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500-year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations

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Abstract The paper reports the main results of the EU project Millennium in the Mediterranean area over the last 500 years. It analyses a long series of temperature from Portugal, Spain, France, Italy and Greece. The series are obtained by combining indices from documentary sources from AD 1500 to the onset of regular instrumental observations. There is an ongoing discussion regarding the proper way of combining documentary and instrumental data and how to translate accurately the conventional indices from −3 to +3 into modern units, i.e. degree Celsius. This paper produces for the first time a number of early instrumental observations, in some cases (i.e. Italy and France) covering 350 years, including thereby the earliest regular observations

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after the invention of the thermometer. These Mediterranean data show that anomalous temperatures usually had only a locally limited effect, while only few extreme events had a widespread impact over the whole region, such as the summer of 2003. During the period from 1850 to the present day, the Mediterranean temperature anomaly was close to the Northern Hemisphere in spring and summer, while it was warmer in autumn and winter. Compared with the long-term instrumental records (i.e. 1655 onwards), the recent warming has not exceeded the natural past variability characterized by heating–cooling cycles with no significant long-term trends.

1 Introduction

This work presents the research activities performed by a large research group in the context of the Sixth EU Framework programme Millennium. The aim is to understand better the past climate of the Mediterranean through the gathering of new information from both documentary proxy (DP) and instrumental observations (IO). The sites under examination (Fig. 1) are located in an area within 35° to 50° N and 10° W to 25° E: most of them are situated in the three large European peninsulas (the Iberian, Italian Peninsula and Balkan). A system of fold mountains, including Pyrenees, Alps and Balkans, separate the Mediterranean from the continental regions of Western and Central Europe. The Mediterranean climate is characterized by the polar-ward (summer) and equator-ward (winter) shift of the Azores subtropical high-pressure cell. As a consequence, during summer the Western Mediterranean is invariably dominated by an anticyclonic circulation, with dry sinking air capping a surface marine layer of varying humidity leading to no rain in Central Mediterranean but thunderstorms in the North. On the other hand, in winter the polar jet stream and

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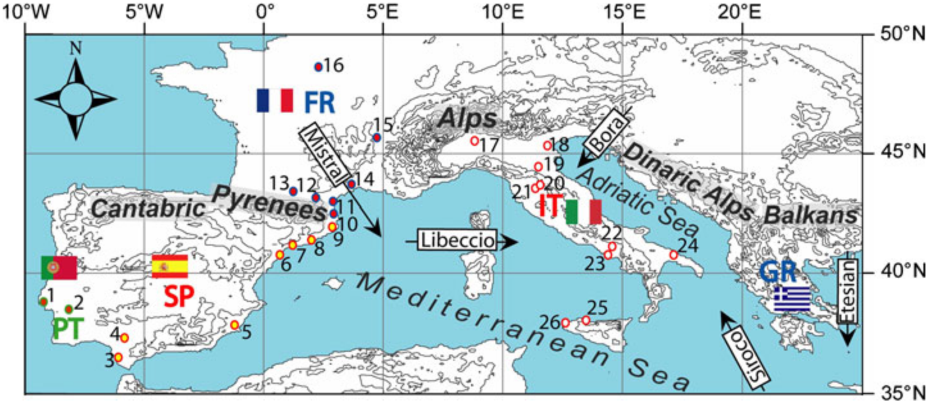


Fig. 1 The Mediterranean Basin with the indicated locations (*circles* with progressive number label and flag colour code) where documentary proxies and/or instrumental observations have been retrieved for use in this paper, divided by countries: Portugal (*PT*), Spain (*SP*), France (*FR*), Italy (*IT*) and Greece (*GR*). The stations are: *1*: Lisbon (PT), *2*: Évora (PT), *3*: Cadiz (SP), *4*: Seville (SP), *5*: Murcia (SP), *6*: Tortosa (SP), *7*: Tarragona (SP), *8*: Barcelona (SP), *9*: Girona (SP), *10*: Perpignan (FR), *11*: Narbonne (FR), *12*: Carcassonne (FR), *13*: Toulouse (FR), *14*: Montpellier (FR), *15*: Lyon (FR), *16*: Paris (FR), *17*: Milan (IT), *18*: Padua (IT), *19*: Bologna (IT), *20*: Vallombrosa (IT), *21*: Florence (IT), *22*: Benevento (IT), *23*: Naples (IT), *24*: Locorotondo, *25*: Palermo (IT) and *26*: Erice (IT)

the associated periodic storms frequently reach the Mediterranean region, bringing heavy rain. More details about the Mediterranean climate can be found in UK Meteorological Office (1962), Reiter (1975), Wallén (1970, 1977), Jeftic et al. (1992), Camuffo et al. (2000a), Xoplaki (2002), Bolle (2003), Xoplaki et al. (2003, 2004), Fletcher and Spencer (2005), Lionello et al. (2006), Luterbacher et al. (2006).

The Mediterranean has an exceptionally large quantity of data available for past climate reconstructions, including documentary proxies (DP) and instrumental observations (IO). A notable effort has been made to gather temperature and precipitation data in a number of countries in the Mediterranean Basin, i.e. Portugal (PT), Spain (SP), France (FR), Italy (IT) and Greece (GR), supplemented by good records consisting of DP for the period 1500–1799 and IO with corresponding metadata from 1655 onwards. However, for sake of shortness this paper will deal only with temperature. The earliest regular instrumental observations started in Italy in December 1654, when temperature readings were recorded up to eight times a day (Camuffo 2002a; Camuffo et al. 2009). A major effort has been devoted to transform early, never-before utilized, or even unknown observations into modern series and units, through rigorous quality controls, validation, correction and homogenization. The series have been expressed in terms of anomalies with respect to the 1961–1990 reference period in order to identify local trends. The high quality of the data permits a high signal-to-noise ratio, allowing for a better identification of long-term temperature evolution. The effort to calibrate written sources by cross comparing DP with IO in the common period revealed some concerns that will be discussed later on. Problems and uncertainties increase going back in time, when both DP evidence and the earliest IO become less frequent and precise. Nevertheless, always keeping in mind these limitations, combining data from these two sources allowed us to compose an interesting overview of the climate of the Mediterranean over the last five centuries.

2 Documentary sources in the Mediterranean area

Documentary proxies (DP) consist of different kinds of first- and second-hand written sources, i.e. narrative, administrative and daily weather logs, with different reliability levels (Enzi and Camuffo 1995; Pfister et al. 1999). Narrative sources (NS) are generic description of events, such as chronicles, annals, diaries, early scientific treatises, poems, correspondence, and compilations of remarkable events, usually known as *Mirabilia*—the Latin word for "extraordinary events". NS can be manuscript or printed, while their characteristics follow the literary genres on fashion during the various historical periods; they were often produced for purposes of communication. NS typically report exceptional climatic events with some impact on the society, e.g. extreme cold or hot, periods of inactivity of mills, drying up of fountains for shortage of water supply, lack of water hindering river navigation, over-abundant rains and rivers in flood, large water bodies completely frozen over an unusually frigid winter.

Administrative sources (AS) are documents written by public officers usually to discuss a specific problem, its impact and the course of action undertaken in order to solve it. AS are objective, reliable, precisely dated and often forming series of events precisely placed in a space and time. This kind of record increased in number with the development of national states (fourteenth to sixteenth centuries), when all over Europe specific departments were created to control the respective territories, sometimes with a special eye for the environment. In some cases the royal power established a centralised control of administration in opposition to the clergy. This happened in France (Garnier 2007) with the Royal Administrative Archives and, starting from the sixteenth century, the king of France created a number of public offices with specific tasks (the Forestry Commission, the Department of Civil Engineering Navy). Scattered in the provinces, governmental officers noted all the main weather events and assumed that risk of atmospheric hazards was randomly distributed in opposition to the determinism supported by the Church. Several Mediterranean towns produced local records, in France these were called "Mercuriales", which included food prices and timing of the harvest. French harvest bans and dates were one of the first-used proxies (Le Roy Ladurie 1971; Chuine et al. 2004). Such public administration bodies evolved over time into great complexity, not only in Europe but also America, Africa and Asia. Ecclesiastical sources (ES) are a particular type of administrative sources. The Catholic Church had a strong control over the territory and often maintained parish registers reporting weather injuries, mortality caused by natural hazards (famines, droughts, snow, floods, pestilences) and other relevant phenomena. Clergy recorded liturgical services and rogation ceremonies commissioned by local communities or authorities in case of adverse weather conditions. *Pro pluvia* were the rogations celebrated for rain in case of draught, while *Pro serenitate* were offered in the hope of a cessation to prolonged rain. The Church organization reached the same level of complexity of the State in economic, fiscal, institutional, judicial, educational and health matters. Daily weather logs (WL) were kept by some early meteorologists and other scholars, e.g. astronomers, natural philosophers, chronicle writers, most of whom were authors with a scientific background. These are a particular category of documents, mainly starting from the sixteenth century and encouraged by the advent of the academies and other scientific societies in the eighteenth century (Camuffo and Enzi 1992a, 1994). The chronological distribution of DP varies widely over the centuries. Information from early Middle Age is rare, but is followed by a progressive increase in data frequency. Administrative sources, usually handwritten, can be mostly found starting from the fifteenth century.

DP can be divided into three main subgroups: (1) the ‘first class’, includes reliable contemporary manuscripts; (2) the ‘second class’ reliable but not contemporary collections; (3) the ‘third class’ less reliable sources that should be rejected (Alexandre 1987; Pfister et al. 1998; Brázdil et al. 2005). It is generally assumed that the dating of contemporary chroniclers who lived the events they describe is reliable. However, it is reasonable and useful to verify the dating accuracy with cross comparison with independent factors, e.g. similar descriptions, historical analysis of social events found in the manuscript, cross checking with astronomical features (e.g. passage of comets, solar and lunar eclipses) whose dating is known from astronomy (Camuffo and Sturaro 2004). This step prevents the spurious multiplication of extreme events. According to Camuffo and Enzi (1992a) and Pfister (1992), non-contemporary material (second class) was not rejected out-of-hand if it was possible to validate it. Validated second-hand reports have been included in this work when they make a proven contribution to the understanding of past climate.

DP are generally commonly used to reconstruct past climates only in the absence of direct IO (Luterbacher et al. 2006) because they are often considered imprecise, highly subjective, qualitative, hardly transformable into quantitative indices, while IO are considered precise, objective, with high resolution. The truth is that proxies are not a duplicate of, or equivalent to, instrumental records, and the information they provide is different. Keeping in mind the above-mentioned differences and limitations, DP often include much more information than IO, which provide a quantitative measurement of selected atmospheric variables at a given instant in time. DP provide a much wider picture of events, telling us what happened in a certain area and for a certain time, often pointing out cause–effect relationships, offering a variety of weather information, and producing a quasi-objective index scale. In general, written proxies provide a qualitative or a semi-quantitative synergistic effect of one or more atmospheric variables (Enzi and Camuffo 1995).

DP are especially useful when they represent the effect caused by a long-term persistence of a certain meteorological variable, e.g. severe cold and water bodies frozen over; or mild winters and early plant growing. DP data need, however, some interpretation followed by a very careful and deep physical and historical validation in order to avoid possible mistakes in dating or interpretation.

DP are easily interpreted when they refer to events conditioned by thresholds. In the Mediterranean area in general, and for some regions in particular, DP indexing for near-normal temperature is a hard task. When the situation was not risky for agriculture, or other human activities, there was no special reason for chroniclers to mention minor departures from the average. Extreme meteorological events and natural hazards are better documented and constitute the best information in this context (Daveau 1997; Barriendos and Martin-Vide 1998; Alcoforado et al. 2000; Camuffo et al. 2000a, b; Piervitali and Colacino 2001; Brázdil et al. 2006; Diodato 2007; Garcia-Herrera 2008). DP are well distributed over the Mediterranean region, and are particularly abundant in Italy, France and Iberia. According to Alexandre (1987), 35% of all documents available for the Middle Age in Central Europe are from Italy. In contrast, DP are less frequently found for the Balkan area, i.e. Greece, and the former Yugoslavian countries, Albania, Bulgaria and Romania that suffered from wars and other challenges from the fifteenth to the nineteenth centuries.

