

Article

Pro-Pluvia Rogation Ceremonies in Extremadura (Spain): Are They a Good Proxy of Winter NAO?

Nieves Bravo-Paredes ^{1,*}, María Cruz Gallego ¹, Fernando Domínguez-Castro ^{2,3} ,
José Agustín García ¹ and José Manuel Vaquero ⁴

¹ Departamento de Física, Universidad de Extremadura, 06006 Badajoz, Spain; maricruz@unex.es (M.C.G.); agustin@unex.es (J.A.G.)

² Fundación ARAID, 50018 Zaragoza, Spain; fdominguez@unizar.es

³ Departamento de Geografía y Ordenación del Territorio, Universidad de Zaragoza, 50009 Zaragoza, Spain

⁴ Departamento de Física, Centro Universitario de Mérida, Universidad de Extremadura, Avda. Santa Teresa de Jornet 38, 06800 Mérida, Badajoz, Spain; jvaquero@unex.es

* Correspondence: nieves@unex.es

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Abstract: Rogation ceremonies are religious requests to God. *Pro-pluvia* rogations were celebrated during dry conditions to ask God for rain. In this work, we have recovered 37 *pro-pluvia* rogations from 14 documentary sources (e.g., ecclesiastical manuscripts, books, and different magazines and newspapers). All of the rogations were celebrated in Extremadura region (interior of southwest of Spain) during the period 1824–1931. Climate of Extremadura is strongly dominated by the North Atlantic Oscillation (NAO). Therefore, *pro-pluvia* rogations have been associated to the NAO index and the relationship between them has been analyzed. The most relevant results are found in the relationship between *pro-pluvia* rogations in month n and the positive values of the NAO index for months $n-1$ and $n-2$, being statistically significant at 95% confidence level. Thus, the results evidence that the rogation ceremonies of Extremadura are a good proxy for the NAO index.

Keywords: NAO; *pro-pluvia* rogation ceremonies; proxy; drought; documentary sources

1. Introduction

Climate proxies, i.e., non climatic variables with a high correlation with climate parameters, are required to know the pre-instrumental climate. There are many natural proxies, such as ice-cores, speleothems, tree-rings, or sea and lake sediments, which have been used to numerous climate reconstructions [1–7]. Out of the natural proxies, documentary sources preserved in archive and libraries are an important source of information to understand the past climate variability. Documentary sources provide instrumental [8,9] and non-instrumental [10,11] measurements of climate variables, direct description of meteorological events [12], and climate proxies (e.g., grape harvest dates, dates of freezing on rivers) [13]. One of the most used documentary proxies in the Mediterranean region for drought reconstruction is the rogation ceremonies [14].

Rogations are religious rites celebrated in order to ask God for certain intentions (take care of kings, wars, appropriate weather, etc.). Rogation ceremonies are common in Catholic religion and they have been celebrated throughout history, since 15th century to the present. For climate reconstruction, rogations related with agriculture and livestock are particularly useful. For example, when there was a notable drought during sowing time, farmers asked God for rain. Rogation ceremonies celebrated in these conditions are called *pro-pluvia* rogations. On the contrary, when people asked God to stop the rain and severe weather, they are called *pro-serenitate* rogations. Therefore, *pro-pluvia* and *pro-serenitate* rogations are useful documentary proxies to identify dry and wet extremes, respectively. Due to

the rogations can be found where Catholic religion was established and historical manuscripts were preserved, rogations can be found in different parts of the world as Europe (mainly), America, and old colonies (as Philippines) [15–21]. *Pro-pluvia* rogations have been studied, among others, to reconstruct periods of drought in the past [17,19,20,22–27]; to reconstruct seasonal and annual rainfall in the Iberian Peninsula (hereafter IP) from 16th century to 20th century [28]; and, to identify climate extremes [16,29]. Also, Vicente-Serrano & Cuadrat [30] used *pro-pluvia* and *pro-serenitate* rogations celebrated in Zaragoza (Spain) as a proxy of the North Atlantic Oscillation (NAO) index.

Different types of documentary sources contain information about the celebration of the rogation ceremonies. In earlier epochs (16th–19th centuries), rogations were registered mainly in ecclesiastical and civil archives. Currently, there are 18 series of rogation ceremonies compiled in the IP [14,23]. Most of these series have been extracted from chapter acts (documents that register the discussion and decisions made during the assemblies of local authorities) and cover from the 16th or 17th to the first half of the 19th. The chapter acts have important advantages to record rogation ceremonies: (i) they can provide continuous series when all the documentation has been preserved (ii) they have around weekly resolution (iii) they are primary sources. Nevertheless, they have an important weakness until now because most of the long and continuous series come from archives of large cities (e.g., Barcelona, Toledo, and Seville). With the industrialization, these cities have been losing its agricultural character. This, joint with changes in the bureaucracy and the French occupation caused a quick drop in the record of rogation ceremonies in Chapter acts during the 19th century [24]. For this reason, the studied period of the works that use rogation ceremonies as climate proxies in Spain ends in the first half of the 19th century. This is an important problem in the use of rogation ceremonies because the overlapping period with meteorological measurements is frequently short or non-existent. The effect of industrialization is lower in rural areas of Iberia, in which is possible to find rogation ceremonies nowadays [31,32]. Unfortunately, in rural areas, frequently, the documentary sources useful to generate long and continuous series of rogations have been lost or are uncatalogued. In this article, different documentary sources as books, newspapers, and magazines have been consulted in order to retrieve rogation ceremonies from rural areas celebrated during the 19th and 20th centuries.

