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ANALYSIS OF AN INTENSE OUTBREAK OF SAHARAN DUST IN THE APULIA REGION: COMPARISON BETWEEN THE WRF-CHEM MODEL AND MULTI-PLATFORM EXPERIMENTAL DATA

U. Rizza[1], C. Mangia[1], P. Ielpo[1], M.M. Miglietta[1], F.Grasso[1]
G. Passerini[2], M. Morichetti[2], C. Iachini[2], S. Virgili[2]
F. de Tomasi[3]
G.P. Gobbi[4], F. Barnaba[4], L. Di Liberto[4]

[1]CNR/ISAC – Unit of Lecce, Italy
[2]UNIVPM – DIISM, Ancona, Italy
[3]Università del Salento, Lecce, Italy
[4]CNR/ISAC – Unit of Roma, Italy

Abstract: In this study, the Weather Research and Forecasting model with online coupled chemistry (WRF-Chem) is applied to simulate an intense Saharan dust outbreak event that took place over the Southern Italy in March 2016.
The WRF model is found to reproduce well the synoptic meteorological conditions driving the dust outbreak: an omega-like pressure configuration associated with a weak cyclogenesis in the Iberian Peninsula. At the end of the simulated period the merging of two minima produce a large depression in the Peninsular Italy.
The model performances in reproducing the atmospheric desert dust load is evaluated using a multi-platform observational dataset of aerosol and desert dust properties, including optical properties from satellite and ground-based sun-photometers, plus in-situ particulate matter mass concentration (PM) data. This comparison allows us to investigate the model ability in reproducing both the horizontal and the vertical displacement of the dust plume, and its evolution in time. The preliminary comparison with satellite (MODIS-AQUA) and sunphotometers (AERONET) showed that the model is able to reproduce well the horizontal field of the aerosol optical depth (AOD) and its evolution in time.
The routinely measurements of ARPA-Puglia revealed the intense dust outbreak with peak PM10 value larger than 300 μg/m^3 during march 23. On the other side, the model-measurements comparison for PM_{10} shows a good temporal matching.
The model-to-measurements comparisons allows the evaluation and the tuning of physics-based emission scheme that is part of the WRF-Chem package release.

Key words: *Dust outbreak, dust contribution to PM_{10}, Gocart Aerosol model, WRF-Chem modeling*

1. INTRODUCTION

Wind erosion in desert and semi-arid regions is the foremost source of tropospheric aerosols. Unfortunately, the estimation of the emission fluxes of mineral dust is still highly uncertain. For instance, dust emissions from the Sahara have been estimated to range between 400 Tg yr^{-1} to 2200 Tg yr^{-1}, with a median flux of 800 Tg yr^{-1} (Schepanski et al., 2016).
Aeolian erosion occurs only when a threshold in the surface wind speed is reached (Fécan et al., 1999). This threshold is strongly influenced by many factors such as soil moisture, rainfall and flooding (ephemeral lakes) and vegetation. The combination of soil moisture and wind related factors create a strong variability in dust emission with seasonal, interannual and longer term cycles
In this context, dust emissions are sporadic and spatially heterogeneous, making difficult any precise assessment of their impacts. Thus, modelling may be considered as a useful approach to quantify dust emissions over arid and semi-arid regions. In this context, numerical modeling of the transport of desert dust is receiving increasing attention from the scientific community, allowing to better understand its impact on the Earth radiation budget. Mineral dust also affects modern human life causing respiratory diseases, reducing air quality but also logistics of goods and humans.
The WRF-Chem model has been previously used to investigate dust storms considering the dust feedback with atmospheric thermodynamics and radiation (Kalenderski et al., 2013). Su and Fung (2015) assessed the model performance in simulating dust concentrations over East Asia using two different dust emission parametrisations. Their results showed important differences when different dust parametrisations were

applied. Rizza et al., (2017) used WRF-Chem to simulate a Saharan dust outbreak event that took place over the Mediterranean in May 2014. The model performances in reproducing the atmospheric desert dust load were evaluated using a multi-platform observational dataset, including optical properties from satellite and ground-based sun photometers and lidars, plus in situ particulate matter mass concentration (PM) data. Differences in dust load prediction between numerical models can be ascribed to different model parameterizations and configurations. In this context, it is important to quantify the sensitivity of model estimates to individual factors.

