

ON THE USE OF THE JESUIT ORDER PRIVATE CORRESPONDENCE RECORDS IN CLIMATE RECONSTRUCTIONS: A CASE STUDY FROM CASTILLE (SPAIN) FOR 1634–1648 A.D.

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Abstract. This work analyses the climatic information content of more than 1000 letters belonging to the private correspondence of the Jesuit order during the period 1634–1648. The information obtained mainly originates in Castille, and it was codified to obtain quantitative indices representative of the evolution of the thermal and rainfall anomalies. The results show that intense rainfall and cold air waves predominated during the study period, in accordance with other results on the climatic evolution of the Iberian Peninsula during the Little Ice Age.

1. Introduction

Discussions on climatic change have underlined the need for having available detailed data series corresponding to the longest possible period. A better understanding of the history of the climate would reveal the natural behavioural mechanisms of climate, and, consequently, contribute to improving climatic models, validating their results. Within the historical period the existence of a cold period designated Little Ice Age (LIA) has been established. The characterisation of this period and even its chronological limits are not well known yet, therefore the term LIA must be used with caution (Bradley and Jones, 1992). Some studies of the historical climate have been centred in specific years, but most of the efforts have been directed to searching long-term trends. It is essential for the development of climatic studies to know with the greatest possible detail the thermal and rainfall characteristics of different regions of the planet, from which the interest and need for studies centred in shorter periods arises (Ball, 1994).

This work analyses the climatic information content of the private correspondence of the Jesuits during the period 1634–1648. This 15-year period is interesting by being located unmistakably within the LIA, immediately before and overlapping with the beginning of the so-called Maunder Minimum period 1645–1715 (Mörner, 1994). Thus, this analysis can throw light on the climatic mechanisms in a region until now little studied in terms of the historical climatology. As we will see, the information refers mainly to Castille (Spain), which allows us to widen the spatial



coverage of this type of study in the Iberian Peninsula, where until now only some works devoted to Andalusia (Rodrigo et al., 1994, 1995a,b, 1996) and to Catalonia (Martín-Vide and Barriendos Vallvé, 1995; Barriendos, 1997) have been published.

The study region is of great interest from the climatic point of view, given its latitudinal position, around 40° N, where outbreaks of disturbances generated by the polar jet can occur. The Atlantic influence is decisive in the climatic characterisation of Castilla, as well as other factors, such as orography and altitude (the main cities with information are Madrid at 667 m, Salamanca at 790 m, and Valladolid at 854 m a.s.l.).

The Jesuit order had great importance in Spain during the 16th and 17th centuries, with a decisive influence in the Court and a spatial coverage that included not only all the Peninsular territory, but also the colonies. In Section 2 the data source is described, and in Section 3 the methodology used to convert it into numerical indices is explained. Section 4 focuses on the seasonal description of the principal information related to temperature and rainfall regimes. In Section 5 the results are discussed in the light of other data (both from Castilla and other regions), and through comparison with the present, emphasising the weather types related to the observed results. Finally, some preliminary conclusions are drawn and recommendations for future studies are suggested.

2. Analysis of the Source: The Jesuit Private Correspondence

Fulfilling one of the principal bylaws of their Rule, members of the Company of Jesus were required to report to their superior and brothers any remarkable events (military, political, ecclesiastic, civil or of any other nature) that occurred in their environment. Reports, gazettes and papers of several classes went from one point to another to be read and commented on. The papers which are the object of this study contain letters that were sent from various Spanish cities to Father Rafael Pereyra (1594–1650), Attorney General of the province of Andalusia in the Colegio of San Hermenegildo of Seville. The main aim of Father Pereyra seems to have been gathering news to elaborate the history of his time, following in Juan de Mariana's steps (1536–1624), author of a 'General History of Spain' published in 1623 (Ballesteros, 1972).

The principal correspondent of Father Pereyra was Sebastián González (c.1648), member of the Jesuits Colegio of the Court in Madrid, who is characterised by his great accuracy and rigour, even to the point of amending letter by letter mistakes and inaccuracies made in his previous letters. Furthermore, we can also mention Andrés Mendo (1608–1684), resident in Salamanca, and Juan Chacón of Valladolid, both known for their theological works (dates of birth and death not given are unknown). There are other letters originating in other regions of the Peninsula, such as Cádiz (4 m a.s.l.) and Granada (670 m a.s.l.) in Andalusia; Badajoz (195 m a.s.l.) in Extremadura; Zaragoza (240 m a.s.l.) in Aragón; Santander (65 m a.s.l.)

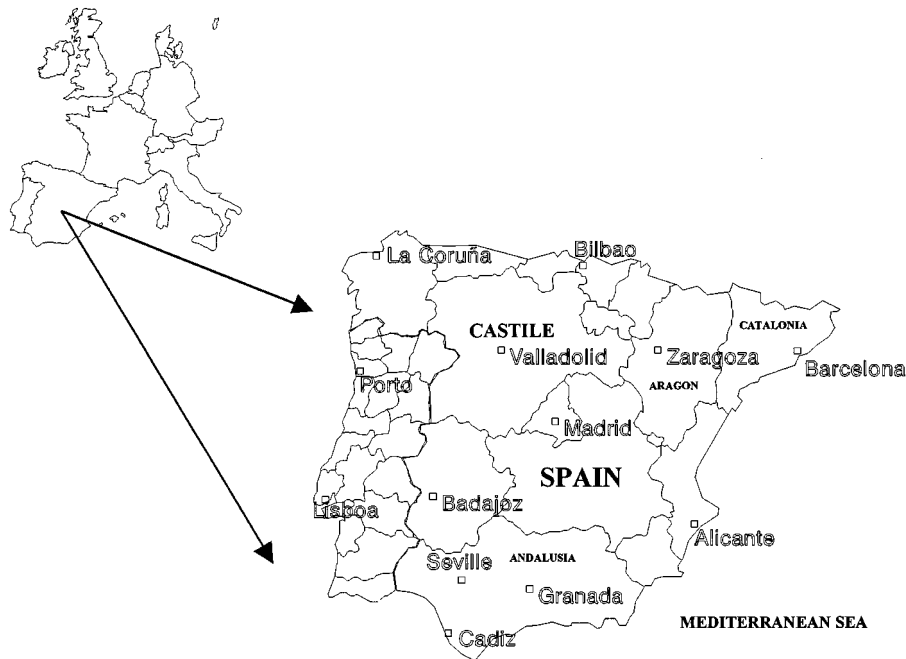


Figure 1. Map of the region in study.

