DOES THE NAO INDEX AFFECT THE PRECIPITATION AMOUNT AND CHEMISTRY IN THE NORTH-EASTERN IBERIAN PENINSULA?

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Abstract:

Modifications in the wind circulation and precipitation patterns have been predicted for the Mediterranean region linked to climate change. The North Atlantic Oscillation (NAO) has attracted much recent interest as a possible indicator of trends in global climate change due to its strong influence on large-scale variations in both atmospheric circulation and the hydrological cycle in the Northern Hemisphere. High NAO indices are associated with a northern shift of the North Atlantic westerlies producing higher precipitation in northern Europe and drier conditions over southern Europe and North Africa. High NAO-related aridity in the south may enhance the African dust load over the Mediterranean. Conversely, low NAO indices have been related with higher precipitation over the Mediterranean and North Africa linked to higher cyclonic activity at lower latitudes.

At a site in the north-eastern Iberian Peninsula (Montseny mountains, 41º46’N, 2º21’E, 700 m.a.s.l) the precipitation chemistry has been analyzed since the early 1980s. We explore here whether the NAO index has had an effect on the precipitation amount and precipitation chemical signal and wet deposition during the last 25 years.

Key words: *precipitation, West Mediterranean, rain chemistry, deposition, long-range transport, cluster analysis, back-trajectories, NAO.*

INTRODUCTION

The atmospheric dynamics in the West Mediterranean Basin (WMB) is conditioned by complex interactions of climatic and topographic effects that include the Azores high-pressure system, continental thermal lows over the Iberian Peninsula (IP thereafter) and the Sahara, orographic effects of the coastal ranges surrounding the Mediterranean coast, marked seasonal variations in temperature, humidity and rainfall and the arrival of frequent African dust intrusions (Millán et al. 1997; Rodríguez et al. 2003). Modifications in wind circulation and precipitation patterns have been predicted for the Mediterranean region (Giorgi and Lionello, 2008), as well as an increase in the arrival of African air masses (Moulin et al. 1997).

The chemical composition of precipitation is affected by the strength of source emissions, the incorporation of components into droplets during transport and the amount of rain available to scavenge components. Therefore, the rain chemistry is strongly influenced by the predominant atmospheric patterns. The North Atlantic Oscillation (NAO) has attracted much recent interest due to its strong influence on large-scale variations in both atmospheric circulation and the hydrological cycle in the Northern Hemisphere. Fluctuations between positive and negative phases of NAO (calculated from the pressure differences between the Icelandic low pressure and Azores high pressure systems) can produce large changes in wind speed, temperature and precipitation across Europe (Hurrell et al. 2003). Although present through the year its fluctuations are of greatest amplitude during the cold season months when the atmosphere is most dynamically active (Stenseth et al. 2003). Because of the relationship between rain chemistry and precipitation amount, we hypothesize here that part of the chemical signature and/or the wet deposition amounts reaching a site in Catalonia (NE Iberian Peninsula) may be influenced by this climatic variability.

Meteorological classification refers to the identification of distinct patterns that influence climate/weather-related variables (Riccio et al. 2007). Over the last several decades, Trajectory Statistical analysis Methods (TSMs) have been used to examine transport patterns and dynamical processes of air masses (Stohl, 1996, 1998). On the other hand, cluster analysis has been widely used to categorize back trajectories (Dorling and Davies, 1995; Jorba et al. 2004) and to identify synoptic weather regimes and long-range transport patterns that affect air pollution (Cape et al. 2000; Salvador et al. 2007).

At a site in the north-eastern Iberian Peninsula (La Castanya, Montseny mountains) the precipitation chemistry has been analyzed since the early 1980s, and previous work has shown a classification of air masses into 8 main clusters (Izquierdo et al 2012). We explore here whether the relationship between the NAO index and the frequency of the main provenances, their chemical rain composition and wet deposition using data covering the last 25 years.

MATERIAL AND METHODS

La Castanya station (LC, 41º46'N, 2º21'E, 700 m.a.s.l) is located in the Montseny mountains of the Pre-litoral Catalan Range. The site is amidst extensive holm-oak (*Quercus ilex* L.) forests in the Montseny Natural Park, 40 km to the N-NE from Barcelona and 25 km from the Mediterranean coast (Fig.1).

Figure 1. Location f La Castanya study site (LC)

We analyse here the rainfall chemistry in the period 1983–2009. Weekly bulk samples were taken to the CREAF laboratory where they were processed according to previously described protocols (Avila, 1996; Avila and Rodà, 2002). Conductivity, alkalinity and pH were measured in unfiltered samples within 48h of sampling. Samples were filtered through 0.45μm membrane filters and stored at -20ºC. Ion chromatography was used to determine the concentrations of Na^+, K^+, Mg^{2+}, Ca^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. We deal with volume-weighted mean concentrations (VWM, in μeq/L) and wet deposition amount (in kg/ha/year) for the main rain chemical components.

