# The Effects of Naturally Produced Dust Particles on Radiative Transfer

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**Abstract** Mineral dust has a profound effect on the radiative budget and energy distribution of the atmosphere. By absorbing and scattering the solar radiation aerosols reduce the amount of energy reaching the surface. In addition aerosols enhance the greenhouse effect by absorbing and emitting longwave radiation. Desert dust forcing exhibits large regional and temporal variability due to its short lifetime and diverse optical properties further complicate the quantification of the Direct Radiative Effect (DRE). The complexity of the above processes, indicate the need of an integrated approach in order to examine these impacts. To this end the radiative transfer module RRTMG has been incorporated into the framework of the SKIRON model. The updated system was used to perform a 6-year long simulation over the Mediterranean region. As it was found, the most profound effect dust clouds have in areas away from the sources is the surface cooling through the “shading” effect. The long wave radiation forcing below and above the dust cloud is considerable and drives changes in the tropospheric temperature. In general dust particles cause warming near the ground and at mid-tropospheric layers and at the same time cooling of the lower troposphere.

## 1 Introduction

Large amounts of mineral dust are produced from arid and semi-arid areas under favorable conditions. Aerosols interact strongly with solar and terrestrial radiation in several ways (Tegen et al. 1996; Haywood et al. 2003; Yoshioka et al. 2005; IPCC 2007; Kallos et al. 2009), also known as “Direct Aerosol Effect – DRE” (IPCC 2007). By absorbing and scattering the solar radiation, aerosols reduce

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the amount of energy reaching the surface (Kaufman et al. 2005; Tegen 2003; Spyrou et al. 2010). Moreover, aerosols enhance the greenhouse effect by absorbing and emitting outgoing longwave radiation (Dufrense et al. 2001; Tegen 2003).

Aerosols act as a cloud condensation nuclei or ice nuclei, thus modifying the microphysical, microchemical, and, hence, optical properties of clouds (Levin et al. 2005; Solomos et al. 2011). Collectively changes in cloud processes due to aerosols are referred to as aerosol indirect effects. Finally, absorption of solar radiation by particles contributes to the reduction in cloudiness, a phenomenon referred to as the semi-direct effect. This occurs because absorbing aerosol warms the atmosphere, which changes the atmospheric stability, and reduces surface flux (IPCC 2007).

The magnitude of the feedback on the radiative transfer depends strongly on the optical properties of particles (single scattering albedo, asymmetry parameter, extinction efficiency), which in turn depend on the size, shape and refractive indexes of dust particles (Tegen 2003; Helmert et al. 2007). The mineral composition of the dust source areas (Tegen 2003), as well as the chemical composition and transformation of aerosols during their transportation (Astitha et al. 2010) are all factors on the optical intensity of dust. Furthermore the vertical distribution of dust, the presence of clouds and the albedo of the surface all contribute to the DRE (Sokolik and Toon 1996; Tegen and Lacis 1996; Liao and Seinfeld 1998; Helmert et al. 2007).

In the present study, the main objective is to quantify the contribution of dust particles on the DRE. To this end, the radiative transfer module – RRTMG (Mlawer et al. 1997; Oreopoulos and Barker 1999; Iacono et al. 2003; Pincus et al. 2003; Barker et al. 2003; Clough et al. 2005; Morcrette et al. 2008; Iacono et al. 2008) has been incorporated into the framework of the SKIRON/DUST model. The SKIRON/Dust system has already the capability to adequately simulate the desert dust cycle using state of the art parameterizations for the uplift, transportation and deposition of aerosols (Spyrou et al. 2010). The addition of the RRTMG radiative scheme has made it possible to model and study the effects of desert dust particles to the radiation balance of the atmosphere.

## 2 Experimental Design

In order to study the effects of desert dust particles to the radiation balance of the atmosphere, simulations for a 6-year period (2002–2007) were carried out with the implementation of the improved SKIRON/Dust modeling system.

The model was integrated over an extended area that covers the European continent, the Mediterranean Sea and northern Africa, as well as a major part of Middle East and Turkey. The horizontal grid increment was 0.24° and in the vertical direction 38 levels were used stretching from the ground surface up to 20 km. A high resolution reanalysis dataset (horizontal resolution of 0.15°) that has been developed in the framework of CIRCE project (Climate Change and Impact

Research: the Mediterranean Environment), was used for the initial and lateral boundary conditions for the meteorological parameters.

