Chapter 1

Mediterranean Climate Variability Over The Last Centuries: A Review

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Chapter 1
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Summary

A necessary task for assessing to which degree the industrial period was climatically unusual against the background of pre-industrial climate variability, is the reconstruction and interpretation of spatial and temporal patterns of climate in earlier centuries. The larger Mediterranean area offers a few long homogeneized instrumental station series with daily to monthly resolution (Italy, Spain, Portugal), a wide range of documentary evidence (i.e. reports from chronicles, daily weather reports, ship logbooks, the time of freezing and opening up of waterways, religious ceremonies, etc.) as well as high and low spatio-temporally resolved natural proxies (tree-rings, tropical and non-tropical corals, speleothems, boreholes, vermetid reefs, etc.). This wealth of climate information makes the Mediterranean area ideal for climate reconstructions at various time and space scales, as well as for the analysis of changes in climate extremes and socio-economic impacts prior to the period of instrumental data. This review describes and discusses the regional coverage, the possibilities and limitations of these proxies and presents yet unexplored archives (marine and land) and their potential for past climate reconstructions (over the last 500-1000 years). We also address the importance of documentary and natural proxies for Mediterranean precipitation and temperature reconstructions at seasonal time scales.

Different proxy types have their specific response region, which suggests using region-specific multi-proxy sets in seasonal climate reconstructions. Preliminary results indicate that for most regions of the larger Mediterranean documentary information on precipitation and tree-ring data are those variables, which are most important for reconstructing summer and winter precipitation. Other proxies such as corals, speleothems and ice cores from Greenland are of limited relevance. Numerous seasonally resolved documentary proxy data and information gathered from natural proxies discussed in this review have been used to reconstruct winter Mediterranean temperature and precipitation fields and averaged time series back to AD 1500. Associated uncertainties, trends and extremes are discussed in this Chapter.

The Mediterranean area experienced several cold relapses and warm periods as well as dry and wet intervals on decadal timescales, on which shorter-period quasi-oscillatory behaviour was superimposed. Substantial winter warming started at the end of the nineteenth century. In the context of the last half millennium, the last winter decades of the twentieth century and the first winters of the twenty-first century were the warmest and driest, in agreement with recent findings from other parts of Europe and the Northern Hemisphere (NH). Cold conditions have been experienced during the Late Maunder Minimum (1675-1715) and the last decades of the nineteenth century. The analysis of anomalously wet and warm winters, averaged over the Mediterranean area, reveals no statistically significant changes since 1500 with respect to frequency and intensity of extreme winters.

Close relationships between large-scale atmospheric circulation patterns and Mediterranean winter climate anomalies were found. Warm and dry winters are linked with a positive North Atlantic Oscillation (NAO) pattern, whereas cold and wet Mediterranean winters are connected with Scandinavian blocking (though with regional differences). Cold and dry winters are related to anticyclonic conditions,

whereas warm and wet winters are connected with cyclonic regimes. Running correlation analyses between the leading atmospheric circulation modes and the averaged Mediterranean temperature and precipitation indicates that the NAO (East Atlantic/Western Russia pattern) has a robust signal on land precipitation (land temperature), whereas the influence on land temperature (precipitation) is fluctuating and depends on the choice of the time window. It is suggested that the latter behaviour reflects local influences, while the former signal is homogeneous throughout the region. We further found indications for teleconnections between Mediterranean and NH climate in past centuries.

A final aspect of this chapter compares empirical temperature and precipitation reconstructions with the model simulations (ECHO-G and HadCM3) for the 1500-1990 period. It is shown that the range of variability reproduced by the climate models is only slightly larger than that of the reconstructions. In the case of temperature, the HadCM3 simulation trends are comparable to those in the empirical reconstructions and slightly smaller than those in the ECHO-G simulations. This is a reasonable feature, since the latter do not include aerosol forcing. Concerning Mediterranean winter precipitation, no trends are reconstructed nor simulated. Both assessments reveal the need for a more thorough study that takes into consideration the behavior of the atmospheric circulation in climate reconstructions and model simulations. We end with an outlook where we highlight several aspects on future research on past Mediterranean climate variability, the potential of new archives for improving spatio-temporal high resolved reconstructions for both land and sea areas, model/reconstruction comparison and impact studies.

1. Introduction

A necessary task for assessing to which degree the industrial period is unusual against the background of pre-industrial climate variability, is the reconstruction and interpretation of temporal and spatial patterns of climate in earlier centuries. The comparison of past climate reconstructions with numerical models can enhance our dynamical and physical understanding of the relevant processes. As widespread, direct measurements of climate variables are only available about one to two centuries back in time, it is necessary to use indirect indicators or ‘‘proxies’’ of climate variability, which is recorded in natural archives (coral reefs, ice cores, tree-rings, boreholes, speleothems, etc.). These archives record, by their biological, chemical and physical nature, climate-related phenomena (Jones and Mann, 2004). The use of natural proxies, especially in a quantitative way, is a more recent tool in paleoclimate research.

Additionally, man-made documentary evidence provides information about past climate variability by means of direct or indirect descriptions of climate related phenomena (e.g. Pfister, 1999, 2005; Chuine *et al.*, 2004; Bartholy *et al.*, 2004; Guiot *et al.*, 2005; Glaser and Stangl, 2005; Przybylak *et al.*, 2005; Brázdil *et al.*, 2005 and references therein; Le Roy Ladurie, 2004, 2005). The Mediterranean area offers a broad spectrum of long high quality instrumental time series, documentary information and and natural archives, both in time and space making this area ideal for climate reconstructions of past centuries, as well as the analysis of changes in climate extremes and socio-economic impacts prior to the instrumental period. Documentary evidence such as written sources, paintings, or flood marks have widely been used for climate reconstruction. In the Mediterranean area, documentary evidence reaches more than two millennia back in time. The question to what extent climate has changed since the classical epoch and whether or not the extensive deforestation was the cause for climatic change in this region has been discussed since the eighteenth century (Brönnimann, 2003). Mann (1790) concluded from written sources that climate has become progressively warmer and drier over time, which he could not explain by land use changes. Others did not support the idea of a progressive climate change. Ideler (1832), for instance, criticised Mann in being too trustful in his documentary sources. The question was discussed by many others, partly in the context of the deforestation and reforestation debate in the nineteenth century (e.g., Rico Sinobas, 1851; Arago, 1858; Fischer, 1879; Günther, 1886; Brückner, 1890). Hence, studies on past Mediterranean climate variability as well as the use of documentary evidence for climate reconstruction have a long scientific tradition.

The temporal resolution among different proxies. Some of the proxy records are annually or even higher resolved (documentary data, growth and density measurements from tree-rings, corals, annually resolved ice cores, laminated ocean and lake sediment cores, and speleothems) and hence record year-by-year patterns of climate in past centuries (Jones and Mann, 2004). Other proxies such as boreholes capture the low-frequency signal. Jones and Mann (2004) review the strengths of each proxy source with emphasis the potential weaknesses and caveats.

Climate records for land areas (compared to marine records) exhibit a high degree of geographical variability due to local peculiarities. The use of a broad collection of proxies may help in disentangling the geographical complexity (e.g. Pla and Catalan, 2005). Each proxy has its advantages and shortcomings. Properties such as sensitivity, reproducibility, local availability and continuity through time differ among them (Mann, 2002a; Pauling *et al.*, 2003; Jones and Mann, 2004).

A number of previous studies have focused on global to hemispheric temperature reconstructions over the past few centuries to millennia, based on both empirical proxy data (Bradley and Jones, 1993; Overpeck *et al.*, 1997; Jones *et al.*, 1997; Mann *et al.*, 1998, 1999; Crowley and Lowery, 2000; Briffa *et al.*, 1998, 2001, 2002, 2004; Esper *et al.*, 2002, 2004, 2005a,b; Cook *et al.*, 2004; Huang, 2004; Pollack and Smerdon, 2004; Moberg *et al.*, 2005) and model simulations including forcing data (e.g., Crowley, 2000; Waple *et al.*, 2002; Bauer *et al.*, 2003; Gerber *et al.*, 2003; González-Rouco *et al.*, 2003a,b; Rutherford *et al.*, 2003, 2005; Zorita *et al.*, 2004, 2005; von Storch *et al.*, 2004; van der Schrier and Barkmeijer, 2005; Mann *et al.*, 2005; Goosse *et al.*, 2005a,b,c). Several of the temperature reconstructions reveal that the late twentieth century warmth is unprecedented at hemispheric scales, and can only be explained by anthropogenic, greenhouse gas (GHG) forcing (Jones and Mann, 2004 and references therein; Moberg *et al.*, 2005).

Hemispheric temperature reconstructions cannot provide information about regional-scale climate variations. Several sources point to differing courses of temperature change in Europe and the generally greater amplitude of variations than recorded for the NH (e.g., Mann *et al.*, 2000; Luterbacher *et al.*, 2004; Jones and Mann, 2004; Brázdil *et al.*, 2005; Guiot *et al.*, 2005; Casty *et al.*, 2005a; Xoplaki *et al.*, 2005). For instance, the European heat wave of summer 2003 was a regional expression of an extreme event, much larger in amplitude than extremes at hemispheric scales (Luterbacher *et al.*, 2004; Schär *et al.*, 2004; Pal *et al.*, 2004; Rebetez, 2004; Stott *et al.*, 2004; Chuine *et al.*, 2004; Schönwiese *et al.*, 2004; Menzel, 2005; Trigo *et al.*, 2005; Casty *et al.*, 2005a; Le Roy Ladurie, 2005; Büntgen *et al.*, 2005a,b). The 2003 June-August mean temperature for the larger Mediterranean land area exceeded the 1961-1990 reference period by around 2.3°C (Luterbacher *et al.* 2004; Stott *et al.*, 2004), and makes it the warmest summer for more than the last 500 years (Luterbacher *et al.*, 2004). Stott *et al.* (2004) suggest, that human influence has likely doubled the risk of a heatwave exceeding this threshold magnitude of around 2°C in this area.

We would like to point out that this review mainly deals with the climate variability over the last few centuries covering the larger Mediterranean area of 30°N-47°N and 10°W-40°E. We will not report about climate reconstructions, climate change and variability over longer time scales. There are many publications (e.g. Araus *et al.*, 1997; Jalut *et al.*, 1997, 2000; Davis *et al.*, 2003; Rimbu *et al.*, 2003a; Felis *et al.*, 2004; Battarbee *et. al.* 2004) dealing with those topics. The new book edited by Battarbee *et. al.* (2004, and references therein) provides a major synthesis of evidence for past climate variability at the regional and continental scale across Europe and Africa, including parts of the Mediterranean. It focuses on two complementary time-scales, the Holocene (approximately the last 11,500 years) and the last glacial-interglacial cycle (approximately the last 130,000 years).

We first report on the availability and potential of long, homogeneized instrumental data, documentary and natural proxies to reconstruct aspects of past climate at local to regional scales within the larger Mediterranean area, including climate extremes and the incidence of natural disasters. We then turn to recent attempts of large-scale multi-proxy field reconstructions for the Mediterranean land areas and discuss the importance of natural and documentary proxies for regional seasonal temperature and precipitation reconstructions. In Section 4 of this Chapter we analyse the reconstructions with respect to the evolution of the averaged Mediterranean winter temperature and precipitation back to 1500 and discuss uncertainties, trends, cold and warm, wet and dry periods and present climate fields of extremes covering the last centuries. We also briefly address the question how major tropical volcanos influenced Mediterranean winter climate over the past. We investigate whether particularly dry and wet as well as cold and warm Mediterranean winters occurred more frequently during the twentieth century, when climate is increasingly affected by human activity through emissions of GHGs, than earlier. For subareas the Palmer Drought Severity Index (PDSI; e.g. Palmer, 1965, Nicault *et al.*, 2005) is derived and changes are discussed in the context of the past. We then analyse the large-scale atmospheric circulation influence on past and present Mediterranean winter climate inclusive extremes at seasonal scale (Section 5). In Section 6 we will briefly comment on the possible teleconnections between Mediterranean climate and other parts of the NH related to past climate. The relations between variability in the Mediterranean region and global tropical oceans, El Niño-Southern Oscillation (ENSO), Indian and African Monsoon and the mid-latitudes for the instrumental period will be discussed by Alpert *et al.* (2005, this book, chapter 2) and Trigo *et al.* (2005, this book, chapter 3). Finally, in Section 7 the climate reconstructions are compared with forced simulations of the climate models ECHO-G and HadCM3. Thereby we address the role of external forcing, including natural (e.g., volcanic and solar irradiance) and anthropogenic (GHG and sulphate aerosol) influences, and natural, internal variability in the coupled ocean-atmosphere system at sub-continental scale. We end with conclusions and an outlook on future directions related to Mediterranean past climate.

2. Past Regional Mediterranean Climate Evidence And Extremes

2.1. Evidence From Early Instrumental And Documentary Data

The Mediterranean offers a few long, high quality and homogeneized instrumental station series covering the past few centuries. In the late 1500 Galileo, the Grand

Duke of Tuscany and the Accademia del Cimento invented the modern meteorological instruments (thermometer, barometer, hygrometer) and started regular observations. From Padova, Milan and the Po Plain (Italy) there are temperature, precipitation and pressure series available at daily to monthly resolution (Camuffo, 1984, 2002a,b,c; Brunetti *et al.*, 2001; Maugeri *et al.*, 2002a,b, 2003; Cocheo and Camuffo, 2002). There are also a few long instrumental temperature, precipitation and pressure series available from southern and northeastern Spain (Rodriguez *et al.*, 2001; Barriendos *et al.*, 2002; Rodrigo, 2002). Alcoforado *et al.* (1997, 1999) and Taborda *et al.* (2004) used combined weather and climate information from Portuguese documentary sources and early instrumental data back to the eighteenth century (Table 1.1).

Apart from natural proxies (Section 2.2), ***documentary proxy evidence*** is increasingly used for regional to continental climate reconstructions and analyses of extremes during the last few centuries before instrumental data became available (Pfister, 1992, 2005; Pfister *et al.*, 1998, 1999; Glaser *et al.*, 1999; Brázdil *et al.*, 1999, 2003, 2004, 2005; Rácz, 1999; Pfister and Brázdil, 1999; Brázdil and Dobrovolny 2000, 2001; Glaser 2001; van Engelen *et al.*, 2001; Shabalova and van Engelen, 2003; Benito *et al.*, 2003a,b; Luterbacher *et al.*, 2004; Chuine *et al.*, 2004; Bartholy *et al.*, 2004; Guiot *et al.*, 2005; Menzel, 2005; Casty *et al.*, 2005a; Glaser and Stangl, 2005; Przybylak *et al.*, 2005; Xoplaki *et al.*, 2005). Documentary evidence is best suited to analyse the impact of natural disasters (e.g. severe floods, droughts, windstorms, frosts, hailstorms, heat waves) on past societies (see Pfister, 1992, 1999, 2005; Martin-Vide and Barriendos, 1995; Barriendos, 1997; Pfister *et al.*, 1998, 1999, 2002; Pfister, 1999; Pfister and Brázdil, 1999; Brázdil *et al.*, 1999, 2003, 2004, 2005 for a review and references therein; Barriendos and Llasat, 2003; Benito *et al.*, 2003a,b). Analysing reports of climate extremes in the context of other proxy climate information enables an investigation of the relationship between fluctuations in mean climate and the frequency of extremes (Katz and Brown, 1992) - a major source of societal concern in light of global warming (e.g. Pfister, 2005). Documentary evidence comprises all non-instrumental man-made data on past weather and climate as well as instrumental observations, prior to the set-up of continuous meteorological networks. Non-instrumental evidence is subdivided into *descriptive documentary data* (including weather observations, e.g. reports from chronicles, daily weather reports, travel diaries, ship logbooks, etc.) and *documentary proxy data* (more indirect evidence that reflects weather events or climatic conditions such as the beginning of agricultural activities, the time of freezing and opening up of waterways, religious ceremonies in favour of ending meteorological stress, etc.). In general, descriptive evidence has a good dating control and high temporal resolution (often down to the single day). The data distinguish meteorological elements and cover all months and seasons. However, descriptive evidence is discontinuous and biased by the perception of the observer (Glaser, 2001; Pfister, 2005). The methods of analysis involves collocating a substantial amount of quality controlled descriptive and proxy evidence for a given region (Pfister *et al.*, 1998, 2002; Bartholy *et al.*, 2004; Brázdil *et al.*, 2005; Glaser and Stangl, 2005; Przybylak *et al.*, 2005; Pfister, 2005). Long series of documentary proxy data are calibrated against instrumental measurements. The spatial and logical comparison and crosschecking of the entire body of evidence collocated for a given month or season allows the assessment of a climatic tendency, which is in the form of an intensity index for temperature and/or precipitation covering the last centuries. Very recently, Pfister (2005) nicely discussed the climate sensitivity of early modern economies, climate impacts and crises during the LIA at European scale pointing to the importance of temporally high resolved information from documentary proxy evidence.

Figure 1.1 presents an example of a document that describes the damages experienced in irrigation network of the city Lleida (Catalonia, Spain) on 10th June 1379. Usually these hydraulic installations experienced slight to moderate damages when snowmelt period in Pyrenees Mountains produce increase of water flow in Segre River. In this case, the damage was particularly large. Then, not only climatic hazards information can be analysed, but also attitude from human communities in previous historical contexts: People and authorities knew about extreme weather events and accepted a certain risk of damage or destruction. They recorded the phenomena by evaluating the damages and by preparing reconstructions.

In the following subsection, we review the availability of documentary evidence from the Mediterranean area and how they used for local to regional climate reconstructions. The compiled information is summarized in Table 1.1.

<Figure 1.1>

IBERIAN PENINSULA

The Iberian Peninsula has large documentary information since the low Middle Age (14-15th centuries) with continuity and homogeneity for a large number of cities. Thus, the Spanish historical archives exhibit great potential for inferences into climate variability at different time-scales and for different territories. García-Herrera *et al.* (2003a) report on the main archives and discuss the techniques, strategies to obtain climate-relevant information from documentary records.

Precipitation patterns are the most evident limiting factor for human activities and natural ecosystems. If climatic change produces quantitative or qualitative alteration of rainfall patterns, human communities and natural ecosystems can be irreversibly damaged. Martin-Vide and Barriendos (1995), Barriendos (1997) and Barriendos and Llasat (2003) used rogation ceremony records from Catalonia (Spain) for precipitation reconstructions (Fig. 1.2). Rogations were an institutional mechanism to drive social stress in front of climatic anomalies or meteorological extremes. Municipal and ecclesiastical authorities involved in the process guarantee the reliability of the ceremony and continuous documentary record of all rogations convoked. On the other hand, duration and severity of natural phenomena stressing society is perceived by different levels of liturgical ceremonies applied (e.g. Martín-Vide and Barriendos, 1995; Barriendos, 1997).

<Figure 1.2>

Rodrigo *et al.* (1998) analysed climatic information in private correspondence of a Jesuit order in Castille (Spain) for 1634-1648. They showed prevalence of intense rainfall and cold waves in that period. Rodrigo *et al.* (1999, 2000, 2001) reconstructed a 500-year seasonal precipitation record for Andalusia (Spain) and derived a winter NAO index based on meteorological information on droughts, abundant rainfall, floods, hail, etc., This information was obtained from a wide variety of documentary sources such as municipal acts, private correspondence, urban annals, chronicles, brief relations describing extreme events, agricultural records, etc.. Results of these studies indicate rainfall fluctuations, without abrupt changes, in the following alternating dry and wet phases: 1501-1589 dry, 1590-1649 wet, 1650-1775 dry, 1776-1937 wet and 1938-1997 dry. Possible causal mechanisms for these variations most likely include the NAO with drought (floods) being related to extreme positive (negative) NAO values. Precipitation in the Canary Islands has been reconstructed using agricultural records for the period 1595-1836 (García-Herrera *et al.*, 2003b). Barriendos and Martin-Vide (1998), Benito *et al.* (2003a,b) and Llasat *et al.* (2003) investigated flood magnitude and frequency within the context of climatic variability for the last centuries for central Spain and Catalonia. The authors found evidence for high flood frequencies in the past, which are similar to present conditions. Comparable catastrophic events have been recorded at least once each century.

Most recently, weather information was obtained from original documentary sources from the northeastern (Barcelona) and southeastern (Murcia) coast of the Iberian Peninsula, respectively (Barriendos and Rodrigo, 2005). The climatic indicators used are ‘pro pluvia’ (ceremonies to obtain rainfall) and ‘pro serenitate’ (ceremonies to stop continuous rainfall events) rogations. These proxy data records offer highest reliability and excellent perspectives in historical climatology for the Roman Catholic cultural world (Martín-Vide and Barriendos, 1995). A numerical index, ranging from -3 (severe droughts) to +3 (catastrophic floods), was established to characterize the seasonal rainfall and its evolution. The information was calibrated against overlapping instrumental data (for Barcelona 1786-1850, in case of Murcia 1866-1900), whereas a cross-validation procedure was employed to confirm the reliability of the calibrations. The regression equations between index values and instrumental data were used to extend seasonal rainfall series for the Iberian Peninsula back in time (Rodrigo *et al.*, 1999; Barriendos and Rodrigo, 2005). Figure 1.3 presents standardized anomalies of seasonal rainfall in Barcelona and Murcia with regard to the 1961-1990 reference period. It shows the fluctuating character of precipitation with important wet (first half of the seventeenth century and around 1850) and dry periods (around 1650 and 1750) during winter (Barcelona). For spring, a wet period in the last decades of the sixteenth century and a dry period from the first decades of the seventeenth century to approximately 1750 has been found for Barcelona. In Murcia, there is a slight decreasing trend of autumn rainfall visible.

<Figure 1.3>

Daveau (1997) analysed private letters of a priest of the Jesuit Order (António Vieira) and has reconstructed weather in Central Portugal from December 1663 to September 1665. It is stated that between December 1664 until March 1665 very long sequences of rainy weather occurred, as well as floods of the large Iberian (Tagus) and Portuguese rivers (Mondego). For example, Vieira writes that in April 1664 there occurred “the greatest cold as in December (in the first half of the month) as well as hot spells similar to those in Guinea (Western Africa) (at the end of the month)”. Alcoforado *et al.* (2000) have used several documentary sources such as diaries, ecclesiastical documents (including references to ‘pro pluvia’ and ‘pro serenitate’ rogation ceremonies, see above) to reconstruct temperature and precipitation variability in southern Portugal, during the Late Maunder Minimum (LMM, 1675-1715). One of the diaries refers to the period from 1696 to 1716 and although non-meteorological news is the thread throughout it, there are detailed descriptions of weather and of the author’s perception of its consequences (Alcoforado *et al.*, 2000). The main conclusions are that, after 1693, conditions in Portugal were rather cold (with snowfall events in Lisbon that hardly ever occur nowadays). Precipitation, on the other hand, showed a very pronounced variability, similar to the present. Taborda *et al.* (2004) extended the study to the whole eighteenth century based on descriptive documentary sources (institutional, ecclesiastical, private and from the press) and early instrumental records (from 1781 to 1793). The winters of 1708/09 (also described in Alcoforado *et al.*, 2000), 1739/40 and 1788/89 were particularly severe. All these winters agree with very cold conditions on a European scale (Luterbacher *et al.*, 2004). In the beginning of the eighteenth century, precipitation shows strong variability (Fig. 1.4) with persistent rain from winter 1706/07 until summer 1709) and droughts during winter 1711/12 and between spring 1714 and autumn 1715. Very strong rainfall variability characterised the 1730s confirmed by the highest frequency of 'pro pluvia' and 'pro serenitate' rogation ceremonies. At the end of the eighteenth century, a period of eight rainy years, beginning in 1783 has to be mentioned. A significant, although low negative correlation, was found between the North Atlantic Oscillation Index (NAOI; Luterbacher *et al.*, 1999, 2002a) and yearly and seasonal precipitation in Portugal (Fig. 1.4).

<Figure 1.4>

Regular meteorological observations in Lisbon begun in December 1815, carried out by M.M. Franzini, due to public health needs (Alcoforado *et al.*, 1997, 1999). Although 1815-1817 meteorological data were published by the Portuguese Academy of Sciences, the subsequent data have been gathered mostly from newspapers. 1817-1854 presents some gaps, one of them lasting nine years (1826-1835). The data were used to study the relation between climate and society (agriculture, human health, necrology). An attempt to construct a reliable meteorological series for Lisbon 1815-to the present is on its way (M. Alcoforado, personal communication).

In summary, climatic research from documentary sources in the Iberian Peninsula is still in its early stages. The current knowledge provides a patchy vision of past climate in Spain and Portugal. Mostly because of lack of funding, there has not been a systematic attempt to explore the main Spanish archives, such as the Archivo de Simancas, and a lot of local archives. Despite of the effort required to collect information from original documentary manuscripts, a tremendous unexploited potential in different documentary funds in many Spanish regions exist: economic information from agriculture (production and tributary statistics), monastic documentary sources for High Middle Age (8-13th centuries), or documentary testimonies from the top of ecological thresholds (farming on medium/high mountains). Most of the information is related to the rainfall, which is of greatest importance for an agricultural economy. In this sense, not much research on temperature has been made so far. The Spanish groups working in the paleoclimatology field have a network called RECLIDO (Climate reconstruction from Documentary sources; www.ucm.es/info/reclido), which summarizes most of the work done in Iberia. In Portugal, research is being carried on to collect data from the early seventeenth century, mostly referring to rainfall and its consequences on agriculture (J. Taborda, personal communication).

FRANCE

Pichard (1999) has studied the variations of climate and hydrology in southern France from documentary sources. They are based on records of extreme events like floods, ice presence, insect invasion, long instrumental records and economical data. Figure 1.5 shows as an example the statistics of floods in the Durance Valley, a river running from the Alps to the Rhone Valley in Avignon. This river was well known in the previous centuries for frequent flooding events. It appears that the period 1540-1900 was characterized by much more frequent floods as compared to the twentieth century. The same kind of situation is also reported for the Rhone Valley. Floodings in the Durance catchment reflect mainly winter and spring precipitation, the most dominant in the Southern Alps. Before 1540, only the period 1330-1410 was also wet. It is assumed that these two wet periods were due to higher winter precipitation and also much more snow precipitation in the Southern Alps.

<Figure 1.5>

As for other parts of the Mediterranean (Xoplaki *et al.*, 2001 for Greece), the wettest climate of the 'Little Ice Age' (LIA) occurred during the periods 1650-1710 and 1750-1820. Guiot *et al.* (2005) recently reconstructed the temperature at Marseille Observatoire (Fig. 1.6) based on a combination of a variety of documentary proxy evidence (among them grape-harvest dates from France) and tree-ring information. They showed a LIA cooling of 0.5°C with maxima of 1.5°C, in phase with western Europe. The recent warming of 1°C was never reached in the context of the last millennium even if it still lies within the confidence interval of the previous centuries (Guiot *et al.*, 2005). The Swiss physicist Louis Dufour (1870) was the first to discover the value of dates on the opening of vine harvests for the reconstruction of temperatures in the pre-instrumental period. He was followed by the French climatologist Alfred Angot (1885) who provided a catalogue of documentary evidence in France (Angot, 1895). French records of grape-harvest dates in Burgundy (Pfister, 1992; Soriau and Yiou, 2001; Le Roy Ladurie and Baulant, 1980, 1981; Le Roy Ladurie, 2004, 2005; Chuine *et al.*, 2004; Menzel, 2005) were used to reconstruct spring-summer temperatures from 1370 to 2003 using a process-based phenology model developed for the Pinot Noir grape (Chuine *et al.*, 2004). The results reveal that summer temperatures as high as those reached in the 1990s have occurred several times in Burgundy since 1370. However, the summer of 2003 appears to have been extraordinary, with temperatures that were probably higher than in any other year since 1370 (Chuine *et al.*, 2004). Le Roy Ladurie (2004) recently presented a very nice overview of the past climate conditions, socio-economic conditions and climate impacts in France.

Summarized, historical written documents in France are insufficiently exploited. After the work of Le Roy Ladurie (1983), grape harvest dates series have shown their potential and recent work of Chuine *et al.* (2004) an Le Roy Ladurie (2005) has proved that it was possible to translate them into quantitative temperature series. However, this has been limited to the non-Mediterranean part of France and Switzerland, even if potentialities for an extension exist (Pichard, 1999). This latter author has shown that much other sources are available, such as religious processions for rain (such as from the Iberian Peninsula, see above), cereal prices series, insect invasions, river floodings and ice presence. All these proxy sources have their own limitations and biases (for example productivity improving in agriculture, variations of the river depth due to sediment transfer, etc.). An integrated approach involving many proxies (Guiot *et al.*, 2005) or in combination with modelling as used by Chuine *et al*. (2004) for grape harvest dates might be a successful way for further research in the area.

<Figure 1.6>

ITALY

Italy has a long history with early civilisation and written documents began in the Roman times. For instance, it was possible to reconstruct the flooding series of the river Tiber for Rome back to 2400 yr BP (Camuffo and Enzi, 1995b, 1996). The river Tiber flooding in Rome offers the opportunity of having one of the longest discharge series in the world. Over the centuries the river response had some minor changes to the meteorological forcing derived from the changes affecting the territory, the banks and urban development in Rome. However, the most important change was the rise of the banks in 1870, which practically reduced, or even stopped the series of floods. Floodings mainly occur in winter (especially in November-December). Strong precipitation events reflect both the air-sea temperature contrast and the occurrence of the Scirocco wind. The Tiber had two major periods of increased overflowing frequency at the beginning of the Spörer Minimum and at the onset of the Maunder Minimum, i.e. 1460-1500 and 1600-1660. The periods 1400-1460, 1500-1600 and 1660 onwards show a very low rate of flooding, which was further reduced after the works in 1870.

Roman literature reports also on major or impressive events that happened more or less in all regions of Italy (and some in Europe too). Part of this information is related to wars or other political or social events, which may affect the objective description. The abundance of the data decreases in the Medieval period, when the social conditions were very bad. Starting with AD 1000 the improvement of the social conditions reflected in a second flourishing of the culture, which culminated 1400-1500. However, during the 1100-1200 period, a number of cities started to fight against the Emperor and other authorities (especially in the North of Italy). With independency, people started to document extreme events, natural hazards, yields, etc. described in annals and chronicles. In 1300 Florence had free schools and all citizens were able to write and read, The 1400-1500 period is rich of literary and historical culture, and is the background for science too, flourished in 1500 with Leonardo da Vinci and Galileo and others. Thus, Italian archives, libraries and museums provide a great number of written historical sources on different aspects of past climate reaching back more than 1000 years (e.g. Camuffo, 1987). Over the centuries, many subjective reports on extremely cold winters can be found. Fortunately, this abundant information can objectively be evaluated per classes of severity. A '*great winter*' was defined when the cold was particularly severe over a large area causing well documented exceptional events e.g. large water bodies frozen, with ice sustaining people and chariots, wine was frozen in butts, death of people, trees and animals. The term '*severe winter*' was used when people, trees and animals were killed, and only minor rivers were frozen over. '*Mild winters'* when ice was missing and plants had early growing and flowering. In northern Italy, the freezing of the Venice Lagoon and its deeper canals was a very useful reference to quantitatively establish the degree of severity over the centuries. This information was based on a large number of citations, pictorial and literary representations (Camuffo, 1987; Camuffo and Enzi, 1992; Camuffo and Enzi, 1994a; Camuffo, 1993, Enzi and Camuffo, 1995a, Camuffo and Sturaro, 2003; Fig. 1.7). Freezing was particularly frequent in the 1400-1600 period and then 1700-1850. The coldest winter in the series was 1708/1709 (most probably the coldest winter in Europe for at least half a millennium, Luterbacher *et al.,* 2004). Other very cold winters were experienced in 1928/1929 and 1788/1789 (Camuffo, 1987).

