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Climate of the Past Discussions

Early Portuguese meteorological records (18th century)

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Abstract

Natural proxies, documentary evidence and instrumental data are the main sources used to reconstruct past climates. In this paper, we present the 18th century meteorologists (either Portuguese or foreigners), who made the first observations at several sites in Continental Portugal, Madeira Island and Rio de Janeiro (Brazil), from 1749 until 1802. Information is given concerning observation site, variables observed, measurement period, methodologies and sources (both manuscript and printed). Some examples from the data usefulness are given: rainfall variability in Madeira (1749–1753) and in Continental Portugal (1781–1793) was reconstructed, allowing to extend towards the late 18th century the well known negative correlation between the NAO index and seasonal rainfall. Furthermore, previously unpublished data for 1783–1784 has allowed analysing the consequences of the Laki eruption in Portugal: foggy and haze days are referred to in summer 1783, but unlike the hot summer observed in Northern and Central Europe, temperatures in Portugal were lower than average. Additionally, observations from Rio de Janeiro in Brazil show that the Laki consequences may well have spread to sectors of the Southern Hemisphere. Although the series are short, the data will be used for climate reconstruction studies focused in Southern Portugal and are also useful to improve the quality of large scale reconstruction datasets.

1 Introduction

The last decades of the 20th century have testified a growing interest in historical climatology, e.g. the description of “climate and its variations during historical times and its impacts on society” (Brazdil et al., 2005, p.365). This interest is not only due to academic curiosity, but mostly because the results of this interdisciplinary research field are also highly relevant for the current discussion on anthropogenic climate change.

The knowledge of the natural climate variability has been deepened, and the availability of longer time series of relevant variables contributes to a more accurate understanding of the anthropogenic effects on climate.

Different authors have synthesised the types of sources used to reconstruct past climates from documentary evidence (diaries, memoir books, daily weather reports, ship logbooks, administrative and ecclesiastic archives, among others), from instrumental data and from natural proxies, such as tree-rings, corals, speleothems, boreholes, ice-cores (Brázdil et al., 2005, 2010a). The lack of sufficient documentary information has hampered studies dealing with the reconstruction of the climate of Portugal during the 17th and 18th centuries (e.g. Luterbacher et al., 2006; Camuffo et al., 2010 for a review). Therefore the relevance of all the 18th century meteorological observations is clear. In this paper instrumental data obtained by Portuguese and foreign observers for Continental Portugal, Madeira and Rio de Janeiro (former capital of the Portuguese colony of Brazil) will be dealt with.

The Enlightenment period was favourable to the development of scientific initiatives; the first observations begun in Europe, in the late 16th and in the 17th centuries (Table 1), that is some time after the invention and development of the meteorological instruments. In the beginning of the 18th century, meteorology had much in common with both natural philosophy and applied mathematics; it overlapped these scientific branches and contributed to their development and to the progressive quantification of "natural philosophy". The meteorologists made essential contributions to the design of physical instruments, including the so-called meteorological instruments used to observe weather.

Several European scientific academies coordinated the first observers' work and encouraged systematic measurement of different weather elements. Unlike other European countries, meteorological observations at the end of the 18th century in Portugal were not performed at standard hours, neither with well-calibrated instruments (Taborda et al., 2004; Trigo et al., 2009). In fact, at this stage such observations were already standard procedure in more developed regions of Europe, such as Scandinavia

(Bergstrom and Moberg, 2002), Northern Italy (Camuffo, 2002a,b; Maugeri et al., 2002) and France and UK (Jones et al., 1999; Slonosky et al., 2001; Slonosky, 2002).

However, climate analysis was not a common procedure. "Climatology [. . .] existed in neither deed nor word in the early 18th century" (Feldman, 1990). The term would be used more widely only in the early 19th century, with the meaning of compiling meteorological data, and performing temporal and spatial analysis. Synoptical interpretation and simple forecast would be coined later, with increasing use throughout the 20th century.

Most of the early instrumental records cover short periods, although a few meteorological sites are still active. A detailed description may be found in Kington (1988), Camuffo (2002a) and Brazdil et al. (2005, 2010b). There was a great progress in meteorological observations until the 1790s. Around the 1790s several political events and war incidents, including the French revolution in 1789, and the following Napoleonic wars disrupted a great number of networks. In any case at the end of the 18th century these activities had made an impact on the Iberian scientists, thanks to the relative numerous contacts with foreign scientific academies, and the support of the state in the enlightened spirit of the time (Barriendos et al., 2000). The scientists' main areas of expertise were grouped in accordance with their foreign counterparts (Medicine, Physics, Mathematics, and Astronomy).

The main objectives of the present work are: (1) to disclose the labour of the first meteorologists working in Portugal (both Portuguese and foreigners), (2) to synthesise the existent early Portuguese instrumental meteorological records of the 18th century including data and metadata and to show their potentials for historical climatic studies and, (3) to demonstrate how the relatively short datasets obtained can be used to expand our knowledge on specific climatic events (e.g. the Laki eruption in 1783/1784) or long-term variability (e.g. NAO and precipitation).

In the following section, an overview of meteorological observations in Europe during the 18th century is carried out and it is intended to introduce the meteorologists working in Portugal and overseas within the context of the scientific community of the late 1700s. Next, in Sect. 3, the 18th century meteorologists are enumerated in chronological order and information is given concerning observation site, variables observed, measurement period, methodologies and sources. Next two topics are further analysed: (1) Laki eruption impact in 1783, and (2) the link between precipitation and NAO index. Some conclusions are outlined in the final section. It should be emphasised that all datasets described here will become available at http://salva-sinobas.uvigo.es/index.php/eng/.

2 Meteorological observations in Europe in the 18th century

Most of the early instrumental records are not continuous in time (Brázdil et al., 2005). However there are still some instrumental series and networks dating back to the mid 17th century, several of them related to scientific academies (Manley, 1974; Jones et al., 1999; Camuffo and Jones, 2002; Slonosky, 2002; Barriendos et al., 2002; Brázdil et al., 2005, 2010b; Luterbacher et al., 2010; Camuffo et al., 2010). The most important networks and short series of the 18th century are summarised on Table 1.

In the last decades of the 18th century, several meteorological treatises were published, the meteorological instruments were improved (see the classical texts by Middleton, 1966 and 1994), and new networks prospered under the initiative of scientific societies, such as the *Société Royale de Médecine* and the *Societas Meteorologica Palatina*. The latter was lead by the Mannheim Academy of Sciences from 1780 until 1792 and it influenced significantly most early Portuguese meteorologists. This renewed interest on meteorology was related to two facts: on the one hand, the application of meteorology to health and to agriculture and, on the other hand, the development of experimental physics.

The *Societas Meteorologica Palatina* “was the first purely meteorological society to be established [in Mannheim] with the primary object of predicting the weather by analysing data collected from a network of stations making systematic daily observations” (Kington, 1988, p.12). Moreover, it fostered an international network aiming at

gathering comparable meteorological observations and, additionally, sent meteorological instruments to every institution and/or observer willing to participate. In this way, the network was capable of extending itself to several European countries. In a speech at the Mannheim Academy, in 1780, Johann Hemmer, court chaplain and director of the Palatine Society, “proclaimed agriculture and medicine to be the primary motives for the project” (Cassidy, 1985).

To a large extent, the meteorological activities of many physicians were prompted on the neo-Hippocratic hypothesis concerning the influence of climate and human health (Démarée, 1996; Brázdil et al., 2005). In fact, the Greek physician and philosopher Hippocrates (460–377 BC), usually regarded as the founder of western medicine, considered the disease as the result of an inbalance between the organism and the environment, including the weather and climate (Brázdil et al., 2005).