In this study, we test the sensitivity of the Weather Research and Forecasting model with chemistry (WRF-Chem) Version 3.6.1 (Grell et al., 2005) to the Land Surface Model (LSM) during a severe dust outbreak. The emission scheme developed by Shao (2004) and implemented in the University of Cologne (S04 hereafter) is used as dust module of the WRF-Chem package. Two different LSM are tested and evaluated against multi-platform experimental data. As case study we consider the outbreak that occurred in south-east Italy on March 23 2016, during which PM_{10} peak intensity of about 1000 $\mu g\ m^{-3}$ were measured by the regional air quality monitoring stations network managed by Environmental Agency of Apulia Region (ARPA-Puglia).

2. MATERIAL AND METHODS

2.1 - Event Description: Synoptic conditions

The evolution of the sea level pressure from NCEP/NCAR reanalysis (http://www.esrl.noaa.gov/psd/data/) shows a weak cyclonic circulation over the western Mediterranean that progressively intensifies and moves eastward, pushing eastward the African anticyclone, which initially affected the eastern half of the Mediterranean. On March 22 at 1200 UTC (figure 1a) a bipolar structure is evident in the Mediterranean basin with a low centered over the Northern Tunisia and an anticyclone over the eastern Mediterranean countries. The WRF-Chem simulation (figure 1b) appears consistent with the evolution represented in the reanalysis, although, the simulated pressure low is more intense in WRF-Chem runs at sea level. NCEP/NCAR reanalysis of the geopotential height map at 700 hPa (figure 1c) on March 22 at 1200 UTC shows a weak depression weak depression over the Iberian Peninsula. As a consequence, central and southern Italy are affected by intense southwesterly currents from Africa. The WRF-Chem simulation (figure 1d) seems consistent with this representation although the pressure minimum is more intense.

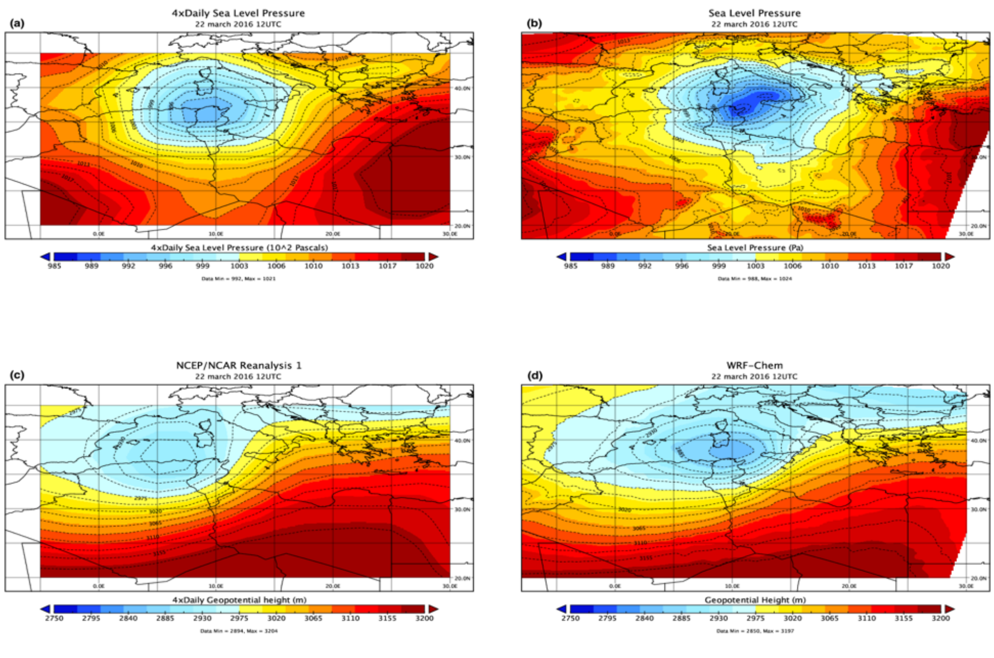

Figure 1: Sea level pressure on March 22 at 1200 UTC for NCEP/NCAR reanalysis (a) and WRF-Chem (b). Geopotential height at 700 hPa for NCEP/NCAR (c) and WRF-Chem (d)

