THE IMPACT OF NORTH ATLANTIC OSCILLATION ON THE ATMOSPHERIC POLLUTANT VARIABILITY IN THE PORTO REGION, PORTUGAL

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ABSTRACT: The North Atlantic Oscillation (NAO) is an important large-scale atmospheric circulation that influences the European countries climate. This study evaluated NAO impact in the air quality in Porto Metropolitan Area (PMA), Portugal, for the period 2002-2006. NAO, air pollutants and meteorological data were statistically analyzed. All data were obtained from PMA Weather Station, PMA Air Quality Stations and NOAA analysis. Two statistical methods were applied in different time scale: principal component and correlation coefficient. Annual time scale, using multivariate analysis (PCA, principal component analysis), were applied in order to identified positive and significant association between air pollutants, such as PM10, PM2.5, CO, NO and NO2, with NAO. On the other hand, the correlation coefficient using seasonal time scale analysis were also applied to the same data. The results of PCA analysis present a general negative significant association between the total precipitation and NAO, in Factors 1 and 2 (explaining around 70% of the variance), presented in the years of 2002, 2004 and 2005. During the same years, some air pollutants (such as PM10, PM2.5, SO2, NOx and CO) present also a positive association with NAO. The O3 shows as well a positive association with NAO during 2002 and 2004, at 2nd Factor, explaining 30% of the variance. From the seasonal analysis using correlation coefficient, it was found significant correlation between PM10 (0.72., p<0.05, in 2002), PM2.5 (0 74, p<0.05, in 2004), and SO2 (0.78, p<0.01, in 2002) with NAO during the March-December (no winter period) period. Significant associations between air pollutants and NAO were also verified in the winter period (December to April) mainly with ozone (2005, r= -0.55, p<0.01). Once that human health and hospital morbidities may be affected by air pollution, the results suggest that NAO forecast can be an important tool to prevent them, in the Iberian Peninsula and specially Portugal.

Key words: North Atlantic Oscillation, air pollutants, Portugal.

1. Introduction

The North Atlantic Oscillation (NAO) is the dominant mode of recurrent atmospheric variability over the North Atlantic (Hurrell, 1995) and is one of the large scale climate phenomena that affect Iberian Peninsula (IP) and Europe. The NAO influences atmospheric variables such as wind speed and direction, air temperature, heat and moisture transports, and precipitation (Hurrell and van Loon 1997; Hurrell *et al.*, 2003).

The NAO index was originally proposed by Walker (1924) as the difference between the Azores and Iceland surface pressure. More recently, other authors (Jones *et al.,* 1997; Osborn *et al*., 1999) have also used the NAO index as the difference of pressure between Lisbon and Iceland or Gibraltar and Iceland. This index is related to the wind intensity over the West of the North Atlantic Ocean. The NAO can be interpreted in terms of large scale atmospheric mass meridional exchange (van Loon and Rogers 1978) or the large scale oscillation of anomalous pressure (Osborn *et al*., 1999). In the last decades it has been strongly correlated with precipitation and mean temperature over some regions of Europe (Hurrell 1995; Hurrell and van Loon 1997). Particularly, it has an important impact in terms of economy and energy on the Iberian countries such as Portugal and Spain (Trigo *et al*., 2002). For instance, in the negative NAO index phase, the Azores high pressure is not intense. Therefore, the moisture transport by the wind is southward, making the winter colder in the North Europe and softer in the IP (Trigo, 2002). According to Garcia *et al*., (2005), in Galicia, when the ENSO influence is less significant the NAO and precipitation are more associated. Trigo *et al*., (2002 and 2004) observed that low values of NAO index are usually associated with precipitation above the mean in Portugal.

The synoptic systems combination on East of North America and strong low pressure over Iceland favors the air pollutants transport (2-3 days) through the North Atlantic until Europe (Trickl *et al*., 2003). Creilson *et al*., (2003) suggested that the NAO can play an important role in the transport processes modulation. Positive phases of NAO index are indicative of a stronger Bermuda-Azores high pressure system and stronger Icelandic low pressure system and thus stronger zonal flow across the North Atlantic from West to East. This flow regime appears to be causing the tropospheric ozone transport across the North Atlantic and into Europe. Moreover, according to Grundström *et al*., (2011), NO e NO_2 were significantly and negatively related to NAO índex.

Understanding the association of NAO phase and increasing in air pollution can help to predict these events. According to Hurrell *et al*., (2009) future changes in anthropogenic aerosols can have a significant regional climate impact in the near future. These changes may be associated to external forcing, both natural (e.g. solar variability, volcanic aerosols) and anthropogenic (greenhouse gases, ozone, and aerosols). In addition, the best possible estimates of future emissions of important air pollutants are needed for making predictions, as well as improving modeling capabilities to accurately simulate how the air pollutants affect the global energy, carbon and sulfur cycles, and how the climate system subsequently responds to that altered forcing.

According to Pokrovsky (2009), climate change is a major cause of the precipitation deficit in Southern Europe during the 1980s and 1990s. In his paper he showed that this phenomenon is related to the Northward displacement of the major route of the air flow transport of Atlantic moisture in summer, spring and autumn.