Meteorological observations were carried out with the aim of understanding the effect of weather on human health and “this hypothesis led to an interest beyond measure in human and animal epidemics” (Démarée, 2004, p.30), including the first continuous meteorological observations in Lisbon by Marino Miguel Franzini, in 1815 (Alcoforado et al., 1997). However, the advent of bacteriological theories of disease in the late 19th century threw the discredit on those theories.

“Agriculturalists hoped that regular observations would succeed in correlating the weather with the success of crops” (Feldmann, 1990). The activities of the Royal Society of Agriculture of Paris, created in 1761, illustrate this fact. Its publication, that was issued four times a year, from 1785 until 1791, included meteorological information, as the correspondent members were deeply interested in understanding the relationships between weather and agriculture (Pueyo, 1995). From the 277 memoirs issued by the Society, 24 are totally devoted to meteorology and 18 include either comments on meteorology or data. Cotte, who would be responsible for a 22 stations network from 1778 to 1789 (Table 1), was among the active members of the Royal Society of Agriculture (Pueyo, 1995).

This link between climatic conditions and agriculture production can be even more relevant in regions with lower crop yields and high inter-annual variability, such as most of the Mediterranean Basin, including Portugal, when compared to France and England. In fact the major meteorological features controlling the development of crops in Portugal, such as cereals (Gouveia and Trigo, 2011) or wine (Gouveia et al., 2011), are highly dependent on the annual cycles of precipitation, soil moisture, humidity, solar radiation and temperature. Thus, all these aspects produce some impact on the harvest volume and quality, and can cause episodes of food shortage and famine, sometimes even epidemics (Xoplaki et al., 2001; Trigo et al., 2009).

3 Meteorological observations in Portugal and overseas

The last decades of the 18th century are marked by the institutional integration of Portugal in the Enlightenment, after a long period of scientific stagnation that was partially amplified by the catastrophic destruction of Lisbon during the 1755 earthquake (that implied the allocation of significant resources for the reconstruction effort in the following decades). In spite of this, two events had most probably an important influence on science development in Portugal: the education reform lead by the powerful prime minister at the time, the Marquis de Pombal, in particular at the University of Coimbra (1772) and the foundation of *Lisbon Royal Academy of Sciences* (LRAS) in 1779 (Nunes, 1997).

The LRAS encouraged the development of scientific research, including Meteorology, that together with Chemistry, Anatomy, Botany and Natural History were included in the first of the three classes in which the LRAS was structured. Moreover, the LRAS was offered newly built thermometers, barometers, hygrometers and "Areometers" (apparently precursors of the anemometers) in 1780, by the *Societas Meteorologica Palatina* (Peixoto, 1997). This gift would have also contributed to the development of meteorology in Portugal. The publication of the first meteorological observations and of meteorological studies in the *Memoirs of Physics and Mathematics* of

the LRAS also denotes its interest on this new science. In the following subsections, the meteorologists will be listed, following the chronological order of their observations. Information will be given on station location, period of observation, variables registered and units and instruments used (whenever available). All the data have been digitised and converted to SI units. Some evident typographical mistakes have been detected and corrected. The digitalized and checked data will be accessible at http://salva-sinobas.uvigo.es/index.php/eng/. We must acknowledge that there are large disparities in the amount of data and metadata available for each observer described below. Nevertheless we are firmly convinced that the combined information provided is valuable and useful to extend long-term climatic series for the regions represented.

3.1 Thomas Heberden (Funchal, Madeira, 1747–1753)

Thomas Heberden (1703–1769) was a physician, fellow of the Royal Society (elected in 1761). He practised medicine on the Spanish island of Tenerife and also in the city of Funchal (capital of Madeira archipelago, Portugal, Fig. 1) and was one of the earliest physicians to recommend Funchal as a sanatorium resort for chest disease patients. His brother William Heberden (1710–1801) was an eminent London physician. Thomas Heberden shared his brother's interests in various aspects of natural philosophy, communicating through a number of papers sent to the Royal Society between 1756 and 1769 (Heberden, 1761, 1765, 1769 and 1770). Moreover, he published two papers on Madeira climate, including meteorological records (Heberden, 1751, 1753).

Heberden supplies monthly and annual data from Funchal from 1749 until 1753: temperature (Fahrenheit scale), air pressure and precipitation, measured twice daily at 07:00 and 15:00 (Fig. 2). We can assume that he refers to local time. No information is given referring to the exact observation site in Funchal and within this city there is a large gradient of temperature and precipitation due to distance to the sea, steep slope and urban geometry (Lopes et al., 2010). He used two thermometers: one exposed on the north side of his house to the open air and the other placed indoors. He made a comparison between two thermometers. Rainfall is measured using a "*funnel 15 inches in diameter*". Rainfall is measured using a "*funnel 15 inches in diameter*".

Heberden (1751) lists the monthly data from the barometer and thermometer for the years 1749–1750 and the monthly averages of precipitation for the years 1747–1750. Heberden (1753) updates the monthly barometric and thermometric data for the period January 1751–June 1753. Heberden (1753) presents a table with the monthly amount of rainfall for the years 1751–1753 and provides some statistical values. Finally, he lists the number of rainy days and the highest amount of daily rainfall for each month. Figures 3a and 3b show monthly temperature and pressure recorded in Funchal, where we can notice the hot summer of 1752 and the drop in pressure in early 1750. Figure 3c shows the monthly rainfall (dark line) and number of rainy days (grey bars), while Fig. 3d provides the monthly highest amount of daily rainfall.

Heberden adds several comments referring to significative meteorological situations and their consequences for humans and agriculture. For example, "the years 1749 and 1750 were such dry years, that the corn was destroyed, and the fruit-trees suffered much, particularly the peach-trees, the fruit either falling to the ground, whilst green, or, of it remained longer on the tree, being full of white worms" (Heberden, 1753). He also refers to the Lesté, Levant, or hot winds (October 1749, February and March 1750) "that are very troublesome" and he established its consequences on human comfort, concluding that "the remedy is to keep ourselves withindoors" (Heberden, 1753).

Heberden's data were compared with more recent ones (1980–1994). 18th century temperature values are found to be 1 to 2 °C above present time corresponding time-series. In fact, we can stress the similarity between historical minima and modern average temperatures. However too many geographical and instrumental parameters may have biased temperature values and direct comparisons may not be carried out directly.

3.2 Veiga (Lamego, 1770–1784)

To the best of our knowledge, the earliest records undertaken in Continental Portugal were carried out by João de Sousa Freire de Araújo Borges da Veiga (Veiga, hereafter) in Lamego, from 1770 until 1784 (Fig. 2). Lamego was an important and prosperous Episcopal city of the Douro valley (Fig. 1), and was marked by economic productions: silk (16–17th centuries) and Port wine (since the 18th century).

There is scarce information concerning Veiga's life, although there are some facts worth to be highlighted (Taborda et al., 2004). Although he was a correspondent member of the LRAS (elected in 1785), he began his meteorological observations in 1770, well before the LRAS foundation. His knowledge and interest on meteorological observations came most probably from his contacts with foreign colleagues. Nunes (1997) refers two foreign scientists with whom Veiga was in contact: João Serrano, Experimental Physics Professor at the *Colegio Imperial* in Madrid and the French Abbé Richard, who wrote a 10 volume work on "Natural History of air and meteors". Furthermore, astronomy was also within Veiga's interests: he published a small booklet on astronomical observations in Salamanca (Nunes, 1997).