2.2 Model setup

In this work, the WRF-Chem model version 3.6.1 has been used. The model domain covers North Africa and Southern Europe with 150 x 120 points, with horizontal grid spacing of 30 km in both directions and 40 vertical levels up to 50 hPa. The simulation lasted 6 days, starting on March 18, 0000 UTC. Boundary and initial conditions were provided from NCAR/NCEP Final Analysis (FNL from GFS) (ds083.2), with 1-degree resolution. An idealized vertical profile for each chemical species is provided to start the model simulation. This vertical profile is based upon northern hemispheric, mid-latitude, clean environmental conditions (Rizza et al., 2017). The Mellor–Yamada–Nakanishi and Niino (MYNN) 2.5 level turbulent kinetic energy (TKE) parameterization is used to describe the planetary boundary layer (Nakanishi et al., 2009). The Eta similarity scheme is chosen to represent the surface layer physics. The short/long wave radiation effects are parameterized using the Rapid Radiative Transfer Model (Iacono et al., 2009) for short-wave (ra_sw_physics = 4) and long-wave (ra_lw_physics = 4). The two-moment cloud microphysics scheme of Morrison et al., (2009) is used for the treatment of the microphysics processes.

The Aerosol-related model settings have been implemented following Rizza et al. (2017). The GOCART scheme (Georgia Tech/Goddard Global Ozone Chemistry Aerosol Radiation and Transport model, Chin et al., 2000) was selected (*chem_opt=300*). It produces output for 8 sectional aerosols species: 4 dust bins (0-2.5, 2.5-5, 5-10, 10-20 μm) and 4 sea salt bins (0.1-0.5, 0.5-1.5, 1.5-5, 5-10 μm). The WRF-Chem model (version 3.6.1) includes three alternative packages for mineral dust emission, two from the GOCART model ("DUST-GOCART" and "DUST- GOCART/AFWA") and a third ("DUSTUOC") from the University of Cologne. This latter is further divided into three emission parameterizations with a progressive level of simplification. In this work we have opted for the S04 scheme (Shao, 2004) and tested its performances in comparison to observations.

2.3 Description of the land surface models

The land-surface is a fundamental component of climate and regional models. It controls the partitioning of energy at the surface between latent and sensible heat, but also the partitioning of available water into evaporation and runoff.

The surface physics uses direct interaction of parameterizations with the other physics schemes. In particular, it receives: (i) precipitation forcing from the microphysics and convective scheme; (ii) downward short/long-wave from radiation scheme; (iii) surface temperature, humidity, and wind from PBL scheme. It provides: (iv) Surface emission/albedo to radiation scheme; (v) heat and moisture fluxes over-land/water points to the PBL scheme. These fluxes specify a lower boundary condition for the vertical transport that is usually performed in the PBL-physics model. There are several land-surface models implemented within the WRF package; they are characterized by various degrees of complexity in dealing with thermal and moisture fluxes among the multiple levels of the soil, vegetation, root, and with canopy effects and surface snow-cover. LSM does not provide tendencies, but does update the land state variables that include the skin temperature, soil temperature profile, soil moisture profile, snow cover, and possibly canopy properties. There is no horizontal interaction between neighboring points in the LSM, so it can be regarded as a one-dimensional column model for each WRF grid-point, based on the two key equations for the surface energy balance and the surface water balance. In this paper, the S04 dust emission model, described in next section, is tested and its sensitivity to two LSM schemes actually implemented within WRF-Chem, namely RUC (Benjamin et al., 2004) and the multi-parameterization Noah-MP (Niu et al., 2011) is analyzed.

An important parameter that controls the intensity of the S04 emission model is the surface soil moisture. It defines: (i) the particle size distribution density functions and (ii) the threshold surface friction velocity. The S04 emission model uses directly the soil-texture DRYSMC parameter that represents the volumetric fraction of the dry soil moisture threshold at which direct evaporation from the top soil layer ends. This parameter has different values for RUC and Noah-MP LSM as it can be verified inside the SOILPARM.TBL look-up table of the WRF-Chem package. It is defined for 19 soil texture classes through a combination of different soil texture, namely: sand, loam, silt and clay (table 1).

