USE OF A CLIMATIC SYNOPTIC CLASSIFICATION TO IDENTIFY AND CHARACTERIZE NO$_2$ POLLUTION PATTERNS OVER THE IBERIAN PENINSULA

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Air pollution in the Iberian Peninsula

Air pollution function (meteorology, emissions & topography)

Total Spanish emissions (kt/year)
Environmental Ministry (2014)

Total daily emissions for Spain (t/day)
Estimated with HERMESv2.0 model (2011)

Total annual NOx emissions for Spain (t/year)
Estimated with HERMESv2.0 model (2011)

Contribution to NOx emissions in Spain by SNAP activity sector
Estimated with HERMESv2.0 model (2011)
The understanding of the relationship of the pollutants’ concentration with the prevailing circulation, both synoptic and local scale, is a key element to explain air pollution dynamics in a given territory. This relationship is primarily examined by classifying the atmospheric circulation.

Flocas et al., 2009

Objectives

1. Objectively classify synoptic circulation on a climatic basis (1983-2012) into typical circulation types (CTs)
2. Explain NO$_2$ surface concentration and dynamics over the Iberian Peninsula
Methodology: synoptic circulation type classification

Automatic and objective classification of synoptic circulation over the Iberian Peninsula

- Sensitivity tests to classification techniques and other parameters affecting the classification
- Selection of a reference configuration based on statistical criteria & objective of the classification

Characterization of CTs

- Pressure and wind fields at surface and 500 hPa geopotential height
- Climatic and monthly frequency, seasonal distribution, persistence, transitions

Objective selection of representative year and days of the CTs

Climatic period (1983-2012) using ERA-Interim reanalysis database

Circulation type classification – sensitivity analyses

Objective synoptic classification → CTs

Temporal stability analysis

Representative year

Representative days of representative year

Comparison method: back-trajectories

Application: NO₂ dynamics assessment

HYSLIP model

CALIOPE - AQFS
### Sensitivity analyses performed

<table>
<thead>
<tr>
<th># test</th>
<th>Studied criterion</th>
<th>Variability range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Classification technique</td>
<td>Correlation techniques (3); Principal Component Analysis (4); Clustering techniques (5)</td>
</tr>
<tr>
<td>2</td>
<td>Number of circulation types</td>
<td>From 2 to 15, 18, 27, 50</td>
</tr>
<tr>
<td>3</td>
<td>Meteorological variable used as proxy</td>
<td>Mean sea level pressure (mslp), 10-meter U and V wind components (UV10), 1000-hPa vorticity (Vort1000), 2-meter temperature (T2m), relative humidity (RH)</td>
</tr>
<tr>
<td>4</td>
<td>Vertical level</td>
<td>Surface, 11 geopotential levels from 1000 to 1 hPa each 100 hPa</td>
</tr>
<tr>
<td>5</td>
<td>Temporal resolution</td>
<td>Data each 6, 12, 24 hours, 06 h mean</td>
</tr>
<tr>
<td>6</td>
<td>Seasonality</td>
<td>Winter, spring, summer, autumn, annual (an)</td>
</tr>
<tr>
<td>7</td>
<td>Horizontal resolution</td>
<td>0.125° x 0.125°, 0.25° x 0.25°, 0.75° x 0.75°, 1.5° x 1.5°, 3° x 3°</td>
</tr>
<tr>
<td>8</td>
<td>Spatial domain</td>
<td>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)</td>
</tr>
</tbody>
</table>

**Explained Variation** criterion + **objective of the classification** enable to select the most useful configuration to identify CTs for air quality applications.
Results of the sensitivity analyses

**Test 1: Classification Technique (clt)**
- clt = - nCT = 6
- iv = mslp vl = surf
- tr = 24h sc = an
- hr = 0.75* d = D01

**Test 2: Number of CTs (nCT)**
- clt = - nCT = -
- iv = mslp vl = surf
- tr = 24h sc = an
- hr = 0.75* d = D01

**Test 3: Proxy Variable (iv)**
- clt = CKM nCT = 6
- iv = - vl = surf
- tr = 24h sc = an
- hr = 0.75* d = D01

**Test 4: Vertical Level (vl)**
- clt = CKM nCT = 6
- iv = press vl = -
- tr = 24h sc = an
- hr = 0.75* d = D01
Results of the sensitivity analyses

**Selected configuration**

<table>
<thead>
<tr>
<th>Classification technique</th>
<th>Temporal res.</th>
<th>6 h</th>
</tr>
</thead>
<tbody>
<tr>
<td># of CTs</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Seasonality</td>
<td>Annual</td>
<td></td>
</tr>
<tr>
<td>Meteo variable</td>
<td>Atmospheric pressure</td>
<td>Horizontal res.</td>
</tr>
<tr>
<td>Vertical level</td>
<td>Surface</td>
<td>Spatial domain</td>
</tr>
</tbody>
</table>

