BAROMETRIC CONNECTIONS BETWEEN THE NORTH OF THE CARIBBEAN SEA AND THE SOUTHWEST OF THE IBERIAN PENINSULA AND THE NAO INDEX

Amílcar Vélez-Flores
Javier Martín-Vide
Rafael Méndez-Tejeda
Dominic Royé

Abstract

This study analyzes possible climatic connections that establish the subtropical anticyclone of the North Atlantic (NASH) between two regions of the Atlantic Ocean. The fundamental importance of NASH is widely known by the scientific community. The condition of its large center of action in the regions around the Atlantic Ocean is the key part in the general atmospheric circulation between tropics, subtropical limits and the mid-latitudes. We have used monthly measures of the atmospheric pressure of San Fernando-Cádiz (Spain), as a reference point of the Southwest area of the Iberian Peninsula, and of San Juan (Puerto Rico) and Guantánamo (Cuba), as reference points for the north of the Caribbean Sea. The analysis also includes the monthly values of the North Atlantic Oscillation (NAO) index. The climatic registers that have been used correspond to a sequence of fifty-four years between 1956 and 2009. The results of the correlations show four months of the year (February, June, August and October) with significant positive statistical values between the atmospheric pressures of San Juan-Guantánamo and San Fernando-Cádiz. They also show three months equally important between the pressures of San Juan-Guantánamo and the NAO index (January, February and March).

Keywords: NASH, Caribbean Sea, Iberian Peninsula, atmospheric pressure, teleconnection, NAO.

Resumen

Este estudio analiza las posibles conexiones climáticas que establece el anticiclón subtropical del Atlántico Norte (NASH, por sus siglas en inglés) entre las regiones del suroeste de la península ibérica y el norte del mar Caribe. Es ampliamente conocido por la comunidad científica el papel fundamental que juega el NASH, por su condición de gran centro de acción, en las regiones que rodean el océano Atlántico, siendo éste una pieza clave en la circulación atmosférica general entre el trópico, el ámbito subtropical y las latitudes medias. Para este análisis se han utilizado las medias mensuales de presión atmosférica de San Fernando-Cádiz (España), como punto representativo del suroeste de la península ibérica, y de San Juan (Puerto Rico) y Guantánamo (Cuba), como puntos de referencia del norte del mar Caribe. Además, se han incluido en el análisis los valores mensuales del índice de la Oscilación del Atlántico Norte (NAO). Los registros climáticos que se han empleado corresponden a series de cincuenticuatro años, comprendidos entre 1956 y 2009. Los resultados de las correlaciones muestran cuatro meses del año (febrero, junio, agosto y octubre) con valores positivos estadísticamente significativos entre las presiones atmosféricas de San Juan-Guantánamo y San Fernando-Cádiz, y tres meses con correlaciones igualmente significativas entre las presiones de San Juan-Guantánamo y el índice NAO (enero, febrero y marzo).

Palabras clave: NASH, mar Caribe, península ibérica, presión atmosférica, teleconexión, NAO

Résumé

Cette étude analyse les liens climatiques observés entre les régions du sud-ouest de la péninsule ibérique et le nord de la mer des Caraïbes. Le rôle que joue l'anticyclone des Açores (NASH en anglais) sur les régions qui entourent l'océan Atlantique est bien connu de la communauté scientifique, et reste un facteur essentiel dans la circulation atmosphérique générale entre les zones tropicales, subtropicales et les latitudes médianes. Pour cette analyse, les moyennes mensuelles de pression atmosphérique de San Fernando-Cádiz (Espagne) ont été choisies comme repère de la zone sud-ouest de la péninsule ibérique, et celles de San Juan (Porto Rico) et Guantánamo (Cuba) ont été retenues comme points de référence pour le nord de la mer des Caraïbes. L'analyse inclut également les valeurs mensuelles de l'Oscillation nord-atlantique (ONA). Les relevés climatiques utilisés ont été réalisés sur cinquante-quatre ans, entre 1956 et 2009. Les résultats de ces corrélations montrent que quatre mois de l'année (février, juin, août et octobre) enregistrent des valeurs positives dont les statistiques sont significatives entre les pressions atmosphériques de San Juan-Guantánamo et San Fernando-Cádiz. Trois autres mois (janvier, février et mars) ont également montré des corrélations significatives entre les pressions atmosphériques de San Juan-Guantánamo et l'ONA.