The NAO is the dominant mode of the climate variability in Northern Atlantic winter [33], being its influence very important for the European climate [34–36]. Some authors show this influence in the IP [37–42]. To quantify the NAO strength, the NAO index is defined as the sea-level pressure difference between the Iceland Low and the Azores High [43]. When the NAO index is positive, dry conditions appear mainly in the climate of the IP due to the northward shift of Azores anticyclone blocks the entry of westerlies in this region. On the contrary, wet conditions appear in the climate of IP when the NAO index is negative. The temporal variability of NAO is high and their influence on the European climate is non-linear [44–47]. Nevertheless, the longest NAO index based on instrumental pressure observations begin in 1821 [43]. Therefore, it is necessary to extend our knowledge of NAO with accurate proxy records for a better understanding of the long term variability of NAO [5,7,44,48,49].

The main aim of the present work is to analyze the relationship between *pro-pluvia* rogations in Extremadura region (interior of southwest of Spain) and the NAO index from 19th century to early 20th century. To reach this objective, we have collected rogation ceremonies from different documentary sources (newspapers and magazines among others) in this region, in which droughts are highly correlated with NAO, as was aforementioned.

2. Study Area and Data

2.1. Study Area

The region of Extremadura is located in interior of the southwest of Spain (latitude between 37°57' and 40°29' N, longitude between 4°39' and 7°33' W). Figure 1 (on the bottom) shows all the locations inside this region where rogation ceremonies (in this work recovered) were celebrated.

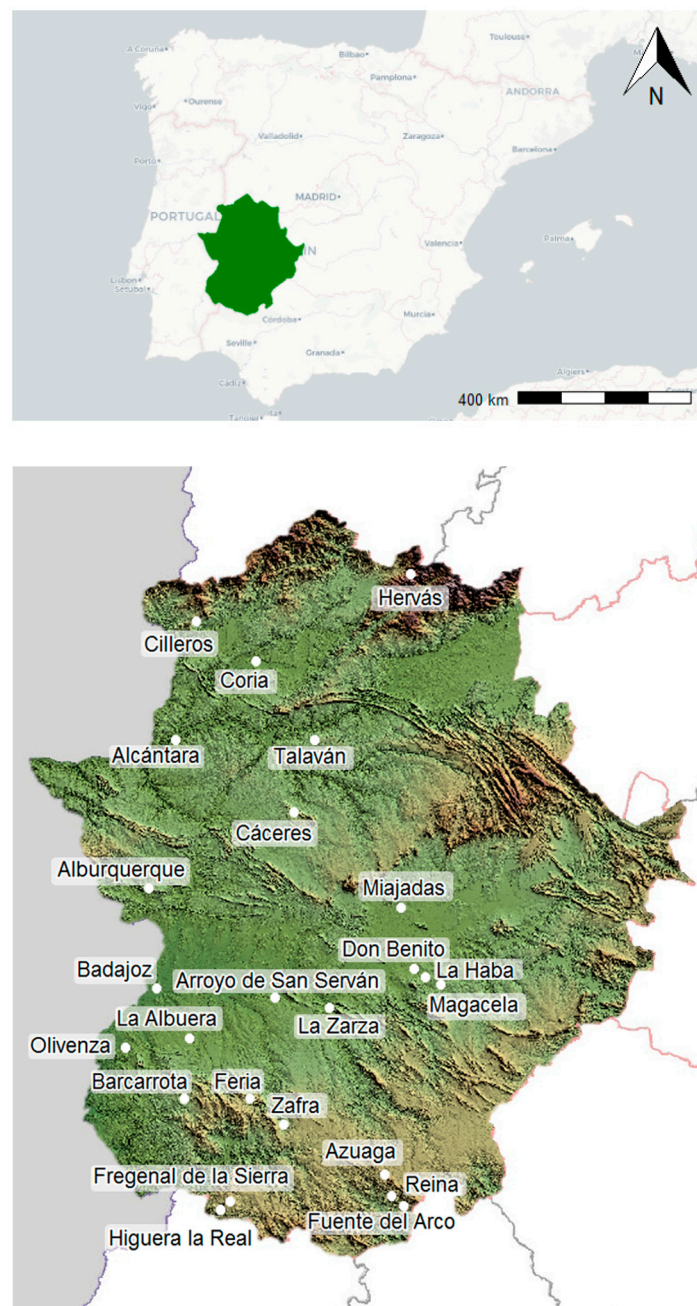


Figure 1. On top, the situation of the region of Extremadura in the Iberian Peninsula. On the bottom, map of Extremadura region (courtesy of Infraestructura de Datos Espaciales de Extremadura - IDE Extremadura) containing the locations where rogation ceremonies were celebrated.

