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Composition and origin of PM_{10} in Cape Verde: Characterization of long-range transport episodes

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HIGHLIGHTS

- PM_{10} sources at Cape Verde were characterized by multiple receptor techniques.
- PM_{10} levels variability was prompted by advections of African mineral dust.
- Mineral dust was frequently mixed with industrial emissions from northern Africa.
- Wildfires occurring at the African continent contributed to the levels of EC.
- Marine air masses strongly influenced the PM_{10} background levels.

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ABSTRACT

A receptor modelling study was performed to identify source categories and their contributions to the PM_{10} total mass at the Cape Verde archipelago. Trajectory statistical methods were also used to characterize the main atmospheric circulation patterns causing the transport of air masses and to geographically identify the main potential source areas of each PM_{10} source category. Our findings point out that the variability of the PM_{10} levels at Cape Verde was prompted by the advections of African mineral dust. The mineral dust load was mainly composed by clay-silicates mineral derived elements (22% of the PM_{10} total mass on average) with lower amounts of carbonates (9%). A clear northward gradient was observed in carbonates concentration that illustrates the differences in the composition according to the source regions of mineral dust. Mineral dust was frequently linked to industrial emissions from crude oil refineries, fertilizer industries as well as oil and coal power plants, located in the northern and north-western coast of the African continent (29%). Sea salt was also registered in the PM_{10} mass during most part of the sampling period, with a lower impact in the PM_{10} levels than the mineral dust one (26%). Combustion aerosols (6%) reached the highest mean values in summer as a consequence of the emissions from local-regional sources. Biomass burning aerosols produced from October to November in sub-sahelian latitudes, had a clear influence in the content of elemental carbon (EC) recorded at Cape Verde but a small impact in the PM_{10} total mass levels. A minor contribution to the PM_{10} mass has been associated to secondary inorganic compounds-SIC. Namely, ammonium sulfate and nitrate (SIC 1–5%) and calcium sulfate and nitrate (SIC 2–3%). The main origin of SIC 1 was attributed to emissions of SO_2 and NO_x from industrial sources located in the northern and north-western African coast and from wildfires produced in the continent. SIC 2 had a clear regional origin in the summer period. However, in the winter period there were probably contributions of soil emissions of evaporate minerals from regions of eastern Algeria. The location of Cape Verde in the Atlantic Ocean at subtropical latitudes, and the absence of relevant local sources of anthropogenic atmospheric pollutants, becomes

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this archipelago, a perfect site to study the impact of external contributions on the background levels of PM_{10} registered over the north-eastern tropical Atlantic.

1. Introduction

Mineral dust and sea salt are the largest sources of natural aerosols worldwide. Saharan desert is one of the most important sources of mineral dust, contributing with more than 1900 million tons per year (Goudie, 2009) and being responsible for almost half of all the Aeolian material provided to the world's oceans (Miller et al., 2004). A persistent outflow of Saharan dust is transported to long distances over the Mediterranean, Europe, North Atlantic Ocean and South America (Swap et al., 1992; Prospero, 1996; Remoundaki et al., 2011; Salvador et al., 2014).

Mineral dust transport has implications on the local, regional and global climate and on environment through the following processes: 1) direct effect on the shortwave and long-wave radiating flux through scattering and absorption; 2) indirect influence on radiation budget through interfering in cloud formation; 3) semi-direct effect on relative humidity, vertical stability and precipitation and 4) affecting physical parameters such as visibility (Goudie and Middleton, 2006; Klüser and Holzer-Popp, 2010; Knippertz and Todd, 2012).

