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Coastal recirculation potential affecting air pollutants in Portugal: The role of circulation weather types

Ana Russo [a, *], Célia Gouveia [a], Ilan Levy [b], Uri Dayan [c], Sonia Jerez [d], Manuel Mendes [e], Ricardo Trigo [a]

[a] Instituto Dom Luiz, Faculdade de Ciências da Universidade de Lisboa, Campo Grande Edifício C8, Piso 3, 1749-016 Lisboa, Portugal
[b] Technion Center of Excellence in Exposure Science and Environmental Health, Technion Israel Inst. of Technology, Israel
[c] Department of Geography, The Hebrew University of Jerusalem, Israel
[d] Department of Physics, University of Murcia, Murcia, Spain
[e] Instituto Português do Mar e da Atmosfera, Rua C-Aeroporto, 1749-077 Lisbon, Portugal

HIGHLIGHTS

- Association between circulation weather patterns, air recirculation and pollution.
- K-means clustering associates the recirculation potential to circulation patterns.
- Ventilation events dominate but recirculation and stagnation occurs frequently.
- High NO2, SO2 and O3 levels events varies substantially among the airsheds.
- Methodology can be adapted to other geographical areas.

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ABSTRACT

Coastal zones are under increasing development and experience air pollution episodes regularly. These episodes are often related to peaks in local emissions from industry or transportation, but can also be associated with regional transport from neighbour urban areas influenced by land-sea breeze recirculation.

This study intends to analyze the relation between circulation weather patterns, air mass recirculation and pollution levels in three coastal airsheds of Portugal (Lisbon, Porto and Sines) based on the application of an objective quantitative measure of potential recirculation.

Although ventilation events have a dominant presence throughout the studied 9-yrs period on all the three airsheds, recirculation and stagnation conditions occur frequently. The association between NO_2, SO_2 and O_3 levels and recirculation potential is evident during summer months. Under high average recirculation potential and high variability, NO_2 and SO_2 levels are higher for the three airsheds, whilst for O_3 each airshed responds differently. This indicates a high heterogeneity among the three airsheds in (1) the type of emission – traffic or industry – prevailing for each contaminant, and (2) the response to the various circulation weather patterns and recirculation situations. Irrespectively of that, the proposed methodology, based on iterative K-means clustering, allows to identify which prevailing patterns are associated with high recirculation potential, having the advantage of being applicable to any geographical location.

1. Introduction

European coastal zones are under increasing pressure from pollution, climate change, erosion, urbanization and tourism. Such pressures threaten entire ecosystems and also have large economic and social impacts (EEA, 2010). Moreover, the human population density of European coastal regions is on average 10% higher than inland, being much higher in some countries, such as Portugal and Spain (EEA, 2010), which increases the pressure on coastal habitats.

* Corresponding author.
E-mail address: acrusso@fc.ul.pt (A. Russo).

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Many coastal cities experience air pollution episodes regularly, often related to high emissions of air pollutants and/or poor dispersion conditions (Mohan and Bhati, 2012), resulting from either local-scale conditions or regional-scale transport (Levy et al., 2010). Several works have been developed in order to understand the importance of weather conditions on pollution (e.g. Barros et al., 2003; Evtyugina et al., 2006; Carvalho et al., 2010; Levy et al., 2010).

The likely impact of wind flow on pollution potential, which is representative of the transport phenomenon and to a great extent of the diffusion, can be understood based on the analysis of special types of flow conditions such as stagnation, recirculation and ventilation (Mohan and Bhati, 2012).

An objective quantitative measure of air mass stagnation, recirculation and ventilation was proposed by Allwine and Whiteman (1994). The Allwine and Whiteman (AW) approach has the advantage of not requiring surface and upper meteorological observations and a previous knowledge of the atmospheric transport and dispersion conditions, but only the hourly wind components, and has been applied by several other authors (Table 1).

Complementary, there exists substantial literature employing other methods (e.g. Seagram et al., 2012; Surkova, 2013). However, such approaches often require detailed 3D wind data over the region, which isn't often available for long periods. Compared to them, and although the AW approach presents some limitations, as it doesn't accounts for terrain complexity, it constitutes a straightforward method to assess the assimilative and dispersal capacities of different airsheds (Mohan and Bhati, 2012).

Moreover, in recent years several studies have been published establishing objective links between circulation weather types (CWTs) and air quality (Dayan and Levy, 2002; Russo et al., 2014). Circulation pattern classification allows studying the climate of a region by stratifying large volumes of meteorological data into a small number of categories on a physically meaningful basis (Ramos et al., 2014).