However, some data have been collated and analyzed (Repapis and Philandras 1988; Grove and Conterio 1994, 1995; Xoplaki et al. 2001; Telelis 2004, 2008).

3 Documentary proxy indexing: a discussion on methodology

In this paper, a special effort was made to transform DP into numerical indices to secure a quantitative evaluation of the local trends of temperature and precipitation over the last 500 years. All DP series produced within MILLENNIUM have been indexed following an agreed protocol, i.e. all information from documentary proxy has been transformed into a numerical value. This value is based on the effects that reflect the severity of the event. However, two kinds of difficulties were found when indexing DP. The first was qualitative, i.e. to establish a clear correlation between this index and a meteorological variable. The second was quantitative, i.e. to transform the DP into a numerical index. Regarding the qualitative aspects, data were selected only when the link between the meteorological event and the index value was clear and reliable. For instance, the thickness of the ice slab formed in the cold season on large water bodies helped to classify winters into severity classes, but a careful interpretation is needed in such cases, and the context changes with space and time. Let us consider for instance two different scenarios regarding a frozen water body. A closed water body e.g. a lake with small exchange of waters—has a cumulative effect and it may form slabs of ice after water has lost enough heat. This may happen either after a long-term light cooling, or after a short-term of intense cooling. A lake has a long-term memory, but may equally respond to short, strong forcing pulses. In contrast, an open water body, e.g. a lagoon with continuous exchange with the sea, has a different behaviour. The heat losses cannot be accumulated and the lagoon has a short-term memory; it cannot freeze merely because the winter was long, but it needs 2 or 3 weeks of very intense cooling, possibly worsened by fresh wind, to freeze over. Not in all severe winters both lakes and the Venice Lagoon were frozen over (Camuffo and Enzi 1992b). In the past times rivers formed marshes of stagnant water where ice slabs were easily formed and later transported by the current until they were eventually stopped at some bend, forming an ice bridge that soon extended from one bank to the other. Marshes were later drained to provide better flow and protection. Over the years, the same river needed a different cold threshold to freeze over. In conclusion, the same cause does not always generate the same effect. DP provide information that depends on the particular nature of each phenomenon and its environmental context, and it may be variable over the course of time. The index classification of events should reflect the climate of the region in order to represent its real exceptionality, but differs from country to country. For instance, to find a lake frozen in the northern regions or on the mountains is frequent (e.g. class-1), but exceptional in southern areas (e.g. class-3). A list of numerical indices and the relative description of event severity is given in Table 1 for temperature. This table helps to transform each DP into a numerical level x_i, in quantitative terms, which range from -3 to $+3$, 0 being the normal. After the first-order individual classification made by reading the descriptions and judging from the effects is concluded, we pass to a second-order ensemble classification. The population of each class should reflect the Gaussian distribution in Table 2, with frequent normal events, less frequent severe, and very rare exceptional ones. Events are classified in terms of standard deviation

Table 1 Temperature indexing from qualitative descriptions of documentary proxy (DP)

Index	Comments
+3	Extremely hot—not applicable for winter, very hardly for summer. Not easy to establish on a objective ground, often mixed and confused with dry and arid, especially in the summertime
+2	Hot—not applicable for winter, hardly for summer. Many people die, but possibly for epidemics; reduced yield or damage to crops probably connected with aridity
+1	Warm. Applicable for hot summer: index established after (subjective) complaints from a number of witnesses. For mild winter: early plant growing and flowering, early migratory bird arrival
0	Normal. Situation as usual, no special comments; sometimes, declared "normal" in the sources
−1	Cold. Complaints for unusual cold and need for heating or heavy clothing; some damage to local agriculture
−2	Severe cold. Applicable for severe winters, hardly applicable for summer. Winter: People, animals and plants killed by cold. Slab of ice cover large water bodies (including the Venice Lagoon). Summer: continuous cloud cover and rains, almost never sunshine
−3	Extremely severe cold. Applicable for great winters, not applicable for summer. In addition to the above descriptions, wine freezes into the barrels, springs and wells frozen over, rivers, lakes and other large water bodies completely covered with a thick slab of ice, supporting carriages and people walking on it

This index has been used for all the Mediterranean locations

(SD) into seven intervals, bound by ±0.5 SD, ±1 SD, ±2 SD or greater. The same methodology was followed for Greece by Xoplaki et al. (2001) but with slightly different intervals, i.e. ±0.7 SD, ±1.4 SD, ±2 SD. If we impose that the frequency distribution of x_i should be the same as IO, this leads to a further improvement of the x_i levels. Now, it is possible to express the index, in terms of temperature (°C). When a period is simultaneously covered with both DP and IO the overlap provides for the possibility of calibration and verification. It is however necessary that both DP and IO have the same distribution, i.e., the same range, mode and SD.

In a Gaussian distribution, the mode coincides with the mean and the 50th percentile and becomes the zero reference of selected periods (e.g. 1961–1990) when computing the respective anomalies. This is simple with IO, a more difficult with DP. By definition, the mode is the most frequently occurring class and, therefore typical of that time and therefore linked to the expectation of the observers who considered it as the 'normal' situation. Temperatures below the "normal" were perceived as

Table 2 Classification in terms of standard deviation (SD) obtainable from the scatter of data

Index	Type	Classification	Population (% of total data)
+3	Extremely high	$x_i > 2$ SD	2.1
+2	Very high	1 SD $< x_i <$ 2 SD	13.6
+1	High	0.5 SD $< x_i <$ 1 SD	15
0	Normal or no comments	−0.5 SD $< x_i <$ 0.5 SD	38.3
−1	Low	−0.5 SD $< x_i <$ −1 SD	15
−2	Very low	−1 SD $< x_i <$ −2 SD	13.6
−3	Extremely low	$x_i <$ −2 SD	2.1

negative (e.g. cold, dryness), above positive (e.g. warm, rainy) and it is this perception that is reflected in the numerical values of indices. The aim here was to establish for each proxy a scale of the correct distribution of the indexed variable, as we know it today, but in modern units. The distribution of temperature is generally Gaussian. The problem provided by DP is that the human factor may increase skewness, emphasizing the most dangerous events, e.g. an unusually hot summer or cold winter. These extremes are well documented for their negative impacts on people and land; on the other hand, the converse position i.e. mild summers or winters, are less threatening and, consequently, less clearly documented. Unfavourable extreme events, which have caused severe damage or social consequences, have a higher probability of being recorded compared with less relevant events that had a minor impact. For this reason we first applied a temporary index based on the documentary text and then made use of the properties of the Gaussian distribution. A large number of random events follow this bell-shaped distribution, characterized by a peak value that corresponds to the most frequent event (i.e. in our case the climatic average), and its width which is characterized by the standard deviation (SD). The number of events included between −1 SD and +1 SD is 68% of the total, 95% between −2 SD and +2 SD and 99.6% between −3 SD and +3 SD, etc. Percentiles can be used therefore to represent points along the Gaussian curve. Therefore, if we start from a set of samples ordered from the smaller to the larger value, and we express them as a percentage, the 0.15 percentile corresponds to 3 SD, the 2.1 percentile to −2 SD, the 13.6 percentile to 1 SD, the 50 percentile to the average, the 86.4 percentile to +1 SD, the 97.9 percentile to +2 SD, the 99.85 percentile to +3 SD etc. As positive and negative values, e.g. hot and cold, are derived from different phenomena and involve different perceptions, it was appropriate to regard positive and negative values in different contexts. The unknown level of the SD of documentary proxy was calibrated from the known values of the instrumental readings. In this way we calibrated our series moving from arbitrary values to an evaluation in degree Celsius. By applying to DP the SD observed with IO for each geographical area, the indexed data were corrected to take account for the bias introduced by writers of such documents.

4 Meteorological networks and individual instrumental observations

The key meteorological instruments (thermometer, barometer, rain gauge and some hygrometers) were invented or improved in Italy in the first half of the seventeenth century thanks to a synergism between the Grand Duke of Tuscany, Ferdinand II De' Medici (1610–1670) and Galileo Galilei (1564–1642), who invented the thermometer in 1597. Ferdinand II was active in refining the instruments and founded the first meteorological network, called *Rete Medicea* (i.e. Medici Network, 1654–1670) for fundamental studies of meteorological variables and climate through the activities of the *Accademia del Cimento* (Academy of Experimental Observations: 1657–1667). This was the first Academy of Sciences, also founded by the Grand Duke, to study Nature through objective instrumental observations as opposed to the Aristotle's tradition based on subjective thought and unverifiable hypotheses. Luigi Antinori was Secretary of the Network while Lorenzo Magalotti occupied the same role for the Academy; Antinori distributed standardised instruments to all stations and established observational practices (Magalotti 1667; Targioni Tozzetti 1780). Daily regular temperature readings were made outdoor with two Little Florentine spirit-in-glass thermometers, one hung on a wall facing north and one facing south, in order to measure air temperature and the effect of sunshine. Readings were scheduled six to eight times a day in Florence (IT), Vallombrosa (IT) Cutigliano (IT), Pisa (IT), Parma (IT), Bologna (IT), Milan (IT), Innsbruck (Austria), and Warsaw (Poland), shortly later followed by Paris. The most famous observers were Vincenzo Viviani, Alfonso Borelli, Fathers Casini and Paceschi. Readings were daily or weekly sent to the Grand Duke, depending on the distance from the station.

Other international networks were later established (Camuffo 2002a). The first attempt was made by Robert Hook in 1660 on behalf of the newly founded Royal Society, London. However, this was a limited attempt. The next international network was successfully created in 1723, when James Jurin (1723) published a plea to join the correspondence network of the Royal Society. The Network was active for the period 1724–1735 for meteorological and medical purposes but, unfortunately it was proposed that observations were made indoors and for two reasons: (1) the need to know more living conditions in often unhealthy houses, (2) most of the early thermometers, made with a glass capillary fixed to a wooden tablet with an iron wire were not resilient to outdoor conditions. Observations were published in the *Philosophical Transactions.* Weather investigations connected with health arose from a very old medical theory inspired by Hippocrates (treatise *On Air*,*Waters and Places*, written 400 BC) and Galen of Pergamon (second century AD) who claimed a relationship between epidemics and climate, which was a reasonable hypothesis, especially in the absence of hygienic conditions and in warm regions.

In France, a similar activity was undertaken 50 years later under the patronage of Louis XIV. Felix Vicq d' Azyr, specialist in anatomy and queen Marie-Antoniette's physician, set up a network of the newly created Societé Royale de Médecine (Royal Society of Medicine), Paris. The aim of the network was to establish a link between weather and health by collecting meteorological observations and medical reports related to man and animal epidemics in France and other countries (Maraldi 1732). Father Louis Cotte collected and published the meteorological observations in *Histoire*, the official journal of the Society for the period 1777–1786. Unfortunately, the Societé Royale de Médecine, was suppressed in 1793 by a French Revolutionary decree.

At the same time, the German Prince-Elector Karl Theodor von Pfalz founded another international initiative: the *Societas Meteorologica Palatina*, Mannheim. Secretary was Jacob Hemmer (1783) who published readings in the *Ephemerides Societatis Meteorologicae Palatinae* (1781–1792). This network was composed of 35 stations in Europe none of which were in Britain or the Iberian Peninsula; although there were three stations in Russia, one in Greenland and two in America.

In Paris (Legrand and Le Goff 1992; Slonosky 2002), Louis Morin started his regular daily observations (1665–1713). The construction of the Paris Royal Observatory, started in 1667 and was completed in 1671, the first director being Gian Domenico Cassini (director 1671–1712) a former member of the *Cimento Academy* who began the series of meteorological observations. His co-worker was Philippe de La Hire (readings 1669–1718) who used a Florentine thermometer probably brought by Cassini from Florence to join the Medici Network. Leading scientists who contributed to the Paris series were René Réaumur, Antoine Laurent de Lavoisier and Urbain Le Verrier. The meteorological observations in Paris started to be published in 1798 in the *Journal de Physique*.

