Climatic Change (2014) 126:107–118
DOI 10.1007/s10584-014-1201-5

The climate in Zafra from 1750 to 1840: history and description of weather observations

M. I. Fernández-Fernández · M. C. Gallego · F. Domínguez-Castro · R. M. Trigo · J. A. García · J. M. Vaquero · J. M. Moreno González · J. Castillo Durán

Received: 19 January 2014 / Accepted: 2 July 2014 / Published online: 14 July 2014

Abstract Weather observations in Zafra during the period 1750 to 1840 have been compiled and studied. Zafra was the capital of the Duchy of Feria, located in the southwest of the Iberian Peninsula. The documentary sources used in this work are weekly reports submitted to the Duke (who lived in Madrid) that contain a section describing the weather of the preceding week or less. Regular and updated meteorological information was vital to the government of this Duchy as farming and ranching constituted the bases of the economic activity in this region, allowing the estimation of crop yield and quality and a better management of the trade of agricultural products. Therefore, this documentary source is exceptional to study the climate of SW Iberia due to its continuity, homogeneity and high temporal-resolution.

1 Introduction

During the last decades there has been a large increment in the research of the climate of the past in southern Europe (Luterbacher et al. 2012; Barriendos and Llasat 2003; Diodato 2007). However, in western Iberia the virtual lack of instrumental data prior to the mid-19th century implies that the retrieval of past climate information must be necessarily obtained from natural proxies (such as trees rings) and documentary sources (such as manuscripts, printed materials or pictures) (Brázdil et al. 2005, 2010).

Electronic supplementary material The online version of this article (doi:10.1007/s10584-014-1201-5) contains supplementary material, which is available to authorized users.

M. I. Fernández-Fernández · M. C. Gallego · F. Domínguez-Castro · J. A. García · J. M. Vaquero (✉)
Departamento de Física, Universidad de Extremadura, Extremadura, Spain
e-mail: jvaquero@unex.es

F. Domínguez-Castro
Departamento de ingeniería Civil y Ambiental, Escuela politécnica Nacional, Quito, Ecuador

R. M. Trigo
IDL-CGUL, Universidade de Lisboa, Lisbon, Portugal

J. M. M. González · J. C. Durán
Centro de Estudios del Estado de Feria, Feria, Spain

Research efforts for the study the climate of the past in Iberia using documentary sources have been mainly focused over Catalonia (northeast Iberian Peninsula) (Barriendos and Martín-Vide 1998) and Andalusia (southern Iberian Peninsula) (Rodrigo et al. 1995, 2012; Rodrigo and Barriendos 2008). However, in the last years we can find other works focused in other regions of Iberia, such as Alcoforado et al. (2000) that reconstructed the temperature and precipitation in southern Portugal during the Late Maunder Minimum (1675–1868). Other authors have looked into the entire Mediterranean basin, such as Camuffo et al. (2010) published temperature reconstruction in the Mediterranean area over the last 500 years combining documentary data and early instrumental observations. Recently, early precipitation instrumental series covering the last 300 years over the Western Mediterranean, including Iberia, were analyzed by Camuffo et al. (2013).

Moreover, some specific studies assessing droughts in Spain from historical documents have been published (Martín-Vide and Barriendos 1995; Domínguez-Castro et al. 2008, 2012, 2014a) and early meteorological readings have been recovered (Alcoforado et al. 2012; Domínguez-Castro et al. 2013a, b). However, to the best of our knowledge, the historical climate in western Spain (especially Extremadura region) has received little attention until now. It should be noted that this region is strongly influenced by the North Atlantic Oscillation (e.g. Trigo et al. 2004) and increasingly prone to major droughts such as the recent events in 2004/2005 (Garcia-Herrera et al. 2007) and 2011/2012 (Trigo et al. 2013). Additionally, the Iberian Peninsula is part of the Mediterranean region that is considered a major hot spot under climate change (Giorgi 2006), with an increased frequency of major heatwaves (Fischer and Schär 2010 and droughts (Hoerling et al. 2012) that are expected to occur in the 21th century. Therefore, the possibility to increase the temporal length of climate related time series of this region is very interesting, as it allows putting into a much longer context the occurrence of climatic extreme events (e.g. floods, drought and heatwaves) in the recent past or in the coming decades.

Up to our knowledge, in southern Europe investigations performed from non-instrumentals historical sources are mainly focused to study hydro-climatic extremes (e.g. droughts and floods), while few papers have been devoted to study temperature variability and extremes from historical documentation (Bullón 2008; Camuffo et al. 2010; Alcoforado et al. 2000; Domínguez-Castro et al. 2014b). In this context, it is particularly interesting the description of the early weather observations in the Duchy of Feria (southwest Spain) in the period 1750–1840.

2 The Duchy of feria

2.1 Location and history

During the Middle Age, the Duchy of Feria was one of the most important secular States of Extremadura, located in the southwest of Spain. The Duchy of Feria consisted of sixteen municipalities located in two separate geographical areas (Fig. 1). The main region was formed by fourteen of these municipalities and the smallest region was composed by the remaining two. As other states, the Duchy of Feria has its origin in the family Suárez de Figueroa, at the end of the 14th century and early of the 15th century, under Spain´s King Enrique III. The family Suárez de Figueroa comes from Galicia (northern Spain) and was the most important noble family which settled in the southern Extremadura due to the enormous dimensions of the state and the importance in the history of Extremadura and Spain (Valencia Rodríguez 2010). The date of incorporation of the different municipalities to the Duchy of Feria is shown in

Fig. 1. Zafra was the capital of the Duchy of Feria and is located in the southwest Spain (38°25'N, 6°25'W) at 508 m above sea level (Fig. 1). Its climate is classified as Köppen type Csa (mild and relatively wet winter with a long dry and hot summer) according to the recent high-resolution Iberian Climate Atlas (AEMET-IM 2011). The average winter monthly temperature (December-January-February) is 8ºC and the summer (June-July-August) monthly temperature is 25ºC. Regarding the precipitation regime, this varies substantially between the wet winter with a monthly average of 80 mm and the dry summer with a monthly average of 15 mm.

