Long-range transport of Saharan dust and chemical transformations over the Eastern Mediterranean

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European Geosciences Union General Assembly 2018
Vienna | Austria | 8-13 April 2018

Introduction

The dust events detected *at the lower troposphere of the Eastern Mediterranean (EM)* contribute to the 50% of the days with PM_{10} loads above the EU limits (Kallos et al., 2007; Astitha et al., 2008) and are found concomitant *with 10 % (urban sites) - 67 % (background sites) of the excesses* (Contini et al., 2014). Also, a recent study at the southmost border of EM (Nastos et al., 2016) declares dust intrusions responsible for *acute health impacts* and *adverse biometeorological conditions*.

The need to systematically investigate the *changes in the atmospheric chemical composition during the transport of African dust towards the Mediterranean basin* is pointed out by a synthesis of several experimental studies (e.g. Metzger et al., 2006; Formenti et al., 2011 Rodriguez et al., 2012; Schulz et al.,2012). Model findings are usually based on (multi-)annual, coarse resolution averages, thus they do not reflect *dust transport and chemistry during different seasons and transport modes* (e.g. Ginoux et al., 2001; Zender et al., 2003; Trebs et al., 2005; Kallos et al., 2007; Astitha et al., 2012; Karydis et al., 2015; Abdelkader et al., 2015).

The present effort updates the model setup (i.e. PMCAMx, WRF and GEOS-CHEM) of two previous studies (Tombrou et al., 2009; Athanasopoulou et al., 2015) to study *3 recent and important Saharan dust events* over the EM. The synergistic use of synoptic patterns, aerosol optical depth retrievals, back-trajectories and ground aerosol measurements confirm its *ability to reproduce source regions of dust, transport pathways, vertical structure and aerosol chemical composition* over the EM. Sensitivity tests aim at investigating the *role of dust as condensation surface for inorganic gases* during different seasons and counting on different dust source regions, pathways, loads and vertical extents.

Methodology and data

The model system used is composed of a *regional photochemical model (PMCAMx)*, which provides the aerosol predictions over the EM, a *regional atmospheric model (WRF/ARW)*, which feeds PMCAMx with the necessary meteorological fields and a *global chemistry transport model (GEOS-CHEM)*, which provides the African dust input to the regional aerosol modeling (**Table 1**). Model simulations are realized during the periods of *04-07.02.2009 (winter case), 27.11-02.12.2010 (late autumn case)* and *18–21.07.2011 (summer case)*.

Supplementary data: *usage & outcome*

●NCEP/NCAR synoptic patterns: *origins and transport paths of Saharan dust towards the EM* **(Fig. 1)**. ●Online available outputs (maps and profiles) of the BSC-DREAM8b model v1.0 (e.g. Pérez et al., 2006a; 2006b; Basart et al., 2012) ●Aerosol chemical composition at Finokalia, Crete (35.34° N, 25.67° E, 250m a.s.l.) and at Penteli, Attica (38.04° N, 23.86° E, 495m a.s.l., 13 km northeast the Athens city center) ●Online available (NASA) satellite retrievals of Aerosol Optical Depth values (AOD at 550 nm) ●Back-trajectories (HYSPLIT): *the current model system is found competent to reproduce African dust production, long-range transport and chemical transformations over the EM.*

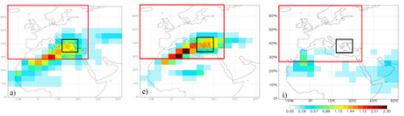

Fig. 1. The dust optical depth (DOD) calculated by GEOS-CHEM during the 3 peak days of the selected dust events: a) 07.02.2009, e) 01.12.2010, i) 20.07.2011) s. *Red rectangle: GEOS-CHEM domain B; Black rectangle: PMCAMx domain*

Table 1. Main characteristics of the WRF meso-scale meteorological model, the GEOS-Chem v8-03-01 global and the PMCAMx regional CTM applications.