Mots-clés : NASH, mer des Caraïbes, péninsule ibérique, pression atmosphérique, télé-connexion, ONA

Received: 7 October 2015 Revision received: 27 September 2016 Accepted: 30 September 2016

1. Introduction: NASH and its influence in the surrounding regions of the North Atlantic

In terms of its localization, orientation, intensity and area of extension, the subtropical anticyclone of the North Atlantic or "North Atlantic Subtropical High" (NASH), usually known as the "High of the Azores" in Europe or "High of the Bermudas" in North America, exerts a big influence over the climatic variabilities of the surrounding regions of the North Atlantic. By the end of the century, Teisserenc de Bort (1883) had identified five types of anomalous winters in Europe according to the NASH position, using maps of monthly measures of atmospheric pressure. On the other side, starting with the decades of the 50s in the 20th century, authors like Klein (1957), Zishka and Smith (1980), Harman (1987), Lamb (1973) or Sahsamanoglou (1990) analyzed the number of occurrences, middle positions, intensity, predominant migration and the seasonality of the NASH.

David *et al.* (1997) analyzed the variability or the intrannual and interannual frequency of NASH, observing two dominant patterns in the intrannual fluctuation of NASH: one, during winter with a weakening in its center of action, and the other one during summer with a strengthening. During winter, NASH, by weakening itself, extends its configuration with slightly lower pressure across the North Atlantic, dividing itself into two centers of action that are situated in the southeastern part of the United States and northwestern Africa. On the other hand, during summer, NASH presents a configuration of maximum values that are concentrated in only one action center over the North Atlantic central area. During the rest of the year NASH shows the migration of its action center of southwest-northeast over the North Atlantic. This migration starts during spring, when the center of NASH is weakened and is located at its most southwestern point, during the month of March. Starting with this month, NASH experiences a shift of its center towards the north, which, in the beginning of May starts to intensify rapidly while expanding its radius of action over the North Atlantic. This expansion and reinforcement of NASH continues during the months of June and July (months of maximum intensity) accompanied by a migration of the northwest, covering a big part of the east of the United States and the southwestern Europe, with maximum values of atmospheric pressure. Between August and September, a reduction begins in NASH's influence area and its center weakens continuously until the winter months. During this season NASH starts to expand once again in a weakened way to cover the width of the North Atlantic, covering the eastern part of North America, Western Europe and the Northern Africa.

Wang (2007) also observed that NASH tends to shift towards the east in equinoctial seasons and to the west in winter and summer (Figure 1). During equinoctial seasons the anticyclone tends to be located to the east of the Atlantic Ocean either because it coincides with the start of the rainy season in North America during springtime or because of its weakening during autumn as it is leaving the summer months behind. On the other hand, during winter season NASH connects the high pressures of the continental North America with Western Europe and Northern Africa, by forming an almost uniform anticyclone bridge. Something similar also happens in Western Europe by connecting another anticyclonic bridge with the thermic anticyclone of Central Europe. Its action radius increases during the summer months giving place to a cellular type configuration with a defined and very strong center which extends over the North Atlantic, reaching the north of the Caribbean and the southeast of the United States. Wang (2007) also established that this migration and development of NASH is directly related with the semiannual characteristics of the atmospheric pressure in the Caribbean region.

NASH has also an important influence on the climate of the Iberian Peninsula, especially during the summer months, because it forms a barrier and diverts the course of the Atlantic depressions of the region

