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Trends of air pollution in the Western Mediterranean Basin from a 13-year database: A research considering regional, suburban and urban environments in Mallorca (Balearic Islands)

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HIGHLIGHTS

- 13-years data of regulated air pollutants have been studied in Mallorca Island.
- Mallorca represents Western Mediterranean atmospheric phenomenology.
- Abatement policies and economic crisis explain most of the observed trends.
- Specific NAO conditions contributed positively to air quality improvement.
- The impact of local and continental abatement measures was differentiated.

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ABSTRACT

This study is focused in the evolution of NO, NO_2, SO_2, O_3 and PM_{10} concentrations, from 2000 to 2012, at urban, suburban and regional observatories in the Balearic Islands (Spain), an insular region in the Western Mediterranean.

At urban and suburban areas, daily patterns of most pollutants are strongly linked to land-traffic emissions, being the regional background less influenced. SO_2 variations, however, are mostly driven by the impact of other sources different from road traffic, including shipping emissions and power generation. Urban NO_x, SO_2 and PM_{10} concentrations exhibit a common weekly pattern, with a very slight accumulation during the weekdays and sharp decreases (15–39%) on weekends.

Our long-term database displays clear decreasing NO and NO_2 concentrations from 2000 onwards, prominent in the urban environment (-1.1 μg/m^3 year), and moderate in suburban and regional areas (up to -0.3 μg/m^3 year). At urban sites, O_3 behaviour ($+1.0$ μg/m^3 year) is opposite to that of NO, one of its main depletion agents. A moderate O_3 increasing trend ($+0.5$ μg/m^3 year) is detected at regional background areas, whereas a modest decreasing trend occurred at the suburban background (-0.4 μg/m^3 year), probably caused by enhanced vehicular emissions over these areas induced by urban planning and mobility policies. Finally, substantial PM_{10} drops are obvious, -0.7 μg/m^3 year at urban and suburban areas, and -0.5 μg/m^3 year in the regional background. Our results link the sharpest declines to air masses from western to northern sectors, pointing to effective pollution abatement strategies at a European scale. Some additional benefits are connected to the implementation of diverse local policies.

The effect of the North Atlantic Oscillation (NAO) was investigated. Negative NAO phases were related to additional air quality benefits, while positive phases mostly contributed to air degradation.

1. Introduction

Atmospheric pollution is one of the most challenging environmental problems to which contemporary societies are faced. Airborne particles are associated with different adverse impacts on

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human health (WHO, 2005, 2013; Samoli et al., 2013; Stafoggia et al., 2013). Similarly, exposure to nitrogen oxides (NO_x), ozone (O_3) or sulphur dioxide (SO_2) can induce some cardiovascular and lung diseases, premature deaths and carcinogenic effects (WHO, 2005, 2013). In addition, these atmospheric pollutants may also affect ecosystems (Bytnerowicz et al., 2007), agriculture (González-Fernández et al., 2014) and historical heritage (Genestar et al., 2014). Furthermore, one of the most relevant effects of atmospheric pollutants is on climate (IPCC, 2007).

Several strategies have been displayed throughout the continent to improve air quality during the period in study. Several laws focused on industries, such as the following directives: limitation of emissions of Volatile Organic Compounds (1999/13/EC); Waste Incineration Plant Emissions (2000/76/EC); National Emission Ceiling Directive (2001/81/EC); Large Combustion Plant Emissions (2001/80/EC); Integrated Pollution Prevention and Control Directives (1996/61/EC, 2008/1/EC); Industrial Emission Directive (2010/75/EU). In addition, measures focused on transport, such as EURO3, EURO4 and EURO5 European emission standards entered into force in January 2000, January 2005 and September 2009, respectively; and Shipping Emission Directives (1999/32/EC, 2012/33/EU) were also applied.

Particulate matter concentrations and gaseous pollutants (NO_x, SO_2, CO and O_3) have been measured on a regular basis in several European regions since the beginning of the 90's. This has allowed the investigation of trends at certain European regions (Colette et al., 2011; Barmpadimos et al., 2012; Cusack et al., 2012; Cerro, 2013; Querol et al., 2014). However, it is not always straightforward to discriminate the origin of the observed trends. Part of the observed PM_{10} changes in the NW Mediterranean can be explained by a decrease in African dust contributions (Pey et al., 2013b). Similarly, a partial decrease has been attributed to the occurrence of favourable meteorological situations connected with the atmospheric circulation over the northern Atlantic (Jerez et al., 2013). In addition, the vast implementation of abatement strategies over specific areas and/or the impact of the economic crisis can be the main reasons to explain such decrease (Cusack et al., 2012).