and Bilbao (34 m a.s.l.) on the Atlantic coast; and Barcelona (94 m a.s.l.), Tarragona (9 m a.s.l.) and Vinaroz (100 m a.s.l.) on the Mediterranean coast. The correspondence includes letters from several European countries such as Portugal, Holland and Italy, and even correspondence of the Jesuit Fathers in America. Father Pereyra added copies of accounts, ambassador dispatches, secretariat letters and official correspondence to the collection. Of the total set of 1097 letters analysed, 85% correspond to Castillian cities, mainly Madrid, Salamanca and Valladolid (Figure 1), those that we have studied in-depth.

The original manuscript collection, kept in the National Historical Archive in Madrid, lacks order and is uncatalogued. Fortunately, the Royal Academy of History of Spain edited the letters in chronological order and noted any mistakes, referring mainly to the transcription of persons and place names. A total of 1097 letters of the collection were published between 1861 and 1865 in 7 volumes within the collection ‘Memorial Histórico Español’ (M.H.E.), volumes XIII to XIX, and are a first-order source to analyse the reign of Felipe IV in Spain. A random check of original manuscripts was made and the conclusion was that the printed version was reliable. The purpose of M.H.E. was to collect and print a great number of unpublished historical sources, such as texts written by historians like Rodrigo Caro (1573–1647), relationships, gazettes, etc. We can find similar collections in other European countries, such as ‘Monumenta Germaniae historica’ published in

1826 in Germany, 'Monumenta Poloniae historica' in 1864 in Poland, or 'Fontes rerum Austriacarum' in 1855 in Austria (Brázdil and Kotyza, 1995).

The collection begins with a letter dated in Madrid on 3rd January 1634 and ends with one dated in Segovia (1005 m a.s.l.) on 15th December 1648. So, it covers a period of 15 years in the first half of the 17th century. The correspondence stops for unknown reasons; it is not known whether by the death of Father Pereyra or Sebastián González or by loss of the original documents from that date. In fact, the year with the fewest letters is 1648, the last one of the period.

Of the 180 months in the study period, there is a lack of correspondence in 9 of them (March and June of 1641, July and October of 1644, January and October of 1647, June, September and November of 1648). Thus, we do not have news of any type in only 5% of the months in the study period. On average 930 letters from Castille are distributed with a frequency of 5 letters per month. However, there is a large fluctuation in the frequency of letters. So, for instance, we only have 24 letters during 1641, while we have 114 letters in 1642. This fluctuation was caused by several reasons, for example, illness of one correspondent, short trips and stays outside the city, or, simply, lack of relevant news to be communicated. Table I summarises the monthly frequency of letters corresponding to each year.

The climatic information appears in the letters for several reasons. Sometimes the authors refer to the climatic conditions to explain why there was a lag in the mail arrival, as, for example, in the letter dated in Valladolid on 18th January 1642 by Alonso de Amaya when he asserts that the mail is delayed because of the snowfalls and intense rains, or in the missives signed by Sebastián González in Madrid on 24th March 1637 and on 27th February 1646, when he mentions the same reason. Other times, the authors mention extreme phenomena of great impact on the socio-economic life. For example, Isidro Monzón writes on 13 May 1645 from Salamanca how the drought affects grass for the cattle and wheat. On occasions, the meteorological phenomena are mentioned in an indirect way, reporting some events the authors witnessed. When Sebastián González described the minister Conde Duque de Olivares' burial, he emphasised that a storm happened that day. He also described local events affected by the meteorology, as in a bullfight on 13th August 1646 that was interrupted by a storm. Finally, many events are mentioned and described by their exceptional character: Sebastián González describes from Madrid on 23 January 1646 the intensive cold and snowfalls of that winter.

Though the climatic information is very interesting, it was not the main aim of the correspondence, which was focused above all on political and military aspects. This compels us to undertake a careful review of the texts, since the collection cannot be understood as a meteorological journal similar, for example, to the meteorological daily record kept by Louis Morin in Paris (Pfister and Bareiss, 1994). The heterogeneous and miscellaneous character of the letters determines the character of the registered climatic news, emphasising extreme phenomena, and explains that climatic information only appears in 9% of the letters (Table I). Given the reasons of appearance of climatic information, we can assume that lack of climatic informa-

TABLE I
 Monthly number of letters and frequency of the correspondence originating in Castilian cities (in bold number of letters with climatic news, in plane number of letters without climatic information). In parenthesis, percentage respect to the total of 930 letters

