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Impacts of natural emission sources on particle pollution levels in Europe

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HIGHLIGHTS

- Windblown dust impacts PM10 levels by 20% in southern Europe in summer and winter.
- Sea-salt increases PM10 levels by about 10 μg/m^3 in Mediterranean Sea in summer.
- In Atlantic Ocean, sea-salt enhances PM10 levels by 6 μg/m^3 during autumn.
- Biogenic emissions increase SOA by more than 90% during summer.
- Biogenic emissions reduce PM2.5 levels in central Europe and Eastern Mediterranean.

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ABSTRACT

The main objective of this work is the study of the impact of windblown dust, sea-salt aerosol and biogenic emissions on particle pollution levels in Europe. The Natural Emissions MOdel (NEMO) and the modelling system consisted of the Weather Research and Forecasting model (WRF) and the Comprehensive Air Quality model with extensions (CAMx) were applied in a 30 km horizontal resolution grid, which covered Europe and the adjacent areas for the year 2009. Air quality simulations were performed for different emission scenarios in order to study the contribution of each natural emission source individually and together to air quality levels in Europe. The simulations reveal that the exclusion of windblown dust emissions decreases the mean seasonal PM10 levels by more than 3.3 μg/m^3 (~20%) in the Eastern Mediterranean during winter while an impact of 3 μg/m^3 was also found during summer. The results suggest that sea-salt aerosol has a significant effect on PM levels and composition. Eliminating sea-salt emissions reduces PM10 seasonal concentrations by around 10 μg/m^3 in Mediterranean Sea during summer while a decrease of up to 6 μg/m^3 is found in Atlantic Ocean during autumn. Sea-salt particles also interact with the anthropogenic component and therefore their absence in the atmosphere decreases significantly the nitrates in aerosols where shipping activities are present. The exclusion of biogenic emissions in the model runs leads to a significant reduction of secondary organic aerosols of more than 90% while an increase in PM2.5 levels in central Europe and Eastern Mediterranean is found due to their interaction with anthropogenic component.

1. Introduction

Particulate matter (PM) pollution problems are generally related to the cumulative effect of natural and anthropogenic emission sources (Im et al., 2011a,b; Markakis et al., 2010a,b; Viana et al., 2014). PM of natural origin contributes many times more to the global aerosol burden by mass than the anthropogenic aerosol (Viana et al., 2014) providing a substantial amount of cloud condensation nuclei (CCN). Natural sources enhance PM levels contributing to the deterioration of the air quality and environment (EEA, 2012, 2008) as well as human health; particles are associated

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with an increase in daily mortality (Schwartz et al., 1996). Thus, proper quantification of natural PM emissions as well as the identification of their impacts on air quality is necessary.

Some of the main natural emission sources of primary and secondary atmospheric aerosols are vegetated areas, oceans, arid and semi-arid areas, soils and volcanoes (NATAIR, 2007; Viana et al., 2014). The natural emission sources studied in this work are windblown dust (WD), sea-salt aerosol (SSA) and biogenic volatile organic compounds (BVOCs) emissions from vegetation for which several studies in the past have revealed their impacts on air quality (Athanasopoulou et al., 2008, 2010; Im et al., 2011b, 2013; Viana et al., 2014). Note that NATAIR (2007) indicated that the major contributors of PM10 natural emissions over Europe were WD and SSA.

Windblown dust is generated by wind action on soils that have not been altered or disturbed by human activities (NATAIR, 2007). Note that WD is often difficult to distinguish from man-disturbed soil (i.e. agricultural activities, road traffic, construction), which enhance PM levels (Pikridas et al., 2013; Tolis et al., 2015) contributing significantly to air quality (Chatzimichailidis et al., 2014). Many efforts have been made in the past in order to study dust impact on air quality (Schaap et al., 2009; NATAIR, 2007) while a review of Tsiouri et al. (2014) indicated the adverse health effects that dust episodes have.

Sea-salt aerosol is one of the major components of the atmosphere as oceans cover 70% of the Earth's surface (Ovadnevaite et al., 2012; Tsyro et al., 2011) and it can be produced when wind disturbs water surface (Blanchard, 1989). SSA plays a significant role in the atmospheric chemistry through its reaction with anthropogenic component leading to changes in chemical composition of particles (Tsyro et al., 2011; Athanasopoulou et al., 2008).

BVOCs emissions from vegetation are the major contributor to total Volatile Organic Compounds (Tagaris et al., 2014). Moreover, they play an important role in PM composition due to their oxidation in the troposphere leading to the generation of secondary organic aerosols (SOA) (Froyd et al., 2010; Kanakidou et al., 2005).