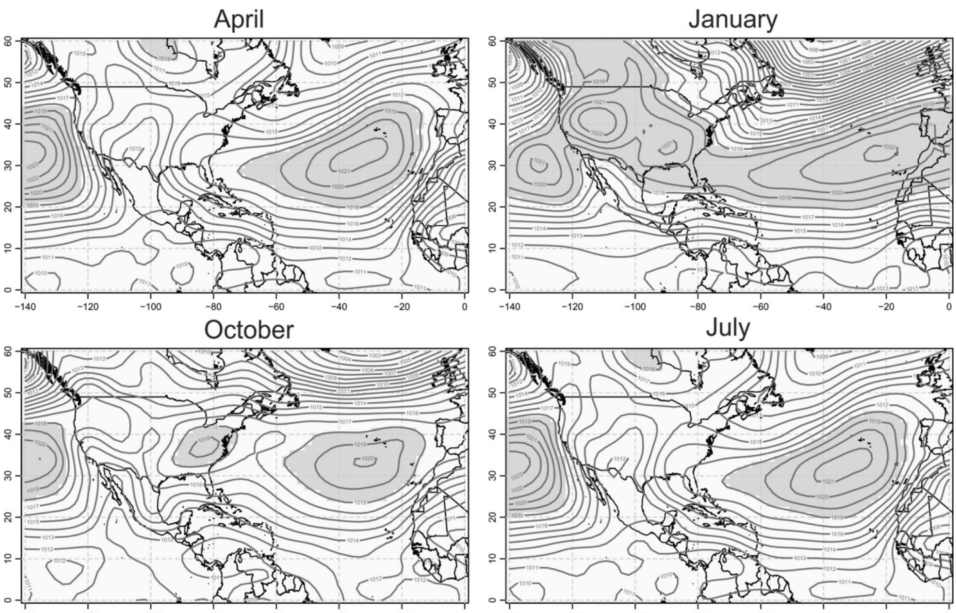


Figure 1: Sea level pressure (hPa) in the spring (April), winter (January), fall (October), summer (July) and showing the seasonal variations of the North Atlantic Subtropical High (NASH) for the period 1950-2006 (Wang 2007). Sea level pressure larger than 1,018 hPa is shaded.

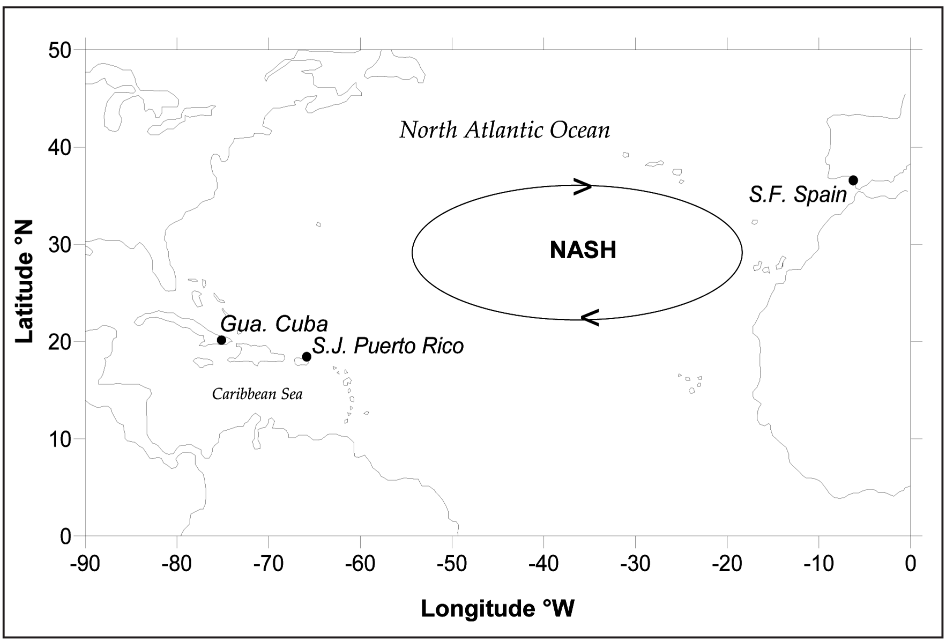
to the North (Martín-Vide y Olcina 2001). On the other hand, during the winter months, the influence of NASH over the Iberian Peninsula loses force, allowing Atlantic storms to enter, which frequently follow a route close to the Gulf of Cádiz, contributing a high percentage to the annual precipitation in the center and south of the Peninsula (Capel Molina 2000).

On the other hand, NASH is a fundamental part of the low frequency of North Atlantic's variability pattern, or the North Atlantic Oscillation (NAO), whose dipoles are constituted by this anticyclone and the low sub-polar pressures in the vicinity of Iceland. NAO index has been traditionally defined as the difference between the previously standardized atmospheric pressures in a point of the Azores islands, usually Ponta Delgada, and a place in Iceland, like Akureyri (Rogers 1984), or between a place on the southwest Iberian Peninsula, like Lisbon of Portugal, and another one of Iceland, using Stikkisholmur (Hurrell 1995) or its capital, Reykjavik, as the representative points of NASH and the low sub-polar pressure, respectively. Gibraltar has also been used as a representative point for NASH (Jones *et al.* 1997). Thus, the winter NAO index can be defined as the measure for the winter months (December to March), of the normalized differences of the atmospheric pressure in Lisbon, Portugal and Stikkisholmur, Iceland (Hurrel 1995). NAO is associated with the change in the "westerlies" which cross the Atlantic to Europe, especially during the winter months (van Loon and Rogers 1978). The positive values of the NAO index demonstrate a reinforcement of the "westerlies" over the mid-latitudes, which are associated with irregular low pressures over the area of Iceland and abnormally high pressures crossing over the subtropical Atlantic. Hurrell (1995) thinks that NAO is the main source of the seasonal interdecadal variability in the general atmospheric circulation of the northern hemisphere and represents the most important teleconection of the Atlantic-European region. Marshall (2001), and other authors, also state that NAO, during the last two decades, has been related to numerous anomalies in the regional climates around the Atlantic.