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1634	1-2	0-10	0-4	0-11	2-9	0-8	0-7	0-6	1-5	0-2	0-4	0-7	4(0.4)-75(8.1)
1635	0-7	0-2	0-6	0-10	0-8	0-5	0-15	1-7	2-11	0-9	1-12	2-6	6(0.6)-98(10.5)
1636	0-3	1-4	0-7	0-5	1-4	1-4	1-4	0-4	0-5	0-4	3-1	0-3	7(0.7)-48(5.2)
1637	3-3	2-2	2-3	0-10	0-3	1-4	0-6	0-4	2-4	0-4	1-6	0-7	11(1.2)-56(6.1)
1638	2-4	5-2	2-7	0-9	1-5	2-5	0-8	0-8	0-7	0-7	0-9	0-7	12(1.3)-78(8.4)
1639	3-5	0-4	2-4	0-9	0-7	2-7	0-10	0-8	0-4	0-3	0-5	0-6	7(0.7)-72(7.7)
1640	0-6	0-3	1-3	0-4	1-0	0-1	0-4	0-4	1-11	0-12	1-13	0-8	4(0.4)-69(7.4)
1641	0-2	0-1	0-0	0-1	1-2	0-0	0-2	0-1	0-1	0-2	0-4	1-6	2(0.2)-22(2.4)
1642	5-10	0-8	0-13	1-14	0-15	0-11	0-11	0-5	2-7	0-4	0-6	1-1	9(1.1)-105(11.3)
1643	0-5	0-6	0-5	0-4	0-6	0-7	0-5	2-5	0-9	1-6	2-3	0-6	5(0.5)-67(7.2)
1644	2-4	1-1	1-2	0-4	0-5	0-2	0-0	0-2	0-1	0-0	0-1	0-1	4(0.4)-23(2.5)
1645	2-7	1-5	0-4	0-3	1-4	0-3	0-5	2-3	0-5	0-6	0-3	0-2	6(0.6)-50(5.4)
1646	2-3	3-1	0-2	0-4	0-5	0-3	0-4	1-3	0-3	0-4	0-4	0-3	6(0.6)-39(4.2)
1647	0-0	0-1	1-0	0-2	3-1	0-5	0-5	0-6	0-3	0-0	0-4	0-1	4(0.4)-28(3.1)
1648	0-2	0-1	0-2	0-2	0-2	0-0	0-1	0-1	0-0	0-1	0-0	1-0	1(0.1)-12(1.3)
Total	20(2.0)	13(1.4)	9(1.0)	1(0.1)	10(1.0)	6(0.6)	1(0.1)	6(0.6)	8(0.9)	1(0.1)	8(0.9)	5(0.5)	88(9.2%)
	63(6.8)	51(5.5)	62(6.7)	92(9.9)	76(8.2)	65(7.0)	87(9.4)	67(7.2)	76(8.2)	64(6.9)	75(8.1)	64(6.9)	842 (90.8%)

tion corresponds to absence of extreme phenomena immediately before the date of the letter. Anyway, the climatological interest of the documentation is undeniable, given the eyewitness nature of the correspondents and the promptness with which they registered the events. Thus, for example, Father Sebastián González, principal correspondent with Father Pereyra, wrote from Madrid at least one letter a week registering all the news of special interest in the Court, including references to meteorological phenomena. The information obtained has been checked with that originated in other sources for the same period, especially the 'Annals of Madrid' by León Pinelo (1592–1660), written between 1640 and 1648 (Fernández Martín, 1971), and several contemporary short documents (Anonymous, 1636a,b).

3. Data

Most of the correspondence analysed is from Madrid, though the information originating in other Castillian cities, such as Salamanca, Valladolid, and, in minor extent, Burgos (854 m a.s.l.), Segovia, Soria (1080 m a.s.l.), and Zamora (667 m a.s.l.), is also very useful. All these cities are located on the Spanish Plateau (Figure 1), and they are affected by similar climatic characteristics, due mainly to their continental conditions, and their location between the Atlantic Ocean and the Mediterranean Basin, which determines the direct influence of the Azores Highs and the Atlantic Lows. All the news referring to these cities has been considered in order to analyse the climatic evolution of the region in the period studied.

As we have seen in the previous section, the frequency of the mail enables us to determine precisely the month (months), day (days), and even the hour when the meteorological phenomena described by the source happened. But this is not possible for all 180 months of the whole period, not only because we do not have correspondence in 9 of them, but also because the correspondence does not always contain climatic news. The number of months with climatic information comprises only 30% of the possible total (Table II), emphasising the months of January and May as those that have more information. The lack of information in April may be related to the absence of extreme phenomena in this month or to the low percentage of letters with climatic information during this month (Table I). If we group the records by seasons of the year, of 60 seasons in the study period, 62% have relevant climatic information, with a predominance of the winter compared to other seasons. The reason for the predominance of winters is the extreme nature of phenomena reported, basically heavy rainfalls and snowfalls, which occur mainly in this season. The seasons corresponding to the agricultural year in the Iberian Peninsula have been considered: spring (March, April, May), summer (June, July, August), autumn (September, October, November) and winter (December, January, February). To fulfil a quantitative study of the obtained information, it seems advisable to use seasonal precision in the analysis.

TABLE II

Number of months, seasons and years with one or more climatic records in Castille. In parenthesis, normalisation factor (15 for each month, season and year; 180 for the total number of months; 60 for the total number of seasons). In column 3 percentage with respect to the possible total number in the period studied

	Number	Percentage
January	8 (15)	47
February	6 (15)	33
March	5 (15)	33
April	0 (15)	0
May	7 (15)	47
June	5 (15)	33
July	2 (15)	13
August	5 (15)	33
September	4 (15)	27
October	2 (15)	13
November	6 (15)	40
December	6 (15)	40
Total months	54 (180)	30
Winter	11 (15)	73
Spring	9 (15)	60
Summer	10 (15)	67
Autumn	7 (15)	47
Total seasons	37 (60)	62
Total years	15 (15)	100

News can be grouped basically in two groups: those items corresponding to the thermal regime (frosts, snowfalls, snow cover, storms, and hail), and those concerning the rainfall regime (intense and/or continuous rains, floods, droughts). 53% of the information is related to the rainfalls, 43% to the temperatures, and the remaining 4% to winds and cloudiness. This distribution contrasts with the results of a similar analysis for Andalusia, to the south of the Iberian Peninsula, for the period 1601-1650 (Rodrigo et al., 1994). In that work, from analysis of various documentary sources, a clear predominance of information on the rainfall regime was obtained, 76% of the news items. From this, it was established that the information in Andalusia was more related to rainfall than to temperature.

