from the AODs at 415 and 863 nm. The AOD at 550 nm is 0.37, and AE is 0.30 at noon (solar zenith angle, SZA, of 20°) suggesting that dust is the dominant aerosol type in the entire atmospheric column (Ciardini et al., 2012). The SSA is estimated following the methodology proposed by Meloni et al. (2006) at SZA = 60°. The obtained values at 415 and 863 nm are 0.76 and 0.92, respectively (Table 1). The pressure, temperature and humidity profiles at 12 UT are obtained from the closest radiosonde station (41.6°N, 12.4°E).

The aerosol extinction profile at 532 nm, determined by lidar measurements, presents two well defined aerosol layers separated by a relative minimum around 1 km altitude (Fig. 1 of Gómez-Amo et al., 2010). This minimum is identified as the top of the planetary BL, separating the lowest atmospheric aerosol layer from the dust, which is found between 1 and 4 km altitude. The average extinction coefficient is about 0.15 km^{-1} between 1 and 3 km, and decreases to zero at 4 km. The average aerosol extinction coefficient is 0.1 km^{-1} in the BL. The AOD of the BL and of the dust layer at 532 nm are obtained by vertically integrating the extinction profile.

The MODerate spectral resolution atmospheric TRANsmission (MODTRAN) version 4.2 model (Berk et al., 1998) has been used for the radiative transfer simulations. The discrete ordinate algorithm with 16 streams and the k-correlated method were used to solve the radiative transfer equation in the SW (0.3–3 μm) and LW (4–100 μm) spectral ranges, respectively. The model vertical resolution is 125 m in the troposphere. Model inputs derived from observations are: vertical profiles of the meteorological variables (temperature, pressure, and relative humidity) and of the aerosol extinction; spectral aerosol extinction (derived from the MFRSR and extended to the 0.3–1 μm spectral range with the Ångström relationship). The other aerosol properties, such as the asymmetry parameter, absorption coefficients, and their spectral dependency, and extinction spectral behaviour above 1 μm are derived from aerosol models as discussed below. Two aerosol layers (from the surface to 1 km and between 1 and 4 km) with different absorption coefficients are defined in the model, while the extinction coefficients and the asymmetry parameter (g) are kept the same for both layers. The spectral extinction coefficients are derived from the mineral dust aerosol type by the Optical Properties of Aerosols and Clouds (OPAC) database (Hess et al., 1998) for wavelengths longer than 1 μm. The asymmetry parameter from the mineral dust aerosol type by OPAC is also used in the entire spectral range, 0.3–100 μm. The spectral absorption coefficients for the BL aerosol are assigned using different aerosol types (urban, clean marine, or desert dust) by OPAC. The absorption of the dust layer is determined using closure relations (Eq. (2) in Gómez-Amo et al., 2010) from 0.3 to 1 μm, with the aim of maintaining the overall columnar properties. The absorption coefficients from OPAC for the assigned aerosol type are used for longer wavelengths. The values of AOD and g are kept fixed in the different simulations, as well as their spectral dependency. The OPAC dust model used in all cases is that

Table 1
Aerosol optical properties at specific wavelengths for the three scenarios: HL (homogeneous layer), ABL (urban aerosols in the boundary layer), and SBL (clean marine aerosols in the boundary layer).

λ(μm)	Column			Boundary layer			Dust layer		
	HL			AOD	ABL	SBL	AOD	ABL	SBL
	AOD	SSA	g		SSA	SSA		SSA	SSA
0.415	0.408	0.76	0.76	0.150	0.68	0.99	0.258	0.81	0.62
0.550	0.375	0.81	0.73	0.138	0.75	0.99	0.237	0.84	0.70
0.863	0.328	0.92	0.70	0.121	0.83	0.99	0.207	0.97	0.88