<Figure 1.7>

Past flooding in Venice is another important factor to understand regional climate variability. Those 'High Water' (Camuffo 1993; Enzi and Camuffo, 1995; Camuffo *et al.,* 2005) occur when the sea level rises more than 110 cm above the mean level (with respect to the yearly average level observed in 1897). They caused enormous problems to the city. For this reason Hith Waters were reported in public and private documents (regular instrumental records, i.e. tide gauge, began in 1872). The problem nowadays is dramatically relevant because of the damage to historical buildings and monuments. Flooding surges are due to a cyclonic circulation moving over western Mediterranean: the Scirocco wind is strong and drags water to Venice; the corresponding pattern of atmospheric pressure over the Mediterranean further displaces further water towards Venice. The sea level rise is increased or decreased by further factors such as luni-solar forces, free oscillations (seiches) in the Adriatic basin, and an additional sea level rise due to global warming. In the past, deep cyclonic circulations generating High Waters in Venice were particularly frequent in the first decades of 1500 and at the turn of the 18th century. Nowadays, the surge frequency has increased exponentially due to the combined effect of soil subsidence and sea level rise. The relative sea level change in Venice is a vital problem for the city and raised 61±11 cm over the last few centuries. The brown belt of the algae which live in the tidal range and the upper front is a good indicator for the average high tide level. This indicator was accurately drawn by Antonio Canaletto (1697-1768) and Bernardo Bellotto (1722-1780) in their 'photographic' paintings (Camuffo *et al.,* 2005).

In northern Italy, the long series of locust invasions constitutes an index of the frequency of easterly circulation in the summertime, which transported swarms originated in the Pannonian plain (Hungary) (Camuffo and Enzi, 1991). Locusts from Anatolia or the Near East infested the Pannonian plain. In the summertime, eastern winds of Bora type, transported the swarms westwards, i.e. from Hungary to northern Italy. Annals and chronicles report the list of the damaged areas, often followed by famine and epidemics, and it is often possible to follow the path and spread of swarms. Locust invasions (and cold summer inflows) were more frequent in the mid fourteenth century, during the Spörer Minimum (1460-1500), with a major peak in the early sixteenth century, and at the very beginning of the Maunder Minimum (1645-1715). Invasions were finished when the Pannonian plain was densely cultivated and the locust eggs were destroyed. In Sicily and the western coast of Italy locust invasions were mainly related to southerly winds (mainly Scirocco) that transported swarms from northern Africa, e.g. in 1566/1572. In southern Italy, parts of the semi-arid territory was left uncultivated and used for grazing sheep, so that it was naturally infested with locusts. The severity of the plague was determined not only due to climatic factors, but also by the effectiveness of the methods used to fight them. Intensive land cultivation was the most effective system that terminated this plague in the first part of the nineteenth century.

Piervitali and Colacino (2001) analysed drought events that occurred in western Sicily during the period 1565-1915 using information on religious processions performed in the small town of Erice (Italy). Together with other documents and manuscripts found in the city library, a drought chronology was reconstructed.

Intense natural pollution in Italy occurred in the past corresponding to the intense volcanic activity, which has since diminished in recent times. Between 1500 and 1900, the Mediterranean volcanoes Etna, Vesuvius, Vulcano and Stromboli were particularly active and caused the so-called *dry fogs* (Camuffo and Enzi, 1994, 1995a). Acid volcanic fogs consist of a more or less dense mist composed of gasses and aerosols with reddish colour and foul smelling. This mist is dry. The most dramatic episode occurred in 1783, due to Icelandic volcanic activity, which affected most of the NH (Franklin, 1784). In Italy, this phenomenon appeared most frequently from late spring-early summer when the volcanic emissions were less easily dispersed in the atmosphere. Two main factors are prominent: the Mediterranean sea was relatively cold giving rise to very stable atmospheric conditions and low dispersion potential. Further, the Azores anticyclone extended over the Mediterranean,which reduced winds. Under such conditions the volcanic emissions, especially those emitted at low levels, remained entrapped in the stable boundary layer, which were then transported towards the land by a gentle breeze. The dry fogs persisted for days or weeks. From the analysis of these pollution episodes, which have occurred in the Po Valley over the last millennium, it is difficult to identify the individual volcano that has determined, the occurrence of each dry fog event. Volcanic clouds crossed Italy from south to north, destroying from one third to half of the maize or wheat yield. It would seem much more reasonable to note that the phenomenon became frequent only after Stromboli became active once again. In agricultural meteorology of the 1800s, the phenomenon was so relevant that sources distinguished between the caustic dry fogs that damaged the vegetation and *damp fogs*, with positive effect because they act as a nutrient. From 1300 to 1900, some 50 anomalous fog events have been noted, 30 of those were certainly corrosive, i.e. of volcanic nature. The frequency of these events culminated between the middle of the 1700s and the middle of the 1800s.

Summarized, the documentation of past climate and extremes in Italy based on documentary evidence is widespread and reliable. The South had different political vicissitudes, but in any case it had a very flourishing culture (e.g. Sicily, Apulia, Naples), with a similar amount of climate and weather descriptions. A number of people wrote diaries, logs, reports and so on, so that the documentation becomes abundant and sometimes also quantitative. There is still much potential in the whole country to collect, read and digitize these climate related information as the State Archives of Italy for instance have shelves for 12,000 km, the State Archive in Venice has 17 km shelves (public and private libraries, monasteries, private collections etc, handwritten and printed documents of any type not included).

SOUTHERN BALKANS, GREECE AND EASTERN MEDITERRANEAN

The Balkan Peninsula (Greece, former Yugoslavian countries, Albania, Bulgaria and Romania) provides rich archives of documentary data. Repapis *et al.* (1989) investigated the frequency of occurrence of severe Greek winters based on evidence from monastery and historical records during the 1200-1900 period. They found evidence, that the coldest periods occurred in the first half of the fifteenth century, in the second half of the seventeenth century and in the nineteenth century. Grove and Conterio (1994, 1995), Grove (2001) and Xoplaki *et al.* (2001) reported on the variability of climate and extremes (severe winters, droughts and wet periods) during parts of LIA using different kind of written sources. Figure 1.8 presents the estimated winter temperature and precipitation conditions for Greece during the 1675-1715 period based on documentary proxy evidence (Xoplaki *et al.*, 2001).

<Figure 1.8>

Xoplaki *et al.* (2001) found, that during these periods more extreme conditions were apparent compared to the late twentieth century. Xoplaki *et al.* (2001) extended the analysis for the 1780-1830 period. Documentary information on 'Medieval Warm Period' and the beginning of LIA in Eastern Mediterranean is provided by Telelis (2000; 2004).

Compared to the wealth of data found in central and western Europe the data density for the southern Balkans, Greece and eastern Mediterranean for the last few centuries is rather low. This may be attributed to the Turkish occupation, which lasted from the fifteenth to the nineteenth century (Xoplaki *et al.*, 2001). However, it is believed that a number of important monastery memoirs covering the last at least half millennium show evidence of optical phenomena from important tropical volcanic eruptions (C. Zerefos, personal communication). It is assumed, that there are detailed documentary data available from the Turkish archives that could be explored and used for climatic reconstructions. Further, it is believed that also early instrumental data from Cyprus, Syria and Greece starting in the 18th century and from Egypt and Malta from the early 19th century can be obtained from different sources.

NORTHERN AFRICA

There is only very limited climate information available from northern African countries based on documentary evidence. A notable exception is the record of *the **flood levels of the Nile river***, which was analysed by hydrologists, climatologists and historians. There are a number of studies dealing with the reconstruction and analysis of the data from written records (Fraedrich and Bantzer, 1991 and references therein; Eltahir and Wang, 1999; De Putter *et al.*, 1998; Kondrashov *et al.*, 2005). Pharaonic and medieval Egypt depended solely on winter agriculture and hence on the summer floods. The rise of the waters of the Nile was measured therefore regularly from the earliest times (e.g. Eltahir and Wang, 1999; Kondrashov *et al.*, 2005 and reference therein). Several authors compiled the annual maxima and minima of the water level recorded at nilometers (generally an instrument that measures the height of the Nile waters during its periodical flood) in the Cairo area, in particular at Rodah Island, from AD 622 to 1922. There is evidence of low Nile floods occurring in the periods 1470-1500, 1640-1720 and a number of low floods from 1774-1792 (Fraedrich and Bantzer, 1991).

SHIP LOGBOOKS AS A NEW DOCUMENTARY PROXY FOR PAST MEDITERRANEAN CLIMATE

Weather observations have been made on board sailing ships as part of a daily routine since the mid-seventeenth century. Procedures for marine observations were not, however, formalised until the International Maritime Conference of 1853 (Maury, 1854). The seeming lack of consistency of record before this date might help to account for the reluctance of climatologists to exploit the earlier records in any comprehensive fashion. Recent studies of ***ships' logbooks*** for the period 1750 to 1850 undertaken as part of the CLIWOC project (Climatological Database for the World's

Oceans, CLIWOC Team, 2003; García-Herrera *et al.*, 2005; Jones and Salmon, 2005; Wheeler, 2005; www.ucm.es/info/cliwoc) and for the period 1680 to 1700 (Wheeler and Suárez Domínguez, 2005) have, however, demonstrated the value of such material as a source of reliable climatic data and information. Studies have also confirmed the availability of a large number of such logbooks for the Mediterranean. After 1850 most ships provided instrumental data, but such provision is exceptional for the years before the mid-nineteenth century. The climatic information contained in these early logbooks falls under three headings; those of wind force, wind direction and general accounts of the weather. The layout of logbooks varied slightly within and between nations but they all contain much the same information, and the presentation exemplified in Fig. 1.9 is typical of its age. Wind direction and force were recorded at noon each day, these observations often being supplemented by additional records at other hours providing an unrivalled picture of short-term variation. Observations were also included on such things as the state of the sea, cloudiness, visibility and the incidence of particular phenomena such rain, snow, thunder and fog. Although based on visual observations and individual judgment, these estimates were made by experienced officers whose abilities would differ little from those of today's deck officers, many of whom continue to make similar records in the logbooks of merchant and military vessels many of which are used by the forecasting services.

<Figure 1.9>

Each of the early records is presented in narrative, non-numerical form. In that sense they differ from the instrumental data gathered in such sources as ICOADS (International Comprehensive Ocean and Atmospheric Data Set, Worley *et al.*, 2005) although they do occasionally provide temperature and barometric data, some from as early as the later eighteenth century. These narrative data, written in the language and vocabulary of the age (and nation), need to be transformed into present-day terms (and English) before they can be subjected to scientific analysis. The CLIWOC project has established procedures and methods whereby these transformations can be made. The project has also assessed the intrinsic reliability of the original observations (Wheeler, 2005). These activities have permitted the construction of a database (Können and Koek, 2005) containing quality-controlled data for the equivalent of 280000 days of observations. Figure 1.10 shows the geographic range and coverage of these CLIWOC data.

<Figure 1.10>

To date, logbook-based studies of the Mediterranean climate have been limited to the geographically peripheral area of the Straits of Gibraltar, and to particular historical events (Wheeler, 1987, 2001). Nevertheless such undertakings have amply demonstrated the advantages of using these data to reproduce daily and seasonal synoptic patterns. These exercises have demonstrated also that such sea-based data can be profitably articulated with those from land stations and do not stand apart as a data set. The CLIWOC project was focused on major oceanic regions and excluded all enclosed seas such as the Baltic and the Mediterranean. There is, however, no shortage of logbooks for the region. Remarkably, the majority of these are to be found not in the archives of Mediterranean states but in the United Kingdom. British political strategy has been based on sea power from the seventeenth century and as long ago as 1680 British warships and fleets were active in the area. With the establishment of bases, particularly in Gibraltar and, though more temporarily, Port Mahon, British interest in the western Mediterranean was to persist, unbroken, for three centuries. It has been estimated (D. Wheeler, personal communication) that for the Mediterranean over the period from 1680 to 1850 there are the equivalent of over 1,000,000 days of data to be extracted from British logbooks of which some 4000 to 5000 are estimated to exist in UK archives (principally in The National Archives in Kew, South West London). From 1700 onwards the record is probably unbroken, with at least one fleet or squadron active somewhere in the Mediterranean at any given time. The number of logbooks varies according to the political climate (war time yields far more records than periods of peace) and Fig. 1.11 summarizes their decadal availability.

<Figure 1.11>

The geographic range of currently available observations is by no means restricted to the British and allied ports. Vessels were based in Naples, Cyprus and Alexandria at different times, and British naval policy required Royal Navy ships to cruise extensively providing thereby something close to the observational network offered by today’s merchant services. Given that military action was frequently necessary against the North African Barbary States, there exists also the opportunity partly to fill the gap noted on a number of occasions in this chapter that prevails over this most southerly sector of the region. It is not known if further archival sources in such historic centres as Venice, Istanbul or Alexandria might yield additional logbooks or similar documents, although S. Enzi and D. Camuffo have confirmed the existence of some logbooks in Italian archives. Further logbook collections are also known to exist in French and Spanish Archives. The French logbooks cover the period 1671-1850. Most of them were prepared during coastal voyages to Spanish or Italian ports. It is estimated that approximately 500 such logbooks are preserved but have remained un-digitised. A further 100 logbooks are preserved in Spain, corresponding mostly to coastal sailing by ships of different Catalonian companies (R. García-Herrera personal communication, Prohom and Barriendos, 2004).

To summarise, logbook data examined thus far offer a number of significant benefits to the climatologists: The data are fixed by time and location, being recorded each day at midday, with a further note that includes the ship’s latitude and longitude. Secondly, the observations are homogenous in that they are recorded using a widely adopted vocabulary and based on a set of common practices that prevailed even during those years and decades before adoption of the Beaufort system. Thirdly, the data should not be regarded as ‘proxy’: they constitute first-hand and direct observations on the weather at the time. Fourthly, and very importantly, they are the only such source of information for the oceanic and sea areas. This is of significance in the Mediterranean as the region, however it may be defined, is focussed on the sea, which represents a significant proportion of its surface area. Fifthly, logbooks provide information that extends back to the late seventeenth century and express therefore conditions at a critical time of climatic evolution that includes the closing decades of the LMM. And, finally, these data are so abundant, that there is a genuine possibility of providing a daily series from 1700 onwards, especially for the western Mediterranean area.

<Table 1.1>

2.2. Evidence From Natural Proxies

In this section, we describe natural proxies that are used to reconstruct climate conditions for sub-Mediterranean areas. They include high-resolution proxies such as tree-rings, speleothems and corals, but also lower resolution natural proxies such as borehole data. In addition we discuss new marine archives (non-tropical coral, deep sea corals) that show much potential for regional climate reconstructions. Table 1.2 summarizes the climate evidence described in detail in Section 2.2.

The first part deals with the climate evidence in the different areas of the Mediterranean based on tree-ring data, followed by descriptions of speleothems and corals and their distribution. The second part of this section provides an overview on lower resolved natural land and marine proxies (boreholes, vermetids, non-tropical corals and deep sea corals).

TREE-RING INFORMATION FROM THE IBERIAN PENINSULA AND ITALY

Many past studies have described the use of ***tree-ring or dendroclimatic data*** to reconstruct past variations in precipitation, temperature, soil moisture, streamflow, the frequency of extreme droughts, and atmospheric circulation indices.

From dendroclimatic reconstructions over the Iberian Peninsula several periods of differentiated climatic conditions have been highlighted over the last several hundred years (Creus-Novau *et al.*, 1997; Saz and Creus-Novau, 1999; Saz, 2004). Creus-Novau *et al.* (1992), Saz *et al.* (2003) and Saz (2004) used tree-ring information to reconstruct temperature and precipitation in different points of the northern half of Spain since the fifteenth and sixteenth centuries and over entire Spain for the last millennium. They used a set of 42 dendrochronologies constructed from more than 1,500 samples of different trees and from some different tree species. More than 90% of the cores were extracted from coniferous. Climate reconstructions obtained from these chronologies allow studying the evolution of spring, summer, fall and winter (and annual) temperature and precipitation since the fifteenth century for nine different weather stations of Spain located in different bioclimatic areas. The results are shown in Fig. 1.12. During the first centuries of the last millennium Iberian climate was characterized by high temperatures and precipitation, as well as by a remarkable climatic regularity that lasted till the mid-fourteenth century, when a shift in Iberian climate took place. This led to increased climate variability with a remarkable reduction in temperatures and an intensified occurrence of precipitation extremes. The LIA, which reached its maximum during the seventeenth century and lasted up to the early decades of the nineteenth century, was also manifested over the Iberian Peninsula as a period of cold conditions and increased climate variability, being also detected from lagoon and coastal sedimentary records (Luque and Juliá, 2002; Desprat *et al.*, 2003). These cold phases coincide with similar periods described in western and central Europe. As for rainfall, the most important dry anomalies appear in the sixteenth and seventeenth centuries, a period with high interannual temperature and precipitation variability. Creus-Novau *et al.* (1995) used tree-ring information to reconstruct the climatic conditions in Galicia (northwestern Spain) for the last centuries.

<Figure 1.12>

Galli *et al.* (1994) used Pinus pinea L. from Ravenna pine forest to check the possibility of reconstructing winter temperatures for the 1653-1985 period for an area close to the Adriatic coast, Italy. Briffa *et al.* (2001) used a large number of tree-ring data from southern Europe (Spain, Italy, southern Balkans, Greece) in order to reconstruct mean averaged central and southern European growing season (April-September) temperature series back to the early seventeenth century.

Recently, Budillon *et al.* (2005), found both hyperpycnal flows from flood-prone stream and tempestites appearing as sand layers in the stratigraphic record of shelf areas are proxies for past storminess. The case study of the Salerno Bay shelf record from Central Italy revealed at least four events related to major storms that occurred in the area during the last 1000 years ((1954, 1879, 1544 and an older unknown event).

TREE-RING INFORMATION FROM SOUTH EASTERN EUROPE AND EASTERN MEDITERRANEAN

Dendroclimatology in the eastern Mediterranean region is still in the early stages of development. Most studies are recent with the exception of a few earlier works. Gassner and Christiansen-Weniger (1942) demonstrated that tree growth is significantly influenced by precipitation in parts of Turkey. B. Bannister, from the Laboratory of Tree-Ring Research at The University of Arizona, was the first dendrochronologist to attempt systematic tree-ring dating of Near Eastern archaeological sites (Bannister, 1970). He collected and analysed tree-ring specimens from an eighth century B.C. tomb in Turkey and carried out preliminary examinations of wood samples from Egyptian coffins. He also collected and cross-dated samples of Cedar of Lebanon (*Cedrus libani*) in Lebanon. Several dendrochronological studies have followed the work of Christiansen-Weniger (1942) and Bannister (1970). For example, a large number of tree-ring chronologies, mainly in Greece and Turkey, for dating archaeological sites are produced by Kuniholm and Striker (1987) and Kuniholm (1990, 1994). During the past six years, dendroclimatology has begun to establish itself in the region through multi-national scientific projects that are interested in understanding climate variability over several centuries. The first dendroclimatic reconstruction (a 396-year-long reconstruction of October-May precipitation based on two chronologies of *Juniperus Phoenicia*) in the Near East was developed by Touchan and Hughes (1999) and Touchan *et al.* (1999) in southern Jordan. They showed that the longest reconstructed drought, as defined by consecutive years below a threshold of 80% of the 1946-1995 mean observed October-May precipitation, lasted four years.

More recently in Turkey, Akkemik (2000) investigated the response of a *Pinus pinea* tree-ring chronology from the Istanbul region to temperature and precipitation. Hughes *et al.* (2001) demonstrated that the cross dating in archaeological specimens over large distances in Greece and Turkey has a clear climatological basis, with signature years consistently being associated with specific, persistent atmospheric circulation anomalies. D'Arrigo and Cullen (2001) presented the first 350-year (1628-1980) dendroclimatic reconstruction of February-August precipitation for central Turkey (Sivas), although it relied on Peter Kuniholm's materials that end in 1980. Touchan *et al.* (2003) used tree-ring data from living trees in southwestern Turkey to reconstruct spring (May-June) precipitation several centuries back in time (Fig. 1.13).

<Figure 1.13>

Their reconstructions show clear evidence of multi-year to decadal variations in spring precipitation. The longest period of spring drought was only four years (1476-1479). The longest reconstructed wet periods were found during the sixteenth and seventeenth centuries. They also found that spring drought (wetness) is connected with warm (cool) conditions and southwesterly (continental) circulation over the eastern Mediterranean. A subsequent reconstruction was developed by Akkemik *et al.* (2005) for a March-June precipitation season from oak trees in the western Black Sea region of Turkey. They found that during the past four centuries drought events in this region persisted for no more than two years. Akkemik and Aras (2005) reconstructed April-August precipitation (1689-1994) for the southern part of central Turkey region by using *Pinus nigra* tree-rings. These various tree-ring studies in Turkey suggest that the duration of dry years generally extends for one or two years and rarely for more than three years. In accordance with other studies, the years 1693, 1725, 1819, 1868, 1878, 1887 and 1893, which were below two standard deviations from the twentieth century long-term mean, were determined as the driest years in the eastern Mediterranean basin (Akkemik and Aras, 2005).

Touchan *et al.* (2005a) were the first to develop a standardized precipitation index (drought index) reconstruction from tree-rings. Their study provided important regional information concerning hydroclimatic variability in the southwestern and south-central Turkey. Touchan *et al.* (2005b) continued their investigations of the relationships between large-scale atmospheric circulation and regional reconstructed May-August precipitation for the eastern Mediterranean region (Turkey, Syria, Lebanon, Cyprus, and Greece). As part of this study, they conducted the first large-scale systematic dendroclimatic sampling for this region from different species. They developed six May-August reconstructions ranging in lengths from 115 to 600 years. The study found no long-term trends during the last few centuries. They also identified large-scale atmospheric circulation influences on regional May-August precipitation. For example, this precipitation season is driven by anomalous below (above) normal pressure at all atmospheric levels and by convection (subsidence) and small pressure gradients at sea level.

A pioneering comparison of their tree-ring data and independent (i.e. sharing no common predictors in the reconstruction procedure) reconstructions of large-scale sea level pressure (SLP; Luterbacher *et al.*, 2002b) and surface air temperature (SAT; Luterbacher *et al.*, 2004) showed that large-scale climatic patterns associated with precipitation and tree-ring growth in this region have been substantially stable for the last 237 years.

D'Arrigo and Cullen (2001), Akkemik *et al.* (2005) and Touchan *et al.* (2005a,b) have begun new investigations linking the dendroclimatic reconstructions to other proxy records, specifically to historical documents. These new studies provide examples of how historians and archaeologists can use dendroclimatic reconstructions to study and interpret the interactions between past human behaviour and the environment. For example, all four studies identified the year 1660 as dry summer while Purgstall (1983) reported that catastrophic fires and famine in Anatolia occurred in the same year.

TREE-RING INFORMATION FROM NORTHERN AFRICA

Morocco has an interesting advantage in North Africa as the westerlies bring humid air towards the Rif and Atlas mountains, making possible the growth of millennium cedars possible on these mountains. Munaut (1982) have sampled about 50 cedar sites (*Cedrus atlantica*), which are a source of important climatic information for that country (Till and Guiot, 1990). Figure 1.14 presents the annual precipitation for Morocco over the last around 1000 years. It appears that the twentieth century was among the wettest of the last millennium. In comparison, the 1600-1900 period was 84 mm dryer than the reference period (1925-1975), i.e. a deficit of about 11%.

<Figure 1.14>

Meko (1985) and Chbouki *et al.* (1995) discussed temporal and spatial variation of Moroccan drought (based on tree-ring information). Till and Guiot (1990) published a 900-year reconstruction of October-September precipitation for three different areas in Morocco, indicating a continuous tendency towards a wetter climate during the twentieth century, and drier conditions than present during the sixteenth, seventeenth and eighteenth century. Serre-Bachet *et al.* (1992) pointed out the fact that the spatial variability of precipitation is difficult to be interpreted as some tree species used for reconstruction are related to winter conditions and others refer to the summer period. Nevertheless they showed that the dry climate periods reconstructed for Morocco and also for Spain reflect a climate out of phase with the rest of Europe, likely under a stronger effect of winter NAO than in eastern Mediterranean regions. Glueck and Stockton (2001) used climate-sensitive Moroccan tree-ring data (and ice core data from Greenland) to reconstruct the winter NAOI back to 1429. It is, however difficult to find a correlation between their NAOI and the precipitation series presented in Figure 1.14 (Till and Guiot, 1990).

SPELEOTHEMS

Speleothems are secondary cave deposits, such as stalactites and stalagmites, formed when calcium carbonate (usually calcite) precipitates from degassing solutions seeping into limestone caves. Usually, most studies use stalagmites due to their simple geometry and rapid growth rate, which typically vary between approximately 0.05 and 0.4 mm yr^{-1}. Provided that annual bands are present and well preserved, the combination of annual band counts and Uranium-series dating results in absolute chronologies with relatively small age uncertainties (Fleitmann *et al.*, 2004). In addition, the thickness of annual bands can be used to reconstruct either temperature (Frisia *et al.*, 2003) or amount of precipitation (e.g., Fleitmann *et al.*, 2004), depending on the environmental settings in and above the cave. For instance, in regions with a predominantly arid to semi-arid climate, the thickness of annual bands is primarily controlled by the availability of water (Fleitmann *et al.*, 2003). Oxygen (d^{18}O) and carbon (d^{13}C) isotopic ratios are currently the most frequently used stalagmite-based climate proxies. Both are capable to provide information on temperature and/or hydrological balance (Schwarcz, 1986; Baker *et al.*, 1997; Bar-Matthews *et al.*, 1997, 2000, 2004; Ayalon *et al.*, 1999; Desmarchelier *et al.*, 2000; Burns *et al.*, 2002; McDermott *et al.*, 2001; Bard *et al.*, 2002; Spötl and Mangini, 2002; Kolodny *et al.*, 2003; Frisia *et al.*, 2003, 2005; Fleitmann *et al.*, 2004; Mangini *et al.*, 2005). The use of d^{13}C as climate proxy, however, has remained somewhat limited as it can be influenced by many, sometimes counteracting, parameters, which do not always relate to climate (Baker *et al.*, 1997). Using conventional sampling techniques (e.g., a dental drill) temporal resolution of isotopic time-series typically ranges from 1 to 20 years. More recently, newly developed analytical techniques (laser ablation inductively coupled mass spectrometry (LA-ICP-MS) allow the measurement of climate-sensitive trace elements (Mg, P, U, Sr, Ba and Na) at much higher (weekly to monthly) resolution (Baldini *et al.*, 2002; Treble *et al.*, 2003; Montagna, 2004). To date, few studies have focussed on the reconstruction of continental climate variability during the past 500-1000 years using speleothems, mainly due to the difficulty in devising high-resolution sampling strategies. The work of Frisia *et al.* (2003) reports on annual growth rates within single annual laminae in three contemporaneously deposited Holocene speleothems from Grotta di Ernesto (Alpine cave in northern Italy), which respond to changes in surface temperature rather than precipitation. Based on monitoring of present-day calcite growth, and correlation with instrumental data for surface climatic conditions, the authors interpreted a higher ratio of dark to light-coloured calcite and the simultaneous thinning of annual laminae as indicative of colder-than-present winters. Such dark and thin laminae occur in those parts of the three stalagmites deposited from 1650 to 1713 and from 1798 to 1840, as reconstructed through lamina counts. An 11-yr cyclicity in growth rate, coupled with reduced calcite deposition during historic minima of solar activity, suggests a solar influence on lamina thickness and temperature, respectively. Spectral analysis of the lamina thickness data also suggests that the NAO variability influenced winter temperatures. More recently, Antonioli *et al.* (2003) and Montagna (2004) examined a stalagmite collected from the Grotta Verde, located on Capo Caccia promontory on the northwest coast of Sardinia (Central Mediterranean Sea). The oxygen isotopic record by Antonioli *et al.* (2003) covers the last ~1000 years and reveals a centennial-scale variability with a resolution of ~20 years. Their climate reconstruction clearly demonstrates the presence of a warm/wet ‘Medieval Warm Period’, a cold/dry LIA and a warming trend since 1700. This rise in temperature ended around the years 1930-1940, and was followed by a relatively cold/dry period between the years 1940 and 1995. Based on these data, Montagna (2004) obtained a millennial-scale seasonally resolved record of precipitation variability from Sardinia. The d^{18}O values show significant changes in precipitation during the last millennium, comparable with the low-frequency signals observed in a long European tree-ring chronology (Esper *et al.*, 2002). The speleothem d^{18}O record between 1600 and 1800 indicates relatively dry and cold conditions corresponding to the LIA, followed by a gradual warmer and wetter trend, culminating in 1975. Moreover, alternating warm/wet and cold/dry conditions mark the period between ~1000 and 1600. Very recently, Mangini *et al.* (2005) reconstructed the air temperature variation during the past two millennia using the d ^{18}O composition of a precisely dated stalagmite from the central Alps. Mangini and co-authors showed that the temperature maxima during the Medieval Warm Period (800-1300 AD) were on average 1.7 °C higher than the minima during the LIA. In addition, the Alpine stalagmite reveals a highly significant correlation with d^{14}C, suggesting the importance of the solar forcing in the Northern Hemisphere during the past two millennia.

