MODELED SAHARAN DESERT DUST RADIATIVE EFFECTS OVER THE IBERIAN PENINSULA AND ATLANTIC OCEAN

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Introduction

Since atmospheric aerosols may provoke important modifications in the Earth radiation budget, these particles play a major role in the global climate system. The aerosol effects are usually classified as: direct, connected to the scattering and absorption of radiation; semi-direct connected with absorbing aerosols that may be responsible for cloud evaporation; and indirect, due to the influence of aerosols on cloud microphysical properties and lifetime.

The difference in net radiative flux at a specific level in the atmosphere, with and without aerosols, defines the so-called aerosol radiative forcing. Precise estimation of its magnitude gives crucial contributions for the assessment of the Earth's radiation budget. However, the magnitude of aerosol radiative forcing and its contribution to global warming is still subject to considerable uncertainty (IPCC, 2007). Aerosols can have either positive or negative contributions to atmospheric radiative forcing, depending on their properties (Liao and Seinfeld, 1998; Kaufman et al., 2002, Santos et al. 2008).

A significant part of the global production of tropospheric aerosols is originated in the deserts.

Within Europe, the Iberian Peninsula (in southwestern Europe) is an exceptional location for desert dust aerosol studies because it is regularly affected by the long-range transport of desert dust plumes originated from Africa (Wagner et al. 2008).

The aim of this work is the analysis of the direct effect of Saharan desert dust storms, through the assessment of the desert dust aerosol radiative forcing at a regional scale, using atmospheric modeling.

Method

The MesoNH model (Lafore et al., 1998) is the nonhydrostatic regional model adopted for this work. This mesoscale model has been developed by the Centre National de la Recherche Meteorologique (CNRM, Meteo France) in cooperation with the Laboratoire d'Aérologie (LA, CNRS). A complete 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 be run in a two way nested mode concerning up to 8 nesting stages.

In the model, the dust emission processes are represented by the DEAD (Dust Entrainment and Deposition) model. DEAD model compute dust fluxes taking into account the surface layer friction velocity, the soil wetness and the percentage of clay and sand in the soil. Dust advection and diffusion are quantified by the MesoNH transport processes. The presence of dust aerosols are taken into account in the radiation and in the cloud microphysical schemes used in the model.

In the simulations performed, the MesoNH is initiated and forced by ECMWF analyses.

In this work, two periods, corresponding to strong desert dust storms, were studied. In 2006, the simulations started on 26 May at 0000 UTC and ended on 30 May at 0000 UTC and, in 2007, the simulations started on 04 September at 0000 UTC and ended on 09 September at 0000 UTC. The first day of each simulation has been used as model spin-up periods.

For this work, MesoNH runs with a two way grid-nesting configuration at 50 km resolution for the larger domain and 10 km resolution for the small one. The larger domain covers a 4000 km x 5000 km area, which includes the dust aerosols source region. The inner domain covers a 1500 x 1800 km area, centered over the Portuguese West coast.

The vertical grid, used in this work, extends from the surface up to 24km altitude, and uses 49 layers in a terrain-following coordinate system.

The instantaneous direct shortwave (SW) dust aerosol radiative forcing (SWF), expressed in units of energy per unit time and area, is defined as:

