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PM_1 variability and transport conditions between an urban coastal area and a high mountain site during the cold season

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HIGHLIGHTS

- The impact of winter-time stagnant conditions on PM_1 levels was studied.
- Measurements were made at a coastal urban area and a high altitude site in Spain.
- Urban PM_1 increases were maxima during the evening rush hour.
- At the mountain site the maximum increase was registered in the early afternoon.
- Pollutant transport from the coast to high sites occurs under specific conditions.

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ABSTRACT

During late autumn and winter, the western Mediterranean basin is often affected by severe pollution episodes (SPE) caused by stagnant weather conditions that produce a notable increase in particulate matter (PM) levels. The main objective of the present study is to evaluate the impact of these episodes on the variability of PM_1 concentrations at an urban and a high mountain station in the western Mediterranean. At the urban site, SPEs caused increases in PM_1 levels of up to 20 μg m^{-3} at 20:00–21:00 UTC due to a decrease in the mixing layer depth during the evening rush hour. In contrast, the highest increments at the high mountain station (~12 μg m^{-3}) were observed around midday. Since there are little anthropogenic emissions in the surroundings of the mountain station, this was most likely the result of aerosol transport from coastal urban areas and photochemical formation of secondary particles during transport. The transport of air pollutants through a complex orography occurs under specific weather conditions.

1. Introduction

It is well known that dispersion conditions, as well as short and long-range transport of pollutants, is a key factor affecting regional air quality (Monks et al., 2009; Squizzato et al., 2012). In this sense, regional background stations can provide valuable information to study the impact of these processes on the variability of pollutant concentrations (Bonasoni et al., 2004; Hinz et al., 2005; Pey et al., 2010; Uglietti et al., 2011). With this purpose, some stations have been recently settled at high altitude locations in the western Mediterranean basin (Nicolás et al., 2014; Pey et al., 2010). The particular geographic, orographic, climatic and demographic features of this region favor the occurrence of episodic events that have a significant impact on pollutant levels such as ozone and particulate matter (PM). Saharan dust outbreaks and recirculation of air masses are the most frequent events in the warm seasons, while the occurrence of stagnant conditions which trap the pollutants in the lower altitude is relatively high during late autumn and winter (Galindo et al., 2013; Gangoiti et al., 2001; Jorba et al., 2013; Nicolás et al., 2011).

The effects of stagnant weather conditions on the concentration and/or composition of urban aerosols have been studied in some previous works (Hai and Oanh, 2013; Kassomenos et al., 2011; Park et al., 2006; Vecchi et al., 2007). The majority of these works were focused on $PM_{2.5}$ and PM_{10} and there are fewer studies addressing the influence of dispersion conditions on the PM_1 fraction. This fraction, which is principally associated with anthropogenic activities, is especially sensitive to atmospheric stability conditions (Masiol et al., 2015; Galindo et al., 2011). Stagnation events are

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usually associated with large-scale high pressure systems with weak surface pressure gradients, resulting in light winds, low mixing heights and cloudless skies. This meteorological situation favors not only the accumulation of primary pollutants (such as elemental carbon) emitted by local sources but also the photochemical formation of secondary aerosols (Ham et al., 2010; Katzman et al., 2010; Mira-Salama et al., 2008; Strader et al., 1999; Yubero et al., 2015). Stagnation conditions can also affect PM levels at rural and regional background sites, although anthropogenic emissions are low compared with those in urban areas (Mira-Salama et al., 2008; Pey et al., 2010; Pietrogrande et al., 2014; Squizzato et al., 2012).

The main goals of the present study are: (1) to assess the impact of periods of highly stable atmospheric conditions on PM_1 concentrations at an urban coastal area in southeastern Spain and, (2) to determine the favorable conditions for aerosol transport from coastal emission sources to a high mountain location during these episodes.

2. Experimental

2.1. Study area: connectivity between the measurements sites

The study area is situated in a semi-arid region within the Spanish Mediterranean basin. The geographic location and the orographic features of the region are described in details in Caballero et al. (2007). Alternatively, a description of atmospheric dynamics and PM events in the area are presented in Nicolás et al. (2014).

The selection of the measurement sites was based on their suitability to achieve the proposed objectives. The site representative of a regional environment (high mountain site, MS) was located on top of Mt. Aitana (38°39′ N; 0°16′ W; 1558 m a.s.l.; Fig. 1a). The monitoring station was situated in a military area (EVA no. 5) belonging to the Spanish Ministry of Defense with very little anthropogenic activity. Therefore, any alteration of the normal levels of atmospheric particles can be easily detected. The second monitoring site (an urban site, US) was a station of the Regional Environmental Surveillance Network located on the outskirts of the city of Alicante (335.000 inhabitants; 38°21′ N; 0°30′ W; 20 m a.s.l.) close to an access road approximately 2 km from the coast (Fig. 1a). This site is representative of a suburban environment.