The percentages of thermal and rainfall news in Castille were very similar. This fact suggests the progressive importance of the temperature regime in the climatic evolution northwards or a greater regularity in precipitation in Castille.

The registered extreme events imply a density of 4.9 items/year. If we considered only the rainfall regime news, the information density is 2.6 items/year, and 2.1 items/year for the thermal news. This information density, with the seasonal coverage of the news given in Table II, provides a limited data base from which certain conclusions on the Castillian climatic characteristics during the period studied can be drawn. Though this information density does not allow an exhaustive quantitative study of the thermal and rainfall regime in Castille during the period, it is at least possible to make a first approach to the analysis of the main extreme events. In fact, every year of the period studied recorded appearance of extreme events. The basic assumption here is that the extreme events are more sensitive to climate variability than average climate and therefore variations in the frequency and intensity of extreme events are the main features of the changes in average climate (Katz and Brown, 1992). In fact, analysis of the behaviour of the climate with regard to extreme phenomena frequency has been carried out in many historical climatology studies (Bradley and Jones, 1992; Wang, 1991), and Font Tullot (1988), in his analysis of the 1956–1986 climate in Spain, characterises this period as a climatic change phase because 29 of the 31 years considered had meteorologically extreme events.

The methodology used to reduce the level of subjectivity of the sources consists in designing an ordinal index to estimate the rainfall and temperature extremes. This index must be based on objective information and not on the individual emphasis of the authors. The principal events related to rainfalls were codified in the following way: hydrological droughts, that is, drought accompanied by the drying of rivers and springs ($P = -2$); meteorological droughts or simply lack of rain without the explicit mention of deficit in the runoff of rivers and springs ($P = -1$); intensive and/or continuous rains ($P = +1$); rains with floods ($P = +2$). When the authors did not comment on the meteorological conditions, the situation was considered as 'normal' and was assigned the index $P = 0$. This index value was also assigned to conditions that may be considered as a 20th century standard, for example when the authors mention rainfall without more details in November and April, the two wettest months today. The reference period 1961–1990 was considered (Guía Resumida del Clima de España, 1995).

In the case of temperatures, given the greater degree of subjectivity inherent to this type of information, the codification is less detailed. The subjective appraisals of the authors on the degree of cold or heat were only taken into account when they were associated with more objective observations, such as the ones related to frosts, snowfalls, thunderstorms, etc. News related to frosts, snowfalls, or excessive cold, unusual for the considered season (spring, summer), were codified as $T = -1$. The index $T = +1$ was assigned to news related to heat in months when it is not usual (between November and February), or to the convective storm appearance between

TABLE III

Characteristic statistics of the rainfall index (P) and thermal index (T) of each season for Castille during the period 1634–1648

	Winter	Spring	Summer	Autumn
P (average)	0.33	0.00	0.33	0.33
P (st. deviation)	0.73	0.84	0.62	0.44
T (average)	-0.33	-0.17	0.27	-0.10
T (st. deviation)	0.45	0.52	0.59	0.43

the end of spring and the beginning of the autumn (May to September), since these phenomena are related to the relative low-pressure presence of thermal origin in the Iberian Peninsula. The value $T = 0$ was assigned to news deemed today as normal (cool in winter, warm in summer), or to the absence of news. The reference period 1961–1990 was again taken into account.

These numerical values were assigned to each site and to each month. The regional monthly index was obtained by averaging the monthly values corresponding to each site within the zone considered. Afterwards, an index was established for each season of the year considering the number of months with records. These indices should be interpreted as a measure of the meteorological anomalies behaviour rather than the mean values of the variables analysed (seasonal rainfall/temperature). The positive values indicate season with rainy/warm events, and the negative values seasons with dry/cold events. In this sense, index values indicate the appearance of extreme phenomena more than general character of the season. The value 0 can suggest the absence of remarkable events ('normality') or the appearance of contradictory events in the same season, which would be an intra-seasonal variability indicium. A detailed analysis of the correspondence allows us to assure that this last situation has not been given. This method of spatio-temporal averaging allows us to filter the strictly local phenomena and reject partially the heterogeneity of the records, related to the spatial distribution of the news and the uncertainties in the perception by the authors of the extreme events. Once the seasonal indices for each of the 15 years of record were estimated, the principal statistics (average, standard deviation) were calculated (Table III). For each series, the average value of the index expresses the general character of the total period, and the standard deviation provides information on the variability of the series. In all the seasons the value of the standard deviation is very high as it corresponds to the extreme nature of the phenomena considered.

Different types of indices have been proposed in historical climatology studies. Difference indices as used by Lamb (1977) for winter severity ($C - M$, where C and M are the number of unmistakably cold and mild months, respectively) are

quite sensitive to changes in the observation sites and missing data, whereas ratio indices, for example, $(R - D)/(R + D)$ where R is the number of floods and D the number of droughts reported (Yao, 1982), show less sensitivity and tolerate gaps and uncertainties in the perception and/or real frequency of the extreme events (Ingram et al., 1981). Our index results from an averaging procedure with positive and negative values for the anomalies. In this sense, it is very similar to unweighted indices proposed by Pfister (1992), where three levels (-1 , 0 , $+1$) are established from monthly data to indicate positive and negative deviations from the class defined as average. In this case the seasonal index levels range between -3 and $+3$. Given the density of our data, only the 30% of the months with records, we have chosen a less detailed index that simply gives information about the fluctuations of rainfall and temperature anomalies from year to year.