2.2 Framework and management of Duchy of Feria

The Duke of Feria lived in Madrid, the Capital of Spain, but he established in 1741 an administrative network, with capital in Zafra, for the management of his properties in the region. A Zafra Accountant informed every week to the Main Accountant, located in Madrid, about events in the Duchy of Feria. For the management of the different locations there were Butlers.

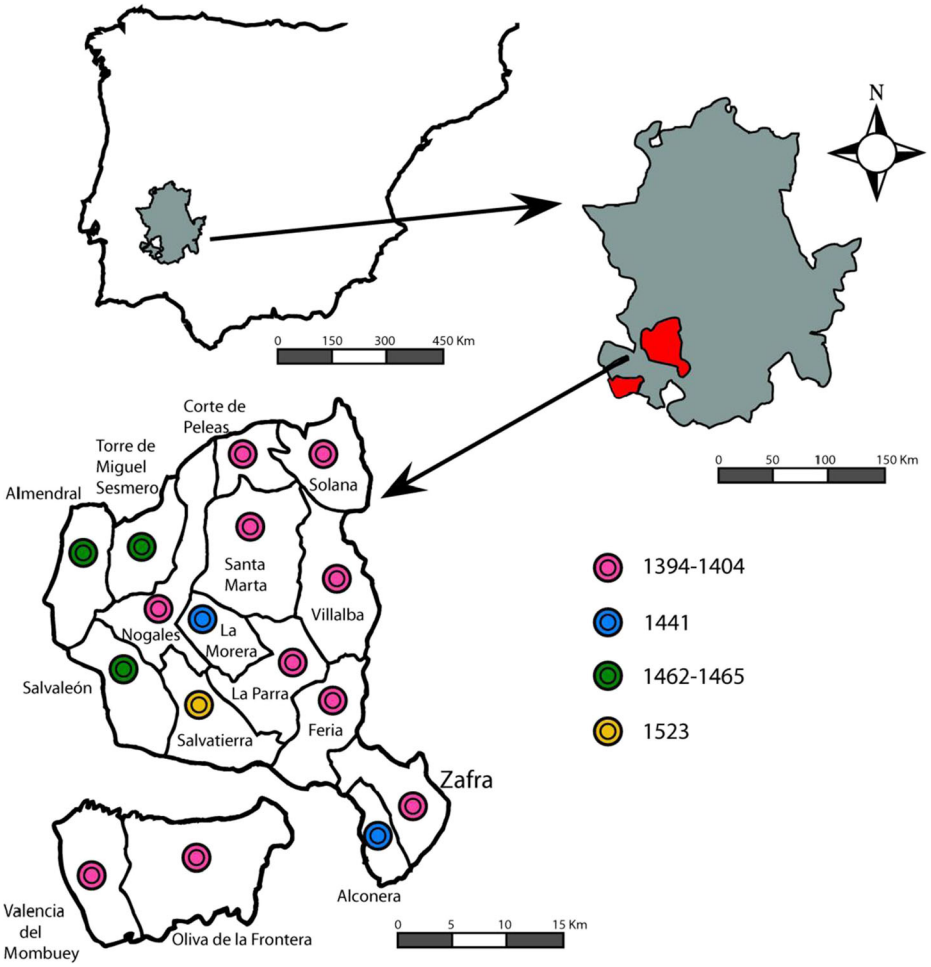
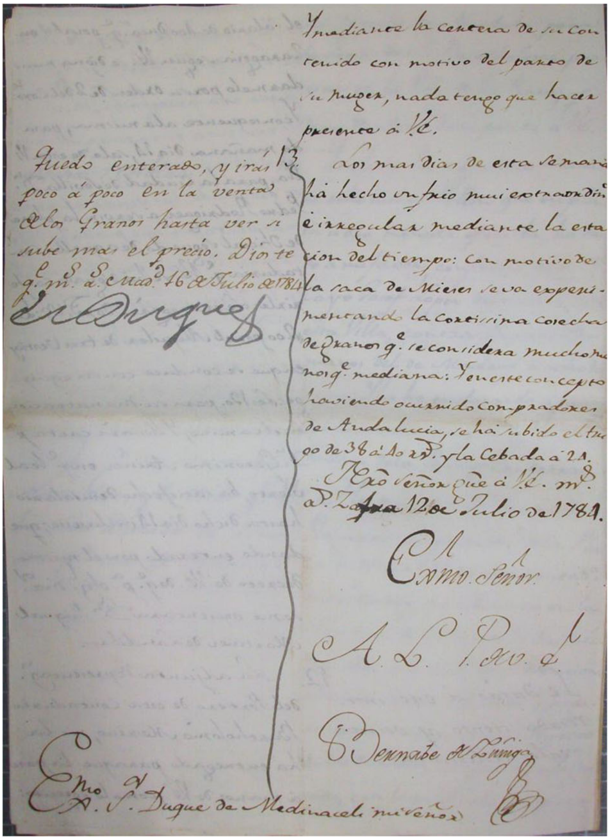


