The Holocene 10,3 (2000) pp. 333–340

Temperature and precipitation reconstruction in southern Portugal during the late Maunder Minimum (AD 1675–1715)

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Received 4 November 1998; revised manuscript accepted 25 July 1999

A HOLOCENE RESEARCH PAPER

Abstract: This paper discusses the research carried out to check the climatic characteristics of the late Maunder Minimum (LMM) (AD 1675–1715) in the southwestern part of the Iberian Peninsula and as an aid towards pressure patterns reconstruction in the NE Atlantic and Europe. Documentary evidence reveals that interannual precipitation variability was similar to the present one, although some very severe dry periods occurred (particularly one in 1694). On the other hand, during the LMM there was a higher percentage of cold winter months, some of them with snowfall. A brief comparison is made with other areas from the Mediterranean. The relationships between weather similarities and differences for particular months is analysed in the light of the reconstructed synoptical patterns, and further research into historical climatic change of southern Europe is suggested.

Key words: Maunder Minimum, climatic reconstruction, Portugal, Mediterranean area, documentary data.

Introduction

The Maunder Minimum relates to a period of reduced solar activity between 1645 and 1715 (Eddy, 1976). Maunder himself was a superintendent at Greenwich Observatory, who discussed the effect on climatic oscillations of modifications in solar spots at the end of the nineteenth century. The term Maunder Minimum has been adopted by several climatologists to characterize a period of notable European temperature decrease and marked climate variability during the 'Little Ice Age'. Mann *et al.* (1998) confirmed recently that a highly significant correlation had been detected between solar irradiance and the Northern Hemisphere temperature during the Maunder Minimum.

By 1994 enough information had been gathered for the reconstruction of the climate of central, western and northern Europe. There was instrumental data for Paris (Pfister and Bareiss, 1994), central England (Manley, 1974; Siegenthaler, 1994), Zürich (Pfister, 1994a) and wind data for Oresund (Denmark) (Frich and Frydendahl, 1994), as well as indexed data for Switzerland (Pfister, 1988; Pfister, 1994b), Germany (Glaser *et al.*, 1994), Italy (Camuffo and Enzi, 1994), Bohemia and Moravia (Brázdil *et al.*, 1994), Iceland (Ogilvie, 1995), the SE of the Iberian Peninsula (Barriendos, 1994), as well as others (see Frenzel *et al.*, 1994).

From the available information, a group of climatologists made the first synoptic interpretation of monthly weather maps for the period 1675–1704 (Wanner *et al.*, 1994). However, data was still lacking and a conclusion could not be drawn as to whether the 'Little Ice Age' was a period of generalized cooling in Europe and the eastern Atlantic or not.

Portugal is located in the southwestern extremity of Europe, on the boundary between the subtropical and the mid-latitude circulation regimes. Its climatic variability is related to the North Atlantic Oscillation and information about this part of Europe is necessary for the reconstruction of climate over the Europe/North Atlantic sector (Luterbacher *et al.*, 2000). The present research began by seeking data in Portugal, a country with no tradition of

 0959-6836(00)HL393RP

historical climatology research. The most abundant information refers to Lisbon (38°43′N, 9°09′W, 95 m) and to Évora (38°34′N, 7°54′W, 309 m; 140 km east of Lisbon and which has a slightly more continental Mediterranean climate). The main sources used for climate reconstruction in southern Portugal are described in the first section of this paper. In the second part, temperature and precipitation evolution in southern Portugal are presented and synoptically interpreted.

Documentary sources

Instrumental data are extremely rare for the late seventeenth and early eighteenth centuries (Bradley and Jones, 1995); so reliable documentary sources had to be used instead. In the case of Portugal, research focused on diaries, as well as on ecclesiastical, *Misericórdias* and municipal institutional sources.

The diary of Manuel de Almeida

The most interesting diary found was the volume of the *Memórias Históricas de Lisboa*, written by a certain Manuel de Almeida between 7 November 1696 and 2 April 1716, and edited by António Pina Cabral in 1948. Manuel de Almeida has not been identified because his name is very common. The only thing we do know is that he was a layman. The account is organized chronologically and, although non-meteorological news is the main thread throughout it, there are detailed descriptions of weather and of what Manuel de Almeida perceived to be its consequences. The fact that these descriptions may have been exaggerated was borne in mind during the analysis. In some cases, the author explicitly states his own doubts about dates – for instance: 'it snowed in Lisbon on the 12th (or 13th?) of March 1684'. This fact only lends itself to making this document trustworthy and it will be now critically analysed since it constitutes, at the present moment, one of our best sources.