The climate of Extremadura is Mediterranean with dry summers and mild winters. Figure 2 shows the mean monthly precipitation of the city of Badajoz (dark grey vertical bars) for the period 1981–2010 and the mean monthly precipitation of the city of Cáceres (light grey vertical bars) for the period 1982–2010. It can be seen that the monthly distribution of the precipitation is similar in both cases (Badajoz and Cáceres), being the values of the mean monthly precipitation of Cáceres slightly higher. The mean annual precipitation of Badajoz and Cáceres is 447 mm and 551 mm, respectively. These cities are in plane areas, but the annual accumulated precipitation exceeds 1000 mm in mountain areas. Regarding to droughts, Domínguez-Castro et al. [50] analyzed the climatology of droughts in Spain based on SPI and SPEI indexes for the period 1961–2014. At scales related with agricultural droughts (3 to 6 months), Extremadura region shows a low number of drought events, but with

the highest duration and magnitude. The climate of Extremadura region is strongly dominated by the NAO due to the proximity to the Atlantic Ocean (mean distance around 250 km) and the lack of important orographic barriers [37–41]. Some authors demonstrated the influence of the NAO on precipitation and droughts in the southwest of the IP [37,38,40,51,52]. In the studies of the IP, Gallego et al. [37] found a correlation approx. equal to -0.6 between the winter NAO and daily rainfall (several indices related to frequency and intensity) for the period 1958–1997. The value of the correlation in the other seasons are lower (approx. equal to -0.2). López-Moreno and Vicente-Serrano [51] and Vicente-Serrano et al. [52] highlights the outstanding influence of positive and negative phases of the wintertime NAO on droughts conditions during the succeeding months for the periods 1901–2000 and 1901–2006, respectively. In the studies of the southwest of the IP, Trigo et al. [41] studied the relationship between NAO index and river basin average precipitation; the highest absolute correlation value was found in December for the Guadiana basin (equal to -0.83 for the period 1973–1998). Therefore, Extremadura is a great region to carry out the study of the relation between rogation ceremonies and the NAO index.

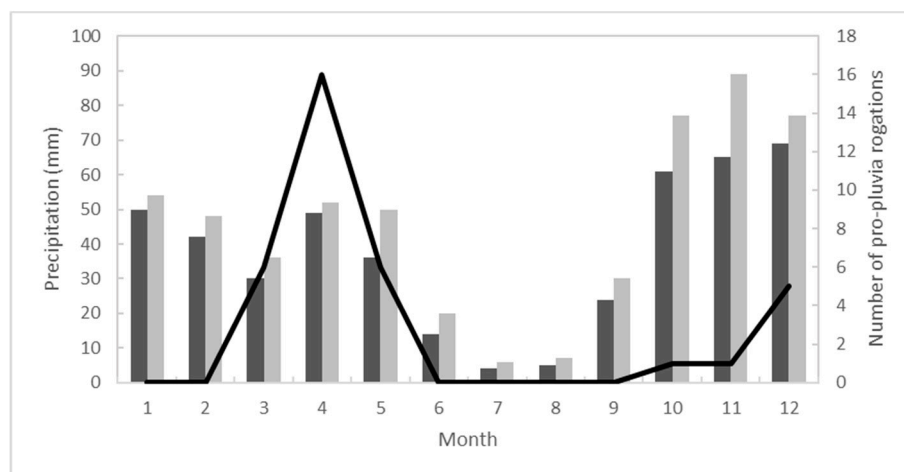


Figure 2. The mean monthly precipitation of Badajoz (dark grey vertical bars) for the period 1981–2010 and Cáceres (light grey vertical bars) for the period 1982–2010. Black line shows the number of *pro-pluvia* rogations celebrated in Extremadura region in the period 1824–1931.

2.2. Data

Ecclesiastical manuscripts of different locations kept in *Archivos Eclesiásticos de Mérida-Badajoz* (Ecclesiastical Archives of Mérida-Badajoz) and digitized newspapers (<https://prensahistorica.mcu.es>) have been consulted to carry out the task of retrieving *pro-pluvia* rogation ceremonies. Table 1 shows the different documentary sources consulted and their main characteristics. Figure 3 shows an example of a rogation ceremony registered in the newspaper *Nuevo día: diario de la provincia de Cáceres* in May 1927 in Cilleros (north of Extremadura) and it can be read: “Religious act. Cilleros brings its patron saint, the Virgin of Navelonga, to the parish in a prayer for rain. [. . .] severe damages occurred in agriculture, due to an extensive drought that is taking place during the current spring. [. . .]”.

Table 1. The different documentary sources consulted.

Type of Documentary Source	Description of the Documentary Source	Documentary Source Consulted
Ecclesiastical manuscript	These manuscripts keep a record of everything related to the parish life of each village or city (papal bull, rogation ceremonies, elections, etc.). In the case of rogation ceremonies, the information is usually extended and contains the date (sometimes only the year), a description of the religious procession and the reasons for the celebration (drought, severe weather, civil war, etc.). They are a primary documentary source.	Ecclesiastical manuscripts of: <i>Archivo Histórico Municipal de Zafra</i> ; <i>Archivo del Convento de Santa Clara de Zafra</i> ; <i>Archivo Parroquia Nuestra Señora de la Candelaria de Zafra</i> . (Zafra). {1}
		<i>Libro de acuerdos y elecciones de alcalde de mayordomo y jurados de la cofradía de Nra. Sra. de la Soledad</i> . (La Zarza) (<i>Archivo Diocesano de Mérida-Badajoz</i>). {2}
Newspaper	Newspapers register the most important things that happened in a region (in villages and towns), such as rogation ceremonies. Usually, newspapers gave the information of rogations one day after their completion. In some cases, they announced future events. The information is usually brief and contains the date (as they are newspapers, the full date always appear), some details of the religious procession and the reasons of the celebration (drought, severe weather, etc.). They are primary documentary sources.	<i>La región extremeña: diario republicano</i> . {3}
		<i>Correo de la mañana</i> . {4}
		<i>Correo extremeño</i> . {5}
		<i>Nuevo diario de Badajoz: periódico político y de intereses generales</i> . {6}
		<i>Nuevo día: diario de la provincia de Cáceres</i> . {7}
		<i>Crónica de Badajoz: periódico de intereses morales y materiales, de literatura, artes, modas y anuncios</i> . {8}
		<i>La montaña: diario de Cáceres</i> . {9}
		<i>Boletín oficial de la provincia de Cáceres</i> . {10}
Magazine	The information contained in magazines is similar than newspapers.	<i>El adarve: periódico político, literario y de noticias</i> . {11}
		<i>Blanco y negro</i> . {12}
Book	The author recovers the history of a village or town. The author is based on different documentary sources, such as ecclesiastical manuscripts, civil archives, etc. It is a secondary documentary source.	<i>Revista de estudios extremeños</i> –[53,54]. {13}
		[55,56] {14}