Fig. 1 Duchy of Feria in the second half of the 18th century. Formation of Duchy of Feria

The local guards and employees gave information about different subjects to the corresponding Butler who would then send this information to the Accountant in Zafra. As soon as possible the Accountant would write and send periodically the "*Consultas*" (Consultations) to the Main Accountant in Madrid. Among the topics covered in the "*Consultas*" appeared news about the crops conditions, information related with the observed weather, and the price of cereal grains and other products. The weather was especially relevant for the Duke in two distinct ways. On the one hand, most crop productions in the Duchy (cereals, olive oil and wine) could not rely on irrigation, therefore appropriate weather conditions were crucial to guarantee good crop yields as it is still the case in western Iberia for non-irrigated crops such as cereals (e.g. Gouveia and Trigo 2008) wine (Gouveia et al. 2011) and olive oil (Santos et al. 2007). On the other hand, the agricultural production (from the Duchy and other states) must be shipped to the larger city markets, including Madrid, where the price achieved would follow the rules of supply and demand. Finally, in a time without good roads, neither train, the transportation of crop productions took several weeks and could be seriously hampered by persistent poor weather conditions (intense precipitation, floods, frost, strong winds, but also by droughts and heatwaves). In a nutshell weather conditions would affect crop production, but also subsequent transportation and management, all of which would be reflected in purchase and sale of cereal grains and other products from Madrid (Barquín 2012). Fig. 2 shows an example of the "*Consultas*", these were written in the right half of a sheet. The Duke replied in the left half and the documents were sent back to Zafra.



Quedo enterado, y irás poco á poco en la venta de los Granos hasta ver si sube mas el precio. Dios te g. m. a. Mad. 16 de Julio de 1784

13

y mediante la certeza de su contenido con motivo del parto de su muger, nada tengo que hacer presente á V.E.

Los mas dias de esta semana há hecho un frio mui extraordin. é irregular mediante la estacion del tiempo: Con motivo de la saca de Mieses se va experimentando la cortissima cosecha de granos q. se considera mucho menos q. mediana: Y en este concepto haviendo ocurrido compradores de Andalucia, se ha subido el trigo de 38 á 40 rs. y la Cebada á 21.

Exmo. Señor que á V.E. m. a. Zafra 12 de Julio de 1784.

Exmo. Señor

A. L. P. de V.E.

Bernabe de Zuñiga

Exmo. Sr. Duque de Medinaceli mi Señor

Fig. 2 Document of July 12, 1784 with the "*Consulta*" written in the right margin of the sheet, and reply by Duke to the left margin

3 The documentary source

3.1 Origins of the documentary source and current condition of the collection

In the fifteenth century, when the Duke of Feria established the capital of his territory in Zafra, he also built a palace to accommodate his court. However, the Duke's visits to Zafra became less and less frequent, in such a way that his palace was occupied by the employees. All the documents generated by butlers and accountants were stored in this palace until 1920 when it was abandoned by the last administrator of the Duchy. In the second half of the twentieth century, when the palace was remodeled, the collection of documents was "re-discovered". Nowadays, these documents are preserved in a specific subsection of the Zafra Municipal Archive denominated "*Consultas y Decretos del Ducado de Feria*". This archive, situated in the current council of Zafra, has become one of the best in the region due to the richness of its funds.

3.2 Description of source

In the eighteenth century, the main source of income in southern Spain was related with ownership of large areas of land. Both farming and ranching were the basis of the economic activity in this region (Sánchez Gómez-Coronado 1993). Therefore, the knowledge of the weather conditions was essential to estimate the quality of the crops and to correctly manage the trade of cereals and other agricultural products, namely wine and olive oil. It is within this context that in August 1750 the Duke of Feria sent a decree-law in order to be kept informed about the weather conditions. The Accountant lived in Zafra, thus the meteorological information appearing in the documents mainly refers to this town that, to a large extent, can be considered representative of the weather in the region. Only on special occasions, generally when extreme events occurred, weather information from other locations was reported. Largest distance between localities of the Duchy of Feria is about 50 km and there are no important landforms. We have computed the correlation coefficients between monthly meteorological measurements in the period 1960–1990 in Zafra and other representative localities of Duchy of Feria. It was found that, the correlation coefficient of the precipitation series of Zafra and Salvaleón was 0.927 (p-value<0.0001) and for Zafra and Valencia del Mombuey was 0.891 (p-value<0.0001) (Fig. 1). For temperature series, the coefficient correlation of Zafra and Valencia del Mombuey is 0.997 (p-value<0.0001). Therefore, it is appropriate to state that the climate of Zafra is representative of this region (AEMET-IM 2011).

The weather information about Zafra is provided for 84 of the years between 1750 and 1840 (i.e. 84 out of 91). Therefore, this documentary source provides almost continuous weekly weather information covering nearly a century. Figure 3 shows the number of days per year with weather information. The green bars indicate the years than have more than 80 % of the days with reports available (63 of 84 years). The yellow bars correspond to the years with less than 80 % and more than 20 % of the days of the year with weather information. The years with less than 20 % of the days with available information are represented with red bars. There are two important gaps in the documentation: the decade of the 1760s and early 1770s and the period 1810–1814. The first gap in the series is due to the fact that the accountants only informed the Duke about economic matters in the Duchy of Feria. The second gap is due to the Napoleonic Wars in Iberia.

The "*Consultas*" are weekly during most of the years of the period 1750–1840. However, sometimes, these reports are more frequent. From April 1772 to July 1775, October, November and December 1780 and November 1835 had two reports per week. In any case this documentary source presents a high temporal resolution during all the period.