CORALS

Apart from tree-ring information, it was shown that annually banded ***reef corals*** from the northernmost Red Sea (28°N-29.5°N) provide proxy records of temperature seasonality and interannual to multidecadal variations in temperature/aridity for the southeastern Mediterranean region (Egypt, Israel, Palestine, Jordan) during the past centuries, the Holocene epoch and the last interglacial period (Felis *et al.*, 2000, 2004; Rimbu *et al.*, 2001, 2003a). Isotopic and elemental tracers, incorporated into the carbonate skeletons of these massive corals during growth, provide proxies of past environmental variability of the surface ocean, reflecting variations in SST and hydrologic balance (e.g. Felis and Pätzold, 2004). In a first step an oxygen isotope record covering the past 250 years derived from a living coral (Fig. 1.15) was compared to instrumental records of gridded SST and land station precipitation from the region (Felis *et al.*, 2000). However, the coral record was not calibrated against a single parameter to provide a quantitative reconstruction because both the temperature and the hydrologic balance at the sea surface influence coral oxygen isotopes. In a second step the coral oxygen isotope record was compared with indices of the Arctic Oscillation (AO)/NAO, and in addition was correlated with NH SLP fields, which revealed the signature of the AO/NAO (Rimbu *et al.*, 2001). In a third step, the coral record was compared to fields of SST and surface wind in the eastern Mediterranean/Middle East region, in order to reveal the physical mechanism for the linkage between the AO/NAO and variations of SST and hydrologic balance in the northernmost Red Sea. This combined analysis of the proxy record and instrumental climate data revealed that the region's interannual to decadal climate variability is controlled by a high-pressure anomaly over the Mediterranean Sea that is associated with the AO/NAO, especially during the winter season. This high-pressure anomaly favours an anti-cyclonic flow of surface winds over the eastern Mediterranean, thereby controlling the advection of relatively cold air from southeastern Europe towards the northern Red Sea (Rimbu *et al.*, 2001).

<Figure 1.15>

Enhanced variance at interannual periods of 5-6 years observed in all coral records from the northernmost Red Sea, which was also detected in a tree-ring based reconstruction of Turkish precipitation covering the 1628-1980 period (D'Arrigo and Cullen, 2001). It was identified as a stable feature of eastern Mediterranean/Middle East climate, and it was shown to be characteristic for the influence of the AO/NAO on the region's climate variability over longer periods (Felis *et al.*, 2000, 2004). Further prominent oscillations identified in the coral-based climate reconstruction of the past 250 years from the northernmost Red Sea have periods of about 70, 22-23 and 8-9 years (Felis *et al.*, 2000). The latter two periods were also identified in the tree-ring based precipitation reconstruction from Turkey (D'Arrigo and Cullen, 2001). To summarize, annually banded reef corals from the northernmost Red Sea provide a unique, seasonally resolved archive for temperature and aridity variations in the southeastern Mediterranean (Egypt, Israel, Palestine, Jordan) and the influence of the AO/NAO on the region's interannual climate variability during the past centuries, the Holocene epoch and the last interglacial period (Felis *et al.*, 2000, 2004; Rimbu *et al.*, 2001, 2003a).

EVIDENCE FROM LOWER RESOLUTION NATURAL PROXIES AND NEW MARINE ARCHIVES

This part provides a short overview on natural land and marine proxies including boreholes, vermetids, non-tropical corals and deep sea corals.

Subsurface temperature information in the Mediterranean from borehole data

Temperature-depth profiles measured in boreholes contain a record of temperature changes at the Earth's surface. The geothermal method of past climate reconstruction based on the information recorded in temperature logs has become well established within the last decade (Lachenbruch and Marshal, 1986; Shen and Beck, 1991; Beltrami and Mareschal, 1995b; Huang *et al.,* 2000; Pollack and Smerdon, 2004). The basic assumption of this method is that climate changes are accompanied by long-term temperature changes of the Earth´s surface, which propagate downwards by heat conduction and can be reconstructed as ground surface temperature histories. In the absence of moving fluids, changes in ground surface temperature (GST) diffuse slowly downwards and are manifested at a later time as anomalies in the Earth's background temperature regime. Because the thermal diffusivity of rock is relatively low (~10-6 m^2 s^{-1}), temperature changes that occurred 1000 years ago are only recoverable in boreholes that are several hundred metres deep. Typically, perturbations penetrate about 20 m/year, 150 m in 100 years and 500 m in a millennium, depending on the thermal properties of the subsurface rocks. Each disciplinary approach to paleoclimate reconstruction has its own strengths and limitations in representing past climate variability. A paleoclimate reconstruction derived from borehole temperatures is characterized by a progressive inability to resolve climatic excursions in the more remote past. The resolving power of a borehole-based reconstruction is not only restricted by the diffusive nature of heat transfer, but also dependent on the level of non-climatic perturbations which affected the site as well as uncertainties in methodological aspects (Mann *et al.,* 2003; Pollack and Smerdon, 2004). Surface factors such as changes in vegetation cover, underground hydrology, topography variations, lateral heat conduction and systematic variations of thermal conductivity of the subsurface rocks can affect the underground thermal regime independently of climate. Therefore, borehole data must be screened carefully before they are analyzed for climate signatures.

Because of decreasing resolution of the method for older events, its most promising application is the GST reconstruction of the last few centuries. The subsurface climatic signal of this period is contained in the uppermost 150-200 m of the temperature profiles, which is the depth reached by most boreholes. In many European and North American sites, the GST history of the last 2 centuries obtained with this method can be compared directly with the observed surface air temperature series measured at nearby meteorological stations. For earlier periods, the geothermal method offers an alternative source of information to infer temperature evolution through the last centuries which can be potentially compared with proxy records at regional and hemispheric/global scales (Beltrami et al 1995a; Rajver et al., 1998; Beltrami, 2002; Briffa and Osborn, 2002).

The international heat flow community has supported the creation of a database of borehole temperature logs as an archive of geothermal signals of climate change (Huang and Pollack, 1998). Currently the database contains 861 borehole temperature profiles, of which 696 are located in the NH. The geographic coverage is densest in North America and Europe, with substantial datasets from Asia. In the Mediterranean area, the coverage of temperature logs is relatively sparse. Nevertheless, some studies have focussed in reconstructing recent climate trends in different parts of the Mediterranean area with the purpose of identifying potential secular warming/cooling in geothermal information and comparing it to available meteorological and proxy evidence.

In the central Mediterranean area Rajver *et al.* (1998) analysed nine boreholes from Slovenia and obtain a warming of 0.7ºC for the last century, which is found to be compatible with meteorological observations. The Ljubljana borehole (1965 m depth) allowed for a 90 Ka reconstruction, which was favourably compared with paleorecords of temperature for neighbouring regions (Hungary and the Alps).

Pasquale *et al.* (2000, 2005) analyse boreholes in the western and eastern parts of the Apennines (Italy). They identify differences in the Tyrrhenian and Adriatic sides which are in correspondence with nearby meteorological observatories and support influence of local scale microclimates, the western side showing a clear warming through the last century in the four analysed boreholes and the Adriatic side presenting clear cooling trends in correspondence with the 1940s to 1980s cold relapse in meteorological observations. In the western Mediterranean area Correia and Safanda (2001) analyse subsurface temperatures in the Atlantic margins, i.e., a borehole close to Evora in Portugal showing a temperature increase of 1ºC since the end of the nineteenth century. Rimi (2000) analysed 10 boreholes in four different climatic types in the north of Morocco. Results show varying warming amplitudes between 3 to 4ºC, which are in some areas amplified by deforestation and mining effects.

The above studies present the potential of subsurface temperature information as an alternative approach to establish the magnitude of secular temperature change in different Mediterranean areas. Proliferation of such studies to cover the larger Mediterranean area would be desirable. Such estimates should be compared with climate proxy reconstructions and model simulations to assess consistency and increase the robustness of our knowledge of past climate variations (González-Rouco *et al.,* 2003a). In Mediterranean areas where the meteorological records are relatively short, borehole reconstructions can increase our perspective of temperature changes in the last centuries. Alternatively, the borehole approach can help to elucidate long-term temperature trends in cases where meteorological observations present potential inhomogeneities.

Mediterranean sea temperatures derived from Vermetids, non-tropical, and deep-sea corals

The oceans exert a very strong influence on the atmosphere due to the continuous exchange of heat and water vapour with the atmosphere and they play a critical role in the chemical balance of the atmospheric system. SST is one of the most important variables for the Earth’s climate system. Changes in SST and their interactions with the atmosphere have the potential to affect the precipitation patterns, causing droughts, storms and other extreme weather events, mainly in regions particularly sensitive and potentially very vulnerable to climate changes, such as the Mediterranean region. Thus, the possibility to derive long high-resolution time series of key climatic parameters such as SST and salinity for the Mediterranean Sea is a fundamental prerequisite for a better understanding the key mechanisms governing climate change in this region. The only possibility to extend our climate database far beyond the instrumental record is studying the elemental and isotopic composition of well-dated natural archives of climate variability. Over the last centuries SST records of high resolution (annual to seasonal) have not been available in the temperate area of the Mediterranean Sea due to the absence of appropriate proxies, such as the corals available in tropical and sub-tropical seas. An exception are the annually banded reef corals of the northernmost Red Sea that provide a seasonally resolved archive of past climate variability for the southeastern Mediterranean region. With this in mind, great attention has been paid in recent years to obtain high-resolution records of SST, salinity and water chemistry for the Holocene in the Mediterranean Sea, using new archives such as vermetid reefs (living reefs, last 500-600 years, 30-50 years resolution), non tropical corals (i.e. living *Cladocora caespitosa*, last 100-150 years, seasonal to weekly resolution), and deep-sea corals (i.e. living *Desmophyllum* *dianthus, Lophelia pertusa, Madrepora oculata*, last 100-150 years, annual to seasonal resolution). These new archives will complement and improve the information derived from the main climate indicators such as foraminiferal tests, alkenones, dinoflagellate cysts, calcareous nanoplankton, and, especially for the Mediterranean Sea, serpulid overgrowth on submerged speleothems (Antonioli *et al.*, 2001). All these latter marine markers enable longer paleoclimate reconstructions but with a much coarser resolution (usually lower than 100-200 years), however, in areas of extremely high sedimentation rates (>80 cm/ka), such as in the distal part of the nilotic cell, southern Levantine Basin, foraminiferal stable isotope composition clearly show the evidence of both the Medieval Warm Period and the LIA, with a resolution of 40-50 years during the last millennium (Schilman *et al.*, 2001).

Vermetids are thermophile and sessile gastropods living in intertidal or shallow subtidal zones, forming dense aggregates of colonial individuals. Vermetids show a wide areal distribution, also being present in the Mediterranean Sea, such as in Syria, Lebanon, Greece, Turkey, Crete, Italy etc. (Safriel, 1966, 1974; Delongeville *et al.*, 1993; Pirazzoli *et al.*, 1989, 1996; Antonioli *et al.*, 1999, 2001; Silenzi *et al.*, 2004; Fig. 1.16).

<Figure 1.16>

Vermetus triquetrus (Bivona-Bernardi, 1832) and *Dendropoma petraeum* (Monterosato, 1892) are the two species forming clusters in the Mediterranean Sea. Presently, living reefs in the NW coast of Sicily present a fossil portion that is maximum about 650 years old, whereas some fossil samples collected in uncemented tempestite deposits date back to 2500 years BP. Vermetids are generally used as indicators of sea level changes and neotectonic stability (Stephenson and Stephenson, 1954; van Andel and Laborel, 1964; Kemp and Laborel, 1968; Laborel and Delibrias, 1976; Angulo *et al.*, 1999; Focke, 1977; Jones and Hunter, 1995; Hadfield *et al.*, 1972; Antonioli *et al.*, 1999, 2002) due to the possibility of precisely dating their calcite skeleton by radiometric methods. Silenzi *et al.* (2004) analysed and compared two sections of *Dendropoma* sp., from NW Sicily, spanning ~ 500 years to the present day (Fig. 1.17).

<Figure 1.17>

The spatial resolution between two neighbouring oxygen data corresponds to 30-50 years time interval. The isotopic records show a clear oscillation, with ? ^{18}O values being more positive than at present during the period between the years 1600 and 1850. Data indicate a maximum difference in ? ^{18}O from the 'LIA' to present day of about 0.38±0.1‰, which corresponds to 1.99±0.37°C SST difference. After the 'LIA', vermetid reefs recorded the warming trend that characterized the last century. This rise in temperature ended around the years 1930-1940, and was followed by a relatively cold period between until 1995. Moreover, the SST reconstruction clearly demonstrates that in the early to mid-1500s, SSTs were warmer than today. The study by Silenzi *et al.* (2004) proved that vermetid reefs have the potential to be excellent indicators of SST variability both in historical time (actual growing reef) and during the Holocene (fossil reefs), allowing paleoclimatic reconstructions at high temporal resolution.

Shallow water scleractinian corals secrete a calcareous skeleton whose minor and trace element composition provides a potentially unique archive of the ambient environment in which it grew (e.g., Felis and Pätzold, 2004). To date, there have been few studies dealing with coral chemistry at high latitudes but none investigated coral species in the Mediterranean Sea. Recently, Montagna *et al.* (2004) and Silenzi *et al.* (2005) targeted a temperate coral species living in the Mediterranean Sea with promising results. This **non-tropical coral** deposits two bands per year, one high-density band forms during periods of low temperatures and low light intensity (autumn-winter), whereas the low-density band corresponds to high temperature and high light intensity (spring-summer). Silenzi *et al.* (2005) demonstrated for the first time the feasibility of using *C. caespitosa* as a paleoclimate archive of SST, through isotopic (d^{18}O and d^{13}C) and elemental (Sr/Ca and Mg/Ca) analyses on a 96-year corallite collected along the continental shelf of the Ligurian Sea. The subsequent work by Montagna *et al.* (2004) further proved the potentiality of *C. caespitosa* as a paleothermometer. Geochemical ratios (Sr/Ca and B/Ca) exhibit a close relationship to the *in-situ* measured (weekly) SST and in particular, B/Ca shows an extraordinary high degree of correlation (r=-0.88, n=130) with SST. Both the studies thus demonstrate the capability of this long-lived (100-150 year) non-tropical coral to preserve SST changes in the Mediterranean Sea at seasonal to weekly resolution over the last 100 years. In addition, the combination of d ^{8}O and trace element ratios (Sr/Ca, B/Ca) will allow to track past salinity changes at the same time resolution of SST. The use of the calibration equations obtained from the Ligurian and the Adriatic Sea will enable the reconstruction of the paleo-SSTs during periods particularly interesting for climate studies.

Deep-sea corals are potentially excellent archives of past oceanographic conditions with their wide depth range providing climate proxies for intermediate and deep waters. Deep-sea corals can be directly dated using high precision ^{234}U/^{238}U-^{230}Th, ^{226}Ra/^{210}Pb and ^{14}C methods (Cheng *et al.*, 2000, Goldstein *et al.*, 2001; Adkins *et al.*, 2002, 2004; Frank *et al.*, 2004). An understanding of the physical and chemical parameters of deep waters is important for climate reconstructions since atmospheric climatic conditions are intimately linked or coupled with the ocean circulation patterns. The great potential of these archives in the deep-water realm stems from the fact that they can provide higher resolution than sediment cores and they are not affected by bioturbation. Moreover, they can span more than 100 years, allowing obtaining decadal changes with seasonal resolution. Fossil deep-sea corals, such as *Lophelia pertusa, Madrepora oculata and Desmophyllum dianthus*, have been widely documented in the Mediterranean basin whereas living specimens seem to be less common and widespread (Taviani *et al*., 2005, and references therein).

Montagna *et al*. (2005a) studied the trace and minor element compositions in two *Desmophyllum dianthus* specimens collected in the Mediterranean Sea and in the Great Australian Bight. The chemical variation of productivity controlled elements, such as P, Mn and Ba seems to reflect changes in seawater concentrations, demonstrating the potentiality of this species to become a powerful archive of deep water chemistry. In addition, the typical water-temperature sensitive elements are the subject of ongoing research, which aims to reconstruct the temperature variations at high resolution in the deep-water realm (Montagna *et al.*, 2005b). These results illustrated the potential use of geochemical composition in deep-sea corals within the Mediterranean Sea, providing an important new approach to help unravel climatic variability with respect to the temporal evolution of the chemical and physical properties of intermediate and deep waters.

<Table 1.2>

3. Large Scale Climate Reconstructions And Importance of Of Proxy Data For The Mediterranean

The first part of this section shortly describes the basic idea how to incorporate climate information from different areas in a statistical way to reconstruct large-scale climate fields. The second part addresses the importance of documentary and natural proxies for Mediterranean precipitation and temperature field reconstructions at seasonal time scales.

Different from local or regional climate reconstructions using a variety of documentary or natural proxies (Section 1 and 2), multivariate statistical climate field reconstruction (CFR) techniques include multivariate calibration of proxy data against instrumental records. CFR seeks to reconstruct a large-scale field, such as surface air temperature, pressure or precipitation using a spatial network of proxy indicators, performing a multivariate calibration of the large-scale information in the proxy data network against the available instrumental data. This so-called 'upscaling' involves fitting statistical models, which are mostly regression-based, between the local proxy data and the large-scale climate. Model fitting is usually based on the overlap period between proxy and instrumental data. It is assumed that the statistical relationships throughout the reconstruction period are stable (concept of stationarity). Because the large-scale field is simultaneously calibrated against the entire information in the network, there is no a priori local relationship assumed between proxy indicator and climatic variable. All indicators should, however, respond to some aspect of local climate during part of the year (e.g. Guiot, 1992, Briffa *et al.*, 2002; Jones and Mann, 2004; Luterbacher *et al.*, 2004; Rutherford *et al.*, 2005; Pauling *et al.*, 2005; Casty *et al.*, 2005a,b; Guiot *et al.*, 2005; Xoplaki *et al.*, 2005). The approach of CFR (e.g. Mann *et al.*, 1998, 2000, 2005; Briffa *et al.*, 2002; Mann and Rutherford, 2002; Luterbacher *et al.*, 2002b, 2004; Rutherford *et al.*, 2005; Pauling *et al.*, 2005; Casty *et al.*, 2005a,b; Zhang *et al.*, 2005; Xoplaki *et al.*, 2005) provides a distinct advantage over averaged climate reconstructions for instance, when information on the spatial response to external forcing (e.g. volcanic, solar) is sought (e.g. Shindell *et al.*, 2001a,b, 2003, 2004; Fischer *et al.*, 2005). Thus, CFR allows insight into both the spatial and temporal details about past climate variations over the Mediterranean region. There are a few CFR reconstructions available covering the Mediterranean area: Guiot (1992) used a combination of documentary proxy evidence and natural proxies (tree-rings, ice core data) to provide fields of annual temperature estimates from 1068-1979 for Europe, including a large part of the Mediterranean area. He found significant connection between northwest Europe and the central Mediterranean region during the LIA, while the western Mediterranean region had not experienced any significant cooling.

Briffa *et al.* (2002) used tree-ring maximum latewood density data to reconstruct large-scale patterns of warm-season (April-September) mean temperature for the period 1600-1887 for the NH, including the Mediterranean. Mann (2002b) used proxy data and long documentary and instrumental records to reconstruct and interpret large-scale surface temperature patterns back to the mid-eighteenth century for the Middle and Near East. This study suggested that interannual temperature variability in these regions in past centuries appears to be closely tied to changes in the NAO.

Luterbacher and Xoplaki (2003) provided a preliminary 500-year long winter mean precipitation and temperature time series over the larger Mediterranean land area, calibrated in the twentieth century and reconstructed from long instrumental station series, documentary evidence and a few tree-ring data. They report also on the spatial temperature anomaly distribution for cold and warm winter extremes.

The first question, however, is which proxies are of relevance for temperature and precipitation field reconstructions at seasonal time scale. Pauling *et al.* (2003) investigated the importance of natural and documentary proxies for seasonal European and North Atlantic temperature field reconstructions. Using a set of 27 annually resolved proxies, they employed backward elimination techniques (e.g. Ryan, 1997) to identify the most important predictor at each gridpoint. These analyses included tree-rings, ice core parameters, corals, a speleothem and indices based on documentary data. For boreal winter (October-March) they found the speleothem from Scotland and tree-rings to be the most important proxy for the western Mediterranean, documentary evidence for the northern basin and parts of northern Africa, whereas the Red Sea coral is of relevance for the eastern basin. For boreal warm-season (April-September) temperatures, tree-rings, documentary data and the speleothem proved to be most important. The importance of the speleothem is particularly striking as only one single series was used in the backward elimination analysis while other proxy types were much more numerous.

We performed a similar evaluation of high-resolution natural and documentary proxies for precipitation field reconstructions, though restricting the analyses over the larger Mediterranean land areas (10°W-40°E; 30°N-47°N). We followed the same method as described by Pauling *et al.* (2003). Since different proxies may record climate conditions at different times of the year, we study the performance of the proxy information for both the boreal cold (October-March) and warm (April-September) season (Pauling *et al.*, 2003). Figures 1.18 and 1.19 (upper panels, respectively) depict the locations of the proxies used for boreal winter and summer (tree-rings, ice cores, one coral, one speleothem, and several precipitation indices based on documentary data). Those proxies have been shown to significantly respond to local and regional precipitation during both the boreal cold and warm season within the twentieth century (not shown). Unfortunately, there are not many proxies fulfilling those criteria and only a few stem from the Mediterranean area. Most of the natural proxies have been downloaded from the World Data Center for Paleoclimatology, Boulder, Colorado, USA (http://www.ngdc.noaa.gov/wdc/wdcmain.html). As documentary indices are not available for the twentieth century, seasonally resolved indices based on instrumental measurements were degraded using a similar approach as Mann and Rutherford (2002), Pauling *et al.* (2003) and Xoplaki *et al.* (2005) Normally-distributed white noise was added to the series to ensure the resulting pseudo-documentary indices are of similar quality as documentary indices derived from documentary evidence. Most of the documentary and natural proxies are available for a few centuries and can, thus, be potentially used for precipitation reconstructions (see below). The gridded precipitation dataset (10°W-40°E; 30°N-47°N; 0.5°x0.5° resolution) from Mitchell *et al.* (2004) and Mitchell and Jones (2005) was chosen as the dependent variable. The common period (1902-1983) of both the predictors and the predictands was used for calibration. Firstly, for each gridpoint multiple regression models were established. Second, all but one predictor at each gridpoint was eliminated using backward elimination techniques. The last predictor at each grid point is regarded as the most important one of the initial predictor set (Pauling *et al.*, 2003). Figure 1.18 (middle) presents the spatial distribution of the last remaining predictor at each gridpoint for the boreal cold season, derived through backward elimination. The pseudo-documentary indices are the most important predictors over large parts of continental Europe, explaining moderate 10-20% of the variance (Fig. 1.18, lower panel).

<Figure 1.18>

There are larger areas in Northern Africa, southeastern Europe and the Near East where tree-ring data are the most important proxy. The Scottish speleothem, the Red Sea coral and the ice core data from Greenland do only indicate small regions where those natural proxies are of major importance. Hence the speleothem is much less important for precipitation than for temperature as described by Pauling *et al.* (2003). The physical interpretation for those patterns is not trivial and outside the scope of this contribution.

Concerning boreal summer, documentary precipitation series are still the most important proxies for large parts of the northern Mediterranean area and regions over the Iberian Peninsula as well parts of Morocco (Fig. 1.19). As for the boreal cold season, those proxies can account for a maximum of around 20% of summer precipitation over those areas. Compared with the cold season, tree-rings have taken the place of the pseudo-documentary precipitation indices over southeastern Europe, Turkey and the Near East. These findings are in agreement with the results presented in Section 2.2. Tree-rings explain between 10% and 20% of the April-September precipitation variability over those areas. Further, tree-rings cover a large area of the Iberian Peninsula and Northern Africa. Surprisingly, ice core data from Greenland seem to be of importance over the southern Near East pointing to possible teleconnections during the twentieth century. It has to be stressed that these findings are only meaningful where summer precipitation regularly occurs and is high enough to exhibit some variability. Over the southern part of the study area this is not the case or only for the late spring months/early autumn. Therefore, the importance of tree-rings for boreal summer precipitation reconstructions over North Africa is clearly limited (Fig. 1.19).

<Figure 1.19>

Further analyses have to prove, whether such relations derived within the twentieth century are stable back in time including more systematic testing of a larger dataset of proxies. It should also be taken into account that not only the proxy type determines the results of this preliminary analysis but also its initial number and location. Pauling *et al.* (2003) used different proxy types situated in the vicinity of each other, which reduces the influence of the location and allows the proxy characteristics to compete in the backward elimination process. These findings, though, have to be further examined for the larger Mediterranean area as well.

Mann *et al.* (1998, 2000), Mann (2002a), Pauling *et al.* (2003), Rutherford *et al.* (2005), Guiot *et al.* (2005), Xoplaki *et al.* (2005) and the results presented above point out that the multi-proxy approach exploits the complementary strengths from each of the proxies to estimate temperature and precipitation change over a large area back in time. Thus, large-scale climate reconstructions based on a careful selection of a combination of temperature/precipitation-sensitive proxies from the whole of Europe, including the Mediterranean, provides a reliable means for reconstructing past regional and seasonal climate variability.

4. Mediterranean Winter Temperature And Precipitation Variability Over The Last 500 Years

This section presents the evolution of Mediterranean temperature and precipitation over the last 500 years using data presented in the Sections 1-3. The reconstructions are based on principal component, multivariate regression and have been extensively calibrated within the twentieth century. The reconstruction of entire temperature and precipitation fields, using multivariate calibration of the proxy data against the instrumental records, allow both spatial and temporal considerations about past climate variability over the Mediterranean (Section 3). An estimate of the Mediterranean mean temperature or precipitation can, for instance, be derived by averaging over the reconstructed patterns (see below). Information regarding the underlying spatial pattern (such as the different Mediterranean sub-areas) is, however, retained (Mann, 2002a). We will further present spatial fields of the coldest and mildest as well as wettest and driest Mediterranean winters derived from the reconstruction period. Further, we also provide anomaly winter temperature and precipitation composites where we highlight the difference between multidecades of mild (wet) minus cold (dry) Mediterranean winters. Using a few natural proxies in combination with documentary data presented in Section 3 (Figs. 1.18, 1.19) and long instrumental station series we fit a statistical model to the winter (December-February average) Mediterranean temperature and precipitation for the land areas 10°W to 40°E and 35°N to 47°N. The reconstructions are based on principal component, multivariate regression and have been extensively calibrated within the twentieth century. The details on the methodology and data used can be found in Luterbacher *et al.* (2004) for temperature and Pauling *et al.* (2005) in case of precipitation. Apart from the description and interpretation in terms of trends and uncertainties, we will also perform a wavelet analysis and will report on the change of distribution of winter ‚extremes' over the last 500 years. In addition, a PDSI is derived from these data for selected areas (Morocco, Italy and Greece).

Figures 1.20 and 1.23 show the averaged winter mean Mediterranean temperature and precipitation anomalies (with respect to 1961 to 1990) from 1500 to 2002. The time series are composed of a reconstructed time period between 1500 and 1900 as well as the gridded Mitchell *et al.* (2004) and Mitchell and Jones (2005) data for the period 1901-2002. Figures 1.20 and 1.23 also present 30-yr smoothed time series employing boundary constraint optimised to resolve the non-stationary late (end of the twentieth century, beginning of the twentyfirst century) behaviour of the time series (Mann, 2004). As proposed by Mann (2004) we employ an objective measure of the quality of fit (MSE, mean-squared error) of a 30-year smooth with respect to the original time series.

The reconstructed winter near-surface air temperature (Fig. 1.20) time series is more stationary than the one for precipitation (Fig. 1.23), especially with respect to the amount of interannual variability. Strong departures from the 1961-1990 irregularly occurred during the entire 500-year period, although warm anomalies appeared to be enhanced during the beginning of the seventeenth century (with 1606/1607 being the warmest winter within the reconstruction period) and during the twentieth century. There is a substantial warming trend starting around 1890.

<Figure 1.20>

Centennial temperature variability increases after 1800. However, the uncertainties (two standard errors, not shown) associated with the averaged winter temperature reconstructions are of the order of ± 1.1°C for single winters up to the 1660s, and decrease to around ±0.5 °C at the end of the nineteenth century. Note that filtered uncertainties of both, Mediterranean averaged near surface air temperature and precipitation are presented in Section 7 (Figs. 1.41, 1.42). The warmest (coldest) winter was 1955 (1891). A glance at the most recent three winters (2002/2003; 2003/2004; 2004/2005; not shown) which are based on the gridded analysis of Hansen *et al.* (2001) reveal, that except for 2003/2004 (0.32°C warmer than 1961-1990), the two other winters were below the 1961-1990 reference period (-0.28°C for 2002/2003 and -0.44°C for 2004/2005).

The spatial anomaly of the coldest (1890/1891; 2.4°C colder than the 1961-1990 reference period) and warmest winter (1606/1607; 1.4°C warmer compared with the 1961-1990 period) for the reconstruction period (i.e. 1500-1900) are presented in Figure 1.21.

The anomaly spatial temperature maps of both winters shows a monopole pattern with above (1606/1607) and below (1890/1891) temperature anomalies all over the Mediterranean area. The largest deviations are found generally north of around 41°N. In the case of 1606/1607, the uncertainties of the reconstructions are rather large (of the order of 1°C averaged over the entire area, smaller in the northern part, larger in the southern and eastern regions) as no instrumental data are available from the area at that time. The reconstructions are based on a few temperature indices derived on documentary evidence from central and eastern Europe and an ice core from Greenland (Vinther *et al,.* 2003a; see Luterbacher *et al.*, 2004, supplementary online material for the used climate information). Thus, these spatial reconstructions of earlier centuries should be treated with caution. The comparison with the absolutely mildest winter (1954/1955) reveals also a monopole pattern, though the largest deviations are found over the southeastern Mediterranean (not shown). The reconstruction of the cold winter 1890/1891 is much more reliable as there are several instrumental data of high quality availalbe, even from the Mediterranean area. Uncertainties are largest along the northern African cost and the southeastern basin (not shown).

<Figure 1.21>

The warmest (coldest) decade was 1993-2002 (1680-1689) whereas the warmest (coldest) 30 Mediterranean winters in a row were experienced from 1973-2002 (1880-1909) with 0.16°C (-0.85°C) departures from the 1961-1990 average.

The anomalous spatial temperature distribution of the warmest and coldest 30 winters is presented in Figure 1.22**.**

<Figure 1.22>

Except for a few single gridpoints, all regions around the Mediterranean area experienced negative temperature anomalies during the 1880-1909 cold period compared with the 1961-1990 mean. For the warmest 30 winters (Fig. 1.22, bottom) from 1973-2002 the most positive departures are found over the northern areas and

northwestern Africa, whereas the southeastern Mediterranean area experienced colder winters compared with the 1961-1990 average.
Fischer *et al.* (2005) recently analysed the European climatic response to major 16 tropical eruptions over the last half millennium. They found winter cooling (though significant only over parts of the Iberian Peninsula and northern Africa) over the entire Mediterranean during the first post-eruption year (in contrast to northern Europe where a winter warming is experienced). The anomaly pattern for the second winter after the eruptions reveals a different pattern with a slight cooling in the western and eastern part and a warming in the remaining parts of the Mediterranean. These anomalies, though are not significant.