The Lamego series consist of tables of annual values (extreme, average, totals) of temperature, precipitation and wind direction. To these, he added the number of sunny, cloudy and partially cloudy days, but unfortunately only referring these as an average of the 15 studied years. Veiga adds a number of qualitative comments on the weather (mostly extreme events, such as the hot 1766 summer), not only relative to the studied period, but also of the preceding years. He also states that the strongest rainstorms are due to west and south winds and that they occur mostly from October until April, which is in agreement with modern objective assessments (Trigo and DaCamara, 2000; Fragoso and Tildes, 2008). Quantitative and qualitative information is included in the seventeen page manuscript, entitled "Meteorological Observations made in Lamego", that he offered to the RLAS (Veiga, 1784).

Veiga's observations site and measurement methodologies are unknown. At the end of the manuscript, there are some comments made by a member of the LRAS in charge of quality control of meteorological data (probably Pretorius – see Sect. 3.3; Nunes, 1997). Measurement methodologies were criticized, particularly referring to temperature and air pressure. In this regard Veiga was asked to send detailed daily tables for a whole year in order to allow the verification of his data. However, no reply from Veiga has been found so far and consequently temperature and pressure data from Lamego will not be dealt with. Precipitation data was used to evaluate inter-annual variability for the 15 years of available data (Fig. 4), although its comparison in absolute terms with current climate normals is strongly limited, not only because the Lamego station does not exist nowadays, but mainly because some doubts persist referring to Veiga's observation methodologies and instruments. The average of the period 1770–1784 (526 mm) is clearly inferior to the value we may infer from Daveau (1977) detailed precipitation map of Portugal (between 900 and 1000 mm). Furthermore, the rainfall average (1960/1961–1989/1990) available for a nearby station (Tarouca, located at a similar altitude) reaches 1000 mm; the latter is in accordance with Daveau's (1977) map.

3.3 Pretorius and Schulze (Lisbon, 1781–1785, 1789, 1793)

Two German scientists came to Lisbon as military officers, integrated into the reorganisation of the Portuguese army: Jacob Pretorius and Henry Schulze carried out diversified and highly accurate meteorological observations between 1777 and 1793 (the former) and in 1789 (the latter) (Fig. 2). The observational activities performed by these two gentlemen were primarily directed to climatic variables (Taborda et al., 2004). However their observations also included astronomical events such as aurora (Vaquero and Trigo, 2005a).

The German engineer Jacob Chrysostomo Pretorius (Pretorius, hereafter) lived in Portugal from 1762 to 1764 and returned again only in 1776. He was then an effective

member of the LRAS (Exact Sciences Class), to whom he offered several studies, most of them on meteorology. He died in 1798. Franzini (1779–1861) wrote that "death did not give him time to organize his meteorological data and extract the results one could have expected from such information" (quoted by Ferreira, 1944, p.4). Henry Schulze came to Portugal in 1776, together with Pretorius and their observations can be considered as being complementary.

Pretorius and Schulze have measured temperature, precipitation, pressure, wind, humidity and cloudiness in Lisbon (Fig. 1). There is also information about extreme events, such as thunder, hail, storms and snow. Although there is no direct reference of the instruments they have used, Pretorius was aware of the importance of instrument accuracy. He offered the LRAS several studies on meteorological instruments (Pretorius, 1781a,b,c, 1782a, 1786a, and an undated manuscript about a barometer) and we may infer that he choose the instruments very carefully (Taborda et al., 2004).

Referring to Pretorius observations, we only possess data from 1781 to 1785, and for 1793, although the series must have been longer. It is probable that meteorological observations were carried out continuously by Pretorius from 1777 to 1793 (or more), starting one year after returning to Portugal. Pretorius refers that precipitation in 1784 was higher than that of the preceding years since 1777 (Pretorius, 1785, p.271). The foundation of the LRAS in 1779 must have given some support to regular observations. Regrettably we have only one year of readings obtained by Schulze and these are relative to the year of 1789 (Schulze, 1790).

Pretorius carried out his measurements in Lisbon, in the "vicinity of *Nossa Senhora das Necessidades* Royal Palace", in the south-western part of Lisbon (Fig. 1), most probably in the Fábrica da Pólvora, where he lived (city district of Alcântara, Taborda et al., 2004). Referring to the thermometer, Pretorius states that the instrument is inserted in a box "varnished tinplate", "which could be placed near a window facing North or in a wind exposed site, although protected against the sun by means of some wooden boards, located some distance away from the instrument" (Pretorius, 1786a, p.232–232). This means that he was shielding his thermometer, but there is no certainty on its location. Schulze's instruments were also located in Alcântara (Lisbon), 13.2 m a.s.l., most probably not far away from Pretorius' observational site.

Pretorius data from 1781 to 1785 were published in four volumes of the *Almanach de Lisboa* (Pretorius, 1782b, 1783, 1785, 1786b). The *Almanach de Lisboa* was first edited by the LRAS, but later printed and sold by the French Jean-Baptiste Reycend (Taborda et al., 2004). Data for 1781 and 1782 are scarce, although annual precipitation data are supplied. On the contrary for the following years, monthly data and information on extreme events are present. For 1793 a table including annual and monthly meteorological data is appended to a three page manuscript (Pretorius, 1794). Schulze presents a five page manuscript and a table of the same type of that by Pretorius with the synthesis of monthly and annual data for 1789 (Schulze, 1790). Unfortunately, daily data have not been found so far; although both observers indicate the number of days of extreme temperatures, rainfall, number of hail days (Pretorius, 1794).

As Schulze and Pretorius's tables (structure, organization, vocabulary) and measurement methodologies are similar, we may suppose that they have worked together or at least that they were aware of each other measurements.

3.4 Bella (Coimbra, 1781)

Giovanni Antonio dalla Bella was a Physics teacher hired by the Portuguese Government. He came to the Nobles' College of Lisbon in 1766 with the aim of organizing the laboratory of experimental physics of this institution. After the widespread education reform imposed by the Marquis of Pombal, Bella went to the University of Coimbra in 1773 (Carvalho, 1982). Among his numerous experiences, he performed a series of measurements of the magnetic force in relation with the distance in 1781, published later in the *Memoirs* of the LRAS. In the context of these measurements, he collected temperature and atmospheric pressure records during his experiments. These meteorological records were published in his papers (Bella, 1797a,b). Bella was registering temperature, pressure, direction of wind and state of the atmosphere for each magnetic

experiment. In total, there are 52 records during the period 22 March–9 July 1781. Unfortunately metadata describing his methods and instruments are not available.

3.5 Velho (Mafra, 1783–1787)

Joaquim da Assumpção Velho (Velho, hereafter; 1753–1793) was vicar of a religious congregation in Coimbra and taught Physics and Mathematics at the *Royal College of Mafra* (outskirts of Lisbon, Fig. 1). He was also a member of the LRAS.

Velho is the Portuguese 18th century meteorologist who provides the most valuable metadata, such as detailed references about station site, instruments and measurement methodologies (Taborda et al., 2004). He carried out daily meteorological observations from 1783 to 1787 at the *Royal College of Mafra* that "is situated four to five leagues [22 to 28 km] NNW of Lisbon [. . .] and 500 to 600 feet above sea level" [152 to 182 m]. He also provides information about the measurement site: "the horizons to the North and the West are entirely free and unobstructed, the Southern horizon is somewhat obscured by a chain of hills culminating in the Serra de Cintra, the Eastern horizon is the most restricted by a few neighbouring hills" (Velho, 1797a, p.450). Velho includes three-daily information on air pressure, temperature and precipitation, as well as observations related to the "state of the sky" (nebulosity) and wind direction and speed (that he inferred from cloud and smoke movement). There are still references to several phenomena, such as storms, hail, lightning and thunder.