All of the above networks had the primary merit of raising the interest in regular daily observations, made with high-quality, standardized instruments, all of them having the same, or a similar exposure, and with readings performed at the same local times. The development of the meteorology is indebted to some leading scientists whose work represents a milestone for the scientific community. Some of these early records were published in contemporary journals while others, handwritten in the original logs and including both observations and notes about instruments, calibrations, and observational methodology, were dispersed in public and private libraries and archives. Within the EU funded projects ADVICE, IMPROVE (Camuffo and Jones 2002) and MILLENNIUM, an effort was made to find the original readings, and recover, correct, adjust to modern standards, homogenize and analyze most of these longest European data series. In this paper we will present only the series that have been made available either in their totality or for some previously unexploited periods (Table 3). The series used in this paper were selected from among a number of available data for the following reasons: (1) exceptional length of the period covered, (2) continuity of the instrumental use, location, observational methodology and careful observers, (3) reliability of the series checked established following a study of data, metadata and the application of homogenisation tests. In those cases where it was not possible to verify the accuracy of an instrumental series from the

Table 3 Instrumental Series produced within MILLENNIUM and/or used in this paper

Country	Location	Length	First observer	MILLENIUM new period	References
Italy	Florence	1654–2007	Rete Medicea	1654–1670	Maracchi (1991); Crisci et al. (1998)
Italy	Vallombrosa	1656–2003	Papeschi and Casini	1656–1670	Gandolfo and Sulli (1970)
France	Paris	1676–2007	Morin	1676–1712	Legrand and Le Goff (1992); Slonosky (2002)
Italy	Padua	1716–2008	Poleni	1716–1769	Camuffo (2002a, b, c); Cocheo and Camuffo (2002); Camuffo and Bertolin (2010)
Italy	Bologna	1716–2007	Beccari	1716–1774	Baiada (1986); Brunetti et al. (2001)
Italy	Naples	1727–2003	Cirillo	1727–1754	Cyrillus (1731–1732)
France	Lyon	1740–2007	Jesuits Fathers	1740–1780	
France	Toulouse	1750–2007		1750–1850	
Italy	Milan	1763–2007	Lagrange		Maugeri et al. (2002)
Spain	Barcelona	1780–2007	Salvá	1780–1825	
Portugal	Lisbon	1783–2007	Velho		Maheras et al. (1994, 1995); Alcoforado et al. (2000); Taborda et al. (2004)
Spain	Cadiz	1787–2004	de Mazzaredo		Barriendos et al. (2002); Rodrigo (2002); Gallego et al. (2007)
Italy	Palermo	1791–2006	Piazzi	1791–1853	Chinnici et al. (2000); Micela et al. (2001)

cross comparison with another used as a reference, but where dendrochronological series were available for the same locality and period, these have been used to assess the reliability of the instrumental series under evaluation. For instance, this procedure has been applied to the early period of the French observations which were compared with tree-ring evidence (Etien et al. 2008).

5 Applied methodology for data analysis

5.1 Data homogenisation by means of direct methods

All the daily data were first transformed into monthly series and then presented as seasonal means (i.e. winter: DJF, spring: MAM, summer: JJA, autumn: SON), except when the time resolution was low and only annual values could be provided. The series were all expressed in terms of anomalies from the reference period (1961–1990) in degree Celsius for temperature. Most of the IO presented in this study concerns the Early Instrumental Period (EIP) 1654–1849, before the extensive standardization of instruments and methods that took place in the second half of the 19th century. It was necessary to get as many metadata as possible in order to reconstruct the detailed "history" of all the readings and perform a first homogenization based on objective information extracted from the station history and other related sources. The next step was to study instrumental problems, calibration, observational methodology, exposure, location; all of which were needed to establish the corrections required for the series (Camuffo 2002b; Cocheo and Camuffo 2002). The methodology is the same as that presented within IMPROVE (Camuffo and Jones 2002) and later applied to the HISTALP dataset (Böhm et al. 2009) for the Greater Alpine Region. Metadata allowed for the proper management of inhomogeneities resulting from the following problems:

1. *Style used to compute the hours of the day.* From the fourteenth century until the French Revolution in 1789, the official day started from the twilight, at the ringing of the *Angelus bell* and subsequent hours were regulated by bell tolls according to the ecclesiastic system. This use is known as 'Canonical Hours' or 'Italian Time'. Being linked to the sunset, the *Italian Time* was variable during the calendar year, and it did not have finer subdivision, given the limited accuracy of early mechanical clocks. Readings taken following the *Italian Time* were transformed into modern time units, i.e. *Central European Time.*
2. *Readings at different times*. In the EIP, readings were often made at different hours during the day. In the case of the Medici Network with six to eight observations per day, this was not a problem because it was easy to extrapolate the maximum and the minimum temperature for each day. In some fortunate cases, observations were made near sunrise and 1 or 2 h after noon. Problems arose when the readings were made at times far removed from those when the minimum and maximum temperatures might be expected e.g. the first reading in the morning made 1 or 2 h after the sunrise, or readings with irregular sampling intervals (for a discussion see Camuffo 2002c). When we had only one observation a day, taken at the same hour, the anomaly was computed as the difference from the available observations (as was the case for Florence, 1751–1766) and the corresponding average for the same hour in the reference period 1961–1990.

In those cases where the hour was not specified, but was always the same, e.g. Naples 1737–1757, the hour was interpreted by comparison with the daily cycle in the modern reference period. In those cases of multiple daily readings the maximum and minimum temperatures were calculated by reference to the daily temperature cycle obtained from the modern hourly distribution, taking account also of its variability during the calendar year. The average daily temperature was the mean from the maximum and minimum temperatures because: (1) no alternative exists for large part of the early period; (2) the maximum and minimum average is in good agreement with the average from 24 hourly readings; (3) the need to use a homogeneous criterion throughout the series.

3. *Original versus Celsius Scale*. In the EIP, all the IO had particular scales, some of them unknown. The scale transformation to Celsius degrees was possible because of: (1) direct information on the instrumental calibration, e.g. the Little Florentine Thermometer (Vittori and Mestitz 1981); the Stancari thermometer used in Bologna had notes in the Beccari log; the Hauksbee thermometer of the Royal Society, London, used in Naples had comments concerning problems with the freezing point (Cyrillus 1731–1732); (2) the availability of simultaneous readings of diverse instruments, one of which with known calibration, e.g. an unknown thermometer used by Beccari in Bologna that was compared with simultaneous Réaumur readings.
4. *Transformation of indoor into outdoor readings*. This is a recurrent problem. In Padua, the second Poleni period (1725–1764) provided indoor temperature readings. However, referring to the simultaneous indoor and outdoor readings made by Morgagni for the period 1740–1768 not more than 1 mile far from the Poleni house, it was possible to transform the whole period 1716–1764 into standard outdoor temperature readings. The indoor–outdoor transformation was reliable except for short spells of 1 or 2 weeks of very cold conditions in winter when the thermal inertia of the building became a factor. Fortunately in the most relevant of such cases some additional observations were made outdoors (e.g. Poleni 1740; Temanza 1755 in Toaldo 1781). Also the earliest period of the Beccari's observations in Bologna, i.e. 1716 to 1741, was with indoor readings only and the data needed to be transformed into outdoor ones. This was possible because, fortunately, later on Beccari made simultaneous outdoor readings with two Réaumur thermometers, and it was possible to establish the indoor–outdoor transfer function with very high correlation coefficient ($R^2 = 0.98$) and transform all the indoor readings into standard outdoor observations.
5. *Overestimate of temperature*. The earliest measurements were made with thermometers exposed outdoors in a wall facing north in order to avoid sunshine, following the recommendations by Luigi Antinori (1654) and Jacob Hemmer (1783), or in a room facing North where fire was never lit, following the recommendations by John Locke in the 1660s and James Jurin (1723). However, in some cases of the earliest period and before the invention of any form of shielding, the absolute maxima might be over-estimated in the case of the thermometer being exposed to some radiation. The first time when any such remedy was applied against the solar radiation was in 1780 and the first mention of a shield was found in 1785, both due to G. Toaldo (Camuffo 2002a). Screens started to be used after 1835 (Middleton 1966). For this reason early very high maxima might be the result of poor exposure of the thermometer.

5.2 Data homogenisation by means of indirect methods

Readings from the EIP are not easy to manage in terms of homogenisation. The standard approach based on applying some statistical tests to the differences (or ratios) among one candidate series and one or more reference series is often problematic as going back in time the number of available series decreases and the factors leading to inhomogeneity increase. Once the series had been homogenised for the above issues by reference to the metadata, the next step consisted of a statistical testing of the records with the Standard Normal Homogeneity Test (SNHT) by Moberg and Alexandersson (1997a, b). Useful references were those series already homogenised and corrected series within IMPROVE, i.e. Padua (IT), Milan (IT), and Cadiz/San Fernando (SP).

5.3 Low-pass filtering

In order to give better evidence the variability at decadal time scale, the final records were filtered with a bell-shaped low-pass filter by Hamming (Wei 1990):

$$D(\tau) = \begin{cases} 0.54 + 0.46 \cdot \cos \frac{\pi \tau}{\tau_m}, \, |\tau| \leq \tau_m \\ 0, \, |\tau| > \tau_m \end{cases}$$

where τ_m is the window, i.e. 11 years, and τ the time variable with 1 year steps.

6 Results and discussion

The present analysis includes only long-term, high-quality time series produced within the MILLENNIUM project and only European stations of Central and Western Mediterranean have been included. It would have been useful to include Greece for its location and in particular Athens for the exceptional length of the series (1891–today). However, this series was tested for homogeneity and found to include suspect or doubtful data before 1979 (Tank 2007) and after 1995 (Repapis et al. 2007) and although the latter period has now been revised by Founda et al. (2009), the series has been excluded because some problems still exist.

In this paper, DP and IO concur together to provide a general view of the climate variability over the last five centuries in the Mediterranean Basin. DP are of the greater relevance to provide information before the instrumental period although they are affected by some subjectivity, with potential gaps and with indexing resolution limited to seven classes. Proxies and instrumental observations have been homogenized thanks to calibration and verification made on a common period for which both DP and IO were available. DP have been adjusted to IO and benefit of the same SD found for IO. However, despite all our efforts, some minor differences persisted between DP and IO. An example is shown in Fig. 2 where indexed DP and IO winter are reported from 1750 to 1800 together with their Hamming filter. The running averages are near-parallel with 0.5°C average difference showing that the information is reasonably reliable. Most of the individual points are reasonably coincident but in some cases, e.g. 1768, 1776 and 1777, the DP departs much more from the IO. When a period is not documented, this is an unavoidable gap in