In total, 37 *pro-pluvia* rogations celebrated in 24 locations of Extremadura (see Figure 1) have been recovered from 1824 to 1931. For each rogation, it has been recorded the month and the year of the celebration. 30 rogations were celebrated in spring, 2 in autumn, and 5 in winter. As most rogations were celebrated in spring months, only *pro-pluvia* rogations celebrated in spring are considered to carry out the study.

To analyze the influence of NAO in the celebration of these rogation ceremonies, we have used the monthly NAO index that was computed by Jones et al. [43]. This NAO index has been computed from the sea-level pressure in Gibraltar and Reykjavik from 1821. It is the unique instrumental NAO index available that completely covers our study period (1824–1931). This index has been widely used in climatological studies over Europe [34–36] and over IP [37–42].



Figure 3. An example of a rogation ceremony registered in the newspaper *Nuevo día: diario de la provincia de Cáceres* in May 1927 in Cilleros (north of Extremadura) and it can be read: “Religious act. Cilleros brings its patron saint, the Virgin of Navelonga, to the parish in a prayer for rain. [...] severe damages occurred in agriculture, due to an extensive drought that is taking place during the current spring. [...]”.

3. Method

It is known that there is a positive (negative) association between the NAO index and dry (wet) events in the IP and, in particular, in the Extremadura region. Rogation ceremonies occurred when these events began to worry the population about their duration and intensity, and the rogations and the NAO index could be associated.

Rogations were celebrated in a given date (month n and year). To analyze the relationship between *pro-pluvia* rogations and the NAO index, the value of the NAO index in that date has been associated to the rogation. Moreover, in the set of 30 rogations celebrated in spring (March, April, and May), there are months containing more than one rogation celebrated in the same year (i.e., rogations were celebrated in different locations in the same month and year). Only one rogation is considered in these months. In this manner, one NAO event (NAO index in a given date, month, and year) is associated with one rogation and there are no NAO events with more weight than the others. In total, 21 dates of spring rogation ceremonies (7 in March, 10 in April, and 4 in May) are used in the analysis. Table 2 summarize the 21 dates of rogations and the principal data of them.

Table 2. 21 dates of spring rogation ceremonies and the principal data of them.

Date	Locations	Documentary Sources (see Table 1)
04/1824	Fregenal de la Sierra	{1}
03/1835	Cáceres	{10}
03/1849	La Zarza, Fregenal de la Sierra	{2}, {14}
03/1859	Olivenza	{13}
04/1859	Fregenal de la Sierra	{14}
05/1867	Badajoz	{8}
03/1868	Cabeza del Buey	{14}
04/1869	Talaván	{10}
04/1881	La Zarza	{2}
05/1891	Fregenal de la Sierra	{14}
04/1896	Badajoz	{1}, {3}
05/1896	Fregenal de la Sierra	{14}
04/1903	Cáceres	{12}
03/1905	Azuaga	{6}
04/1905	La Haba, Fregenal de la Sierra	{6}, {14}
03/1907	Different locations (not specified)	{11}
04/1907	Zafra	{1}
05/1925	Coria, Reina, Fuente del Arco	{9}, {4}
04/1927	Cilleros, Coria	{7}
04/1929	Magacela, La Albuera, Arroyo de San Serván, Coria, Alcántara	{5}, {7}
03/1931	Miajadas	{7}

3.1. Anomalies in the NAO Index

Pro-pluvia rogations were celebrated when there truly was a need for rain. So, a deficit of precipitation had occurred in the previous months. As was aforementioned in Section 2.1., the agricultural droughts (3 to 6 months) in Extremadura region show the highest mean duration i.e., from 10 to 20 weeks. Therefore, it is possible to find out anomalies in the monthly NAO index in previous months related to the precipitation deficits. Specifically, this fact occurs in winter months when the influence of NAO in the precipitation is higher. NAO index anomalies are calculated using as reference period the complete study period (1824–1931). To study the possible influence of two previous winters on the months of the celebration of the rogation, anomalies in the monthly NAO index are calculated from the month of the celebration of the rogation up to two winters before (that is 15 months, see Figure 4). Monthly anomalies are computed for each of the 21 dates of rogations and the monthly average is calculated.

