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WRF-Chem simulation of a saharan dust outbreak over the mediterranean regions.

WRF-Chem simulação para a invasão de poeira sobre as regiões do Mediterrâneo.

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Abstract

A fully coupled meteorology-chemistry-aerosol model (WRF-Chem) is applied to simulate the Saharan dust outbreak over the Mediterranean regions. Two dust emission schemes, namely, those of Jones et al., (2010), and Shao (2001) are evaluated using the the GOCART aerosol model. To investigate the performance of each dust emission scheme, a case study was carried out for a Mediterranean dust event that took place between 21 and 23 May 2014. Considering the time average Aerosol Optical Depth, simulation results reproduced satisfactorily the outbreak and transport pattern of dust plumes. However, the estimated dust emission amounts in each scheme differ greatly due to the presence of several tuning parameters, that must be adjusted considering satellite and ground based experimental data.

***Keywords**: Sahara Dust, WRF-Chem simulations, dispersion of aerosols, GOCART aerosol model*

Resumo

Um modelo acoplado meteorológico-químico-aerossois (WRF-Chem é aplicado para simular a invasão de poeira do Sahara sobre as regiões do Mediterrâneo. Dois esquemas de emissão, Jones et al., (2010) e Shao (2001) são avaliados usando o modelo de aerossol GOCART. Para investigar o desempenho de cada um dos esquemas de emissão de poeira, um estudo de caso para um evento de emissão de poeira sobre o Mediterrâneo ocorrido entre 21 e 23 de Maio de 2014. Considerando a média no tempo da profundidade ótica devido a aerossois, os resultados reproduziram satisfatoriamente o padrão de transporte e invasão das plumas de poeira. Contudo, os montantes de emissão de poeira estimados em cada esquema diferem significativamente devido a presença de vários parâmetros de ajuste, que devem ser calibrados considerando-se dados experimentais de satélite e observações em terra.

1 Introduction

Mineral dust aerosols are well recognised to be one of the most important types of aerosols since they affect climate (Tegen *et al.*, 1996), air quality (Liu *et al.*, 2006) and human health (Mallone *et al.*, 2011).

Influence on the earth's climate may occur in many ways, not all of them yet well known. The radiative heating effects produced by aerosol absorption of short- and longwave radiation has been found to produce changes in net heating rates (Alpert *et al.*, 1998) that can modify the atmospheric circulation. Aerosols can also indirectly affect climate across their action as cloud condensation nuclei. Playing an important role in the global radiative budget by scattering and/or absorbing solar and terrestrial radiation (Tegen *et al.*, 1996) they impact the vertical profile of wind and temperature and the precipitation rate (Choobari *et al.*, 2014).

The assessment of aerosol radiative forcing effect on climate requires global data on aerosol properties and amounts over both the oceans and the continents. Sahara Desert hosts the maximum aeolian soil dust emission and atmospheric dust loading in the world (Choobari et al., 2014), and probably accounts for almost half of all the aeolian material supplied to the world's oceans. Since finer dust particles may be transported over thousands of kilometers from the source regions (Goudie and Middleton, 2001), Saharan dust may be important in modifying climate at global scale when transported northward across the Mediterranean region, or westward across the Atlantic Ocean.

Numerous dust models exist and have been applied in different cases studies to investigate global and regional dusts budget. However, large diversity exists in simulated dust budgets among different models. This can be attributed to different model parameterisations such a dust emission and deposition schemes as well as to various model configurations, lateral meteorological conditions and land-surface properties (Uno *et al.*, 2006, Huneeus *et al.*, 2011).

The objective of this study is to perform a preliminary evaluation of the performances of the Weather Research and Forecasting with Chemistry model (WRF/Chem) in simulating the transport of mineral dust over the Mediterranean regions. Vertical dust flux parameterizations were assessed by applying two different dust emission schemes, namely, those of Jones et al. (2010), and Shao (2001) (hereinafter denoted as AFWA and S01 schemes, respectively) in WRF/Chem.

2 WRF-Chem model configuration

The WRF/Chem is a fully coupled online community model for the prediction and simulation of weather, dispersion, air quality, and regional climate (Grell et al, 2005). It is presently released as part of the Weather Research and Forecasting (WRF, http://www2.mmm.ucar.edu/wrf/users/) modelling package. It simulates trace gases and particulates with the meteorological fields, which considers a variety of coupled physical and chemical processes such as transport, deposition, emission, chemical transformation, and radiation. It has the following advantages: (i) all transport done by meteorological model; (ii) same vertical and horizontal coordinates; (iii) same physics parameterization for subgrid scale transport; (iv) no interpolation in time; (v) ideally suited to study feedbacks between chemistry and meteorology; (vi) ideally suited for air quality forecasting on regional to cloud resolving scales.