Reported events

All the information is qualitative in nature, and therefore subjective. The author mentions either short extreme weather events or writes about the weather for some months or parts of months. Data on individual days, although interesting in themselves, were not used for the monthly reconstruction of the climate. The intensity of certain episodes, especially heavy rainfalls, may be assessed through their consequences, which at times are described in great detail.

Selection criteria

The text highlights the periods before and after the days in which noteworthy events take place, according to the author: important dates concerning the royal family, such as royal births, christenings, weddings, funerals or digressions, the arrival and departure of fleets to and from Brazil, battles, *autos-de-fé*, fires, murders and religious festivities. The only climatic-hydrologic facts that deserve mention in themselves are the floods, largely urban. The inflated prices of staple foods, which Manuel de Almeida associates with the inclemency of the weather, occasionally deserve his attention.

The selection of facts depends on the date of writing. The author starts writing in 1696, and briefly describes events back to 1680 with the help of some scattered notes. This first part is more concise, featuring an average of 36 lines per year between 1680 and 1695, whereas there are 100 lines for each year after 1696.

Monthly variability of the available information

Information is very unequally distributed throughout each year, and more frequent in the winter months, particularly January, for the following reasons: (a) each yearly chronicle opens with an account of the weather conditions at the outset of each year; (b) there would, in fact, have been several extremely cold months of January during the period covered in the text. In contrast, there is much less information about summers. During these 37 years, there is information about only eight summers against 25 winters.

Other individual sources

Some other individual (and not institutional) sources have also been used. Most of them consist of manuscripts written by members of the educated class of that period and are related to social, cultural and meteorological events. The writings of José Soares da Silva and the priest João Baptista de Castro were examined.

J.S. da Silva was a member of the Royal Academy of History. Approximately every fortnight between 1701 and 1716, he wrote his 'Gazette written in the form of a letter' (*Gazeta composta em forma de carta*), which often included information about extreme weather events or meteorological characteristics of a period (manuscript; Silva, 1931). J.B. Castro studied in a Jesuit school and for some time he lived in Rome, where he worked for Pope Clement XIII. When he returned to Portugal, he organized a Chronological Opuscule (*Opúsculo chronológico*), in which he wrote on important events in Portugal every year. Meteorological news about 1704 and 1709 was found in this manuscript.

Ecclesiastical sources

Pro-pluvia and pro-serenitate rogation ceremonies

Droughts and excessive precipitation, the latter in the form of rainfall of devastating proportions or of excessive year-long humidity, were prior to the nineteenth century in most parts of Europe taken as God's punishment. His forgiveness had therefore to be sought by means of various religious rites, individual as well as collective. In Spain, *pro-pluvia* processions were common, organized by the local ecclesiastical authorities and funded by civil authorities, the Town Halls in particular. The systematic use of the Minutes of the Chapter Edicts (*Acordãos do Cabido*) allowed Barriendos (1997) to reconstruct the chief drought episodes between the fifteenth and nineteenth centuries for several Spanish cities.

In Portugal, however, the rogation ceremonies that deserved written notice were rare during the LMM. Only four references were found. Two *pro-pluvia* ceremonies were recorded: one of them in 1694 with supplications for an end to a drought that had lasted a year and another one at the end of the winter 1712. The *pro-serenitate* ceremonies took place in 1684 and 1708. Ongoing research has revealed that rogation ceremonies were carried out more frequently during the second half of the eighteenth century.

Other sources about weather phenomena

The most useful information found in ecclesiastical news refers to periods of excessive rainfall when religious events, such as processions, had to be postponed. In Évora there are numerous references to rainy spells in January, mostly with regards to the procession on St Sebastian's day (20 January) and sometimes previous and following weeks. The 'weather' was important whenever it hindered the regular course of routine religious ceremonies, and this is the reason why it is mentioned at all in several ecclesiastical documents. For the LMM period, however, only two observations were found among the Minutes of the Chapter Edicts (*Acordãos do Cabido*) and from the Book of Memoirs and Records (*Livro de Lembranças e Assentos*), both from Évora.

Misericórdias sources

The *Misericórdias* were charitable institutions founded in the sixteenth century in Portugal by Queen Leonor (wife of Manuel I) at the time of the discoveries. They were set up in many towns and organized into brotherhoods (*confrarias* – groups of religious or secular Christians) with the aim of giving spiritual and material support to the local people. Each *Misericórdia* had its own church. All sort of important records were gathered in the Books of Minutes and Recollections (*Livros de Actas e Lembranças*): religious festivities organized by each *confraria*, food distribution, health care, etc. Weather information was sometimes appended to the description of the *Misericórdia* activities, and data referring to 1704 and from 1710 to 1715 was used.