A daily meteorological analysis was undertaken based on 96-h isosigma back-trajectories at 12:00h UTC and 1500m asl by using the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) 4.0 dispersion model from the Air Resources Laboratory (ARL, available at http://www.arl.noaa.gov/ready/hysplit4.html, Draxler and Rolph, 2003). This height can be taken as representative of the mean transport wind at a synoptic scale within the upper boundary layer. The meteorological input was obtained from the ARL (Air Resources Laboratory) reanalysis database for the early 10-year monitoring period (1984-1993), and from FNL (1998-2004) and GDAS (Global Data Assimilation System) (2005-2009) from the NCEP (National Center for Environmental Prediction) for the most recent period (1998-2009).

Cluster analysis statistically aggregate observations into clusters such that each of them is as homogeneous as possible with respect to the clustering variables (Sharma, 1996). To compose each cluster, HYSPLIT has a grouping module based on variations in the Total Spatial Variance (TSV) between different clusters which is compared to the spatial variance (SPVAR) within each cluster component. The final number of clusters is determined by a change in TSV as clusters are iteratively paired (Draxler et al. 2009). This clustering methodology was applied to the daily trajectories obtained for an early (1984-1993) and recent (1998-2009) period at Montseny.

Our rain chemistry database consisted of weekly observations; however, trajectories were obtained daily. We estimated a daily chemical concentration for the days with precipitation by proportionally correcting weekly chemical concentrations by the precipitation contribution of the rainy days to the weekly amount. The rainy days within each week and their precipitation amount were obtained from records at LC, and from the AEMET stations (Spanish Meteorological Service) of Turó de l'Home and Tagamanent which are 7 and 8 Km distant from LC, respectively. Precipitation events of <3 mm were not included, and only the days with rainfall amount of >0.02 mm were considered for the determination of rain days within a week.

We analyse here the bulk rainfall chemistry for each cluster in en both, the early (1984-1993) and the recent (1998-2009) periods. Volume-weighted mean concentrations (VWM, in μeq/L) and wet deposition amount (in kg/ha/year) for the main rain components were correlated (lineal correlation) with NAOi for the winter period (DJFM).

RESULTS

1) The influence of NAO on atmospheric transport routes

Transport patterns for air masses arriving at LC were identified by cluster analysis: 8 main transport routes were found (Izquierdo et al. 2012; Fig. 2). The NAOi showed significant positive correlations with Regional and SE cluster frequencies, and negative with the W+NW trajectories (Fig.2, Table 1). Clusters showing similar relationship to NAOi and presenting broadly similar provenances were pooled together; thus a Western group was formed as the sum of C2, C3, C4 and C8a, and a Northern group was formed with C1 and C8b. Regional and SE trajectories accounted for 23% and 14% respectively, and W+NW trajectories, 33% of rainy days (Table 1).

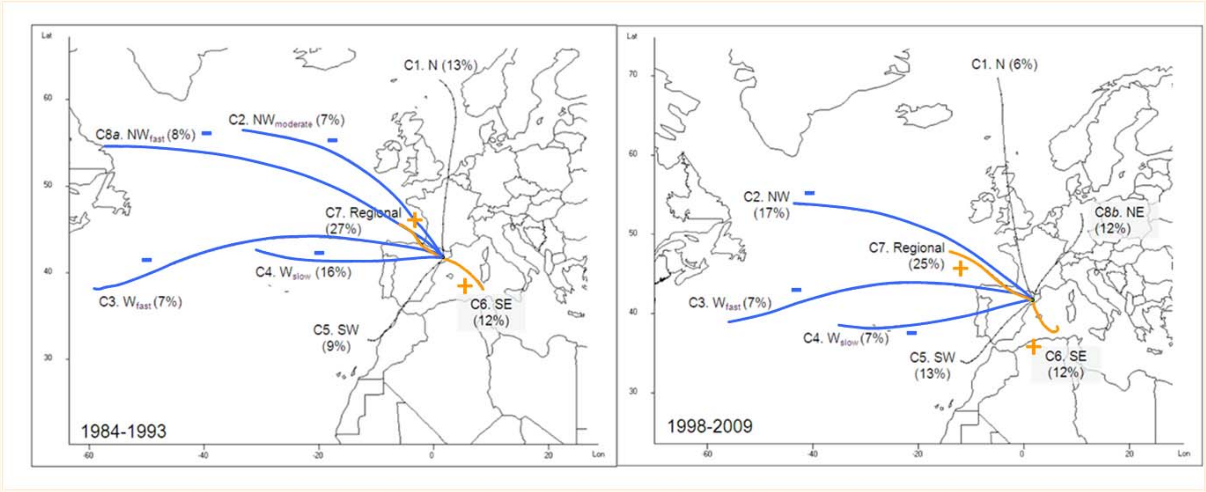


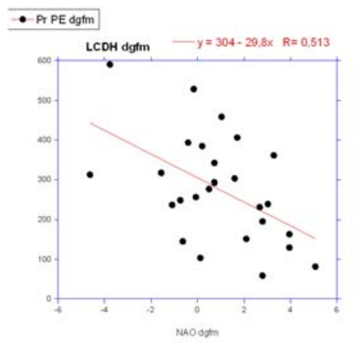
Figure 2. Centroids and frequency of 72-h back-trajectories associated to each cluster for two study periods from LC, at 1500 m.a.s.l. (modified from Izquierdo et al. 2012).