$$SWF = F_{AER}^{net} - F_{CLEAN}^{net} \qquad (1)$$

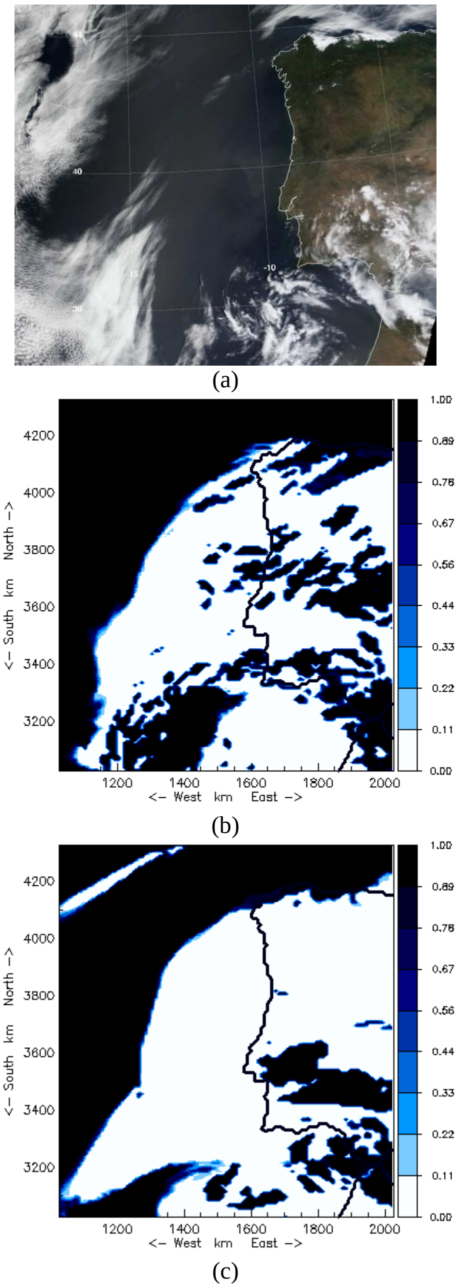
F_{AER}^{net} corresponds to the net shortwave irradiance that suffered an external perturbation due to aerosols and F_{CLEAN}^{net} corresponds to the net shortwave irradiance, at the same level, that did not suffer the perturbation.

For this work, the net shortwave irradiance F^{net}_{CLEAN} is obtained in the dust free simulation and F^{net}_{AER} is obtained in the simulation where desert dust scheme is activated.

Results and Discussion

The modeled results presented are related to the smallest embedded domain (10km resolution).

The MODIS RGB images for 27 May 2006 and 07 September 2007 are shown in Figs. 1a and 2a.



(a)

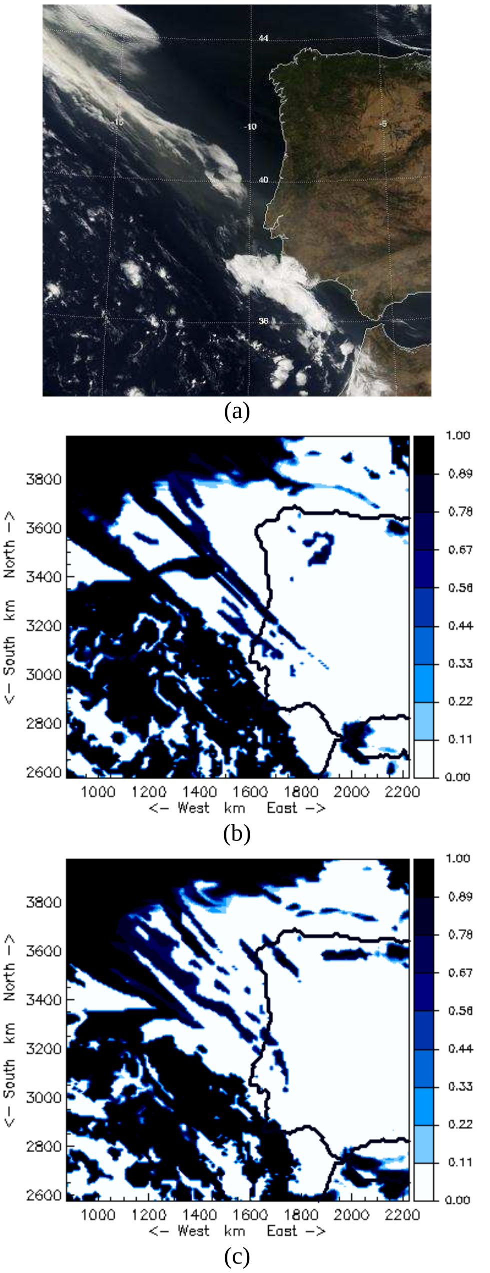
(b)

(c)

Fig. 1.- MODIS RGB image (a) and corresponding simulated total cloud fraction in the presence of desert dust aerosols (b) and in their absence (c), for 27 May 2006 (1200UTC).