Municipal sources

Several references to 'weather conditions' were found in municipal sources. The minutes of the Lisbon and Évora town halls (*Actas das Câmaras Municipais*) were used. As climatic paroxysms triggered the implementation of a number of measures aimed at attenuating their respective consequences, these sources have proved to be quite useful. Information about water shortage or poor-quality water, insufficient wheat production and decrease of milk or meat production was found in the Évora Town Hall minutes. In the Lisbon documents no weather-related information has been found for the Late Maunder Minimum. The information from Évora was carefully analysed and compared with the well-known historical facts. Reports on economic and social measures taken were used whenever its climatic causes were explicitly stated. When Portugal took part in the War of the Spanish Succession between 1705 and 1715, there was no wheat in Évora because most of it was sent to the battlefront, and consequently no data was extracted from the Évora Town Hall minutes for this period.

Methods

Climatic reconstruction

In order to reconstruct the climate during the LMM, we chose to adapt the methodology developed by Pfister (1988; 1995) and used by other researchers such as Barriendos (1994) and Glaser (1996). Each month was given an index according to available information. If sufficient proxy information (in a quantitative form) is available, the value of the indices concerning temperature and precipitation varies between a maximum deficit for a particular phenomenon (−3) and a maximum surfeit (+3), with the value 0 corresponding to months regarded as 'normal'. Index setting is a rather delicate task which, in the present case, depended on the intensity of the depicted consequences (qualitative information). Therefore, only the indices +1 (high temperature or heavy rainfalls) and −1 (cold weather or drought episode) were assigned to each month. When combined, these yield to seasonal values ranging from +3 to −3 and to annual indices from +12 to −12. The value 0 refers either to indications of normal conditions or absence of information. The lack of information very often means that the month was a normal one in view of the fact that the weather was not considered something to write about. However, it cannot be concluded that all the months for which no information exists were normal ones.

The indices were set independently for Lisbon (1680–1716) and Évora (1675–1715). On the basis of present-day climatic variability (Alcoforado, 1984; Maheras *et al.*, 1994) and through comparison of the 17 months for which there was parallel information for Lisbon and for Évora, an index was developed for southern Portugal based on the joint data for the two cities.

Available data

The detail of the monthly information, which was used for climate reconstruction is obviously not always the same. Some examples are given in Table 1. As can be noted, even one single source may give sufficient direct information concerning a month or several weeks. For the period 1675–1715, there are observations concerning hydric phenomena in 33% of the 480 months. From those, 83.8% of the data was obtained from one source, 15.2% from two different sources and 1% from three sources. When more than one source was available, no contradictions were found except on two occasions. In this case no information was considered. Out of the total set of months, 20% provide thermal data. In this case the only source of direct information was the diary of Manuel de Almeida (in Cabral, 1948). If we consider winter separately, then thermal data for 35% of the months is available.

Precipitation data is therefore more reliable, although interesting thermal information was extracted.

Temperature and precipitation reconstruction between AD 1675 and 1715

Temperature

The results for the LMM were compared with a recent reference period 1961–90. For this reference period, months were assigned −1 index, when their temperature and/or precipitation value was inferior to the mean −1 standard deviation. +1 corresponds to values superior to the mean +1 standard deviation.

With regard to the annual temperature index, there is a large difference between the percentage of 'normal' months between the LMM (81%) and the reference period 1961–90 (53%). We may therefore suppose that a lot of information is lacking and it is advisable not to draw any conclusions (Figure 1, right).

If, on the other hand, we consider winter (Figure 1, left) then there is only a 14% difference in the percentages of 'normal' months (67% for the LMM and 53% for 1961–90). In this case, we may analyse the graph and conclude that the LMM was colder: 28% of cold months during the LMM, against only 7% during the recent period. As stated before, most of the information we possess refers to cold winters (17 out of 40). Only for two years (out of 40) did we find references to mild winters (1699 and 1707; Figure 3). On the other hand, there is a higher percentage of 'warmer' months during the 1961–90 period than during the LMM (Figure 1).