This study will be focused on Portugal, which is the most Western country in Europe. The NAO impact over this country can lead to drought episodes and air quality decrease and the vice versa. The main objective of this study is to evaluate the air quality and its association with NAO index variability, seasonally and annually, in the Porto Metropolitan Area (PMA), from 2002 to 2006.

2. Methodology

5.1 Location of the study area

Portugal is the most Western country that constitutes the IP. Figure 1 shows the relative low pressure system position and the Azores anticyclone during the North Hemisphere winter and summer seasons. The North Atlantic is localized between 90°W and 0° in this figure. The main region to be studied is Porto Metropolitan Area (PMA) which is constituted of the Porto (41°08' N and 8°40' W) costal city and to the North and East satellite cities around it, in Northern Portugal. The top - right part of figure 1 highlights the PMA region.

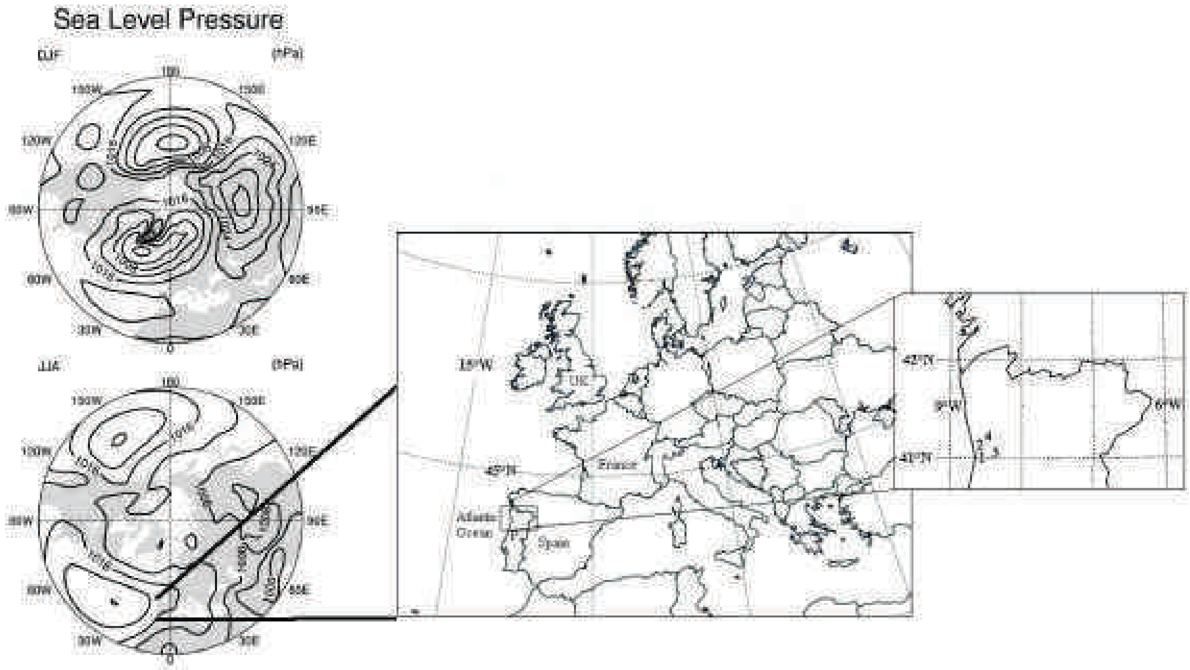

Figure 1. Mean sea level pressure for (top and left) boreal winter (December–February) and (bottom and left) boreal summer (June–August).

The data is from the NCEP/NCAR reanalysis project for the 1958–2006 period (Kalnay et al., 1996) and the contour increment is 4 hPa. The Western Europe map is shown at the centre, and a zoom of the North of Portugal appears at the right. The numbers indicate the PMA air quality stations location as the sequence: 1. Antas and Boavista, 2. Senhora da Hora, Matosinhos and Perafita, 3. Baguim and Ermesinde, 4. Custoias, Vermoim, Vila Nova da Telha and Leça. The meteorological station (Pedras Rubras) is located between 2 and 4 air quality stations.

5.2 Meteorological and air quality data

The data set is composed of meteorological data; weather reanalysis for the NAO index and air pollution, from 2002 to 2006.

The Pedras Rubras meteorological station from the "Instituto Meteorologia de Portugal" (Portuguese Meteorological Institute) was selected for this study. This station presents the most complete meteorological time series, which includes daily temperature (Tair) (°C), air pressure (hPa), relative humidity (Hr) (%), precipitation (Prec) (mm) and wind velocity (m/s), for example, and it is located in the center of the PMA as depicted in figure 1.

The monthly and daily NAO data were obtained from the NOAA archives (http://www.noaa.gov/). NOAA archives follow the Hurrell at al. (1995) methodology. NAO index is based on boreal winter, because the NAO pattern is strongest during this season, also playing an important role on ocean environment. The analysis herein developed will be based upon December to March averages between Lisbon, Portugal and Iceland (Rogers, 1985). NAO data from NOAA was used in this study which refers to the monthly index based on the difference of normalized sea level pressures (SLP) between Ponta Delgada, Azores and Stykkisholmur/Reykjavik, Iceland, until 2003. After that, the values were reconstructed based on Ponta Delgada observational data and NCEP/NCAR Reanalysis data (1948-2003).