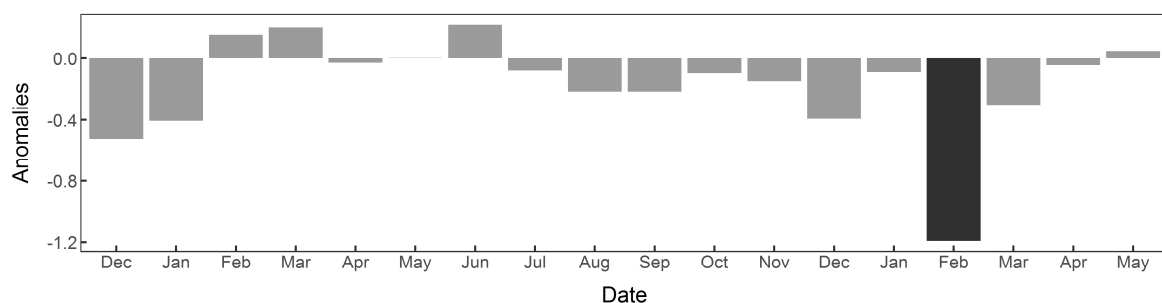


Figure 4. Monthly anomalies in the NAO index from the month of the celebration of the rogation ceremonies (right end of the x axis) to two winters back in time (left end of the x axis). Dark grey bar is the statistical significant anomaly at the 95% confidence level.

To study the statistical significance of the anomalies, Piechota and Dracup [57] used a bootstrap resampling procedure. A similar method is used in this study. 21 random values of the NAO index in

each month of the year are selected to form an aggregate composite, and anomalies are calculated in each month. This method is performed 500 times, and the monthly mean and the standard deviation of the dataset of the bootstrap resampling are calculated to determine significance anomalies in the NAO index at the 90% confidence level.

3.2. Relationship between Pro-Pluvia Rogations and the NAO Index

In order to study the statistical significance of the anomalies, the values of the NAO index in the previous months ($n-1$, $n-2$ and $n-3$) have been linked to the rogation in month n .

Association between two or more qualitative variables can be analyzed through contingency tables. Two variables comprise the contingency tables in this study: the NAO index (which is sorted in rows in intervals of 0.5) and the *pro-pluvia* rogations celebrated (and not celebrated). Considering the total months of the NAO index in each interval, the percentage of *pro-pluvia* rogations celebrated (and not celebrated) is calculated in each interval. Also, the distribution of the no dependency of both series is calculated as the average of the percentages calculated before. Finally, the relationship between the percentage of *pro-pluvia* rogations and the NAO index is analyzed by means of a chi-squared test at the 95% confidence level, being the null hypothesis (H_0) the no-dependency of both series.

To carry out the study, the analysis has been divided into three parts:

1. From a general point of view, the relationship between *pro-pluvia* rogations in month n and the NAO index in months n , $n-1$, $n-2$ and $n-3$ has been analyzed. A contingency table was made for each case with 20 degrees of freedom.
2. Rogations are celebrated in a given day (a rogation could be celebrated at the beginning or at the end of the month, and the NAO index contribute in the same way in both cases). Due to that, two running averages of the NAO index are calculated taking two and three months for the windows length. For the series calculated with a window length of two months, the mean value of months n and $n-1$ and the mean value of months $n-1$ and $n-2$ of the NAO index has been associated to the rogation celebrated in month n . For the series calculated with a window length of three months, the mean value of months n , $n-1$ and $n-2$ and the mean value of months $n-1$, $n-2$ and $n-3$ of the NAO index has been associated to the rogation celebrated in month n . A contingency table was made for each case with 16 degrees of freedom.
3. Two NAO winter indexes have been calculated: namely, NAO_{DJF} , equal to the mean value of the NAO index in months December, January, and February; and NAO_{DJFM} , equal to the mean value of the NAO index in months December, January, February and March. *Pro-pluvia* rogations celebrated in the same year are grouped and the value of the NAO winter index has been associated with them. A contingency table was made for each case with 13 (NAO_{DJF}) and 12 (NAO_{DJFM}) degrees of freedom.

4. Results and Discussion

As was aforementioned, we are going to work with 21 dates of spring *pro-pluvia* rogations, looking for anomalies in the monthly NAO index. Figure 4 shows the monthly anomalies of the NAO index averaged for the 21 spring rogations, from the month of the celebration of the rogation ceremonies (March, April, or May; at right end of the x axis) to two winters back in time (left end of the x axis). Dark grey bar is the statistical significant anomaly at the 95% confidence level.

Figure 4 indicates that winter anomalies are negative. This indicates that, in these months, the Azores anticyclone is northward shift giving higher positive values of the NAO index than the normal conditions. Only the anomaly value of the previous February to the celebration of rogations is statistically significant. In any case, anomalies are negative since July. The fact that the immediately previous February presents a high anomaly value is indicative of unusual dry conditions. Therefore, the celebration of the *pro-pluvia* rogations after this month could not be casual. In fact, as it can be seen in Figure 2, there are two maximums in the precipitation of Badajoz and Cáceres (spring and

autumn) coinciding when *pro-pluvia* rogations are celebrated (black line). *Pro-pluvia* rogations are directly connected with agriculture and livestock, as can be seen in Figure 2. In Extremadura, sowing time is in spring and autumn and the mean precipitation in autumn is greater than that of spring. Therefore, fields are wet in autumn months and there are fewer rogations celebrated when water availability permits normal crop growing. Also, the vegetation activity in spring months is high and dependent on sufficient rainfall [58]. On the contrary, as the mean precipitation is lower in spring, it is possible that a dry winter can trigger severe drought conditions difficult to alleviate with early spring precipitations. So, fields are dry and it can be a problem if the rain is scarce. Thus, the precipitation in winter can be playing an important role in the celebration of rogation ceremonies in spring months. The development of drought occurs progressively and its effects appear in agriculture when several months of scarce rainfall have accumulated. So, there could be a relationship between the celebration of *pro-pluvia* rogations and the NAO index in previous months.