4 Weather observations

4.1 Weather reports from documentary sources

The weather observations were realized by different accountants along the period 1750–1840. If we analyze each decade, it can be observed that in the 1750s and 1760s decades, the weather descriptions were extensive and information about the harm or benefit caused by the weather on the crops and wheat prices are also provided in the reports. However, between 1751 and 1780 there are gaps in the wheat price series, after that, there is continuous information from January 1780 to January 1810. The price of the cereals and other grains can provide indirect information about the weather and the harvest. A bad harvest could increase the price of cereals and lead to a general crisis of subsistence. However, the price of cereals increases during periods of war in Iberia (Salazar Anuncibay 2005).

These reports contain extensive information about precipitation and temperature. Below, we show some weather reports as examples:

January, 21st 1782 "The weather is unsettled, with frequent cold mornings and at night". ["El tiempo sigue revuelto, pero con muchos fríos por la mañana y noche".]

April, 18th 1785 "The weather continues very nice for the crop fields with much appreciated light rains." ["Continúa el tiempo muy benigno a los campos cayendo algunas lluvias muy ligeras que es lo que necesitan".]

December, 26th 1785 "This week it has been raining in abundance". ["En esta semana ha llovido con mucha abundancia".]

August, 18th 1828 "The heat has returned in excess". ["Han vuelto con exceso las calores".]

All the weather descriptions have been transcribed into a document available for the researches as an electronic material supplementary to this article. Thus, from weather observation, annual percentage of reports that indicate rainfall and no rainfall in the period 1750–1840 have been calculated. Two wet periods have been identified (1782–1789 and 1799–1807). The first period has been also identified by Alcoforado et al. (2012) in Portugal (1784–1789) and Domínguez-Castro et al. (2013a) in Seville (1783–1786). Likewise, two dry periods (1796–1799 and 1816–1819) were identified. The drought of 1817 was the most

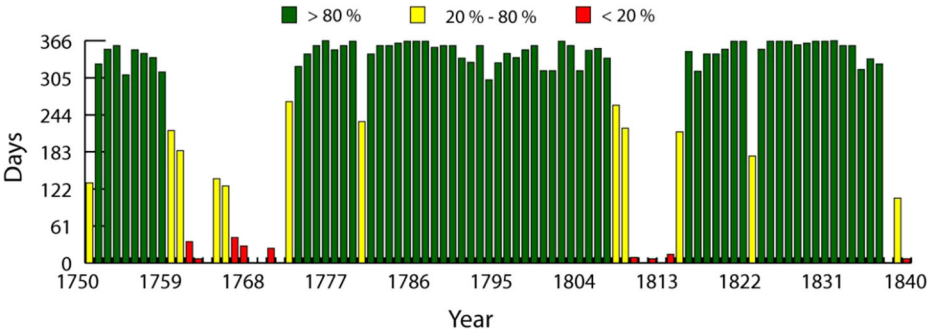


Fig. 3 Number of days with weather information in each year during the period 1750–1840

extended drought in Iberia during the period 1750–1850 (Domínguez-Castro et al. 2012). For temperature, the annual percentage of reports that indicate cold/warm days have been also obtained (see Fig. 4).

The "*Consultas*" also present information about dates of "pro-pluvia" rogations. These ceremonies "are a typical ritual of the Roman Catholic Church that was used in all the Spanish Empire to sight for the end of the Divine punishment of drought period" (Domínguez-Castro et al. 2008; Martín-Vide and Barriendos 1995). In Zafra, most of the rogations were carried out in spring except in 1804 when the rogation corresponds to autumn.

Figure 5 shows the monthly wheat price during the entire period. If we analyze the price of wheat between 1780 and 1810, we can observe that the lowest price appeared between 1781 and 1785. The highest prices appeared between 1804 and 1807. This latter feature could be due to the beginning of a war period in Iberia related with the Napoleonic wars. In general, it is very difficult to find a clear relationship between wheat and climate due to these other confounding socioeconomic features. Figure 5 also shows the dates of rogation (yellow bars) that are not continuous in time".

4.2 Meteorological measurements in Zafra

For some years of 1820s, instrumental data of temperature were recorded in Zafra by the Duchy´s accountant of Feria. Specifically, the meteorological records are referred to the years 1824 (only one record) 1826 (fourteen readings) and 1827 (fourteen readings). Temperature readings were taken with a thermometer with Reáumour scale. Unfortunately, metadata describing the methods and instruments are not available. Most of the meteorological observations only contain one daily measurement and the hour of the readings is unknown in general. Some reports contain two daily readings. These reports are: June 26, 1826; August 14,