The NAO Index data, obtained from NCEP/NCAR website, were analyzed monthly with mean standardized at 500 hPa height anomalies. According to Barnston and Livezey (1987), it was obtained information from the Climate Data Assimilation System in the analysis region 20°N-90°N between January 1950 and December 2000. This procedure isolates the primary tele-connection patterns for all months which are linearly interpolated to the day in question, and therefore it accounts for the seasonality inherent in the NAO patterns, and allows time series of the patterns to be constructed (www.cpc.ncep.noaa.gov/data/teledoc/teleindcalc.shtml). Figure 2 shows the NAO index monthly variability from 2002 to 2006. This figure clearly indicates the periods of positive and negative NAO index and, therefore, it will help to analyze its impact on the IP.

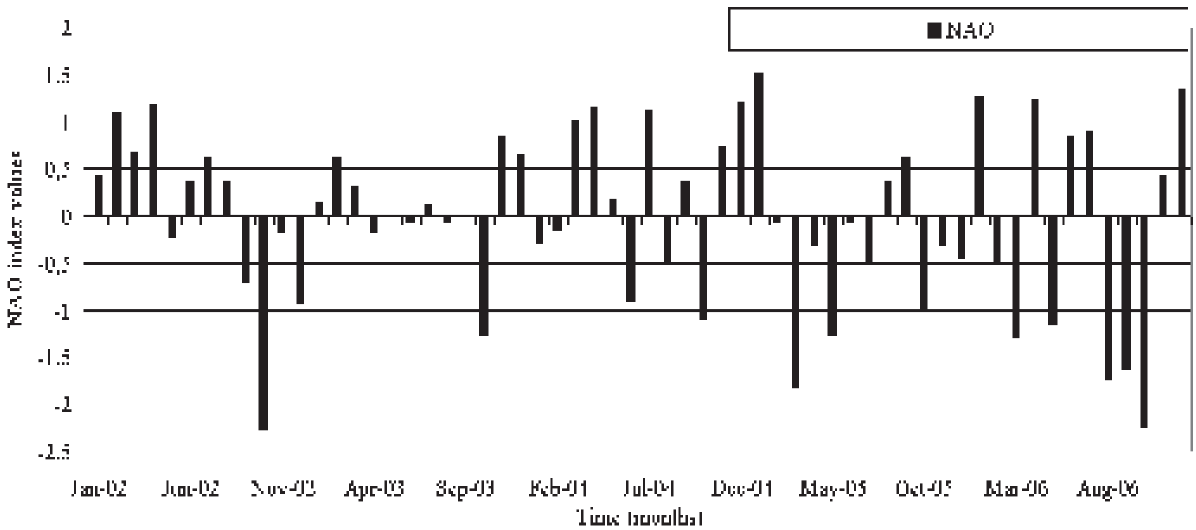

Figure 2. NAO index monthly variability from 2002 to 2006 (extracted from: NCEP/NCAR website).

The air quality stations selected are from the “Agência Portuguesa de Ambiente” (Portuguese Environmental Agency, PEA, see Figure 1). Some of these stations are urban and close to the roads. However, for example, the Matosinhos station is located in a residential area, near the sea. Additionally, this station is at 8 Km from the Francisco Sá Carneiro International Airport to the Southwest, being close to industrial sources (petro-chemical industry, wooden transformation and steel mills) and vehicular emissions.

The stations measure photochemistry pollutants: Ozone (O_3), Monoxide and Dioxide Nitrogen (NO, NO_2, respectively), Carbon Monoxide (CO), inhalable (coarse) Particulate Matter (PM_{10}) and Sulfur Dioxide (SO_2). The only station to measure fine Particulate Matter $PM_{2.5}$ is Vermoim. The air pollutants database is hourly and it can be found for download in the website (http://www.qualar.org). The ozone concentration is 8-hourly composite average and the PM date is based in the lag of 7 hours. Daily mean was calculated from the data series, except for the O_3 that used the daily maximum. All the data are represented in $\mu g.m^{-3}$.The pollution mean, minimum and maximum levels in the area are presented in the Table 1.

Table 1. Descriptive statistics for all studied variables (Air pollutants and Meteorological Variables). Std. Dev. Mean Standard deviation from 2002 to 2006.

Variables	Valid N	Mean	Minimum	Maximum	Std.Dev.
Precipitation (mm)	1826	3,06	0,00	94,0	7,58
Tair_mean (°C)	1826	15,02	0,00	30,5	4,95
Tair_maximum (°C)	1826	19,52	0,00	38,1	5,58
Tair_minimum (°C)	1826	11,02	-2,40	24,3	4,85
O_3 ($\mu g/m^3$)	1826	71,45	4,80	218,3	30,35
PM_{10} ($\mu g/m^3$)	1781	40,23	3,12	183,6	23,87
SO_2 ($\mu g/m^3$)	1795	7,44	0,30	60,7	5,85
NO ($\mu g/m^3$)	1793	14,51	0,11	98,6	14,49
CO ($\mu g/m^3$)	1823	500,35	183,12	1670,8	219,60
NO_2 ($\mu g/m^3$)	1783	31,39	6,48	122,7	13,51
$PM_{2,5}$ ($\mu g/m^3$)	1069	24,89	0,00	148,0	22,31

The air pollutants series had statistical treatment which was based on weighted values, considering Custóias as the geographically central station with the greatest weighted value, 0.50, followed by Leça and Senhora da Hora, 0.25, Antas, Matosinhos and Vermoim, 0.15, Baguim, Vila Nova da Telha, Boavista, Ermesinde and Perafita, 0.10. This weighted time series were filled by arithmetic means. This choice was base on the major correlation (>0.70, $p<0.05$) between the stations that measure each pollutant. If the missing data is large, as for the variable CO, only the arithmetic means was used.