The objective of this study is to analyze the relation between CWTs, potential recirculation and air pollutants affecting Portugal based on the AW approach. For that, an iterative K-means clustering analysis is performed assigning the CWTs to the recirculation potential of three different coastal airsheds. The concentration levels of NO_2, SO_2 and O_3 are analyzed in terms of wind flow conditions over the three airsheds and are associated with prevailing CWTs. Previous studies on pollution over Portugal have focused, among other topics, on air pollution modelling (Barros et al., 2003), on the association between prevailing circulation patterns and pollution (Barros et al., 2003; Saavedra et al., 2012; Russo et al., 2014), or even on the influence of sea breezes (Evtyugina et al., 2006). The added value of the present study lies on its purpose of establishing linkages between CWTs, pollutants and potential recirculation which will allow scrutinizing the carrying capacities of the airsheds and to rank these based on their potential.

2. Data

2.1. Air quality data

This study focuses on data from three air quality monitoring stations in the agglomerations of the two major Portuguese cities, Lisbon and Porto, and near a major industrial area (Sines) (Fig. 1). These three stations (Beato, Custóias and Monte Velho) are respectively located near the cities of Lisbon, Porto and Sines, which have high social and economic importance. They all are located on the shores of the Atlantic Ocean and exposed to moist Atlantic air flows reaching western Iberia (Trigo and DaCamara, 2000), mainly in winter months.

Despite the impact of the ocean that diminishes the effects of aerosols and gaseous pollutants, all the studied areas have been affected by several high pollution episodes in the last two decades (Russo et al., 2014). Moreover, most of the national emissions are concentrated along the western coast of Portugal (Monteiro et al., 2007). The traffic sector represents, compared to industrial activities, a major source of air pollution emissions on the national scale (Monteiro et al., 2007). Nevertheless, the three agglomerations encompass important industrial poles and, thus account for most of the industrial emissions. Lisbon and Porto areas accommodate large populations (approximately 2 and 1.2 million habitants, respectively) and therefore produce large traffic emissions, whereas Sines has approximately 45 thousand habitants.

Portugal is covered by an air quality monitoring network composed of urban, traffic, industrial, suburban and rural monitoring stations. Only background monitoring stations were chosen with the expectation that the confounding effect of local urban vehicular NOx emissions would be limited (Russo et al., 2014). The dataset comprises three of the most critical gaseous pollutants (O_3, SO_2 and NO_2) (Monteiro et al., 2007) recorded hourly by the monitoring stations, between 1999 and 2007.

2.2. Meteorological data

Hourly zonal (u) and meridional (v) wind components were retrieved for the years 1999–2007 from a hindcast regional climate simulation covering the whole Iberian Peninsula (IP) with a spatial resolution of 10 km (Lorente-Plazas et al., 2014). This simulation was performed with the MM5 mesoscale model (Grell et al., 1994) driven by the ERA40 reanalysis (Uppala et al., 2005) up to 2002 and by ECMWF analysis data from 2003 onwards. The simulation adopts exactly the same settings described in Jerez et al. (2013) and Lorente-Plazas et al. (2014). Jerez et al. (2013) and Lorente-Plazas et al. (2014) showed the reliability of the simulated wind field by comparison with an observational database evenly distributed over the whole IP, indicating that the simulation is able to reproduce the main regional circulation patterns as well as the temporal variability of the wind series. For this study, the u and v components were extracted for three sets of 9 points of the simulation grid (Fig. 1, darker markers) around Lisbon, Porto and Sines. The 9 grid

Table 1
Summary of some previous works.

Authors	Period	Local	Annual R_{avg}	Higher R_{avg} season	Weather patterns	Pollution
Venegas and Mazzeo, 1999	2 years	Argentina	0.16–0.25	Summer and Spring	No	No
Levy et al., 2008a	5 years	Israel	0.27–0.53	Autumn	Yes	Yes
Levy et al., 2010	2000–2004	Israel	–	–	Yes	Yes
Nankar et al., 2009	1995–2000	India	0.21–0.27	Summer	No	No
Pérez et al., 2011	2002–2005	Spain	–	Summer	Yes	Yes
Charabi and Al-Yahyai, 2011	2000–2005	Oman	–	Summer	No	No
Present Work	1999–2007	Portugal	0.10–0.39	Summer	Yes	Yes