Figs. 1b and 2b present the modeled cloud fraction in the presence of desert dust aerosols (dust scheme switched on) and the modeled cloud fraction when desert dust is not considered (dust scheme switched off) is presented in Figs. 1c and 2c, for 27 of May 2006 and 07 September 2007, respectively.

From Figs 1b, 1c, 2b and 2c it can be observed that, when the desert dust scheme is taken into account in MesoNH calculations, the total cloud fraction, for both days, is higher than the total cloud fraction in the absence of desert dust aerosols.



(a)

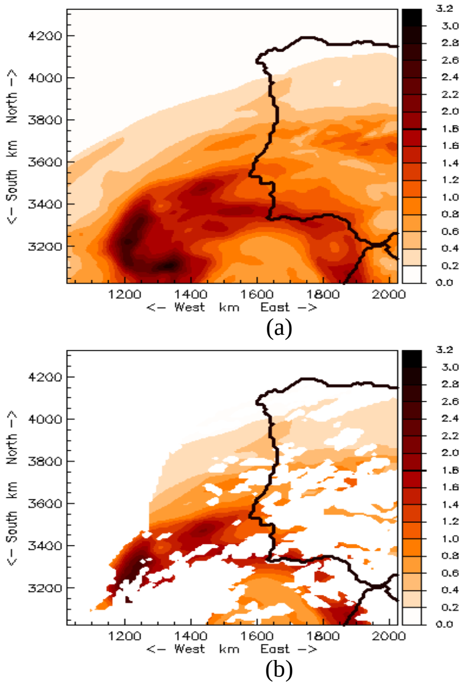
(b)

(c)

Fig. 2.- Same as Fig. 3 for 07 September 2007.

The total cloud fraction simulated pattern seems to be in agreement with the actual situation also for the other days considered in this study though, all the simulated results obtained seem to overestimate the cloud fraction as seen by the satellite (Figs.1a and 2a), particularly when desert dust aerosols are considered in the simulations.

The simulated aerosol optical depth (AOD) in the dust simulation, at 1200 UTC, for 27, 28 and 29 May 2006 and for 06, 07 and 08 September 2007 are presented in Figs. 3a, 4a, 5a, 6a, 7a and 8a, respectively.

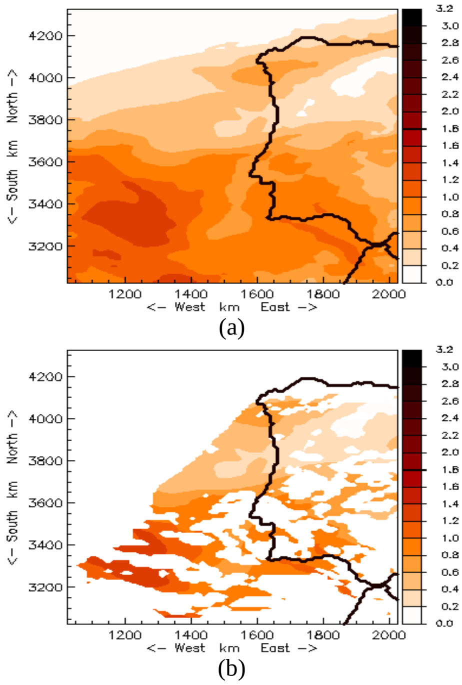


(a)

(b)

Fig. 3.- Simulated aerosol optical depth (AOD) for all sky conditions (a) and considering only the clear sky areas (b) for 27 of May 2006 (1200 UTC).