Since the 60's tourism is the most relevant economic sector in Mallorca. Besides of vehicular traffic, which is a major atmospheric pollution source in Mallorca, important emissions to the atmosphere are released from the energy sector, from a large waste incineration plant and from a cement factory. Furthermore, harbour and airport emissions may be significant at specific areas and/or for certain pollutants, especially during the warm season. Although air quality in Mallorca can be currently considered as good from a legislative point of view, particulate matter concentrations and specific gaseous pollutants exceed in different areas the European Directives targets, like the limit value for human health protection for NO_2 at urban areas, or the target value for human health protection for O_3 at regional environments. Up to date, the University of the Balearic Islands have led a number of studies on air pollution in the Balearic Islands (Mateu et al., 1998 and references therein). Additionally, a campaign performed in the suburbs of Palma de Mallorca in 2004–2005 was devoted to study PM_{10} and $PM_{2.5}$ concentrations, composition and sources (Pey et al., 2009, 2013a).

At a local scale, a number of abatement strategies have been implemented since 2000, mainly in Palma de Mallorca. Specifically, a considerable promotion of public transport was launched in 2000; bus-taxi lanes were delimited in 2002; several underground car parks were built in 2003; park-pay neighbourhood restricted and pedestrian areas have been implemented since 2004; improvements in the ring road have been introduced since 2005; the use of low consumption vehicles have been promoted since 2006; investments in public transport were done in 2007; and a wide range of measures, included in the Palma Air Quality Improvement Plan 2008 (Balearic Government, 2008) were adopted in the period 2008–2011. As a consequence of the economic crisis, a less ambitious plan (Palma Air Quality Improvement Plan 2011–2015) was finally approved (Balearic Government, 2013). Definitely, the financial crisis has been one of the most effective abatement measures. A 4% yearly reduction in vehicular traffic have been estimated since 2009, reversing the evolution from 2000 to 2008.

In this work we present a synopsis of recent trends (2000–2012) on various air quality metrics observed in the Mallorca Isle. The combined assessment at different environments allow us to discern changes induced by the implementation of regional policies from those caused by the enactment of continental strategies. Moreover, the effect of North Atlantic Oscillation index (NAOi) on different metrics, environments and seasons is evaluated.

2. Methodology

2.1. Monitoring network and data availability

More than a decade of uninterrupted measurements by the air quality monitoring network of the Balearic Islands Government provide, for the first time at an insular location in the Western Mediterranean Basin, the opportunity to study the trends and the variability of different air quality metrics. Hourly data of NO, NO_2, SO_2, O_3 and PM_{10} from 2000 to 2012 were compiled, being thereafter revalidated and used in this study.

According to the criteria included in the European Directive 2008/50/EC, the monitoring sites used in this work are classified in urban, suburban, and regional background. The location of the different monitoring sites is presented in Fig. 1.

In order to simplify the analysis, a merged database for each pollutant (O_3, NO, NO_2, SO_2 and PM_{10}) was built-up for each type of environment, as in Cerro (2013). This decision smoothens sporadic local influences in the case of the regional background conditions (4 sites), and converges into a better representation of suburban background conditions in Mallorca (2 sites). In the following sections urban, suburban and regional background environments will be referred to as UB, SB and RB respectively.

For this study, only those pollutants measured uninterruptedly since 2000 were considered: ozone (O_3), nitrogen monoxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and particulate matter PM_{10}. In addition, two essential criteria included in the guidelines of the European Environmental Agency (EEA, 2009) have been followed to decide which monitoring sites were selected for the analysis of trends: 1) the annual data coverage should be over 75%; 2) at least 8 of the last 10 years of data exist.

2.2. Monitoring techniques and data quality

All the measurements performed in the air quality network of the Balearic Islands comply with the European directives in terms of reference methods (as EN standards), or equivalent ones after the demonstration of their equivalence with respect to those. Specifically, EN 14212 for SO_2, based on ultraviolet fluorescence spectrophotometer; EN 14211 for NO_2, based on chemiluminescence detection; and EN 14625 for O_3, based on ultraviolet spectrophotometry, were used. These methods describe the measurement principle and operating characteristics of the equipment, but also specify the minimum criteria for quality assurance in a week maintenance, two-week verification and quarter calibration. These criteria have been strictly followed in the monitoring network under study.

The methods used for PM_{10} monitoring comprised real-time absorption of beta radiation and tapered oscillating microbalance.