5.3 Statistical Methods

2.3.1 Statistical tools

In this study, two distinct statistical tools were applied to the meteorological and air quality data. After the descriptive statistics (average and maximum) treatment the meteorological and air quality information was analyzed through Pearson correlation coefficient, r, for seasonal variability and Principal Components Analysis (PCA), for annual variability. PCA technique deals with higher amount of data, which is the main reason for this distinction.

The PCA is a multivariate technique in which a number of related variables are transformed in a smaller set of uncorrelated variables (e.g. Jackson 1991). The technique RPCA (Rotated Principal Component Analysis) rewrites the original data matrix into a new set of components that are linearly independent and ordered by the amount of the variance they explain. Therefore the component weights calculated express the correlation between the original variables. The procedure adopted consisted of grouping in the same component parameters with the same temporal variability. A correlation matrix is determined having as input air pollutants and meteorological variables. The RPCA technique started with the calculation of the *eigenvalues* and *eigenvectors*, and the matrix of the correlation coefficients between the variables. This methodology has been applied to identify the sources of air pollution since early 70's, as described in Hopke (1991). The source apportionment techniques that were employed to identify and quantify the major particle pollution source classes affecting a monitoring site in metropolitan area, in USA, were analyzed for Thurston and Spengler (1985). These identifications were estimated by applying a new approach to apportion mass among various PCA source components such as the calculation of Absolute Principal Component Scores and the subsequent regression of daily mass and elemental concentrations on these scores. One advantage of the PCA source apportionment approach developed is that it allows the estimation of mass and source particle characteristics for an unconventional source category such as transported (coal combustion related) aerosols, being a quite useful technique.

2.3.2 Time scales

A time scale of 10 days average for each variable at each specific year will be use to analyze all the dataset in order to optimize the impact of NAO index variability on all variables. The objective of this average is to avoid the chaotic variability intrinsically linked to daily values. This procedure is according to Bojariu and Gimeno (2003). These authors used the NCEP-NCAR reanalysis data covering the boreal winters of the 1958–1997 period and found that the high-frequency component of the NAO could be interpreted as a stochastic process with an e-folding time scale of 9.5 days. These authors also indicate that due to a lack of memory, the NAO index should have no correlation from year to year if its forcing remains unchanged, generating a flat white spectrum.

This time scale was applied to RPCA for annual analysis as well as seasonal analysis, using correlation coefficients.

3. Results and Discussions

The results are divided into two parts: the analysis of the inter-annual air pollutants and NAO associations, using RPCA and the seasonal air pollutants and NAO, using correlation analysis.

6.1 Inter-annual variability analysis using RPCA

This section shows the results of CP analysis which includes NAO index and air pollutants. Tables 2, 3, 4, 5 and 6 show the Factor Analysis using the Principal Component Method (PCM) results with VARIMAX rotation, from 2002 to 2006 (Tables 2 to 6, respectively). They show two Factors with NAO index associations, total precipitation and air pollutant concentrations. The pollutant $PM_{2.5}$ was not included in the tables 2 and 3 because there is no data until November 2003.

Table 2. Principal Component Analysis with Factor Loadings (Varimax normalized), based in the weighted mean (excepted CO which used an arithmetic mean) from all PMA air quality stations and NAO for the 2002 year. Bold forms show significant values above 0.7. Positive and negative loadings over 0.30 are underlined.

2002	Factor 1	Factor 2	Cummunalities
Prec_mm	0.24	**-0.78**	0.64
Tair_mean	**-0.71**	0.15	0.49
O_3	<u>-0.62</u>	<u>0.58</u>	0.73
PM_{10}	<u>0.38</u>	**0.84**	0.78
SO_2	0.10	**0.88**	0.73
NO	**0.96**	0.10	0.95
CO	**0.95**	0.02	0.93
NO_2	**0.80**	<u>0.38</u>	0.82
NAO	0.01	<u>0.60</u>	0.43
Expl.Var	3.57	2.95	
Prp.Totl	0.40	0.33	

Table 3. As in Table 2 but for the 2003 year.

2003	Factor 1	Factor 2	Cummunalities
Prec_mm	-0.21	**0.74**	0.63
Tair_mean	0.00	**-0.87**	0.78
O_3	-0.13	<u>-0.65</u>	0.48
PM_{10}	**0.87**	<u>-0.36</u>	0.83
SO_2	<u>0.49</u>	-0.15	0.40
NO	**0.74**	<u>0.59</u>	0.93
CO	**0.74**	<u>0.65</u>	0.97
NO_2	**0.89**	0.08	0.82
NAO	0.28	0.15	0.21
Expl.Var	3.02	2.68	
Prp.Totl	0.34	0.30	

Table 4. As in Table 2 but for the 2004 year.