In 1783, Velho used the barometer built by Magalhães (the same as Pretorius). He writes: The barometer which I use was made in London by the great craftsman Mr. Nairne under the guidance of our fellow-countryman J. J. Magalhães, with all the corrections and additions with which this great master has perfected the instrument. The thermometer, also made in London, by the same craftsman, is made of mercury and was constructed according to Mr. Réaumur principles, but with Mr. Fahrenheit scale. It is constantly exposed to the open air outside a north facing window in my office. The pluviometer consists of a funnel made from sheet of lead with a six inch diameter at the mouth, which catches the rain and ends in a tube from the same material. It passes through a window where it pours the water into a lead cylindrical pot which has the same diameter as the mouth of the funnel. A body floats in this pot and a stick in the centre passes through the cover of the pot. It marks the elevation of the water on a ruler graduated according to the divisions of the *French king foot* (Velho, 1797a, p.450). Velho indicates very clearly that the thermometer is constantly exposed outside. The position of the instruments outside was advised at the end of the 18th century to make the data more easily comparable and more representative of the area (Kington, 1988). In the following years Velho changed for another barometer that he also describes in detail (Velho, 1797b, p.475). As no other indication concerning instrument type is included, we may infer that no changes occurred in instrument type after 1784.

Data from Lamego, Lisbon (Lisboa) and Mafra provide sufficient information to characterize the rainfall of the 1780s and to confirm Kington's statement (1988, p.2) that the 1780s contain several positive and negative rainfall extremes. Like in other Mediterranean regions (Font Tullot, 1988), an extremely rainy period occurred between 1784 and 1789, following and followed by dry periods, as can be observed in Fig. 4, although no conclusions may be drawn relatively to absolute rainfall differences (owing to discrepancies in measurement methodologies and instruments). Data from Lisbon and Lamego, as well as documentary data confirm the occurrence of a drought period in Portugal in 1779, and the corresponding tragic influences on agriculture and water availability (Taborda et al., 2004). This can be related to the persistence of a blocking anticyclone on Central Europe, as confirmed by Luterbacher's sea level pressure (SLP) field reconstructions (Luterbacher et al., 2002a). In this regard, the anticyclone reconstructed for March 1779 would generate an Easterly flux over Iberia (Fig. 5 left).

The three following years were also rather dry (638.4 mm in 1781 and 554.9 mm in 1782 in Lisbon) with the exception of April 1782 when 162.4 mm were measured by Pretorius. Frequent low pressure centres located SW from the British Isles, as one can infer from SLP reconstructions (Fig. 5 right, Luterbacher et al., 2002a) would have then caused heavy precipitation in Lisbon.

1783 seems to be a turning point, as rainfall increases in Lisbon and Lamego, but in 1784 the increment continues (Fig. 4). Pretorius (1785, p.271) writes: "The year of 1784 is the wettest on record in Lisbon since 1777 [. . .]". In Lisbon, 906.8 mm of rain were measured in 1784 (162.4 mm more than in the preceding year) and 1221.4 mm were recorded in Mafra (480 mm more that in 1783). Documentary sources mention that *pro-serenitate* rogations (Alcoforado et al., 2000) took place in 1784: "If this country has been exempted of intense cold, (. . .) as is occurring in the rest of Europe, rain has been so continuously strong that the Cardinal Patriarch of Lisbon ordered public rogations in every church, to obtain serenity of the sky" (Newspaper *Gazeta de Lisboa*, no. 11, 16 March 1784). December 1784 is the wettest month of the Mafra series (312.5 mm) and was also very rainy in Lisbon (239.1 mm) (Fig. 6). Precipitation intensity was the highest at the end of the month (55.1 mm on the 29th, Fig. 7). Taborda et al. (2004) shows that the interpretation is in agreement with the daily synoptic charts reconstruction for Europe by Kington (1988), presenting an extensive low pressure centre influencing the Iberian Peninsula during the last week of December 1784 (Fig. 8).

Brázdil et al. (2010a) refer the devastating floods that took place in Central Europe in winter and spring 1783–1784. Most of them were due to intense snow melt and heavy rainfal. However, the floods in Southern France in December 1783 were mostly caused by sustained rains (Brázdil et al., 2010a). According to our results, December 1783 was also wet in Lisbon and in Mafra, but the precipitation was lower than in December 1784 (Figs. 6 and 7).

The following years of 1785–1787 can be considered as the continuation of the rainy period (Figs. 4 and 6). Although 1785 is slightly drier than 1784, total rainfall increased once more in the following years. In Mafra, the 1786 annual value attains 1429.7 mm. From Schulze writings one may infer that precipitation was also in excess of 1000 mm in Lisbon in 1786 (Schulze, 1790, fl.3 and Taborda et al., 2004). Although one should be careful while comparing with current values, those are certainly very high precipitation annual totals: Mafra/Tapada precipitation more recent average refers to the period

1941–1960 and accounts 751.6 mm. In Lisboa/Geofísico, the main Lisbon station, the rainfall average for the period 1941–1970 reaches 714.4 mm. Moreover, there are further reports of *pro serenitate* rogations in March 1786 in Lisbon (Newspaper Gazeta de Lisboa, no. 12, 24 March). After 1789, precipitation decreases once more and in 1791 there are documents referring to the lack of water for agriculture in Southern Portugal (Taborda et al., 2004).

Although Velho infers wind direction with a crude method (only based on the movement of the clouds and smokes), it is interesting to combine his precipitation and wind data (Fig. 9): the highest amounts of rain occur with compass wind direction predominantly from W, SW and S winds, as Veiga had also noted for Lamego and which is similar to modern climatological analysis (Trigo and Dacamara, 2000; Fragoso and Tildes, 2008).

3.6 Lopes (Oporto, 1792)

José Bento Lopes (Lopes, hereafter) was a physician, graduated by the University of Coimbra, concerned about public health issues. His readings were performed in 1792 and took place twice a day; in the morning, between 7 and 8 h, and in the afternoon, between 15 and 16 h. Data on air pressure are expressed in English inches while the thermometer had a Fahrenheit scale. Lopes used a hygrometer with 60 subdivisions (30 to measure the degree of dryness and 30 to measure the degree of moisture). The meteorological and medical data were published in volume I of a medical journal (Anno Medico, 1796).

3.7 Dorta (Rio de Janeiro, 1781–1788)

Bento Sanches Dorta (BSD hereafter, Coimbra, Portugal, 1739 – São Paulo, Brazil, 1794) was an astronomer and geographer sent to Brazil by the King of Portugal in charge of a geographical mission, with the main task of determining the actual limits

of the Portuguese colony (Carvalho, 1982). He was a member of the LRAS having published numerous papers in its *Memoirs* (Dorta, 1797, 1799a,b; 1812a,b).

The sheer quantity and apparent quality of his wide range scientific observations have been used recently in different publications by some of us. Thus Vaquero et al. (2005) have showed the added value of the sunspot observation undertaken by BSD during the solar eclipse that took place on 9 February 1785. Based on the outstanding number of geomagnetic declination measurements observations performed by BSD, Vaquero and Trigo (2005b) analyzed the instruments and measure methods. Unusual observations of low latitude auroras australis obtained by BSD between 1781 and 1788 were linked with the geomagnetic declination values carefully registered in his papers and the solar storms that occurred (Vaquero and Trigo, 2006). Furthermore, the observations of BSD and the out of the ordinary weather conditions, such as abnormal mist (haze) and dry fog that happened in the years following the Laki eruption are dealt with in Trigo et al. (2010). Only very recently have we looked at the meteorological observations of BSD to assess the late 18th century climate of Rio de Janeiro (Farrona et al., 2011).

