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PM_{10} air quality variations in an urbanized and industrialized harbor

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ABSTRACT

In this paper we investigate the PM_{10} pollution episodes associated with meteorological situations in an urban and industrialized coastal site of the southern part of the North Sea, representative of a typical harbor for trade. In a first part, the spatio-temporal variability of PM_{10}, SO_2, NO_x and O_3 concentrations at the urban scale suggests that both regional air masses and local emissions affect harbor's pollution. In a second part, hierarchical clustering analysis (HCA) performed on meteorological data and PM_{10} concentrations reveals two main air quality (AQ) regimes. The first one is related to low PM_{10} levels, which occur under low-pressure conditions due to meteorological conditions favoring a good dispersion of pollutants. The second one is characterized by higher PM_{10} concentrations appearing under high-pressure conditions. The highest polluted days are characterized by the highest temperatures and hardly any rain. These pollution episodes predominantly occur during sea breeze days, but also as the result of occasional industrial releases. The HCA proved to be an appropriate method to define AQ regimes and to identify meteorological conditions favoring or not PM pollution episodes in Dunkerque conurbation.

1. Introduction

Harbors for trade are highly urbanized and industrialized, which often results in a poor air quality (AQ) (Gariazzo et al., 2007; Georgieva et al., 2007; Marr et al., 2007; Moreno et al., 2004). If gaseous pollutants like O_3 (Beaver and Palazoglu, 2006; Wang et al., 2001), SO_2 (Kim Oanh et al., 2005) or NO_x (Zhou et al., 2005) have been well-detailed in terms of sources and evolutions of the concentrations, the complex behavior of atmospheric particulate matter (PM) still needs further investigations. The study of the impact of atmospheric PM on air quality in coastal areas shall therefore include the spatio-temporal evolutions of PM_{10} in order to discriminate the marine component from the anthropogenic one. Indeed PM_{10} are target species of the World Health Organization (WHO, 2001) and the European Union framework Directive on ambient AQ assessment (EU, 1999), due to their adverse effects on human health and environment. Coastal sites display specific meteorological patterns, like sea/land breezes phenomena, playing an important role in the dispersion, transformation, removal or accumulation of air pollutants (Gariazzo et al., 2007; Baumgardner et al., 2006a,b). The occurrence of sea breezes in coastal areas may promote pollution episodes, mainly because the relatively cool and stable surface layer associated with a sea breeze hampers the dispersion of pollutants (Damato et al., 2003). In addition, pollutants can be trapped in land–sea breeze circulations (Bouchlaghem et al., 2007; Lo et al., 2006). In the Mediterranean harbor of Barcelona, Viana et al. (2005) observed that the harbor's PM levels were highest at night, due to the joint effect of the

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atmospheric stability, the small height of the thermal boundary layer and the low winds. They also suggested that the reverse daytime sea breeze may sometimes recirculate PM to the land thus worsening the air quality over inhabited areas. Similar observations have been made in other coastal sites in the world, in Hong Kong (Lo et al., 2006) or in Salina Cruz (Baumgardner et al., 2006a). The harbor of Dunkerque (51°N, 2°E), France, is representative of highly urbanized and industrialized coastal areas where atmospheric pollution is a major issue. Located on the eastern coast of southern North Sea, the harbor of Dunkerque and its surrounding industries contribute to major emissions of pollutants such as NO_x, SO_2, CO, CO_2, VOCs and PM. The climate corresponds to an oceanic tempered zone, with dominant wind direction from the SW and sea breezes from the NNE (Bigot and Planchon, 2003).