The influence that NAO exerts over meteorological anomalies and the climatic variability of the Iberian Peninsula is also well known (Rodó *et al.* 1997; Zorita *et al.* 1992; Esteban-Parra, *et al.* 1998; Trigo *et al.* 2002; Pozo-Vázquez *et al.* 2000; Martín-Vide y Fernández 2001). Martín-Vide and Fernández (2001) observe how NAO contributes a good part of the variability in rainfall of the southwest centre of the Iberian landmass during the months of October to March, including both, being negative, the correlation between its index and precipitations during the cited months. Castro *et al.* (2011) have confirmed the considerable relationship between the NAO index and the rain patterns in the region, especially during winter and spring.

On the other hand, the NAO index of the Caribbean region has not been studied as extensively as that of the Iberian Peninsula. Malgren *et al.* (1998) analyzed the relationship between the median annual precipitation in Puerto Rico and NAO, and observed that the NAO index during winter is negatively correlated with the precipitation. So, there are abundant precipitations registered through a major part of the territory with a negative index and precipitations of small amounts during the positive phases of NAO. Giannini *et al.* (2001) also found that when NAO presents positive values, a reinforcement of the trade winds is produced, which causes the cooling of the North Atlantic's surface, so, affecting the deep convection and impeding the cloud formation, especially during the beginning of the rainy season during spring time.

The purpose of this study is to analyze the monthly behavior of the atmospheric pressure in the area of the NASH influence at its extreme northeastern point, the southwest of the Iberian Peninsula and the north of the Caribbean (Map 1). To do so, linear correlations have been analyzed using the *r* of Pearson, between the monthly means of the atmospheric pressure of San Juan and Guantánamo and the monthly means of the atmospheric pressure of San Fernando and Cádiz, on one side,



Map 1: Geographical location of meteorological stations (Gua, Guantánamo; S.J., San Juan; S.F., San Fernando) and the North Atlantic Subtropical High (NASH).

and corresponding monthly NAO indexes, on the other, for a period of more than 50 years, from 1956-2009.

2. Data basis

2.1 Daily series of atmospheric pressure.

The series of the data basis for the Caribbean area have been daily entries of the atmospheric pressure of San Juan, Puerto Rico and Guantánamo, Cuba for the period between 1956 and 2009 (Table I and Figure 2), originating from the "National Climatic Data Center" (NCDC) of the "National Oceanic and Atmospheric Administration" (NOAA), of the United States of America federal government. For the Iberian Peninsula we used the daily series of the atmospheric pressure for San Fernando, Spain, from the European IMPROVE project (Camuffo and Jones 2002), for the period 1956-1989 (Table I and Figure 2), complementing it with the daily series of Cádiz, Spain, atmospheric pressure from the "State Meteorological Agency of Spain" (AEMET), for the period of 1990-2009 (Table I and Figure 2). For monthly NAO indexes we have used the ones established by James W. Hurrell of the "Climate Analysis Section" from the "National Center for Atmospheric Research" in Boulder, Colorado, which has been calculated as the difference between the standardized values of the average monthly atmospheric pressure of Lisbon and Stykkisholmur.

It has been found that atmospheric pressure series of San Juan and Guantánamo reasonably fit to the normal distribution.

Table I: Latitude, longitude, annual average of atmospheric pressure (***hPa***) and standard deviation "***S***" (***hPa***) of San Fernando (1956-1989), Cádiz (1956-1989), San Juan (1956-2009) and Guantánamo (1956-2009).

Stations	Latitude	Longitude	Mean (*hPa*)	*S* (*hPa*)
San Fernando	36.3ºN	6.1ºW	1015.8	3,4
Cádiz	36.3ºN	5.4ºW	1015.8	3,0
San Juan	18.2ºN	66.0ºW	1015.7	1,5
Guantánamo	19.9ºN	75.2ºW	1014.8	1,5