**Classification**

- *technique C-k means*
- **Temporal res.** 6 h
- **# of CTs** 6
- **Seasonality** Annual
- **Meteo variable** Atmospheric pressure
- **Horizontal res.** 0.75° x 0.75°
- **Vertical level** Surface
- **Spatial domain** D01
Circulation types identified (data base 1983-2012)

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
### Characteristics of the CTs identified in 1983-2012

<table>
<thead>
<tr>
<th></th>
<th>CT1 - NW advection</th>
<th>CT2 - Summer reduced surface pressure gradient</th>
<th>CT3 - E/NE advection</th>
<th>CT4 - Atlantic high with polar maritime advection</th>
<th>CT5 - W/NW advection</th>
<th>CT6 - Western Atlantic zonal advection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency (%)</strong></td>
<td>23.9</td>
<td>22.4</td>
<td>21.3</td>
<td>12.0</td>
<td>10.4</td>
<td>10.1</td>
</tr>
<tr>
<td><strong>Most frequent month</strong></td>
<td>JUL</td>
<td>AUG</td>
<td>MAY</td>
<td>JAN</td>
<td>APR/OCT</td>
<td>JAN</td>
</tr>
<tr>
<td><strong>Seasonal frequency (%): DJF/ MAM/ JJA/ SON</strong></td>
<td>10.1/26.1/ 43.5/ 20.3</td>
<td>11.7/26.2/ 35.8/ 26.3</td>
<td>25.9/28.5/ 23.5/22.0</td>
<td>49.8/19.9/ 4.4/25.9</td>
<td>26.0/28.7/ 10.4/35.0</td>
<td>54.3/16.4/ 1.9/27.4</td>
</tr>
<tr>
<td><strong>Mean / Max persistence (days)</strong></td>
<td>2.9 / 23</td>
<td>2.9 / 22</td>
<td>3.8 / 19</td>
<td>2.7 / 27</td>
<td>3.0 / 17</td>
<td>2.9 / 19</td>
</tr>
<tr>
<td><strong>Transitions</strong></td>
<td>CT2</td>
<td>CT1</td>
<td>CT2</td>
<td>CT6</td>
<td>CT1</td>
<td>CT4</td>
</tr>
</tbody>
</table>
Representative year

<table>
<thead>
<tr>
<th>Year</th>
<th>CT1</th>
<th>CT2</th>
<th>CT3</th>
<th>CT4</th>
<th>CT5</th>
<th>CT6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983-2012</td>
<td>NW advection</td>
<td>Summer reduced surface pressure gradient</td>
<td>E/NE advection</td>
<td>Atlantic high with polar maritime advection</td>
<td>W/NW advection</td>
<td>Western Atlantic zonal advection</td>
</tr>
</tbody>
</table>

1983-2012

2012
## Characteristics of the CTs: 1983-2012 vs year 2012

<table>
<thead>
<tr>
<th>Period</th>
<th>CT1 - NW advection</th>
<th>CT2 - Summer reduced surface pressure gradient</th>
<th>CT3 - E/NE advection</th>
<th>CT4 - Atlantic high with polar maritime advection</th>
<th>CT5 - W/NW advection</th>
<th>CT6 - Western Atlantic zonal advection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most frequent month</td>
<td>1983-2012 2012</td>
<td>JUL</td>
<td>AUG</td>
<td>MAY/FEB</td>
<td>JAN</td>
<td>APR/OCT</td>
</tr>
<tr>
<td>Seasonal frequency (%): DJF/ MAM/ JJA/ SON</td>
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<td>10.1/26.1/43.5/20.3</td>
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<tr>
<td>Mean / Max persistence (days)</td>
<td>1983-2012 2012</td>
<td>2.9/23</td>
<td>2.9/22</td>
<td>3.8/19</td>
<td>2.7/27</td>
<td>3.0/17</td>
</tr>
<tr>
<td>Transitions</td>
<td>1983-2012 2012</td>
<td>CT2/CT5</td>
<td>CT1/CT5</td>
<td>CT2/CT4</td>
<td>CT6/CT2</td>
<td>CT1/CT2</td>
</tr>
</tbody>
</table>
Representative days

Daily score minimizes the differences between the daily grid and the average grid of a given CT.

\[ DS_t = \sum_{i=1}^{n} |v_{t,i} - \bar{v}_i| \]

For each day \((t)\) within a given CT, the Day Score \((DS)\) is calculated as the sum of the absolute value of the differences between the daily value and the average value of the meteorological variable of the CT for each cell \((i)\) of the grid.