Keeping in mind these results, the relationship between the celebration of *pro-pluvia* rogations in month n and the monthly NAO index in previous months (n , $n-1$, $n-2$ and $n-3$) will be studied in more detail while using the contingency tables. Figure 5 shows the percentage of *pro-pluvia* rogations celebrated corresponding to each interval of the NAO index. Figure 5 shows the association between *pro-pluvia* rogations and the NAO index in months n (a), $n-1$ (b), $n-2$ (c) and $n-3$ (d). Black lines are the distribution of the null hypothesis (no-dependency of both series) for each case. Regarding to rogations were celebrated when dry conditions appear and these conditions are related to positive values of the NAO index [30,41,59], it can be seen in Figure 5b–d that the number of positive values of the NAO index is greater than the number of negative values, that is, focusing only on the NAO index axis. On the contrary, in Figure 5a, negative values of the NAO index are almost equal to the number of positive values. A possible explanation could be in the day of the celebration of the *pro-pluvia* rogation: if the rogation ceremony is celebrated at the beginning of the month, the n NAO index has no relation with the drought that trigger the rogation ceremony.

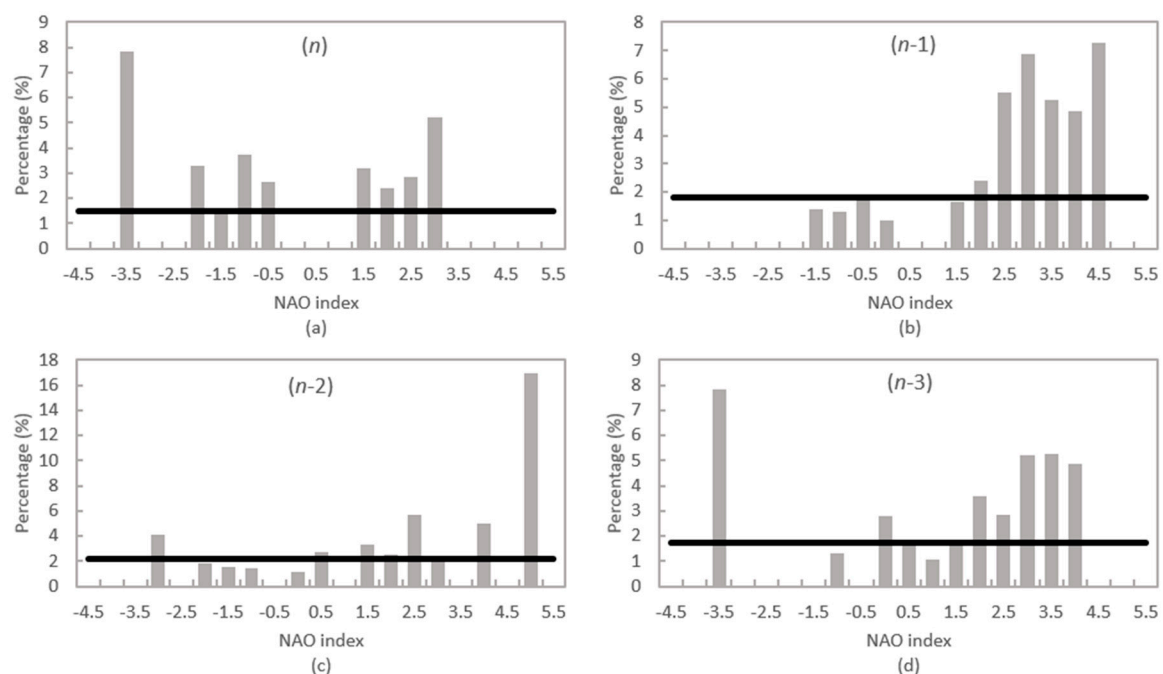


Figure 5. All plots show the percentage of *pro-pluvia* rogations celebrated in spring associated to the NAO index in months n (a), $n-1$ (b), $n-2$ (c) and $n-3$ (d). All black lines are the distribution of the null hypothesis for each case.

Focusing on the percentages: the extreme intervals of the contingency tables (not shown) contain fewer NAO events than the central intervals; if there are rogations associated to values of the NAO

index in these intervals, the percentage of *pro-pluvia* rogations increases. In Figure 5, the results for months $n-1$ and $n-2$ agree with the fact of drought are related to the positive values of the NAO index due to the high percentage of *pro-pluvia* rogations related to positive intervals. Also, results for the month n disagree, the percentage of *pro-pluvia* rogations related to positive values of the NAO index are less than the negative values. The highest percentage is found in a high negative value of the NAO index. Results for month $n-3$ show that a high percentage corresponds to positive values of the NAO index. Nevertheless, the highest percentage is found in a negative value of the NAO index. This could be an outlier.

Trying to smooth the problem of the day of the celebration of the rogation (mentioned before), two running averages are calculated, as was described in Section 3. Figure 6 shows the percentage of *pro-pluvia* rogations celebrated corresponding to each interval of the running averages of the NAO index. Figure 6 shows the association between *pro-pluvia* rogations celebrated and the mean value of months: n and $n-1$ of the NAO index (a); n , $n-1$ and $n-2$ (b); $n-1$ and $n-2$ (c); $n-1$, $n-2$ and $n-3$ (d). Black line is the distribution of the null hypothesis for each case.