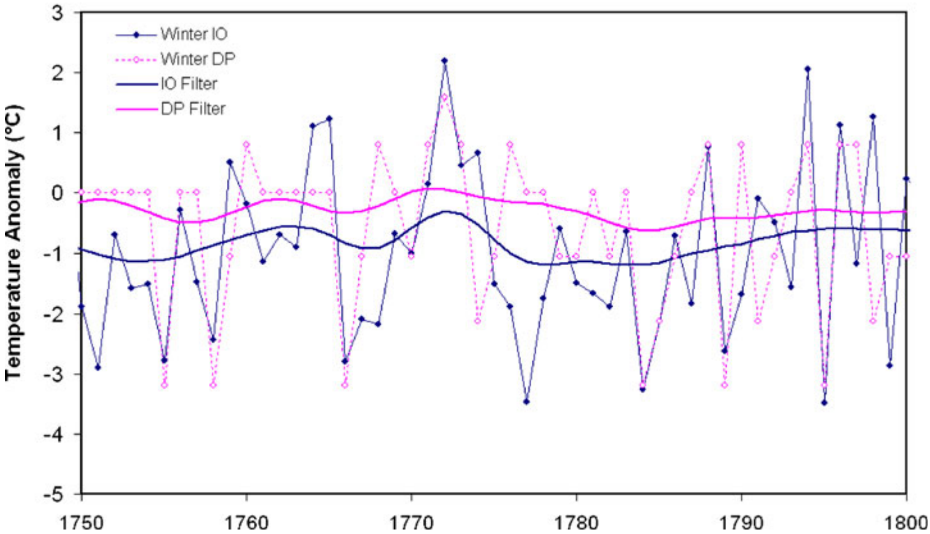


Fig. 2 Example of documentary proxy (*DP*) and instrumental observations (*IO*) of winter air temperature in Italy for the period 1750–1800. *Open circles* and *dotted thin line* refer to DP; *full circles* and *continuous thin line* to IO. *Thick lines* refer to 11-year filter, *pink* to DP, *blue* to IO

knowledge and no information. However, when a period is well documented but the chroniclers failed to report any weather information, the index is interpreted as a zero, i.e. a normal situation, as shown in Fig. 2. This justifies the high number of "normal" events in the indexing. In general this is a correct procedure, but sometimes it may be misleading. Another problem is the true zero DP level. As a result of the nature of DP records, it is not possible to establish trends or express them in terms of anomaly with respect to a given period as 1961–1990. In the case of IO continuing to the present-day the matter is less complicated. However, matters are different for DP because the writer living centuries ago noted some events because he judged them 'anomalous' or 'exceptional' making reference to his experience and time. DP are intimately referred to their contemporary period, with a floating zero reference level. In our graphs the DP zero has been established to be coincident with the average of the whole available period of instrumental data (i.e. the average anomaly of all available IO). This choice, although arbitrary, avoids unjustified jumps in level when passing from DP to IO. So, the records that we got from superimposing DP and IO are useful in improving our knowledge about the Little Ice Age (LIA) but remain nevertheless partly inhomogeneous. From the mathematical point of view, a filter should be applied to homogeneous and continuous series but whatever the nature of the calibration and validation exercises, DP and IO preserve some differences in nature and have a slightly different confidence levels (e.g. DP have potentially missing or contradictory data, as discussed in Fig. 2). For this reason we preferred not to mix these two different forms of data and preserve each signal separately hence we preferred to interrupt the low-pass Hamming filter and introduce a break in the continuity when passing from the DP to the IO series. In the cases where the DP and IO overlap the filter is applied to IO only.

The result of the analysis for each country is reported in Figs. 3, 4, 5, 6, 7 and 8 which illustrate temperature anomalies from 1500 to the present. Extreme events

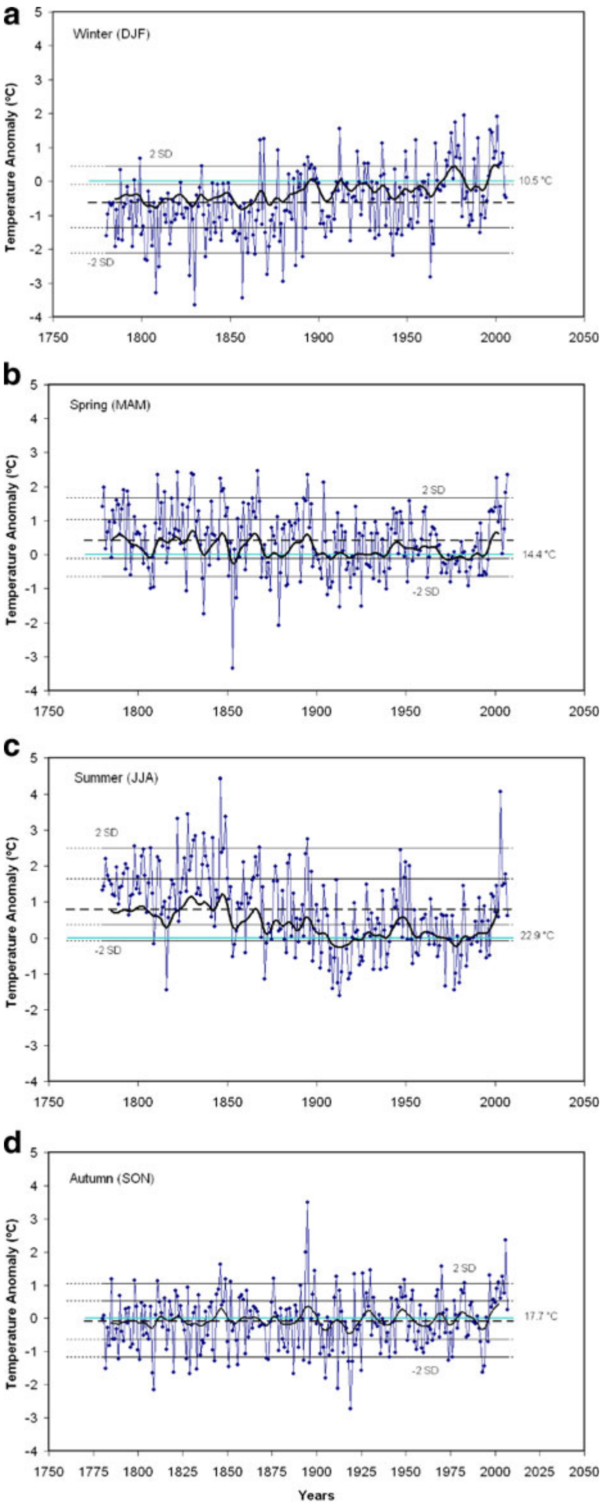


Fig. 3 Seasonal temperature anomaly (°C), reference period 1961–1990, Barcelona, Spain. **a** Winter (months *DJF*), **b** spring (*MAM*), **c** summer (*JJA*), **d** autumn (*SON*). Only IO. Continuous *thick black line* refers to 11-year Hamming filter, The *thick cyan line*, i.e. the Zero Anomaly line, is the seasonal 1961–90 reference period indicated on the right. *Thick dotted line* is the average of all IO, *Parallel thin dotted lines* are for ±1 and ±2 SD computed on IO. Positive and negative SDs are different, because the distribution is skew

Fig. 4 **a–d** Seasonal temperature anomaly (°C) for Cadiz, Spain

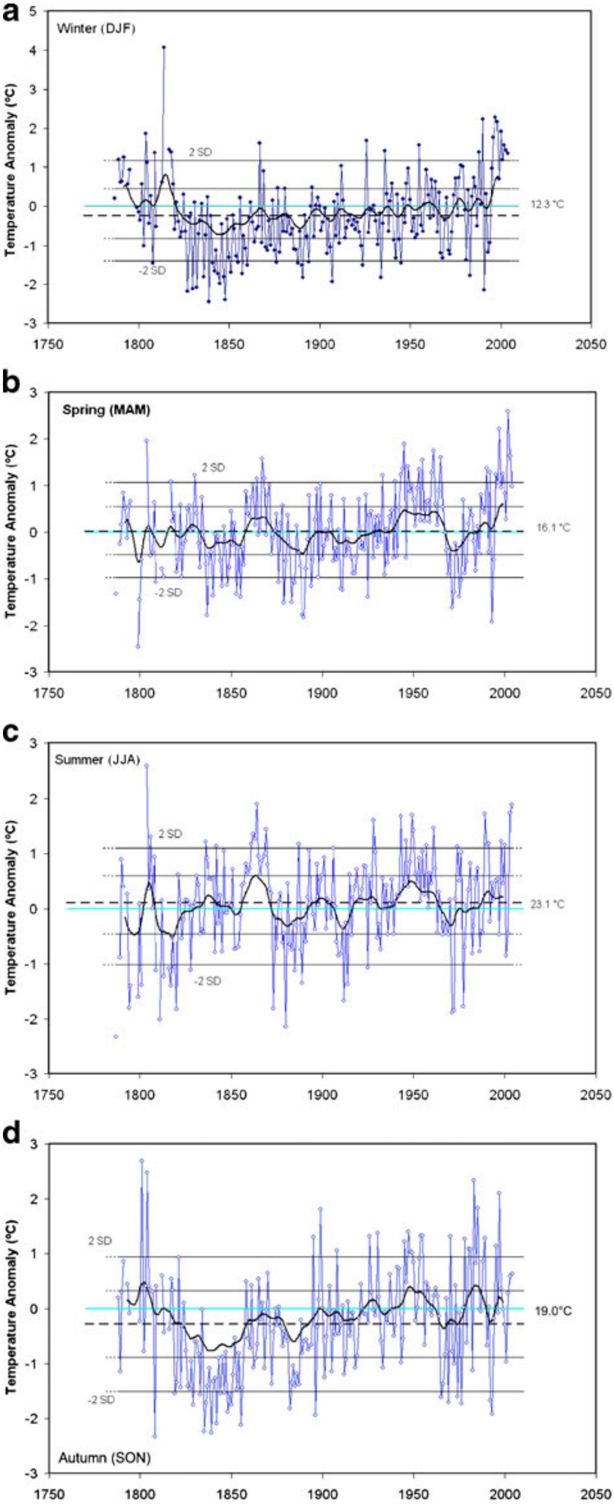


Fig. 5 **a**–**d** Seasonal temperature anomaly (°C) as in Fig. 4, but for France. *Open circles* and *pink dotted thin line* refer to the index from DP; *full circles* and *continuous blue line* to IO. *Continuous black line* for Hamming filter

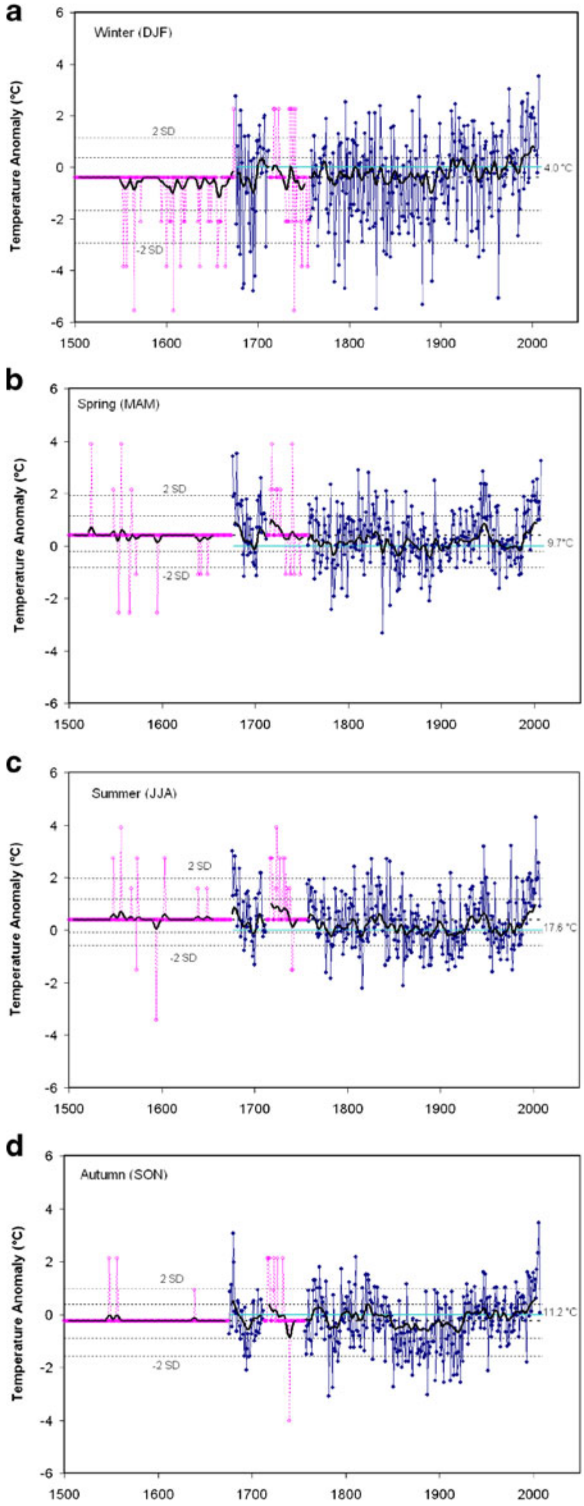


Fig. 6 **a**–**d** Seasonal temperature anomaly (°C) as in Fig. 4, but for Northern-Central Italy