2004	Factor 1	Factor 2	Cummunalities
Prec_mm	-0.09	**-0.72**	0.54
Tair_mean	-0.65	0.34	0.80
O_3	-0.57	0.66	0.86
PM_{10}	0.62	**0.73**	0.91
SO_2	-0.08	**0.82**	0.62
NO	**0.95**	0.01	0.93
CO	**0.99**	0.04	0.98
NO_2	**0.76**	0.54	0.94
$PM_{2.5}$	**0.76**	0.54	0.87
NAO	0.04	0.44	0.53
Expl.Var	4.19	3.05	
Prp.Totl	0.42	0.30	

Table 5. As in Table 2 but for the 2005 year.

2005	Factor 1	Factor 2	Cummunalities
Prec_mm	**-0.77**	0.15	0.69
Tair_mean	0.33	**-0.77**	0.95
O_3	-0.01	-0.40	0.62
PM_{10}	**0.92**	0.21	0.96
SO_2	**0.78**	-0.13	0.64
NO	0.18	**0.93**	0.85
CO	0.38	**0.90**	0.97
NO_2	0.65	0.65	0.89
$PM_{2.5}$	**0.86**	0.34	0.92
NAO	0.45	0.11	0.22
Expl.Var	3.68	3.07	
Prp.Totl	0.37	0.31	

Table 6. As in Table 2 but for the 2006 year.

2006	Factor 1	Factor 2	Cummunalities
Prec_mm	-0.20	-0.68	0.54
Tair_mean	-0.65	0.51	0.73
O_3	-0.46	**0.73**	0.78
PM_{10}	**0.55**	**0.75**	0.93
SO_2	0.12	**0.75**	0.71
NO	**0.96**	-0.12	0.93
CO	**0.94**	0.07	0.94
NO_2	**0.80**	0.32	0.82
$PM_{2.5}$	**0.88**	0.36	0.97
NAO	0.37	0.06	0.40
Expl.Var	4.34	2.64	
Prp.Totl	0.43	0.26	

A general negative significant association between the total precipitation and NAO index is observed, in both Factors 1 and 2, presented in the years of 2002, 2004 and 2005 and weaker association in 2003 and 2006. Additionally, some air pollutants (such as PM_{10}, $PM_{2.5}$, SO_2, NO_x and CO) present a positive association with NAO. The O_3 shows a positive association with NAO during 2002 (0.58) and 2004 (0.66), at 2nd Factor, explaining 30% of the variance, and negative with precipitation. The index shows positive loading for NAO with 0.44 (2004) and 0.60 (2002), and is negatively associated with precipitation, -0.78 (2002) and -0.72 (2004). All the years of 2002, 2004 and 2005 present the highest associations with some of air pollutants (PM_{10}, SO_2 and $PM_{2,5}$) having loadings above 0.70. The communalities are usually higher as well. Ozone, PM_{10}, $PM_{2.5}$, SO_2 and NO_2 are positively associated.

Specially, the year of 2005 presents the best result at Factor 1, explaining 37% of the variance, which shows positive association of NAO (0.45) with the air pollutants (PM_{10}, 0.92, $PM_{2.5}$, 0.86, SO_2, 0.78 and NO_2, 065) and negatively with precipitation (-0.77). However, the communality of NAO index is low during this year (0.22), having only a few cases of association.

The year of 2006 also shows NAO index positively associated (0.40) with pollutants (from PM10 with 0.55 to NO with 0.96) and negatively with precipitation (-0.20), although it is not as clear as in the previous years.

The total amount of rainfall in 2002 and 2004 (Table 7) during late spring and summer (May to September) shows the highest values (over 200 mm) observed which probably caused a significant impact on air pollutants concentration. On the other hand, 2003, 2005 and 2006 have the lowest precipitation (lower than 200 mm) which could explain, partially, the smaller associations. Additionally, the year of 2003, which had the highest heat wave of the whole period, shows the weakest association with NAO and air pollutants at Factor 1. NAO index during April to October was close to zero (Figure 2).

Table 7. Annual and May-September precipitation for Porto Area.

Year	Annual Precipitation (mm)	May –Sep Precipitation (mm)
2002	1536,7	398,3
2003	1374	172,9
2004	978,2	258,7
2005	609,2	101,5
2006	974,1	169,6

Summarizing, NAO index is clearly related to SO_2, $PM_{10,}$ $PM_{2.5,}$ with less weight to ozone, CO and NO_x and negatively associated with the total precipitation. Precipitation negative association indicates that mainly PM and SO_2 could be scavenged through rainfall and partially to other air pollutants. Therefore, PM_{10}, SO_2, $O_{3,}$ CO, NO and NO_2 seasonal concentration could be partially explained by precipitation and its association with NAO variability, which is shown in the section 3.2.

