Characterization of coal power plants plume dynamics under typical synoptic conditions over the Iberian Peninsula

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Abstract- *This work describes the pollution plumes of seven Spanish coal power plants under the most typical meteorological conditions that affect the Iberian Peninsula at synoptic scale. The aim is to understand how meteorology modulates the plume dynamics (length, altitude, orientation) and their contribution to NO_2 and SO_2 surface concentration. Using the BSC-ES operational air quality forecasting system (CALIOPE-AQFS), the behavior of the plumes is analyzed for a representative day of each of the six most common synoptic situations. The results show that the plumes from Atlantic facilities are mainly driven by synoptic conditions whereas for power plants located over the Mediterranean and on mountainous regions, mesoscale dynamics dominate. Moreover, when the injection of the pollutants is done within the planetary boundary layer there is an increase in the NO_2 and SO_2 surface concentrations close to (<15-20 km) the sources.*

I. Introduction

Air pollution can be defined as a situation in which substances are present in the atmosphere at concentration sufficiently high above their normal levels to produce a measurable effect on humans, ecosystems or materials [1]. The concentration of pollutants in the atmosphere depends on interlinked processes: the emission from natural and anthropogenic sources, the transport and transformation of the pollutants, and the deposition. The exceedances of air quality limit values in Spain are related to Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), Ozone (O_3) and particulate matter [2]. The combustion of fossil fuels for the generation of electricity is an important contributor to NO_2 and SO_2 emissions. In Spain, despite the increase in the wind and solar electricity production, coal power plants still contribute with ~20% of the electricity generation [3]. In 2012, the associated annual emissions were ~14% of NO_2 and ~52% of SO_2 total Spanish emissions [4].

TABLE I
CHARACTERISTICS OF THE STUDIED POWER PLANTS

Power plant / Acronym	Installed capacity (MW)	Stack height (magl)	NO_2 / SO_2 emissions ($Gg.year^{-1}$)
As Pontes / ASP	1 468	356	7.46 / 4.99
Aboño / ABO	921	225	8.13 / 5.83
Compostilla / COM	1 341	290	8.38 / 3.79
Guardo-Velilla / GUA	498	176	3.07 / 0.82
Andorra / AND	1 101	343	10.00 / 11.71
Carboneras / CAR	1 159	200	9.80 / 13.99
Los Barrios / LBB	568	230	5.39 / 2.53

III. Objective

This work aims to characterize the dynamics of the plumes from coal power plants under the typical meteorological conditions affecting the Iberian Peninsula in order to better understand the role of these large point emission sources on air quality.

IV. Methodology

There are currently 16 coal power plants (combustion installations with boilers > 300MWt) in Spain, seven of which have been selected in this study among those with highest electricity generation in 2012 (Table 1). The power plants have varied structural and topographical characteristics.

The present work uses a synoptic classification objectively established over the Iberian Peninsula for air quality purposes [5]. This classification identifies six typical circulation types (CTs) for the present climate (1983-2012) using a k-means clustering technique on daily sea level pressure. The six CTs consistently represent different advective patterns towards the Iberian Peninsula. The two most common CTs occur in summertime, replacing one another. NWadv (23.9% of climatic frequency) is a NW advective pattern characterized by the arrival of polar maritime air masses towards the Iberian Peninsula. IBtl (22.4%) is compatible with the development of the Iberian thermal low with net advection from North African air masses. ENEadv (21%), especially frequent in spring, is the result of a blocking anticyclone over central Europe that leads to E-NE advection towards the Iberian Peninsula. AtlHi (12%) is a winter anticyclonic situation that enables the arrival of Atlantic air masses towards the Iberian Peninsula, whereas ZonWadv (10%) is characterised by zonal Atlantic maritime advection. WNWadv (10%) is typical of transitional seasons and it presents unstable conditions over the Iberian Peninsula with W-NW advection. A representative day of each CT is objectively identified by [5] in the year 2012.

The characterization of the plume dynamics is performed on the representative day of each CT by means of the CALIOPE-AQFS (Fig. 1). Several evaluations of the modelling system give confidence to the results [6, 7]. The specific plumes are obtained following a zero-out approach The characterization comprises a comprehensive analysis of the emissions, the synoptic and mesoscale meteorology and the surface and total column mass of NO_2 and SO_2.