In this study, WRF-Chem is configured to cover North Africa and Southern Europe with 160x90 grid points centered at lat=30.6°, lon=18.7°, a 50 km grid resolution and 40 vertical levels to 50 hPa.

Table 1: namelist parameters for AFWA/S01 runs

	AFWA	S01
Land surface	3	3
PBL	5	5
Surface similarity	1	1
Microphysics	2	2
SW radiation	4	4
LW radiation	4	4
Dust mechanism	300/3	300/4
Aerosol/radiation feedback	2	2

Boundary and initial conditions are assimilated from NCAR/NCEP Final Analysis (FNL from GFS) (ds083.2): 1 degree resolution, every 6 hours. As showed in table 1, the following physical schemes are used: the Mellor–Yamada–Nakanishi and Niino (MYNN) 2.5 level turbulent kinetic energy (TKE) parameterization for the planetary boundary layer (PBL); the Monin–Obukhov similarity scheme and the RUC Land Surface Model are chosen to represent the surface layer physics and the land surface parameterization. The Rapid Radiative Transfer Model (RRTMG)) for both short-wave and long-wave radiation is used for the aerosol direct radiative effect (Mlawer et al., 1997). Aerosol optical properties is calculated through Maxwell-Garnett approximation scheme (Bohren and Huffman, 1983), with aerosol-radiation feedback turned on.

The background emissions are obtained from the PREP-CHEM preprocessor package (Freitas *et al.*, 2011) a very useful tool to generate the anthropogenic/biogenic/biomass emissions in the WRF-Chem grid. It reads the global emissions from RETRO/EDGAR anthropogenic database and the GOCART static background fields and provides them the program convert_emission (included in WRF-Chem package) to produce the gridded netCDF emission files for the WRF-Chem runs. The GOCART (Giorgia Tech/Goddard **G**lobal **O**zone **C**hemistry **A**erosol **R**adiation and **T**ransport model, aerosol module (Chin et al., 2000) is available within the WRF/Chem model (chem_opt=300) and produces forecasts for 7 bulk aerosol species: Hydrophobic and hydrophilic organic carbon (OC1, OC2); Hydrophobic and hydrophilic black carbon (BC1, BC2); Other GOCART primary (PM2.5, PM10) and Sulfate; and for 9 Sectional aerosols species: 5 dust bins (0.5, 1.4, 2.4, 4.5, 8.0 μm) and 4 sea salt bins (0.3, 1.0, 3.2, 7.5 μm).

Two model simulations are conducted for a Mediterranean dust event occurred in the spring of 2014. The goal is to examine the difference between two dust emission schemes (AFWA and S01), and to investigate the performances of each scheme in reproducing Sahara dust outbreak in the Mediterranean.

3 Dust emission parameterization

In dust emission parameterization, the most important parameters are: the threshold friction velocity at which dust particles begin to move, the horizontal sand flux, and the vertical dust flux. The emission of transportable dust particles may be also classified considering the surface wind conditions. Under strong wind conditions the wind-shear at the surface is the governing dynamic parameter and the dust emission is generally a function of the surface friction velocity occurring when a threshold value is reached. Under these conditions two main dust emission mechanisms have been recognized: saltation bombardment (Marticorena and Bergametti, 1995) and aggregate disintegration (Shao, 2004). Another important mechanism, when the lower troposphere is under low wind convective conditions is the direct aerodynamic lifting (Klose and Shao, 2012).

3.1 AFWA emission scheme

The emission schemes AFWA (Jones et al., 2010) is coupled with the GOCART aerosol model within WRF-Chem to study the sensitivities to dust emission scheme. The AFWA scheme calculates the vertical dust flux emission F as:

$$\begin{cases} F = G \times EROD^{\gamma} \times \alpha \times \beta \\ \beta = 10^{0.134(\%clay - 6)} \end{cases}$$

where EROD is the fraction (0-1) of erodible grid cell (figure 1a), G is the saltation flux that is calculated following Marticorena and Bergametti (1995), α is a constant to fudge the total emission of dust, γ is the exponential tuning constant for erodibility, and β is the sandblasting mass efficiency that is calculated considering the soil clay fraction (figure 1b). It is important to point that in the AFWA scheme, the relationship between vertical and horizontal fluxes is only related to the soil clay content. The AFWA emission scheme contains two other tuning parameters, namely the friction velocity tuning constant (ustune) and the volumetric soil moisture tuning parameter (smtune). All of these tuning parameters are set to their default value for this preliminary study.

