Science of the Total Environment 541 (2016) 701–713

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

A model-based analysis of SO_2 and NO_2 dynamics from coal-fired power plants under representative synoptic circulation types over the Iberian Peninsula

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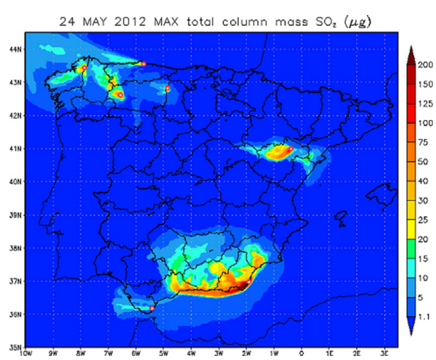
HIGHLIGHTS

- Synoptic circulation controls coal-fired power plants plumes from Atlantic facilities.
- A combination of synoptic and mesoscale circulations drives Mediterranean plumes.
- Under Atlantic dominated circulation types, pollution plumes can reach up to 250 km.
- Emission injection within the PBL favours fumigation close to the source (<20 km).
- Hourly contribution to SO_2 and NO_2 ranges 2–25 μg m^{-3} and 1–15 μg m^{-3}, respectively.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 May 2015
Received in revised form 21 September 2015
Accepted 22 September 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Synoptic classification
Coal-fired power plants
SO_2/NO_2 plumes dynamics
CALIOPE-AQFS
Air quality modelling
Mesoscale
Emissions

ABSTRACT

Emissions of SO_2 and NO_2 from coal-fired power plants are a significant source of air pollution. In order to typify the power plants' plumes dynamics and quantify their contribution to air quality, a comprehensive characterisation of seven coal-fired power plant plumes has been performed under six representative circulation types (CTs) identified by means of a synoptic classification over the Iberian Peninsula. The emission and the transport of SO_2 and NO_2 have been simulated with the CALIOPE air quality forecasting system that couples the HERMES emission model for Spain and WRF and CMAQ models. For the facilities located in continental and Atlantic areas (As Pontes, Aboño, and Compostilla) the synoptic advection controls pollutant transport, however for power plants located along the Mediterranean or over complex-terrains (Guardo, Andorra, Carboneras, and Los Barrios), plume dynamics are driven by a combination of synoptic and mesoscale mountain–valley and sea–land breezes. The contribution of power plants to surface concentration occurs mainly close to the source (<20 km) related to a fumigation process when the emission injection takes place within the planetary boundary layer reaching up to 55 μg SO_2 m^{-3} and 32 μg NO_2 m^{-3}. However, the SO_2 and NO_2 plumes can reach long distances (>250 km from the sources) especially for CTs characterised by Atlantic advection.

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http://dx.doi.org/10.1016/j.scitotenv.2015.09.111
0048-9697/

1. Introduction

Air pollution is a threat for human health (Brunekreef and Holgate, 2002; Gurjar et al., 2010; WHO, 2013) and the environment (de Vries et al., 2014). In the last years, the European Union has established limits to the emission of air pollutants (National Emission Ceilings Directive 2001/81/EC) and legally binding limit values for air quality (Directive 2008/50/EC) in order to reduce the exposition of people and ecosystems to harmful concentrations of pollutants. Partially due to these policy actions, during the 2001–2012 period, the SO_2 and NO_2 concentration at the remote rural European Monitoring and Evaluation Programme (EMEP) stations in Spain declined 3.6 to 7.7%/year and 2.8 to 3.7%/year, respectively (Querol et al., 2014).

Despite the increase in renewable electricity production in Spain by 50% in the 2008–2012 period (REE, 2013) and the use of cleaner technologies and fuels (ORDEN PRE/77/2008), the contribution of coal-fired power plants to the electricity generation pool was 19.3% in 2012, 54,721 GWh for the Spanish Iberian Peninsula (REE, 2013), being the second technology in electricity generation in 2012 after nuclear (22.1%) and before wind power (18.1%). Although SO_2 and NO_2 emissions from energy industry (SNAP01) have been reduced by 29.7% and 12.5% during the period 2008–2012, respectively (MAGRAMA, 2014); they were still significant in 2012 corresponding to a 41% and 22% of the SO_2 and NO_2 total Spanish emissions, respectively. The emissions from coal-fired power plants were the main contributor within the SNAP01 with 79% and 55% of SO_2 and NO_2 emissions, respectively.

The synoptic scale circulation is considered to play a significant role in air pollution both transporting primary and secondary pollutants through long distances (Vivanco et al., 2012; Putero et al., 2014) and controlling the effect on the local meteorological conditions (Kassomenos et al., 1998; Menut et al., 1999, Segura et al., 2013). Several studies relate how different circulation types (CTs) establish dissimilar effects on health for respiratory (Jamason et al., 1997; de Pablo et al., 2013), cardiovascular, and digestive diseases (Morabito et al., 2006, de Pablo et al., 2008).