4. Climatic Conditions in Castille During the Period 1634–1648

4.1. WINTER

In this report, winters are identified by the year that corresponds to the month of January. On average, the winters of the period studied were characterised by being rainy ($P = +0.33$) and cold ($T = -0.33$). The rainfall series emphasised two drought years, 1639 and 1645 (Figure 2). All the thermal anomalies detected are negative (Figure 2).

As notable examples of these general winter characteristics, we have the years 1636, 1642 and 1646. In 1636 heavy and intensive rainfalls are recorded the first week of February, in Burgos on 3 February (Anonymous, 1636b), in Valladolid, where the rivers Pisuerga and Esgueva flooded on 4 February (Anonymous, 1636b), and in Madrid on 5 February. The Valladolid flood had wide echo in the whole country, as is deduced from the fact that it was outlined in the 'Annals of Granada' written in Andalusia by Henriquez de Jorquera (Marín Ocete, 1934). This winter was also characterised as being very rainy in Andalusia (Rodrigo et al., 1994).

Perhaps the most notorious year of the period is 1642, due to the geographical spreading of the events that happened, especially during January. A letter from Valladolid dated 4 January, describes how the intense rains bring fear of a new flood. To the rain news are added those of intense cold and snowfalls throughout the month of January (see letters from Madrid on 15 January, Valladolid on 18 January, and Salamanca on 25 January). The heavy rains had begun the previous months and were not restricted to Castille. A letter from Badajoz (Extremadura) dated 25 December 1641 already described intensive rains in this city, and the heavy rains statements in points of Andalusia are many, as in Jaén (510 m a.s.l.) and the flood of Seville (31 m a.s.l.) by the Guadalquivir river at the end of January (Ortiz de Zúñiga, 1677; Morales Padrón, 1981; Marín Ocete, 1934). The rains also affected areas of Aragón and Catalonia, and coincided with wind storms on the coast of Portugal and the Mediterranean Sea.

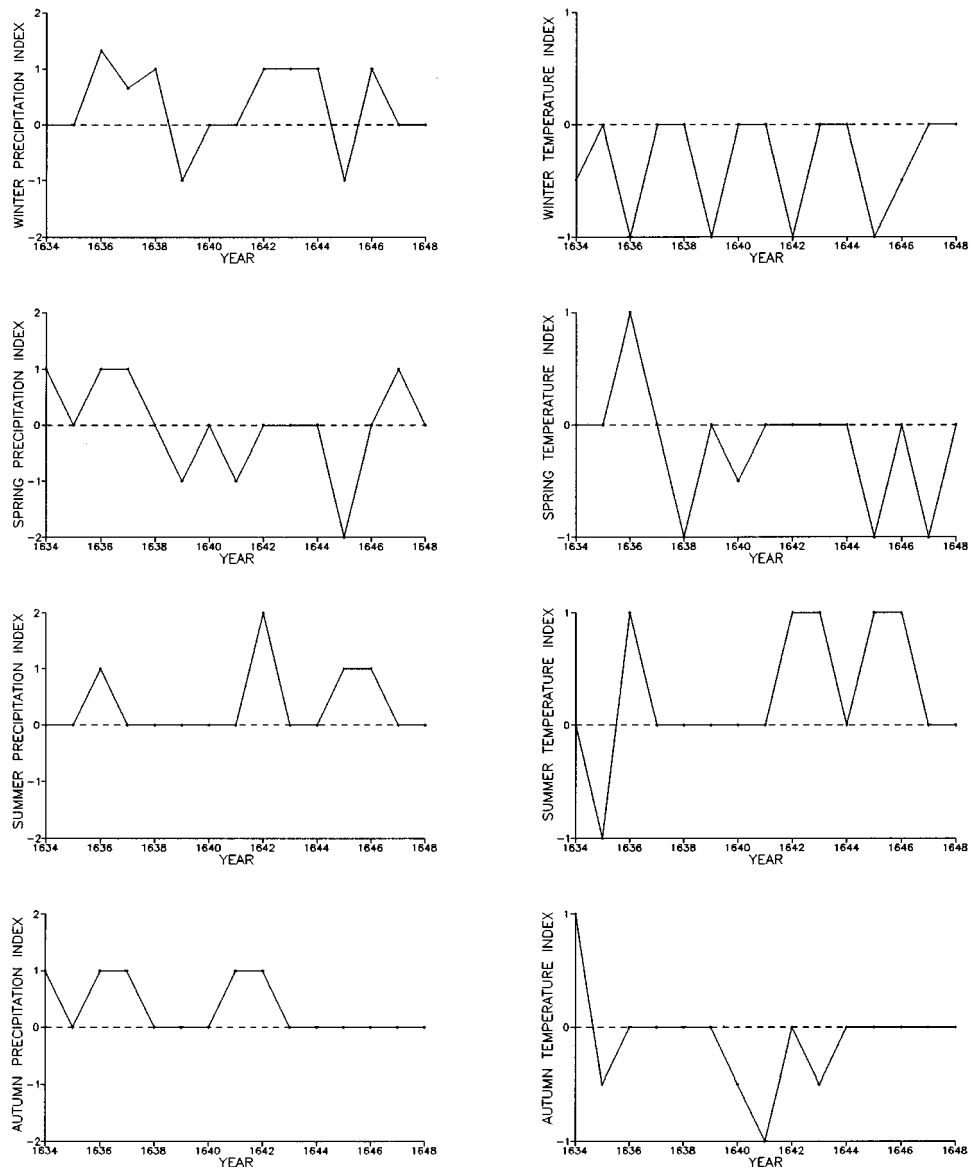


Figure 2. Rainfall Index (left) and thermal index (right) for winter, spring, summer and autumn (from top to bottom) in Castille during the period 1634–1648.

