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# USE OF A CLIMATIC SYNOPTIC CLASSIFICATION TO IDENTIFY AND CHARACTERIZE $NO_2$ POLLUTION PATTERNS OVER THE IBERIAN PENINSULA

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**Abstract**: Air pollution is directly associated to emissions and is strongly influenced by meteorology and topography. This work characterizes $NO_2$ concentration over the Iberian Peninsula (IP) under typical circulation types (CTs) using the CALIOPE air quality forecasting system (www.bsc.es/caliope) running at high temporal (1h) and spatial resolution (4 km x 4 km) using the bottom-up HERMES emission model. CTs are identified by means of an automatic and objective synoptic classification on a climatic basis (1983-2012) using meteorological data from the ERA-Interim reanalysis. Sensitivity analyses to parameters affecting the resulting classification are performed by means of the cost733 classification software in order to maximize its quality and to be applied on the air quality characterization. The identified CTs are described in terms of frequency, persistence, transitions, and location of high and low pressure areas. The six identified CTs discriminate typical synoptic patterns that are in agreement with the literature. The relationship between CTs and $NO_2$ concentration dynamics are analysed in representative days of the CTs. For all the CTs, there is a synoptic control of $NO_2$ concentration in areas of the central, northern, and southern IP. The orientation, strength and concentration of $NO_2$ plume from urban and industrial/energy generation areas depend on synoptic forcing. However, in Mediterranean coastal areas, in four of the CTs (69% of climatic frequency) synoptic advection is weakened due to topographic barriers and mesoscale meteorology (land-sea and mountain-valley breezes) regulates $NO_2$ dynamics.

***Key words:*** *Air Quality modelling, synoptic classification, circulation types, CALIOPE-AQFS,* $NO_2$.

## INTRODUCTION

Synoptic meteorology studies the dynamics of the atmosphere occurring on scales of thousands of kilometres, such as semi-permanent high and low pressure systems (Seinfeld and Pandis, 2006). The circulation of air masses at synoptic scale affects not only the long-range transport of atmospheric pollutants but it also controls the meteorology at mesoscale (scales of hundreds of kilometres, covering phenomena such as land-sea breezes and mountain-valley winds). The relationship of the pollutants' concentration with the prevailing circulation, both synoptic and mesoscale is a key element to explain air pollution dynamics in a given territory (Flocas *et al.*, 2009). Moreover, within the planetary boundary layer, mesoscale dynamics are influenced by topography, increasing the complexity of the air mass dynamics, especially over complex terrains such as the Iberian Peninsula (IP).

In recent years, several works have shown high correlation between air quality at ground level and specific circulation types (CTs) over the IP. For example, exceedances of the particulate matter (PM10) daily limit value in urban and rural monitoring sites in central Spain have been related to Saharan dust outbreaks driven by southern/southeastern winds towards the IP during late spring and summer result of a thermal low over northern Africa (Salvador *et al.*, 2013). In relation to ozone ($O_3$), in summer, when the IP is under the influence of the Azores high, with high temperatures, intense solar radiation, and stagnant conditions, sea-breezes have been proven to control $O_3$ surface concentration in Spanish Mediterranean coastal areas (Castell-Balaguer *et al.*, 2012). However, the relationship between synoptic meteorology and $NO_2$ concentration over the IP has not been explored yet.

## OBJECTIVE

The present work aims to identify typical circulation types by means of an objective and automatic synoptic classification performed on a climatic basis (1983-2012) to explain $NO_2$ surface concentration and plume dynamics over the Iberian Peninsula.

