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Surface ozone concentration trends and its relationship with weather types in Spain (2001–2010)

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HIGHLIGHTS

- Tropospheric ozone concentration shows an upward trend throughout all seasons.
- Ozone upward trend is in line with a reported decrease of NO_X emissions and with an increase in surface solar radiation.
- Synoptic meteorology is associated with ozone levels.
- Median concentrations were significantly lower in days with Anticyclonic weather.

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ABSTRACT

This paper assesses the temporal variations of surface ozone concentrations during the period 2001–2010 in 3 regions of Spain with different geographical and socioeconomic features (northern coastland, central inland and northeast inland), as well as its link with atmospheric circulation. Specifically, daily surface atmospheric patterns over the aforementioned regions are characterized using NCEP/NCAR reanalysis data and an objective classification scheme in order to study the relationship between synoptic weather types and daily ozone levels. The results show that tropospheric ozone concentration has a tendency towards an increase during the study period, both during daytime and nighttime. Moreover, in general, this upward trend is seen throughout all of the seasons. The observed trends are in line with a reported decrease of NO_X emissions and increase in surface solar radiation during the 2000s in Spain. On the other hand, interestingly, median concentrations were statistically significantly lower in days with anticyclonic weather conditions than in the rest of meteorological situations, while days with a directional weather type showed higher median levels of ozone concentration, with maximum values in days with northern and eastern component. Due to the detrimental effect that ozone has on human health, the relationship between synoptic weather patterns and daily ozone levels shown in this work could potentially be used for implementing pollution level alert protocols depending on forecast weather types.

1. Introduction

Since the discovery of ozone and its first measurements in Europe at the end of the nineteenth century, background ozone concentrations have more than doubled, showing a significant increase during the last few decades, both in rural and urban areas (e.g., Volz and Kley, 1988; Parrish et al., 2012; Querol et al., 2014; Paoletti et al., 2014). This increment in ozone concentrations is alarming given its effects on living beings and their ecosystems, but also because, even though different hypotheses have been formulated to explain its cause, the concrete reasons behind this upward trend are still debated, making it difficult to implement control measures for ozone levels.

The analysis of tropospheric ozone concentrations is highly important since, apart from being a greenhouse gas, its strong oxidant properties, at certain levels, can affect animals, vegetation, materials and have an effect on human health not only for predisposed patients, such as asthma sufferers and children, but also

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for previously healthy individuals (Yanga et al., 2012; Halonen et al., 2010).

Ozone is a secondary pollutant which follows clear seasonal and daily cycles, presenting higher values in the summer and during daytime and lower concentrations in the winter and at night, which is determined by its photochemical generation processes (Sebald et al., 2000; Dueñas et al., 2004; Gerasopoulos et al., 2006; Zvyagintsev et al., 2008). Its formation process is highly dependent on air mass exchange between the stratosphere and the troposphere, surface dry deposition, temperature, solar radiation, NO_X emissions and environmental concentrations of volatile organic compounds (e.g., Trainer et al., 2000). Thus, most studies have shown a strong relationship between ozone concentration levels and solar radiation, air temperature, relative humidity and wind speed and direction (e.g., Adame et al., 2010; Thompson et al., 2001; Dueñas et al., 2002; Demuzere et al., 2009; Sekiya and Sudo, 2012).

Synoptic scale meteorological patterns determine the conditions for the long-range transport of ozone, while also affecting the interaction among ozone precursors, facilitating its formation and destruction. Specifically, several approaches have been used with the intention of describing their relationships to ozone concentrations and the meteorological conditions that affect its formation, destruction and transport processes, such as categorizing a wide variety of complex meteorological variables in different atmospheric circulation (e.g., García et al., 2005; Tang et al., 2009).

For decades, climatologists have dealt with the topic of systematize atmospheric circulation conditions by means of a catalog of weather types (WTs), which has led to the existence of several classification methods (for additional details see, for example, Philipp et al., 2010). Traditional manual subjective methods, such as those proposed by Lamb and Britain (1972) for the British Islands, or by Hess and Brezowsky (1952) for Central Europe, have been combined with or even replaced by objective or semi-automatized techniques which allow for the analysis of large amounts of data in less time and effort (e.g., Esteban et al., 2006; Beck and Philipp, 2010; Philipp et al., 2010).