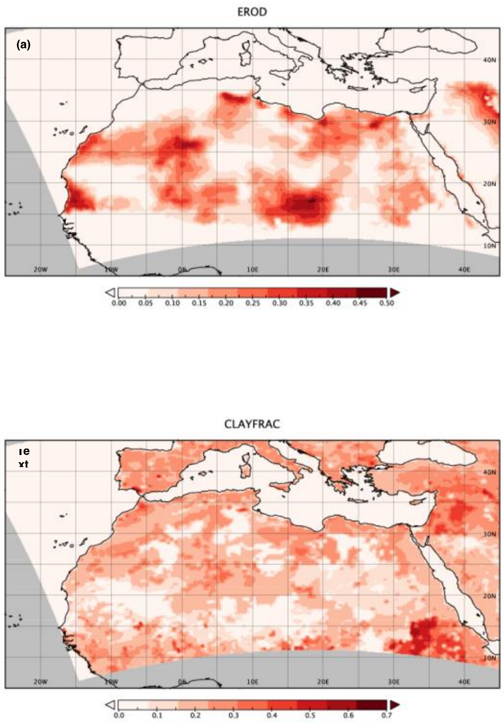

Figure 1 - Geographyc dataset: (a) Dust Erosion data; (b) clay soil fraction.

3.1 Shao emission scheme

Shao (2001) proposed a new dust emission parameterization that considers explicitly the two major emission mechanisms described above. In particular, the aggregate disintegration was newly parameterized by Shao (2001) with the assumption that dust aggregates disintegrate as they strike the surface. He proposed a size-resolved dust emission equation by supposing that particles are divided into n particle-size intervals and expressed the total dust flux as an integral of the dust emission rate for particles of size d_i by saltation of particles of size d_s:

$$F = \int_{d_1}^{d_2}\int_{0}^{d_1} \tilde{f}(d_i,d_s)p(d_s)p(d_i)\delta d_i \delta d_s$$

Here $p(d_{i,s})$ can be regarded as a combination of two idealized particle size distributions, known as minimally disturbed particle size distribution $p_m(d_{i,s})$, and fully disturbed particle size distribution $p_f\ (d_{i,s})$. Full details of this formulation may be found in Shao (2001) and Kang et al. (2011).

3. Results and conclusions

As case study we considered the period from 16 May 2014, 0000 UTC to 25 May, 2300 UTC when occurred a strong outbreak of Saharan dust over the Mediterranean regions. In particular, the AERONET/GSFC stations (http://aeronet.gsfc.nasa.gov/new_web/index.html) located in the Mediterranean basin, have registered a peak value for the Aerosol Optical Depth (AOD) for the days 21 and 22.
During the simulated period, the synoptic meteorological conditions had the following features: the 500 hPa geopotential height maps (not showed) indicated for the first three days (16-17-18) a prevalence of zonal flow in the southern Mediterranean. The following days (19 to 24) were characterised by an omega-like circulation that brought south-westerly flows over the western Mediterranean. At lower levels (850 hPa), for the period 16-22 may, it may be evidenced an intensification of the high pressure over the African continent and of the low over Spain and Morocco producing a strengthening of southerly wind in the central Mediterranean. From May 22 to 24, the low pressure moved eastward and northward, producing a rotation of the low level wind over the western Mediterranean from west-northwest. At the end of the period, a cyclonic circulation prevailed over the Mediterranean, but with weak winds over most of the basin; a high pressure of limited extension from Libya to southern Italy determined southerly currents confined over the southern Mediterranean.
The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on board the NASA Terra and Aqua platforms are uniquely designed with wide spectral range, high spatial resolution, and near daily global coverage to observe and monitor the Earth changes including tropospheric aerosols (Kaufman et al., 1997). Figure 2 shows the total Aerosol Optical Depth (AOD) at 550 nm during May 21, 2014. This figure is obtained merging MODIS AOD retrieval from the "Deep Blue algorithm" (Hsu et al., 2006) that is only available over land, with the Dark-Target (DT) aerosol algorithm that derives aerosol properties including aerosol optical depth (AOD) over land and ocean. It is well evident the outbreak of dust aerosols in a wide area in the south-western