The averaged Mediterranean winter precipitation series (Fig. 1.23) clearly indicates reduced variability prior to around 1780, an indication of a low number of proxy information available (Pauling *et al.,* 2005). Low-frequency variations also tend to rise over the centuries. The uncertainties (two standard errors, not shown) associated with the averaged winter precipitation reconstructions are of the order of 40 mm at 1500 and reduce to approximately 20 mm at the end of the nineteenth century. There is clear evidence of an extended dry period (with respect to the 1961-1990) at the turn of the twentieth century, followed by wet conditions with maximum in the 1960s (see also Xoplaki *et al.*, 2004 and Trigo *et al.*, 2005 this book).

<Figure 1.23>

A striking phenomenon is the negative winter rainfall trend since the 1960s (Cullen and deMenocal, 2000; Goodess and Jones, 2002; Xoplaki *et al.*, 2004; Trigo *et al.*, 2005 this book), which seems to be unprecedented as inferred from this reconstructed long-term time series. This negative trend can be at least partly be explained by the positive trend of the NAO (e.g. Dünkeloh and Jacobeit, 2003; Xoplaki *et al.* 2004; Trigo *et al.,* 2005 this book and references therein). The Figure 1.23 clearly reveals that enhanced anomalies only appeared after 1800. It is possible that this is an artefact of the statistical reconstruction approach, or a low number of proxies, rather than a real climate feature of the time period 1500 to 1800. Therefore, particular care is required when interpreting changes in extreme values. In general, the frequency and amplitude of intense anomalies from the long-term mean is steadily increasing between 1500 and 2002. The winter of 2002/2003 (not shown) was distinctly wetter than the 1961-1990 average. The absolute driest (1988/1989) and wettest (1962/1963) winters were observed within the twentieth century. Figure 1.24 presents anomaly maps of the driest (1881/1882, 45mm drier than the 1961-1990 period) and the wettest (1837/1838, 45mm wetter than the 1961-1990 period) winters of the reconstruction period. The wet Mediterranean winter of 1837/1838 was characterized by positive precipitation anomalies stretching from southwestern Europe and northwestern Aftrica over Italy towards the Balkans. Drier, though not significant conditions are found from Tunisia to the Near East region and parts of Turkey. This anomaly pattern strongly resembles the correlation map between the winter NAOI and Mediterranean winter precipitation (i.e. Cullen *et al.,* 2002; Xoplaki, 2002). Indeed, the instrumental NAOI for the 1837/1838 winter (Vinther *et al,*. 2003b) indicates a strong negative value. In the case of the dry Mediterranean winter of 1881/1882 widespread negative precipitation anomalies are found over the northern Mediterranean, Iberia and northwestern Africa, whereas more precipitation was received within a band stretching from Italy, Tunisia over Greece towards Libya and the Near East. This winter was connected to a strongly positive NAOI.

<Figure 1.24>

The wettest (driest) decade was 1961-1970 (1986-1995). The wettest (driest) multi-decadal periods (30 Mediterranean winters in a row) were from 1951-1980 (1973-2002) with 5 mm (-15 mm) departures from the 1961-1990 average.
The spatial distribution of these anomalies is presented in Figure 1.25.

<Figure 1.25>

The spatial distribution of the 30 driest Mediterranean winters (1973-2002) indicates, that especially the central part, the southern Balkans and the eastern Mediterranean experienced dryness (Fig. 1.25, top). There are, however, areas that received more precipitation compared with 1961-1990. Concerning the 30 wettest winters over the last 500 years, (Fig. 1.25, bottom) there is not a uniform distribution. Drier areas are next to regions with positive rainfall anomalies.

A more sophisticated picture of changes in climate variability over the larger Mediterranean area is drawn by the wavelet spectra in Figure 1.26. The method uses the Morlet wavelets (Torrence and Compo, 1998) and is designed to describe the relative importance of different time scale within different sub-periods of a time series. Mediterranean winter precipitation reveals basically two signals (top panel): At the interannual up to decadal time scales variability continuously increases, especially after 1800 with a peak during the most recent 30 years (compare Fig. 1.23). It is interesting to note, that Hurrell and van Loon (1997) report on the spectral peak of the winter NAO at about 6–10 years over the last decades of the twentieth century in agreement with similar spectral power found in the Mediterranean winter near surface air temperature presented in Figure 1.26 (top).
In addition, there is a strong multi-decadal component, which, however, is partly beyond the cone of influence (continuous line) - a sector that cannot be interpreted because of the temporal limitation of the time series. With respect to temperature (Fig. 1.26, bottom), variability is more equally split up into different time scales. Interannual and decadal variations slightly dominate but not persistently during the entire period. Interannual variability may be somewhat enhanced since 1850 (Fig. 1.20). The most striking feature is the multi-centennial trend since the middle of the nineteenth century.

<Figure 1.26>

A basic question is whether particularly dry and wet as well as cold and warm winters occurred more frequently during the twentieth century, when climate may be partly affected by human activity through emissions of GHGs (Houghton *et al.*, 2001). The analysis of climate extremes and their changes requires a very careful procedure. There is large uncertainty in the estimate of extremes, simply because they represent infrequent events with small sample size (Palmer and Räisänen, 2002). In order to use the entire information from the precipitation time series, a Gamma distribution is fitted to the data. The Gamma distribution is an appropriate statistical distribution to describe precipitation amount at various time scales. The parameters of the Gamma distribution can be determined using the method of L-moments (Hosking, 1990). The Gamma distributions are fitted to the high-pass filtered time series (Fig. 1.27) in order to remove the effect of enhanced low-frequency variability and transient climate features. Thus, an extreme is defined as a certain departure from the decadal-mean background state. Fitting the theoretical distribution separately to running 50-year time windows between 1500 and 2002 incorporates the aspect of climate change. The top panel in Fig. 1.27 shows the Gamma distributions fitted to some exemplary periods. As expected, the Gamma distribution for winter precipitation is similar to a normal distribution. During the centuries, the shape of the distribution is getting broader. This implies that variability in the time windows steadily increases (Fig. 1.23). In addition, the mean is shifted towards a lower value in the most recent 50-year period, although the negative rainfall trend in recent decades has been removed (Fig. 1.23). Winters with anomalously abundant precipitation are defined by means of return values given return times of 5, 10, 20 and 50 years. Longer return periods may theoretically be derived but are subject to enhanced uncertainty, since within the reference period the distribution is based on only 50 years. The changes in the various return values over all running 50-year time windows are depicted in the middle panel of Fig. 1.27. It is obvious that anomalously wet winters become more frequent over the centuries (e.g. Hennessy *et al.*, 1997; Milly *et al.*, 2002; Christensen and Christensen, 2003). This can either be illustrated as a decrease in the return times or an increase in the return values. An adequate picture can be drawn for excessively dry winters (not shown). Note that it is still unclear to which extent this intensification of extreme winters arises from the reconstruction method or from a real climate change signal.

<Figure 1.27>

The final issue is to estimate whether the enhanced frequency of extreme winters during recent decades in the Mediterranean region is indeed statistically significant. The linear trend is no suitable measure for extreme changes, because the latter do usually not obey a normally distributed random process (Zhang *et al.*, 2004). Therefore, a Monte Carlo sampling is carried out in order to estimate the uncertainty range of different extreme value estimates and to compare the resulting confidence intervals with each other (Kharin and Zwiers, 2002). This approach consists of the following steps: new samples are drawn from the fitted statistical distribution. For each new sample the return values are determined. Repeating this 1000 times with a randomised selection of new samples leads to a distribution of estimated return values instead of one (uncertain) estimate from the given data. Typically, the return values are normally distributed over a large number of Monte Carlo samples (Park *et al.*, 2001). Thus, the standard deviation and confidence intervals indicate the level of uncertainty of the extreme value estimate. Given two different time windows like for instance the first and last 50 winters of the long-term time series, a change in the return values is defined to be statistically significant at a certain error level, if the corresponding confidence intervals of the return value estimates are not overlapping between both periods. For instance the 1 % significance level is reached, if the 90 % confidence intervals are separated from each other. In principle, this test evaluates changes in extreme values with respect to the level of uncertainty of the extreme value estimate itself. The bottom panel in Figure 1.27 illustrates the statistical significance of changes in the occurrence of excessively wet winters during the period 1953-2002 compared with all previous periods until 1952. At first sight, the changes are significant at the 1 % level with respect to the first 300 winters of the time series. This is not astonishing, since variability is substantially lower in the early part of the data set (Fig. 1.23). On the other hand, it is also evident that the last decades were not characterized by a significantly enhanced number of wet winters compared with the climate conditions between 1850 and 1952. For shorter return periods like 5 years, the changes are even less pronounced. Assuming that the low level of interannual variability is related to the reconstruction, there is no indication that excessively wet winters have significantly changed during the last centuries. The same holds for anomalously dry winters (not shown).

<Figure 1.28>

The same method has also been applied to Mediterranean winter near-surface temperature (Fig. 1.28). The basic difference is that the normal distribution is used to fit annual-mean temperatures. A widening of the distributions is also visible (top panel). Transient changes in the return values are less apparent than in the case of precipitation (middle panel; e.g. Domonkos *et al.*, 2003). Periods with reduced and enhanced warm (and cold) winters are alternating over the centuries. A considerable shift occurred between the late eighteenth century with less pronounced warm periods and the second half of the nineteenth century with excessively warm winters. However, this shift is not part of a consistent climate change signal. This is also inferable from the bottom panel in Fig. 1.28: statistically significant changes in the occurrence of anomalously warm winters between the last 50 years and previous times are only found with respect to the late eighteenth century. The same holds for cold winters (not shown).

This analysis of long-term time series of Mediterranean winter precipitation and temperature demonstrates that changes in extreme values cannot easily be detected. Although an enhancement of excessively wet and dry winters is at first sight apparent from the time series in Figure 1.23, a careful estimate of the statistical significance of changes in anomalous rainfall winters reveals that the twentieth century situation does not stand out from climate conditions in previous centuries. The signal with respect to the period 1500-1800 is barely convincing, given the systematic underestimation of climate variability (and thus uncertainties) during this early reconstruction period. In terms of near-surface temperatures practically no coherent changes in the occurrence of warm and cold winters can be unmasked. Thus, there is no evidence that the behaviour of Mediterranean climate extremes at this interannual time scale is inconsistent with natural climate fluctuation during earlier centuries. Note that this does not imply that climate change signals do not exist at other time scales like for instance daily extreme events (Paeth and Hense, 2005). In addition, it is conceivable that the long-term trends during the last decades may be outstanding. Finally, this analysis is based on regional-mean time series. It is still possible that remarkable changes have occurred in many subregions of the Mediterranean Basin, which do not show up in the regional mean due to opposing tendencies and compensatory effects (e.g. Xoplaki, 2002; Luterbacher and Xoplaki, 2003).

Another application of reconstructed temperature and precipitation over the Mediterranean can be used for applications such as the PDSI. The PDSI is an index related to the amount of water available for plants. It is normalized and calibrated for the region where it is calculated (Wells *et al.*, 2004). PDSI is a complex combination of temperature and precipitation. It has a memory of several years, so that winter and summer PDSI are highly correlated. Winter PDSI can be considered here as the water availability at the beginning of the growing season. We have calculated the PDSI for three regions: Morocco, Italy, and Greece. Figure 1.29 shows that the long-term (centennial) variations are quite similar between the three regions, but the decennial variations can be different. The 1660-1900 period appears to be wet (positive values of PDSI), in agreement with the flood records of Durance River (France, see Fig. 1.5), and we can observe a slow decreasing of the water available from the beginning of the twentieth century to today.

<Figure 1.29>

Nevertheless it is not clear for Italy, which remains wet during most of the twentieth century. The fact that the LIA was humid is certainly due to lower temperature (and then lower evaporation) during the warm season, as we have seen for Morocco that precipitation was rather low during this season. In the contrary, the low PDSI during the period before 1650 should be explained by higher temperature as Moroccan precipitation does not appear to be particularly low.

5. Connection Between The Large-Scale Atmospheric Circulation And Mediterranean Winter Climate Over The Last Centuries

This section is devoted to the connection between the winter large-scale atmospheric circulation and the Mediterranean climate over the last few centuries, the main modes and the changing influence through time.

5.1. Major Atmospheric Circulation Patterns Associated With Mediterranean Winter Climate Anomalies

Based on objectively reconstructed seasonal mean SLP grids for the North Atlantic European area covering the 500-year period from 1500 to 1999 (Luterbacher *et al.*, 2002b), the major circulation patterns associated with warm, cold, dry and wet Mediterranean winters have been derived according to guidelines described in detail by Jacobeit *et al.* (1998). At first, all temperature or precipitation winter 0.5°x0.5° grids (Luterbacher *et al.*, 2004; Pauling *et al.*, 2005; Figs. 1.20, 1.23) 1500-2002 were averaged for the whole Mediterranean land area. Second, those winters that differ from the overall mean by more than one standard deviation have been selected as warm, cold, dry and wet seasons, respectively. For each of these samples, the corresponding seasonal mean SLP grids have been submitted to T-mode principal component analyses with varimax rotation resulting in major circulation patterns (Figs. 1.30-1.33) explaining around 90% of the SLP variances during these anomalous Mediterranean winter seasons. Due to the T-mode (columns denote SLP gridpoints, rows are the winters (years) of the Principal Component Analyses (PCA), only very few cases with reflected patterns (significantly negative time coefficients) do occur; thus, the sign of the anomalies in Figures 1.30-1.33 is valid for nearly all cases represented by the corresponding circulation pattern (Jacobeit *et al.*, 1998).

For wet seasons, Figure 1.30 depicts as the most important pattern (47% of explained variance) a configuration resembling the NOAA-CPC Scandinavian pattern in its positive mode with high pressure anomalies centred around the Baltic Sea and low pressure anomalies covering the Mediterranean area. This blocking pattern is consistent with a negative NAOI characterizing most of the Mediterranean wet patterns. An exception is pattern 3 with its cyclonic centre above southern Great Britain reaching up to the western Mediterranean. Patterns 2-4 have less explained variance (between 10 and 18%) and a wet impact only in different parts of the whole Mediterranean.

<Figure 1.30>

Mediterranean dry patterns (Fig. 1.31) mostly depict a positive NAO index mode except for pattern 4 that reveals an anomalous configuration with high-pressure deviations from the central Mediterranean to the Icelandic region. The most important dry pattern (nearly 57% of explained variance) includes well-developed westerlies in higher mid-latitudes and anticyclonic conditions throughout the Mediterranean region. In contrast to that, pattern 3 implies an opposition between the western and the eastern Mediterranean, similar to the positive mode of a recent canonical correlation pattern, which is strongly linked to various indices of the Mediterranean Oscillation (Dünkeloh and Jacobeit, 2003). However, pattern 3 only accounts for 12% of the variance during the historical 500-year period. Pattern 2 which in turn is related to drier conditions in the eastern Mediterranean, has no distinct anomaly centre in the western region; thus, the Mediterranean oscillation might have been less developed during historical times than during the twentieth century.

<Figure 1.31>

Among the Mediterranean warm patterns (Fig. 1.32) the positive NAO mode known from the dry seasons recurs again as most important one (~40% of explained variance). The other patterns change the sign of the anomaly centres compared with the dry patterns thus allowing for regional warm air advection (from the SW or the SE in patterns 2 or 3, respectively) or a distinct anticyclonic regime (like in the western part of pattern 4).

<Figure 1.32>

The Mediterranean cold patterns (Fig. 1.33) include modes from both the wet and the dry analyses: the most important one (41% of explained variance) largely reproduces the first wet pattern. It corresponds to a blocking configuration with easterly to northeasterly airflow towards the Mediterranean. The other patterns are known, with slight modifications, from the dry analysis, depicting different anticyclonic centres, which organize cold air advection into different parts of the Mediterranean area.

<Figure 1.33>

5.2. Mediterranean Climate Variability Since The Mid-Seventeenth Century In Terms Of Large-Scale Circulation Dynamics

Based on objectively reconstructed monthly mean SLP grids for the North Atlantic/European area covering the period back to 1659 (Luterbacher *et al.*, 2002b), large-scale circulation dynamics have been investigated in terms of frequency and within-type changes of major dynamical modes (Jacobeit *et al.*, 2003). Some of these changes might have affected the Mediterranean region whose low-frequency variations in winter temperature and precipitation are reproduced in Figure 1.34. Thus, the last decades of the seventeenth century became cooler and wetter in the Mediterranean area. They were marked by an increased importance of the surface Russian High pressure pattern with easterly dry and cold airflow advancing further to the west. The first half of the eighteenth century became warmer and drier in the Mediterranean region was dominated by large-scale westerly patterns before another period with increasing Russian High influence coincided with wetter Mediterranean conditions. Around the turn from the eighteenth to the nineteenth century westerly patterns prevailed again and led to drier and warmer winters in the Mediterranean area. Subsequently, until the mid-nineteenth century, the Russian High pattern strengthened once more with easterly dominance and distinct cyclonic influence in the central Mediterranean (Jacobeit *et al.*, 2003). This caused a period of increasing rainfall and decreasing temperatures. During the second half of the nineteenth century the Russian High retreated gradually and was replaced by different westerly patterns, which induced a Mediterranean rainfall minimum around 1900 (see also Fig. 1.23 above Section 4). Afterwards, the well-known changes of the twentieth century took place with a sustained warming and an initial rainfall increase being replaced by a sharp decline during the last four decades (Fig. 1.34; see also Trigo *et al.*, 2005, this book).

<Figure 1.34>

5.3. Running Correlation Analysis Between The Large-Scale Atmospheric Circulation And Mediterranean Winter Climate Over The Last Centuries

A further investigation has been made on the strength and change of the correlation between the averaged Mediterranean winter precipitation and temperature time series and atmospheric circulation for the 1764-2002 period using 30-yr running correlation. This period has been reconstructed independently (only station pressure data used for the SLP reconstruction, see Luterbacher *et al.*, 2002b; Touchan *et al.*, 2005b; Casty *et al.*, 2005b). Reconstructed Eastern North Atlantic/European SLP fields become reliable from 1764 onwards. We calculated the first and second winter SLP Empirical Orthogonal Function (EOF) that account together for approximately 68% of total variance of European winter SLP. We estimated significance levels of the 30-yr running correlations between the EOFs and Mediterranean precipitation and temperature, respectively, from 1000 Monte Carlo simulations of independent white noise processes. Thus, this analysis is an indication of potential instabilities through time and the importance of the main European atmospheric modes on regional winter Mediterranean climate. The first EOF of winter (December-February) SLP for the period 1764-2002 explains 44% of the total winter SLP variability and reveals the well-known dipole pattern, resembling the NAO (not shown). The spatial correlation between the NAOI and Mediterranean winter temperature and precipitation for the twentieth century and interpretations is given in Cullen *et al.* (2002), Xoplaki (2002), Dünkeloh and Jacobeit (2003) and in Trigo *et al.* (2005, this book). The second EOF of winter SLP (explaining around 24%) is a monopole pattern with negative anomalies centred over the British Isles (not shown). The Mediterranean area is at the southern border of this negative anomaly pattern. This pattern strongly resembles the East Atlantic/Western Russia (EATL/WRUS) pattern, which is one of the two prominent patterns that affect Eurasia during most of the year. It has been referred to as the Eurasia-2 pattern by Barnston and Livezey (1987). The spatial correlation between the EATL/WRUS and Mediterranean winter temperature and precipitation for the last decades of the twentieth century as well as its importance for the Mediterranean climate is given in Xoplaki (2002), Dünkeloh and Jacobeit (2003) and in Trigo *et al.* (2005, this book). The second SLP Principal Component (PC) correlates significantly at the 99% level with the (EATL/WRUS index over the common period 1950-2002 (not shown). Thus, this PC can be considered a 'proxy' for the winter East Atlantic/Western Russia pattern back to 1764.

Figure 1.35 presents the 30-year running correlation between the first and second PC of winter SLP and averaged winter Mediterranean surface air temperature 1764-2002. Except for the short period at the beginning of the nineteenth century, the correlation between the first PC (resemblance with the NAO) and the averaged Mediterranean temperature is mostly significantly negative (Fig. 1.35 top). It should, however be mentioned, that there are regional differences between the NAO and Mediterranean winter temperature. For instance, the winter NAOI is significantly negative correlated with the winter air temperature over a huge area mainly in the southeastern part, including central Algeria, Libya and Egypt, southern Italy, Greece, Turkey, Cyprus and the entire Near East countries (Cullen and deMenocal, 2000; Xoplaki 2002).

In agreement with those findings, the combined analysis of a seasonally resolved coral oxygen isotope record from the northernmost Red Sea (Felis *et al.*, 2000) and reconstructed climate fields over the eastern North Atlantic and Europe (Luterbacher *et al.*, 2002b) revealed the important role of the AO/NAO for eastern Mediterranean/Middle East winter climate on interannual timescales since 1750 (Rimbu *et al.*, 2005). These findings are consistent with other evidence of a connection between the NH annular modes (AO or NAO) and eastern Mediterranean/Middle East climate variability in past centuries (Cullen and deMenocal, 2000; Felis *et al.*, 2000; Rimbu *et al.*, 2001; Cullen *et al.*, 2002; Mann, 2002b; Luterbacher and Xoplaki, 2003). The combined analysis of proxy records derived from fossil corals of the northernmost Red Sea and simulations with a coupled atmosphere-ocean circulation model (ECHO-G) revealed an AO/NAO influence on the region's interannual and mean climate during the late Holocene and last interglacial period 2900 and approximately 122000 years ago, respectively (Felis *et al.*, 2004).

On the other hand, the areas from Iberia to Italy, the southern Balkans towards the Black Sea return non-significant correlations between the NAO and wintertime air temperature. Positive relationships are prevalent over the northwestern Mediterranean coast, central and eastern Europe with maximum values north of 45°N (Cullen and deMenocal, 2000; Xoplaki 2002). Thus, in these running correlations there are compensatory effects between areas with negative, and positive correlations, which obviously change through time. Further, the differences might also be related to not constant transfer functions over time. Finally, the question arises to which extent climatic patterns during the twentieth century (calibration period of the statistical models) represent the entire range of climate variability (e.g. Luterbacher and Xoplaki, 2003).

The bottom part of Figure 1.35 clearly shows stable significantly positive correlation between the second PC of winter SLP and averaged winter Mediterranean temperature back to 1764. The EA/WRUS pattern in its negative phase tends to bring increased anomalous southwesterly circulation connected with significant higher overall Mediterranean winter temperatures.

<Figure 1.35>

Figure 1.36 presents the 30-year running correlation between the first and second PC of winter SLP and averaged winter Mediterranean precipitation 1764-2002. The upper panel of Fig. 1.36 indicates significantly negative correlations between the first PC of winter SLP (similar to the NAO) and averaged Mediterranean winter precipitation. The spatial correlation map between the winter NAOI and Mediterranean precipitation (Cullen and deMenocal, 2000; Xoplaki, 2002) supports these findings. Except for southeastern part of the Mediterranean the remaining areas reveal negative correlations. In terms of PC2, the running correlations are mostly positive from around 1850.

<Figure 1.36>

The figures above show that PC1 (PC2) has a robust signal on Mediterranean mean land precipitation (temperature), while the influence on Mediterranean mean land temperature (precipitation) is fluctuating and depends on the time window. It is suggested, that PC1 (PC2) impact on Mediterranean precipitation (temperature) is rather homogeneous throughout the region, while the impact on temperature (precipitation) is not so homogenous and sub-regional processes can provide different signals, which can eventually cancel.

6. Teleconnection Studies With Other Parts Of The Northern Hemisphere

Recent findings of idealised SST anomaly experiments by Hoerling *et al.* (2001, 2004) and Hurrell *et al.* (2004), indicate that SST variations have significantly controlled the North Atlantic circulation and the Mediterranean. They are related to the NAO, with the warming of the tropical Indian and western Pacific Ocean being of particular importance. A review on the influence of extratropical teleconnections and ENSO on Mediterranean climate for the recent instrumental period is provided by Alpert *et al.* (2005, chapter 2, this book). Here we mention a few examples and the potential on possible teleconnections covering the last few centuries.

A preliminary approach to identify regional patterns of teleconnections in a northern hemispheric scale, based on extreme conditions observed in a small area like Greece has been reported by Zerefos *et al.* (2002). They have performed superimposed epoch analysis. Winter and summer cold and warm years (25%-75%-precentiles, respectively) are used as key-dates. They are calculated from the Athens air temperature records on temperature NCEP reanalysis data since 1948 (Kalnay *et al.*, 1996; Kistler *et al.*, 2001). Their analyses included cases with dry and wet quintiles as calculated from the Athens precipitation records on mean SLP data (Trenberth and Paolino, 1980), available since 1899. The results are presented in Figures 1.37ab, 1.38ab, 1.39ab, and 1.40ab for winter and summer, respectively. The figures clearly show closed contours over Greece of the appropriate sign of the departure from the mean, both in near-surface air temperature and mean SLP.

<Figure 1.37>

<Figure 1.38>

In the case of air temperature these anomalies are related to opposite sign of anomalies between Greece and over northwestern Europe, clearly seen in the lower quartile cases for both winter and summer.

<Figure 1.39>

<Figure 1.40>

For the dry and wet cases, these opposing sign contours are more evident in summer. Moreover, in summer and in all cases examined, anomalies of the same sign as those observed over Greece and southeastern Europe appear as well over parts of south Asia. These patterns need also to be evaluated from documentary records and compared to model analysis for northwestern and southeastern Europe and Asia (e.g. Wang, 2002; Hsu, 2002). The teleconnection pattern seen in Figure 1.39 has been tested with independent documentary evidence mostly from monastery data (in case of Greece from Repapis *et al.*, 1989; Xoplaki *et al.*, 2001 and for China from the "*Reconstruction of Climate Data from Ancient Chinese History*"). Preliminary results (Table 1.3) indicate that the teleconnection pattern is probably confirmed only for the long-lasting drought period AD 305-340. For comparison, the percentage of drought days in all other years from AD 1 to 1909 (excluding the periods AD 305-340, 551-559, 741-742, 1040-1046) for the same region in Northern China (Henna) is 13.5%. Further analysis will also allow to investigate the relationship and its change trough time between Mediterranean regions with published evidence from paleoclimate reconstructions over the last centuries to millennia in China (Wang and Zhao, 1981, Zhang and Crowley, 1989; Song 1998, 2000; Wang *et al.*, 2001; Yang *et al.*, 2002; Qian and Zhu, 2002; Ge *et al.*, 2003, 2005; Qian *et al.*, 2003ab; Paulsen *et al.*, 2003; Sheppard *et al.*, 2005).

<Table 1.3>

Jones (2004) and Jones *et al.* (2004, 2005) have recently studied a high resolution record of lake oxygen isotope change from a varved crater lake in continental central Turkey (i.e., the semi-arid Cappadocia sub-region). It records changes in summer evaporation, by comparing it with the records of Indian and African (Sahel) Monsoon rainfall at an annual resolution through the instrumental period. They have found that the relationships show periods of increased evaporation in the continental Central Anatolia region of Turkey associated with periods of increased Monsoon rainfall in India and Africa, and this relationship is also found to hold through the last 2000 years when using comparative proxy records of both Monsoon systems. According to the findings of Jones (2004) and Jones *et al.* (2004, 2005), the largest inferred shifts in the atmospheric circulation over this time frame occurred around AD 530 and 1400, and are linked to shifts between relatively warm and cold periods of the NH climate.

In contrast to the stable influence of the AO/NAO over longer periods, the influence of the ENSO on southeastern Mediterranean climate is strongly non-stationary. The analysis of observational data reveals significantly positive correlations between SST anomalies in the tropical Pacific and in the eastern Mediterranean Sea/northern Red

Sea during the mid-1930s to late-1960s (Rimbu *et al.,* 2003a). The correlations jump to negative values in the 1970s. The 1970s shift in the ENSO teleconnection on southeastern Mediterranean climate, which is also documented in a coral record from the northernmost Red Sea (Felis *et al.,* 2000), is not unique. Similar shifts occurred frequently in the last 250 years, suggesting that the ENSO impact on the region is modulated at interdecadal timescales (Rimbu *et al.*, 2003a).

There seems to be also a connection between past and present Nile flood maxima and ENSO events (Eltahir and Wang, 1999; Kondrashov *et al.,* 2005 and references therein). The coherency between ENSO index and the Nile flood has a distinguished peak at the time scale of 4-5 years, which is close to the ENSO time scale (Eltahir and Wang, 1999). The possible physical connections are discussed in Eltahir and Wang (1999) and Kondrashov *et al.* (2005) as well. Further, the drought events that occurred in western Sicily during the 1565-1915 period were compared with ENSO (Piervitali and Colacino, 2001). Results show, that in periods of many drought events a reduction of ENSO events occurred and vice versa.

7. Mediterranean Winter Temperature And Precipitation Reconstructions In Comparison With The ECHO-G And HadCM3 Models

Models can help us determine how we might have expected the climate system to have changed given past changes in boundary conditions and forcings, which we can compare to inferences derived from paleoclimatic data (Jones and Mann, 2004). Internal variability generated in coupled ocean-atmosphere models can be verified against the long-term variability evident in proxy-based temperature reconstructions of the past centuries. This section deals with the comparison between the 500-year winter temperature and precipitation reconstructions discussed in Section 4 and the ECHO-G and HadCM3 models.

Two simulations have been made using the ECHO-G atmosphere-ocean GCM (Legutke and Voss, 1999). This model consists of the spectral atmospheric model ECHAM4 (Roeckner *et al.*, 1996) and the ocean model HOPE-G (Wolff *et al.*, 1997) both developed at the Max Planck Institute of Meteorology in Hamburg. The atmospheric spectral model is used with a T30 horizontal resolution (approx. 3.75°x 3.75°) and 19 vertical levels. The ocean component is HOPE-G with an equivalent horizontal resolution of 2.8°x 2.8° and 20 vertical levels. A constant in time flux adjustment was applied to avoid climate drift. The simulations were driven with estimations of external forcing factors (solar variability, atmospheric GHG concentrations (CO_2, CH_4) and radiative effects of stratospheric volcanic aerosols) for the period 1000 (1550) to 1990 derived from the data provided by Crowley (2000): Annual global mean concentrations of CO_2 and CH_4, were derived from polar ice cores. The values of N_2O were used as in previous scenario experiments with this model (Battle *et al.*, 1996; Roeckner *et al.*, 1999). Short wave radiative forcing from solar irradiance (^{10}Be concentrations in ice cores and sun spots observations) and volcanic activity (from ice core acidity) are aggregated into a global annual value. Changes in ozone concentrations, vegetation, tropospheric aerosols and orbital parameters have not been considered. Two simulations of the ECHO-G climate model (Erik and Columbus, see Fig. 1.41) are produced with the same external forcing specification. Both experiments were made with slight different versions of the model, in which the computer and the Fortran versions were different. Further technical

details, descriptions and results with these simulations are specified in von Storch *et al.* (2004), Zorita *et al.* (2003; 2004), and González-Rouco *et al.* (2003a,b).
HadCM3 is a finite-difference model with a horizontal resolution of 2.5° latitude x 3.75° longitude. This simulation was forced with both natural and anthropogenic forcings for the 1750 to 2000 period. It complements a separate run with natural-only forcings from 1500-2000. The natural forcings were volcanic (for four equal-area latitude bands), orbital and solar. The anthropogenic forcings were well-mixed greenhouse gases, aerosols, tropospheric and stratospheric ozone changes, and land surface changes. See Tett *et al.* (2005) for more detail. The main differences in the external forcing with respect to the ECHO-G simulation are the inclusion of the effect of anthropogenic tropospheric aerosols, ozone, other trace greenhouse gases and land-use changes.
Figure 1.41 presents a comparison between the empirically reconstructed winter average Mediterranean (10°W-40°E; 30°N-47°N) land based surface air temperature reconstructions 1500-1990 (Fig. 1.20, section 4) together with associated filtered 2 standard errors and model-based estimates over the period 1500-1990. A similar comparison has been presented for the Alpine area and the European continent (Raible *et al.*, 2005). The simulations include full three-dimensional atmosphere-ocean general circulation models (ECHO-G and HadCM3).