6.2 Seasonal pollutants and NAO index using correlation coefficient

The annual correlation between NAO index and air pollutants had inferior results than the correlation considering only the months March to December. Poknousky (2009) has shown that the winter rainfall rate is more uniformly distributed in various latitude belts across Europe than in the summer, but more intense precipitation occurs in Southern Europe because of strong moisture transport into this area from the Atlantic Ocean. The atmospheric circulation patterns seem to have moved Northward during the late 1980s and 1990s possibly responding to the global warming (Poknouksy, 2009). As a consequence, the climate in Southern Europe became drier and rain amounts reduced primary in the warmer part of the year. In contrast, the rain rate has been increasing in the colder part of the year. This led to a wetter climate in the winter and a drier in the summer. As according to Poknousky (2009), the correlation herein used was focused over winter months (Dec to March) and separately in summer months (March to December).

3.2.1 Summer

Comparing monthly NAO oscillation and air pollutants concentrations it was found an association with significant correlation coefficient above 0.50, as indicated in Table 8. for the March-December period. For instance, the correlation coefficient between PM_{10} and NAO for 2002 was 0.72 ($p<0.05$); $PM_{2,5}$ in 2004 was 0.74 ($p<0.05$) and SO_2 was 0.78 ($p<0.01$) in 2002 and 0.84 ($p<0.01$) in Apr-Dec 2005.

Table 8. Annual and March-December (Mar-Dec) periods correlation between pollutants and NAO. The bold form presents the biggest correlation coefficients (> 0.50, p<0.05* or p<0.01**) between pollutant and NAO index.

NAO/POL 2002	O_3	PM_{10}	SO_2	NO	CO	NO_2	
Annual Correlation	0.08	**0.66***	**0.70***	-0.03	-0.18	0.12	
Corr.Mar-Dec	0.34	**0.72***	**0.78****	-0.38	-0.49	0.00	
NAO/POL 2003	O_3	PM_{10}	SO_2	NO	CO	NO_2	
Correl anual	-0.31	0.15	-0.18	0.38	0.40	0.07	
Corr.Mar-Dec	-0.24	0.17	-0.23	0.38	0.36	0.05	
NAO/POL 2004	O_3	PM_{10}	SO_2	NO	CO	NO_2	$PM_{2.5}$
Correl anual	0.04	0.22	0.17	0.09	0.17	0.21	0.31
Corr.Mar-Dec	-0.08	0.50	0.11	0.33	0.43	0.45	**0.74***
NAO/POL 2005	O_3	PM_{10}	SO_2	NO	CO	NO_2	$PM_{2.5}$
Correl anual	-0.28	0.25	0.39	0.23	0.25	0.13	0.32

Corr.Mar-Dec	-0.27	0.24	0.60	-0.05	-0.14	0.00	0.19
NAO/POL 2006	O_3	PM_{10}	SO_2	NO	CO	NO_2	$PM_{2.5}$
Correl anual	-0.26	0.20	0.08	0.35	0.27	0.30	0.25
Corr.Mar-Dec	-0.18	0.20	0.08	0.31	0.17	0.27	0.30

The PM and SO_2 are significantly correlated with NAO mainly in 2002 and $PM_{2.5}$ (0.74, $p<0.05$) in 2004. In 2002, five months had positive phases and other five presented negative phases (Figure 1). On the other hand, in 2004, 7 months are registered with positive phases and in the others years, the negative phase was dominant.

3.2.2 Winter analysis

The same comparison was performed between NAO and air pollutants is presented in Table 9, however for winter period December to April.

Table 9. NAO index and air pollutants correlation for December- April (Dec-Apr) period. Bold forms show values with significant correlation ($p<0.05$* or $p<0.01$**).

2002	NAO/POL	O_3	PM_{10}	SO_2	NO	CO	NO_2	
	Corr.Jan*-Apr	<u>0.14</u>	0.04	0.00	0.01	-0.09	0.02	
2003	NAO/POL	O3	PM_{10}	SO_2	NO	CO	NO_2	
	Corr.Dec-Apr	-0.09	**0.42****	0.007	**0.20****	**0.21****	**0.24****	
2004	NAO/POL	O_3	PM_{10}	SO_2	NO	CO	NO_2	$PM_{2.5}$
	Corr.Dec-Apr	**0.35****	-0.05	-0.07	**-0.23****	**-0.25****	**-0.26****	-0.08
2005	NAO/POL	O_3	PM_{10}	SO_2	NO	CO	NO_2	$PM_{2.5}$
	Corr.Dec-Apr	**-0.55****	-0.13	**-0.17***	**0.26****	**0.31****	0.03	**0.26****
2006	NAO/POL	O_3	PM_{10}	SO_2	NO	CO	NO_2	$PM_{2.5}$
	Corr.Dec-Apr	**0.32****	-0.02	-0.06	**-0.21****	**-0.22****	**-0.23****	-0.04

* Air pollution and NAO index data analysis begin in 2002 January

Table 9 presents correlation coefficient values where the values under 0.50 present a significant *p*. From this table, in few cases, when the air pollutant had positive (negative) correlation in the Mar-December period, it had negative (positive) correlation in the Dec-April period. This result could explain why it was not found any significant annual statistical correlation. On other hand, the results are consistent when the atmospheric chemistry is considered. For instance, when the O_3 has positive correlation, the NO and NO_2 present negative one, suggesting that the presence of a clean sky and high temperature can allow the O_3 formation, and therefore the decreasing of the NO and NO_2.