The model runs were carried out using two different setups: (a) by neglecting the effects of dust particles on the radiative parameters (NDE) and (b) by including the dust-radiation interaction mechanisms (WDE).

In order to evaluate the SKIRON/Dust model calculations related to air temperature for the 6-year period comparisons are realized between model results and actual data. The observations for the comparisons were retrieved from ~600 monitoring stations of ECMWF.

## 3 Results

Using model outputs from the two different simulations and temperature data from the ECMWF stations a number of statistical scores (Wilks 1995) were calculated for each season (Fig. 1). By including the DRE processes the SKIRON/Dust model manages to reproduce the surface temperature in greater detail, thus improving the model performance.

In order to quantify the energy redistribution in the atmosphere the average vertical temperature difference (WDE-NDE) was calculated. The vertical cross-sections of daily average dust concentration and temperature along the pathline at 18°E are illustrated in Fig. 2 upper right, lower respectively. The section was created to include source areas that are particularly active during March to May, specifically Lake Chad. This way we are able to examine the dust feedback in greater detail.

The presence of dust particles in the atmosphere drives changes in the tropospheric temperature as seen in the vertical cross-section of temperature difference between the two model setups (WDE-NDE) for the transient months of the 6-year studied period (Fig. 2 lower). The feedbacks are more profound near source areas, but are present in mid-latitude areas as well.

More specifically a temperature decrease in the upper-troposphere near the top of the dust layer is observed due to reflection. The dust particles reflect the incoming solar radiation back towards the top of the atmosphere (Fig. 2 lower). On the contrary, in the mid-troposphere there is an increase in temperature due to solar radiation absorption from the dust layer. During the day the energy absorbed by the dust layer raises its temperature while at night long-wave radiation is emitted toward the ground surface. The combined effect of these processes is the reduction in the air temperature near ground over dust source areas.

Furthermore, over dust affected African areas the long-wave radiation emitted by the dust layer toward the ground superimposed with the long-wave radiation emitted from the ground surface increases the temperature near to the surface (Fig. 2 lower).