## METHODS

Circulation of air masses is dynamic, and the various states of the atmosphere are not clearly separated. Synoptic classifications enable the establishment of discrete CTs by categorizing the continuum of atmospheric circulation based on their similarities (Beck and Philipp, 2010). Contrary to manual methods, automatic synoptic classifications identify CTs from a systematic analysis of one or more input meteorological variables (iv) using a particular classification technique (clt). However, a synoptic classification is also sensitive to the number of CTs considered (nCT), the vertical level of the meteorological variable (vl), the temporal resolution (tr), the seasonality (se), the horizontal resolution (hr), and the domain size (d). In order to identify the most objective set-up for the synoptic classification to be used in air quality characterization sensitivity tests to the aforementioned criteria have been performed (Table 1). The software used to derive the classifications is cost733class software developed within the COST733 Action "Harmonisation and Applications of Weather Type Classifications for European Regions" (Philipp *et al.*, 2014). The performed sensitivity tests used ERA-Interim reanalysis data from the European Centre for Medium-Range Weather Forecast.

**Table 1.** Characteristics of the performed sensitivity tests for the climatic period 1983-2012. Elements between commas indicate the tested variable in each case study.

| # test | Studied criterion | Variability range |
|---|---|---|
| 1 | Classification technique (clt) | Correlation techniques (3); Principal Component Analysis (4); Clustering techniques (5) |
| 2 | Number of circulation types (nCT) | From 2 to 15, 18, 27, 50 |
| 3 | Meteorological variable used as proxy (iv) | Mean sea level pressure (mslp), 10-meter U and V wind components (UV10), 1000-hPa vorticity (Vort1000), 2-meter temperature (T2m), relative humidity (RH) |
| 4 | Vertical level (vl) | Surface, 11 geopotential levels from 1000 to 1 hPa each 100 hPa |
| 5 | Temporal resolution (tr) | Data each 6, 12, 24 hours, 06 h mean |
| 6 | Seasonality (se) | Winter, spring, summer, autumn, annual (an) |
| 7 | Horizontal resolution (hr) | 0.125º x 0.125º, 0.25º x 0.25º, 0.75º x 0.75º, 1.5º x 1.5º, 3º x 3º |
| 8 | Spatial domain (d) | D00 (18.75N – 76.5N / 33.75W – 31.5 E), D01 (24.75N – 62.25N / 25.5W – 20.25 E), D02 (30N – 50.25N / 13.5W – 13.5 E) |

The Explained Variation (EV) was used as metric to quantify the quality of the performed classifications. EV is a measure of the separability between CTs and the within-CT variability and it is calculated considering the Euclidean Distance among days in one CT and the distance among all the days with independence on the CT they are classified into. EV ranges 0-1 with higher EV values showing better classification results. Identified CTs were characterised in terms of total and monthly frequency, maximum and mean persistence of the episodes, and transitions between CTs both for the climatic period and for a representative year (identified by means of a temporal stability analysis following a cross-validation process similar to that used in García-Valero *et al.*, 2012).

$NO_2$ concentration maps for the IP are provided by the CALIOPE air quality forecasting system (CALIOPE-AQFS, Baldasano *et al.*, 2011) on the IP domain (4 km x 4 km). The CALIOPE-AQFS' meteorological driver is the WRF-ARW model, initialized by the GFS/FNL global data (0.5º x 0.5º), the chemical transport model is the CMAQ, that uses MOZART4-GEOS5 forecast as chemical boundary conditions (1.9º x 2.5º). The emissions are estimated by the High-Elective Resolution Modeling Emission System (Guevara *et al.*, 2013) using mainly a bottom-up approach in the IP. An assessment of the relationship between $NO_2$ concentration and CTs has been performed using 2012 CALIOPE forecasts over five areas of interest of the IP: Madrid, Barcelona and Seville metropolitan areas and, Algeciras and Asturias industrial/energy generation areas.

**RESULTS**

The reference set-up for the climatic synoptic classification uses the cluster-based CKM classification technique on 24-hour (12:00 UTC) mslp data with 0.75º horizontal resolution. The classification is performed without seasonalization over a 15x106 $km^2$ domain (D01), centred over the IP. Six climatic CTs are obtained which explain 48% of the synoptic circulation variability. The centroids of pressure of each CT were plotted (Fig. 1) enabling the identification of the location of high and low pressure areas and the atmospheric circulation in the climatic period, the representative year (2012) and on representative days of 2012 (identified using a score that minimizes the sum-of-squares distance between the mean sea level pressure mslp grid of the day and the mslp grid of each climatic CT).