In the initial collection of instruments (thermometer, pluviometer, and evaporation pan) there was not a barometer that only arrived from Europe in 1784. The instruments were located “in the camera of my room”, located 50 spans and 4 inches above the sea level. This camera had three opened windows toward the southwest (Dorta, 1797b, p.346) and was situated in the castle hill of the city.

BSD measured other important weather parameters such as rainfall and evaporation and computed the monthly mean value of all these variables. Finally, he registered the wind direction in an 8-directional compass from which he derived the monthly mean wind direction in the morning and in the afternoon (Dorta, 1812a, p.76).

BSD was a keen observer performing seven times per day, from 06:00 to 18:00 LT every two hours during the period 1781–1783, raising to eight times per day after the arrival of the barometer in August 1784 until December 1788 (Dorta, 1799a, p.346). Based on these sub-daily observations he computed monthly averages namely, mean temperature and pressure in the morning, at midday and in the afternoon. These values were calculated as the arithmetic mean of all the observations made. In the diary he also wrote the maximum and minimum temperature, however he admitted he did not know if these values were correctly measured because, as mentioned above, he only checked the thermometer at some pre-defined hours throughout the day (Dorta, 1812a, p.74).

Additionally to these quantitative observations BSD was interested to gather relevant qualitative information describing the state of the sky. As he said, “The four qualities of the day which shape the years, namely: clear, variable, cloudy, overcast; there should add 365” (Dorta, 1812b, p.115). He computed the monthly mean of number of days of thunder, rain, fog, aurora australis, zodiacal light, and clear, variable and cloudy days. In fact, at the end of each year BSD would summarize all weather patterns observed during that year, where he described the extreme and/or interesting events and he specified the date on which they happened.

3.8 Murdock (Madeira, 1793–1802)

William Gourlay, Fellow of the Royal College of Physicians of Edinburgh and physician of the British Factory at Madeira, published in 1811 a treatise on the Natural History of Madeira containing monthly accounts of weather from 1793 to 1802. For each month, data on monthly temperature and pressure (maximum, minimum and mean) and a description of weather are available (Gourlay, 1811, 39–66 pp.).

According to Barral (1854), the observer was James Murdock and the place of observation was named “Sitio do Vale” [Place of the valley] (400 feet above the sea level). Barral (1854) indicates that there are no metadata for this observer and he classified this record as “doubly”. While temperature time series present a reliable seasonal range and inter-annual variability, the same cannot be said in relation to the pressure data. In fact, pressure does not present the usual inter-annual variability and the number of consecutive similar values is very high.

Figure 10 shows the temperature record after some minor typographical errors corrected. The extreme monthly temperature recorded were 28.9 °C (September 1802) and 10.6 °C (January 1802). The yearly extreme temperature recorded were 19.1 °C and 19.0 °C (years 1798 and 1799, respectively) and 17.5 °C (1800). Murdock includes in his observations interesting comments about the state of weather and its relation with agriculture, especially on the plantations at different altitudes.

4 Some examples

4.1 Laki eruption impact in 1783

The year 1783 deserves particular attention due to “foggy weather” and the “almost permanent fog during day and night”, which dominated the state of weather for a considerable number of days during June and July. According to Pretorius (1785, 270 and 272 pp.), the extract of meteorological observations on the 1783 and 1784 of this event gives the following testimony: “But what makes this year [1783] more notable among many in the past was the summer haze. Between June 22 and July 6 we had 14 days with a permanent haze throughout the day and night, and shortly thereafter this was succeeded by the same phenomena during 8 days, from July 12 to 20” and it should be noted that the same kind of fog and haze dominated over our boreal hemisphere.

It is now widely accepted among the scientific community that the main culprit for this unusual weather was the Icelandic Laki eruption, that took place between June 1783 and February 1784. The amount of gases and aerosols released by Laki were so large that provoked widespread impacts in Europe (Thordarson and Self, 2003). These impacts include increase mortality in the UK (Witham and Oppenheimer, 2005) and Continental Europe (Grattan et al., 2005), but also the devastation of pastures and livestock in Iceland (Steingrimsson, 1998), and to a less extent in the British Isles, France, and Benelux. The large-scale circulation pattern prevalent at the time advected the plume of smoke and haze towards Northern Europe (Stothers, 1999; Démarée et al.,

1998) but affecting the entire European continent from Lisbon to Moscow (Thordarson and Self, 2003).

The year of 1783 is relatively well covered by Portuguese observers being two based in Continental Portugal (Pretorius in Lisbon and Velho in Mafra, Taborda et al., 2004) but also with important complementary observations being made in Rio de Janeiro by BSD (Fig. 11).

In fact similarly to Pretorius, Velho also recorded foggy and dry fog (haze) during periods that the German refers, in particular between 26 June and 2 July and between 13 and 20 July. However, Velho makes further references to fog and misty sky during the months that span between June and August (Taborda et al., 2004). During these three months, 67.2 % of allusions to fog and cloudy sky are associated with winds from the north and northwest winds and 81.3 % to winds from the north, northwest and west (Taborda et al., 2004).

Perhaps more unexpected is the recent description of possible association between unusual dry fogs over Rio de Janeiro and the Laki eruption, although further work must be done to evaluate the robustness of such link (Trigo et al., 2010). The progress of the number of foggy days per month witnessed by BSD between 1781 and 1788 can be seen in Fig. 11.

The summer of 1783 for both sites with observations in Portugal (Lisbon and Mafra) were characterized by relatively mild (even slightly colder) conditions, possibly due to aerosol concentration in the atmosphere that would decrease summer maximum temperatures; on the contrary most of Western Europe experienced particularly hot weather. As an example, we are presenting average summer temperatures in Mafra: in 1783 and 1784 they are circa 2 °C inferior to those of the two following years (Table 2). Thus, in Central England, the summer of 1783 and, in particular the month of July, is considered one of the hottest the last three centuries (Kington, 1980, 1988), as well as in Southern Moravia (Brazdil et al., 2003) and in Germany (Jacobeit et al., 1997). The most probable physical mechanism responsible for such high temperatures is the existence of persistent blocking patterns that dominated the atmospheric circulation for

several months and are known to induce warm and dry conditions in Western Europe (Trigo et al., 2004). In fact, the early summer months of 1783 were dominated by a strong anticyclone over Europe, that promoted the subsiding of air including the dry sulphurous fog towards the surface (see Figs. 6 and 7 in Thordarson and Self, 2003).

4.2 Correlation between the precipitation and the NAO index between 1780 and 1793

The North Atlantic Oscillation (NAO) is relatively well known since the early works of Walker (1924) and represents the most important large-scale pattern of circulation in the Northern Hemisphere (Wallace and Gutzler, 1981). In a nutshell, the NAO mode corresponds to a large-scale meridional alternation of atmospheric mass between the polar low pressure system closes to Iceland and the subtropical anticyclone near the Azores (Hurrell, 1995; Trigo et al., 2002). In the last two decades, a growing number of research papers have examined the relationship between winter precipitation in Europe and the NAO index and, especially, for the Iberian Peninsula (Hurrell, 1995; Trigo et al., 2004; Gallego et al., 2005). In particular it has been shown that extreme events such as the outstanding drought of 2005 (Garcia-Herrera et al., 2007) and record winter precipitation of 2009–2010 (Vicente-Serrano et al., 2011) are closely related to prolonged episodes of positive and negative values of the NAO index, respectively. Besides the long-term precipitation dataset available for Lisbon since 1865 we now have two additional small datsets of rainfall data for the Lisbon region; Lisbon and Mafra (see Sects. 3.3 and 3.5) that we can use to confirm the relationship between winter rainfall in Lisbon, during the 1780s, and the existing reconstructions of the NAO index (Cook et al., 2002; Luterbacher et al., 2002b).