During the NAO index negative phase, frontal systems are more frequent in the Iberian Peninsula (IP) and therefore, there is more precipitation what impact economically in agriculture and energy sectors (Trigo *et al*, 2002). This synoptic situation can contribute to the pollutants scavenging (Cancio, 2008). On the other hand, with a positive phase the air pollutants accumulation is observed, being in agreement with the high correlation between air pollutants and NAO index phases showed in the figure 3.

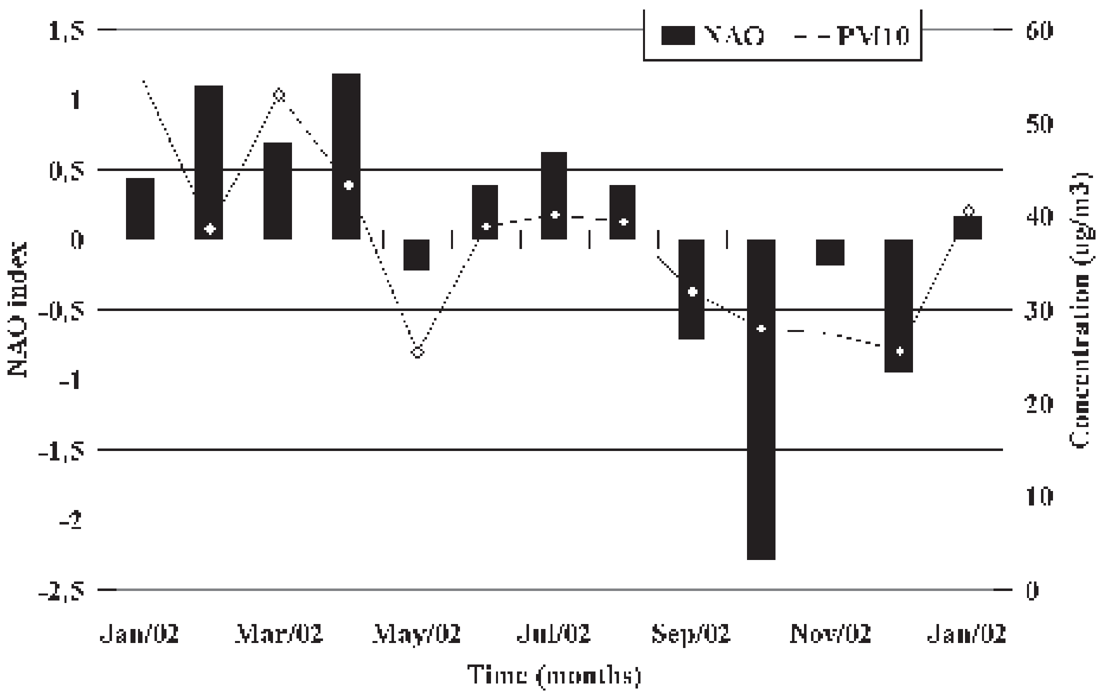

Figure 3. The variation of the PM_{10} weighted monthly mean concentration (full line) and the NAO (chart bar) for the 2002 year. Pearson correlation, r = 0,66; p = 0,02, r^2 = 0,43 and regression equation, y= - 2,36 + 0,06x

Summarizing the Tables above, air pollutants variability is also clearly dependent on different meteorological time and spatial scales and intensities. The North Atlantic Oscillation is a synoptic scale phenomenon but it also affects meso-scale phenomena. On the other hand, the air pollutants concentration variability may be influenced by many different scales. It is important to notice that some studies have already suggested that climate change can modify the intensity and regularity of the NAO (Trigo, 2004); affecting the atmospheric general circulation and it could have a direct impact on air pollutants dispersion in different scales.

4. Conclusion

The NAO favors the increase (positive) or the decrease (negative) of zonal winds which indirectly affects the air pollution concentrations in larger areas. These atmospheric circulations influence the main synoptic cyclone trajectories that cross the Atlantic Ocean having an impact on the precipitation variability in the Northern Europe (Hurrell, 1995). Therefore, NAO positive phase (intensification) in the Iberian Peninsula (Southern Europe) is characterized by clean sky, low temperatures and weak wind which occur in November and December. As a result, the air pollutant variability is also affected by this pattern.

In summary, positive NAO phase helps to increase air pollutants concentrations, because the atmospheric conditions difficult its dispersion or scavenge by precipitation. The opposite occurs at negative phase. Therefore, this article indicates that the synoptical characteristic that occur with NAO index phase have an important impact in the air quality. Particularly, the photochemical pollutants are better explained and correlated with NAO index during the winter period. Furthermore, in the March to December (2002) and April- December (2002 and 2005) periods the PM and SO_2 were also significantly correlated with NAO index.

Once that human health and hospital morbidities may be affected by air pollution, the present results suggest that a good NAO climate forecast is important to prevent them. This prevention could help the decision makers towards public health organization in the Iberian Peninsula and specially Portugal.

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5. References

Barnston, A. G., and Livezey, R. E., (1987) Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Mon. Wea. Rev*, 115, 1083-1126.

Bojariu, R.; Gimeno, L., (2003), Predictability and numerical modelling of the North Atlantic Oscillation, *Earth-Science Reviews*, Volume 63, Issues 1-2, 145-168

Cancio, J. López; Castellano, A. Vera; Hernandez, M. Chaar; Bethencourt, R. Garcia; Ortega, E. M., (2008) Metallic species in atmospheric particulate matter in Las Palmas de Gran Canária, *Journal of Hazardous Materials* 160, 521–528.