The three most common CTs account for 67.6% of the climatic frequency (CT1, CT2, and CT3) and they mainly occur in summertime replacing one another (Table 2). CT1 (23.9%) is a NW advective CT characterized by the arrival of polar maritime air masses towards the IP. CT2 (22.4%) depicts a reduced surface pressure gradient, enabling the development of the Iberian Thermal Low together with a North African advection. CT3 (21%) is characterised by a blocking anticyclone over central Europe that leads to E/NE advection towards the IP. CT3 is especially frequent in spring and summer although present all year long. When the high pressure subsides, CT3 tends to be replaced by CT2. In winter, two CTs are especially frequent, the CT4 (12%) and the CT6 (10%). The former is an anticyclonic situation that enables the arrival of Atlantic air masses towards the IP, whereas the latter is characterised by a zonal Atlantic maritime advection. Finally, the CT5 (10%) presents unstable conditions over the IP with W/NW winds and precipitation, and it is typical of spring and autumn. Topographic barriers in central and eastern IP (Iberic and Baetic Systems, Catalan Mountain range) weaken the progression of westerlies on their way to the Spanish Mediterranean coast in CT5 but not in CT6.

**Table 2.** Characteristics of the identified CTs for the climatic period (1983-2012) and the representative year (2012).

| | Period | CT1 - NW advection | CT2 - Summer reduced surface pressure gradient | CT3 - E/NE advection | CT4 - Atlantic high with polar maritime advection | CT5 - W/NW advection | CT6 - Western Atlantic zonal advection |
|---|---|---|---|---|---|---|---|
| Frequency (%) | 1983-2012<br>2012 | 23.9<br>21.9 | 22.4<br>21.6 | 21.3<br>8.8 | 12.0<br>17.8 | 10.4<br>20.5 | 10.1<br>9.3 |
| Most frequent month | 1983-2012<br>2012 | JUL<br>JUL | AUG<br>AUG | MAY<br>FEB | JAN<br>JAN | APR/OCT<br>APR/NOV | JAN<br>DEC |
| Seasonal frequency (%): DJF, MAM, JJA, SON | 1983-2012 | 10.1/26.1/ 43.5/ 20.3 | 11.7/26.2/3 5.8/ 26.3 | 25.9/28.5/2 3.5/22.0 | 49.8/19.9/ 4.4/25.9 | 26.0/28.7/ 10.4/35.0 | 54.3/16.4/ 1.9/27.4 |
| | 2012 | 2.5/37.5/ 37.5/22.5 | 15.2/20.3/ 43.0/21.5 | 56.3/43.8/ 0.0/ 0.0 | 56.9/21.5/ 6.2/15.4 | 5.3/21.3/ 29.3/44.0 | 50.0/5.9/ 5.9/38.2 |
| Mean / Max persistence (days) | 1983-2012<br>2012 | 2.9 / 23<br>3.6 / 10 | 2.9 / 22<br>2.6 / 8 | 3.8 / 19<br>4.6 /18 | 2.7 / 27<br>3.8 /15 | 3.0 / 17<br>3.0 /10 | 2.9 / 19<br>3.5 / 10 |
| Transitions | 1983-2012<br>2012 | CT2<br>CT2/CT5 | CT1<br>CT1/CT5 | CT2<br>CT4 | CT6<br>CT2 | CT1<br>CT1/CT2 | CT4<br>CT5 |

Regarding $NO_2$, CT2 presents the highest mean $NO_2$ concentration (Fig. 2). Despite being a typical summer pattern when $NO_2$ emissions are at its annual minimum (Guevara *et al.*, 2013), the lack of surface advection favours the accumulation of $NO_2$. On the other hand, the most infrequent CT6 has, on average, the second highest $NO_2$ concentration of all the CTs, especially in Madrid where high $NO_2$ concentration is probably related with a low height of the planetary boundary layer (300 m at 12:00 UTC, as forecasted by the WRF-ARW model, compared to ~600 masl for CT4; 1500 masl for CT3 and CT5; and 1800 masl for CT1 and CT2).