From Figs. 3a, 4a and 5a, regarding the May 2006 desert dust (DD) episode, it is possible to observe that the modeled dust plume, has its source in the North of Africa, travels through the South of Continental Portugal and Atlantic Ocean, dispersing all over the center of Continental Portugal and towards Madeira Island. From Figs. 6a, 7a and 8a, for the September 2007 desert dust (DD) episode, the dust plume makes a way into the south of the Iberian Peninsula, travels through the Portuguese country, and continues to the Atlantic Ocean in the NE region of Portugal.



(a)

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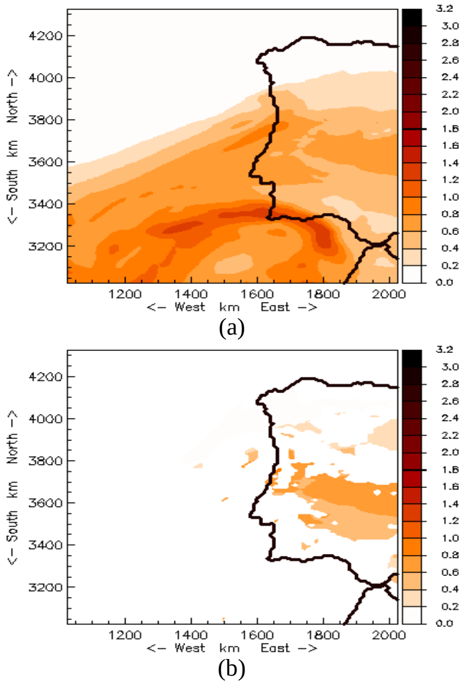
Fig. 4.- Same as Fig. 3 for 28 May 2006.



(a)

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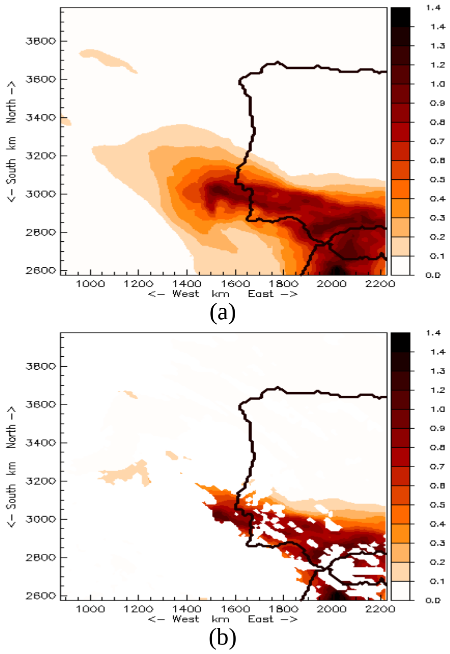
Fig. 5.- Same as Fig. 3 for 29 May 2006.

Since the main objective of this work is to estimate the direct radiative forcing due to desert dust aerosols, the cloudy regions are not considered and the assessment of desert dust radiative forcing is therefore only made for clear sky conditions (Figs. 3b, 4b, 5b, 6b, 7b and 8b).

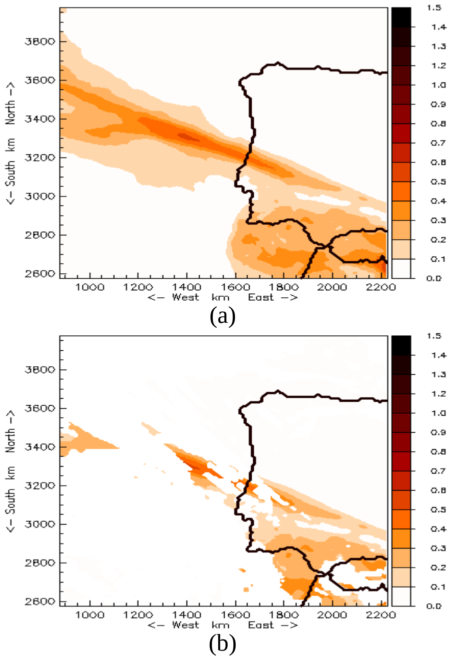


(a)

(b)

Fig. 6.- Same as Fig. 3 for 06 September 2007.