Another fact that may confirm that there were very cold spells during the LMM is related to the presence of snowfall. In the 37 years spanned by the diary of Manuel de Almeida, snowfall in Lisbon is reported eight times (December 1680; January 1693, 1703, 1704, 1709, 1716; March 1684; April 1699) which shows a clear difference in relation to present conditions (only two snowfalls during the last 40 years, both in February 1954), and suggests that the 'feeling' of coldness, as expressed by the author, may be due to lower temperatures than those registered today, as well as to different synoptical patterns or higher frequency of circulation types that occur nowadays (Luterbacher, 1998). On 1 February 1954, for example, it snowed in Lisbon when there was a deep depression, centred at the east of the Iberian Peninsula; it was associated with a meridional circulation pattern (up to 500 hPa) and advention of a very cold and relatively unstable airmass. This particular synoptical situation will not be visible on the mean monthly pressure pattern reconstruction (Luterbacher *et al.*, in ADVICE Final Report, 1998; Luterbacher *et al.*, 2000), because the snow spells never lasted a sufficiently long time.

According to our sources, the 1680s were 'normal' except for the cold winters of 1681 and 1688 (Figure 2). Unlike other places in Europe, the years 1683/84 and 1684/85 were not particularly cold (or information is lacking). Nevertheless, there were some very severe cold spells in the 1690s (winters in 1692/93 and 1693/94; and springs in 1694 and 1698; Figure 3). According to Font Tullot (1988), this decade was the coldest of the 'Little Ice Age' in Spain. For this country, the severe winter of 1693/94 is mentioned by the aforementioned source, by Matute y Gaviria

Table 1 Listing of available data relative to four of the studied months

1 source: January 1703
Precipitation index: +1; temperature index: −1
1–20: cold weather, rain and snow; NW wind; 20–25: no rain. 25–31: cold and rain again, numerous floods (Almeida, in Cabral, 1948).

2 sources: January 1694
Precipitation index: −1; temperature index: −1
It was extremely cold in December 1693 and the weather was very cold and dry during the following year. It did not rain between mid-December 1693 and June 1694. The harvests were very poor and the people were hungry. In April and the following months, several rogation ceremonies took place in Lisbon (M. Almeida, in Cabral, 1948: 30–32). The spring dryness is confirmed in the Municipal sources of Évora, and the lack of winter rain may be inferred (*Actas da Câmara Municipal de Évora*, Vol. XXVII, Folio 11, 28/5/1694).

3 sources: January and February 1708
Precipitation indices: +1; no temperature indices
In Lisbon, there was no day without rain in January. In February and March it rained even more (Almeida, in Cabral, 1948: 65–66). From mid-December until the end of January it rained nearly every day and there were very frequent and intense floods, causing several damages (Silva, manuscript, 15 February 1708). Heavy rains continued to fall in February and March, causing numerous floods (Silva, manuscript, 20 and 29 February 1708). On 20 February, it was decided that special prayers to God should be made on account of the heavy rains in Évora (*Codices Eborensis Capituli* 14 VI).

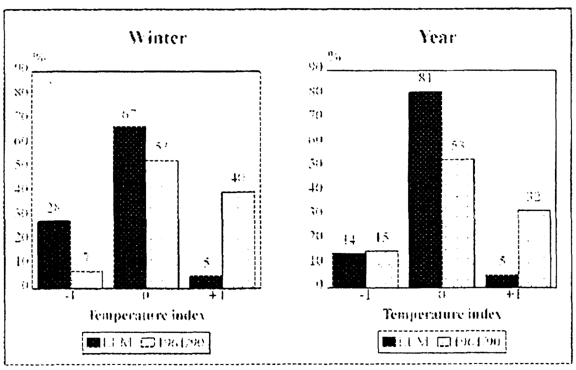

Figure 1 Temperature indices referring to the LMM and 1961–90 (southern Portugal).

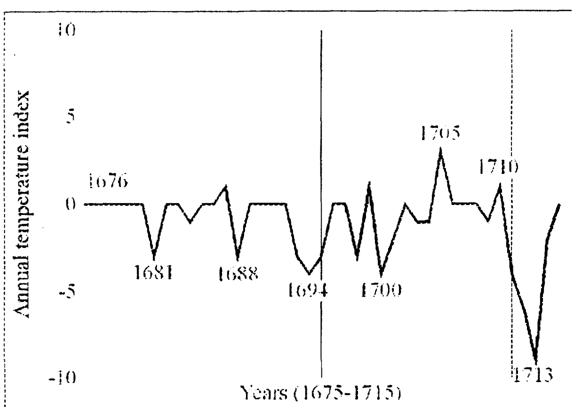

Figure 2 Annual temperature index for southern Portugal between 1675 and 1715 (see text for details).