The analysis of $NO_2$ plumes in 2012 representative days shows that there is a synoptic control of $NO_2$ concentration in urban and industrial/energy generation areas of the central, northern, and southern Spain (Fig. 1). For example, in the Madrid area, synoptic advection, together with topography (Central System ~2500 masl), establish the dominant orientation and strength of the $NO_2$ urban plume which differs between the CTs. The Cantabrian Mountains are a barrier to latitudinal movement of air masses at surface leading to a longitudinal transport of $NO_2$ in the north Atlantic coast of the IP, mainly parallel to the coast and W/E depending on the CT. However, in Mediterranean coastal areas, in 4 CTs (CT1, CT2, CT4, and CT5, accounting for 69% of climatic frequency) topographic barriers (Iberic and Baetic System) weaken the progress of Atlantic air masses and mesoscale meteorology (land-sea and mountain-valley breezes) regulates $NO_2$ dynamics. Only under the influence of Central Europe advection (CT3, 21%) and Atlantic zonal advection (CT6, 10%), synoptic forcing controls $NO_2$ transport along Mediterranean coastal areas.

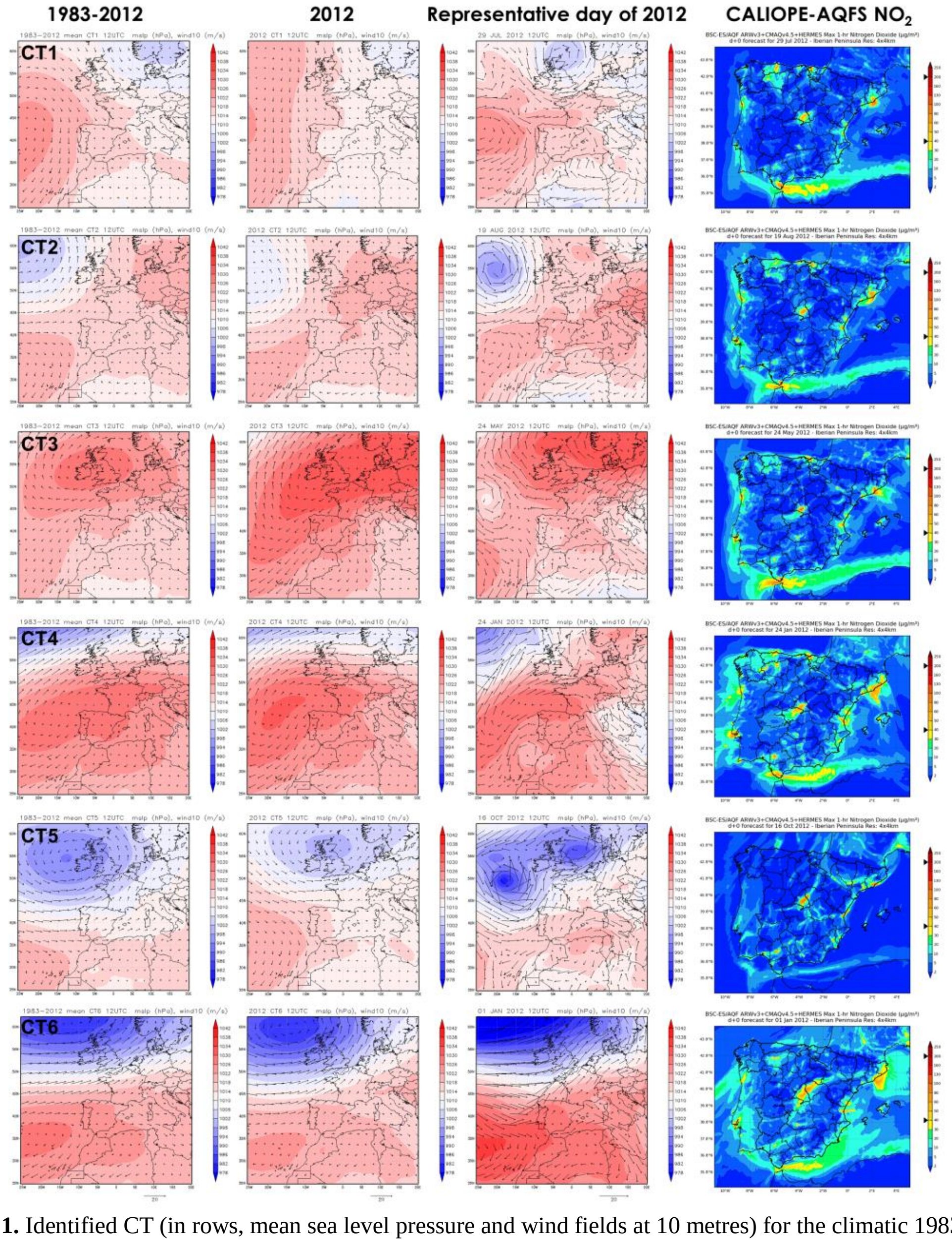