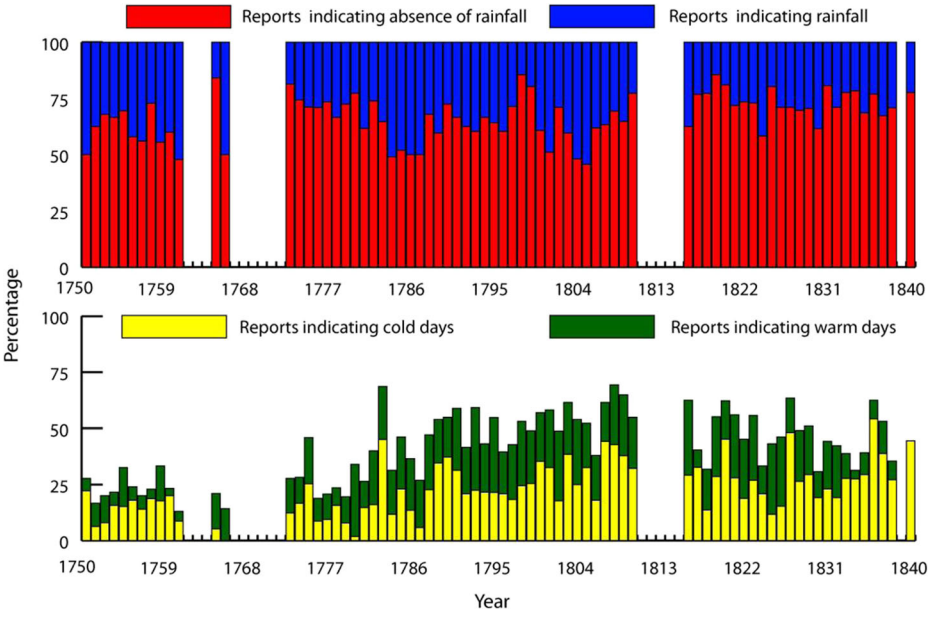


Fig. 4 Upper panel shows the annual percentage of reports without rainfall in Zafra (red) and reports indicating rainfall in Zafra (blue). Lower panel shows the annual percentage of reports indicating cold (yellow) and warm (green) days

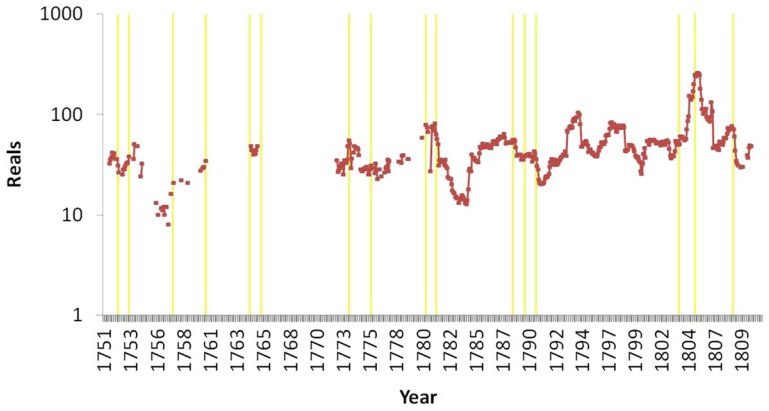


Fig. 5 Price of wheat (in Reals) and dates of pro-pluvia rogations (yellow bars) during the period 1750–1810

1826; July 2, 1827; and July 16, 1827. Information about measurements conditions is only provided for August 14, 1826 (43.75° Celsius in the sun-light and 31.25° Celsius in the shade). Fig. 6 shows the time evolution of daily temperature record. The daily average of temperature in Zafra in the period 1960–1990 is represented in black while the corresponding daily maximum and minimum values for the same period are represented in grey. Red points represent the observed temperature values in the years 1826 and 1827. For the reports which present two daily measurements, the maximum values are plotted in red and minimum value in blue, except for the very hot day of August 14, 1826, where yellow and green points represent the maximum and minimum temperatures. All temperature values observed in 1826 and 1827, except August 14, 1826 and April 9, 1827 appear between the maximum and minimum values of the reference period 1960–1990. Most of the values observed in summer exceed the average values while the values observed in winter are below the average values.

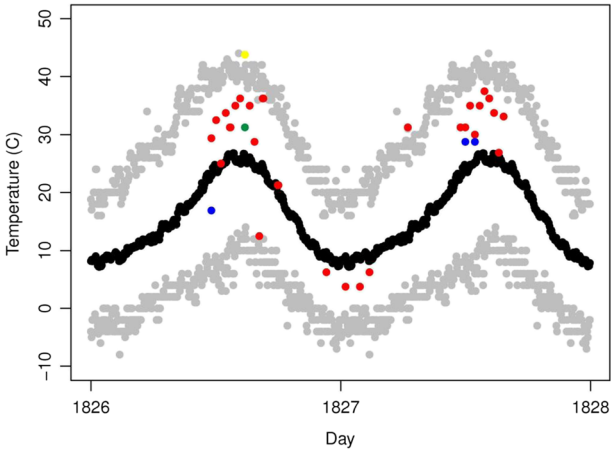


Fig. 6 Daily temperature in the years 1826 and 1827 (red). The second readings on June 26, 1826; July 2, 1827; and July 16, 1827 are represented in blue. Yellow and green points represent the maximum and minimum temperature on August 14, 1826. Black points represent the average of temperature in Zafra for each day in the period 1960–1990 and grey points the maximum and minimum values for the same period

4.3 Other meteorological phenomena observed in the weather observations

In the analyzed reports of the Duchy of Feria were recorded descriptions of other relevant meteorological events such as snowfalls, hails, storms and frosts. During the studied period some well know external drivers of climate took place, including the Dalton minimum of solar activity (Vaquero 2007) and the large eruptions of Lakigar (Thodarson and Self 2003) and Tambora (Stothers 1984; Trigo et al. 2009). This could affect to the occurrence of these meteorological phenomena. Figure 7 (left column) shows, for the period 1750–1840, the number of weeks in each year in which it snowed, it hailed, there were storms, and it froze. This figure (right column) also shows the percentage of years that present different meteorological events in the period 1750–1840 and for a modern period (1960–1990). This allows to compare the ancient and current epochs in terms of the occurrence of these meteorological events. These meteorological events may have a major influence on crops, although this will be determined by the epoch of year when they occur. Additionally, these hazardous weather phenomena may also have an important impact on transportation. Note that, it was impossible to construct daily series of such meteorological events due to that the weekly weather reports sometime do not indicate the number of days in each week in which it snowed, it hailed, there were storms and it froze.