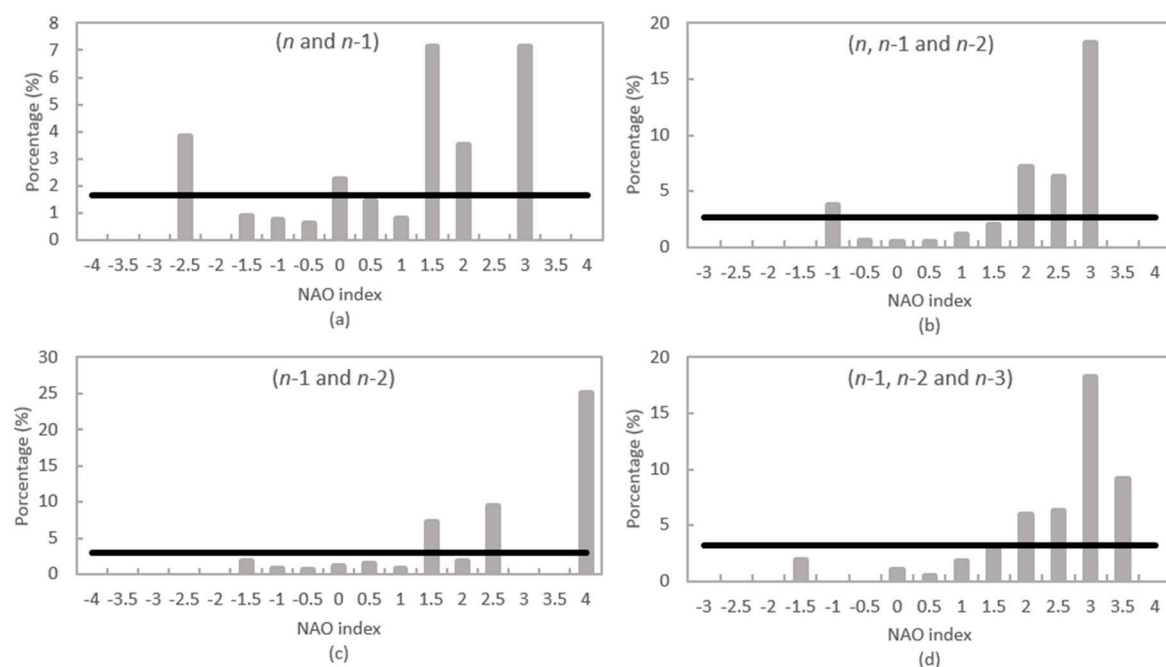


Figure 6. Percentage of *pro-pluvia* rogations associated to the average value of NAO for: (a) n and $n-1$; (b) n , $n-1$ and $n-2$; (c) $n-1$ and $n-2$; (d) $n-1$, $n-2$ and $n-3$. Black line is the distribution of the null hypothesis for each case.

Unlike Figure 5a, the number of negative values of the NAO index is less than the number of positive values in Figure 6a,b (focusing only in the NAO index axis and in plots with month n). This is due to running averages are calculated with the previous months (in Figure 5 there are more positive values of the NAO index in previous months).

In the case of the percentages, it can be seen the same as in Figure 5 (in previous months). There is a high percentage of *pro-pluvia* rogations corresponding to positive values of the NAO index and the highest percentages are related to high positive values of the NAO index. That is, it occurs when the NAO index in month n does not take part in the analysis (Figure 6b,c). As we have aforementioned in the discussion of Figure 5, this is very reasonable, because the month in which the rogation is celebrated has less influence in the drought that trigger the rogation than the previous months. Additionally, droughts are long duration events, specifically in southwest of Spain [50].

Finally, two NAO winter indexes were computed. Figure 7 shows the percentage of *pro-pluvia* rogations celebrated (grouped in the same year) corresponding to each interval of the NAO winter index: NAO_{DJF} (a) and NAO_{DJFM} (b). Black line is the distribution of the null hypothesis for each case.

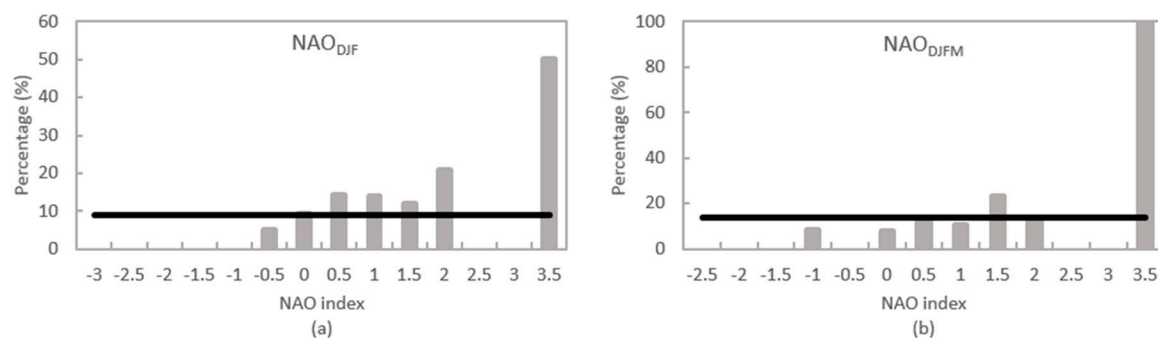


Figure 7. Percentage of *pro-pluvia* rogations celebrated in each interval of the NAO_{DJF} (a) and NAO_{DJFM} (b). Black line is the distribution of the null hypothesis for each case.

It can be seen in both plots (Figure 7a,b) that the number of positive values of the NAO winter index are much greater than negative values. Also, most percentages correspond to positive values in both. In this analysis, only the average of the NAO index in winter is considered; i.e., month n is removed from the analysis and the direct effect of the previous month are shown.