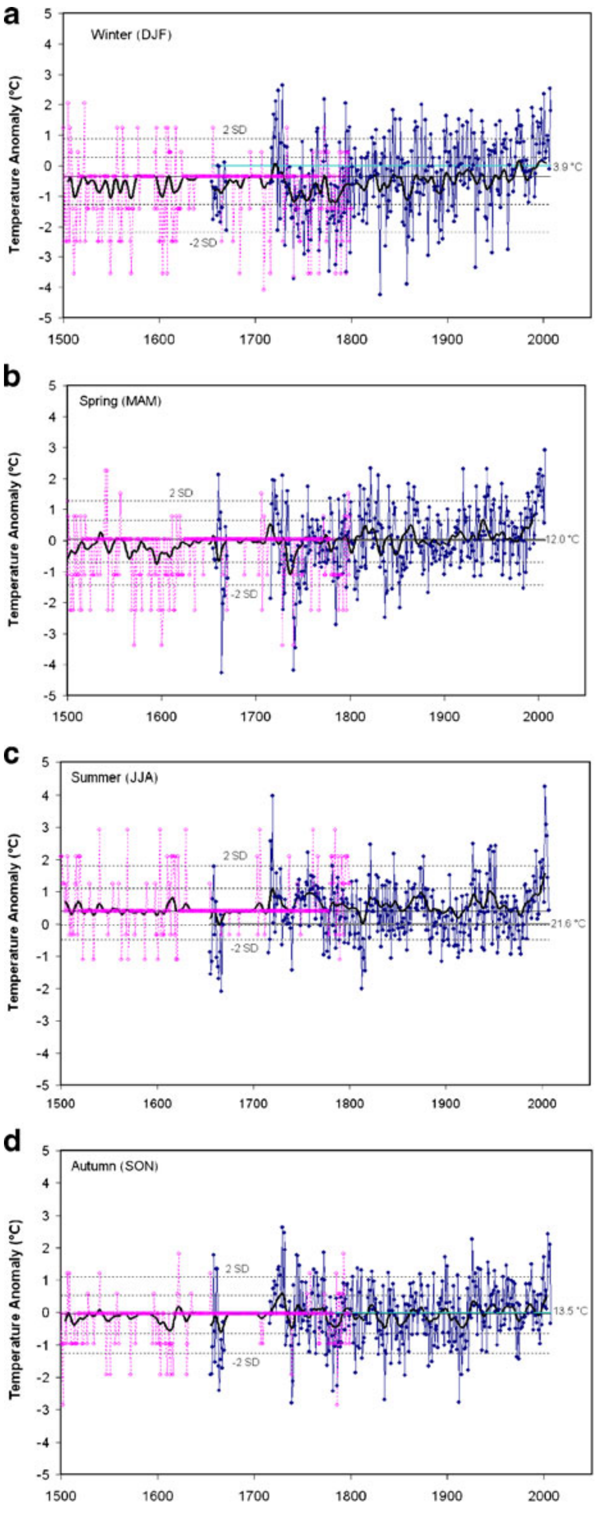
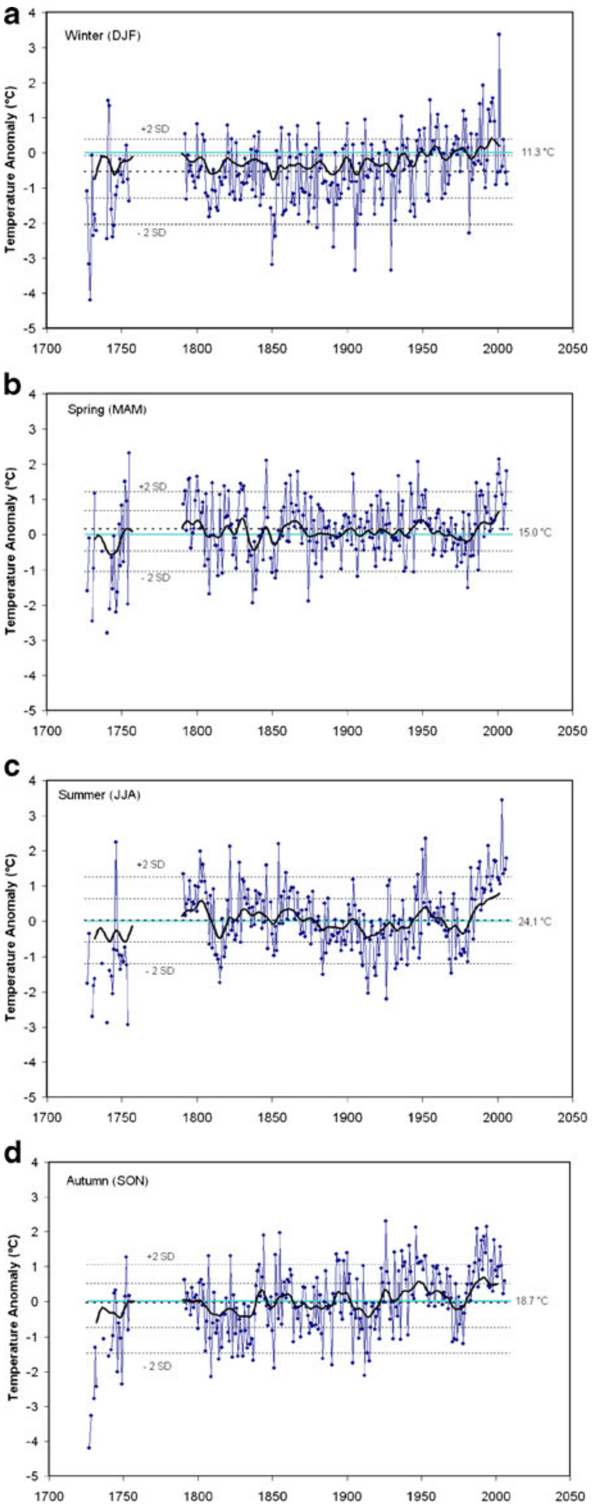


Fig. 7 **a–d** Annual temperature anomaly (°C) as in Fig. 4, but for Southern Italy. Only IO



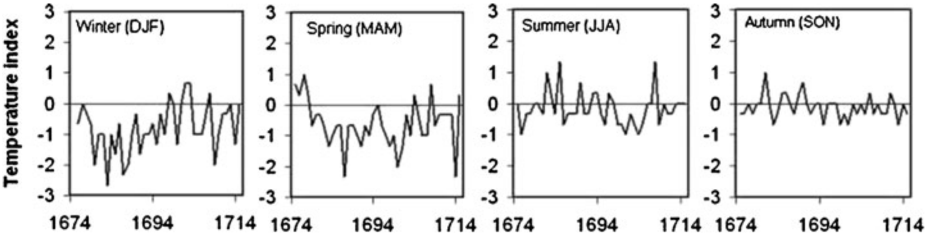


Fig. 8 Seasonal index of temperature in Greece for the period 1675–1715 from documentary sources

and some periods with increased frequency of anomalous weather are evident. For their nature, no trends can be established with DP. A foreword is necessary concerning the stations in the Iberian peninsula, i.e. Cadiz and Barcelona. Atlantic perturbations cross the Iberian peninsula before entering the Mediterranean and loose their strength passing over the land. Cadiz is on the Atlantic side and exposed to westerly winds. Barcelona is on the Mediterranean coast and exposed to easterly conditions. This causes a marked climate difference between Cadiz and Barcelona that changes season by season (Oñate and Pou 1996). As Cadiz and Barcelona belong to different climatic regions, it is impossible to apply tests for homogeneity between them. Although some uncertainty may remain, these two series have been recovered with the highest accuracy and verified on the grounds of metadata and statistical tests. The cross comparison, i.e. the Pearson determination coefficient R^2, between these two series and the nearby countries (Table 4) shows that Barcelona with the other Mediterranean stations, i.e. France and Italy, has an average R^2 greater than 0.5. The less Mediterranean Cadiz has a lower correlation, i.e. $R^2 > 0.4$ in winter and spring, but is almost zero correlated in the other seasons. Cadiz and Barcelona show an average teleconnection (i.e. $R^2 > 0.4$) in spring and winter, no correlation in summer and autumn. At a regional or national level, temperature trends are evident (Figs. 3–8, geographically distributed) only for particular periods, i.e., Barcelona (SP) where in winter (Fig. 3a) a warming trend started in 1880 and, in contrast, in summer (Fig. 3c) a cooling trend started in 1850. The present-day warming started later, around 1990. Other periods are characterized by unusual features, for example cold 1820 to 1862 in winter and autumn, in Cadiz (SP) (Fig. 4a and d) and again between 1850 and 1925 in summer and autumn in France (Fig. 5c and d). Hot conditions prevailed between 1923 and 1975 in autumn in Southern Italy (Fig. 7d).

We should note that in DP, the winter severity is established through the main consequences, e.g. people killed or large water bodies frozen over. In IO the seasonal averages for most of the years famous for their severe winters, e.g. 1709, 1789 and 1929, are not characterized by the lowest seasonal temperatures (see also Luterbacher et al. 2009) but were determined by spells of very cold air persisting for two, three, or more weeks. The impact was tremendous, but the principal cause was generally limited to a short period. The comparison between DP famous years and IO averages seems contradictory unless we consider, instead of the seasonal averages, the more detailed monthly averages in which cold spells are recognizable. We should keep in mind that if we change the way of presenting data, e.g. by passing from daily, monthly or seasonal averages, as the extreme years characterized by the most severe hot or cold weather will change.

Table 4 Analysis of the seasonal correlation (R^2) between individual temperature series

	N Italy	S Italy	France	Barcelona SP	Cadiz SP
Winter					
N Italy	1	0.47	0.76	0.65	0.32
S Italy		1	0.33	0.51	0.44
France			1	0.64	0.36
Barcelona SP				1	0.51
Cadiz SP					1
Spring					
N Italy	1	0.68	0.75	0.53	0.41
S Italy		1	0.46	0.49	0.26
France			1	0.54	0.48
Barcelona SP				1	0.40
Cadiz SP					1
Summer					
N Italy	1	0.59	0.56	0.51	0.15
S Italy		1	0.39	0.50	0.24
France			1	0.50	0.10
Barcelona SP				1	0.03
Cadiz SP					1
Autumn					
N Italy	1	0.49	0.64	0.53	0.07
S Italy		1	0.38	0.35	0.12
France			1	0.53	0.10
Barcelona SP				1	−0.07
Cadiz SP					1

Table 5 summarises those extreme events evident but not datable in Figs. 3–8. Extreme values of temperature are generally randomly distributed in time and space, except when extremes are found at the same time in a number of countries. Table 6 identifies countries simultaneously affected by extreme events. The geographical extension of anomalous seasons is limited and variable, in only a few cases reaching a large-scale area. The most outstanding events were: a severe winter in 1830; a spring killing frost in 1837; a hot summer in 2003 and 2004. For further details on this anomalous year 2003 see also Luterbacher et al. (2004).