Europe exhibits a large seasonal and spatial variability of natural emission sources (Schaap et al., 2009). Southern Europe and in particular the Eastern Mediterranean has been extensively used in the past as study area for simulating natural emissions. Its special climatic conditions, especially during the summer period (dry climate, northerlies) (Athanasopoulou et al., 2008, 2010; Kanakidou et al., 2011; Poupkou et al., 2014), enhance the production of WD. On the other hand, northern Europe and more specifically the Atlantic Ocean are characterized by strong winds during winter enhancing the transport of sea-spray to the continental areas (Tsyro et al., 2011). Biogenic emissions are also significant in the northern Europe (Poupkou et al., 2010).

Natural emissions are an important contributor to background pollution levels in cities and therefore the study of the air quality in Europe by incorporating both natural and anthropogenic sources into photochemical modelling systems and air quality forecasting systems (Marecal et al., 2015) is necessary in order to take the appropriate measures against air pollution.

The aim of the current study is to assess the atmospheric particulate pollution from windblown dust, sea-salt and biogenic emissions in Europe. Up to now, in most cases, the intra-European emissions from windblown dust are usually neglected in the air quality simulations due to the absence of dust emission schemes for Europe in addition to the fact that desert dust transport events are much more severe and frequent (Gerasopoulos et al., 2006; Perez et al., 2008; Remoundaki et al., 2013). However, also windblown dust emitted in Europe is considered to be an important natural source that should be taken into account in regional air quality simulations. Moreover, sea-salt and biogenic emissions are also significant natural sources that impact particle pollution levels in Europe. In the past, many studies have revealed the impact of natural emissions on air quality. However, most of them have studied separately the impact of different emission sources (Tsyro et al., 2011; Tagaris et al., 2014). Furthermore, previous modelling studies are usually presenting results focusing mostly on specific time periods within a year when the natural emissions are at maximum (Im, 2013; Tagaris et al., 2014). This work aims to present a comprehensive study of the impact of the most important natural sources in terms of particle pollution individually and all together by incorporating them into a well-documented photochemical modelling system using a new validated Natural Emissions MOdel (NEMO) that integrates in a single package updated emission methodologies (Liora et al., 2015). Thus, this study builds on the previous research of Liora et al. (2015) where the application and evaluation of NEMO was examined through its incorporation into an air quality modelling system applied on a high spatial resolution grid which covered Europe and the adjacent areas for a whole year. Section 2 presents a description of the modelling system and the emission data used as well as the simulation scenarios examined. In Section 3, the contribution of each natural emission source to total particle emissions and the air quality simulation results are discussed. Simulations are performed for different emission scenarios in order to study the impact of each natural emission source on PM levels. The conclusions of the study are summarized in Section 4.

2. Materials and methods

2.1. Modelling system

In the present study, the modelling system consisted of the Weather Research and Forecasting model (WRF v. 3.5.1; Skamarock et al., 2008) and the three-dimensional Comprehensive Air Quality Model with extensions (CAMx v.5.3; ENVIRON, 2010). The MACC reanalysis (Inness et al., 2013) run with the coupled model IFS-MOZART (Morcrette et al., 2009; Stein et al., 2012) and the EMEP MSC-W model (Simpson et al., 2012) provided the concentration data used as boundary conditions for the CAMx simulations. The Natural Emissions Model (NEMO; Liora et al., 2015) was used for the calculation of the natural PM emissions from WD and SSA as well as the BVOCs emissions from vegetation including isoprene, terpenes and other volatile organic compounds (OVOCs). The Model for the Spatial and Temporal Distribution of Emissions (MOSESS; Markakis et al., 2013) was used to spatially, temporally and chemically process the 2009 TNO-MACCII anthropogenic emission database (Kuenen et al., 2014). In addition, monthly potential anthropogenic PM emissions of mineral dust from agricultural activities and annual potential PM emissions from road traffic re-suspension were provided by The Netherlands Organisation (TNO). The anthropogenic dust emission data which had been estimated using the LOTOS-EUROS model (Schaap et al., 2009) were temporally and spatially analysed for the 30 km horizontal resolution grid using the model MOSESS as well as temporal profiles provided by TNO and taking into account the restriction that mineral dust emissions were forced to zero during precipitation events.

Aerosol processes, in CAMx, were modelled using a static two-mode fine/coarse scheme for the representation of the particle size distribution; fine were particles with diameter up to 2.5 μm while coarse were the larger particles with diameter from 2.5 μm to 10 μm. Fine particles ($PM_{2.5}$) were speciated as sulphates (PSO4), nitrates (PNO3), particulate ammonium (PNH4), sodium (Na), particulate chloride (PCl), primary organic aerosols (POA), primary elemental carbon (PEC), crustal, other primary fine particle and secondary organic aerosols (SOA). Coarse particles ($PM_{2.5\text{-}10}$) were