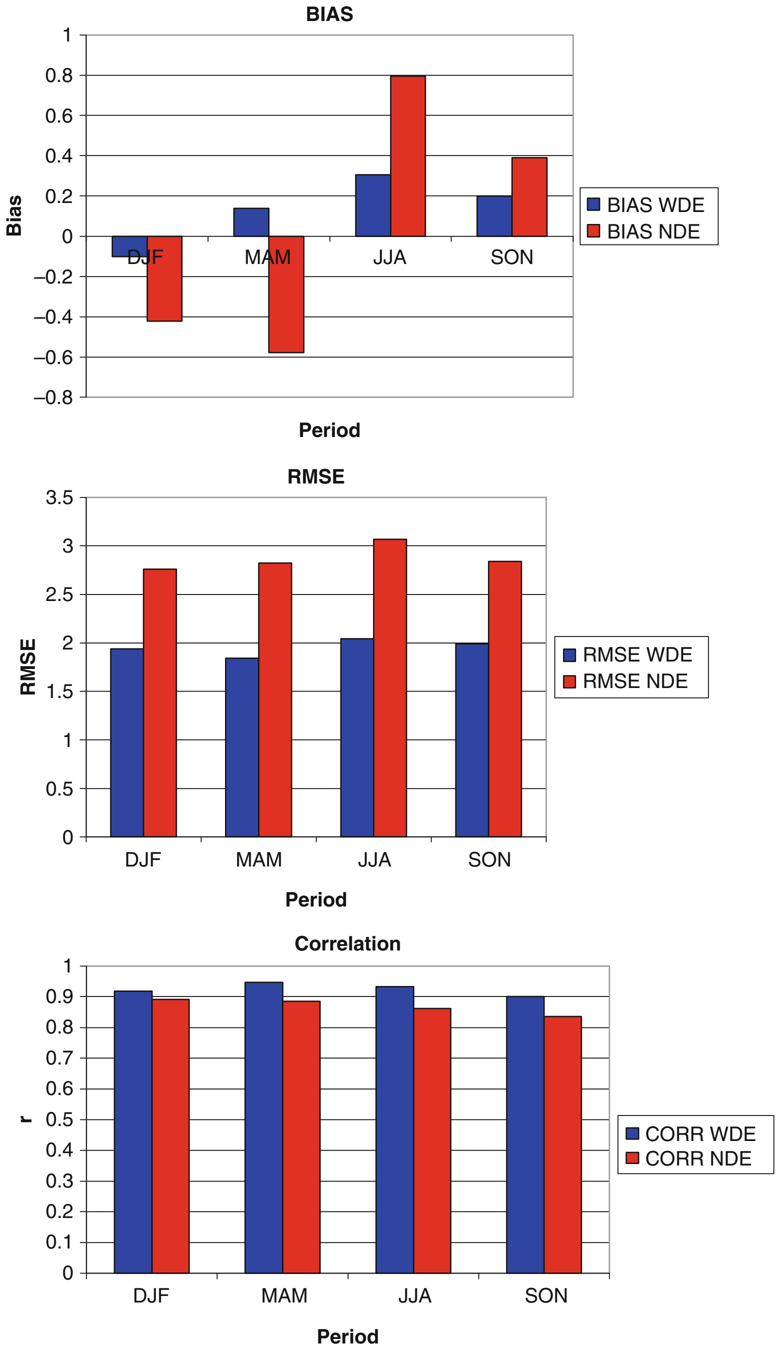


**Fig. 1** Statistical parameters: Bias (*upper*), RMSE (*middle*), correlation coefficient (*lower*) for the 6-year period of simulations (2002–2007) with dust effects (WDE) and without dust effects (NDE)

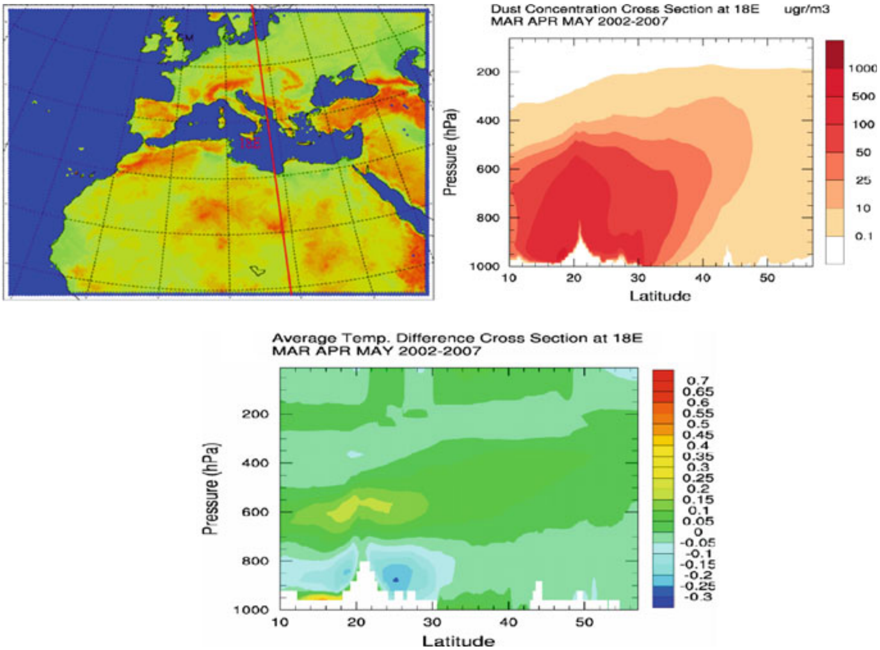


**Fig. 2** Daily average dust concentration (*upper right*) and temperature differences (*lower*) cross section at 18°E (*upper left*) for the months March–April–May during the 6-year period (2002–2007)

## 4 Conclusions

In the present study, the effects of desert dust particles to the radiation balance of the atmosphere across the Greater Mediterranean Region were investigated with the implementation of SKIRON/Dust modelling system. The extensive analysis of the 6-year model runs covering the period 2002–2007 revealed important findings, as summarized below:

1. The suspension of desert dust particles decreases the calculated energy amounts reaching the ground.
2. The air temperature is decreased above the dust layer due to reflection.
3. On the contrary heating rates inside the dust plume are increases due to radiation absorption.
4. The extinction of incoming solar radiation causes lower tropospheric cooling.
5. The absorbed energy is emitted towards the ground increasing the temperature of surface layers with high dust concentration.
6. By including the dust feedbacks in the radiative calculations the model performance is improved.

In general desert dust is a significant climate factor. The direct feedback of natural aerosols on radiative transfer changes the energy distribution in the atmosphere and cannot be neglected in weather and climate studies.

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