**Figure 1.** Identified CT (in rows, mean sea level pressure and wind fields at 10 metres) for the climatic 1983-2012 period (first column), in the year 2012 (second column) and representative days of 2012 (third column) and $NO_2$ concentration of representative days of 2012 at 12:00 UTC as forecasted by the CALIOPE-AQFS (fourth column).

## CONCLUSIONS

An objective and automatic synoptic classification is developed to be used in air quality applications over the Iberian Peninsula. The identified CTs that characterize the air masses dynamics are consistent with previous literature, and are useful to explain $NO_2$ concentration and transport patterns. Together with topographic features, synoptic circulation is found to be a key driver of $NO_2$ urban and industrial/energy-generation-areas plumes in northern, central and southern areas of Spain whereas in Mediterranean coastal areas, mesoscale phenomena dominates $NO_2$ transport dynamics.

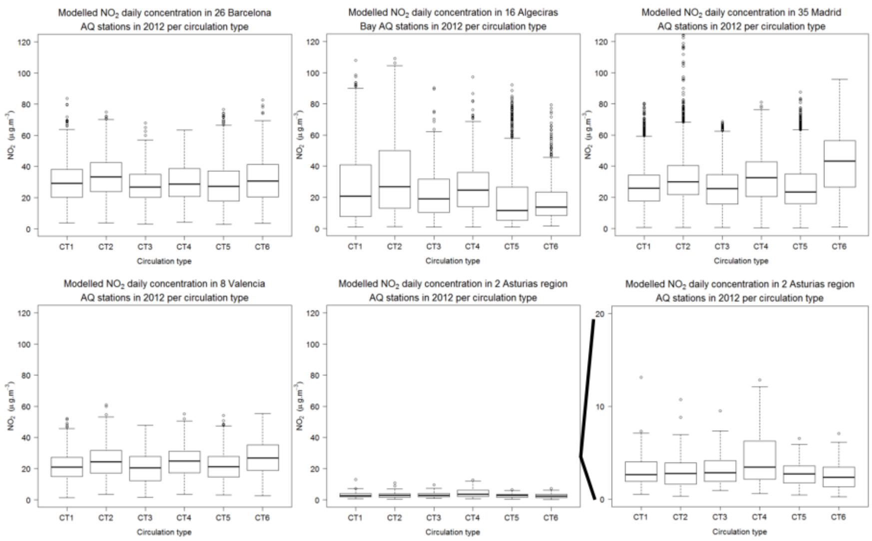


**Figure 2.** Boxplots showing the relationship between the $NO_2$ concentration in 2012 per circulation type in 5 areas within the Iberian Peninsula. Data extracted from the CALIOPE-AQFS forecast for 2012.


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