<Figure 1.41>

Except for the Columbus (ECHO-G) simulation the two other simulations Erik (ECHO-G) and the HadCM3 tend to fall well within the 2 standard error bands of the filtered reconstruction. Both HadCM simulations seems to be more at variance with the reconstruction before 1900. This feature is because the period 1901-1930 is a reference for all curves and the ECHO-G integrations have larger trends than the HadCM3 starting from the mid-nineteenth century. The smaller trends in the HadCM simulation are probably due to a different climate sensitivity and the inclusion of aerosol forcing which acts to reduce GHG warming especially in summer over continental areas. Also, the response of the main North Atlantic modes of circulation (NAO, EA, etc.) can play an important role in determining long-term regional temperature trends (e.g. Xoplaki *et al.*, 2003) in the Mediterranean region, thus differences in the simulated temperature response in both models can also partially be related to the response of the internal dynamics in each model and simulation which should be addressed with more detail in the future. Furthermore, ensemble runs of past simulations are needed (e.g. Yoshimori *et al.*, 2005; Goosse *et al.*, 2005c).
Prior to the twentieth century, all simulations tend to show a similar range of variability. The Columbus run presents the most extreme episodes at the end of the seventeenth century and first half of the nineteenth century. The first extreme episode occurs at the time of the well-know Maunder Minimum in solar activity. A temperature minimum at this time can be found in both ECHO-G simulations and in the reconstructions. The second extreme episode in the Columbus simulation (around 1825) is not found in the reconstructions and the other two simulations over the Mediterranean and would be in phase with the Dalton Minimum in solar activity. Some discussion on the occurrence of these minima at hemispherical and global scales in the ECHO-G simulations and in reconstructions can be found in González-Rouco *et al.* (2003ab), Zorita *et al.* (2004), and Wagner and Zorita (2005).
Figure 1.42 presents a comparison between the empirically reconstructed winter Mediterranean (10°W-40°E; 30°N-47°N) land based precipitation reconstructions

1500-1990 (Fig. 1.23) together with associated filtered 2 standard errors and model-based estimates over the period 1500-1990. It is noticeable that one of the ECHO-G simulations (Erik) falls well within the uncertainty bands of the reconstruction through the five centuries. Columbus and the HadCM3 simulation tend to exceed the lower uncertainty band. This is due to a slightly larger simulated variability than reconstruction and to the reference period used, which produces some relative shift of these simulations to lower precipitation values in the first four centuries. In general, the simulated interannual variability of winter Mediterranean precipitation seems to be larger than that of the reconstruction. The behaviour of precipitation in the larger Mediterranean area is strongly related to dynamics in the North Atlantic -European area (Dünkeloh and Jacobeit, 2003; Xoplaki *et al.*, 2004; Trigo *et al.*, 2005, this book). For specific regions, smaller scale Mediterranean cyclogenesis (see Lionello *et al.*, 2005 this book) plays a determinant role and other large-scale patterns as ENSO or the African Monsoon (see Alpert *et al.*, 2005 this book) have been named as possible sources of precipitation variability. Progress in understanding the differences in simulated and reconstructed variability will come also from further assessment of the behaviour of large-scale modes of circulation in the simulations and reconstructions (e.g. Luterbacher *et al.*, 2002b) as well as the limits of the model simulations in reproducing smaller scale convective precipitation. The reconstructions and the model simulations show no clear response to changes in the external forcing. This is also supported by the lack of coherence between rainfall in simulations with similar versions of the model (ECHO-G) and the same external forcing. Also the lack of correlation between the winter NAOIs of the simulations at all time scales has to be addressed. Also the correlation with the reconstructed winter NAOI is not significant, and no trend is discernible in the twentieth century. Therefore, the internal variability seems to be larger than the potential signal caused by variations in the external forcing.

<Figure 1.42>

7.1 Past Climate Variability And Its Relations to Volcanism, Solar Activity And GHG Concentrations: Reconstructions And Models

Recent studies (Lionello *et al.*, 2005a,b) have compared in detail model results from the ECHO-G simulations of the past centuries with the spatial temperature reconstruction for the European and Mediterranean region (Luterbacher *et al.*, 2004), focusing on the relative role of the external forcing and of the NAO dynamics. Only winter is considered in the comparison. The model simulation and the reconstruction present important differences, which do not allow reaching certain conclusions on the role of the Solar Volcanic Radiative Forcing (SVRF) on the Mediterranean climate. According to the model dynamics, the SVRF only slightly correlates with winter European temperature at multidecadal time scales and the two forced simulations show a disagreement over Northern Europe and Northern Africa (not shown). In fact, during this season, the effects of the internal dynamics are superimposed to that of the SVRF forcing. Consequently, the average winter temperature difference between the two simulations is well correlated (0.59) with the difference between their winter NAOIs. The reconstruction shows a different behaviour. Correlation between reconstructed temperatures and SVRF is significant only at the multidecadal time scales over Northern Europe, while over Southern Europe values are negative.

Consequently, the correlation between simulations and reconstruction is low over most of southern Europe (not shown, Lionello *et al.*, 2005a). An overestimation of the climate sensitivity to SVRF by the ECHO-G model is possible: its results are likely to be very inaccurate also because of the poor representation of the regional details of the Mediterranean region. Another possibility is that the SVRF might contain some error, or its spatial variability, which is not explicitly described in the experiments, might have important effects in southern Europe. Finally, inaccuracies in the reconstruction cannot be ruled out. Identifying the relationships between the main regional climatic patterns and the radiative forcing due to solar activity, volcanic eruptions and GHG concentration is a key point to assess the model capability to predict future scenarios at the regional scale. A low correlation between radiative forcing (RF) and regional climate and the lack of interactions between RF and the internal climate variability would limit the possibility to reconstruct and to predict regional climate, especially in the Mediterranean region. In general, if present results are confirmed, a considerable part of the Mediterranean temperature changes is associated with the internal, unpredictable climate dynamics, and simulations of future climate scenarios could be skilful only at the multidecadal time scales, where the SVRF influence is stronger. However, future RF variations are expected to be much larger than the ones that characterized past climate, and it is possible that the RF influence on the climate might be stronger.

Additional modeling studies of the response to solar and volcanic forcing have been done with the NASA Goddard Institute for Space Studies (GISS) models. These have been used to examine the spatial patterns of the equilibrium response to solar irradiance changes and both the short and long term response to volcanism in a historical context (Shindell *et al.*, 2001a, 2003, 2004; Schmidt *et al.*, 2004). Many of these studies were performed with a relatively coarse resolution (8° by 10°) version of the GCM with 23 layers and a mixed-layer ocean. The model emphasized the representation of stratospheric dynamics, and included a detailed treatment of the forcings such that volcanic aerosols were specified with latitudinal and vertical time-varying distributions and solar irradiance variations were spectrally resolved. The latter plays a significant role in solar forcing since most of the variability is at short wavelengths that is primarily absorbed in the stratosphere. The model also included the chemical response of stratospheric ozone to solar variability. Focusing on the Maunder Minimum period, the model produced the generally cooler conditions of the late seventeenth century in comparison with the late eighteenth century (Shindell *et al.*, 2003). Solar forcing provided the dominant contribution, largely by introducing a prolonged negative wintertime NAO phase (Luterbacher *et al.*, 1999, 2002a), consistent with earlier studies and with proxy reconstructions (Shindell *et al.*, 2001a). Volcanic forcing contributed to a general cooling during this period, but with little spatial structure at multi-decadal scales. Stratospheric ozone's response to solar variability played an important role in the outcome in those simulations, amplifying the large-scale dynamic changes by around a factor of two. The results matched large-scale proxy network reconstructions in many areas of the NH, including the cooling in northern Europe during the late seventeenth century (e.g. Luterbacher *et al.*, 2004). As noted previously, the decade with the coldest Mediterranean winter temperatures in the proxy based reconstruction was 1680-1689 (Section 4, Fig 1.20). However, the model failed to reproduce the opposite polarity anomaly centered over the eastern Mediterranean. Newer simulations with a more sophisticated version of the GISS GCM called modelE have been carried out for the case of volcanic eruptions. The simulations, run at 4°x5° resolution and again with 23 vertical layers, reveal that the model is able to capture the spatial pattern of the short-term response to volcanic eruptions much better than the earlier model (Shindell *et al.*, 2004). This pattern is almost identical to the longer-term solar response pattern, and the newer model captures both the northern European (Luterbacher *et al.,* 2004) and opposite polarity Eastern Mediterranean responses (Shindell *et al.,* 2004). Since this pattern is also thought to occur largely via the same processes as the longer-term solar forcing, this raises the possibility that models may soon be able to reproduce historic Mediterranean climate variability much better than they have in the past.

8. Conclusions

The larger Mediterranean area offers a remarkably high quality and quantity of long instrumental series, a wide range of documentary data (Section 2.1) as well as high and low spatio-temporally resolved natural proxies (tree-rings, speleothems, corals and boreholes; Section 2.2). The recognition of correlated chemical and isotopic signals in new marine archives (e.g. non-tropical coral, the vermetid reefs and the deep-sea corals) provide an important new approach to help unravel climatic variability in the Mediterranean basin for the last few centuries (Section 2.2). This multi-proxy climate information make the larger Mediterranean area very suitable for climate reconstructions at different time scales, as well as the analysis of changes in climate extremes and socio-economic impacts prior to the instrumental period. However, there are still a lot of archives with documentary proxy evidence unexplored, as has been shown for the Iberian Peninsula, Italy, France, the Balkans, Greece, the Southeastern Mediterranean area, possibly the northern African countries as well as ship logbooks. Further, the coverage of northern Africa with respect to natural, annually resolved proxy climate data is sparse. Exceptions are tree-ring records from Morocco (work in Algeria and Tunisia just started) and coral records from the northernmost Red Sea (Egypt, Israel, Jordan). To the best of our knowledge no annually resolved proxy climate data exists so far from the Mediterranean coastal region of Libya and Egypt. More tree-ring work in these regions as well as non-tropical corals and vermetid reefs could help to fill this gap. Further, there is potential in the Eastern Mediterranean, mainly in Turkey, for new speleothem data which may provide information on the precipitation conditions over the last centuries to millennia. Approximately one third of the country is underlain by carbonate rocks and caves are frequent. Those caves are geographically well-distributed, making a north-south and west-east transect across Turkey possible (D. Fleitmann, personal communication).

The data generated by the various studies presented and discussed in this review contribute to the regional, national and international scientific and resource management communities. Internationally, these data will fill critical gaps in multiple global climate databases valued by programs such as PAGES, CLIVAR, NOAA-OGP, and NASA-EOS. For instance, tree-ring evidence from the southeastern Mediterranean is especially useful for investigations of interannual to multi-century scale climate variability, ranging from climate system oscillations to recurrent regional drought episodes. Regionally, it is important to provide a decadal to multi-century perspective on climate variability to local managers of land and water resources. Given the significance of water in the region and its strategic importance, this could have considerable impact on international water resource policy, management and political agreements between countries in the region. The Mediterranean is a water deficit region and in parts there is a history of conflict over land and natural resources. This information will aid in anticipating and, hopefully lessening the likelihood of conflict over scarce water resources.

We addressed the question on the importance and limitations of documentary and natural proxies for Mediterranean precipitation reconstructions at seasonal time scale. We found that different proxy types have their specific response region, which suggests to use region-specific multiproxy sets in seasonal climate reconstructions and confirm recent findings devoted to near surface air temperature (Pauling *et al.,* 2003). Documentary precipitation and tree-ring data are those proxies, which are the most important both for boreal winter and summer precipitation covering large areas around the Mediterranean. Other proxies such as corals, speleothems and ice cores are relevant for smaller restricted areas. In order to verify the preliminary conclusions more systematic testing of a larger dataset of proxies is needed, considering additional data around the Mediterranean areas resolving seasonal resolution. It should also be taken into account that not only the proxy type determines the results but also its initial number, location and quality.

Numerous seasonally resolved documentary proxy data and information gathered from natural proxies discussed in Section 2 and 3 have been used to derive winter Mediterranean temperature and precipitation fields and averaged time series back to 1500 (Section 4). It turned out that rather moderate seasonal to multidecadal precipitation and temperature variability was prevalent over the last few centuries. Several cold relapses and warm intervals as well as dry and wet periods on decadal timescales, on which shorter-period quasi-oscillatory behaviour was superimposed have been found. In the context of the last half millennium, however, the last winter decades of the twentieth/twenty first century were the warmest and driest. The analysis of anomalously wet and warm winters in Section 4 has revealed that in the regional-mean time series of Mediterranean winter precipitation and temperature no statistically significant changes with respect to the frequency and intensity of extreme winters have occurred since 1500.

The relationship between large-scale atmospheric circulation patterns and Mediterranean winter climate anomalies during the last 500 years (Section 5) may be generalised in the following way: warm and dry winters linked with positive NAO modes (first patterns in Fig. 1.30); cold and wet winters connected with Scandinavian blocking (first patterns in Fig. 1.31). Cold and dry winters could be related to different anticyclonic regimes (patterns 2-4 in Fig. 1.32), whereas warm and wet winters are connected with different cyclonic regimes (patterns 2-4 in Fig. 1.33).

Running correlation analyses between the leading patterns derived from the large-scale atmospheric circulation and the regional averaged Mediterranean temperature and precipitation reveals, that the NAO (East Atlantic/Western Russia) has a robust signal on Mediterranean mean land precipitation (temperature), whereas the influence on Mediterranean mean land temperature (precipitation) is fluctuating and depends on the time window. It is suggested, that PC1 (PC2) of large scale SLP impact on Mediterranean precipitation (temperature) is rather homogeneous throughout the region, while the impact on temperature (precipitation) is not so homogenous and sub-regional processes can provide different signal which can eventually cancel (the signal is non-significant for the last few centuries). Section 6 showed that there are indications for possible teleconnections between Mediterranean and NH climate in past centuries. Finally, the comparison among the reconstructions of Mediterranean winter temperature and land precipitation with the ECHO-G and HadCM3 simulations (Section 7) shows that the range of variability reproduced by the climate models for the period 1500 to 1990 is only slightly larger than that of the reconstructions (Section

4). In the case of temperature, the HadCM3 simulation trends are comparable with those in the empirical reconstructions (Section 4) and slightly smaller than those in the ECHO-G simulations. This is a reasonable feature, since the latter do not include aerosol forcing. As for the case of Mediterranean precipitation, no trends are reconstructed nor simulated (Fig. 1.42). The variability of Mediterranean precipitation is also slightly larger for the simulations compared to the reconstructions. Both assessments reveal the need for a more thorough study that takes into consideration the behaviour of the atmospheric circulation in climate reconstructions and model simulations.

9. Outlook

Despite the fact that there are many proxy data available from the larger Mediterranean area, the uncertainties of the climate reconstruction increase back in time. In order to improve reconstruction skill in time and space and expand climate estimates further back in time, one main aim is therefore to enlarge the spatio-temporal coverage of high resolution, high quality, accurately dated, natural and documentary proxy evidence from all countries along the Mediterranean Sea, as there are many sources which have not yet explored and regions with scarce information (i.e. North African coastal regions) and those sensitive to climate change. Archives of the Islamic world, yet unexplored, are believed to provide documentary evidence on past weather and climate. Attention should be also paid to ship logbooks of which many thousands have now been located, as a major and reliable data source points to a more comprehensive review of climatic variation in the region than has hitherto been the case. Another interesting source of data is related to agricultural production, which may be inferred from the taxes paid by farmers and recorded in municipal and ecclesiastic accounts books. New high-resolution marine archives and application of isotopic and geochemical proxies will be of much relevance for past SST, salinity, near surface air temperature and rainfall reconstructions. Such new archives will provide weekly to annual resolution records for the Mediterranean Sea, using rather low cost sampling and analytical techniques. More research and tree-ring sampling in the entire Mediterranean region are required as tree-ring information is probably the most important proxy for large areas around the Mediterranean. For instance, even though many chronologies were developed from the southeastern Mediterranean, this is not enough to faithfully represent an area that expands almost 2,000 km from east to west and 1,500 km from north to south. This remains one of the largest mid-latitude semiarid regions without an adequate network of climate sensitive tree-ring chronologies. Recently, R. Touchan started a large-scale systematic sampling in Morocco, Tunisia, and Algeria. This project (supported by NSF-ESH) will establish a multi-century network of North African climate records based on tree-rings, by extending and enhancing the existing tree-ring dataset geographically and temporally. This network will then be used to study interannual to century scale climate fluctuations in the region, and their links to large-scale patterns of climate variability. Up to date 15 chronologies from Morocco and Tunisia were developed. The length of the chronologies range from 113 (Dahallia, Tunisia) to 1082 (Col Du Zad, Morocco) years. The incorporation of the multiproxy data with a high spatio-temporal coverage, together with sophisticated reconstruction methodologies (bearing in mind the extreme character of some of the data, linear and non-linear approaches) will provide a broader picture of past Mediterranean climate variability covering the last few centuries, not only averaged over the entire area but for specific sub-regions including the Mediterranean Sea. An important issue for future investigation on past temperature and precipitation extreme is the application of the analysis technique described in Section 4 to shorter time scales and individual subregions of the Mediterranean basin in order to infer whether significant changes of opposite sign may have happened at different sites. Further analyses, however, have to take into consideration sub-areas as current conditions clearly indicate different impacts of major teleconnection patterns within different Mediterranean regions.

The combination of highly resolved climate reconstructions and model climate simulations offer extended scientific understanding on the climate response to external forcing (e.g. the direct radiative and the poorly investigated dynamical response to tropical eruptions over the Mediterranean).

Another approach to draw a better picture of past climate variability over the Mediterranean area covering the last millennia is to combine high and low resolution climate proxies using sophisticated reconstruction methods as demonstrated for the NH by Moberg *et al.* (2005).

Future work involving climate reconstructions and model simulations can benefit our understanding of Mediterranean climate variability at several levels. Model simulations can be used as a pseudo reality in which gridpoint variables can be degenerated with noise and treated as pseudo-proxies to replicate reconstruction methods within the simulated world (Zorita and González-Rouco, 2002; Mann and Rutherford, 2002; Zorita *et al.*, 2003; González-Rouco *et al.* 2003; von Storch *et al.* 2004; Mann *et al.*, 2005). The simulation of relevant large-scale climate regimes for Mediterranean variables can be comparatively studied with reconstructions of atmospheric circulation. This should provide knowledge about the potential response of relevant circulation regimes to external forcing and aid in understanding differences among simulations and reconstructions (Casty *et al.*, 2005c). Further, the range of simulated variability for precipitation and temperature in simulations of the last millennium in comparison with multi-proxy reconstructions can help estimate uncertainties in scenario simulations of future climate change. In addition, the assessment of the deficiencies of model simulations in reproducing temperature and precipitation at smaller scales, in particular that related to Mediterranean cyclogenesis, can help improve model parameterizations. Understanding of variability at smaller spatial scales and a better simulation of involved processes can be achieved with regional climate modelling and statistical downscaling. Model studies investigating the role of processes, such as the stratospheric ozone chemical response to solar variability or the ocean circulation response to solar or volcanic perturbations, can help to determine how regional patterns are setup and why model results differ at regional scales. Last, but not least, the assessment of the changes in the dynamics associated to extreme climate episodes through the last millennium registered both in climate simulations and in empirical reconstructions will help better understand the mechanisms involved in extremes and related impacts.

As shown in this review, the Mediterranean is a region with evident singularities in pluviometric patterns. It produces relatively frequently climatic hazards as floods and droughts. Due to demographic and touristic developments, people are increasingly exposed to “climatic hazards”. Thus, climatic research must be focused on both, modelling and reconstruction of extreme meteorological and climatic events. For reconstruction of rarely occurring extreme events, research on historical documentary sources and fluvial/lacustrine sediments for instance is needed to identify, analyse and reconstruct them and put them in a long-term context. Only with this knowledge urban and regional planning can produce long-term strategies for climatic hazards prevention.

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The reconstructed temperature and precipitation data for the last 500 years can be obtained from the first author.

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Figure captions

Fig. 1.1. left: An example of a document that describes the damages in irrigation network of the city Lleida (Catalonia, Spain) on 10th June 1379. right: painting of a historical flood event in Barcelona, Spain 1862 (Amades, 1984).

Fig. 1.2. left: Manuscript recording one severe rogation ceremony following drought in Girona city (Catalonia, NE Spain), April 1526. Historical City Archive of Girona. This ceremony consists in a pilgrimage from Girona to St. Feliu de Guixols (20 km.) to immerse one relic in sea-water (mummified head of Sain Feliu). right: Saint Narcisus was the first bishop of Girona. His relics were displayed into the Cathedral in rogations both for drought (pro pluvia) and during long periods of rain (pro serenitate; Martín-Vide and Barriendos, 1995; Barriendos, 1997)

Fig. 1.3. top: Reconstruction of winter precipitation anomalies at Barcelona, middle: spring at Barcelona and bottom: autumn at Murcia back to the sixteenth century. Dashed line: seasonal rainfall standardized anomalies (reference period 1961-1990); Continuous line: 11-year running average (Barriendos and Rodrigo, 2005).

Fig. 1.4. Annual precipitation index in southern Portugal (Taborda *et al.*, 2004).

Fig. 1.5. Reconstruction of the Durance river (France) flood events by Guilbert (1994) reconstructed from documentary sources: number of months with floods per decades.

Fig. 1.6. Reconstruction of the summer (April-September) temperature in Marseille-Observatoire compared with observations (all the values are expressed in °C as departures from the 1961-1990 mean of 19.5°C). The reconstructions are obtained from tree-ring series combined with documentary data (wine harvest dates, number of months with ice in the Rhone River etc.). In grey is the confidence interval at the 90% level (Guiot, J., *et al.*, 2005, The last millennium summer temperature variations in western Europe as based on proxy data, Holocene 15, 489-500) Copyright 2005, Edward Arnold (Publishers) Limited.

Fig. 1.7. 1000 years of Venice Lagoon freezing (Camuffo, 1997)

Fig. 1.8. top: Averaged winter temperature and bottom: precipitation conditions for Greece estimated from documentary proxy evidence (Xoplaki *et al.*, 2001). Values of plus (minus) 3 indicate exceptionally warm (cold) in case of temperature and wet (dry) for precipitation. An index of 0 for a particular winter means normal conditions compared with the 1901-1960 average.

Fig. 1.9. An example of a Spanish logbook page from 1797 (Courtesy of the Archivo del Museo Naval (Archive of the Naval Museum), Madrid, Spain).

Fig. 1.10. CLIWOC version 1.5 data coverage. Each dot represents a daily observation.

Fig. 1.11. Decadal distribution of logbooks in British archives from the Mediterranean region for the 1670-1840 period. The graph shows the number of ships and logbooks estimated from the earliest years to 1850.

Fig. 1.12. Annual mean temperature and total annual precipitation in northeastern Spain during the 1500-1900 period. Grey curve: standardized anomalies (reference period 1850-1900). The black curve is a 15-yr running average (Saz, 2004).

Fig. 1.13. Time series plot of reconstructed May to June precipitation, 1339-1998. Horizontal solid line is the mean of the observed data. Horizontal dashed line is the arbitrary threshold of 120% of the 1931-1998 mean May-June precipitation (80.33 mm). Horizontal dotted line is the arbitrary threshold of 80% of the 1931-98 mean May-June precipitation (53.55 mm). The instrumental record is in grey. Preliminary reconstructions of spring precipitation in southwestern Turkey from tree-ring width. Touchan *et al.*, 2003, International Journal of Climatology, 23 Copyright © [2005] the Royal Meteorological Society, first published by John Wiley & Sons Ltd.)

Fig. 1.14. Reconstruction of annual (October to September) precipitation (averaged on the whole of Morocco) by Till and Guiot (1990) from 46 cedar tree-ring series. The precipitation anomalies are expressed in departures from the period 1925-1970 in mm/year. In grey are the uncertainties for each year.

Fig. 1.15. Coral oxygen isotope record from Ras Umm Sidd (northernmost Red Sea, 28°N) near the southern tip of the Sinai Peninsula (Felis *et al.*, 2000). Detrended and normalized mean annual time series, based on bimonthly resolution data. On interannual to multidecadal timescales, coral oxygen isotopes reflect variations in temperature/aridity. Pronounced cold/arid conditions occur during the 1830s. Note that on interannual to decadal (NAO) timescales colder/more arid conditions in the northernmost Red Sea are associated with increased precipitation along the southeastern margin of the Mediterranean Sea and decreased precipitation in Turkey. Bold line represents 3-year running average.

Fig. 1.16. Vermetid reefs world distribution (black dots). The vast majority of species is located in several world seas and oceans, between 44°N and 44°S (Silenzi *et al.*, 2004).

Fig. 1.17. left: Vermetid reef mushroom-like type near Capo Gallo promontory (NW Sicily) and right: Vermetid reef platform type near S. Vito lo Capo (from Silenzi *et al.*, 2004).

Fig. 1.18. Boreal winter (October to March). top: Locations of the natural and documentary proxies used in this study. middle: Spatial distribution of the most important predictors for boreal winter (October to March) precipitation over the larger Mediterranean area. For the legend see top panel. bottom: correlation of the most important predictor (Fig. 1.18 middle panel) with local precipitation over the period 1902-1983. All values above 0.21 are statistically significant at the 5 % level (t-test). As different proxies have been used to produce this correlation map, the correlation sign changes over small spatial scales. These changes often correspond to changes of the most important predictor (Fig. 1.18 middle panel).

Fig. 1.19. as Fig. 1.18, but for boreal summer (April-September) precipitation.

Fig. 1.20. Winter (DJF) averaged-mean Mediterranean temperature anomalies (with respect to 1961-1990) from 1500 to 2002, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions; data from 1901 to 2002 are derived from Mitchell *et al.* (2004), Mitchell and Jones (2005). The thick black line is a 30-year smooth 'minimum rough' constraint (mean squared error, MSE=0.866) calculated according to Mann (2004). The dashed horizontal lines are the 2 standard deviations of the period 1961-1990. The warmest and the coldest Mediterranean winters for the reconstruction and the full period are denoted.

Fig. 1.21. Anomalous surface air temperature for the warm Mediterranean winter 1606/1607 (top) and the cold Mediterranean winter 1890/1891 (bottom) (with respect to 1961-1990).

Fig. 1.22. Anomalous winter (DJF) temperature composites. top: Averaged-mean Mediterranean land surface air temperature for the 30 coldest winters in a row (1880-1909) over the last 500 years minus the 1961-1990 reference period (in °C). bottom: as top, but for the 30 warmest winters (1973-2002 minus 1961-1990). Data from 1880-1900 are reconstructions, data from the twentieth/twenty first century stem from Mitchell *et al.* (2004) and Mitchell and Jones (2005).

Fig. 1.23. Winter (DJF) averaged-mean Mediterranean precipitation anomalies (with respect to 1961-1990) from 1500 to 2002, defined as the average over the land area 10°W to 40°E and 35°N to 47°N (thin black line). The values for the period 1500 to 1900 are reconstructions (Pauling *et al.*, 2005); data from 1901 to 2002 are derived from Mitchell *et al.* (2004) and Mitchell and Jones (2005). The thick black line is a 30-year smooth 'minimum slope' constraint (mean squared error, MSE=0.856) calculated according to Mann (2004). The dashed horizontal lines are the 2 standard deviations of the period 1961-1990. The driest and the wettest Mediterranean winters for the reconstruction and the full period are denoted.

Fig. 1.24. Anomalous precipitation for the wet Mediterranean winter 1837/1838 (top) and the dry Mediterranean winter 1881/1882 (bottom) (with respect to 1961-1990).

Fig. 1.25. Anomalous winter (DJF) precipitation composites. top: Mediterranean land precipitation for the 30 driest winters in a row (1973-2002) over the last 500 years minus the 1961 to 1990 reference period (in mm). bottom: as top, but for the 30 wettest winters (1951-1980 minus 1961-1990). Data are taken from Mitchell *et al.* (2004) and Mitchell and Jones (2005).

Fig. 1.26. Morlet wavelet spectra of regional-mean winter Mediterranean precipitation and near-surface temperature from 1500-2002. The values denote the wavelet power. Values larger than 4 are statistically significant at the 5% level.

Fig. 1.27. top: Gamma (G) distributions fitted to different 50-year periods of Mediterranean winter precipitation. midle: Time series of estimated return values between 5 and 50 years, referring to different 50-year periods between 1500 and 2002. bottom: Statistical significance of changes in extreme annual precipitation for

different return periods, testing the last 50 years (1953-2002) against all previous 50-year periods between 1500 and 1952.

Fig. 1.28. Same as Fig. 25 but for near-surface temperature, using the normal distribution.

Fig. 1.29. Reconstruction of the winter PDSI (Palmer Drought Severity Index) at three gridpoints (Morocco: 32.5°N, 5°W; Italy: 37.5°N 15°E; Greece: 40°N, 22.5°E) along a west-east gradient, using tree-ring series, with, in grey, the 90% confidence interval. Red dots represent the observed series (Nicault *et al.*, 2005).

Fig. 1.30. Major four circulation patterns associated with wet Mediterranean winter seasons (DJF) in the 1500-1999 period, derived according the procedure developed in Jacobeit *et al.* (1998) (using normalized T-mode principal component scores).

Fig. 1.31. Same as Fig. 1.30, but for dry Mediterranean winter seasons.

Fig. 1.32. Same as Fig. 1.30, but for warm Mediterranean winter seasons.

Fig. 1.33. Same as Fig. 1.30, but for cold Mediterranean winter seasons.