Historical precipitation data recovered shows higher values compared with the values of the more recent period (1865–2010). For example, the accumulated values of winter precipitation (DJFM) in Lisbon during the winters of 1783–1784 and 1784–1785 recorded by Pretorius are 555 and 582 mm, respectively. These values correspond to the 92 and 89 percentile values of winter precipitation in the official series of Lisbon during the period 1865–2010. Moreover, the NAO index reconstructions of Luterbacher et al. (2002b) and Cook et al. (2002) show negative or near zero values in the years that have historical records of precipitation in Lisbon and Mafra. Therefore, both data sets are compatible.

The relationship between the average monthly precipitation for winter (DJFM) and the winter NAO index (DJFM) is shown in Fig. 12. The black dots represent the values of the instrumental period (1865–2000). We used the historical rainfall series of Lisbon employed in recent assessment of drought and wet events over Western Iberia (Garcia-Herrera et al., 2007; Vicente-Serrano et al., 2011) and the NAO index values provided by Jones et al. (1999). Squares and circles represent the historical values of precipitation of Mafra (1783–1787) and Lisbon (1783–1785, 1789 and 1793), respectively while colour indicates the origin of the reconstructed NAO index time series: red (Cook et al., 2002) and blue (Luterbacher et al., 2002b).

In spite of the small set of precipitation data available for Lisbon and Mafra in the late 18th century, it shows a similar behaviour to that provided by the long-term dataset for the modern period (1865–2010). In particular we can note that the decade of 1780s was wetter than the long-term average in the Lisbon region and that the corresponding reconstructed NAO values were predominately negative.

We would like to stress the values observed for the winter of 1783–1784. According to several authors this winter was wetter than the average over large sectors of Europe (e.g. D'Arrigo et al., 2011) and may be influenced by a number of different physical mechanisms. In fact while some authors stress the influence of external driving mechanisms such as the recent eruption of Laki in June 1783 (Thordarson and Self, 2003), or the deep minimum of 11-yr solar cycle around 1784 (Vaquero, 2004), others point to large variability of internal modes such as a combined negative phase of the North Atlantic Oscillation and an El Niño-Southern Oscillation (ENSO) warm events.

5 Conclusions

European wide temperature and precipitation reconstructions clearly point to the fact that more information is still needed for a better understanding of climate change in Europe. Therefore, any new data from Portugal may help bridging existing spatial and temporal gaps in coverage of Southwest Europe.

The early instrumental data from Portugal and Brazil that were presented in this paper are the first short series available in a period for which climate reconstruction has been mostly based on documentary data (Taborda et al., 2004; Trigo et al., 2009). Systematic observations of different weather elements were encouraged by scientific academies and data quality is sometimes very good. Given the novel and innovative nature of the information, some scientists (particularly Velho and Pretorius) were concerned with legitimizing their results through the descriptions concerning instrument exposure, type and location, as well as instrument site. Pretorius and Velho were among the first in Iberia to take their measurements outside (Barriendos at al., 2000). However, most data values may not be directly compared to current ones in absolute terms due to the following facts: (i) instruments were not always properly calibrated; (ii) scales were not normalized; (iii) exact station location and site are often unknown; (iv) instruments (e.g. thermometers) were not shielded (temperatures are often higher than nowadays); or (v) no metadata is available. Although units used by the different observers (or the same observer) are quite different, it has been possible to convert them into SI units.

Similarly to other European countries early Portuguese meteorologists had to face serious difficulties to carry on regular and reliable observations: (i) the instruments were not easy to get; (ii) as they were not shielded, they were frequently damaged by storms; (iii) there were no explicit and general measuring rules; (iv) most of the observers were not trained (lack of precision in readings, lack of discipline in observation time).

Despite these facts, the data collected gave information and lead to the understanding of several climatic features of the 1700s in Continental Portugal, Madeira and Rio de Janeiro, such as annual and monthly temperature and precipitation variability (e.g. the very rainy years of the early 1780s in Continental Portugal) and extreme meteorological events. Furthermore quantitative evidence of the Laki eruption impact in 1783 was supplied for Continental Portugal and Rio de Janeiro, and the data also allowed establishing correlations between rainfall and NAO index.

With the instrumental data that we have described here and the documentary data we possess for the decade 1780–1790, we are starting the construction of a "calibrating period", that is a period with overlapping instrumental and documentary data (Brázil et al., 2010b, p.17), in order to transform Portuguese indices (Alcoforado et al., 2000; Taborda et al., 2004) into precipitation values. Our future objective is to extend this calibrating period well into the beginning of the 19th century and to reconstruct a long series for Southern Portugal, also based on Frazini's series available for Lisbon (1815–1825; 1835–1856, Alcoforado et al., 1997), and recently digitized meteorological series from Southern Portugal.

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Table 1. Early short instrumental series in Europe (Sources: Kington, 1988; Jones et al. 1999; Pfister and Barreis, 1994; Camuffo, 2002a,b; Brázdil et al., 2005).

Series/network	Period	Number of meteorological stations	Science Academy	Organizer/observer
Rete Mediceae	1653–1667	10 stations in Italy, France, Austria and Poland	Accademia del Cimento	Grand Duke of Tuscany
One series	1665–1713	1 station (Paris)		L. Morin
One series	1706–1734	1 station (Delftt/Rijnsburg)		N. Cruquius
One series	1716–1737	1 station (Bologna)	Accademia delle Scienze e delle Arti	J. B. Beccari
Network in Central Europe	1717–1726 1727–1730	11 stations		J. Kanold (doctor) A. E. Büchner
International network	1724–1735		Royal Society of London	J. Jurin
National network (France)	1778–1789	22 stations	Société Royale de Médecine	L. Cotte
National network (Italian Peninsula)	1785–1811	32 stations		G. Toaldo
International Network	1780–1792	39 stations from Greenland to Rome and from La Rochelle to Moscow	Societas Meteorologica Palatina	J. Hemmer
Spanish series	1780–1825 1737 1786–1797 1792–1799 1786–1795	Barcelona Madrid Madrid Mahón (Baleares) Cadiz	Academia Médico-Matritense Naval Observatory	F. Salvá F. Fernández P. A. Salanova J. Bals J. Sánchez Buitrago

Table 2. Average annual and summer temperatures (°C) in Mafra (Taborda et al., 2004).

	1783	1784	1785	1786	1787
Average annual temperature	–	13.1	14.7	14.8	14.4
Average summer Temperature	17.5	17.3	19.4	19.5	18.1

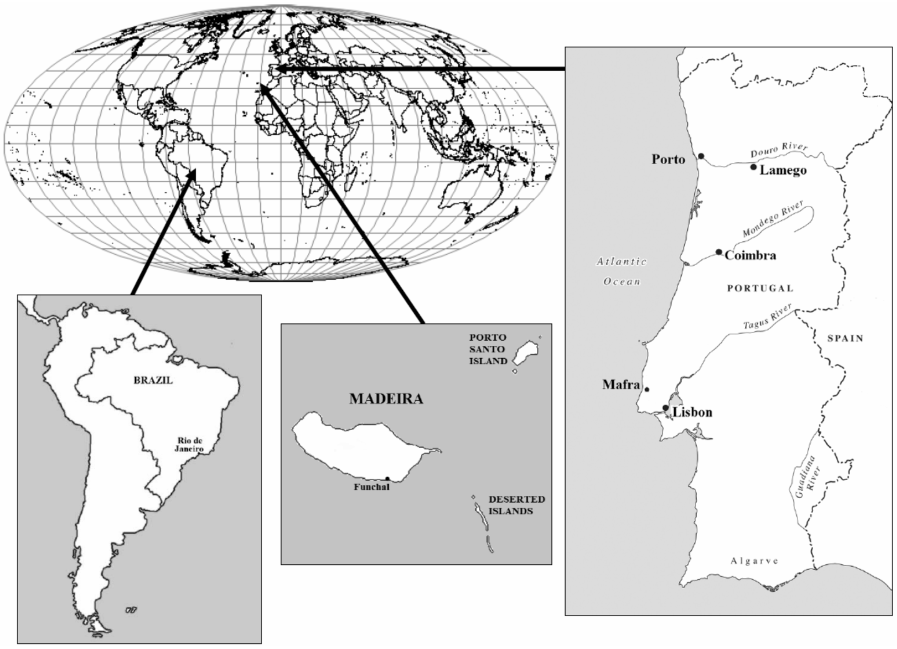

Fig. 1. Location maps.