In 1646, the cold weather with snowfalls in Madrid during January was followed by rains that penalised the mail around the end of February. That year, emphasis was made on the news of the flood of the Ebro river in Zaragoza, because of heavy rains and snowfalls, recorded in a letter dated 6 February.

The two drought years according to their seasonal averaged indices also registered heavy snowfalls in Salamanca, as reports the correspondence on 29 January

1639 and on 14 January 1645, when there are recorded not only snowfalls, but also permanency of the snow layer during more than eight days.

4.2. SPRING

As in winter, we have a predominance of cold anomalies in spring, with $T = -0, 17$. Concerning the rainfalls, on average it does not seem to have been a clear predominance of dry or wet anomalies ($P = 0$), though there were three drought years (1639, 1641 and 1645) that seem to suggest a predominance of droughts between 1638 and 1646 (Figure 2). The thermal anomalies detected are mainly negative (Figure 2), except in the year 1636, in which a typical convective storm is described in Madrid on 20 May.

The drought of 1645 had an important impact on the agricultural resources and cattlemen. In addition, it was accompanied by cold air invasions that, according to a letter from Salamanca dated 13 May, were more normal in January than in spring. The spring of 1647, on the contrary, is characterised by being cold and rainy, with impacts on buildings in Madrid (letter dated 26 March) and loss of crops by excessive rains (letter from Madrid dated 21 May). In fact, on 4 June, Sebastián González says that there is a shortage of bread in Madrid. Impacts of the rain on the fortifications of Badajoz (letter dated 26 March) and storms in the Atlantic coasts of Galicia (26 March) were also registered.

4.3. SUMMER

In summer we have a high level of agreement between both indices, as a result of considering the thunderstorms indicative of high temperatures. Thus, the mean values are positive for the rainfall index ($P = +0, 33$) and the thermal index ($T = +0, 27$). Negative rainfall anomalies are not appreciated (Figure 2) since the normal conditions in summer are dry sunny weather. Concerning the thermal anomalies, there is only one case of negative anomaly, the summer of 1635 (Figure 2). This summer the prevailing cool was recorded in a letter from in Valladolid dated 7 August when it was described that 'weather is so cold that we must use winter clothes'.

The summer of 1636 is characterised by a thunderstorm in Toledo (letter dated 24 June), and by a similar storm in Madrid in July (letter dated 15 July). Heavy east winds were recorded in Cádiz (Andalusia) this month (letter dated on 26 July) which shows the typical thermal conditions on the Peninsula, with warm air invasion from the north of Africa. Similar conditions were registered in the summer of 1642, when the news of a hailstorm in Burgos around the end of August (letter dated 2 September; Marín Ocete, 1934) is added to information on heavy east winds in the Mediterranean coasts (letter from Barcelona dated 4 July and Vinaroz dated 7 July), and a thunderstorm in Seville on 8 June (Morales Padrón, 1981). These storms were recorded on the occasion of the statement of the Conde Duque de Olivares' burial, who had been Felipe IV's prime minister, and they

were also registered by Henríquez de Jorquera in his 'Annals of Granada' (Marín Ocete, 1934) and by a short correspondance printed in the year 1646 and collected by Father Pereyra. The following summer a storm is mentioned on 13 August in Madrid (letter dated 14 August) that stopped the development of a bullfight. This storm followed several references to excessive heat in Extremadura (letters from Badajoz on 26 June and on 9 July).

4.4. AUTUMN

The general characteristics of autumn are very similar to those of the winter, with $P = +0,33$ and $T = -0,1$. Years with drought are not registered (Figure 2), and most of the thermal anomalies are negative (Figure 2). The year 1641 was characterised by being very rainy and cold at least in November, as suggested in the letter dated 21 January 1642 in Madrid, where the persistence of rains and cold during three consecutive months is commented upon. The appearance of negative thermal anomalies in November is the most outstanding aspect of the autumn data, suggesting the eruption of winter conditions at least a month in advance with respect to what is normal today. Thus it occurs also in 1635, when intense cold and snowfall information during November is recorded in letters from Madrid dated 24 November, 27 November, and Valladolid on 2 December. This situation was repeated in the year 1643 as is indicated by the references to snowfalls and even to deaths provoked by the cold in the letters from Madrid dated 24 November and in the province of Zamora during this month.

5. Discussion

The only one absolutely reliable test of the results is to prove whether they agree with contemporary instrumental data, which unfortunately do not exist. The better test, then, is to see whether there is other evidence (from different sources of data or from other neighboring regions) that show similar characteristics (Wang and Zhang, 1992). However, the correlation will only be possible in a generic and qualitative way (Baron, 1992).

Alvarez Vázquez (1986) analysed the evolution of the climatic conditions in Zamora (North Castille) during the 17th, 18th, and 19th centuries from the study of the processions and rogatives related to droughts and floods. The data of Alvarez Vázquez also includes the spring droughts in 1639, 1641, and 1645. His data on floods in the basin of the Duero River in 1634 (he does not specify the season of this flood) seem coherent with our value of the rainfall index in spring and autumn ($P = +1$). On the other hand, he also recorded the floods in the winter of 1636. This author, from analysis of the rogatives and processions, obtains the same conclusion of our study: the climatic conditions were characterised by rains, frosts and cold temperatures, or by droughts accompanied by high temperatures.