(1886) and by Rodrigo (1996). According to Camuffo and Enzi (1994: 246), 1694 was a cold winter, but not one of the most severe in northern Italy, and the Venetian lagoons did not freeze (Camuffo, 1987).

The pressure patterns reconstruction (Luterbacher *et al.*, In ADVICE Final Report, 1998; Luterbacher *et al.*. 2000) showed that during the LMM the air pressure was frequently higher over NE Scandinavia, particularly in winter. This fact led to advection of cold and dry air towards central and southern Europe. The findings with regard to Portugal show that this cold advection also reached the most southwesterly parts of Europe. A good example

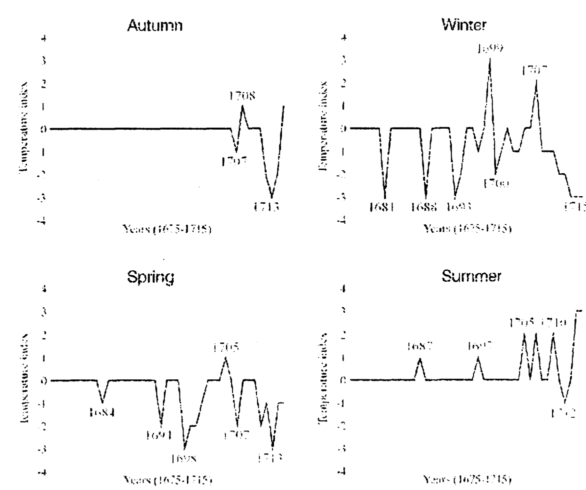

Figure 3 Seasonal temperature index for southern Portugal between 1675 and 1715 (autumn = September–November; winter = December–February, etc.).

of this occurred in January and February 1694, when an anticyclone centred over the Atlantic but spread over northern Europe causing NE flux towards southwestern Europe (this was a very dry period as well).

The main differences between Portugal and central Europe in winter exist towards the end of the LMM. After 1700, the cold period continued in Portugal, especially in 1700 and between 1711 and 1715, while further north and east the temperature rose (with the exception of 1709). According to pressure pattern reconstruction (Luterbacher *et al.*, in ADVICE Final Report, 1998; Luterbacher *et al.*, 2000), in some of the months (such as November 1707), an Atlantic anticyclone spread over Europe at the latitude of Portugal originating a continental eastern flow towards Portugal. Simultaneously a westerly air-flow occurred in western and northern Europe, causing relatively mild winters.

The coolest period of the LMM occurred earlier in central Europe (1690s) than in eastern Europe (beginning of the eighteenth century) (Pfister, 1994a: 296). In southwestern Europe the coldest period would have also occurred at the beginning of the eighteenth century. The winter temperature decrease in Portugal, particularly at the end of the LMM, is comparable with the one referred to by Serre-Bachet (1994: 271) at grid point 35°N–10°W (southwestwards from Portugal), 'where the cooling is recorded only from 1703'. Thus it seems that in southern Europe the greatest similarities occurred in places at the same longitude. More

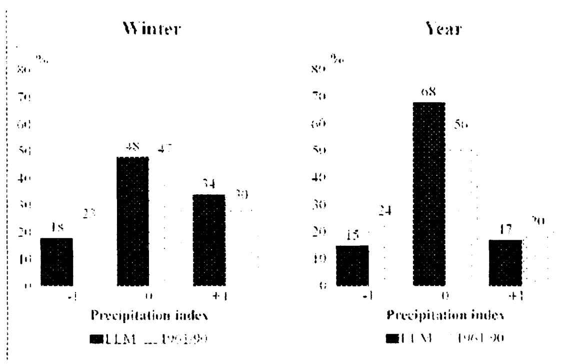

Figure 4 Precipitation indices referring to the LMM and 1961–90 (southern Portugal).

evidence is necessary to prove this, but we can suppose that even small longitude variations highly contributed to explain climate variability in southern Europe, owing to frequent meridional circulation.

During the LMM summers, a negative pressure anomaly occurred over the British Isles (Luterbacher, 1998; Luterbacher *et al.*, 2000). That means that strong westerlies were blowing towards western Europe, where low summer temperatures occurred. In southern Portugal there is hardly any recorded news about cool summer months (only June 1712) or about very hot summers, except: 1687 and 1697 (one hot month per year); 1705, 1707 and 1710 (two months per year); 1714 and 1715 (three hot months both years). During most of the LMM period, the limit of the perturbated western circulation might have been located northwards of the Iberian Peninsula, which could have been 'protected' by the Azores Anticyclone. During the two very long-lasting 1714 and 1715 summers, advection from the E and SE may have occurred.

