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Characteristics of the east Mediterranean dust variability on small spatial and temporal scales

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HIGHLIGHTS

- Using cluster analysis to detect dust presence in a comprehensive PM10 database.
- Dust events' duration was delineated on a high (half-hourly) temporal resolution.
- Small scale variability in dust presence was found in both time and space.
- The detected correlation of dust with elevation ASL hints about the dust dynamics.
- Important methodology for fine-tuning dust exposure for epidemiological studies.

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ABSTRACT

The presence of naturally–occurring dust is a conspicuous meteorological phenomenon characterised by very high load of relatively coarse airborne particulate matter (PM), which may contain also various deleterious chemical and biological materials. Much work has been carried out to study the phenomenon by modelling the generation and transport of dust plumes, and assessment of their temporal characteristics on a large (>1000 km) spatial scale. This work studies in high spatial and temporal resolution the characteristics of dust presence on the mesoscale (>100 km). The small scale variability is important both for better understanding the physical characteristics of the dust phenomenon and for PM exposure specification in epidemiological studies. Unsupervised clustering–based method, using PM_{10} records and their derived attributes, was developed and applied to detect the impact of dust at the observation locations of a PM_{10} monitoring array. It was found that dust may cover the whole study area but very often the coverage is partial. On average, the larger the spatial extent of a dust event, the higher and more homogeneous are the associated PM_{10} concentrations. Dust event lengths however, are only weakly associated with the PM concentrations (Pearson correlation below 0.44). The large PM concentration variability during spatially small events and the fact that their occurrence is strongly correlated with the elevation above sea level of the reporting stations (Pearson correlation 0.87, p–value $< 10^{-5}$) points to small scale spatiotemporal dynamics of dust plumes.

1. Introduction

Dust storms originating in the world's deserts transport particulate matter (PM) from the sources to distances of up to thousands of km and may collect along their trajectory additional pollutants and allergens (Goudie, 2014). The presence of dust in the earth's atmosphere is an interesting phenomenon that was studied extensively with the goal of improving our understanding of its formation, transport and characteristics (eg Prospero et al., 2002; Goudie and Middleton, 2006; Maghrabi et al., 2011; Israelevich et al., 2012). The health effects of dust raised concerns and many studies looked at its possible association with various medical outcomes (eg the recent reviews by Karanasiou et al., 2012; Goudie, 2014, and references therein). Most of the studies looked at the dust phenomenon variability on a large (>1000 km) spatial scale (Querol et al., 2009; Pey et al., 2013) or at one single location (Koçak et al., 2007; Ganor et al., 2009; Mallone et al., 2011; Krasnov et al., 2014).

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To the best of our knowledge, the variability of dust presence at the mesoscale has not been looked at to date.

Many different methods have been utilised for studying airborne dust. Early work usually used chemical speciation in order to assess the contribution of natural sources to the total PM levels (eg, Ganor and Foner, 2001; Rodríguez et al., 2002). Particles with large fractions of Si, Al, Ca and other crustal components were attributed to mineral dust. Such methods involve costly and tedious analysis of filter data samples. Later studies sought methods that could be employed in a cheaper and more efficient manner. Following Escudero et al. (2005), in most cases an array of tools is used for the initial identification of dust episodes (Escudero et al., 2007a; Querol et al., 2009; Pey et al., 2013). These include back–trajectory analysis, satellite imagery, meteorological maps, and aerosol concentration maps from dust models. Mallone et al. (2011) used light detection and ranging (LIDAR) for detection of dust in Rome. The dust contribution is usually estimated using various measures of PM_{10} levels and their difference from some background values (Koçak et al., 2007; Escudero et al., 2007b; Querol et al., 2009; Dadvand et al., 2011; Mallone et al., 2011; Pey et al., 2013; Krasnov et al., 2014). Ratios of pollutant concentrations are used for verification (eg Mallone et al., 2011). In some cases only remote sensing (Zhang et al., 2006; Evan et al., 2006) or modelling outputs (Mitsakou et al., 2008; Jiménez-Guerrero et al., 2008) were used in dust studies.