The method devised by Jenkinson and Collison (1977) can be considered an automatized version of Lamb's classification, and it is based on a group of indices related to the direction and vorticity of the geostrophic flux calculated on sea level pressure (SLP) data. Several authors have used this classification method in recent years with the aim of finding a relationship between WTs and different environmental phenomena of natural and anthropogenic origin such as heavy snowfalls, droughts, landslides, soil erosion, and pollution (e.g., Cortesi et al., 2013; Nadal-Romero et al., 2013; Andrade et al., 2011).

This paper assesses the temporal variations (i.e., cycles and trends) of surface ozone concentrations for the period 2001–2010 in 3 regions of Spain with different geographical and socioeconomic features and suggests a new hypothesis to explain the increase in ozone concentrations in Spain. Daily surface synoptic circulation patterns over the aforementioned regions are also characterized using NCEP/NCAR reanalysis data in order to study the relationship between synoptic weather patterns and daily ozone levels. Our results could potentially be used for implementing pollution level alert protocols depending on forecast weather types. The datasets and methods used in this study are described in Section 2. The results are presented and discussed in Section 3, both the ozone variability and trends (Section 3.1) and its relationship with atmospheric circulation patterns (Section 3.2). Finally, conclusions of this study are presented in Section 4.

2. Methods

2.1. Sites description

The present work analyzes ozone concentration series from 3 Spanish regions (Fig. 1): central inland (Madrid), northeast inland (Saragossa) and northern coastland (Santander). The first area of study is situated at the center of the Iberian Peninsula under Mediterranean climate conditions, affected by its inland location. This area is characterized by different stations located at the metropolitan area of Madrid, the national capital and the most populated city in Spain. The surrounding area (the Autonomous Community of Madrid) ranks first in regional contribution to the national Gross Domestic Product (GDP). The industrial and manufacturing sector accounts for 13% of its economy. The second studied area is located in the Ebro valley and is characterized by stations located in Saragossa city. In this area (northeast inland Iberian Peninsula) climate characteristics are that of a semi-desert Continental Mediterranean climate. Saragossa is the fifth most populated city in Spain, and ranks fourth in the Spanish Economy Activity Index (Índice de Actividad Económica, IAE). The third and last region included in this work is Cantabria, situated in the northern region of Spain, which has mountainous and maritime characteristics. Its capital and most populated city is Santander. Cantabria has a humid temperate oceanic climate, and it is much less populated than the other two regions in this study, its population amounting to 1.26% of that of the country.

Hourly data of tropospheric ozone concentration for a period of 10 years between 1 January 2001 and 31 December 2010 were obtained from the Consejería de Medio Ambiente of Madrid, the City Council of Saragossa and the Consejería de Medio Ambiente of Cantabria. These government agencies measure ozone concentrations using ultraviolet absorption-based instruments. Two different filtering criteria were applied when selecting the measuring stations: 1) Only stations which were free from the direct influence of local point sources and were therefore representative of background boundary layer air would be included; 2) Once data was validated and daily average values were calculated, stations having fewer than 85% of daily data points were discarded. In addition, the homogeneity of the different series was confirmed by plotting and comparing their respective histograms. The resulting 9 measuring stations were (Fig. 1):

- Cantabria: Castro Urdiales (east of Santander), Reinosa (south of Santander), Tetuán (in the urban center of Santander) and Zapatón (southwest of Santander).
- Madrid: Aranjuez (south of Madrid city), Majadahonda (northeast of Madrid city) and Móstoles (southwest of Madrid city).
- Saragossa: Roger the Flor and Picarral (both located in the urban center of Saragossa city).

The number of data points and completeness of the validated hourly series (once anomalous data were removed) are shown in Table 1. Daily concentration values were calculated by averaging the 24 h period between 8 a.m. and 7 a.m. of the following day.

2.2. Weather types classification

The objective method to classify the original Lamb's WT catalog developed by Jenkinson and Collison (1977) was used to classify WTs, using daily mean SLP data (2.5 × 2.5° latitude–longitude) from the NCEP/NCAR Reanalysis Project (Kistler et al., 2001).

Daily circulation WTs were determined using physical or geometrical approaches, such as the direction and strength of airflow and the degree of vorticity. The following indices were