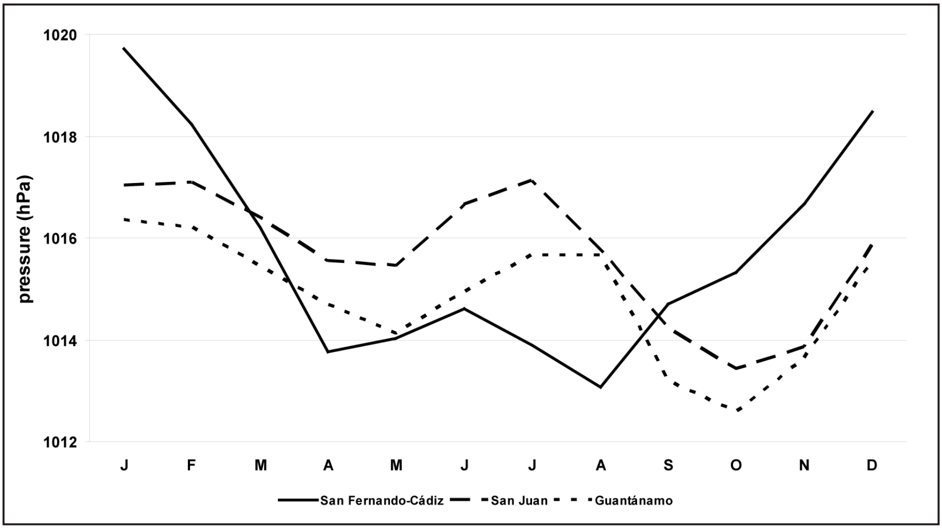


Figure 2: Monthly means of atmospheric pressure of San Fernando-Cádiz, San Juan and Guantánamo over the period 1956-2009.

2.2 Homogenization of the average monthly atmospheric pressures

Starting with the daily series of the atmospheric pressure we have obtained the monthly averages of San Juan, Guantánamo, San Fernando and Cádiz. It would be advisable to check the homogeneity of the resulting monthly series, although they come from observatories and institutions with guaranteed quality of their meteorological data. This will be done so they can be statistically analyzed with a climatic purpose. We have used Thom's tests, or the wind runs, for them. Thom's is the homogeneity test recommended by the World Meteorological Organization for climatic data with unknown or abnormal distributions (Sneyers 1992). The test consists of accounting for the number of wind runs or span series, which are above or below the median, and that this result can be found within a threshold determined by the number of data from the series (Thom 1966). This number of wind runs can be symbolized by *R*, calculating then the statistic *Z* (1):

$$Z = \frac{R-(n+2)/2}{\sqrt{\mathrm{n\,(n-2)\,/\,4\,(n-1)}}} \quad (1)$$

and *n* being the number from the series. If $|Z| < 1.96$, than the series is homogenous at a confidence level of 95% or of a significance of $\alpha = 0.05$.

The four meteorological seasons used present the value |Z| < 1.96 in all of the monthly atmospheric pressures measured, so we can consider them as homogeneous on a significance level of $\alpha = 0.05$.

3. Methodology

Once we corroborated the homogeneity of the series, we proposed a standardized index of the atmospheric pressure to represent the north of the Caribbean by using the standardized values of the monthly averages of San Juan and Guantánamo. To do this, the two barometric series are converted into series of *Z* values, subtracting them from the corresponding averages and dividing this difference by the standard deviation. The sum of the two value series of *Z* gives the index for the atmospheric pressure of San Juan-Guantánamo.

The series of the monthly averages of the atmospheric pressure of San Juan and Guantánamo (1956-2009) show significant correlations with each other, according to Pearson's *r*, during all the months of the year (Table II).

Table II: Pearson correlation's coefficient *r* and *p*-values for monthly atmospheric pressure of San Juan and Guantánamo over the period 1956-2009. (Significant values in bold, α=0.05).

	J	F	M	A	M	J	J	A	S	O	N	D
r	**0.66**	**0.83**	**0.78**	**0.78**	**0.82**	**0.77**	**0.68**	**0.81**	**0.67**	**0.64**	**0.62**	**0.58**
p-value	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

On the other hand, to represent the southwest of the Iberian Peninsula we utilized the series of atmospheric pressure from San Fernando and Cádiz for the periods of 1956-1989 and 1990-2009, respectively. Both series of atmospheric pressure had to be combined because the meteorological station of San Fernando suffered an important disruption in their registers at the beginning of 1990, demonstrating significant deviations due to anterior measurements that altered its homogeneity. For this reason the series of the atmospheric pressure of Cádiz was added because its high correlation of the atmospheric pressure series of San Fernando during almost all the months, with the exception of July, during the period of 1956-1989 (Table III), being that they are cities with little more than 11 kilometers separating them.

Table III: Pearson correlation's coefficient *r* and *p*-values for monthly atmospheric pressure of San Fernando and Cádiz over the period 1956-1989. (Significant values in bold, α=0.05).