Considering the results, *pro-pluvia* rogations are associated with negative values of the NAO index in the month n , while positive values of the NAO index are associated in most cases with other months. This means that it would not be appropriate to associate *pro-pluvia* rogations with month n .

The desynchronization between *pro-pluvia* rogations (celebrated in the month n) and the NAO index (months $n-1$, $n-2$ and $n-3$) can be explained by the long average drought duration in southwest of Spain. The average duration is around 15 weeks in agricultural droughts [50]. In addition, there is a delay of one month between the NAO index and the hydrological variables in the IP. Trigo et al. [41] found this delay between NAO winter index (DJF) and rivers flow.

The chi-squared test was computed for the three parts of the analysis (Section 3.2). Table 3 summarizes the results of the chi-squared test (p -value) for all cases. All of the cases are statistically significant at the 95% confidence level. The most relevant cases have an asterisk.

Table 3. Results of the chi-squared test for all analysis of the relationship between *pro-pluvia* rogations and the NAO index. Asterisks (*) show the most relevant cases. 1., 2., and 3.: see Section 3.2.

1.	Month	n	$n-1$	$n-2$	$n-3$
	p -value	5.34×10^{-6}	$7.30 \times 10^{-7*}$	$6.37 \times 10^{-18*}$	1.07×10^{-5}
2.	Average of months	n and $n-1$	n , $n-1$ and $n-2$	$n-1$ and $n-2$	$n-1$, $n-2$ and $n-3$
	p -value	7.57×10^{-6}	5.47×10^{-20}	$2.62 \times 10^{-36*}$	2.68×10^{-17}
3.	NAO winter index	NAO _{DJF}	NAO _{DJFM}		
	p -value	2.55×10^{-51}	$2.82 \times 10^{-130*}$		

As Table 3 shows, in the study 1, the lowest values of the p -value are found in the analysis in the months $n-1$ and $n-2$. In the study 2, the average of months $n-1$ and $n-2$ shows the smallest p -value. This is in accordance with the results show in Figures 5 and 6 and the sense of the celebration of *pro-pluvia* rogations. That is, rogations were celebrated when dry conditions appear. On the contrary, when the month n takes part in the analysis, results get worse. Finally, the relationship between *pro-pluvia* rogations and the NAO winter index (NAO_{DJFM}) shows the best results (in Figures and Table 3). All of this results are in accordance with that shown in the figures.

Thus, results suggest that *pro-pluvia* rogations are a good proxy for the NAO index (in particular for the NAO winter index). Moreover, *pro-pluvia* rogations should be associated to the NAO index in previous months (specifically in month $n-1$ and $n-2$).

5. Conclusions

Ecclesiastical manuscripts and different newspapers and magazines have been consulted to carry out the task of retrieving rogation ceremonies. Other studies about rogation ceremonies are done in cities where historical archives are preserved and only ecclesiastical or municipal documents are taken into account. Books, and different newspapers and magazines, have also been consulted in this work. The advantage of these documentary sources lies in the preservation of this information in rural areas, in which the municipal and ecclesiastical documentary sources are frequently lost or not available. Also, these documentary sources cover the 19th and 20th centuries. Thus, the documentary sources consulted in this study have a great potential to extend the knowledge of rogation ceremonies in the IP during the second half of 19th century and during the 20th century.

A set of 37 *pro-pluvia* rogations celebrated in different locations have been retrieved from 1824 to 1931 in Extremadura region (SW of Spain). Among them, 30 *pro-pluvia* rogations were celebrated in spring, 2 in autumn, and 5 in winter. Finally, 21 dates of spring *pro-pluvia* rogations (corresponding to 30 different rogations ceremonies in several places) are used to carry out the analysis.

Results from the analysis of the NAO monthly anomalies averaged for our 21 dates of spring *pro-pluvia* rogations show that the value for February is statistically significant at the 95% confidence level. Although the values for previous months are not statistically significant, anomalies are negative since July. That is, continuous dry conditions are present in the months before the celebration of rogations ceremonies.

There is not a clear relationship between the celebration of *pro-pluvia* rogations in month n and the NAO index of this month. This is due to the fact that *pro-pluvia* rogations correspond largely to negative values of the NAO index in month n . While positive values of the NAO index are associated in most cases with other months. In fact, the results of the analysis of the relationship between *pro-pluvia* rogations celebrated in month n and the NAO index for months $n-1$ and $n-2$ show high correlations, specifically in month $n-2$. Therefore, our results indicate that historical spring *pro-pluvia* rogations celebrated in Extremadura region are a good proxy for the reconstruction of historical positive values of NAO index during the previous winter or early spring.

This work has important implications for the study of rogation ceremonies as climate proxy. Firstly, we have demonstrated that rogation ceremonies in Extremadura region have a significant NAO signal. This opens the possibility to reconstruct NAO positive values in pre-instrumental period from rogation ceremonies series of the region. There are many documentary sources in Extremadura with high potential to provide information about rogation ceremonies in pre instrumental period (e.g., Zafra rogation ceremony series from 1750 to 1850, Dominguez- Castro et al. [23]). Secondly, this study has demonstrated that rogation ceremonies in rural areas during the 19th and early 20th century have an important climate signal and can be retrieved from different documentary sources. This finding opens the way to enlarge the available rogation ceremony series from cities with information from nearby rural areas up to the early 20th century. This work must be done with caution due to the possible influence of technological development and other socioeconomic factors, but this will allow understanding of the better the climate signal of the rogations thanks to a longer overlapping period among rogation and instrumental series.

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