To test the results, without other sources of data for the region, one should attend to the results originating in neighboring regions. In this sense we can emphasise the similarity of the Castille data with the seasonal evolution of rainfall in Andalusia, to the south of the Iberian Peninsula. In previous papers (Rodrigo et al., 1995b, 1996), the evolution of the rainfalls in Andalusia was analysed from documentary sources different from those used for this work. The principal conclusions were predominance of positive rainfall anomalies, above all in winter and autumn, and the appearance of droughts with greater frequency in spring during the 16th and 17th centuries. Positive values of the index were also found in winter for the years 1636, 1642, 1643, 1644, and 1646; and in spring for 1647; in summer for 1642 and 1646; in autumn for 1641 and 1642. Negative index values in Andalusia were also found in spring of 1641. These results agree with the conclusions by Creus and Puigdefábregas (1984). During the LIA, in Andalusia a rainfall increase was found from dendroclimatic analysis. On the other hand, this similarity between Castille and Andalusia corresponds to the climatic situation in the Iberian Peninsula for the instrumental period. In fact, from a principal component analysis conducted on more than 40 meteorological stations distributed over the Iberian Peninsula, Andalusia and Castille can be interpreted as belonging to a same climatic region, and in Spain the rainy periods are associated with the cold ones, while the warm periods are associated with the dry ones (Esteban-Parra, 1995).

For the Northern Hemisphere as a whole, one of the coldest intervals during the LIA was from about 1570 to 1730 (IPCC, 1996). The increase in the variability and the greater frequency of extreme events, with an increase in rainfalls and a generalised decrease of temperatures, have been found in other European regions, including northern Italy (Camuffo and Enzi, 1992), Switzerland (Pfister, 1992), the Low Franconia in Germany (Glaser and Hagedorn, 1991), and the Czech Lands (Brázdil, 1996). In his analysis of historical storms of the North Sea, British Isles, and Northwest Europe, Lamb (1991) found that the cold and disturbed climate seemed to have had a culminating phase between about 1560 and 1720. North Africa also recorded wet conditions from 16th century to the first half of the 17th century (IPCC, 1996).

With regard to the period studied, 1634–1648, we have found that our positive rainfall indices coincide with information on floods of the river Tiber on 22 February 1637, the river Bormida (Tanaro Valley) around 20 August 1646, Tamaro and Bormida rivers on 9 April 1647 and Belbo river on February 1646 (Pavese et al., 1992). In relation to temperatures, a cooling trend in winter temperature is observed from 1630s onwards, culminating at the end of the century in Switzerland (Pfister, 1994) and during the 1620s and 1630s in Iceland (Ogilvie, 1994). Winter severity index by Lamb (1977) was negative for the 1630s and 1640s, with cold winters in England in 1645 and 1646, coinciding to our negative thermal index. Le Roy Ladurie (1983), from the analysis of grape harvest dates in southern France, infers that the years 1639–1643 were wet and cold. This author, from the combined analysis of grape harvest dates and glacial development in the Alps, has

established the period 1640–1653 as characteristic of the main phase of the LIA in Europe. However, Camuffo (1987, 1993) does not include events related to the freezing of the Venetian lagoon or sea surges at Venice corresponding to these years, characterizing the 17th century at Venice as mild and rainy. According to Grove and Conterio (1994), the incidence of extremes could differ markedly in the eastern and western Mediterranean. In fact, according to a dendroclimatic research (Serre-Bachet et al., 1992), there was a stronger connection between the climate of Western Europe and Italy than between Italy and the Iberian Peninsula and North Africa. The differences found between the climates of Italy and Spain are due to the fact that we consulted papers which mainly refer to the climate of Northern Italy, which is linked with the climate of Western Europe, whereas Southern Italy is more linked with the Iberian Peninsula and Greece.

Among the principal meteorological phenomena detected in the period 1634–1648, we find intense rains and cold weather with heavy snowfalls. Thus, for example, in the autumn of 1636 we find information on continuous rains in Madrid from at least 18 October to 11 November. This amounts to 13 rainy days in October and 11 in November, values higher than the average number of days with rain >1 mm in the reference period 1961–1990, 8.5 and 10.6, respectively (Guía Resumida del Clima de España, 1995). The correspondence reports on continuous rains in the winter of 1642 in letters from Madrid and Valladolid on 4, 15, 18 and 21 January. This supposes continuing rainfalls for 16 days, and contrasts with the mean values calculated for the instrumental period, 10.6 days in Madrid and 11.5 days in Valladolid. In relation to snowfalls, it emphasizes continued snowfalls during 9 days in Salamanca, from 5 to 14 of January of 1645. This value equals practically the annual average number in the instrumental period (9,3) and exceeds widely the average number of days with snowfall for the month of January (only 2). It seems clear that we have recorded a set of phenomena that may be considered as extreme according to the instrumental period standards.

However, to show clearly in which respect the climate during this period was remarkable, we need to refer not to modern averages, but to modern extremes, and to modern 15-year periods of similar character, considering season by season. First of all, we chose 1961–1990 as the reference period in the 20th century. The second step was to elaborate a catalogue of extreme events during this period, from the extensive information contained in the bibliography (Capel Molina, 1972, 1983a, 1983b; Font Tullot, 1986, 1988, 1989; García de Pedraza et al., 1990). We will focus our attention on cold waves, intense rainfall, and droughts.

Among the main cold waves that affected the Iberian Peninsula for the reference period, we can mention the cold waves from 21 December 1970 to 3 January 1971 and from 6 to 16 February 1983. In the first one there were recorded snowfalls in Valladolid with minimum temperatures of -5°C on 26 December, -6°C on 29 December, -11°C on 31 December, -13°C on 1 January, and -14°C on 2 January (Capel Molina, 1972). In relation to the second one, minimum temperatures in Salamanca were -5°C on 8 February, -7°C on 9 February, -8°C on 10 February,

-8°C on 11 February, -12°C on 12 February, -10°C on 13 February and $+2^{\circ}\text{C}$ on 17 February, when the cold wave is considered to have ended. In Madrid, minimum temperatures recorded were -4°C on 8 February, -7°C on 10 February, -9°C on 12 February, -10°C on 13 February, and -10°C on 14th February. On 17 February, the minimum temperature recorded was $+4^{\circ}\text{C}$ (Capel Molina, 1983a). These minimum temperature values are the absolute minima during the reference period.