Precipitation

There is more information relative to rainfall than temperature during the LMM. In this case, however, no large differences were found between the frequencies of dry and wet months between the two periods, as can be seen in Figure 4. In southern Portugal, the LMM was characterized by a great precipitation variability (Figure 5), as was the case in the eighteenth and early nineteenth centuries (Alcoforado *et al.*, 1997; and ongoing research) and during the subsequent instrumental period (Alcoforado, 1984).

Most of the winter months were wet or 'normal', except 1681, 1689, 1693 and 1694, as well as the last winters of the LMM: 1711–12 and 1714–1715 (Figure 6). Nowadays the precipitation variability in Lisbon is more dependent on the duration of the rainy season, i.e., rainfall in spring and autumn, than on rain intensity in winter (Alcoforado, 1984). That was also the case during the LMM. Hardly any information was found relating to the autumn in the first 15 years of the LMM, but after the drought of 1694 great interannual variability took place in autumn, with rainfall deficit periods also in 1697, 1700, 1707 and 1714–15. In spring, dry seasons were found to have occurred at the beginning of the series (1676, 1680), in 1694, in 1698 and at the end of the period.

According to our sources, there were frequent drought periods that occurred simultaneously with cold spells, in winter and early spring. Their synoptic causes are presented above.

If a winter drought continued into spring, then the consequences in agriculture and water shortage became significant. In 1694, the drought lasted from January 1693 until October 1694 (shortly interrupted by a 'normal' autumn in 1693) and there were rogation ceremonies in Lisbon. There can be no doubt of the water shortage. This drought occurred all over Portugal and in central and southern Spain (Toledo and Sevilla; Barriendos, 1997). In Italy there is reference to a dry year (Camuffo and Enzi, 1994: 246). The other long droughts of the LMM in Portugal were between March and June 1680, winter 1681, spring 1698, spring 1699, spring and autumn 1700, winter 1712 and between January 1714 and January 1716 (Figure 6). For a great part of the year 1714, the drought stretched from Portugal to Italy and to the eastern Mediterranean (Font Tullot, 1988; Barriendos, 1997; Camuffo and Enzi, 1994; Grove and Conterio, 1994).

In Portugal, summer is normally a dry season (1931–60 mean precipitation in Lisbon in July was 3.1 mm, and in August 4.3 mm). With only one exception in 1701 (Figure 6), no LMM summer rainfall excess is indicated in our sources; this was not the case further north in Europe. The reason is the same as the aforementioned one, which explains why temperatures were not particularly low: the westerlies do not seem to have affected Portugal in the summer. No precipitation deficit was inferred because of the lack of rain in July and August, as this is usual in southern Portugal.

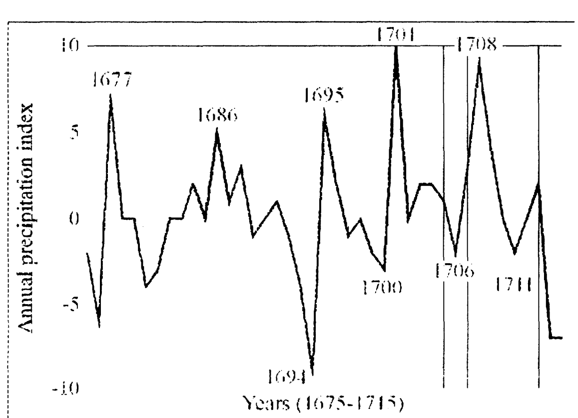

Figure 5 Annual precipitation index for southern Portugal between 1675 and 1715 (see text for details).

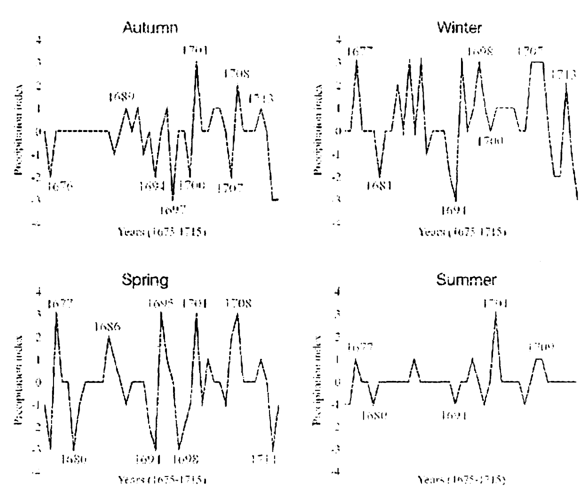

Figure 6 Seasonal precipitation index for southern Portugal between 1675 and 1715. (autumn = September–November; winter = December–February; etc.).