According to Figure 7 top panel, there were reports of snow for 29 of the 84 years in the documents. The accountant recorded two years with several weeks with snow, namely in 1774 and 1832 (3 weeks per year). In the period 1750–1799, the accountant recorded 14 years with snowfall. However, between 1800 and 1840 15 years with snowfall were recorded. As expected, the months in which most snow weeks occur in the period 1750–1840 were January and February. However a few cases of snow weeks in March and April were also observed. It is interesting to note that a snowfall was recorded on 4 February of 1827 in Cadiz (Gallego et al. 2007), Madrid (Domínguez-Castro et al. 2013a) and Zafra (this work). If we compare the current period (1960–1990) with the period 1750–1840, one can observe that in the period 1750–1840 there are several years with three weeks with snow (2.38 % of the years). However, in the period 1960–1990 there are no years with two and three week with snow.

From 1750 to 1840, 17 years with hail were recorded. The years that recorded the largest number of weeks with hail were 1804, 1831, 1836 and 1837 (2 weeks per year), being more frequent in summer and spring. Most of the years (up to 80 %) do not present any week with hail. In the current period there are many more years with 1 or more weeks with hail. The average number of weeks per year in spring with hail in the period 1960–1990 was 1.23 weeks per year while for the historical period from 1750 to 1840 was less than 1 week.

There were 37 years with thunderstorm reports in the period 1750–1840. The months when thunderstorm records were more frequent were June, July and September. 1803 and 1825 were the years in which the accountant recorded the largest number of weeks with thunderstorms (6 weeks per year). However, for the current climate period there are years which present up to 13 weeks with thunderstorms. The average number of weeks per year with thunderstorm during the period 1750–1840 was 1.03 and in the period 1960–1990 was considerably higher (4.94). It is particularly remarkable that, in general, there are few hails and thunderstorms reported by Duchy´s accountant during the period 1750–1840. This could be due to that these meteorological events had small or no impact on the crops (e.g. some summer thunderstorms). A similar situation is observed in Cadiz during the first half of the 19th century (García-Herrera 2008).

Finally, the years of most weeks with frost were 1802, 1806, 1807, 1816, 1820 (7 weeks per year) and 1822 (with 8 weeks). Frosts usually appear in winter months. Nevertheless, frosts also were recorded in March 1801, 1807, 1814, 1820 and 1822, in April 1807, 1828 and 1837 and May 1827. The current period presents one year with 13 weeks with frosts. Again, this

mismatch could be due to the fact that the accountant considered the frost typical of winter months. So, this meteorological event went unreported in the "*Consultas*".

5 Conclusions

In recent decades, there have been many works on climate variability from documentary sources in Spain. Most works have been biased towards Andalusia (southern Spain) and