	J	F	M	A	M	J	J	A	S	O	N	D
r	**0.90**	**0.92**	**0.93**	**0.71**	**0.80**	**0.39**	*0.32*	**0.59**	**0.69**	**0.87**	**0.95**	**0.96**
p-value	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.024**	*0.069*	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

To analyze the barometric behavior between the northeast and southwest ends of NASH we calculated the coefficient of the Pearson's *r* correlation between the standardized index of the atmospheric pressure of San Juan-Guantánamo, the atmospheric pressure of San Fernando-Cádiz, and the NAO index for the period of 1956-2009, by month, in the following order:

a) Monthly values of the standardized index of the atmospheric pressure of San Juan-Guantánamo with monthly average values of the atmospheric pressure of San Fernando-Cádiz.

b) Monthly values of the standardized index of San Juan-Guantánamo with monthly NAO indexes.

The significance of the coefficients values in correlation was determined by the values of *p* or "*p*-value" according to the significance levels of $\alpha = 0.05$.

3. Results

3.1 Barometric correlations between San Juan-Guantánamo and San Fernando-Cádiz

The correlation using Pearson's *r* between the atmospheric pressure index of San Juan-Guantánamo and the atmospheric pressure of San Fernando-Cádiz, by month, shows four months of the year with significant and positive values: February, June, August and October (Table IV).

The month of February presents the largest positive correlations with an *r*-value of 0.40 and a *p*-value of 0.003, giving this correlation a level of confidence superior to 99%. The next highest value of correlation corresponds to the month of June, with a positive Pearson's *r* of 0.37 and a p-value of 0.006. The values of August with *r* equal to 0.28 and *p* being 0.042 while October has an *r* equal to 0.27 and a value of *p* 0.050, are included, although they are close to the significance threshold.

Table IV: Pearson correlation's coefficient *r* and *p* values between monthly mean of atmospheric pressure index of San Juan-Guantánamo and monthly mean atmospheric pressure of San Fernando-Cádiz over the period 1956-2009. (Significant values in bold, α=0.05).

	J	F	M	A	M	J	J	A	S	O	N	D
r	0.24	**0.40**	0.11	0 .03	-0.07	**0.37**	0.18	**0.28**	-0.05	**0.27**	0.05	0.10
p-value	0.083	**0.003**	0.432	0.831	0.618	**0.006**	0.197	**0.042**	0.722	**0.050**	0.722	0.476

3.2. Barometric correlation between San Juan-Guantánamo and the NAO index

The North Atlantic Oscillation presents a certain correlation between the atmospheric pressure of San Juan-Guantánamo during the months of January, February and March, below the existing one between the same pattern of teleconnection and the pressure in the southeast of the Iberian Peninsula (Table V). The first three months of the year show a positive correlation with a maximum value of Pearson's *r* of 0.48, and the *p*-value of 0.000 during the month of February. January and March also present significant correlations with Pearson's *r* of 0.41 and 0.39 and *p*-values are 0.002 and 0.003, respectively.

Table V: Pearson correlation's coefficient *r* and *p* values between monthly mean index of atmospheric pressure of San Juan-Guantánamo and monthly mean NAO index over the period 1956-2009. (Significant values in bold, α=0.05).

	J	F	M	A	M	J	J	A	S	O	N	D
r	**0.41**	**0.48**	**0.39**	0.11	0.19	0.10	-0.03	0.20	-0.20	0.07	-0.24	0.21
p-value	**0.002**	**0.000**	**0.003**	0.432	0.172	0.476	0.831	0.151	0.151	0.618	0.083	0.131

4. Discussion and conclusions

The North Atlantic Subtropical High (NASH), which forms part of the high subtropical belt in one of the most important action centers of the planet (Davis 1997), exerts great influence over the climate of the Iberian Peninsula (Martín-Vide and Olcina 2001). The presence of NASH acts as an insurmountable obstacle for Atlantic storms, which move along its northern edge, thus reaching Europe mostly at latitudes above those of the Iberian Peninsula. This explains the modest rainfall, with some exceptions, of southern and central Spain and Portugal. Likewise, NASH influences the general barometric synopsis and precipitation in the area of the Caribbean and the southeast of the United States (Wang *et al*. 2010; Li *et al.* 2011). Just as with other subtropical cyclones, their dynamic and thermodynamic characteristics, as well as their seasonal behaviors are intimately related with the ocean's water (Seager *et al.* 2003; Mysaka and Nakamura 2005).

The importance of NASH is obvious, including from a historical point of view. NASH acted like a steering wheel that made it possible to travel, before steam power, starting at the end of the 15^{th} century, from Spain to the Caribbean by southern edge, taking advantage of the constant trade winds from the northeast. Likewise, moving up in latitude, westerlies pushed those sailing ships from the Tropics to the European coasts across the northern border of it. Historical climatology has used the duration of the voyages of maritime mail between Spain and the Spanish colonies in the Caribbean and their distances as a proxy in the reconstruction of the presence and intensity of NASH, a fundamental piece of the dipole of the North Atlantic's Oscillation (Wheeler and García-Herrera 2008).