	DRYSMC Noah	**DRYSMC RUC**	**Soil type**
1	0.010	0.045	'SAND'
2	0.028	0.057	'LOAMY SAND'

3	0.047	0.065	'SANDY LOAM'
4	0.084	0.067	'SILT LOAM'
5	0.084	0.034	'SILT'
6	0.066	0.078	'LOAM'
7	0.067	0.100	'SANDY CLAY LOAM'
8	0.120	0.089	'SILTY CLAY LOAM'
9	0.103	0.095	'CLAY LOAM'
10	0.100	0.100	'SANDY CLAY'
11	0.126	0.070	'SILTY CLAY'
12	0.138	0.068	'CLAY'

Table 1: Soil Parameter in Land Surface Models

4. RESULTS

4.1 - Comparison PM_{10} – daily data

Particulate matter (PM_{10}) concentrations monitored in two sites of the regional air quality monitoring network (ARPA-Puglia) were used for comparison, i.e. the station Taranto (40.52 lat, 18.12 long and Brindisi (40.63 lat, 17.95 long). During the dust event both stations registered an average daily value of PM_{10} of about 300 $\mu g\ m^{-3}$ with peak of 1000 $\mu g\ m^{-3}$ in some hours.
Figure 2 shows modelled (green/red curves) and in situ-measured (black curve) daily averaged PM_{10} values for Brindisi (a), and Taranto (b) stations. Results evidence large differences between the two numerical schemes adopted. Simulations with NoahMP setup show a good reproduction of the March 23 peak (figure 2 a,b)) while the RUC setup tends to a great overestimation in terms of mass.

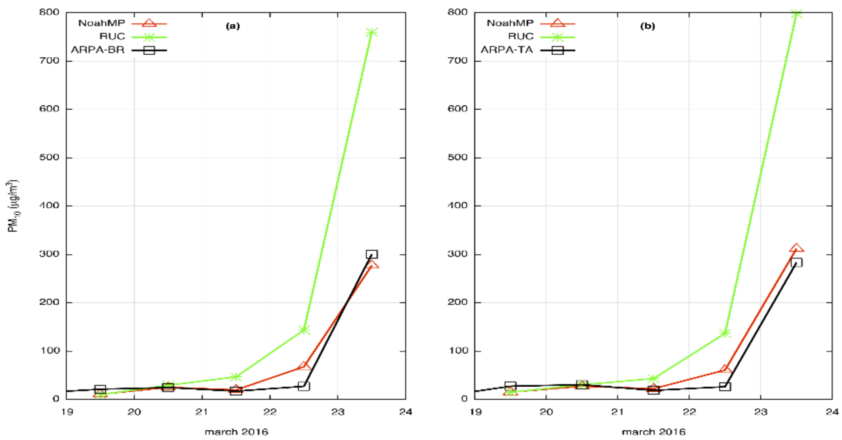

Figure 2: Comparison between measured PM_{10} data (black lines) and WRF-Chem in Noah-MP setup (red lines) and RUC setup (green lines) for Brindisi (a) and Taranto (b) ARPA-Puglia stations.

5. CONCLUSIONS

To evaluate the capability of WRF-Chem to simulate dust aerosol outbreaks in the Mediterranean basin, two sensitivity experiments were conducted by applying the S04 dust emission scheme with soil properties generated from two different LSM, namely Noah-MP and RUC. The two different setup were evaluated during a severe dust outbreak episode occurred on 23 March 2016 in the Central Mediterranean, and registered in the monitoring stations of Apulia Region. Comparison between simulations and ground level measured PM10 data shows a general over-estimation in term of total mass for the RUC run. On the contrary, the Noah-MP run gives better results, especially for the daily averaged PM_{10}. This suggests that the Noah-MP LSM, used in combination with the S04 dust emission scheme, is more suitable to apply in severe dust outbreaks in the considered area. Other parameters of the S04 emission scheme should be similarly deepen studied to find the best combination of physical and aerosols related setup.

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