Fig. 2. Meteorological data availability in Portugal and overseas during the 18th century (yellow: annual data; red: monthly data; green: daily data; grey: lost data).

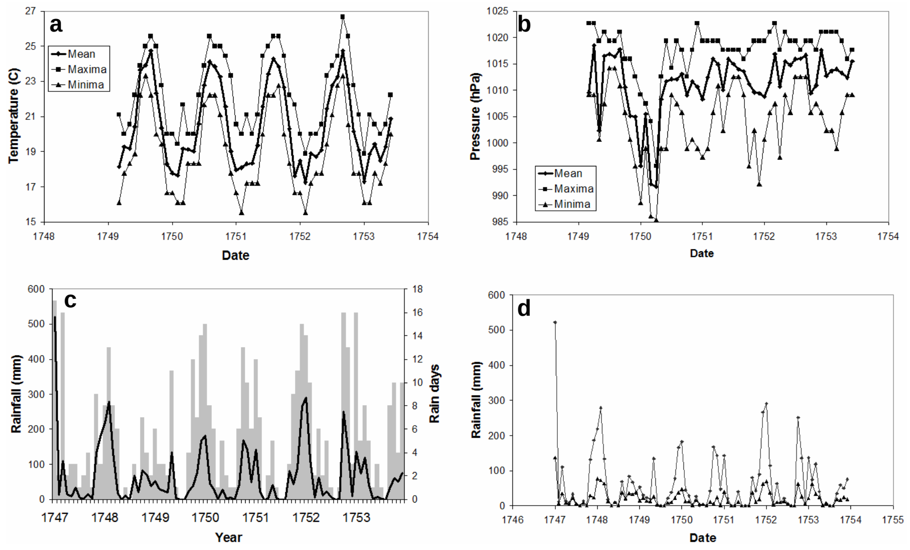

Fig. 3. Meteorological parameters recorded in Funchal by Heberden from March 1749 to June 1753 (temperature and pressure) and from January 1747 to December 1753 (rainfall). **(a)** Monthly temperature values **(b)** Monthly pressure values. **(c)** Monthly rainfall (dark line) and number of rain days (grey bars) **(d)** Monthly rainfall (grey line) and largest daily amount of water, which fell in any day of the respective month (dark line).

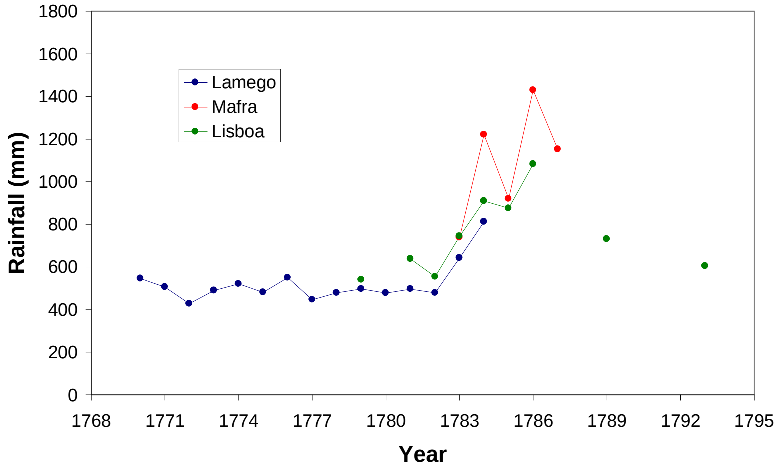

Fig. 4. Precipitation in three meteorological Portuguese sites in the 18th century (Taborda et al., 2004).

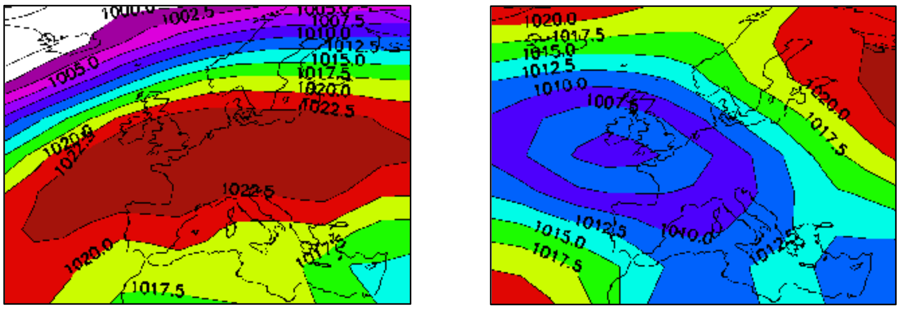

Fig. 5. Reconstruction of monthly sea level pressure fields in Europe in March 1779 (left) and in April 1782 (right) (Luterbacher et al., 2002a).

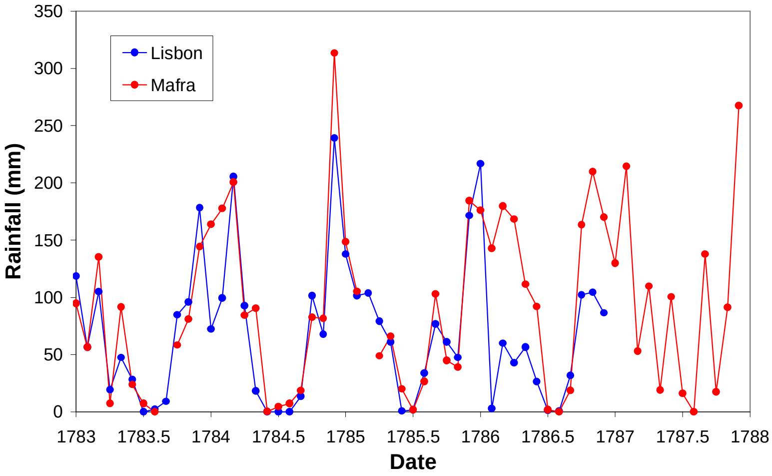

Fig. 6. Monthly rainfall in Lisbon and Mafra from 1783 to 1789.