Circulation-type classification summarises a complex series of synoptic conditions into a catalogue containing a small number of predominant modes of atmospheric circulation or CTs (Barry and Perry, 1974; Beck and Philipp, 2010; Philipp et al., 2014). Each CT is associated with a number of distinctive meteorological behaviours and predominant flow characteristics (Shahgedanova et al., 1998). Several CT classifications have been performed over the Iberian Peninsula (IP) for different applications. Recently, an objective classification based on a climatic database has been developed for air quality purposes and could be used to analyse the plume dynamics under representative CTs (Valverde et al., 2014).

The dispersion of the pollutants emitted at high stacks relies on combination of meteorological fields and is affected by topography (Palau et al., 2005, 2009). Plume dispersion at power plants, refineries and incinerators has been analysed in impact assessments studies under particular pollution episodes over Spain (Salvador et al., 1992; Hernández et al., 1995, 1997; Puig et al., 2008; Baldasano et al., 2014). However, there is no a comprehensive characterisation of the plume dynamics from coal-fired power plants considering the influence of (1) the facilities characteristics, (2) the topography, and (3) the synoptic conditions affecting the IP. Understanding the plume dynamics and the specific contribution of power plants to air pollution under representative CTs can improve the power grid management in the context of environmental sustainability.

The objective of this work is twofold. First, to characterise the plume dynamics for selected Spanish coal-fired power plants under representative CTs over the IP, describing the role of emissions, meteorology, and topography. Second, to determine the contribution of SO_2 and NO_2 surface concentration of each power plant under each CT.

The paper is organised as follows. Section 2 describes the methods and data used. Section 3 characterises the power plants' plume dynamics and analyses their contribution to surface SO_2 and NO_2 concentration. Finally, Section 4 discusses the synoptic circulation role on plume dynamics over the IP.

2. Methods

This section presents the facilities that have been chosen for this study together with the circulation type classification used. The CALIOPE air quality forecasting system (CALIOPE-AQFS), whose characteristics are presented, is used in a case study context to characterise the power plants plume's dynamics.

2.1. Power plants selection

There are currently sixteen Spanish coal-fired power plants (combustion installations with boilers >300 MWt) in the IP. Seven facilities have been selected for this study considering those with highest contribution in terms of energy generation (>950 GWh $year^{-1}$) (Table 1 and Fig. 1). They represent 63.7% of the installed capacity and 79.4% of the 2009 electricity production of coal-fired power plants.

2.2. Selection of the episodes of study

The present work uses the synoptic classification established in Valverde et al. (2014) which objectively identifies six CTs over the IP (Table 2 and Fig. 2) over the present climate (1983–2012). The three most common CTs account for 67.6% of climatic frequency and mainly occur in the summertime, replacing one another. NWadv (23.9%) is a N/NW advective pattern characterised by the arrival of polar maritime air masses towards the IP; IBtl (22.4%) depicts a reduced pressure surface gradient, enabling the development of the Iberian thermal low with net advection of North African air masses; ENEadv (21%) is especially frequent in spring and summer as a result of a blocking anticyclone over Central Europe that leads to E/NE advection towards the IP. During the winter, the most frequent CTs are the AtlHi (12%) which is an anticyclonic situation that enables the arrival of Atlantic air masses towards the IP and the ZonWadv (10%) which is characterised by zonal Atlantic maritime advection. Finally, WSWadv (10%) is typical of transitional seasons presenting unstable conditions with western-southwestern winds and precipitation.

Following Valverde et al. (2014), one day for each CT was identified as representative of the synoptic scale circulation following an objective procedure (Table 2). On the representative day of each CT, the atmospheric circulation over the IP domain corresponds with the one characterising each CT. This selection of days is used to analyse power plants plume dynamics because the obtained conclusions are representative of the existing synoptic variability over the IP for the present climate (1983–2012).

2.3. Air quality simulations

The CALIOPE-AQFS (www.bsc.es/caliope) operationally provides 48-h forecast concentrations of main pollutants over the IP at high spatial (4 km × 4 km) and temporal resolution (1 h); the system is described and evaluated in detail elsewhere (Baldasano et al., 2008, 2011; Pay et al., 2011, 2012, 2014). It integrates the Weather Research and Forecasting model which uses the advanced research dynamical solver, WRF-ARWv3.5 (Skamarock and Klemp, 2008), a specific emission model (HERMESv2; Guevara et al., 2013, 2014), the Eulerian area-limited Community Multi- scale Air Quality model (CMAQv5.0.2; Byun and Schere, 2006), and an off-line mineral dust atmospheric model (BSC-DREAM8bv2 (Pérez et al., 2006a,b; Basart et al., 2012).

WRF-ARW runs over Europe (the mother domain) at 12 km × 12 km horizontal resolution using initial and boundary conditions from the