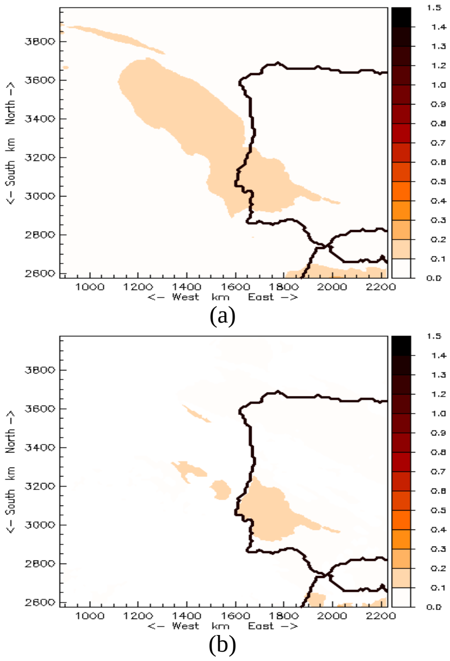
Comparing the MODIS RGB image from Fig 2a with Fig. 7a, it can be observed that the desert dust plume patterns are very well represented by the model since a good agreement is found between the actual situation and the simulated AOD.



(a)

(b)

Fig. 7.- Same as Fig. 3 for 07 September 2007.



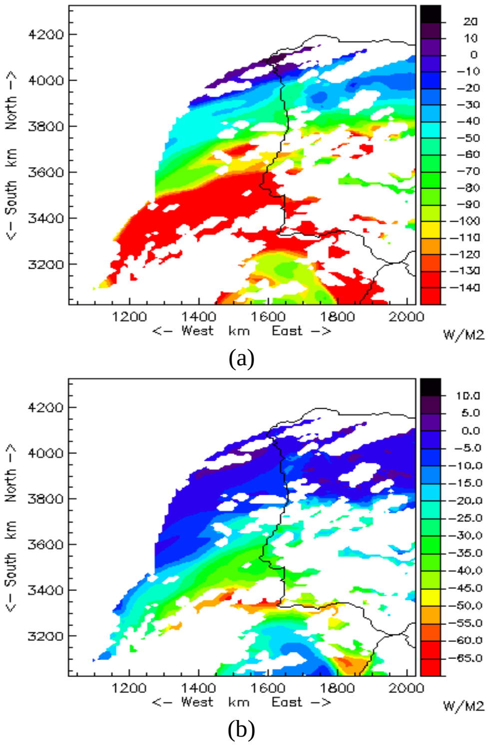
(a)

(b)

Fig. 8.- Same as Fig. 3 for 08 September 2007.

In order to investigate the effect of Saharan desert dust storms, an assessment of the desert dust aerosol direct radiative forcing [Eq. (1)] is made.

Figs 9, 10, 11, 12 and 13 show the SW radiative forcing (SWF), at the TOA and at the surface levels, obtained for the days considered in this study.



(a)

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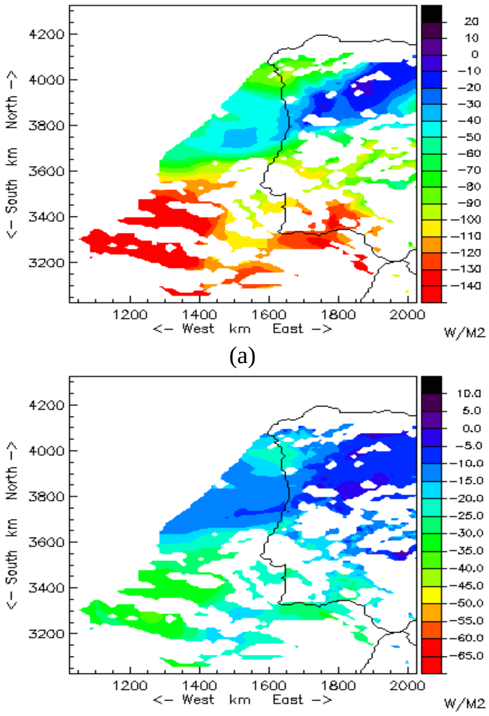
Fig. 9.- Surface (a) and Top of the atmosphere (b) aerosol SW radiative forcing for 27 May 2006 (1200UTC).