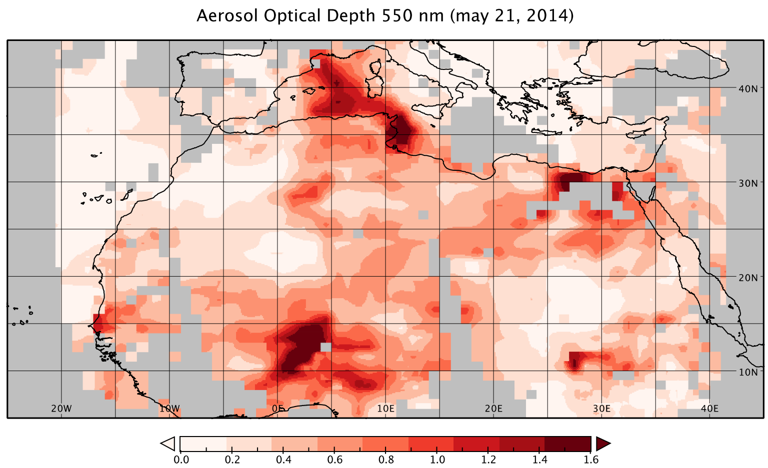

Figure 2 - Time Averaged Map of Aerosol Optical Depth 550 nm (Deep Blue, Land-only+ Dark Target) daily 1 deg. [MODIS-Aqua MYD08_D3 v051]; over 2014-05-18 - 2014-05-25, Region 24.6094W, 0.7031N, 58.7109E, 47.1094N.

Mediterranean. This region comprises the coasts of Tunisia and Algeria up to the southern coast of France, passing between Sardinia and Balearic Islands. This a consequence of the synoptic conditions at 500 hPa (omega-like circulation) and 850 hPa prevalence of southern winds.

The total AOD is obtained from WRF-Chem simulations integrating vertically the extinction coefficient at 550 nm, that is:

$$AOD = \int_0^{ztop} extcof\,55(z)\,dz$$

where ztop is the top of the domain (≈ 20 km).

In figure 3 it is reported the correspondent total AOD from the two WRF/Chem simulations. Figure 3a is obtained using the AFWA dust emission scheme, while the figure 3b considers the S01 emission scheme. Both figures are daily averages for May 21.

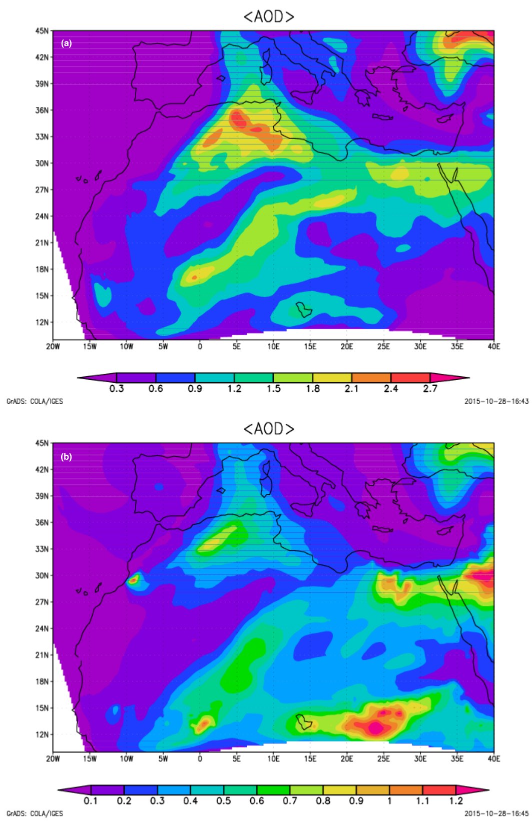

Figure 3: Time Averaged Map of Aerosol Optical Depth 550 nm from WRF-Chem simulation: (a) AFWA dust emission model; (b) S01 dust emission model

Simulation results reproduced reasonably the outbreak and transport pattern of dust plumes in the south-western Mediterranean. Anyway, it is important to point out that the estimated dust emission amounts in each scheme differed greatly and that the AFWA scheme generally produces higher dust emissions than the S01 scheme. This may be easily explained by the fact that the AFWA scheme considers vertical dust flux to be related only to clay content, while the vertical dust flux in the S01 schemes considers a four-class texture soil type, and for each class a proper value for the soil plastic pressure (surface hardness).

Despite a general spatial agreement, some discrepancies are also evident in some areas, which need further analysis and a deeper sensitivity study of the dust emission model with respect to the several tuning parameters that are introduced in each emission scheme. A sensitivity the WRF parameterization for the PBL and the land-surface is also required.

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