Saharan dust events exert significant effects upon air quality and, consequently, on human health and well-being. Several epidemiological studies showed an association between atmospheric particulate matter (PM) and an increase in morbidity and rate of mortality (Krewski et al., 2004; Samet and Krewski, 2007; Almeida et al., 2014a; Cruz et al., 2015). According to the WHO (2013) new evidence suggests that short-term exposures to coarse particles (including crustal material) are associated with adverse respiratory and cardiovascular effects on health, including premature mortality. Desert dust episodes have been linked with hospital admissions and mortality in a number of recent epidemiological studies. In Italy, the work developed by Sajani et al. (2010) suggests an association between respiratory mortality in the elderly and Saharan dust outbreaks. In Greece, Nastos et al. (2011) showed that during a Saharan dust episode the hospital admissions due to respiratory diseases were 3-fold higher than the mean daily admissions. Pérez et al. (2008) and Jiménez et al. (2010) found that increases in PM_{10} levels linked to inflows of Saharan dust raised the risk of mortality in Barcelona and Madrid (Spain), respectively. More recently, Reyes et al. (2014) found a significant increase in respiratory-cause hospital admissions in Madrid associated with increases in PM_{10} and $PM_{2.5-10}$ concentrations during African dust outbreaks.

It should also be noted that aside from mineral dust, anthropogenic pollutants (Rodríguez et al., 2011) and microorganisms (Palmero et al., 2011) have been transported during Saharan dust events. Saharan storms are thought to be responsible for spreading lethal meningitis spores throughout sub-saharan Africa, during the dry season, where up to 250,000 people, particularly children, contract the disease each year and 25,000 die (Pérez et al., 2014 and references therein).

Cape Verde (CV), an archipelago composed by 10 islands located offshore of western Africa coast, is highly influenced by Saharan dust events (Chiapello et al., 1995, 1997). However, the Saharan dust impact on the PM_{10} levels currently registered at CV has not been estimated before. Otherwise, at CV islands a significant mixing of aerosols is expected due to the presence of sea salt and anthropogenic aerosol emissions, aside from desert mineral dust. However, uncertainties exist in the quantification of the highly variable distribution of this modified aerosol.

The main goal of this study was to investigate the influence of long-range transport episodes of PM on the concentration levels and chemical composition of PM_{10} registered at CV, a remote background site located in the north-eastern tropical Atlantic Ocean. This position in the Atlantic Ocean represents an important area to study and characterize Saharan/Sahel mineral dust transported over west Africa and the adjacent Tropical Atlantic Ocean.

In order to contribute for a better understanding and impact of the different sources, a 13-month measurement campaign was performed at Santiago Island in the scope of the project "Atmospheric aerosol in CV region: seasonal evaluation of composition, sources and transport" (CV-Dust) (Almeida-Silva et al., 2013, 2014; Fialho et al., 2014; Gonçalves et al., 2014). The main atmospheric circulation patterns causing the transport of air masses at the synoptic scale were characterized by means of an objective classification methodology of air mass back-trajectories arriving over CV. Then, the main PM_{10} sources contributing to the levels registered at CV during the sampling period, were identified by the Positive Matrix Factorization receptor model. Finally, the potential source areas of each PM_{10} source category were identified by a specific trajectory statistical method, the Redistributed Concentration Field method, and interpreted.

2. Materials and methods

2.1. Sampling

A surface field station was implemented in the surroundings of Praia City at Santiago Island (14°55′ N 23°29' W, 98 m asl), where aerosol sampling, with different samplers, was performed (Fig. 1).

PM was collected simultaneously with two low-volume samplers (Tecora and Partisol) and one Hi-Volume sampler (Tisch) all with standard PM_{10} inlet heads, between January 2011 and January 2012, performing 140 parallel samples. The sampling time ranged between 6 and 96 h, decreasing during Saharan dust episodes and increasing during periods with low PM concentrations in order to collect convenient aerosol masses in the exposed filters. This procedure reduced the risk of filter clogging, decreased the differences between masses collected in the different filters, benefited the chemical analysis, reduced the measurement errors and equalized them among the different samples. Nuclepore polycarbonate filters with 0.4 μm pore size, Teflon filters with 0.45 μm pore size and quartz filters were used with Tecora, Partisol and Hi-volume samplers, respectively. Before and after sampling Nuclepore and Teflon filters were stored in petri dishes and quartz filters were stored in aluminum foils. After sampling filters were stored at a temperature of −20 °C until gravimetric and chemical analysis.

2.2. Gravimetric and chemical analysis

PM_{10} mass concentrations were quantified by gravimetric method with a micro balance (±1 μg, polycarbonate and teflon filters) and with an analytical balance (±0.1 mg, quartz filter). The collected filters were weighed in a controlled clean room (class