An analysis of the correlation between individual temperature series (Table 4) shows that in spring and winter all the stations are positively correlated (i.e. Pearson coefficient $R > 0.33$). The same holds in summer and autumn except for Cadiz (SP) where $-0.33 < R < +0.33$ with the rest of the stations. A comprehensive Mediterranean dimension is provided by combining all the individual series to obtain only one comprehensive series for temperature. The Power Spectrum Analysis performed on the composite Mediterranean temperature series at annual (Fig. 9) and seasonal level shows annual cycles at 57.3, 34.4 (Bruckner), 26.5, 12.7 (Schwabe) and 2.2 years (quasi-biennial) at the 95% confidence level. In spring the same cycles are visible; in summer only the Bruckner; in autumn 26.5, 4.1 years and other shorter ones; in winter 78, 3.5 years and shorter. Wavelet Analysis at an annual scale (Fig. 10) confirmed the same cycles. Previous studies that made comparisons between regional and hemispheric/global past trends in surface temperature and precipitation/drought during the last millennium shown dramatic differences (Jones and Mann 2004) and

Table 5 Extreme seasons: coldest winters/hottest summers, spring killing frost

Location period	Temperature extremes	Year
Spain, Barcelona 1787–2007	Coldest winters	1808, 1827, *1830*, 1857, 1871, 1880, 1963
	Hottest summers	1822, 1828, 1846, 1849, *2003*
	Spring killing frost	*1837*, 1853, *1855*, 1879, 1913, 1925
Spain, Cadiz 1805–2004	Coldest winters	1827, *1830*, 1832, 1839, 1845, 1848, 1907, 1991
	Hottest summers	1804, 1864, 1869, 1928, 1943, 1949, 1950, 1961, 1989, *2003*, *2004*
	Spring killing frost	1799, *1837*, 1889, 1890, 1971, 1993
France 1500–2007	Coldest winters	1565, 1608, *1684*, 1685, 1695, 1697, *1740*, *1784*, 1795, *1830*, 1880, 1891, 1963
	Hottest summers	1556, 1676, 1724, 1826, 1842, 1846, 1947, 1976, *2003*
	Spring killing frost	1553, 1565, 1595, 1782, 1785, 1799, *1837*, 1845, 1887, 1962
Italy, North-Central Area 1500–2008	Coldest winters	1503, 1549, 1571, *1740*, 1766, 1777, *1784*, *1830*, *1855*, *1858*.
	Hottest summers	1516, 1540, 1603, 1718, 1720, *2003*, *2004*, 2005
	Spring killing frost	1515, 1664–1665, 1729, *1740*–1743, 1747, 1785, *1837*, 1853, 1883, 1984
Italy, South Area 1727–2006	Coldest winters	1728, 1729, 1850, 1891, 1905, 1929
	Hottest summers	1746, 1802, 1822, 1854, 1950, 1952, 1994, *2003*
	Spring killing frost	1730, *1740*, 1742, 1746, 1754, *1837*, 1874
Greece 1675–1715	Coldest winters	1683, 1687, 1709
	Hottest summers	1685, 1682, 1708
	Spring killing frost	1687, *1714*

In italics the most relevant events

Table 6 Geographical distribution of the most extreme events

1684	Murcia, Cadiz: humid winter; Greece: humid winter and autumn; France: cold winter.
1701	Portugal, Murcia, Barcelona: humid autumn; Portugal humid spring; Barcelona: dry winter.
1714	Portugal: dry autumn; Northern-Central Italy: humid autumn, Greece: dry winter, spring and summer, spring killing frost.
1740	Barcelona: humid winter, Murcia: humid spring; Cadiz/Sevilla: humid winter; France: humid autumn and cold winter; Northern-Central Italy: dry summer and autumn, cold winter, spring killing frost; Southern Italy: spring killing frost.
1784	Barcelona: humid winter; France: humid summer; France, Northern-Central Italy: cold winter.
1830	Barcelona, Cadiz, France, Northern-Central Italy: cold winter; France: dry winter.
1837	Portugal: dry spring and autumn; Barcelona: dry winter; Cadiz/Sevilla, France, Italy: spring killing frost; Cadiz/Sevilla: dry autumn.
1855	Portugal: humid spring; Portugal, Cadiz/Sevilla: humid autumn; Barcelona: spring killing frost; Northern-Central Italy: coldest winter.
1858	Cadiz/Sevilla**:** humid autumn; France, Northern-Central Italy: dry winter; Northern-Central Italy: cold winter.
1884	Portugal, Murcia: humid spring; Murcia: humid autumn; France: dry autumn.
1896	Barcelona: humid summer; France: humid autumn; Northern-Central Italy: humid summer.
1931	Murcia: dry winter; France: humid spring; Northern-Central Italy: dry summer.
1936	Barcelona: dry winter; Cadiz/Sevilla: humid spring; France: humid winter and summer.
2003	Spain, France, Italy: hot summer; Barcelona, Northern-Central Italy: dry summer; Northern-Central Italy: dry spring.
2004	Murcia: humid spring and autumn; Cadiz, Northern-Central Italy: hot summer.

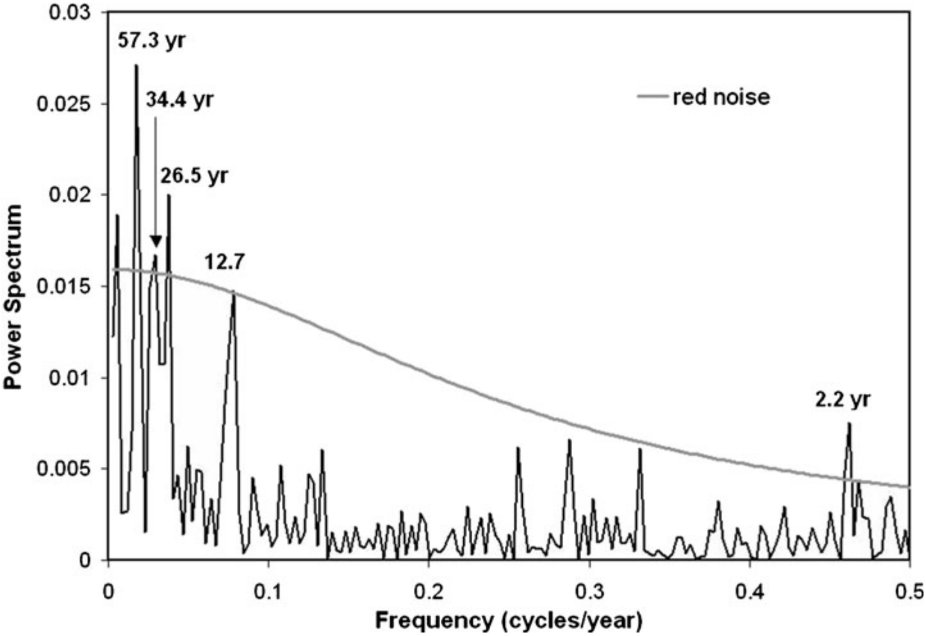


Fig. 9 Power spectrum analysis of annual temperature for the whole set of Mediterranean series of instrumental observations. *Gray line*: red noise at 95% confidence level. Significant annual cycles at 57.3, 34.4 (Bruckner), 26.5, 12.7 (Schwabe) and 2.2 years (quasi-biennial)

local to global comparisons are hardly justified. However, it is interesting to see the sensitivity of the Mediterranean, i.e. to what extent the Mediterranean responded to the climate forcing factors in comparison with the Northern Hemisphere, witnessed in the well-known IPCC 2007 graph (Le Treut et al. 2007).

In the common period 1850–2007, the annual average temperature (Fig. 11) in the Northern Hemisphere had minor oscillations until 1909, then a net warming from 1910 to 1940, followed by a stationary period that preceded the recent warming

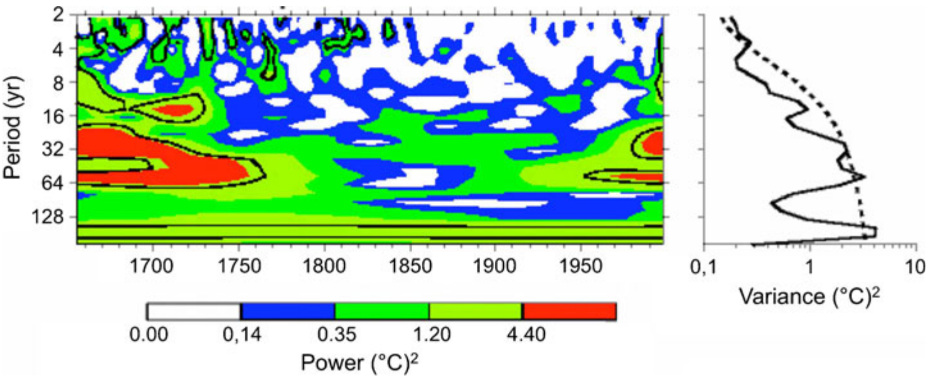


Fig. 10 Wavelet analysis of annual temperature in the Mediterranean. Significant annual cycles at about 60 and 30 years

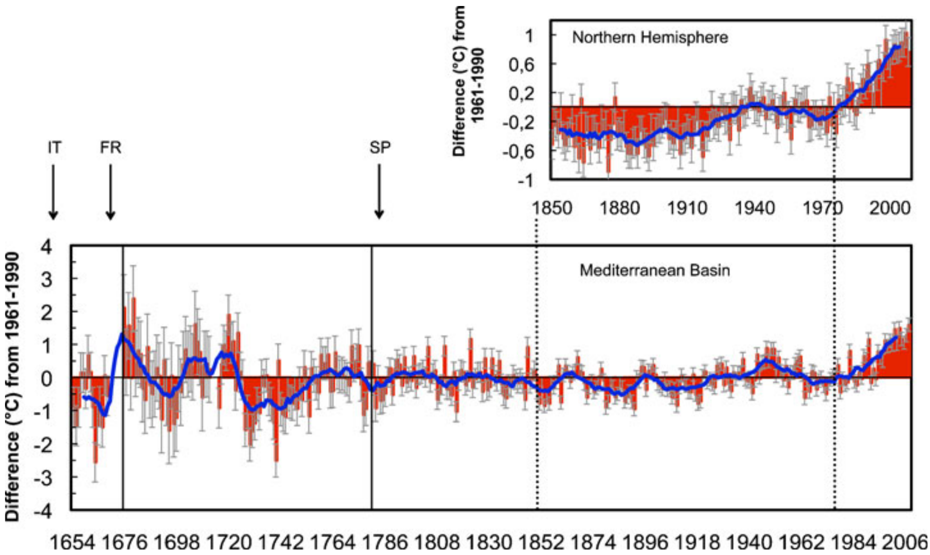


Fig. 11 Comparison between the annual temperature anomaly from instrumental observations in the Mediterranean Basin and the Northern Hemisphere. *Top*: IPCC 2007 Northern Hemisphere temperature difference for 1850 to 2006 relative to the 1961–1990 mean (Le Treut et al. 2007). *Bottom*: Annual temperature difference in the Mediterranean Basin for 1655 to 2007 relative to the 1961–1990 mean. Labels *IT*, *FR* and *SP* indicate the starting point of series from Italy, France and Spain, respectively. *Vertical thin lines*: 12-month averages; *thick continuous line*: 11-year moving average

since 1970. The Mediterranean had more regular oscillations around the same average level, followed by the same warming after 1970. The similarity between the Northern Hemisphere and the Mediterranean can be pinpointed with the Pearson's correlation coefficient calculated for the temperature $R^2(T)$ and the temperature time derivative $R^2(dT/dt)$, which is representative of the common warming/cooling tendency (Table 7). This table shows that, in the 1950–today period, a high correlation dominates for both temperatures and their trends. In the previous 1850–1949 period, the Mediterranean climate oscillation generates an alternation of correlation and anti-correlation of both temperatures and trends, as already discussed. At the seasonal level (Fig. 12), both the Mediterranean and the Northern Hemisphere show (Fig. 12a) a close winter agreement; in spring (Fig. 12b) and summer (Fig. 12c) the Mediterranean is generally warmer than the Northern Hemisphere; in autumn (Fig. 12d) there is again a good agreement. On the longer time scale, i.e. 1650 to

Table 7 Pearson's correlation coefficient calculated for the temperature $R^2(T)$ and the temperature time derivative $R^2(dT/dt)$, in the Northern Hemisphere and the Mediterranean

Year	1860	1865	1870	1875	1880	1885	1890	1895	1900	1905	1910	1915	1920	1925	1930
$R^2(T)$	−0.4	−0.4	−0.8	0.8	0.9	0.0	1.0	0.1	1.0	−0.9	−0.8	0.6	0.9	−0.2	−0.5
$R^2(dT/dt)$	0.3	0.4	0.0	0.3	0.2	0.6	0.4	0.2	0.6	0.6	−0.5	−0.6	−0.7	0.3	0.2
	1935	1940	1945	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	
$R^2(T)$	0.9	−0.9	−0.1	0.9	0.4	1.0	0.9	0.6	0.9	0.8	0.5	0.9	1.0	1.0	
$R^2(dT/dt)$	−0.2	0.7	−0.7	−0.4	0.7	0.2	0.9	0.8	0.6	0.2	0.6	0.9	0.2	0.6	