Fig. 1.34. 31-year running averages of Mediterranean winter (DJF) temperature (grey line) and precipitation (black line) for the period 1500-2002.

Fig. 1.35. 30-year running correlation between the first (a) and second (b) Principal Component of winter SLP and averaged winter Mediterranean surface air temperature 1764-2002. The 90% and 95% correlation significance levels have been calculated with Monte Carlo simulations.

Fig. 1.36. Same as Fig. 1.35, but for averaged winter Mediterranean precipitation (RR).

Fig. 1.37. Average near surface air temperature for cold years in Greece (lower 25%) for (a) Summer (JJA; contour interval 0.25°C), upper panel, and (b) winter (DJF, contour interval 0.5°C), lower panel.

Fig. 1.38. Average near surface air temperature for warm years in Greece (upper 75%) for (a) summer (JJA; contour interval 0.5°C), upper panel, and (b) winter (DJF; contour interval 0.5°C), lower panel.

Fig. 1.39: Average mean sea level pressure for dry years in Greece for (a) summer (JJA; contour interval 0.5 hPa) upper panel, and (b) winter (DJF; contour interval 0.5 hPa), lower panel.

Fig. 1.40. Average mean sea level pressure for wet years in Greece (a) summer (JJA; contour interval 0.5 hPa), upper panel, and (b) winter (DJF; contour interval 0.5 hPa), lower panel.

Fig. 1.41. Comparison between empirically reconstructed winter average Mediterranean (10°W-40°E; 30°N-47°N) land based surface air temperature

reconstructions (1500-1900), Mitchell *et al*. (2004), Mitchell and Jones (2005) gridded data (1901-1990) (Fig. 1.22) and model-based estimates over the period 1500-1990. Shown are 30-year Gaussian smoothed series with respect to the reference period 1901-1930. The simulations include full three-dimensional atmosphere-ocean general circulation models (ECHO-G (Erik, Columbus) and HadCM3) based on varying radiative forcing histories. The filtered reconstructions are presented with their 30-year filtered 95% confidence interval. See text for details.

Fig. 1.42. Same as Fig. 1.41, but for averaged Mediterranean winter land precipitation.

Table 1.1: Compilation of long early homogenised instrumental data and documentary proxy evidence from the Mediterranean (see Section 2.1 for details)

Location	**Time period**	**Type of 'proxy'**	**Temporal resolution**	**Parameter**	**References**
Padova (Italy)	1721-present	Instrumental records	Daily/monthly	Precipitation	Camuffo (1984)
Padova (Italy)	1721-present	Instrumental records	Daily/monthly	Temperature, pressure	Camuffo (2002a,b,c); Cocheo & Camuffo (2002)
Milan (Italy)	1763-present	Instrumental records	Daily/monthly	Temperature & pressure	Brunetti *et al.* (2001); Maugeri *et al.* (2002,a,b)
Po Plain (Italy)	1765-present	Instrumental records	Daily/monthly	Pressure	Maugeri *et al.* (2003)
Barcelona (Spain)	1780-present	Instrumental records	Daily/monthly	Pressure	Rodriguez *et al.* (2001)
Cadiz-San Fernando (Spain)	1786-present	Documentary & Instrumental records	Daily/monthly	Temperature & pressure	Barriendos *et al.* (2002)
San Fernando (Spain)	1821-present	Instrumental records	Monthly	Precipitation	Rodrigo (2002)
Southern Portugal	1700-1799	Documentary & early instrumental	Monthly, seasonal	Temperature, precipitation, drought	Taborda *et al.* (2004)
Lisbon (Portugal)	1815-present	Early instrumental	Daily & monthly	Temperature & precipitation	Alcoforado *et al.* (1997, 1999)
Spanish Mediterranean Coast; 37N-43N, 2W-4E	1300-1970	Documentary	Extremes	Frequency of extreme events (flood magnitude)	Barriendos & Martin-Vide (1998)
Catalonia (Spain; 40N-43N, 0E-4E)	1521-1825	Documentary, rogations	Extremes, annual	Drought indices	Martin-Vide & Barriendos 1995
Catalonia (Spain) 40N-43N, 0E-4E	1521-1825	Documentary, rogations	Extremes	Frequency of drought, weather	Barriendos & Llasat 2003
Barcelona (Spain)	1521-2000	Rogations	Extremes, monthly & seasonal	Precipitation, droughts, floods	Barriendos (1997); Barriendos & Martin-Vide (1998)

Murcia (Spain)	1570-2000	Rogations	Extremes,, monthly & seasonal	Precipitation, droughts, floods	Barriendos & Rodrigo (2005)
Spain, 5 points 36N-44N; 9W-4E	1675-1715	Documentary, rogations	Annual	Rainfall indices, droughts, excessive rainfall	Barriendos (1997)
Castille (Spain)	1634-1648	Correspondence & documentary evidence	Extremes, irregular	Precipitation (snowfalls, droughts, floods), temperature, general weather conditions	Rodrigo *et al.* (1998)
Andalusia (Spain)	1500-1997	Miscellaneous documentary evidence	Extremes, monthly, seasonal	Precipitation, droughts, floods	Rodrigo *et al.* (1999, 2000)
Canary Islands (Spain)	1595-1836	Agricultural records	Extended winter	Precipitation, wetness/drought	García-Herrera *et al.* (2003b)
Spain	Last centuries-present	Miscellaneous documentary, early instrumental data	Daily, monthly & seasonal	Compilation of different past climate related topics, weather, temperature & precipitation, logbook information, tropical cyclones, etc.	http://www.ucm.es/info/reclido/
Central Portugal	1663-1665	Correspondence	Irregular (from 2 to 17 monthly weather information)	Temperature, precipitation (droughts, floods)	Daveau (1997)
Southern Portugal	1675-1715	Different documentary sources	Monthly, seasonal	Temperature, precipitation (droughts, floods)	Alcoforado *et al.* (2000)

Southeastern France	1200-1999	Documentary & early instrumental	Wet period	Hydrological parameters (e.g. floods, Annual maxima discharges)	Guilbert (1994), Pichard (1999)
Burgundy (France)	1370-present	Grape harvest from documentary evidence	Spring-Summer	Temperature	Le Roy Ladurie (1983, 2004, 2005); Chuine *et al.* (2004);
Marseille (France)	1100-1994	Documentary evidence, isotopes, tree-rings,	Summer	Temperature	Guiot *et al.* (2005)
Venice (Italy)	6th century-present	Documentary sources	Irregular, winter severity	Frozen lagoon, 'temperature'	Camuffo (1987)
Venice (Italy)	1700-present	Iconographic sources	Irregular	Algae belt level & sea level rise	Camuffo & Sturaro (2003, 2004)
Venice (Italy)	782-present	Documentary sources	Irregular	Flooding tides, Scirocco & Bora wind	Camuffo (1993); Enzi & Camuffo (1995)
Northern & central Italy	579-present	Documentary sources	Irregular	Locust invasions, Scirocco & Bora wind	Camuffo & Enzi (1991)
Tiber & Po rivers (Italy)	BC 414 -present	Documentary sources	Irregular	Precipitation, flood magnitude/frequency	Camuffo & Enzi (1996)
Padova (Italy)	1300-present	Documentary sources, early instrumental records	Irregular	Storms, hailstorm, thunderstorm	Camuffo *et al.* (2000b)
Western Mediterranean & Adriatic sea	Last millennium	Documentary sources	Irregular	Atmospheric circulation, sea storms	Camuffo *et al.* (2000a)
Italy	1374-present	Documentary sources,	Irregular	High pressure situations (based on dry fog & volcanic clouds)	Camuffo & Enzi (1994b, 1995c)
Italy	1500-1799	Documentary sources,	Irregular, extremes	Precipitation (droughts, floods), temperature, extreme	Pfister *et al.* (1999); Glaser *et al.* (1999); Brazdil *et al.* (1999); Camuffo & Enzi (1992, 1994a; 1995b)

Southern Italy	1300-1900		Irregular	High pressure, low dispersion (based on dry fogs)	Camuffo & Enzi (1994, 1995c)
Sicily (Italy)	1565-1915	Religious processions	Extremes	Precipitation (drought)	Piervitali & Colacino (2001)
Greece (northern part)	1200-1900	Documentary evidence	Severe winter extremes	Temperature	Repapis *et al.* (1989)
Greece & southern Balkans, partly Cyprus	1675-1830	Documentary evidence	Monthly, not continuous	Temperature & precipitation, inclusive droughts, floods	Xoplaki *et al.* (2001)
Egypt	622-present	Nilometer, documentary evidence	Irregular, seasonal	Flood levels of the Nile river	Fraedrich & Bantzer (1991); Eltahir & Wang (1999); Kondrashov *et al.* (2005 & references therein)
Eastern Atlantic oceanic area	1750 to 1854	Ships logbooks	Daily	Pressure fields, storm frequencies, wind force, wind direction & general weather	www.ucm.es/info/cliwoc

Table 1.2: Compilation of temporally 'high resolved' natural proxies from the Mediterranean (see section 2.2 for details)

Location	**Time**	**Archive**	**Temporal resolution**	**Parameter reconstructed**	**Reference**
Northern Spain	1500-present	Tree-rings	Seasonal	Temperature, precipitation	Saz (2004)
Spain	1000-present	Tree-rings	Seasonal	Temperature, precipitation	Creus-Novau *et al.* (1997); Saz & Creu-Novau (1999)

Galicia (Spain)	1500-present	Tree-rings	Annual	Temperature, precipitation???	Creus-Novau *et al.* (1995)
Adriatic coast (Italy)	1653-1985	Tree-rings	Winter	Temperature	Galli *et al.* (1994)
Mediterranean Basin	1000-2000	Tree-rings	Annual	Temperature, precipitation	http://servpal.cerege.fr/ webdbdendro/
Mediterranean Basin	1700-2000	Tree-rings	April-September	Temperature	Briffa *et al.* (2001)
Morocco	1000-1979	Tree-rings	Annual	Precipitation	Munaut (1982)
Morocco (regional)	1100-1979	Tree-rings	October-September	Precipitation	Till & Guiot (1990)
Morocco	1429-2000	Tree-rings	Winter	NAO, precipitation	Glueck & Stockton (2001)
Southern Jordan	1600-1995	Tree-rings	October-May	Precipitation, Drought	Touchan *et al.* (1999)
Istanbul (Turkey)	1887-1995	Tree-rings	Annual	Positive correlation between Jan-Feb/Jul-Aug precipitation and tree-rings; positive corr between Mar-Apr temp but negative correlation with May-Jul temp	Akkemik (2000)
Black sea (Turkey)	1635-2000	Tree-rings	Annual	Mar-Jun precipitation	Akkemik *et al.* (2005)
Southern central Turkey	1689-1994	Tree-rings	Annual	Apr-Aug precipitation	Akkemik & Aras (2005)
Sivas (Turkey)	1628-1980	Tree-rings	Annual	Feb-Aug precipitation	D'Arrigo & Cullen (2001)
Southwestern Turkey	1339-1998 1776-1998	Tree-rings	May-June	Precipitation	Touchan *et al.* (2003)
The land area of most Turkey & adjoining region	1251-1998	Tree-rings	Drought	Precipitation Index	Touchan *et al.* (2005a)
Eastern Mediterranean	1400-2000	Tree-rings	May-August	Precipitation	Touchan *et al.* (2005b)

Central Anatolia Turkey, (Nar Gölü: 38°27'30''E; 38°22'30''N; 1363 masl)	~300-2001	Proxy record from d^{18}O analysis of a varved lake sediment sequence	Annual	Summer evaporation (or drought)	Jones (2004), Jones *et al.* (2004, 2005)
Catalonia (Spain) 40N-43N, 0E-4E	3000 BP-present	River sediments	Instantaneous maximum discharge	Flood magnitude / frequency / extremes	Benito *et al.* (2003)
Italian Alps	1650-1713 & 1798-1840	Speleothems (growth rate)	Annual	Temperature	Frisia *et al.* (2003)
Central Alps	2000 BP-present	Speleothems/d^{18}O	Annual	Temperature	Mangini *et al.* (2005)
Sardinia (Italy)	950-present	Speleothems/d^{18}O	Seasonal	Precipitation	Antonioli *et al.* (2003); Montagna (2004)
Northernmost Red Sea	1750-1995 98 yr at 2.9 kyr ago 44 yr at 122 kyr ago	Annually banded reef corals, (oxygen isotopes, Sr/Ca)	Bimonthly	SST, hydrologic balance	Felis *et al.* (2000, 2004); Rimbu *et al.* (2001, 2003a)
Intertidal area in warmer Mediterranean waters	1400-present	Vermetids**,** (Dendropoma petraeum)	30-50 yrs	SST Sea-level	Silenzi et al. (2004)
From ~200 m to ~1200 water depth in the Mediterranean Sea	1950-present	Deep-Sea corals, (Lophelia pertusa, Madrepora oculata & Desmophyllum dianthus)	Seasonal to Annual	Sea-water chemistry Biological productivity	Montagna (2004) Montagna *et al.* (2005a,b)
From 0 to~40 m water depth in the Mediterranean	1850-present	Non-tropical corals, (Cladocora caespitosa)	Monthly to weekly	SSS Sea-water chemistry	Silenzi *et al.* (2005)
Slovenia	1500-1980s/1990s	9 Boreholes-subsurface temperature profiles	Secular temperature trends	Ground surface temperature variations (after inversion)	Rajver *et al.* (1998)
Slovenia-Ljutomer	30000 BP-1992	Boreholes-subsurface temperature profiles	Glacial & Holocene to secular temperature trends	Ground surface temperature variations (after inversion)	Rajver *et al.* (1998)

Central-Northern Italy	1750-1980s/1990s	8 Boreholes-subsurface temperature profiles	Secular temperature trends	Ground surface temperature variations (after inversion)	Pasquale *et al.* (2004)
Evora (Portugal)	1700-1997	1 Borehole-subsurface temperature profile	Secular temperature trends	Ground surface temperature variations (after inversion)	Correia & Safanda (2001)
Morocco	Last 100 to 300 yrs	1 Borehole-subsurface temperature profile	Temperature change in the last 100 to 300 years.	Ground surface temperature variations (after inversion)	Correia & Safanda (2001)

Table 1.3: Simultaneous droughts in Greece and China derived from documentary evidence

Periods of drought in Greece	Number of drought years in Henna (Northern China) within each period
AD 305-340	16 drought years out of 36 (44%)
AD 551-559	1 drought year out of 9 (11%)
AD 741-742	0 out of 2
AD 1040-1046	0 out of 7
All other years from AD 1 to 1909, excluding the periods AD 305-340, 551-559, 741-742, 1040-1046)	251 drought years out of 1855 (13.5%)

Fig. 1
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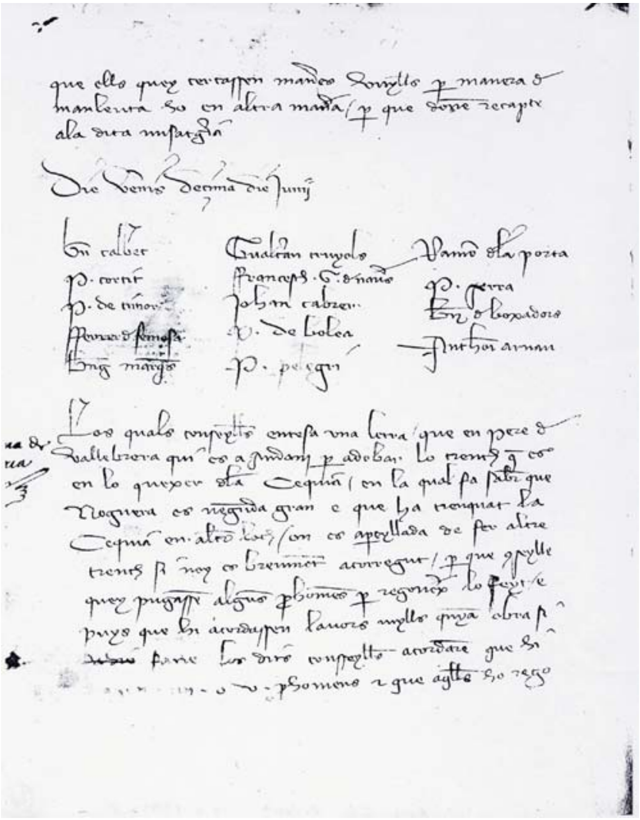

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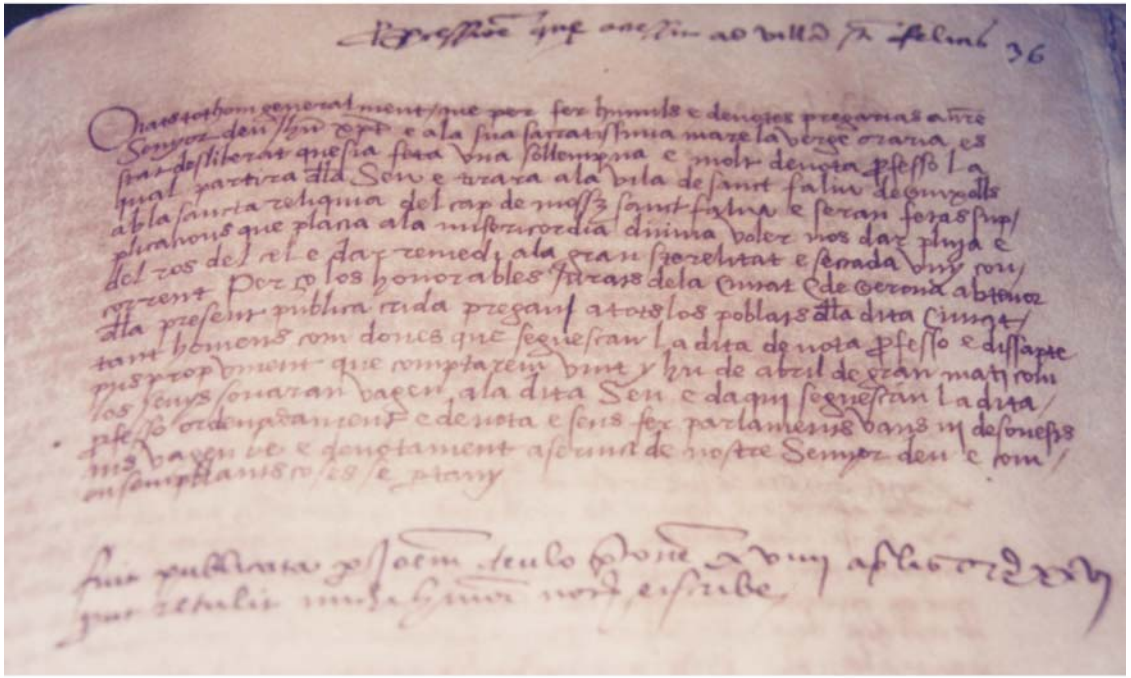

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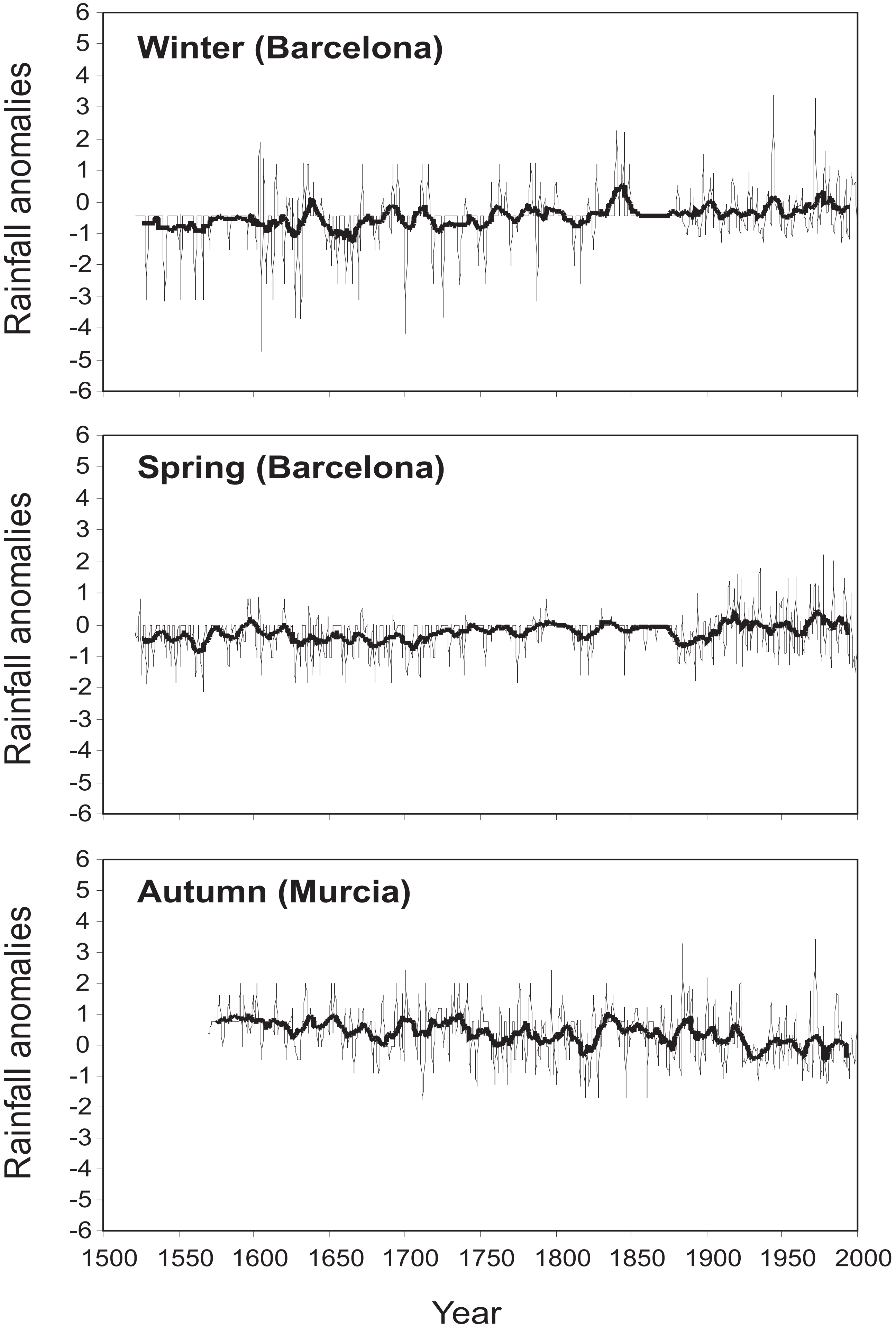

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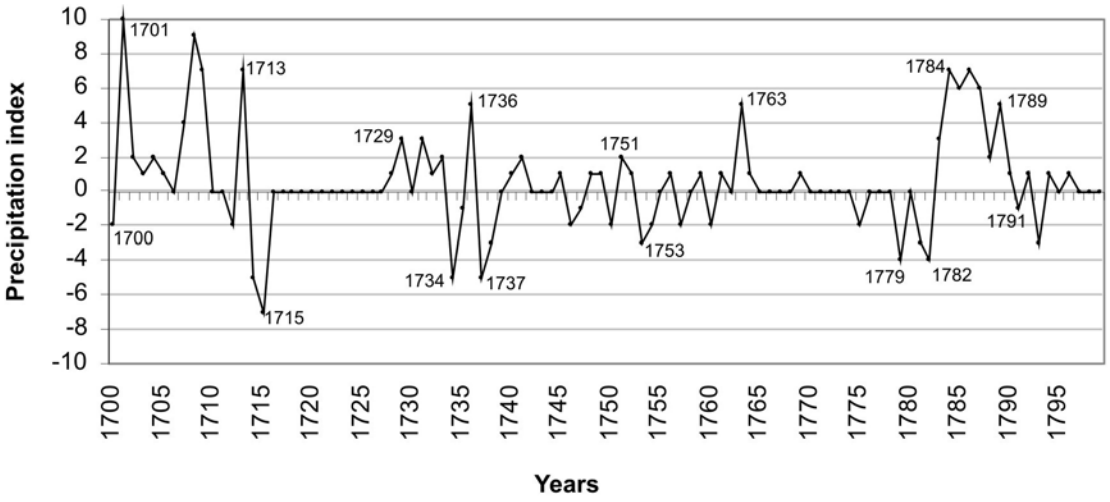

Fig. 5
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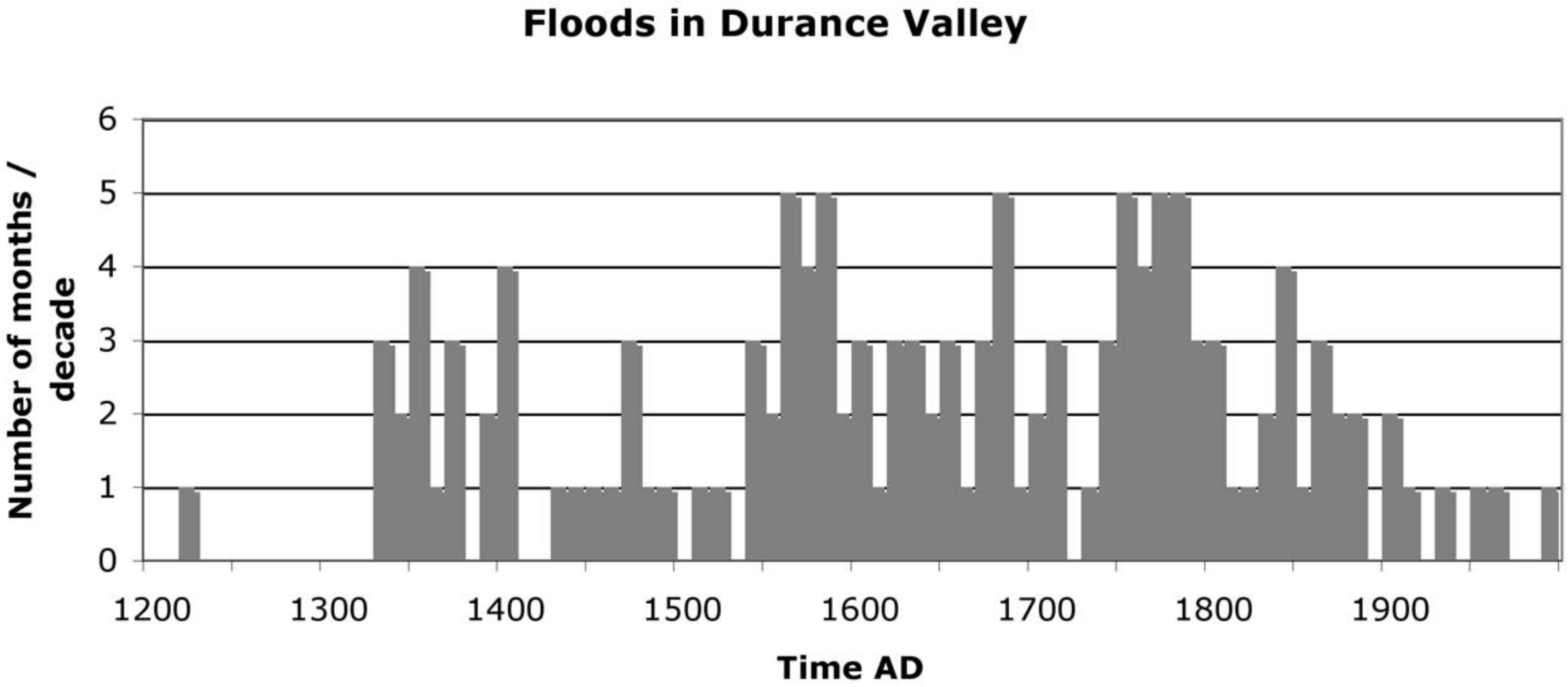

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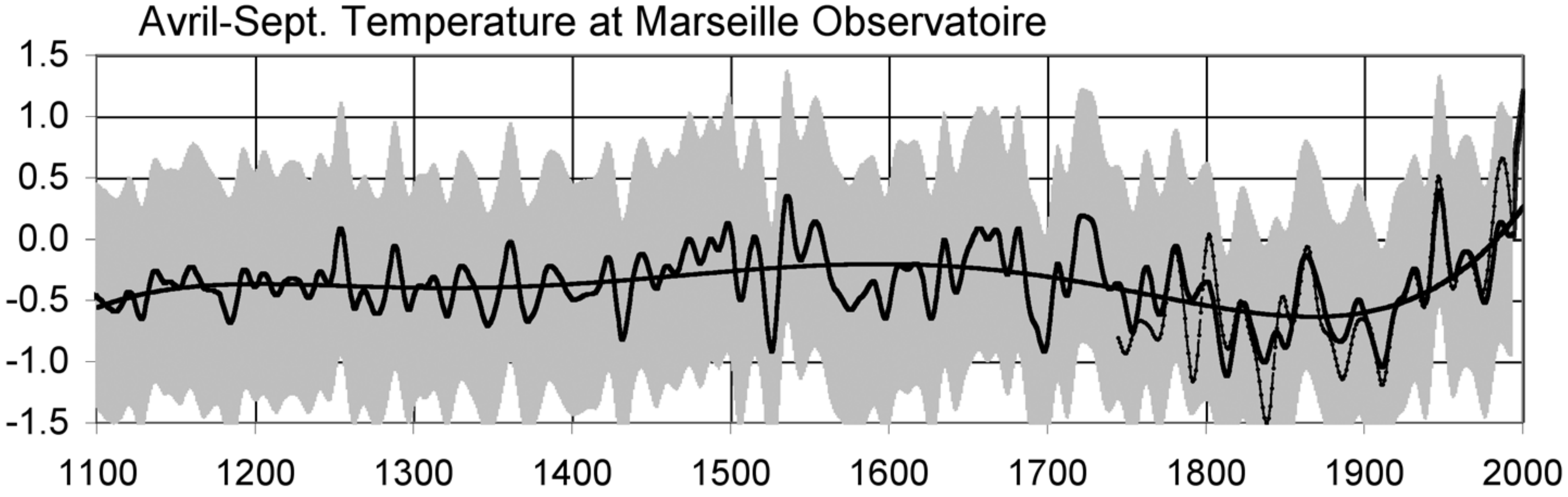