(a)

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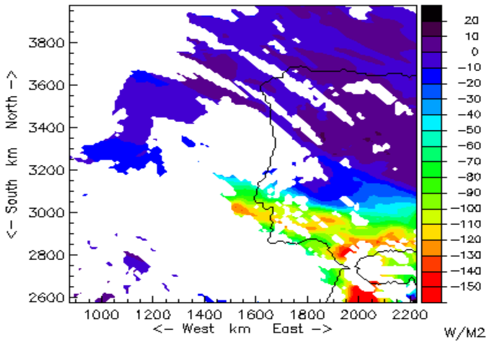
Fig. 10.- Same as Fig. 9 for 28 May 2006 (1200UTC).

Considering the SWF, at the TOA (TOASWF) and at the surface (SurfSWF) levels, for all the days in the study (Figs. 9, 10, 11, 12 and 13), over the Iberian Peninsula and nearby Atlantic Ocean regions, it is possible to observe that the presence of desert dust aerosols in the atmosphere provokes, in the majority of the cases, a cooling effect both at the TOA and at the surface, since negative values of TOASWF and SurfSWF are found. Nevertheless, this cooling effect is more pronounced at the surface than at the TOA.



(a)

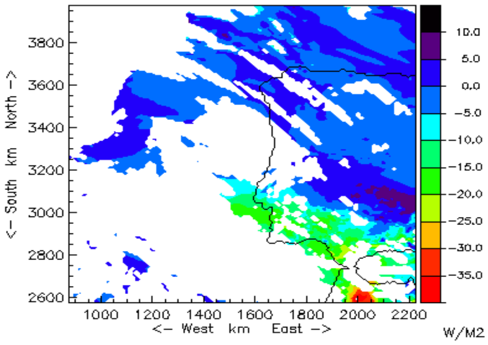


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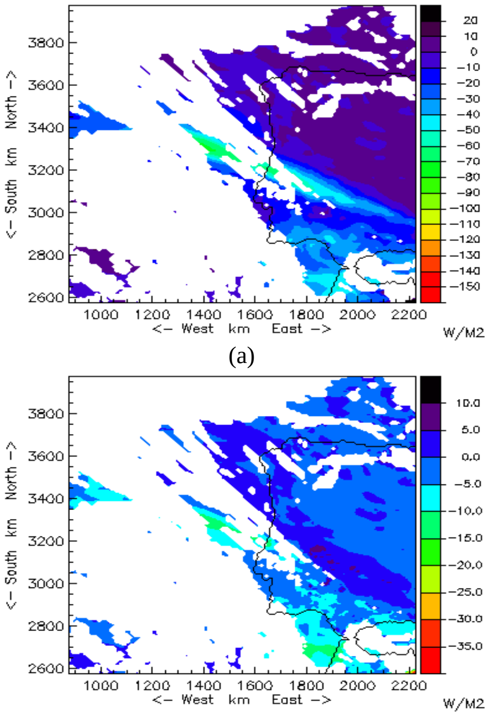
Fig. 11.- Same as Fig. 9 for 06 September 2007 (1200UTC).