\(n\) is the number of cells of the grid; and \(\bar{v}_i\) is the arithmetic mean of the input variable on each \(i\) cell of the domain for all days belonging to the CT.

Representative Day Score \((RDS)\) minimizes the value of the DS identifying the representative day for each CT.

\[ RDS = \min(DS_t) \]

<table>
<thead>
<tr>
<th>CT1</th>
<th>CT2</th>
<th>CT3</th>
<th>CT4</th>
<th>CT5</th>
<th>CT6</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW advection</td>
<td>Summer reduced surface pressure gradient</td>
<td>E/NE advection</td>
<td>Atlantic high with polar maritime advection</td>
<td>W/NW advection</td>
<td>Western Atlantic zonal advection</td>
</tr>
</tbody>
</table>
Confirmation: 1983-2012 vs 2012 vs mean episode

CT1 – NW advection

CT2 – Summer reduced surface pressure gradient
Confirmation: 1983-2012 vs 2012 vs mean episode

**CT3 – E/NE advection**

1983-2012 mean CT 00UTC mslp (hPa), wind10 (m/s)

1983-2012

2012

R.Episode

**CT4 – Atlantic high with polar maritime advection**

1983-2012 mean CT 00UTC mslp (hPa), wind10 (m/s)

1983-2012

2012

R.Episode
Confirmation: 1983-2012 vs 2012 vs mean episode

CT5 – W/NW advection

CT6 – Western Atlantic zonal advection
Confirmation: Back trajectories

CT1 – 29/07/2012
NW advection

CT2 – 19/08/2012
Summer reduced surface pressure gradient

CT3 – 24/05/2012
E/NE advection

CT4 – 24/01/2012
Atlantic high with polar maritime advection

CT5 – 16/10/2012
W/NW advection

CT6 – 01/01/2012
Western Atlantic zonal advection
CALIOPE: Air Quality Forecasting System

**CALIOPE modules**

**Meteorology**
- WRF-ARWv3.5
- 38 sigma levels (top 50 hPa)
- IBC: GFS (NCEP)
- 33 layers/50 hPa

**Emissions**
- HERMESv2
- EU: HERMES-DIS (EMEP data)
- Spain: HERMES-BOUP

**Chemistry**
- CMAQv5.0.1
- CB05/AERO5
- BC: NCAR MOZART4
- 15 layers/50 hPa

**Mineral dust**
- BSC-DREAM8bv2
- Mineral PM10 and PM2.5

**Post-process**
- Kalman Filter (puntual y 2D)

**Air quality forecast**
- O₃, NO₂, SO₂, CO, PM10, PM2.5, Benzene

**48h forecast**
- Concentration maps, emis, meteo
- Air quality indexes

**Diffusion**
- Web [www.bsc.es/caliope](http://www.bsc.es/caliope)
- Smartphone

**Near real-time evaluation**
- Air quality stations networks
- Satellites

**Web**
- www.bsc.es/caliope
**NO$_2$ dynamics on the RD of each CT**

<table>
<thead>
<tr>
<th>CT1</th>
<th>CT2</th>
<th>CT3</th>
<th>CT4</th>
<th>CT5</th>
<th>CT6</th>
</tr>
</thead>
<tbody>
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<td>NW advection</td>
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<td>Atlantic high with polar maritime advection</td>
<td>W/NW advection</td>
<td>Western Atlantic zonal advection</td>
</tr>
</tbody>
</table>
**NO₂ per CT**

### Modelled NO₂ daily concentration in 26 Barcelona AQ stations in 2012 per circulation type

- **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

### Modelled NO₂ daily concentration in 16 Algeciras Bay AQ stations in 2012 per circulation type

### Modelled NO₂ daily concentration in 35 Madrid AQ stations in 2012 per circulation type

### Modelled NO₂ daily concentration in 8 Valencia AQ stations in 2012 per circulation type

### Modelled NO₂ daily concentration in 20 Asturias region AQ stations in 2012 per circulation type

[Map of Spain showing Barcelona, Madrid, Valencia, and Algeciras]
In central, northern, and southern IP: synoptic control of NO$_2$ concentration in urban and industrial/energy generation areas. In Madrid: synoptic circulation and topography modulate the distance and direction of the urban plume:

- Central System is a topographic constraint preventing NW winds (CT1) & Reduced surface pressure gradient (CT2) → stagnant conditions, urban plume remains over metropolitan area.
- Urban plume transported to the SW through the Tajo valley CT3 (~100 km) & CT4 (~250 km).
- Urban plume transported to the NNE CT5 (~250 km) & NE CT6 (~200 km).

In Mediterranean coastal areas, synoptic circulation with Atlantic dominance (4 CTs accounting for 69% of climatic frequency) is weakened by topographic barriers (Iberic and Baetic System) and mesoscale meteorology regulates NO$_2$ dynamics.