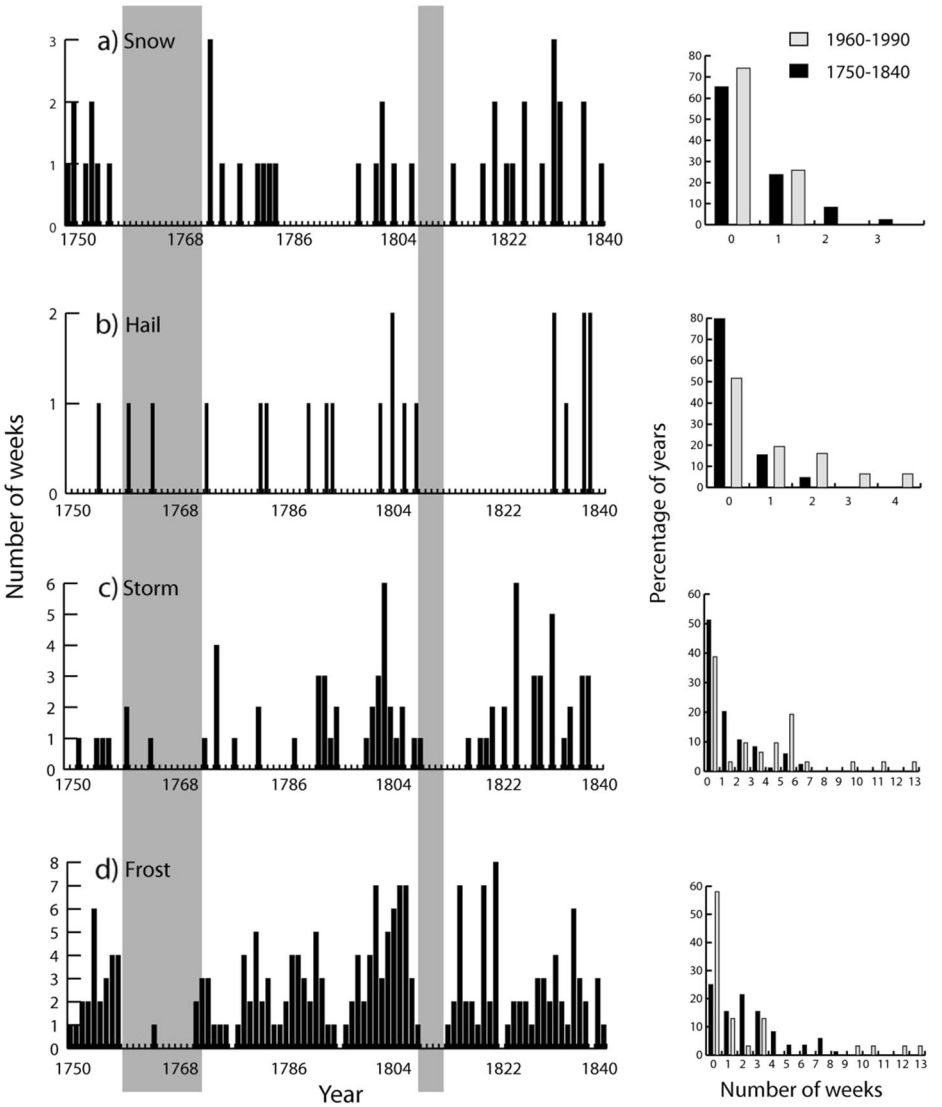


Fig. 7 Left panel shows **a** number of weeks with snowfall, **b** number of weeks with hail, **c** number of weeks with thunderstorms, and **d** number of weeks with frost for the period 1750–1840. Grey columns show the periods with few or without records (1760s and early 1770s and 1810–1814). Right panel shows the percentage of years that presents different meteorological events in the period 1750–1840 (black) and the current period (1960–1990) (grey)

Catalonia (northeast Spain). However, the historical climate in western Spain has received scarce attention. We have here presented the early weather descriptions in Zafra (southwest Spain) relative to the period 1750–1840 using documents related to the administration of the Duchy of Feria. These documents are conserved in a specific section denominated "*Consultas y Decretos del Ducado de Feria*" of the Municipal Archive of Zafra. This unusual source of information improves the knowledge about the climate of the past in the southwest Iberian Peninsula. The weather reports present high temporal resolution as they were usually dispatched on a weekly basis and they cover nearly one century, almost devoid of any meteorological measurements in the region. In addition, these reports present the early meteorological measurements in Zafra in 1826–1827 which increase the available meteorological data for the first half of the 19th century. On the other hand, this documentary source contains information about wheat price which help to provide information about the weather and detailed descriptions of meteorological events as hail, frost, thunderstorm and snowfall. In summary, here we have presented the first long-term weather descriptions available in the southwest Spain from 1750 to 1840 in order to improve the knowledge about past climate variability and extremes.

Acknowledgements Support from the Junta de Extremadura (Research Group Grant No. GR10131) and FCT (Klimhist, PTDC/AACCLI/119078/2010) are gratefully acknowledged. Fernando Domínguez-Castro was partially supported by the Prometeo Project, Secretariat of Higher Learning, Science, Technology and Innovation (Ecuador Government).

References

AEMET-IM (2011) Iberian Climate Atlas.Agencia Estatal de Meteorología y Instituto de Meteorologia, Madrid

Alcoforado MJ, Nunes MF, García JC, Taborda JP (2000) Temperature and precipitation reconstruction in southern Portugal during the late Maunder Minimum (AD 1675–1715). The Holocene 10:333–340. doi:10.1191/095968300674442959

Alcoforado MJ, Vaquero JM, Trigo RM, Taborda JP (2012) Early Portuguese meteorological measurements (18th century). Clim Past 8:353–371. doi:10.5194/cp-8-353-2012

Barquín R (2012) Analysis of Spanish regional wheat prices (1765–1855). Historie & Mesure XXVI: 77–104

Barriendos M, Llasat MC (2003) The case of the "Malda" anomaly in the western Mediterranean basin (ad 1760–1800): an example of a strong climatic variability. Clim Chang 64:191–216

Barriendos M, Martín-Vide J (1998) Secular climatic oscillations as indicated by catastrophic floods in the Spanish Mediterranean coastal area (14th-19th centuries). Clim Chang 38:473–491

Brázdil R, Pfister C, Wanner H, von Storch H, Luterbacher J (2005) Historical climatology in Europe-the state of the art. Clim Chang 70:363–430. doi:10.1007/s10584-005-5924-1

Brázdil R, Dobrovolný P, Luterbacher J, Moberg A, Pfister C, Wheeler D, Zorita E (2010) European climate of the past 500 years: new challenges for historical climatology. Clim Chang 101:7–40. doi:10.1007/s10584-009-9783-z

Bullón T (2008) Winter temperatures in the second half of the sixteenth century in the central area of the Iberian Peninsula. Clim Past 4:357–367

Camuffo D, Bertolin C, Barriendos M et al (2010) 500-year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations. Clim Chang 101:169–199. doi:10.1007/s10584-010-9815-8

Camuffo D, Bertolin C, Diodato N et al (2013) Western Mediterranean precipitation over the last 300 years from instrumental observations. Clim Chang 117:85–101. doi:10.1007/s10584-012-0539-9

Diodato N (2007) Climatic fluctuations in southern Italy since the 17th century: reconstruction with precipitation records at Benevento. Clim Chang 80:411–431. doi:10.1007/s10584-006-9119-1

Domínguez-Castro F, de Miguel JC, Vaquero JM, Gallego MC, García-Herrera R (2014a) Climatic potencial of Islamic chronicles in Iberia: extreme droughts (AD 711–1010). The Holocene 24(3):370–374. doi:10.1177/0959683613518591

Domínguez-Castro F, Ramos AM, García-Herrera R, Trigo RM (2014b) Iberian extreme precipitation 1855/1856: an analysis from early instrumental observations and documentary sources. Int J Climatol. doi:10.1002/joc.3973

Domínguez-Castro F, Santisteban JI, Barriendos M, Mediavilla R (2008) Reconstruction of drought episodes for central Spain from rogation ceremonies recorded at the Toledo Cathedral from 1506 to 1900: A methodological approach. Global Planet Change 63:230–242. doi:10.1016/j.gloplacha.2008.06.002