This study has found relations between the Caribbean Sea and the Iberian Peninsula in NASH. These results are of considerable importance to highlight the connection between mid-latitudes and tropical zone. The particularities and differences of both regions (Westerlies and baroclinic low pressure systems from mid-latitudes and Trade winds and easterly waves and, eventually, cyclones from tropical zone) deserve analysis.

Upon correlating, by month, the atmospheric pressure at the ends of a hypothetical diagonal of SW to NE, from the Caribbean to the southwest of the Iberian Peninsula, represented by San Juan-Guantánamo and San Fernando-Cádiz, respectively, we see its statistical significance, with a maximum p- value of 0.5 during four months, February, June, August and October. Although the summer emerges with greater representation we cannot identify a time of the year with a clearly higher correlation between the cited observatories. In any case, the peak of NASH's strength and best defined configuration is during the northern summer, dominant in the Atlantic Basin (Davis *et al.* 1997), which would more clearly influence the pressure of the Caribbean and the tropical Atlantic, and the southwest of the Iberian Peninsula, and we would see a closer relationship between the two regions.

The positioning of NASH in the current literature is a bit confusing. Generally speaking, we can affirm that NASH, just like the other subtropical anticyclones are stronger during summer than winter over the oceans, are localized to the north of its average yearly position, with more than 1025 hPa in its nucleus. During winter it weakens and positioned more to the south than normal, but, because of the anticyclonic bridges, it becomes linked with anticyclones of European and North American thermic nature (Wang 2007).

Therefore, although it seems paradoxical, the atmospheric pressure is higher during winter than in summer in a large part of the Iberian Peninsula (in this case we also have to add that during summer thermic lows are produced by the intense warming of the Iberian landmass), although the regional circulation during summer is much more notable because of the anticyclone of the Azores-Bermudas than during winter. This, without a doubt, lowers the correlation between the atmospheric pressure of the southwest Iberian Peninsula and the Caribbean.

Finally, the correlation between the atmospheric pressures of San Juan-Guantánamo and the NAO index are significant and positive during the months of January, February and March, months during which, together with December, the NAO dipole usually is very well defined, exerting in this way a greater influence over the barometric area of the North Atlantic. In other words, the north of the Caribbean and NAO show connected barometric behaviors during these months of the year and so forms the mentioned pattern of teleconnection, which influences a large part of the North Atlantic.

Although the found correlations of both analyses are not very great, it can be concluded that the atmospheric pressure in the southwest Iberian Peninsula and NAO demonstrate a relationship with the atmospheric pressure in the north Caribbean during some months of the year (February in winter and June and August in summer and, to a lesser extent, in October, autumn). So, it can be considered that NASH, during the aforementioned months, takes on the role of a connecting axis, northeast-northwest, between atmospheric pressures of both sides of the ocean.

Acknowledgements

This research is placed in the project CGL2011-29263-C02-01 (Ministerio de Economía y Competitividad, España) and within the framework of the Climatology Group 2009 SGR 443 (Generalitat de Catalunya). I wish to thank the National Weather Service of San Juan Offices NOAA for their assistance with the collection of the Caribbean data.

References

Camuffo, D., and P. H. Jones. 2002. *Improved Understanding of Past Climatic Variability from Early Daily European Instrumental Sources*. Dordrecht: Kluwer Academic Publishers.

Capel, J. 2000. *El clima de la península ibérica*. Barcelona: Ariel.

Castro, A. *et al.* 2011. "May the NAO Index be Used to Forecast Rain in Spain? *Atmosfera* 24(3):251-265.

David, R.E. *et al.* 1997. "The North Atlantic Subtropical Anticyclone." *Journal of Climate* 10:728-744.

Esteban-Parra, M.J. *et al.* 1998. "Spatial and Temporal Patterns of Precipitation in Spain for the Period 1880–1992." *Int. J. Climatol* 18:1557-1574.

Font Tullot, I. 2002. *Climatología de España y Portugal*. Salamanca: Universidad de Salamanca.

Giannini, A. *et al.* 2001. "Interdecadal Changes in the ENSO Teleconnection to the Caribbean Region and the North Atlantic Oscillation." *J. Climate* 14:2867-2879.

Harman, J. 1987. "Mean Monthly North American Anticyclone Frequencies 1950–79. *Mon. Wea. Rev.* 115:2840-2848.

Hurrell, J.W. 1995. "Decadal Trends in the North Atlantic Oscillation and Relationships to Regional Temperatures and Precipitation. *Science* 269:676-679.