Discussion

The scarcity (or the absence of continuity) of data referring to the LMM from the different countries of the Mediterranean does not yet permit us to analyse quantitatively and systematically the main differences between them, as was done in a recent study where temperatures from Lisbon, Barcelona, Florence, Malta, Athens, and Jerusalem (1860–1990) were compared in order to identify anomalously warm and cold months in the Mediterranean basin (Maheras *et al*., 2000). The spatial distribution of the positive and negative thermal anomalies were explained in the light of the different circulation patterns in this area.

Nevertheless, on the basis of available information (Camuffo, 1987; Camuffo and Enzi, 1994; 1995; Le Roy Ladurie, 1983; Grove and Conterio, 1994; Barriendos, 1997; Serre-Bachet, 1994; Serre-Bachet *et al*., 1995), we may state that hot months or cold months on the one hand, and dry or humid months on the other, did not often coincide from the Iberian Peninsula to Italy, and even less so to Greece, during the LMM.

Meridional circulation originates normally greater weather differences within the Mediterranean than zonal circulation; but wave amplitude governs temperature and precipitation spatial variability. For example, in March 1700, according to sea-level pressure reconstruction (Luterbacher *et al*., in ADVICE Final Report, 1998; Luterbacher *et al*., 2000), a surface anticyclone produced a drought in Portugal and Spain (Barcelona, Girona and Toledo annual values in Barriendos, 1997), while a deep surface depression induced heavy rainfall in northern Italy (Camuffo and Enzi, 1994: 246–47). It probably also rained in southern France, because Grove and Conterio (1994) state that the olive production was spoiled and Le Roy Ladurie (1983) writes that the vine harvest was six days late. Northeasterly airflow caused cold weather and snowfall in the eastern Mediterranean, including a great deal of snow in Crete (Grove and Conterio, 1994).

Zonal circulation is more prone to originate weather similarities within the Mediterranean. By western circulation, rainy weather occurs in Portugal and Spain, sometimes also in southern France and Italy. Winter temperatures will then be high all over the Mediterranean (Maheras *et al*., 2000). Eastern circulation often generates dry weather, cold in winter and hot in summer. Maheras *et al*. (2000) verified that in winter when the cold air, proceeding from northeast Europe, moves along the southern flank of a large anticyclone oriented E–W, from Jerusalem to Lisbon, then negative thermal deviations to the mean occur all over the Mediterranean (Maheras *et al*., 2000: Figure 11b). In January 1714, a somewhat similar situation may have occurred, as confirmed by sea-level pressure reconstruction (Luterbacher *et al*., in ADVICE Final Report, 1998). Cold weather and drought were recorded for Portugal, northern Spain (data for 1714 as a whole in Barriendos, 1997) and eastern Mediterranean. This was 'possibly the most severe and widespread winter drought (. . .) affecting the whole region from central and southern Greece to the Black sea area' (Grove and Conterio, 1994: 275). The presence of a blocking high covering large areas of Europe explains that the drought was also recorded in Bohemia and Moravia (Brázdil *et al*., 1994), England (Siegenthaler, 1994), Germany (Glaser *et al*., 1994) and Switzerland (Pfister, 1994b).

January 1709 is a month which deserves further study, as it was extremely cold in a large part of western and central Europe (Pfister *et al*., 1994). 'In many parts of Europe this may have been the coldest winter month within the last five hundred years' (Pfister *et al*., 1994: 345). January 1709 was also extremely cold in the western and central Mediterranean: there is evidence referring to Lisbon, Seville (Palomo, 1984), Girona (manuscript from Constans), southern France (Le Roy Ladurie, 1983), northern Italy (Camuffo, 1987; Camuffo and Enzi, 1994: 246–47) and former Yugoslavia. The lagoons of Venice and the river at Girona froze and allowed the crossing of people (Girona) and of carriages and artillery (Venice). Palomo writes about an 'unusually cold winter' in Seville. It snowed in Lisbon, Girona and Venice. The cold paroxysm took place during the first decade of January. Lachiver (1991, quoted by Pfister *et al*., 1994) writes that the advection of Arctic air progressed across France, from north to south, from 5 to 7 January. These results tie in with our sources, where it is clear that the cold wave began on the 6th in Venice and southern France, on the 7th in Girona and on the 8th in Lisbon, showing that the cold airmass also progressed across the Pyrenees. The cold wave lasted three weeks in Portugal, Catalonia, France and northern Italy.