Domínguez-Castro F, Ribera P, García-Herrera R et al (2012) Assessing extreme droughts in Spain during 1750–1850 from rogation ceremonies. Clim Past 8:705–722. doi:10.5194/cp-8-705-2012

Domínguez-Castro F, Vaquero JM, Rodrigo FS et al (2013a) Early Spanish meteorological records (1780–1850). Int J Climatol. doi:10.1002/joc.3709

Domínguez-Castro F, Trigo RM, Vaquero JM (2013b) The first meteorological measurements in the Iberian Peninsula: evaluating the storm of November 1724. Clim Chang 118:443–455. doi:10.1007/s10584-012-0628-9

Fischer EM, Schär C (2010) Consistent geographical patterns of changes in high-impact European heatwaves. Nat Geosci. doi:10.1038/NGEO866

Gallego D, García-Herrera R, Calvo N, Ribera P (2007) A new meteorological record for Cádiz (Spain) 1806–1852: Implications for climatic reconstructions. J Geophys Res 112, D12108. doi:10.1029/2006JD008272

Garcia-Herrera R, Paredes D, Trigo RM et al (2007) The outstanding 2004–2005 drought in the Iberian Peninsula: the associated atmospheric circulation. J Hydrometeor 8:483–498

García-Herrera R (ed) (2008) El clima de Cádiz en la primera mitad del siglo XIX según los partes de Vigía. Fundación Unicaja, Málaga

Giorgi F (2006) Climate change hot-spots. Geoph Res Lett 33, L08707. doi:10.1029/2006GL025734

Gouveia C, Trigo RM (2008) Influence of climate variability on wheat production in Portugal. In: Soares A, Pereira MJ, Dimitrakopoulos R (eds) Quantitative geology and geostatistics: geoENV VI—geostatistics for environmental applications. Springer, Dordrecht, pp 335–347

Gouveia C, Liberato MLR, DaCamara CC, Trigo RM, Ramos AM (2011) Modelling past and future wine production in the Portuguese Douro Valley. Clim Res 48:349–362

Hoerling M, Eischeid J, Perlwitz J, Quan X, Zhang T, Pegion P (2012) On the Increased Frequency of Mediterranean Drought. J Clim 25:2146–2161. doi:10.1175/JCLI-D-11-00296.1

Luterbacher J, García-Herrera R, Akcer-On S et al (2012) A review of 2000 years of paleoclimatic evidence in the Mediterranean. In: Lionello P (ed) The Climate of the Mediterranean region: from the past to the future. Elsevier, Amsterdam, The Netherlands, pp 87–185

Martín-Vide J, Barriendos M (1995) The use of rogation ceremony records in climatic reconstruction: a case study from Catalonia (Spain). Clim Chang 30:201–221

Rodrigo FS, Barriendos M (2008) Reconstruction of seasonal and annual rainfall variability in the Iberian Peninsula (16th-20th) from documentary data. Global Planet Change 63:243–257. doi:10.1016/j.ploplacha.2007.09.004

Rodrigo FS, Esteban-Parra MJ, Castro-Díez Y (1995) Reconstruction of total annual rainfall in Andalusia (southern Spain) during the 16th and 17th centuries from documentary sources. Theor Appl Climatol 52:207–218

Rodrigo FS, Gómez-Navarro JJ, Montávez Gómez JP (2012) Climate variability in Andalusia (southern Spain) during the period 1701–1850 based on documentary sources: evaluation and comparison with climate model simulations. Clim Past 8:117–133. doi:10.5194/cp-8-117-2012

Salazar Anuncibay CJ (2005) El Precio histórico de la vida: evolución de los precios del trigo y la cebada en la comarca de Valles alaveses (Rivabellosa, 1591–1849). [Vitoria-Gasteiz]: Fundación Sancho el Sabio

Sánchez Gómez-Coronado M (1993) El ducado de Feria al final del Antiguo Régimen, Badajoz

Santos FL, Valverde PC, Ramos AF, Reis JL, Castanheira NL (2007) Water use and response of a dry-farmed olive orchard recently converted to irrigation. Biosyst Eng 98(1):102–114

Stothers RB (1984) The great Tambora eruption in 1815 and its aftermath. Science 224:1191–1198

Thodarson T, Self S (2003) Atmospheric and environmental effects of the 1783–1784 Laki eruption: A review and reassessment. J Geophys Res 108(D1):4011. doi:10.1029/2001JD002042

Trigo RM, Añel J, Barriopedro D et al (2013) The record Winter drought of 2011–12 in the Iberian Peninsula, in Explaining Extreme Events of 2012 from a Climate Perspective. Bull Am Meteorol Soc 94(9):S41–S45

Trigo RM, Pozo-Vazquez D, Osborn TJ, Castro-Diez Y, Gámis-Fortis S, Esteban-Parra MJ (2004) North Atlantic Oscillation influence on precipitation, river flow and water resources in the Iberian Peninsula. Int J Climatol 24:925–944

Trigo RM, Vaquero JM, Alcoforado MJ, Barriendos M, Taborda J, García-Herrera R, Luterbacher J (2009) Iberia in 1816, the year without a summer. Int J Climatol 29:99–115. doi:10.1002/joc.1693

Valencia Rodríguez JM (2010) El poder señorial en la Edad Moderna: La Casa de Feria (siglos XVI y XVII), Badajoz

Vaquero JM (2007) Historical sunspot observations: a review. Adv Space Res 40:929–941