	WRF	GEOS-Chem	PMCAMx
Chemical and Physical mechanisms	Planetary boundary layer (PBL) parameterization: YSU (Hong et al., 2006) (standard run). BOULAC (Bougeault and Lacarrère, 1989) and QNSE (Sukoriansky et al., 2005) are used in 2 additional scenarios.	NO_x-O_x-hydrocarbon-aerosol species module (the SOA module by Chung and Seinfeld, 2002 and Henze et al., 2008 is included). The mechanism is combined to the ISORROPIA II aerosol thermodynamics (Fountoukis and Nenes, 2007).	Gaseous chemistry: SAPRC99 (Carter, 1990), Inorganic aerosol chemistry: ISORROPIA II (Fountoukis and Nenes, 2007), Organic aerosol chemistry: VBS (Shrivastava et al., 2008; Lane et al., 2008), Detailed chemical composition (SO_4, NO_3, NH_4, POA, SOA, EC, Na, Cl, Mg, Ca, Mg) distributed over ten discrete and internally mixed size sections, in the diameter range 0.04-40 μm (cut-off diameters: 0.04, 0.08, 0.1, 0.3, 0.6, 1.2, 2.5, 5, 10, 20, 40 μm)
Initial, Lateral and Boundary conditions	National Centers for Environmental Prediction (NCEP) operational Global Final Analyses (1.0°×1.0°)	From the global GEOS-chem simulation (4.0°×5.0°)	From the global GEOS-chem simulation (0.5°×0.667°)
Input data	Sea surface temperature (SST): Real-Time Global SST analysis data (0.5°×0.5°) Land use categories: 24 Soil categories: 16 (US Geological Survey)	Anthropogenic emissions: GEIA, EMEP, Piccot et al. (1992), Duncan et al., 2003, Yevich and Logan, 2003 Natural emissions: MEGAN, Price and Rind, 1992, Yienger and Levy, 1995, Wang et al., 1998 Meteorological data: Goddard Earth Observing System (GEOS-5)/NASA Global Modeling and Assimilation Office	Anthropogenic, agricultural, forests: Hellenic Ministry of Environment (2002); EMEP Sea-salt and dust: Athanasopoulou et al., 2008; 2010 Meteorological data: from the WRF simulation (0.056°×0.056°)
Vertical grid	35 sigma levels (from ca.10 m agl to 50 hPa)	47 hybrid eta levels (from ca. 50 m agl to 0.01 hPa)	14 levels (from surface to ca. 5.8 km)
Parent and nesting domains (extended areas of)	A. Europe (0.5°×0.5°) B. Greece and Italy (0.167°×0.167°) C. Aegean Archipelago (0.056°×0.056°)	A. Global domain (4°×5°) B. Europe (0.5°×0.667°)	Aegean Archipelago (0.056°×0.056°)

Results

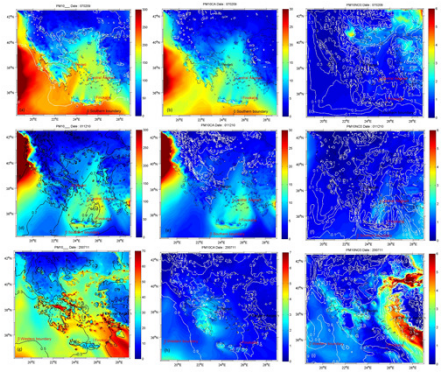

Fig. 2. *Spatial distribution of the daily average total PM10 (*left*), PM10 Ca (*center*) and NO_3^- (*right*) concentrations* (PMCAMx outputs, in μg m^{-3}) over the EM during representative days of the dust events of winter (a, b, c), late autumn (d, e, f) and summer (g, h, i). Isopleths show *the contribution* (values from 0 to 1) *of dust to the daily average surface concentrations*. They refer to the results presented in Fig. 3, i.e. the boundary (0), Finokalia (I), Aegean (II) and Athens (III).