(a)

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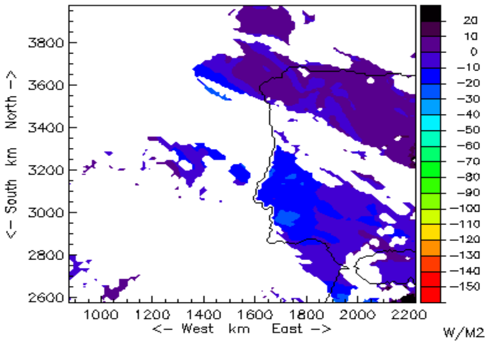
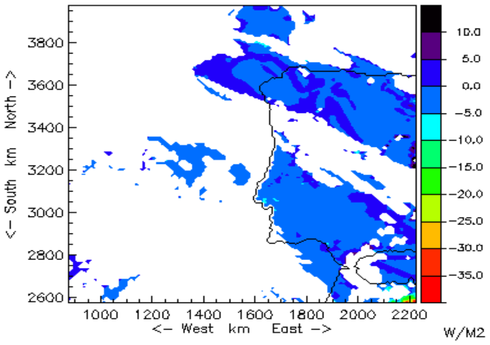
Fig. 12.- Same as Fig. 9 for 07 September 2007 (1200UTC).



(a)



(b)

Fig. 13.- Same as Fig. 9 for 08 September 2007 (1200UTC).

This situation also occurs for 29 May 2006 but not so evident, due the fewer data available (Fig. 5b) over the Iberian Peninsula and nearby Atlantic Ocean regions. Considering the large lack of simulated clear sky results over the sea region for the 29 May, it is decided not to include this day for the subsequent studies.

Table 1 presents the values of the modeled SWF at the TOA and surface levels, spatially averaged, as well as the corresponding, spatially averaged, AOD for the days under study, over sea regions.

	TOASWF (W/m^2)	**SurfSWF** (W/m^2)	**AOD**
27 May	-32	-197	1.6
28 May	-32	-159	1.2
06 September	-16	-116	0.9
07 September	-8.0	-55	0.4
08 September	-2.2	-12	0.1

Table 1.- Averaged SWF at the TOA and surface levels and corresponding averaged AOD.

Regarding the desert dust (DD) event of May 2006, table 1 shows that the SWF on 27 May present lower values (SWF averaged value of -32 W/m^2 at the TOA and -197 W/m^2 at the surface) compared with the corresponding values for 28 May (SWF averaged value of -32 W/m^2 at TOA and -159 W/m^2 at the surface). These differences can be related to the fact that the AOD values, on 27 May, are higher (AOD averaged value of 1.6) than the AOD values for 28 May (AOD averaged value of 1.2).

If one looks now at the DD episode that occurred in the beginning of September 2007, the SWF on 06 September presents lower values (SWF averaged value of -16 W/m^2 at TOA and -116 W/m^2 at the surface) compared with the corresponding values for 07 September (SWF averaged value of -8 W/m^2 at TOA and -55 W/m^2 at the surface) and with the corresponding values for 08 September, which presents a SWF averaged value of -2.3 W/m^2 at TOA and -12 W/m^2 at the surface. This last day also corresponds to the day where lower AOD values are found, comparing to the previous days.

Comparing now the May 2006 DD episode with the September 2007 DD episode, in table 1, it can be observed that the May 2006 DD episode is more effectual, presenting AOD values higher than the corresponding ones in September 2007. Correspondingly the SW cooling effect, both at the TOA and surface levels is more pronounced in May 2006 than in September.

In both episodes, there is a net SW heating effect in the atmosphere due to the presence of DD aerosols, since the difference between the SWF at TOA and at the surface is always positive; and as expected is more pronounced for May 2006 episode than for the one in September

Conclusions

This work aims to investigate the direct effect of Saharan desert dust storms that occurred in the end of May 2006 and in the beginning of September 2007, through the assessment of the desert dust aerosol radiative forcing (SWF both at the TOA and at the surface levels) at a regional scale. The method uses simulated parameters obtained from regional atmospheric modelling.

From the simulated results it is possible to observe that the model overestimates the total cloud fraction, nevertheless the pattern is, generally, in agreement with the actual situation.

The dust plume pattern is very well represented comparing with the actual situation represented by MODIS sensor.

When desert dust aerosols are present in the atmosphere, a SW cooling effect is found both at the TOA and at the surface, being more negatively pronounced at the surface than at the TOA.

Acknowledgments

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