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Modeling Saharan desert dust radiative effects on clouds

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ABSTRACT

This work aims at studying the Saharan desert dust storm effects on clouds. This is done through the investigation of the possible modifications that mineral desert dust aerosols may exert on clouds, modifying their properties and also through the estimation of the cloud radiative forcing in the presence of this type of aerosols, during strong desert dust events that occurred in the end of May 2006 and in the beginning of September 2007. The assessment of the cloud radiative forcing is made at a regional scale both at the top of the atmosphere (TOA) and at the surface levels. The results are obtained from numerical simulations with a mesoscale atmospheric model (MesoNH) over Portugal area and nearby Atlantic Ocean.
From the results obtained it is possible to observe that, for all days under study, a cooling effect is always found both at the TOA and surface levels. Also, for these two levels and for clouds developing in a dusty atmosphere, a more pronounced cooling effect (more negative cloud radiative forcing values) is found compared with the corresponding cloud radiative forcing values for clouds developing in a dust free atmosphere.

1. Introduction

Saharan desert is considered the most important dust source in the world, being responsible for up to half of the global dust emissions. Desert dust (DD) particles, present in the atmosphere, interact with solar and terrestrial radiation, modulating the Earth's radiation balance, being responsible for large uncertainties when assessing climate forcing by atmospheric aerosols (Forster et al., 2007; Santos et al., 2008; Haywood et al., 2011a,b). The magnitude and even the sign of DD radiative forcing (both direct and semi-direct or indirect through the effects on cloud formation and precipitation processes) are still difficult to evaluate (Hansen et al., 1997; Haywood and Boucher, 2000; Rosenfeld et al., 2001; Lohmann and Feichter, 2005).

Clouds themselves are among the most important regulators of the Earth's radiation budget, playing therefore an essential role in the scenarios behind climate change projections. However, the awareness of the cloud contribution to radiative forcing is still limited (Forster et al., 2007). Clouds may warm or cool the atmosphere depending on their microphysical properties and heights; and these properties are subject to changes due to cloud–aerosol interactions.

Portugal represents an interesting location in Europe for the study of desert dust–cloud interactions, since this country is frequently on the pathway of the desert dust plumes advected from North Africa, particularly in spring and summer seasons (Elias et al., 2006) and on the pathway of cloud systems coming from the Atlantic Ocean and transported by the westerly and southwesterly winds.

In meteorological studies, clouds and aerosols, and their interactions, must be realistically considered. Regional atmospheric models are of significant use, simulating several mesoscale circulations and aerosol–cloud interactions (Costa et al., 2009). Currently, mesoscale models have associated schemes

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of transport and diffusion of aerosols (Grini et al., 2006; Tulet et al., 2006, 2008; Todd et al., 2008; Mallet et al., 2009; Tulet et al., 2010; Bou Karam et al., 2010; Chaboureau et al., 2011; Kocha et al., 2012).

The aim of this work is the study of the Saharan desert dust storm effects on clouds and on the modification of their optical properties. This is done, on one hand, through the investigation of the relationship between mineral desert dust aerosols and cloud properties and, on the other hand, through the assessment of the cloud radiative forcing in the presence of DD aerosols, for two case studies in two different years, 2006 and 2007. The results are obtained from numerical simulations with a mesoscale atmospheric model over Portugal area and nearby Atlantic Ocean. The selected periods correspond to strong Saharan desert dust storms which having left the African continent, travel over the Atlantic Ocean and penetrate over the Southwestern part of the Iberian Peninsula.

The first event selected for the study occurred on 27, 28 and 29 May 2006 and the second one was on 06, 07 and 08 September 2007.

The next section briefly describes the method followed to estimate the cloud radiative forcing at the top of the atmosphere (TOA) and at the surface levels. Section 3 presents the results obtained and conclusions are given in Section 4.

2. Material and methods

The MesoNH model (Lafore et al., 1998) is the atmospheric model used in this work. This mesoscale, nonhydrostatic model has been jointly developed by the Centre National de la Recherche Meteorologique (CNRM, Meteo France) and the Laboratoire d'Aeérologie (LA, CNRS). A full description of MesoNH model may be found at http://mesonh.aero.obs-mip.fr/. MesoNH is able to simulate atmospheric circulations from small to synoptic scales (horizontal resolution ranging from a few meters to several tens of kilometers) and it can run in a two way nested mode concerning up to 8 nesting stages.