Table1. Correlation coefficient (R; linear correlation) of NAOi vs. frequency of rainy days by provenance groupings, and number of rainy days for groupings and their contribution to the total.

Clusters	correlation coefficient	N Rainy days	Rainy days vs. total rainy days
N (C1)+NE (C8b)	n.s.	179	12%
W (C3+C4)+ NW(C2+C8a)	- 0.41*	486	33%
SW (C5)	n.s.	250	17%
SE (C6)	0.58**	202	14%
Regional (C7)	0.51*	342	23%
Total		1459	100%

*p<0.05 **p<0.01

2) The influence of NAOi on precipitation amount



Precipitation amount at LC showed a negative significant correlation with winter NAOi (R= -0.51; R^2= 0.26; Fig. 3). Studies in the spatial patterns of the correlation between NAO and precipitation in the Iberian Peninsula have shown the strongest negative correlations in the central and western part of the peninsula and moderate to low correlations in the northeast (López-Bustins et al. 2008; González-Hidalgo et al 2009; Castro et al 2011). Our results are consistent with R^2values in the range 0.2-0.3 estimated for the NE (Castro et al 2011).

Figure 3. Relationship between precipitation and NAOi for winter

3) The influence of NAO on the chemical composition and deposition fluxes

Atmospheric components (gases and aerosols) are incorporated in rainwater through the process of rainout (incorporation as CCN or droplets) or washout (scavenged as rain falls). Washout-related ions are strongly depleted from the atmosphere as rain proceeds, thus showing a negative relationship with rain amount. Because the NAOi is also negatively related to precipitation, a direct relationship between ion concentrations and NAOi could be envisaged. Our data showed such positive relationships of NAOi with rain concentrations for NH_4^+, NO_3^-, SO_4^{2-} and Cl^- (Table 2) in the winter period. Sulphate was the second most abundant aerosol compound (after organic matter) measured at LC and is associated with shipping and power generation emissions (Cusack et al. 2012). Other sources of SO_4^{2-} derive from African mineral dust from gypsum soils and salt-lakes in specific areas of North Africa (Rodríguez et al. 2011). However, the lack of correlation between NAOi and Ca^{2+} (a strong indicator of African provenance also contained in gypsum, Table 2) and the lack of correlation of NAOi with SE flows suggests other sources for SO_4^{2-}. The fact that SO_4^{2-}, NO_3^- and NH_4^+ show similar correlations with NAOi may indicate that polluted air flows coming from Mediterranean which carry pollution from ship emissions and from the growing industrialisation in Eastern Europe are associated with positive NAO phases. On the other hand, our results reinforce the hypothesis that Atlantic advections (associated with negative phases of the NAO) would have a cleaning effect on the atmosphere, similarly as found in Cusack et al. (2012), since negative significant correlations were not observed (Table 2).

Finally, wet deposition amounts (which are calculated as the product of rain concentrations times rainfall amount) did not show significant correlations with NAOi for all chemical compounds. Thus, although NAOi influenced the rain chemistry for SO_4^{2-}, NO_3^- NH_4^+ and Cl^-, it did not affect their deposition fluxes.

Table 2. Correlation coefficients between NAOi and chemical components in precipitation. Only significant correlations ($p<0.05$) are shown.

Element	**NAO djfm (n=26)**
Pr	**-0.51**
H^+ VWM	
Na^+ VWM	
K^+ VWM	
Ca^{2+} VWM	
Mg^{2+} VWM	
NH_4^+ VWM	**+0.52**
NO_3^- VWM	**+0.46**
SO_4^{2-} VWM	**+0.50**
Cl^- VWM	**+0.42**

CONCLUSIONS

Cluster classification of provenances at a site in the NE Iberian Peninsula indicated that western air flows corresponded to negative NAO indices, while positive NAOi were associated to regional and south-western circulations. Precipitation amount was inversely correlated with NAO. Conversely, the annual mean concentration of some pollutants (SO_4^{2-}, NO_3^- NH_4^+) and a marine element (Cl^-) were positively correlated with NAO. This suggests that Atlantic advections have a cleaning effect at this site, even if they have to cross over the Iberian Peninsula, while Mediterranean advections carry more pollutants, presumably from ship traffic in the Mediterranean and from increasing industrialization in Eastern European countries.

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