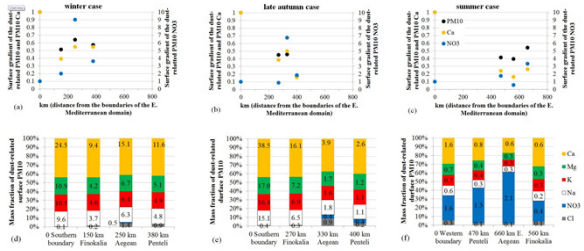

Fig. 3. *The surface gradient rate of the dust mass of total PM_{10} and PM_{10} Ca^{2+} and PM_{10} NO_3^-* (normalized to the boundary values; a-c) and *the mass fractions* (%) *of the dust part of PM_{10}* (mass concentrations in μg m^{-3} are labeled; d-f), as the dust plume penetrates to the EM during the 3 dust events. The location of the four sites is marked in Fig. 2, at the map of each event (0, I, II and III). Their distance from the selected site with the representative boundary values (at site 0 or at 0 km) is also given at the bottom.

Conclusions

The dust loads during the cold (summer) period events were high (light) and vertically extended (in the free troposphere). In all cases, *dust originated from the northwest and/or west Saharan desert and reached the EM from the west/southwest*.

The strongest dust influence (winter case) led to high daily surface concentrations of calcium (e.g. 5 and 3.4 μg m^{-3} in PM_{10} model outputs and observations respectively, at Finokalia). The respective concentrations during the late autumn event are significantly lower (approximately by half), while the values during the summer case are below1 μg m^{-3}. From those quantities, *the predicted African dust fraction accounted for more than 70 % (90 % during the cold period cases) and its surface gradient (dissipation ratio for the cold period cases) downwind the dust flow is ca. -10 % per 100 km*.

Surface particulate nitrate concentrations over the EM are reversely affected by the approaching dust loads. The highest total absolute concentrations (up to 6 μg m^{-3}), as well as their dust fraction (ca. 70 %) occur during summertime, while the dust-bound nitrate mass during the cold period events is insignificant (below 0.5 μg m^{-3}). This is attributed to a combination of reasons: the availability of nitric acid is higher during summer, thus, the potential for its heterogeneous and irreversible reaction with mineral dust species is higher. Accumulation of aerosol particles in the atmosphere is favored by the low precipitation rates during summertime. The low deposition rates over the sea create a homogeneous field of nitrate over the EM, which is gradually built towards the Aegean Sea and downwind. Consequently, mineral species dominate the dust-related PM_{10} concentrations (up to 98 %) during the cold period events, while *the effective formation of nitrate salts during summertime makes them account from 20 to 60 % of the dust-bound aerosol mass*.

PM_{10} sodium over the Aegean Sea is apportioned to the Saharan dust intrusions by 50% and the rest originates from sea-salt, while the fraction of sulfate bound to dust is found insignificant.

Acknowledgments

This study is a part of the research project "AERAS-EtS" within the framework of the Action "Supporting Postdoctoral Researchers" of the Operational Program "Education and Lifelong Learning", co-financed by the European Social Fund (ESF) and the Greek State. E. Athanasopoulou and E. Gerasopoulos acknowledge the funding received by ERA-PLANET (www.era-planet.eu), trans-national project SMURBS (www.smurbs.eu) (Grant Agreement n. 689443), funded under the EU Horizon 2020 Framework Programme, for the participation in this conference. N. Mihalopoulos and E. Gerasopoulos acknowledge support from ACTRIS-2_INFRAIA EU project. The Barcelona Supercomputing Center (http://www.bsc.es/projects/earthscience/BSC-DREAM/) is also acknowledged for the provision of data from the BSC-DREAM8b (Dust REgional Atmospheric Model) model v1.0. E. Athanasopoulou thanks C. Fountoukis and S. N. Pandis for the use of the updated PMCAMx code, D. Paraskevopoulou for the use of the aerosol data from Penteli station and C. Theodosi, G. Kouvarakis for the use of the aerosol data from Finokalia station.

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More results from this study (incl. the cited references) are given in: Athanasopoulou E., A. Protonotariou, G. Papangelis, M. Tombrou, N. Mihalopoulos, E. Gerasopoulos, *Long-range transport of Saharan dust and chemical transformations over the Eastern Mediterranean*, **Atmospheric Environment**, Volume 140, September 2016, Pages 592-604, ISSN 1352-2310, http://dx.doi.org/10.1016/j.atmosenv.2016.06.041, 2016.