Parameterizations are included for turbulence (Bougeault and Lacarrére, 1989), shallow and deep convection (Bechtold et al., 2001) and cloud microphysics (Cohard and Pinty, 2000). MesoNH is also coupled to an externalized surface model (SURFEX) which computes the fluxes between the atmosphere and the surface (e.g. Salgado and Le Moigne, 2010), taking into account the soil–vegetation–atmosphere exchanges (Noilhan and Mahfouf, 1996).

A dust module is considered in the MesoNH model. Mineral desert dust is parameterized by Grini et al. (2006) where the three log-normal modes are generated and transported by the ORILAM log-normal aerosol scheme (Tulet et al., 2006). The ORILAM model integrates emission, sedimentation, dry and wet deposition (Tulet et al., 2010) and size distribution of aerosols (Crumeyrolle et al., 2011). The dust emission processes are represented by the Dust Entrainment And Deposition model (DEAD: Zender et al., 2003), which is able to calculate dust fluxes from wind friction speeds. These dust fluxes are calculated as a function of saltation and sandblasting processes (Marticorena and Bergametti, 1995). The DEAD model is introduced on-line in the SURFEX surface scheme, mentioned before, where dust mass fluxes are sent to the atmosphere consistently with the fluxes of momentum, energy and humidity.

The model uses the Morcrette and Fouquart (Morcrette and Fouquart, 1986; Morcrette et al., 1986) ECMWF (European Centre for Medium-Range Weather Forecasts) radiative transfer model to compute both the short-wave and long-wave radiative fluxes. The Delta Eddington approximation (Joseph et al., 1976) is used to compute the radiative fluxes emerging from cloud and aerosol layers in the short-wave spectral region. The standard formulation of absorptivity/emissivity of longwave radiation for aerosols is used in the ECMWF model. For shortwave effects the dust refractive index values used are the ones followed by Tulet et al. (2008).

In the simulations performed, the MesoNH was initiated and forced by six-hourly ECMWF analyses. A time period of about a week in May 2006 was considered for the study of the first event, with the simulations starting at 00:00 UTC on 26 May and ending at 00:00 UTC on 30 May. For the September 2007 DD episode a time period of about 5 days was considered, starting at 00:00 UTC on 05 September and ending at 00:00 UTC on 09 September. The first day of both simulation periods considered has been used as a model spin-up period.

For this work, MesoNH model run in a two way nested mode on two grids. For the May 2006 episode and in the horizontal plane, the coarser domain had 60×90 grid points, with 50 km grid spacing (Fig. 1a), and the finer domain had 150×225 points and a space resolution of 10 km, as shown in Fig. 1b. The largest domain is defined between 5°S and 50°N latitude and 25°W and 15°E longitude (which contains the potential dust source) and the smallest domain defined between 28°S and 47°N latitude and 20°W and 4°W longitude (which contains the study area).

Concerning the September 2007 episode, the coarser domain had 80×100 grid points, with 50 km grid spacing in the horizontal plane, as shown in Fig. 1c, and the finer domain had 180×180 points and a space resolution of 10 km (Fig. 1d). The largest domain is defined between 8°S and 55°N latitude and 28°W and 16°E longitude (dust source region) and the smallest domain defined between 33°S and 49°N latitude and 20°W and 0°E longitude (study area).

The vertical stretched grid used in this work, consists of 49 layers from the surface up to 24 km altitude, distributed mostly in the lower troposphere (20 layers in the first 2 km altitude). The first layer is situated approximately 10 m above the surface, and the first grid length is about 20 m. A constant stretching (in %) factor is imposed in altitude, up to a constant grid length of 2 km near the top.

The selected days are chosen taking into account the visual inspection of MODIS RGB images (http://modis-atmos.gsfc.nasa.gov/IMAGES/) confirming that desert dust episodes are occurring in those days.

In order to determine the origin of the air masses arriving to the regions of study, the 72-hour air mass backward trajectories, ending over selected regions of the area of study, are calculated at several altitude levels, using HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model available from the U.S. National Oceanic and Atmospheric Administration (NOAA) (Draxler and Hess, 1998). The air mass backward trajectories are calculated for a site within the region considered in the MesoNH simulations and considering the minimum time lag between the backward trajectories hour and the hour of the simulated results.