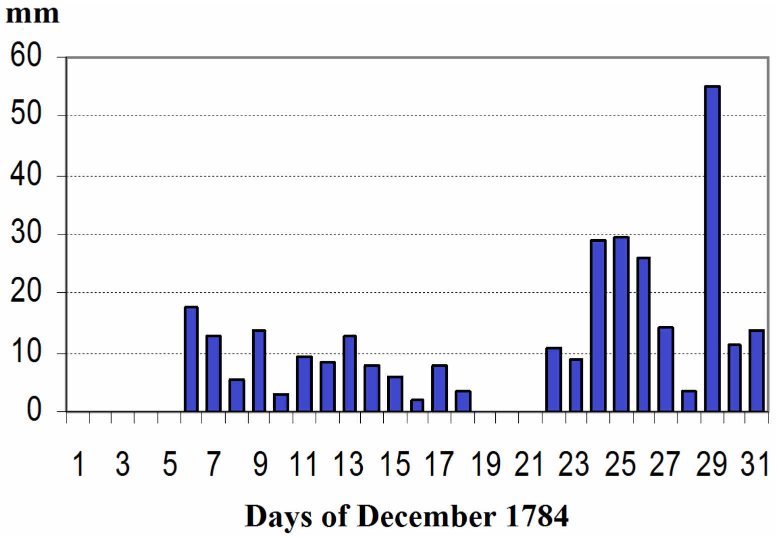

Fig. 7. Daily precipitation in Mafra in December 1784.

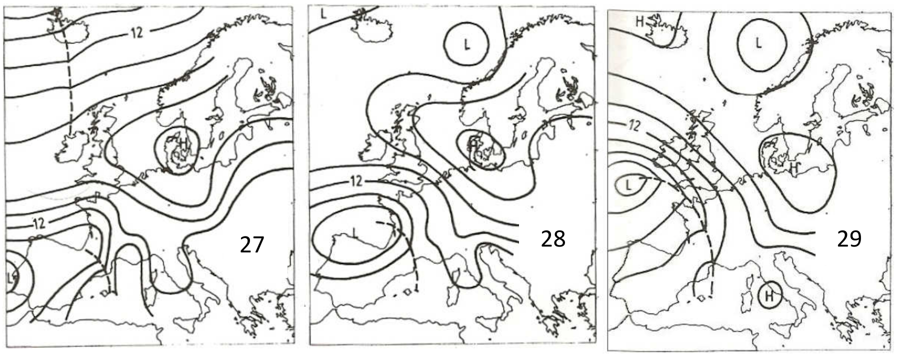

Fig. 8. Reconstruction of daily sea level pressure fields in Europe from 27 to 29 December 1784 (Kington, 1988).

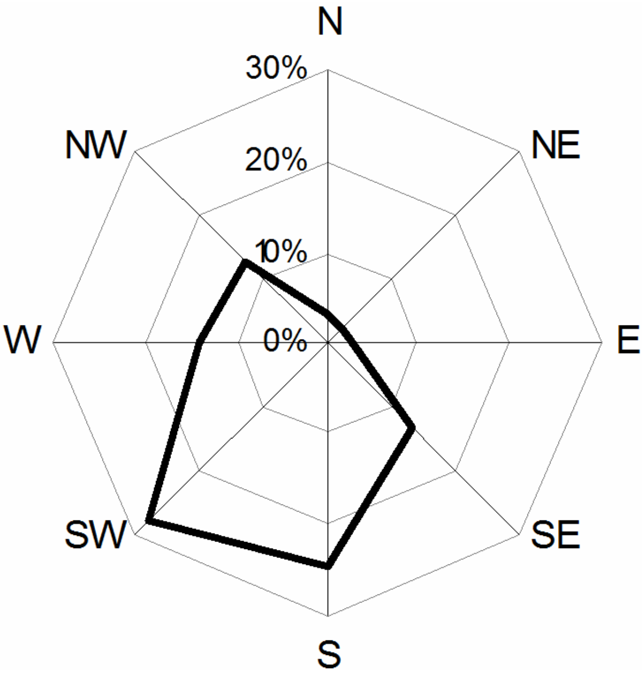

Fig. 9. Percentage of rainfall in Mafra (1783–1787) by wind direction, according with Velhos data (Taborda et al., 2004).

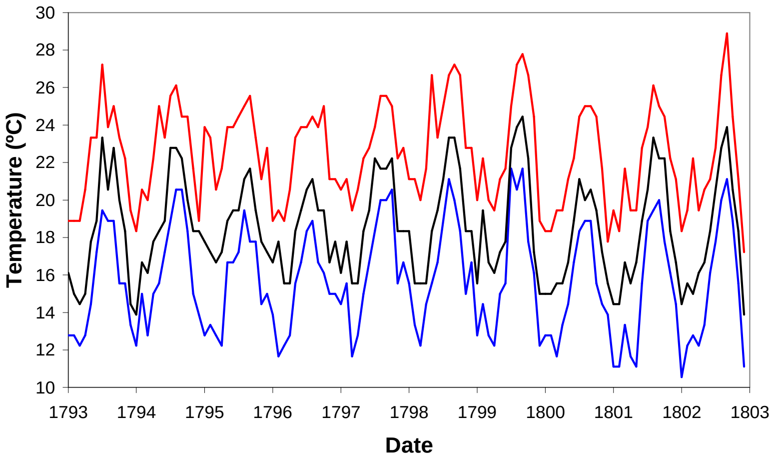

Fig. 10. Maxima (red), minima (blue) and mean (black) temperature at Madeira recorded by Murdock from 1793 to 1802.

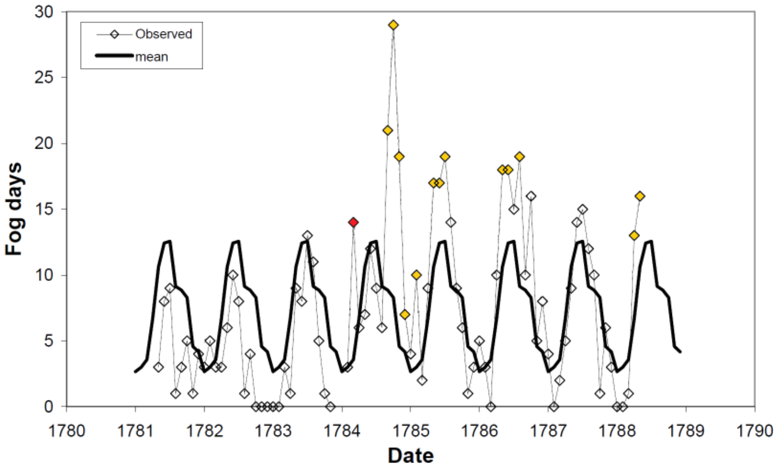

Fig. 11. Monthly values of number of fog days (nfd) recorded by BSD between 1781 and 1788 compared with the monthly climatology (bold line). The outstanding values that lie above the corresponding 1s (2s) values were filled with yellow (red) color.

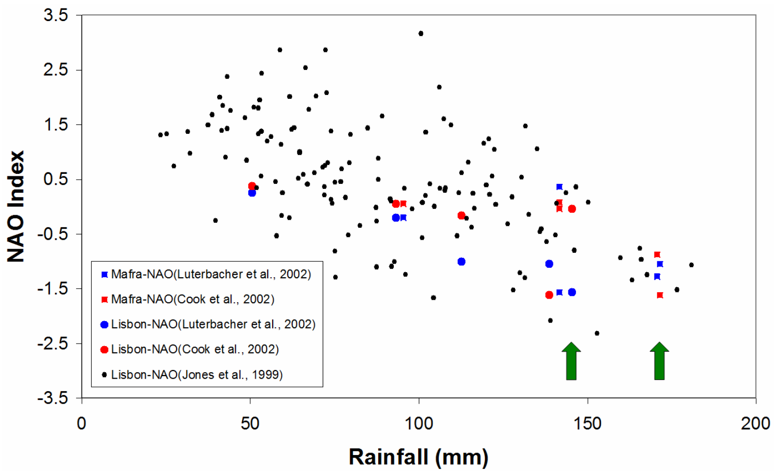

Fig. 12. Relationship between the average monthly precipitation for winter (DJFM) and the winter NAO index (DJFM). Arrows show the values for the 1783–1784 winter (see text for details).