All the above mentioned studies considered dust presence on a daily basis. The qualitative nature of the dust identification methods which they used, and the manual work which they require, set limits on the spatial and temporal extent of the phenomena which they were able to resolve. A daily temporal resolution seems compatible with epidemiological studies as health outcome rarely, if at all, are given at a higher resolution. It may also be sufficient for large scale studies concerned with dust contributions at the seasonal or annual time scales in a large spatial area. However, the turbulence associated with the transport of dust may be of much smaller temporal and spatial scales. Understanding the spatiotemporal variability of dust presence requires a much finer temporal resolution of the relevant data and an adequately spaced array of sensors. A scheme utilising those data have to function in an automatic manner. Ganor et al. (2009) introduced an algorithm to automatically detect dust presence using half–hourly PM_{10} data series. However, their algorithm was calibrated using daily dust observations at a specific location. Daily calibration data are too coarse to capture the high temporal variability that Ganor et al. (2009) expected to detect. (They assumed, correctly, that dust events may be as short as three hours.) Subsequent analysis also found some errors and omissions in the calibration data which were not detected during the original work. Moreover, as noted by Ganor et al. (2009), their calibration data may not be suitable for use in other locations, as indeed was found later by Viana et al. (2010).

This work explores the spatiotemporal variability of dust presence at the half–hourly temporal resolution in an area which is about 250 km by 40 km, using 19 monitoring stations reasonably spaced within it. The analyses are based on dust detection scheme that utilises only half–hourly PM_{10} concentration observations and their attributes. Unlike the above mentioned studies, our clustering classification scheme does not require calibration information. It is an unsupervised optimisation scheme (Liao, 2005; Hastie et al., 2009) which looks for hidden features in the data. It has been used extensively in the signal processing and pattern recognition fields (Liao, 2005) and we show it can be applied in environmental studies like ours which employ time series of substantial length.

2. Study area

The study area includes the Israeli shoreline and the western slopes of its coastal mountain range (see Fig 1). Local anthropogenic PM sources in the area are mainly transportation and large industrial plants. Additional major source of fine PM are secondary particulates transported from eastern and southern Europe (Asaf et al., 2008). Dust storms transport mineral dust to the region from the Sahara and the Arabian peninsula during the winter and the transition seasons. The dust contributes significantly to the total PM load (10–20% of the PM_{10} concentrations; Ganor et al., 2009) and there has been increasing interest in its impact on the population's health (eg Vodonos et al., 2014).

3. Data

PM monitoring and meteorological data were obtained from the Technion Centre of Excellence in Exposure Science and Environmental Health's air pollution monitoring data archive. The database includes all the half–hourly air quality monitoring data observed in Israel from 1997 to date. The data pass quality assurance and quality control processing before being released for use. The PM_{10} data used in this work are from standard monitoring stations (ie comply with the EU Council Directive 1999/30/EC for protection of human health), with at least 84% complete records for the years 2004–2013. The raw data were recorded by a tapered element oscillating microbalance (TEOM) devices (Thermo Scientific 1400) that provides a continuous direct mass measurement of particle mass. Table 1 provides descriptive statistics of the PM_{10} records and Fig. 1 shows the geographical locations of the stations. Note that the station numbers are ordered from south to north and that all the stations except 4 and 13 are within 35 km from the shoreline. Most of the stations are at elevations of less than 300 m above sea level. The only exception is station 4, located in Jerusalem at 786 m above sea level. Three of the PM_{10} stations (numbers 9, 10 and 15) also observe simultaneously $PM_{2.5}$. Most of the stations observe ambient temperature, and wind direction and speed. A few of them also observe relative humidity, barometric pressure and insolation.

Daily synoptic system classification at 12:00 UTC for the eastern Mediterranean during the study period 2004–2013 was calculated following Alpert et al. (2004). The method is based on a semi–objective classification of geopotential height, temperature and the horizontal wind components at the 1000 hPa level. Alpert et al. (2004) defined 19 synoptic systems characteristic to the eastern Mediterranean, which can be lumped into six groups: Red Sea Troughs (RST), Persian Trough (PT), High to the West (HW), Siberian Highs (SH), Winter Lows (WL) and Sharav Low (SL). Detailed description of the synoptic systems and their grouping as well as the classification can be found in Alpert et al. (2004).

4. Methods

4.1. Dust presence detection using cluster analysis

The major characteristic of naturally–occurring dust is an unusually high PM load. Dust-related PM tends to be of the coarser fractions (Koçak et al., 2007) and thus the main variable which we used for the detection of dust was the PM_{10} concentration. For each PM_{10} monitoring location, the half-hourly time points in 2004–2013 were grouped to dust–related or normal points based on the PM_{10} concentration, and the corresponding running maximum and minimum series, as explained below. Additional meteorological and air quality variables were also considered but were not used in the final classification for three reasons: (a) with the exception of the $PM_{2.5}/PM_{10}$ concentration ratio, none of them seems to contribute a considerable power for the clustering process beyond what the PM_{10} concentration and its attributes provide. (b) using additional variables, with values in a dynamic range much