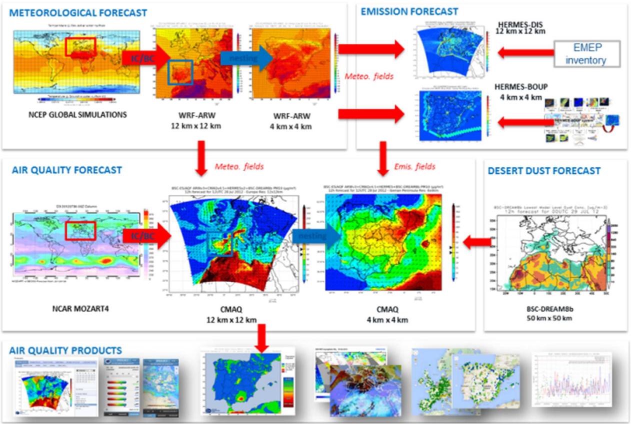

Fig. 1. Schematic view of the CALIOPE- air quality forecasting system www.bsc.es/caliope. The CALIOPE couples the dedicated HERMES emission model, the WRF-ARW meteorological model, the CMAQ chemical-transport model and the BSC-DREAM8b mineral dust model [6].

RESULTS AND DISCUSSION

The plume dynamics are comprehensively described in [7] using hourly NO_2 and SO_2 surface concentration maps total column mass maps (Fig. 2), vertical cross-sections, planetary boundary layer height, wind speed and direction and, the vertical vorticity at each power plant on each representative day.

The analysis of the transport dynamics of NO_2 and SO_2 emissions for each CT does not show a common behavior for the seven studied power plants. It is possible to define two kinds of power plants depending on their plume dynamics. On the one hand, there are facilities whose plume dynamics are mainly driven by synoptic winds (the plume follows the characteristic advective pattern of the CT). This is the case of power plants on the Atlantic region of the Iberian Peninsula ASP, ABO and COM. On the other hand, there are facilities located over the Mediterranean and in complex topographic areas (AND, CAR, LBB and GUA) whose plumes are driven by a combination of the synoptic advection and mesoscale processes (sea-land breezes and wind-channelling by river valleys).

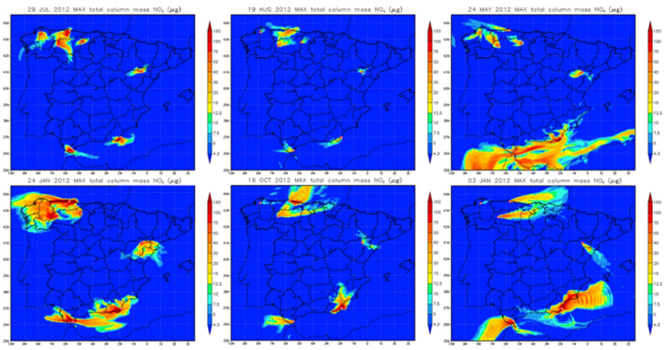

Fig. 2. Daily maximum NO_2 total column mass (µg) in the Iberian Peninsula associated to the emissions in the seven analyzed power plants on the representative day of each CT.

The maximum surface contribution of each power plant under the six CTs shows similar patterns for NO_2 and SO_2, although SO_2 contributions are generally higher. However, there are significant differences between power plants (largest contributions in CAR, ABO, and LBB) and synoptic conditions (AtlHi and NWadv present higher contributions than the other CTs).

For the synoptic-dominated power plants the plume length is larger for CTs characterised by Atlantic advection (NWadv, AtlHi, WSWadv and ZonWadv) than for CTs with non-Atlantic advection (IBtl and ENEadv). For NO_2, 76 km vs 24 km, respectively (Fig. 2). For SO_2, 81 km vs 45 km, respectively. Furthermore, the contribution to surface NO_2 concentration is lower for Atlantic advection CTs than for non-Atlantic advection CTs, 11.8 and 14.8 µg $NO_2.m^{-3}$, respectively.

For the power plants that are along the Mediterranean (CAR, LBB) and/or in complex topographic areas (AND, GUA) the NO_2 and SO_2 contributions are higher under winter/autumn CTs (on average 19.2 µg $NO_2.m^{-3}$ and 16.4 µg $SO_2.m^{-3}$), during which emissions are maximal than during the summer/spring CTs (11.6 µg $NO_2.m^{-3}$ and 5.6 µg $SO_2.m^{-3}$).

Overall to all the power plants, close to the source contributions (< 15-20 km) are larger when the injection of the emissions is done within the planetary boundary layer (PBL), usually at midday under summer CTs. On autumn/winter CTs the PBL height is lower than the injection height, favouring horizontal dispersion of the plume.

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