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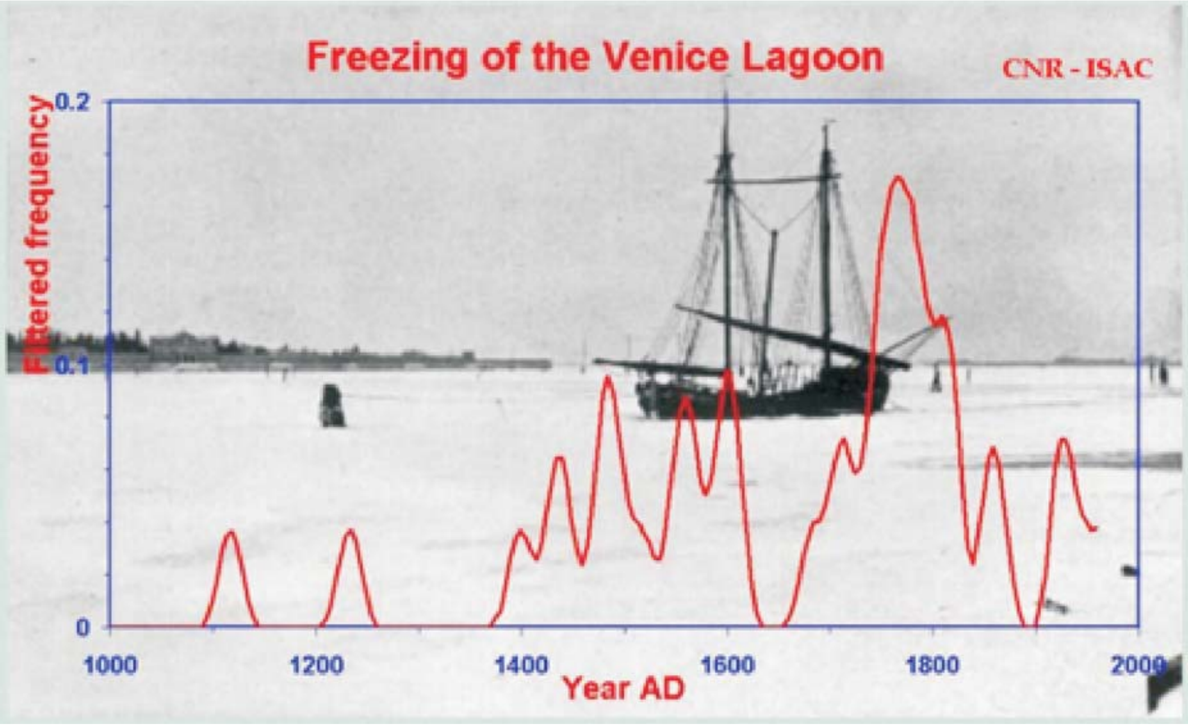

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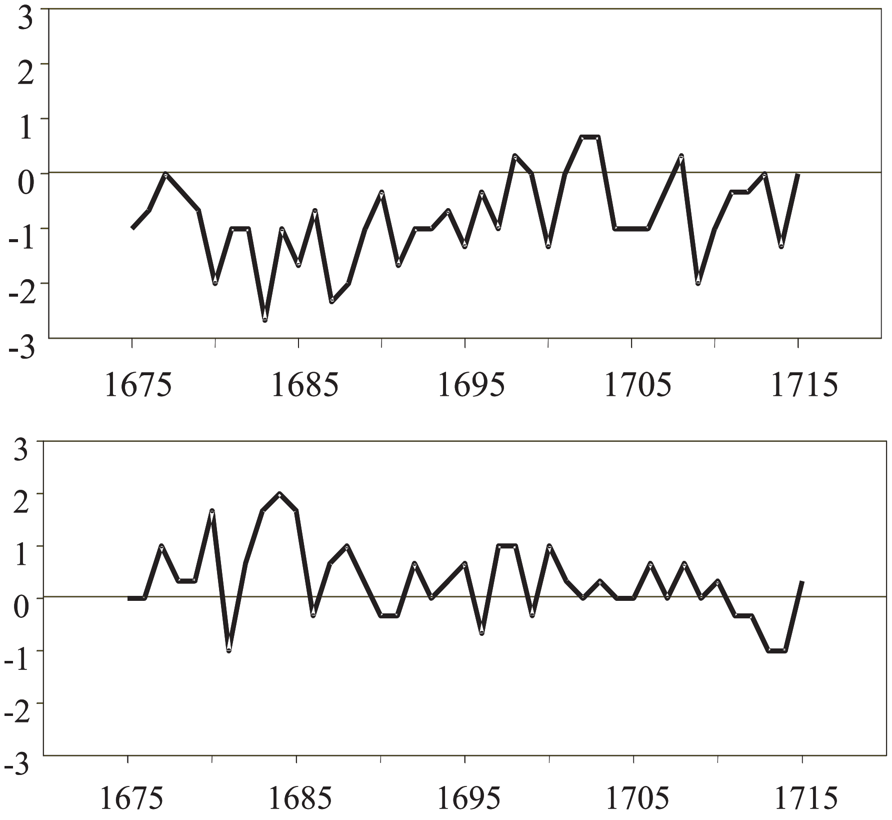

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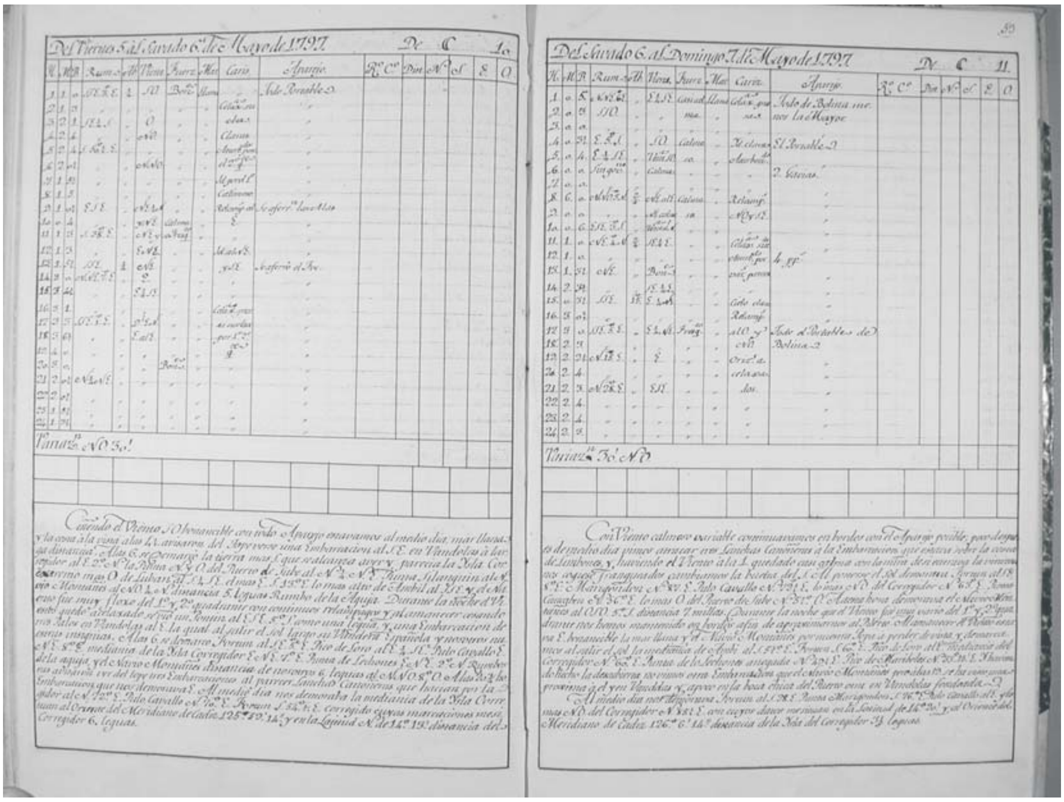

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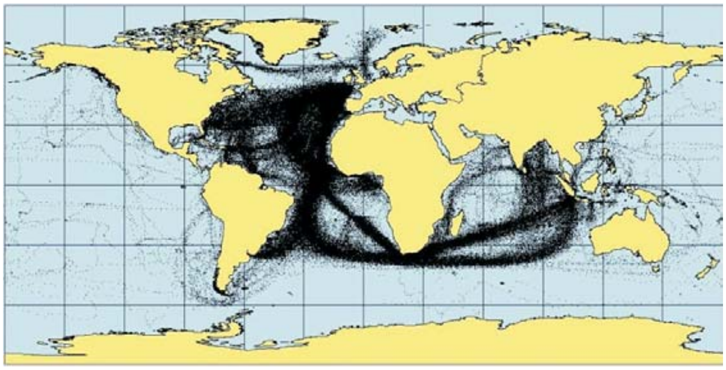

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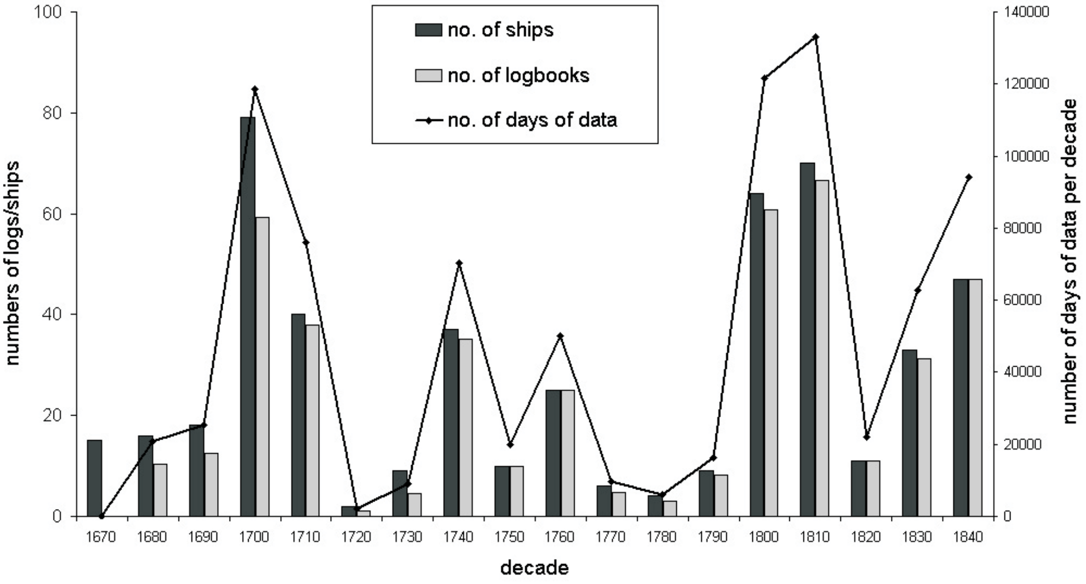

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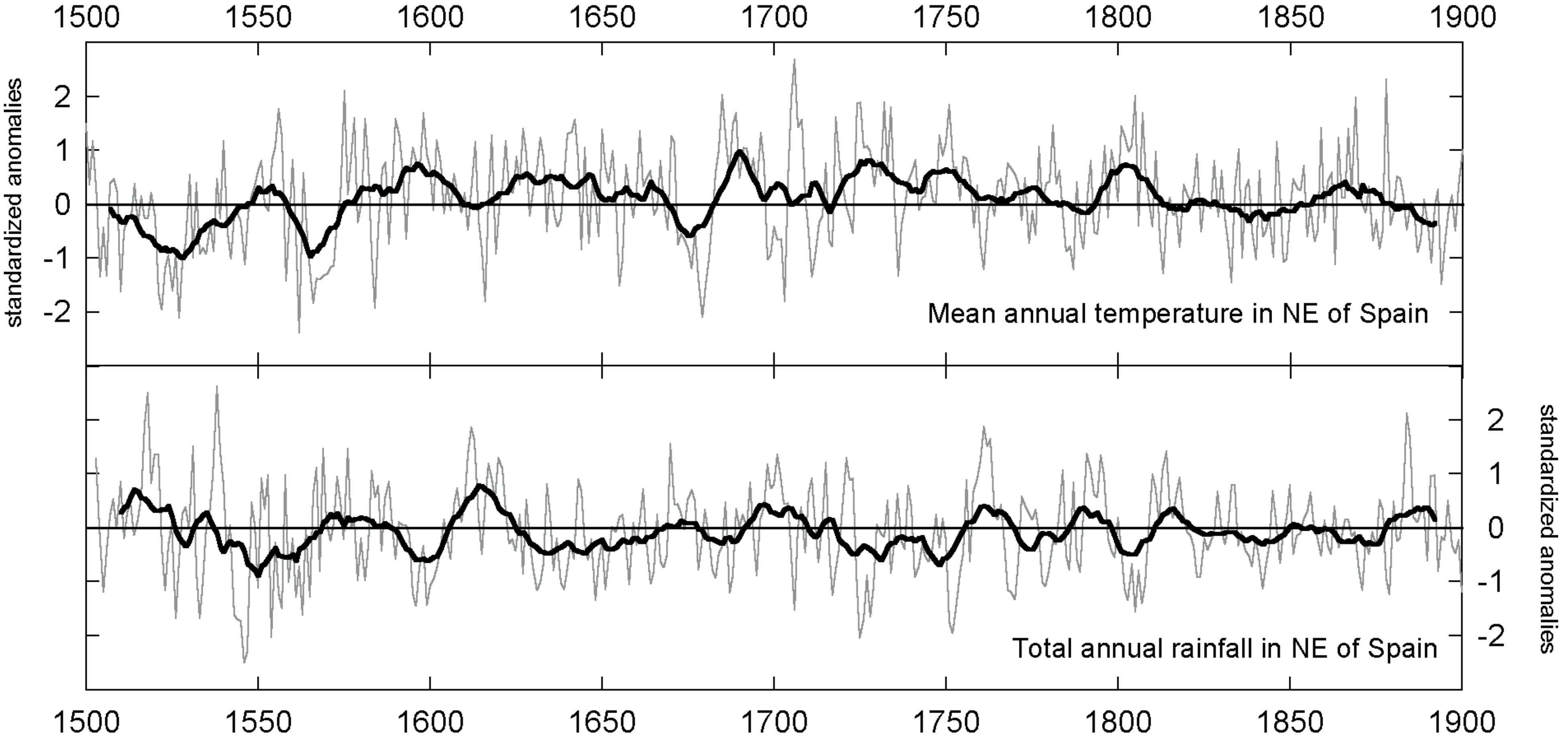

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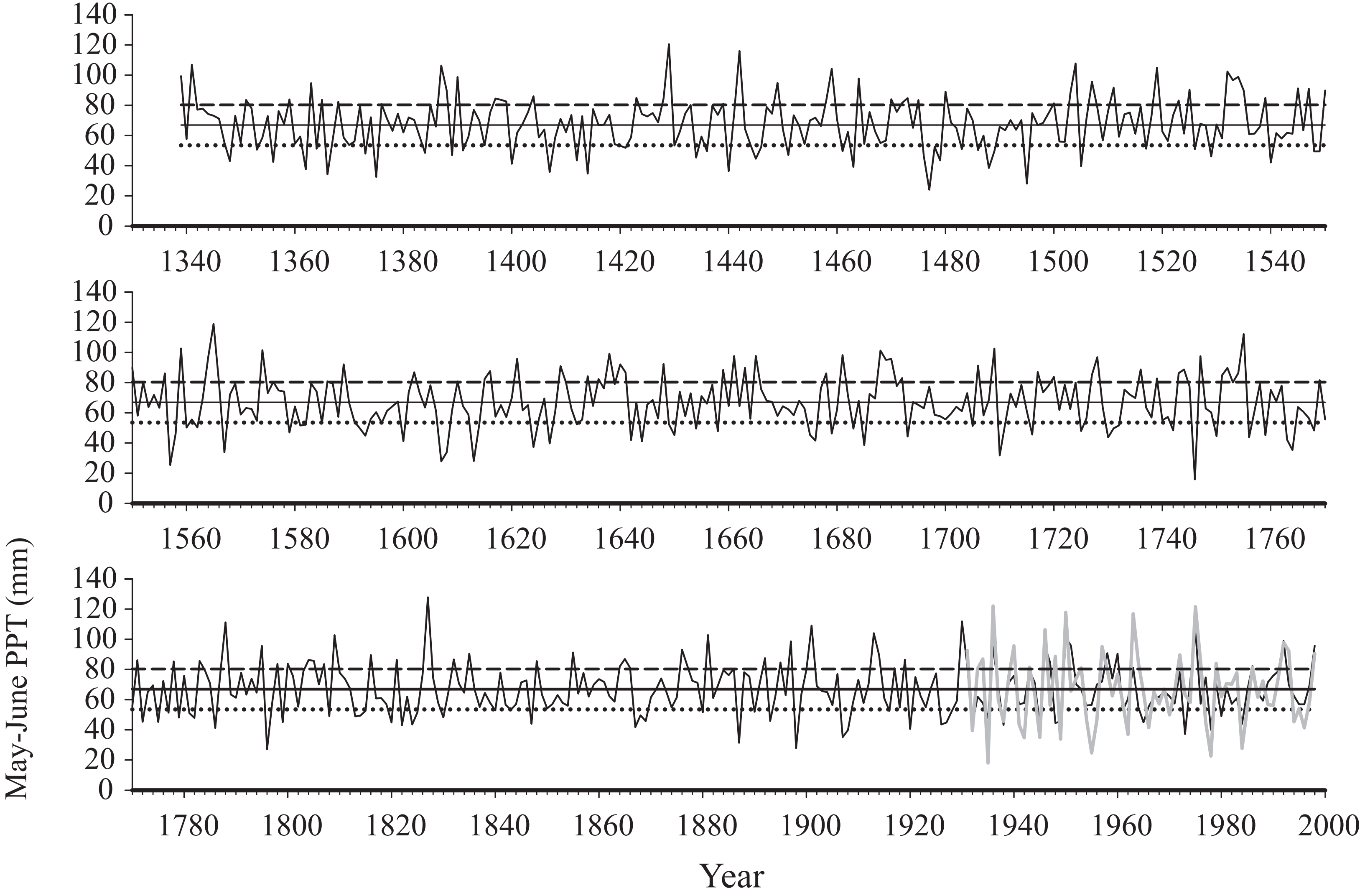

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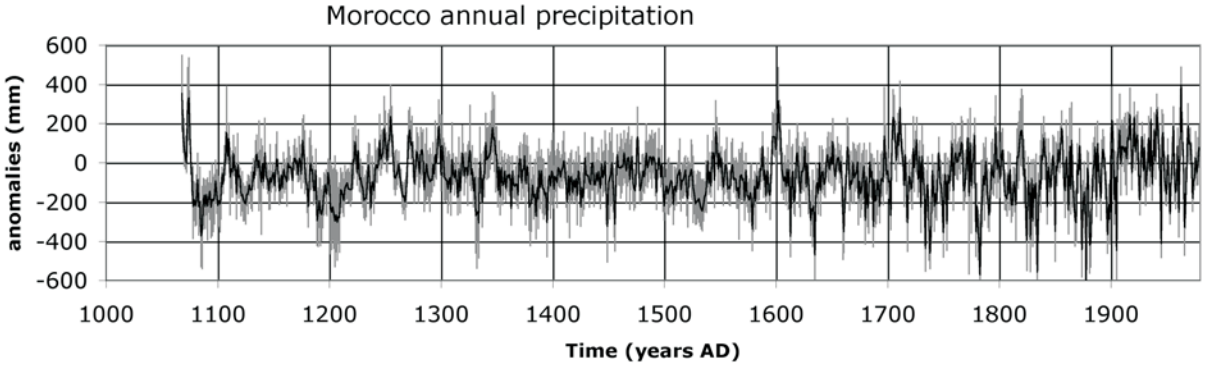

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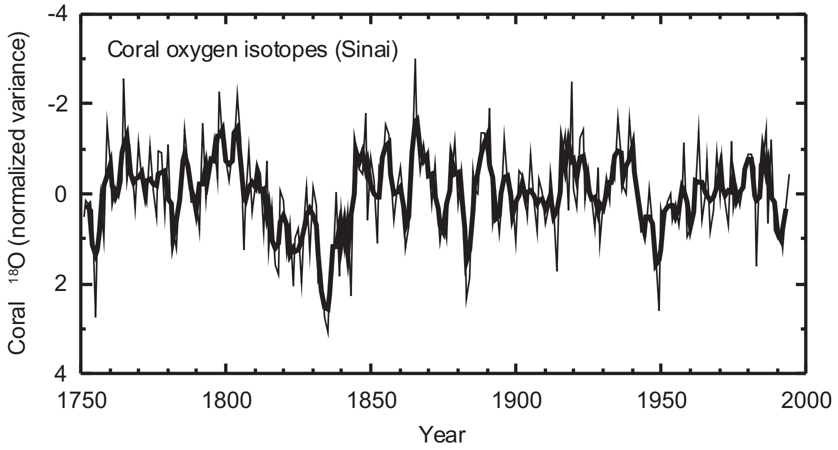

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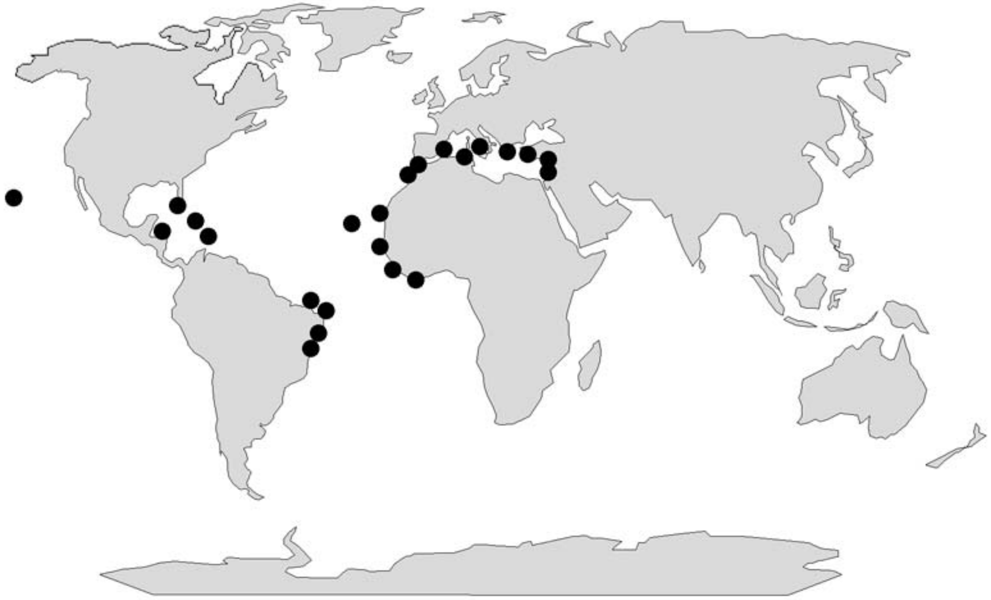

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Fig. 18
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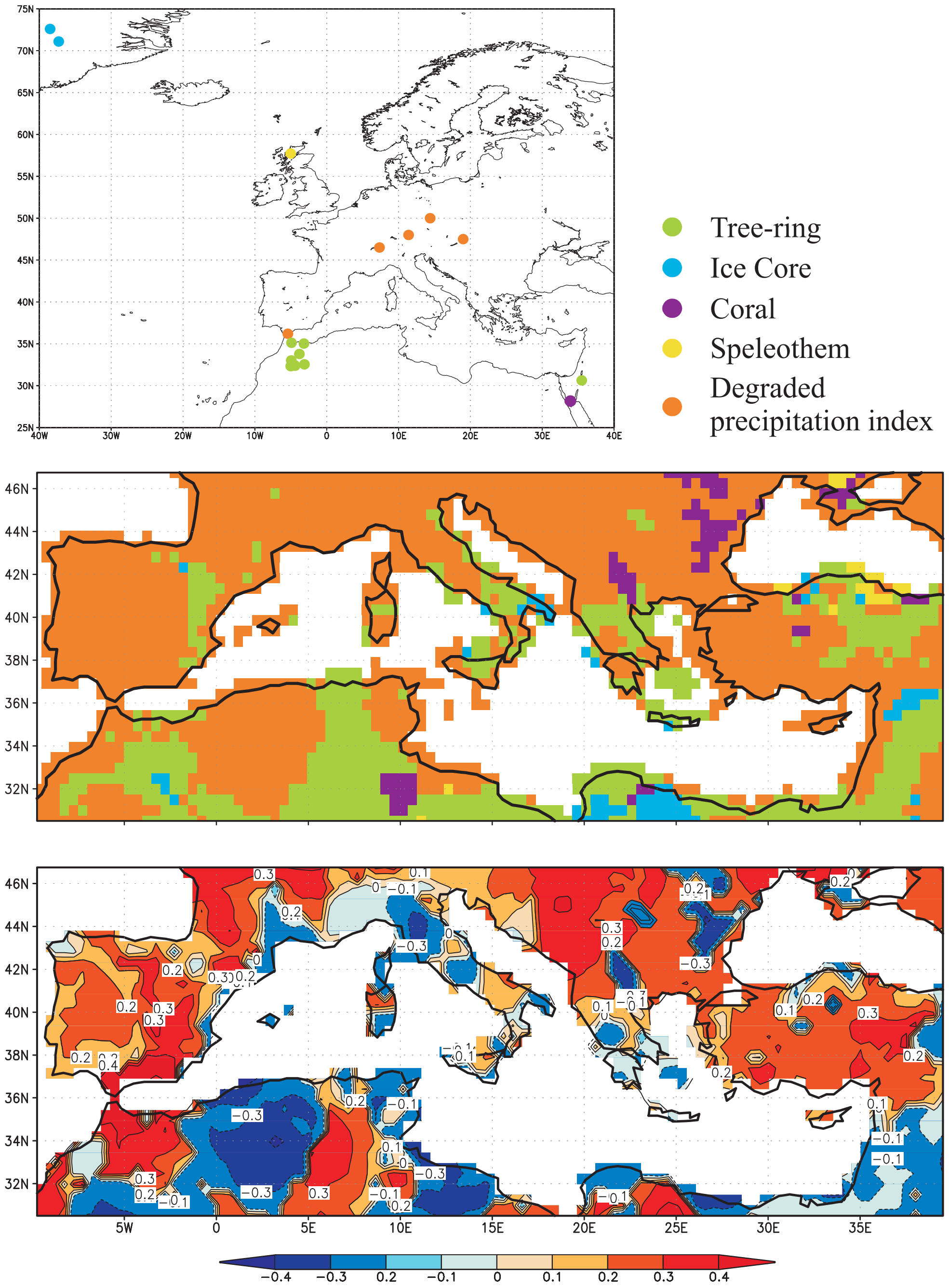

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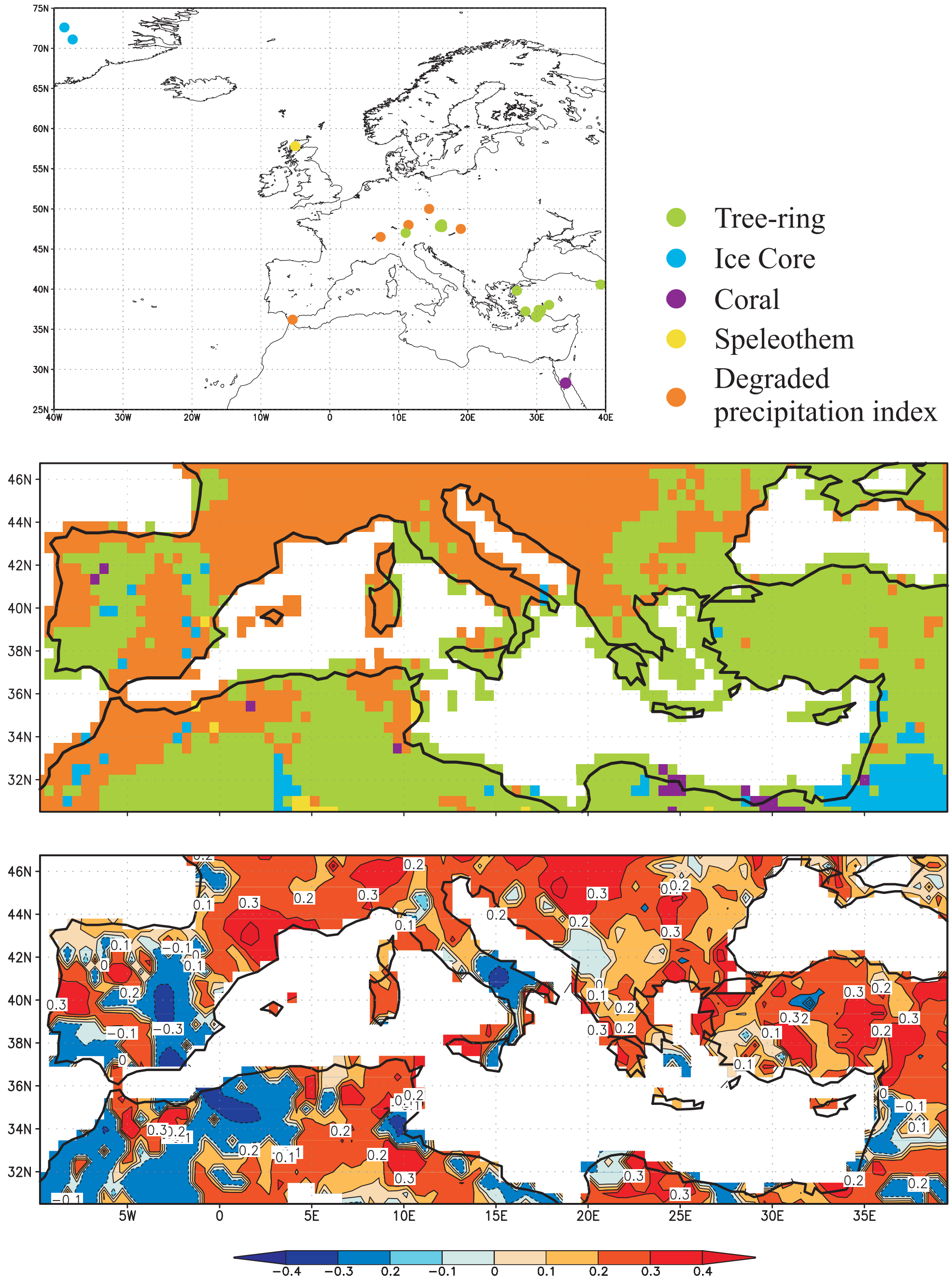