Creilson, J.K.; Fishman, J.; Wozniak, A.E., (2003) Intercontinental transport of tropospheric ozone: a study of its seasonal variability across the North Atlantic utilizing tropospheric ozone residuals and its relationship to the North Atlantic Oscillation, *Atmospheric Chemistry Physics* 3, pp. 2053–2066.

Garcia, N.O., Gimeno, L., de La Torre, L., Nieto, R., Añel, J.A., (2005) North Atlantic Oacillation (NAO) and precipitation in Galicia (Spain), *Atmósfera*, 18, 25-32.

Grundström, M.; Linderholm, H.W.; Klingberg, J.; Pleijel, H., (2011) Urban NO_2 and NO pollution in relation to the North Atlantic Oscillation NAO. *Atmospheric Environment* Volume 45, Issue 4, 883-888

Hopke, P.K., (1991) Receptor Modeling for Air Quality Management. *Elsevier*, Amsterdam.

Hurrell, J. W., (1995) Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation, *Science*, 169, 676–679.

Hurrell, J.W., Van Loon, H., (1997) Decadal variations in climate associated with the North Atlantic Oscillation. *Climate Change*, 36, 301-326.

Hurrell, J.W., Kushnir, Y., Visbeck, M., Ottersen, G., (2003) An Overview of the North Atlantic Oscillation. The North Atlantic Oscillation: Climate Significance and Environmental Impact, J.W. Hurrell, Y. Kushnir, G. Ottersen, and M. Visbeck, Eds. Geophysical Monograph Series, 134, pp. 1-35.

Hurrell, J.W., Delworth, T., Danabasoglu, G., Drange, H., Griffies, S., Holbrook, N., Kirtman, B., Keenlyside, N., Latif, M., Marotzke, J., Meehl, G.A., Palmer, T., Pohlmann, H., Rosati, T., Seager, R., Smith, D., Sutton, R., Timmermann, A., Trenberth, K.E., Tribbia, J., (2009) Decadal Climate Prediction: Opportunities and Challenges. Community White Paper, *OceanObs '09.*

Jackson, D.A., Somers, K.M., (1991) Putting things in order: the ups and downs of detrended correspondence analysis. *American Naturalist* 137:704-712.

Jones, P.D., Jónsson, T., Wheeler, D., (1997) Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. *Int. J. Climatol.* 17, 1433-1450.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Leetmaa, A., Reynolds, R., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Jenne, R., Joseph, D., (1996) The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society* **77**: 437–472.

Lee, D.S., Fahey, D.W., Forster, P.M., Newton, P.J., Wit, R.C.N, Lim, L.L., Owen, B., Sausen, R., (2009) Aviation and global climate change in the 21st century, *Atmospheric Environment,* doi: 0.1016/j.atmosenv.2009.04.024

Lyon, B., Barnston, A. G., (2005) The Evolution of the Weak "El Niño" of 2004-2005. *CLIVAR Variations*, Spring 2005, Vol. 3, No. 2.

NCEP, National Center for Environmental Prediction
Available: http://www.cpc.ncep.noaa.gov/data/teledoc/teleindcalc.shtml,
Assessed: 4 June 2009

NOAA. National Oceanic and atmospheric Administration
Available: http://www.noaa.gov

Osborn, T.J., Briffa, K.R., Tett, S.F., Jones, P.D., Trigo, R.M., (1999). Evaluation of the North Atlantic Oscillation as simulated by a climate model. *Climate Dyn.*, 15, 685-702

Pokrovsky, Oleg M., (2009) European rain rate modulation enhanced by changes in the NAO and atmospheric circulation regimes, *Computers & Geosciences* 35, 897–906

Rogers, J. C., (1985) Atmospheric circulation changes associated with the warming over the North Atlantic in the 1920s, *J. lim. Appl. Meteor,, 24*, 1303–1310.

Thurston, G. D., Spengler, J.D., (1985) A quantitative assessment of source contributions to inhalable particulate matter pollution in metropolitan Boston Massachusetts USA, *Atmospheric Environment,* 19(1):9-26.

Trickl, T., Cooper, O.R.; Eisele, H., James, P., Mücke, R., Stohl, A., (2003) Intercontinental transport and its influence on the ozone concentrations over central Europe: Three case studies, *Journal of Geophysical Research* 108 (D12), 8530

Trigo, R. M., Osborn, T. J., Corte-Real, J., (2002) The North Atlantic Oscillation influence on Europe: climate impacts and associated physical mechanisms. *Climate Res.,* 20, 9-17.

Trigo, R. M., Pozo-Vázquez, T. J., Osborn, Y., Castro-Díez, S., Gámiz-Fortis, M. J., Esteban-Parra, (2004). North Atlantic Oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula. *Int. J. Climatol.*, 24: 925–944.

Van Loon, H., Rogers, J.C., (1978) The seesaw in Winter temperatures between Greenland and Northern Europe. Part I: general descriptions. Monthly Weather Review, 106: 296-310.
Walker, G.T., (1924) Correlations in seasonal variations of weather, *IX Mem. Ind. Meteorol. Dept.*, 24, 275-332.