Fig. 12 Comparison between the anomaly of seasonal temperature on the Mediterranean Basin (MB) for 1655–2007 and the Northern Hemisphere (NH) for 1850–2008 (IPCC 2007) (Le Treut et al. 2007). **a** Winter, **b** spring, **c** summer and **d** autumn. *Blue thin line*: MB anomaly; *black thick line*: MB 11-year moving average; *pink line*: NH anomaly and *yellow thick line*: NH 11-year moving average

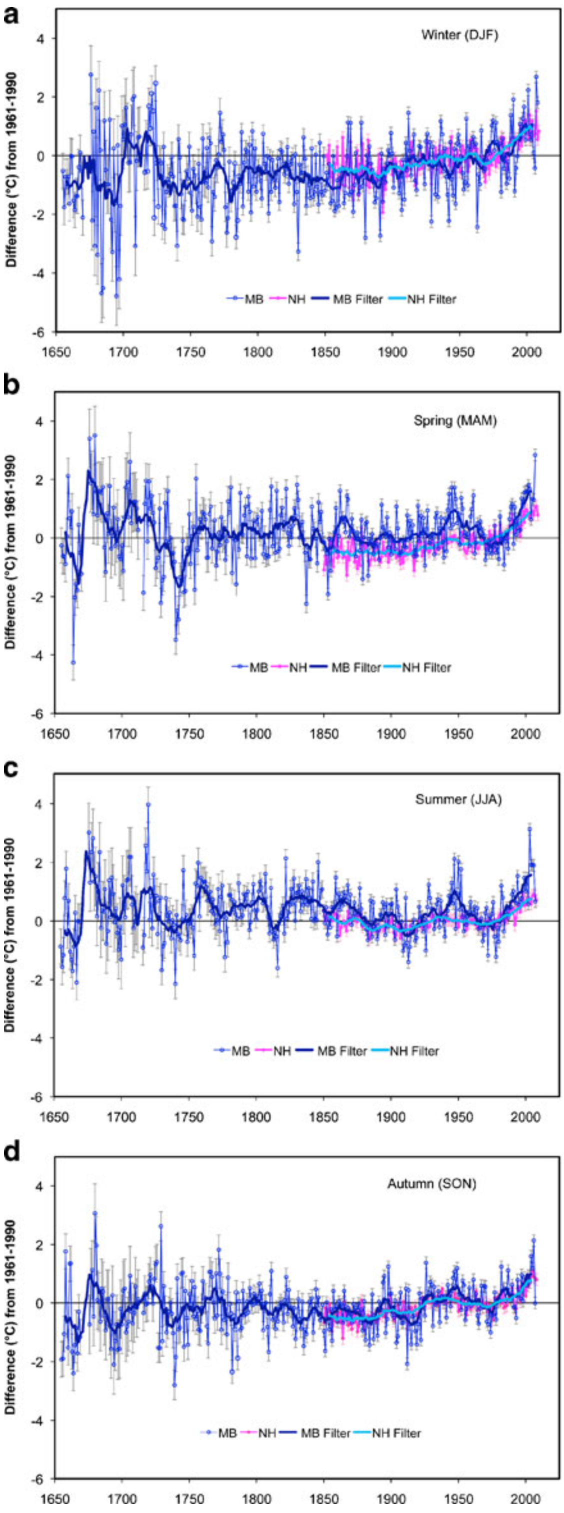


Table 8 Error bars of the Mediterranean annual temperature series for the different sub-periods

	Sub-period	Error bar (°C)
Temperature	1500 to 1653	±1.2
	1654 to 1675	±0.6
	1676 to 1715	±1.0
	1716 to 1726	±0.6
	1727 to 1779	±0.5
	1780 to 1786	±0.4
	1787 to 1849	±0.3
	1850 to nowadays	±0.2

the present, the reconstructed Mediterranean temperature series (Figs. 11 and 12) show a repetition of heating and cooling cycles, evident also in individual series (Camuffo and Bertolin 2010) and different countries. Apparently, the cycles in the seventeenth and eighteenth centuries reach or even exceed the level of the present-day warming, and this is also confirmed by dendrochronology evidence (Etien et al. 2008). However, this early period is based on a limited number of instrumental stations with the consequence that local departures may have a larger incidence in comparison with the subsequent period. The pronounced cycles prior to 1750 should be considered as being subject to a wider uncertainty band, as reported in Figs. 11 and 12 and specified in Table 8. In addition, we should keep in mind three factors: first, the number of Mediterranean stations used in this work is much smaller than the number used by IPCC 2007 for the Northern Hemisphere and, therefore, less representative; however, the quality of individual series is higher; second, even at the Mediterranean scale, the number of operative stations in the early period was much smaller than today, but the same problem holds for IPCC too; third, at the global scale we see that at high and at low latitudes the tendency to warming or cooling is opposite, and the Mediterranean is in the belt between these opposite tendencies: any oscillation over this wide latitudinal range may have a large impact at the Mediterranean scale, thus justifying the observed cycles, remarkable on the Mediterranean, but small on the global scale.

7 Conclusions

In this paper, documentary data and instrumental observations combine to extend our knowledge of the behaviour of temperature in the Mediterranean Basin over the last 500 years, especially in relation to the recent global warming. Precipitation has also been analysed, but it will be discussed elsewhere. A tremendous effort was made to gather, combine and homogenize data of a different nature including a huge quantity of documentary sources and a limited number of extremely long instrumental series. Some unknown instrumental series have been checked for problems, discontinuities and errors and are here presented for the first time and extend back up to 1654. Although they originated at the dawn of meteorological observations, their quality has been carefully assessed. Now these retrieved data provide a long-term general view of the climate features and their variability in the Mediterranean Basin.

From the comparison between documentary sources and instrumental observations, it was clear that famous extreme events happened in the course of a few days or weeks, rarely of months, and may by masked by seasonal averages. From this point of view, extreme features in chronicles or annals may appear in a different light when compared with instrumental readings, depending on the averaging time range selected in data processing.

DP are convenient for establishing the occurrence of extreme events, year-by-year variability, the existence of some time periods in which, cold or warm situations were repeated, but not for identifying long-term trends. The latter can be assessed only with IO, and for the first time we can see the climate variability from purely instrumental observations over the past 350 years or so.

In this paper the instrumental observations cover the exceptional length of three and a half centuries. In the last 40 years we observe that all the Mediterranean stations are in line with global warming. However, looking at the long-term time scale, warm and dry periods are not exceptional for the Mediterranean, which was characterized by a sequence of warming–cooling and rainy–dry cycles depending on the relative influence of the Atlantic, the eastern side and Africa. In the future, it will be interesting to see if such oscillation modes will persist and how they will combine with global warming.

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References

Alcoforado MJ, Nunes MF, Garcia JC (2000) Temperature and precipitation reconstruction in Southern Portugal during the late Maunder Minimum (AD 1675–1715). Holocene 10(3):333–340

Alexandre P (1987) Le climat en Europe au Moyen Age. Contribution à l’histoire des variations climatiques de 1000 à 1425, d’après les sources narratives de l’Europe occidentale. Ecole des Hautes Etudes en Sciences Sociales, Paris

Antinori L (1654) Correspondence between Giacomo Micaglia and Luigi Antinori, letter dated December 1654, Manoscritto Galileiano 307, Posteriori di Galileo Tomo 48, Accademia del Cimento Parte III, carteggio vol. 33, Osservazioni meteorologiche 12, National Central Library (BNCF), Florence

Baiada E (1986) Da Beccari a Ranuzzi: la meteorologia nell'Accademia Bolognese nel XVIII secolo. In: Finzi R (ed) Le meteore ed il frumento: Clima, agricoltura, meteorologia a Bologna nel '700. Il Mulino, Bologna, pp 99–261

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

Barriendos M, Martin-Vide J, Peña JC, Rodríguez R (2002) Daily meteorological observations in Cádiz-San Fernando. Analysis of the documentary sources and the instrumental data content (1786–1996). Clim Change 53:151–170

Böhm R, Jones PD, Hiebl J, Brunetti M, Frank D, Maugeri M (2009) The early instrumental warm-bias: a solution for long central European temperatures series 1760–2007. Clim Change. doi:10.1007/s10584-009-9649-4

Bolle HJ (ed) (2003) Mediterranean climate. Springer, Berlin

Brázdil R, Pfister C, Wanner H, von Storch H, Luterbacher J (2005) Historical climatology in Europe—the state-of-the-art. Clim Change 70:363–430

Brázdil R, Kundzewicz ZW, Benito G (2006) Historical hydrology for studying flood risk in Europe. Hydrol Sci J 51(5):739–764

Brunetti M, Buffoni L, Lo Vecchio G, Maugeri M, Nanni T (2001) Tre secoli di Meteorologia a Bologna. ISAO-CNR, Bologna; Istituto di Fisica Generale Applicata-Università di Milano; Osservatorio Astronomico di Milano-Brera. CUSL, Milan

Camuffo D (2002a) History of the long series of the air temperature in Padova (1725–today). Clim Change 53(1–3):7–76

Camuffo D (2002b) Calibration and instrumental errors in early measurements of air temperature. Clim Change 53(1–3):297–330

Camuffo D (2002c) Errors in early temperature series arising from changes in style of measuring time, sampling schedule and number of observations. Clim Change 53(1–3):331–354

Camuffo D, Bertolin C (2010) Recovery of the early period of long instrumental time series of air temperature in Padua, Italy (1716–2007). J Phys Chem Earth. doi:10.1016/j.pce.2010.02.002

Camuffo D, Enzi S (1992a) Critical analysis of archive sources for historical climatology of Northern Italy. In: Frenzel B (ed.) European climate reconstructed from historical documents: methods and results. Fischer, Stuttgart, pp 65–74

Camuffo D, Enzi S (1992b) Reconstructing the climate of Northern Italy from archive sources. In: Bradley RS, Jones PD (eds) Climate since 1500 A.D. Routledge, London, pp 143–154

Camuffo D, Enzi S (1994) The climate of Italy from 1675 to 1715. In: Frenzel B (ed) Climatic trends and anomalies in Europe 1675–1715. Fischer, Stuttgart, pp 243–254

Camuffo D, Jones P (eds) (2002) Improved understanding of past climatic variability from early daily European instrumental sources. Kluwer, Dordrecht

Camuffo D, Sturaro G (2004) Use of proxy-documentary and instrumental data to assess the risk factors leading to sea flooding in Venice. Glob Planet Change 40:93–103

Camuffo D, Secco C, Brimblecombe P, Martin-Vide J (2000a) Sea storms in the Adriatic sea and the western Mediterranean during the last millennium. Clim Change 46:209–223

Camuffo D, Cocheo C, Enzi S (2000b) Seasonality of instability phenomena (hailstorms and thunderstorms) in Padova, Northern Italy, from archive and instrumental sources from AD 1300 to 1989. Holocene 10(5):651–658

Camuffo D, Bertolin C, Jones P, Cornes R, Garnier E (2009) The earliest daily barometric pressure readings in Italy: Pisa, 1657–8 and Modena, 1694 and the circulation index over Europe, 1694. The Holocene 20(3):1–13. doi:10.1177/0959683609351900

Chinnici I, Foderà Serio G, Granata L (2000) Duecento anni di meteorologia all'Osservatorio Astronomico di Palermo. Osservatorio Astronomico G.S. Vaiana, Palermo

Chuine I, Yiou P, Viovy N, Seguin B, Daux V, Le Roy Ladurine E (2004) Grape ripening as a past climate indicator. Nature 432:289–290

Cocheo C, Camuffo D (2002) Corrections of systematic errors and data homogenisation in the Padova series (1725–today). Clim Change 53(1–3):77–100

Crisci A, Gozzini B, Maracchi G, Meneguzzo F (1998) La serie storica delle temperature medie mensili di Firenze. Proceeding: Due secoli di osservazioni meteorologiche a Mantova, aspetti scientifici e storici, Mantova 22 ottobre 1998, 143–158