Intense rainfalls were also recorded for the reference period. So, in 1961 and 1962 winter's extreme rainfall caused flooding of the Duero river, the main river in the region. With regards to spring, we can mention the heavy rainfalls caused by a storm on 22 April 1968, with 52 mm recorded in Madrid (the monthly average is 54 mm). On 9 June 1975, 76 mm were recorded in Valladolid (monthly average 37 mm), and in the autumn of 1972 rainfalls were recorded in Madrid with 74 mm on 22nd September (monthly average 30 mm) and 51 mm on 3 November (monthly average 64 mm). While heavy rainfalls in winter are caused by Atlantic lows with their associated fronts, moving through the region for 3 to 5 days, the main responsible mechanisms in spring, summer, and the beginning of autumn are heavy thunderstorms, convective in origin and shorter in duration (Capel Molina, 1983b).

Finally, we can mention the important droughts in the autumn and winter of 1974–1975, and from November 1988 to February 1989, one of the longer drought situations in the reference period (Font Tullot, 1989).

From these examples, we can see that historical extremes were similar, both in intensity and duration, to the modern ones. In order to search for differences between the historical period and the reference period, we must compare 15-year periods of similar character, season by season. From the extremes recorded for the reference period, we found the 15-year periods with greater presence of extremes. In relation to cold waves, this period is 1971–1985, heavy rainfalls in 1961–1975 and droughts in the period in 1967–1981. The results of the comparison are shown in Table IV. We can see that the number of seasons with negative temperature anomalies is higher in the historical period than in 1971–1985, the modern period with a greater number of cold waves. This situation occurs in every season, except summer, where we have only one historical record. The reason may be the low data density in the historical period compared with the instrumental period. With regard to heavy rainfalls, the modern period 1961–1975 has a higher frequency of seasonal extremes. The number of seasonal extremes was found to be nearly the same in winter, spring and summer, whereas the main difference was found in autumn, when the responsible prevalent mechanism is the convective rainfalls, as we have seen above. In addition, the modern period is characterised by being one of the wettest during not only the reference period, but also the complete 20th century record, above all the early 1960s (Font Tullot, 1988). Finally, the number of dry seasons is very high in the modern period, except summer, which is normally a dry season. If we compare the historical period with the wettest period, 1961–1975, we find that during 1961–1975 there were 17 dry seasons (6 winters, 4 springs, and 7

TABLE IV

Seasonal distribution of the principal thermal anomalies detected ($T < 0$, $P \neq 0$) in Castille for 1634–1648 and comparison with similar periods in the reference period 1961–1990. In parenthesis, percentage with respect to the total number of seasons

	Winter	Spring	Summer	Autumn	Total
<i>T</i> < 0					
1634–1648	6 (40%)	4 (27%)	1 (7%)	4 (27%)	15 (25%)
1971–1985	5 (33%)	3 (20%)	2 (13%)	1 (7%)	11 (18%)
<i>P</i> > 0					
1634–1648	7 (47%)	4 (27%)	4 (27%)	5 (33%)	20 (33%)
1961–1975	7 (47%)	5 (33%)	5 (33%)	9 (60%)	26 (43%)
<i>P</i> < 0					
1634–1648	2 (13%)	3 (20%)	0 (0%)	0 (0%)	5 (8%)
1967–1981	9 (60%)	6 (40%)	0 (0%)	7 (47%)	22 (37%)

autumns); that is more than in the historical period. In this period we must mention the drought from autumn to spring of 1963–1964, the droughts of autumn-winter 1970–1971 and 1974–1975 and the droughts of winter-spring of 1961 and 1970. In all these cases, the dry conditions prevailed during more than one season, with a heavy impact on agriculture. In the historical period this situation only appeared in two occasions, corresponding to winter and spring of 1639 and 1645.

In summary, we can conclude from this comparison that the historical extremes were similar to modern ones, but with slight differences in frequency. 1634–1648 was slightly colder than the coldest period in the reference period, the autumns were characterised by fewer convective rainfalls, and there were fewer dry seasons.

The analysis of the weather types responsible for principal extreme phenomena detected in each season can help us to interpret the dynamic behaviour of the atmosphere in the study period. As we have seen, the period 1634–1648 in Castille can be characterised by the frequent presence of cold waves and the lack of droughts, in comparison with the more important extreme 15-year periods in the reference period, 1961–1990. Concerning the cold air waves, the fundamental causes are the invasions of NE continental polar air or NW maritime polar air, provoked by northeastern or northerly flows with dominant high pressure centers over Northern and Northwestern Europe (Wanner et al., 1994). Heavy snowfalls, storms, and frosts characterise these waves of cold air produced mainly during the winter. This situation corresponds to the expansion southwards of the circumpolar vortex, with a meridian hemispheric circulation. On the other hand, the drought conditions are related to the evolution of the subtropical anticyclones and the development of

the so-called 'Iberian anticyclone' linked to a zonal hemispheric circulation regime (Font Tullot, 1989). This situation was rarely found in our data. This substantially meridional character of the circulation is directly related to the cold conditions detected in the same period in Western Europe, given the positive correlation for the Northern Hemisphere between the values of the zonal index and the temperature (Kozuchowski, 1993), and could explain the differences found between Spain and central and eastern Mediterranean.

The study presented here must be understood as a preliminary one, given the chronological limitation and the data density of the used documentation, but it clearly shows the potentiality of using this type of document in climatic reconstruction studies. Of course, it is necessary to widen the database to obtain a very clear image of the evolution of the climatic conditions in Castille during the Little Ice Age. These aspects, a fairly adequate comparison with information from other neighbouring regions, will allow us to analyse the spatio-temporal variability of the climatic phenomena during the Little Ice Age, and, consequently, to establish some conclusions on the climatic change phenomena in the Iberian Peninsula.

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