The route from Alicante to Mt. Aitana runs through valleys and mountains that rise as we approach the regional background site. Air masses passing over coastal metropolitan areas can carry urban atmospheric pollutants inland through the valleys. When the air masses reach the mountain barrier, these pollutants can be transported up-slope by mountain breezes and reach the top of the mountain range (Pey et al., 2010). However, the orographic profile between both sites (~37 km length in straight line, Fig. 1b) complicates the transport of pollutants from the coast inland.

2.2. Meteorological differences between the measurement sites

Despite the proximity between the two monitoring sites, significant differences of meteorological parameters can be observed (Table 1). These variations are caused by the difference in altitude among the two locations. During the measurement period (from October 2010 to February 2011) the temperature at the high mountain site was on average 9 °C lower than at the urban area. The temperature gradient, quite constant during the whole study period, was approximately −6.2 °C km^{-1}. Considerable differences between wind speed and relative humidity were also found. Average wind speed was about 7 times higher at the mountain site than at the coastal urban area. As regards relative humidity, it was also higher at MS, especially in November. This was not unexpected since, as air masses coming from the sea are transported up through the valleys and mountain slopes, the decrease in ambient temperature causes an increase in relative humidity.

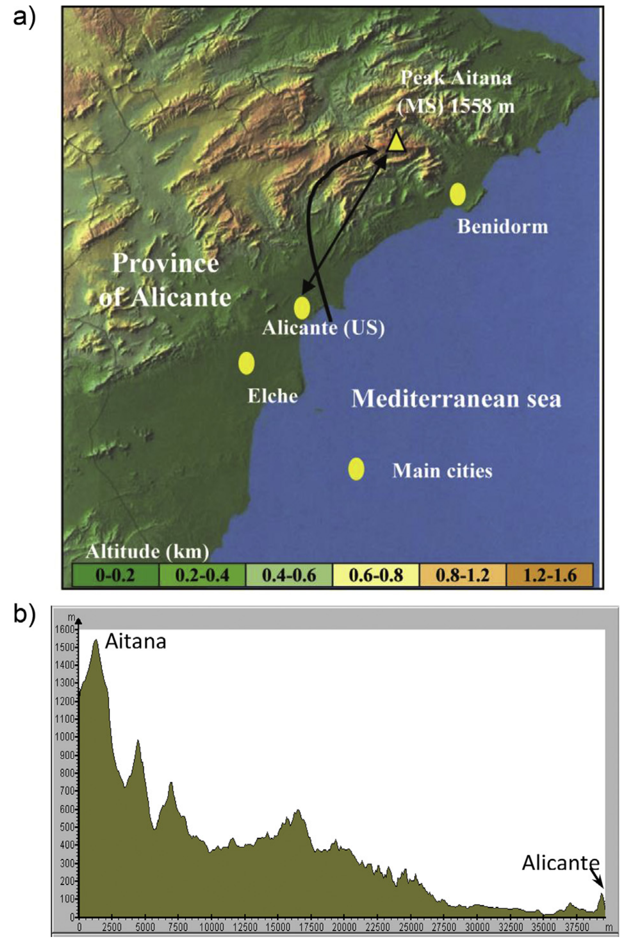

Fig. 1. (a) Location of the monitoring sites in southeastern Spain. The dashed line represents the most probable route of air masses along the orographic channels; (b) Topographic profile of the trajectory between the two monitoring sites as the crow flies.

Table 1
Meteorological parameters measured at the urban site (US) and the high mountain site (MS) during the study period.

Period	T_{US} (°C)	T_{MS} (°C)	RH_{US} (%)	RH_{MS} (%)	v_{US} ($m \cdot s^{-1}$)	v_{MS} ($m \cdot s^{-1}$)
Oct-2010	18.6	9.9	62.5	63.6	0.8	5.4
Nov-2010	14.9	4.0	56.5	81.5	1.2	7.9
Dec-2010	11.2	3.8	64.6	67.4	0.9	7.0
Jan-2011	11.5	2.4	65.5	77.9	0.8	5.9
Feb-2011	11.9	3.5	58.6	66.5	1.0	7.0
Global	13.7	4.7	61.5	71.4	0.9	6.7

T: Temperature; v: Wind speed; RH: Relative Humidity.

It is interesting to point out that solar radiation is systematically higher at the mountain site because it is frequently above the cloud layer. During the cold months differences in radiation intensity are low (119 W m^{-2} at MS against 112 W m^{-2} at US); however, variations are more significant during summer.

2.3. Data collection and analysis

As indicated in the previous section, the study period was from