Cyrillus N (1731–1732) An account of an extraordinary eruption of mount Vesuvius in the month of March, in the year 1730, Extracted from the meteorological diary of that year at Naples, Communicated by Nichol. Cyrillus, M. D. R. S. S. Philos Trans 37:336–338

Daveau S (1997) Os tipos de tempo em Coimbra (Dez.1663–Set. 1665) nas cartas do Padre António Vieira. Finisterra-Revista Portuguesa de Geografia XXXII 64:109–115

Diodato N (2007) Climatic fluctuations in Southern Italy since 17th century: reconstruction with precipitation records at Benevento. Clim Change 80:411–431

Enzi S, Camuffo D (1995) Documentary sources of the sea surges in Venice from A.D. 787 to A.D. 1867. Nat Hazards 12:225–287

Etien N, Daux V, Masson-Delmotte V, Stievenard M, Bernard V, Durost S, Guillemin MT, Mestre O, Pierre M (2008) A bi-proxy reconstruction of Fontainebleau (France) growing season temperature from A.D. 1596 to 2000. Clim Past 4:91–106

Fletcher CA, Spencer T (eds) (2005) Flooding and environmental challenges for Venice and its lagoon: state of knowledge. Cambridge University Press, Cambridge

Founda D, Kambezidis HD, Petrakis1 M, Zanis P, Zerefos C (2009) A correction of the recent air-temperature record at the historical meteorological station of the National Observatory of Athens (NOA) due to instrument change. Theor Appl Climatol 97:385–389. doi:10.1007/s00704-008-0084-7

Gallego D, Garcia-Herrera R, Calvo N, Ribera P (2007) A new meteorological record for Cádiz (Spain) 1806–1852: implications for climatic reconstructions. J Geophy Res 112:D12108

Gandolfo C, Sulli M (1970) Vallombrosa 1872–1989: serie ultracentenaria di misure di precipitazioni e di temperatura in ambiente forestale. Ann Ist Sper Selvic 21:147–181

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

Garnier E (2007) La ville face aux caprices du fleuve XVIe–XVIIIe siècle. Hist Urbaine 18:41–60

Grove JM, Conterio A (1994) Climate in the eastern and central Mediterranean. In: Frenzel B (ed) Climatic trends and anomalies in Europe 1675–1715. Fischer, Stuttgart, pp 275–285

Grove JM, Conterio A (1995) The climate of Crete in the sixteenth and seventeenth centuries. Clim Change 30:223–247

Hemmer JJ (1783) Descriptio instrumentorum meteorologicorum, tam eorum, quam Societas distribuit, quam quibus praeter haec Manheimii utitur. Ephemerides Societatis Meteorologicae Palatinae, Tomus 1:57–90

Jeftic L, Milliman DJ, Sestini G (1992) Climatic change and the Mediterranean. Edward Arnold, London

Jones PD, Mann ME (2004) Climate over past millennia. Rev Geophys 42:RG2002, doi:10.1029/2003RG000143

Jurin J (1723) Invitatio ad observationes Meteorologicas communi consilio instituendas a Jacobo Jurin M.D. Soc Reg Secr et Colleg Med Lond Socio Philos Trans 379:422–427

Legrand JP, Le Goff M (1992) Les observations météorologiques de Louis Morin. Monographie n°6, Météorologie Nationale, Paris

Le Roy Ladurie E (1971) Times of feast, times of famine: a history of climate since the year 1000. Doubleday, Garden City, N.Y., 426 pp

Le Treut H, Somerville R, Cubasch U, Ding Y, Mauritzen C, Mokssit A, Peterson T, Prather M (2007) Historical overview of climate change. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 93–127

Lionello P, Malanotte-Rizzoli P, Boscolo R (2006) The Mediterranean climate: an overview of the main characteristics and issues. Elsevier, Amsterdam

Luterbacher J, Dietrich D, Xoplaki E, Grosjean M, Wanner H (2004) European seasonal and annual temperature variability, trends, and extremes since 1500. Science 303:1499–1503

Luterbacher J, Xoplaki E, Casty C, Wanner H, Pauling A, Kuettel M, Rutishauser T, Broennimann S, Fischer E, Fleitmann D, Gonzalez-Rouco JF, Garcìa-Herrera R, Barriendos M, Rodrigo FS, Gonzalez-Hidalgo JC, Saz MA, Gimeno L, Ribera P, Brunet M, Paeth H, Rimbu N, Felis T, Jacobeit J, Duenkeloh A, Zorita E, Guiot J, Turkes M, Alcoforado MJ, Trigo R, Wheeler D, Tett SFB, Mann ME, Touchan R, Shindell DT, Silenzi S, Montagna P, Camuffo D, Mariotti A, Nanni T, Brunetti M, Maugeri M, Zerefos C, De Zolt S, Lionello P, Nunes MF, Rath V, Beltrami H, Garnier E, Le Roy Ladurie E (2006) Mediterranean climate variability over the last centuries: a review. In: Lionello P, Malanotte-Rizzoli P, Boscolo R (eds) The Mediterranean climate: an overview of the main characteristics and issues. Elsevier, Amsterdam

Luterbacher J, Koenig SJ, Franke J, van der Schrier G, Della-Marta PM, Jacobeit J, Küttel M, Gonzales-Rouco FJ, Zorita E, Xoplaki E, Stössel M, Rutishauser T, Wanner H, Pfister C, Brázdil R, Dobrovolný P, Camuffo D, Bertolin C, Moberg A, Leijonhufvud V, Soderberg J, Allan R, Wilson R, Wheeler D, Barriendos M, Glaser R, Riemann D, Nordli O, Limanówka D, van Engelen A, Zerefos CS (2009) Circulation dynamics and its influence on European and Mediterranean winter climate over the past half millennium: results and insights from instrumental data, documentary evidence and coupled climate models. Clim Change. doi:10.1007/s10584-009-9782-0

Magalotti L (1667) Saggi di naturali esperienze fatte nell'Accademia del Cimento. Nuova stamperia di Gio. Filippo Cecchi, Florence

Maheras P, Alcoforado MJ, Guika S (1994) Les saisons, les années et les périodes sèches et humides au Portugal durant la dernière période séculaire. Publ Assoc Intern Climatol 6:191–199

Maheras P, Alcoforado MJ, Guika S, Vafiadis M (1995) Relations entre les périodes sèches et humides et les indices de circulation au Portugal, durant le dernière période séculaire. Publ Assoc Intern Climatol 7:241–248

Maracchi GP (1991) A brief history of meteorology in Florence from the beginnings to the present. CIESIA-IATA, Florence

Maraldi M (1732) Observations Météorologiques faites pendant l'année 1732. Histoire de l'Académie Royale des Sciences 1732:494–497

Maugeri M, Buffoni L, Delmonte B, Fassina A (2002) Daily Milan temperature and pressure series (1763–1998): Completing and homogenising the data. Clim Change 53:119–149

Micela G, Granata L, Iuliano V (2001) Due secoli di Pioggia a Palermo. Osservatorio Astronomico di Palermo. G.S. Vaiana and University of Palermo, Palermo

Middleton KWE (1966) A history of the thermometer and its use in meteorology. Hopkins, Baltimore

Moberg A, Alexandersson H (1997a) Homogenization of Swedish temperature data. Part I: homogeneity test for linear trends. Int J Climatol 17:25-34

Moberg A, Alexandersson H (1997b) Homogenization of Swedish temperature data. Part II: homogenized gridded air temperature compared with a subset of global gridded air temperature since 1861. Int J Climatol 17:35–54

Oñate JJ, Pou A (1996) Temperature variations in Spain since 1901: a preliminary analysis. Int J Climatol 16:805–815

Pfister C (1992) Monthly temperature and precipitation in central Europe 1525–1979: quantifying documentary evidence on weather and its effects. In: Bradley RS, Jones PD (eds) Climate since AD 1500. Routledge, London, pp 118–142

Pfister C, Luterbacher J, Schwarz-Zanetti G, Wegmann M (1998) Winter air temperature variations in western Europe during the early and high middle ages (AD 750–1300). Holocene 8:535–552

Pfister C, Brázdil R, Glaser R, Barriendos M, Camuffo D, Deutsch M, Dobrovolný P, Enzi S, Guidoboni E, Kotyza O, Militzer S, Racz L, Rodrigo FS (1999) Documentary evidence on climate in the sixteenth-century Europe. Clim Change 43(1):55–110

Piervitali E, Colacino M (2001) Evidence of drought in western Sicily during the period 1565– 1915 from liturgical offices. Clim Change 49:225–238

Poleni G (1740) Ioannis Poleni ad nobilissimum virum comitem Alexandrum de Pompeiis patricium veronensem Epistola, qua nonnullae observationes astronomicae et meteorologicae continentur. Commentaria Academiae Scientificae Petropolitanae VIII:439–452

Reiter ER (1975) Weather Phenomena of the Mediterranean Basin. EPRFNPS, Monterey

Repapis CC, Philandras CM (1988) A note on the air temperature trends of the last 100 years as evidenced in the eastern Mediterranean time series. Theor Appl Climatol 39:93–97

Repapis CC, Philandras CM, Kalabokas PD, Zanis P, Zerefos CS (2007) Is the last years abrupt warming in the national observatory of Athens records a climate change manifestation? Global NEST J 9(2):107–116

Rodrigo FS (2002) Changes in climate variability and seasonal rainfall extremes: a case study from San Fernando (Spain), 1821–2000. Theor Appl Climatol 72:193–207

Slonosky V (2002) Wet winters, dry summers? Three centuries of precipitation data from Paris. Geophys Res Lett 29:1895–1898

Taborda JP, Alcoforado MJ, Garcia JC (2004) O Clima no Sul de Portugal no século XVIII. Reconstituição a partir de fontes descritivas e instrumentais. Geo-Ecologia, 2, Centro de Estudos Geográficos, Lisbon

Tank AK (2007) "EUMETNET/ECSN optional programme 'European Climate Assessment & Dataset (ECA&D)"Algorithm Theoretical Basis Document (ATBD) KNMI Royal Netherlands Meteorological Institute (http://eca.knmi.nl/dailydata/datadictionaryhomogeneity.php)

Targioni Tozzetti G (1780) Notizie degli aggrandimenti delle Scienze Fisiche accaduti in Toscana nel corso di anni LX del secolo XVII. Tomo I. Bouchard, Florence

Telelis I (2004) Meteorological Phaenomena and the Climate in Bysantium. 2 volumes (in Greek, summary in English). Athens Academy, Athens

Telelis I (2008) Climatic fluctuations in the eastern Mediterranean and the middle east AD 300–1500 from byzantine documentary and proxy physical paleoclimatic evidence—a comparison. Jahrbuch der Österreichischen Byzantinistik 58:167–208. doi:10.1553/joeb58

Toaldo G (1781) Saggio Meteorologico della vera influenza degli Astri, delle Stagioni e mutazioni di Tempo. Manfrè, 2nd edn. Stamperia del Seminario, Padua

UK Meteorological Office (1962) Weather in the Mediterranean. Her Majesty Stationery Office, London

Vittori O, Mestitz A (1981) Calibration of the Florentine little thermometer. Endeavour 5(3):113–118

Xoplaki E (2002) Climate variability over the Mediterranean. Ph.D. thesis, University of Bern, Switzerland. http://sinus.unibe.ch/klimet/docs/phd_xoplaki.pdf

Xoplaki E, Maheras P, Luterbacher J (2001) Variability of climate in meridional Balkans during the periods 1675–1715 and 1780–1830 and its impact on human life. Clim Change 48:581–615

Xoplaki E, Gonzalez-Rouco FJ, Luterbacher J, Wanner H (2003) Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs. Clim Dyn 20:723–739

Xoplaki E, Gonzalez-Rouco JF, Luterbacher J, Wanner H (2004) Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. Clim Dyn 23:63–78

Wallén CC (ed) (1970) Climates of northern and Western Europe. Elsevier, Amsterdam

Wallén CC (ed) (1977) Climates of central and Southern Europe. Elsevier, Amsterdam

Wei AM (1990) Time series analysis. Addison-Wesley, Redwood City