In Barcelona and Valencia:

- Land-sea and mountain-valley breezes transport urban plume inland/outland and parallel to the coast on a daily cycle CT1, CT2, CT4 & CT6 (20-30 km)
- Synoptic forcing controls NO$_2$ transport along Mediterranean coastal areas under CT3 (anticyclonic circulation establishes transport of the urban plume to the E/NE ~40-50 km) and CT6 (zonal winds transport urban plume to the W ~80 km).
Conclusions

An objective and automatic methodology to classify synoptic circulation is developed.

The synoptic classification is applied to study air quality patterns over the Iberian Peninsula.

The three most common CTs account for 67.6% of climatic frequency (CT1, CT2, and CT3) and mainly occur in summertime, replacing one another.

- CT1 (23.9%) is a NW advective pattern characterized by the arrival of polar maritime air masses towards the IP.
- CT2 (22.4%) depicts a reduced pressure surface gradient, enabling the development of the Iberian thermal low with net advection of North African air masses at 500 hPa geopotential height.
- CT3 (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.

In winter two CTs are especially frequent, CT4 and CT6.

- CT4 (12%) is an anticyclonic situation that enables the arrival of Atlantic air masses towards the IP.
- CT6 (10%) is characterised by zonal Atlantic maritime advection.

CT5 is typical of transitional seasons

- CT5 (10%) presents unstable conditions over the IP with W-NW winds and precipitation.

Together with topographic features, synoptic circulation is found to be a key driver of NO₂ urban and industrial/energy-generation-areas plumes in northern, central and southern areas of Spain whereas in Mediterranean coastal areas, mesoscale phenomena dominates NO₂ transport dynamics.

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Thank you for your attention

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**Evaluation of the CALIOPE-AQFS for NO₂ in 2013**

**Annual NO₂ evaluation in 2013**  
CALIOPE-Air quality forecasting system against observations from the Spanish AQ network

<table>
<thead>
<tr>
<th>Type of station</th>
<th># stations</th>
<th>OBS (µg.m⁻³)</th>
<th>MOD (µg.m⁻³)</th>
<th>Bias (µg.m⁻³)</th>
<th>r</th>
<th>RMSE (µg.m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>358</td>
<td>18.9</td>
<td>18.3</td>
<td>-0.65</td>
<td>0.48</td>
<td>13.9</td>
</tr>
<tr>
<td>Urban</td>
<td>167</td>
<td>25.8</td>
<td>24.8</td>
<td>-1.05</td>
<td>0.55</td>
<td>17.6</td>
</tr>
<tr>
<td>Suburban</td>
<td>108</td>
<td>17.3</td>
<td>17.0</td>
<td>-0.29</td>
<td>0.46</td>
<td>13.8</td>
</tr>
<tr>
<td>Rural</td>
<td>83</td>
<td>7.3</td>
<td>7.0</td>
<td>-0.32</td>
<td>0.37</td>
<td>6.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Emission</th>
<th># stations</th>
<th>OBS (µg.m⁻³)</th>
<th>MOD (µg.m⁻³)</th>
<th>Bias (µg.m⁻³)</th>
<th>r</th>
<th>RMSE (µg.m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic</td>
<td>73</td>
<td>31.6</td>
<td>29.9</td>
<td>-1.68</td>
<td>0.54</td>
<td>19.4</td>
</tr>
<tr>
<td>Industrial</td>
<td>96</td>
<td>15.7</td>
<td>14.8</td>
<td>-0.83</td>
<td>0.45</td>
<td>12.3</td>
</tr>
<tr>
<td>Background</td>
<td>189</td>
<td>15.7</td>
<td>15.5</td>
<td>-0.16</td>
<td>0.47</td>
<td>12.7</td>
</tr>
</tbody>
</table>
Evaluation of the CALIOPE-AQFS for NO₂ in 2013

<table>
<thead>
<tr>
<th>NO₂</th>
<th>Bias (µg/m³)</th>
<th>r</th>
<th>RMSE (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muy Eueno (MB)</td>
<td>ME &lt; 5</td>
<td>r &gt; 0.60</td>
<td>RMSE &lt; 5</td>
</tr>
<tr>
<td>Eueno (E)</td>
<td>5 ≤</td>
<td>MB</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Aceptable (A)</td>
<td>10 ≤</td>
<td>MB</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>Malo (M)</td>
<td>20 ≤</td>
<td>MB</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>Muy Malo (MM)</td>
<td>MB ≥ 30</td>
<td>r ≤ 0.10</td>
<td>RMSE ≥ 35</td>
</tr>
</tbody>
</table>

Mean Bias | r | RMSE