We may suppose there was a large planetary ridge on the Atlantic, giving rise along its eastern border to northerly (or northeasterly) winds in western Europe (including western and central Mediterranean areas). This interpretation is partially supported by the surface pressure reconstruction for January 1709 (Luterbacher *et al*., in ADVICE Final Report, 1998) in which there is also a low over central Italy (and probably a valley on the upper levels of the troposphere). This would explain the instability which gave rise to snowfall. However, as the weather was not homogeneous throughout the whole month, a more detailed pressure reconstruction will be necessary to fully understand this cold wave, which does not seem to have progressed further east. According to Grove and Conterio (1994), there is no evidence of cold weather in the eastern Mediterranean and more specifically in Greece in January 1709.

In February and March, neither very cold weather nor snow were reported in Portugal, unlike further north in Europe and Italy where all the winter months were very cold and snowy (Camuffo and Enzi, 1994: 246). This was probably due to a different relative position of the anticyclone over the Atlantic and the direction of the airflow, that arrived from the west in Portugal, according to the surface pressure reconstruction (Luterbacher *et al*., in ADVICE Final Report, 1998). However, as stated above, these maps represent monthly means and a study based on daily data would be very interesting, considering that this period represents a very cold spell during the already warmer period in northern Europe (Glaser *et al*., 1994).

Conclusion

The LMM was rather a cold period in Portugal at least after 1693 and particularly in winter and spring. During the 1690s the cold spells coincided with those of central, western and southern Europe, when strong high-pressure centres occurred over northern Europe. In the early 1700s, when temperature was already rising in other places, such as England (Manley, 1974) and central Europe (Pfister, 1994a), there were still some very cold winter months in southern Portugal (with relation to Portuguese standards). The early 1700s also represent the coldest period at grid point 35°N–10°W, southwestwards from the Algarve (Serre-Bachet, 1994). Some of the cold months in Portugal occurred during westerly circulation in central Europe, northwards from an anticyclone which originated cold eastern air flow towards the Iberian Peninsula. However, the lack of data for a longer period does not permit us to state whether the LMM cooling in southern Europe was exceptional or not. According to Serre-Bachet (1994), 'as far as these reconstructions, mainly based on tree-rings, are reliable (. . .), the Maunder Minimum cooling was not exceptional in comparison with other cool episodes' (p. 273).

Precipitation interannual variability is similar to the present one. Even during the present decade, very dry years have alternated with others with excessive rainfall (1996–97 and 1997–98). Rogation ceremonies were a rarity during the LMM, and their number increased during the eighteenth century (Taborda, oral information) which confirms the 'normality' of precipitation interannual variability of the LMM. Subsequent to heavy rains, great material damages and even loss of life in the LMM are referred to in our sources. Nowadays, the consequences of heavy rainfalls in Portugal seem to be getting worse and worse; but this is also due to the human choice of land use (construction near – or in – dry valleys, river channelling, deforestation). In November 1997, there were deaths and severe damage in the Alentejo (the region where Évora is located) due to flash floods, with a recurrence period of 50 or 100 years and subsequently forgotten by the following generations. However, those extreme weather events are a normal characteristic of a Mediterranean climate and cannot be directly attributed to 'global climate change'.

The latitudinal influence and the consequent exposure to western circulation (either anticyclonical or pertubated) or eastern airflux is not the only key to explain the similarities or differences in thermal or hygric excesses within the Mediterranean area. The present study and Maheras *et al.* (2000) confirm that 'the interest lies in the discontinuity of climatic conditions in the two halves of the Mediterranean basin' (Grove and Conterio, 1994: 284), but they also show that spatial variability is more nuanced than that, given that meridional circulation is responsible for greater spatial weather differences than just east–west contrasts. More data and joint research will be necessary in order to achieve an understanding of climate teleconnections within the Mediterranean area as well as of its historical climate change.

Acknowledgements

The study was carried out with the support of the ADVICE project (CE ENV4-CT95-0129-PL951090). The authors are particularly indebted to Professor Heinz Wanner, who suggested their participation in the ADVICE project, Professor Christian Pfister for the stimulating and useful discussion about this topic, Professor Dario Camuffo for sending several papers referring to Italy, Dr Mariano Barriendos for sending us unpublished information and data from Matute y Gaviria, Palomo and Constans, PAGES for financing a trip to a very productive meeting in Barcelona as well as the referees for their pertinent suggestions.

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