The understanding of air pollution in such areas requires high spatial resolution of the monitoring network, long time series with a fine temporal resolution (Yuval and Broday, 2006) and suitable statistical approaches for data analysis (Flemming et al., 2005; Gong et al., 2005), including pollution and meteorological data. The application of statistical tools (i.e. principal component analysis, backward trajectories analysis, …) on PM_{10} data have shown that the spatial and temporal variations of PM_{10} are governed by synoptic, local meteorological conditions (Augustin et al., 2006; Gupta and Kumar, 2006; Buchanan et al., 2002; van der Wal and Janssen, 2000), and local sources, especially in urban and industrial sites (Aldrin and Haff, 2005; Artinano et al., 2003, 2004; Yang, 2002). Hierarchical clustering analysis (HCA) is convenient to group data into clusters and is useful to define meteorological regimes (Darby, 2005; Fovell and Fovell, 1993). As far as air pollution is concerned, HCA was particularly applied to ozone, secondary pollutant strongly influenced by the meteorological conditions (Beaver and Palazoglu, 2006; Ludwig et al., 1995; Eder et al., 1994), but rarely to PM_{10} (Lu et al., 2006). This technique provides a graphical result describing the complex patterns of the AQ. In this study, a selection of statistical tools is applied to both pollution and meteorological data to explain the spatio-temporal variability of PM_{10} at the urban scale and identify AQ regimes related to PM_{10} levels and local weather conditions. These tools were applied to the air quality database of Dunkerque in 2002. The meteorological characteristics of year 2002 are indeed close to the seasonal averages calculated over 30 years by the French National Weather Service “Météo-France”. Besides the year 2002 does not show any exceptional weather anomaly, contrary to the summer heatwave in France in 2003. Therefore, this work aims at describing complex situations by means of usual statistical techniques for more effective and proactive decisions to improve future AQ.

2. Data

A general map of Dunkerque city and its suburbs is shown in Fig. 1. The harbor and heavy industrial activities are located in the northern part of Dunkerque while the population is more concentrated in the central part of the area under study. The regional air quality (AQ) monitoring network (ATMO Nord Pas-de-Calais) of Dunkerque consists of 11 stations covering 65 km^2. They are classified as traffic (T), urban (U), suburban (S) and industrial (I) (Table 1). The mean inter-station distances are 2 km in the urban zone and 6 km in the suburban one. Ten stations are located inside the agglomeration and one (S4) is located along the coast, 40 km far from the influence of industrial emissions (Fig. 1). The concentrations of SO_2, NO, NO_2, CO, O_3, PM_{10} and recently $PM_{2.5}$ have continuously been monitored (Table 1) and data are available on an hourly basis. Hourly averages of temperature (T), pressure (P), wind speed (WS) and wind direction (WD) are available at two meteorological stations (M1 and M2). Based on linear correlations, no significant difference was observed between M1 and M2 datasets. The correlation coefficients (r^2) calculated for WS, WD, T and P measured at these two stations are 0.8, 0.8, 0.97 and 0.98, respectively. Relative humidity (RH) and rainfall (R) are monitored at M3 station and data are only available on a daily mean. From a statistical point of view the year 2002 was suitable for the study because of a nearby-complete dataset (3.5% of missing AQ hourly data). The monthly values of T, P, RH observed for 2002 are in the following range: 6–19 °C, 1008–1021 hPa, 75–86%, respectively. The corresponding values measured during the former 30 years are 5–18 °C, 1010–1018 hPa, 80–85% for T, P, and RH, respectively. Thus, 2002 is representative of the weather of the studied area. A total of 782 mm of rain was recorded in 2002 that is analogous to the mean value (730 mm). The annual wind rose shows a prevailing SW sector (Fig. 1) with a 6.2 m/s mean speed. One year of data such as 2002 is sufficient to apply statistical tools and define accurate AQ regimes (Einax et al., 1997).

3. Statistical methodology

The measurements of air pollutants and meteorological quantities were analysed using univariate and multivariate statistical tools. First, the air pollutant dataset was screened through the box-whisker plot representation (Fig. 2), which provides an excellent visual summary of the data distribution, allowing the identification of outliers and a comparison of the datasets (Einax et al., 1997). Finally, the HCA was used to group observations that are close together in the variables space at many dimensions as there are variables. Initially, each observation represents its own cluster. Then, two clusters merged to form a new cluster. The process is repeated to obtain only one cluster. The Ward's method (Ward, 1963) is generally chosen as the aggregation algorithm because it minimizes the loss of information associated with each cluster and provides a robust classification (Lu et al., 2006; Sirois, 1998; Mangiameli et al., 1996; Kalkstein et al., 1987). Ward's aggregation defines the distance between two clusters in terms of the increase in the sum of squared deviations around the cluster mean that would occur if the two clusters were joined. HCA results are represented by a dendrogram. Two variables with the highest similarity is characterized by the shortest Euclidian distance between them. This method requires a complete dataset and missing data were dropped from the analysis. Since HCA cannot be applied to the variables having different units,