Hurrell, James & National Center for Atmospheric Research Staff, eds. Last modified August 16, 2016. "The Climate Data Guide: Hurrell North Atlantic Oscillation (NAO) Index (station-based)." <https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based>.

Jones, P.D. *et al.* 1997. "Extension to the North Atlantic Oscillation Using Early Instrumental Pressure Observations from Gibraltar and South-West Iceland." *Int. J. Climatol* 17:1433-1450.

Klein, W. H. 1957. "Principal Tracks and Mean Frequencies of Cyclones and Anticyclones in the Northern Hemisphere." Weather Bureau Research Paper 40, 60 pp.

Lamb, H. H. 1973. "The Seasonal Progression of the General Atmospheric Circulation Affecting the North Atlantic and Europe." University of East Anglia Research Publ. 1, 83 pp.

Li, W. *et al.* 2011. "Changes to the North Atlantic Subtropical High and Its Role in the Intensification of Summer Rainfall Variability in the Southeastern United States." *American Meteorological Society* 24:1499-1506.

Malgren, B. *et al.* 1998. "El Niño-Southern Oscillation and North Atlantic Oscillation Control of Climate in Puerto Rico." *J. Climate* 11:2713-2717.

Martín-Vide, J., and D. Fernández. 2001. "El índice NAO y la precipitación mensual en la España peninsular." *Investigaciones geográficas* 26:41-58.

———, and J. Olcina-Cantos. 2001. *Climas y tiempos de España*. Madrid: Alianza.

Marshall, J. 2001. "North Atlantic Climate Variability: Phenomena, Impacts, and Mechanisms." *International Journal of Climatology* 21:1863-1898.

Miyasaka, T., and H. Nakamura. 2005. "Structure and Formation Mechanisms of the Northern Hemisphere Summertime Subtropical Highs." *Journal of Climate* 18:5046-5065.

Pozo-Vázquez, D. *et al.* 2000. "An Analysis of the Variability of the North Atlantic Oscillation in the Time and the Frequency Domains. *International Journal of Climatology* 20:1675-1692.

Rodó, X. *et al.* 1997. "Variations in Seasonal Rainfall in Southern Europe during the Present Century: Relationships with the North Atlantic Oscillation and the El Niño-Southern Oscillation." *Clim. Dyn.* 13:275-284.

Rogers, J.C. 1984. "The Association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. *Mon. Wea. Rev*. 112:1999-2015.

Sahsamanoglou, H.S. 1990. "A Contribution to the Study of Action Centres in the North Atlantic. *International Journal of Climatology* 10(3):247-261.

Seager, R. *et al.* 2003. "Air–sea Interaction and Seasonal Cycle of the Subtropical Anticyclones. *J. Climate* 16:1948-1966.

Sneyers, R. 1992. "On the Use of Statistical Analysis for the Objective Determination of Climatic Change. *Meteorologische Zeitschrift* 1:247-256

Teissereng de Bort, L. 1883. « Etude sur l'hiver de 1879–80 et recherches sur la position des centres d'action de l'atmosphere dans les hivers anormaux. » Bureau Central Meteor de la France, Annales, 1881(4):17-62.

Thom, H.C.S. 1966. "Some Methods of Climatological Analysis." Technical Report No. 81, WMO, Geneva.

Trigo, R. *et al.* 2002. "The North Atlantic Oscillation Influence on Europe: Climate Impacts and Associated Physical Mechanisms. *J. Clim. Res.* 20:9-17.

van Loon, H., and J.C. Rogers. 1978. "The Seesaw in Winter Temperatures between Greenland and Northern Europe, Part 1: General description." *Mon. Wea. Rev.* 106:296-310.

Wang C. 2007. "Variability of the Caribbean Low-Level Jet and Its Relations to Climate. *Clim. Dyn.* 29:411-422.

Wang, H. *et al.* 2010. "Intensification of Summer Rainfall Variability in the Southeastern United States during Recent Decades." *J. Hydrometeor* 11:1007-1018.

Wheeler, D., and R. García-Herrera. 2008. "Ships' Logbooks in Climatological Research: Reflections and Prospects. *Ann. N Y Acad. Sci.* 1146:1-15.

Zorita, E. *et al.* 1992. "The Atmospheric Circulation and Sea Surface Temperature in the North Atlantic Area in Winter: Their Interaction and Relevance for Iberian Precipitation." *J. Clim.* 5:1097-1108.

Zishka, K.M., and P.J. Smith. 1980. "The Climatology of Cyclones and Anticyclones over North America and Surrounding Ocean Environs for January and July, 1950-77." *Mon. Wea. Rev.* 108:387-401.