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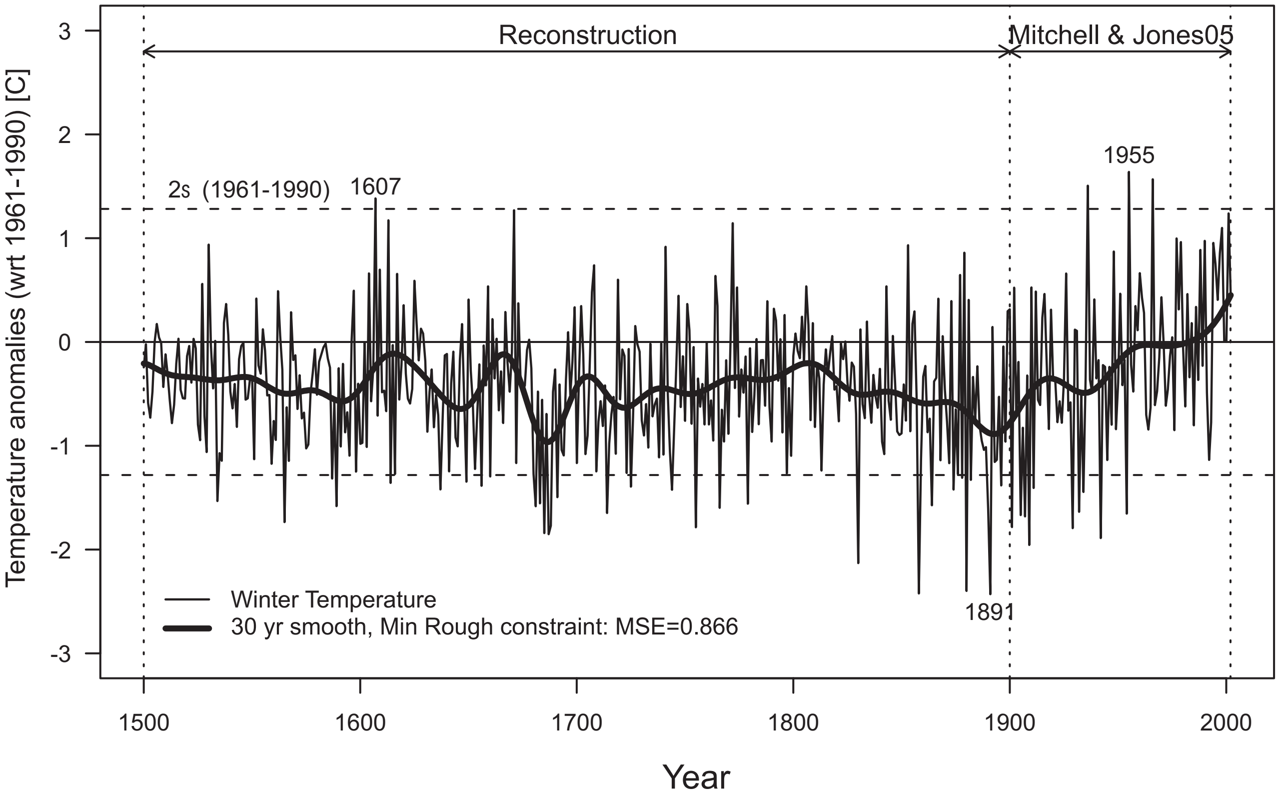

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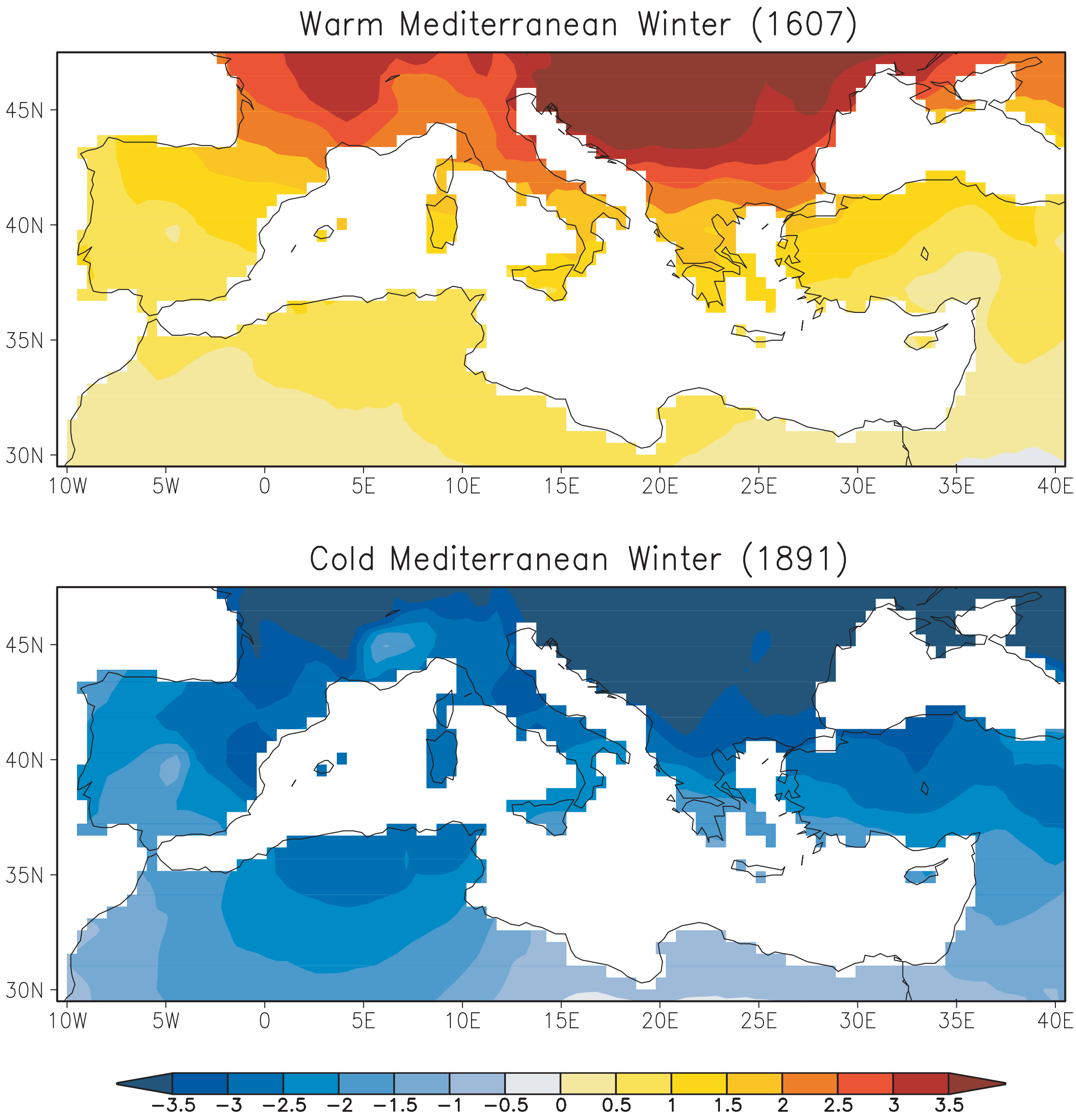

Fig. 22
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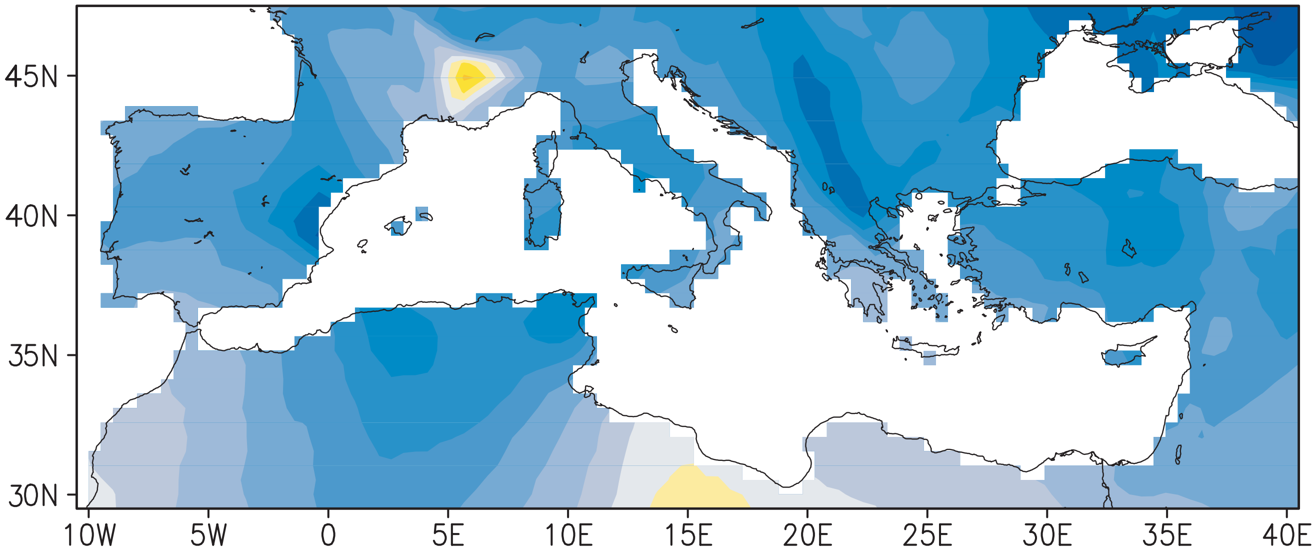
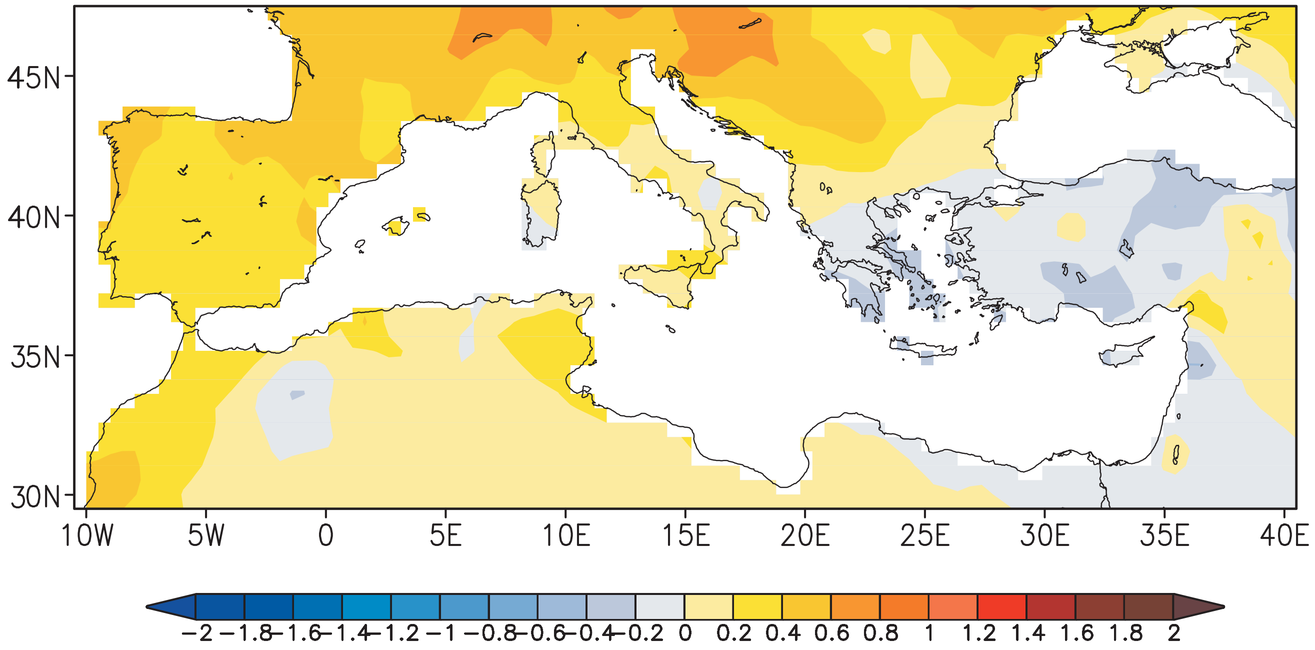
Winter TT 1880-1909 minus 1961-1990



Winter TT 1973-2002 minus 1961-1990



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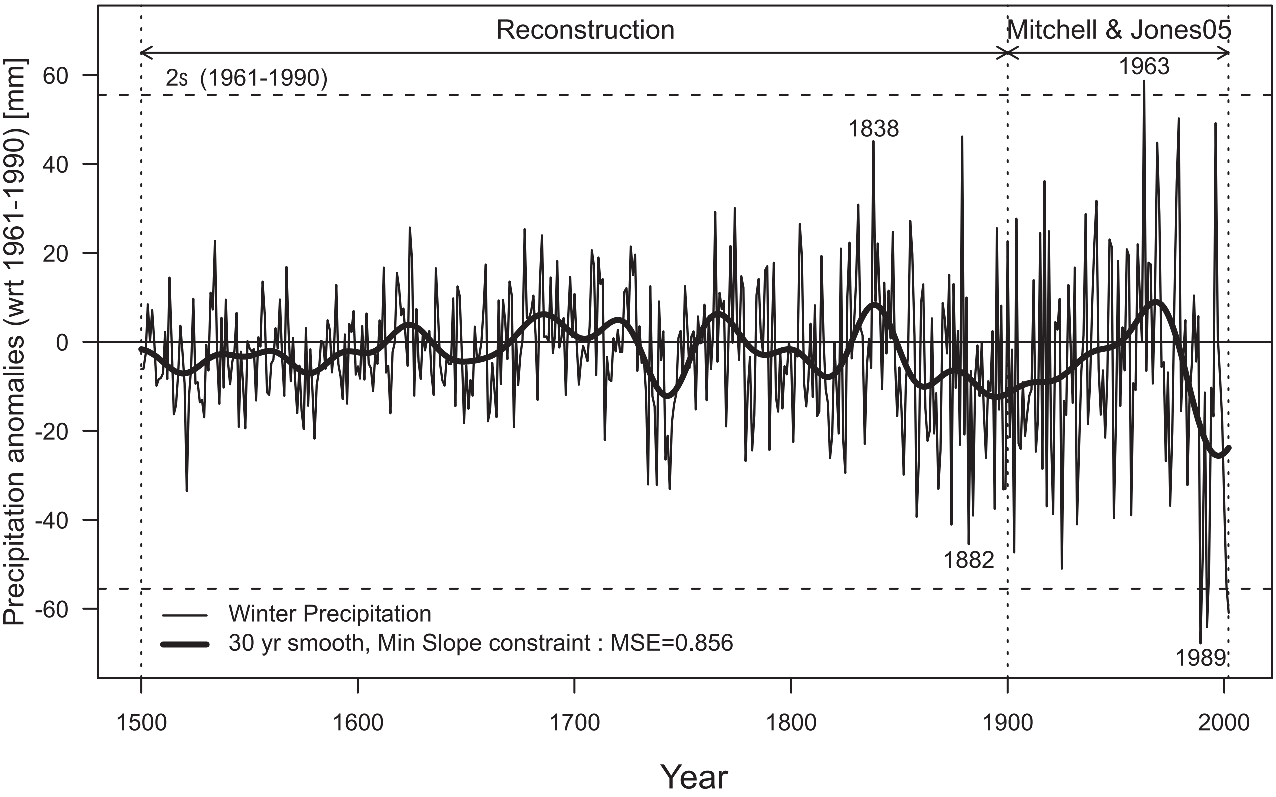

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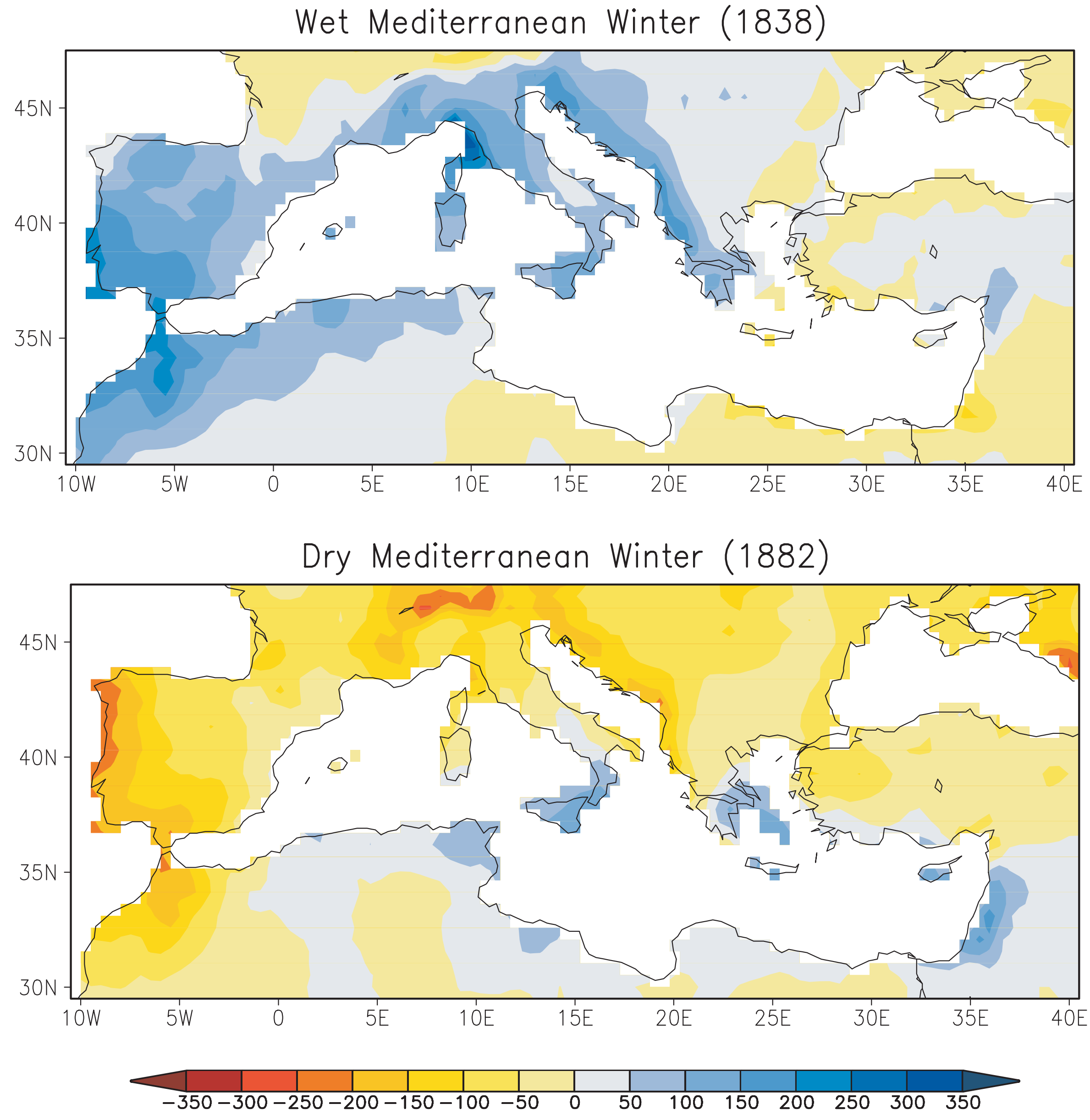

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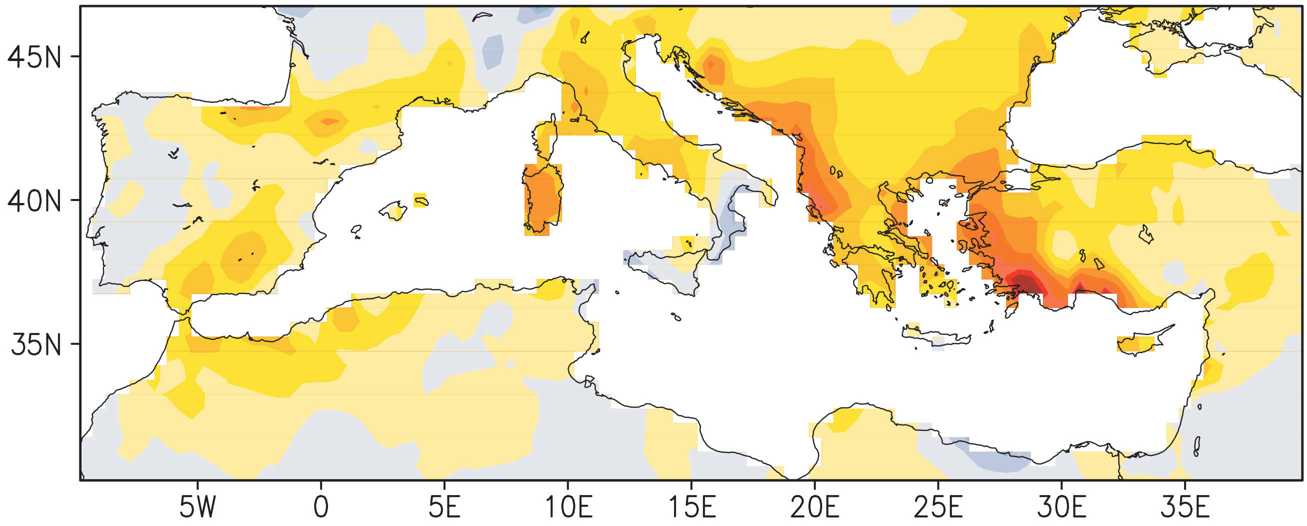
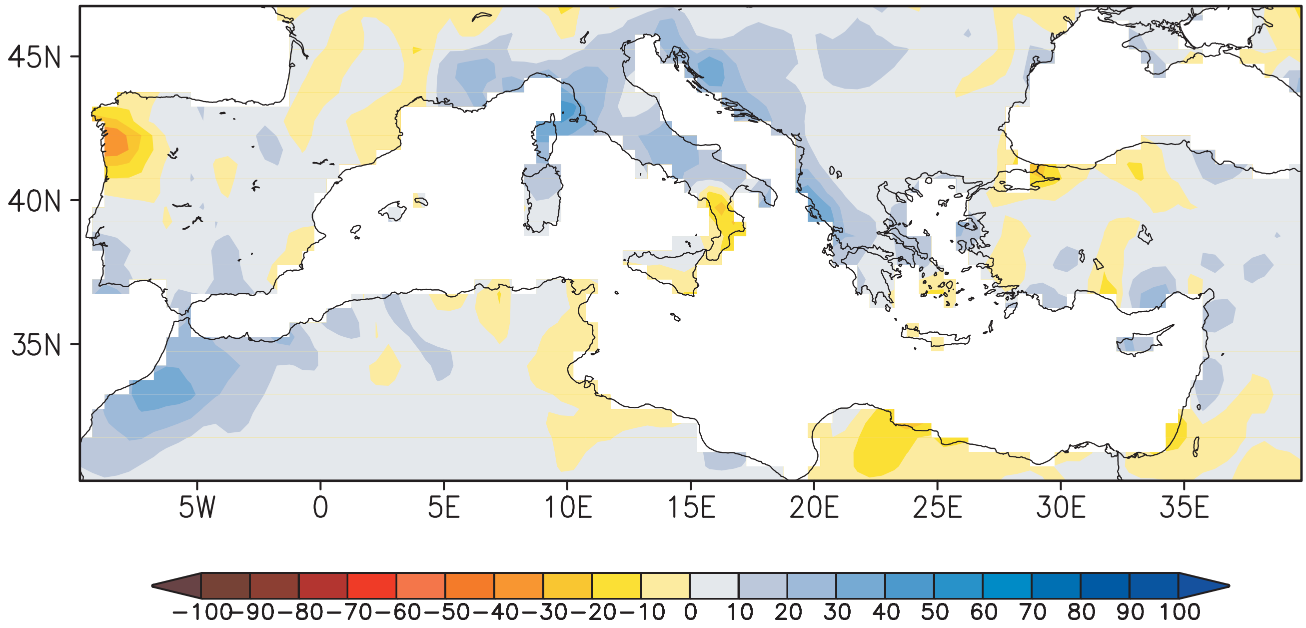
Winter Prec 1973-2002 minus 1961-1990



Winter Prec 1951-1980 minus 1961-1990



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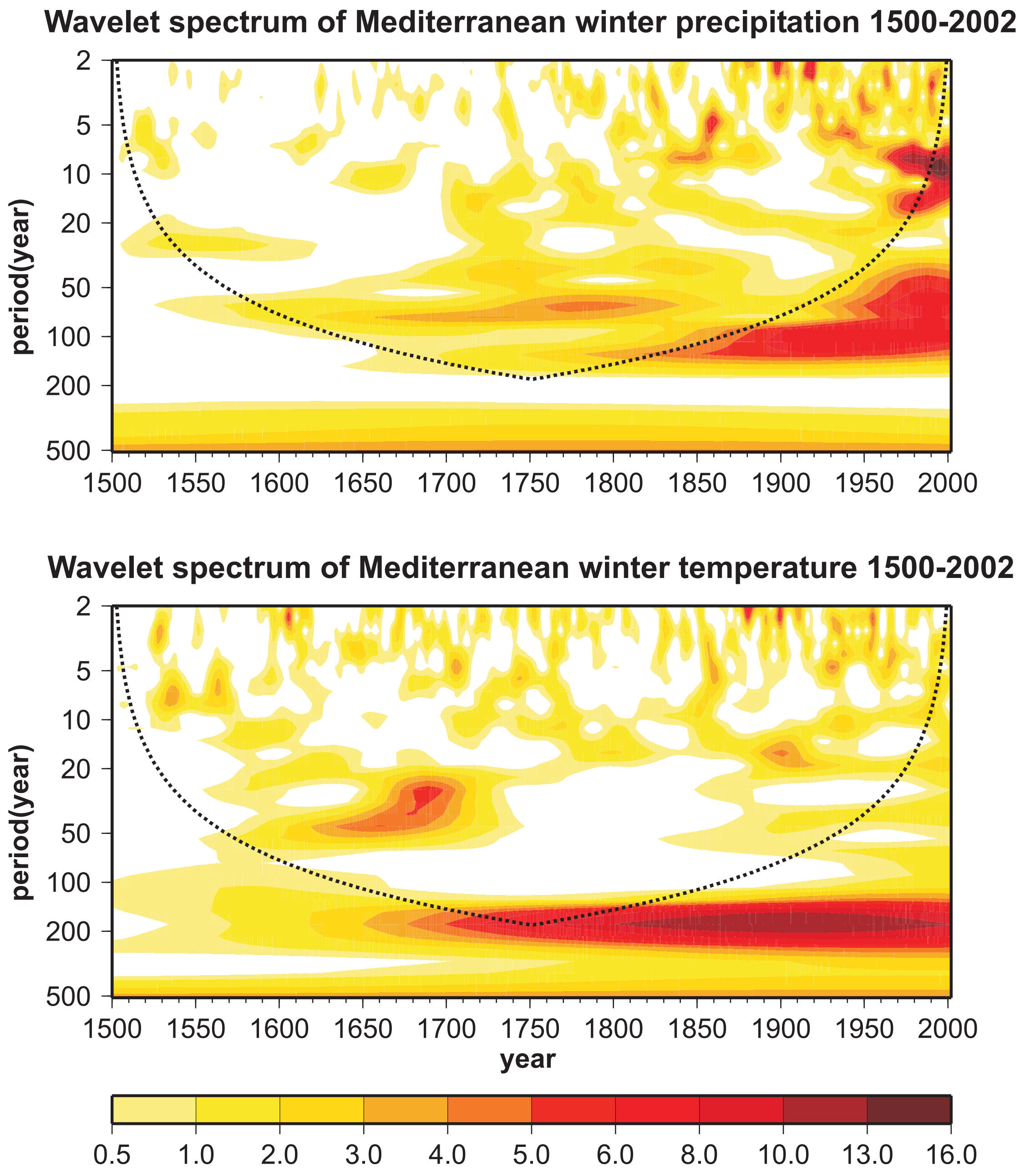
Wavelet spectrum of Mediterranean winter precipitation 1500-2002

Wavelet spectrum of Mediterranean winter temperature 1500-2002

Fig. 27
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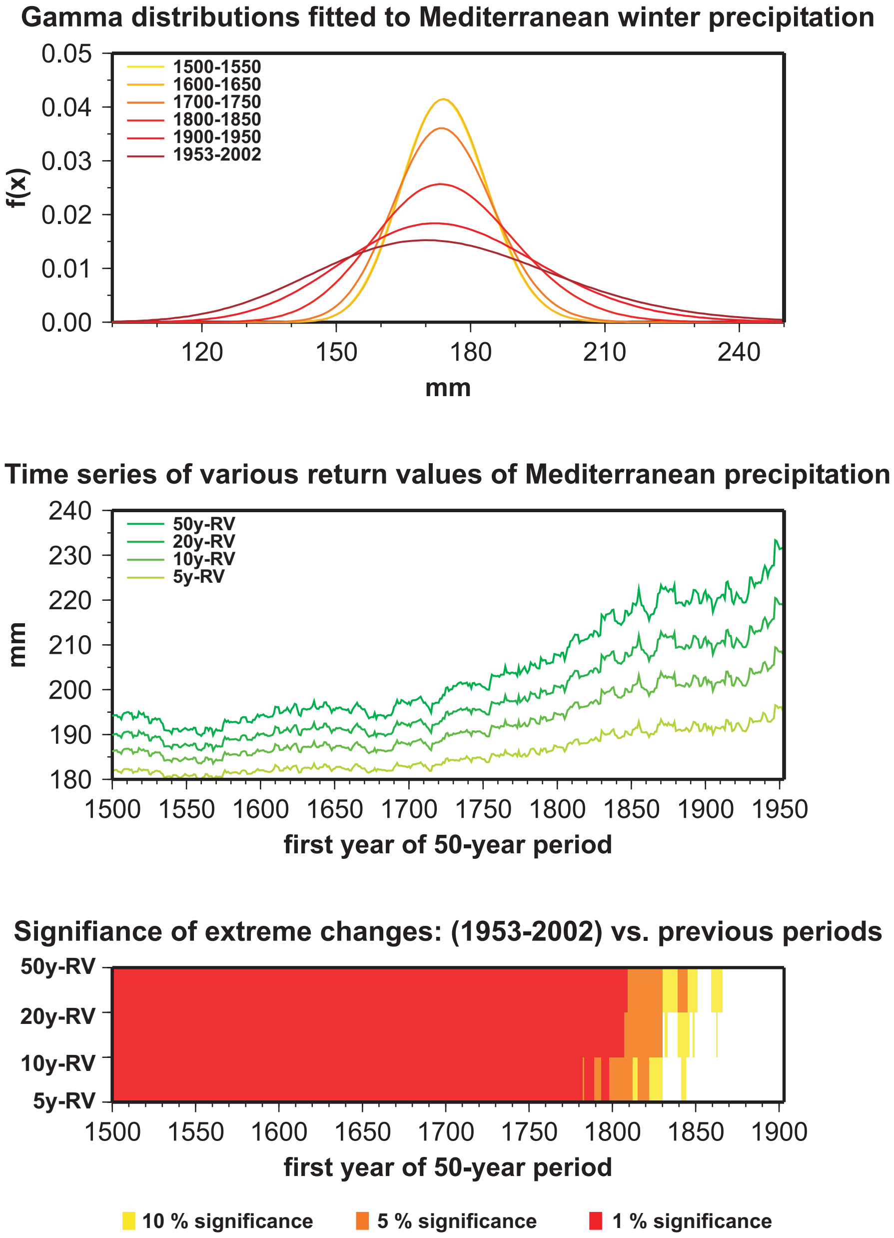

Gamma distributions fitted to Mediterranean winter precipitation

Time series of various return values of Mediterranean precipitation

Signifiance of extreme changes: (1953-2002) vs. previous periods

Fig. 28
Luterbacher et al.

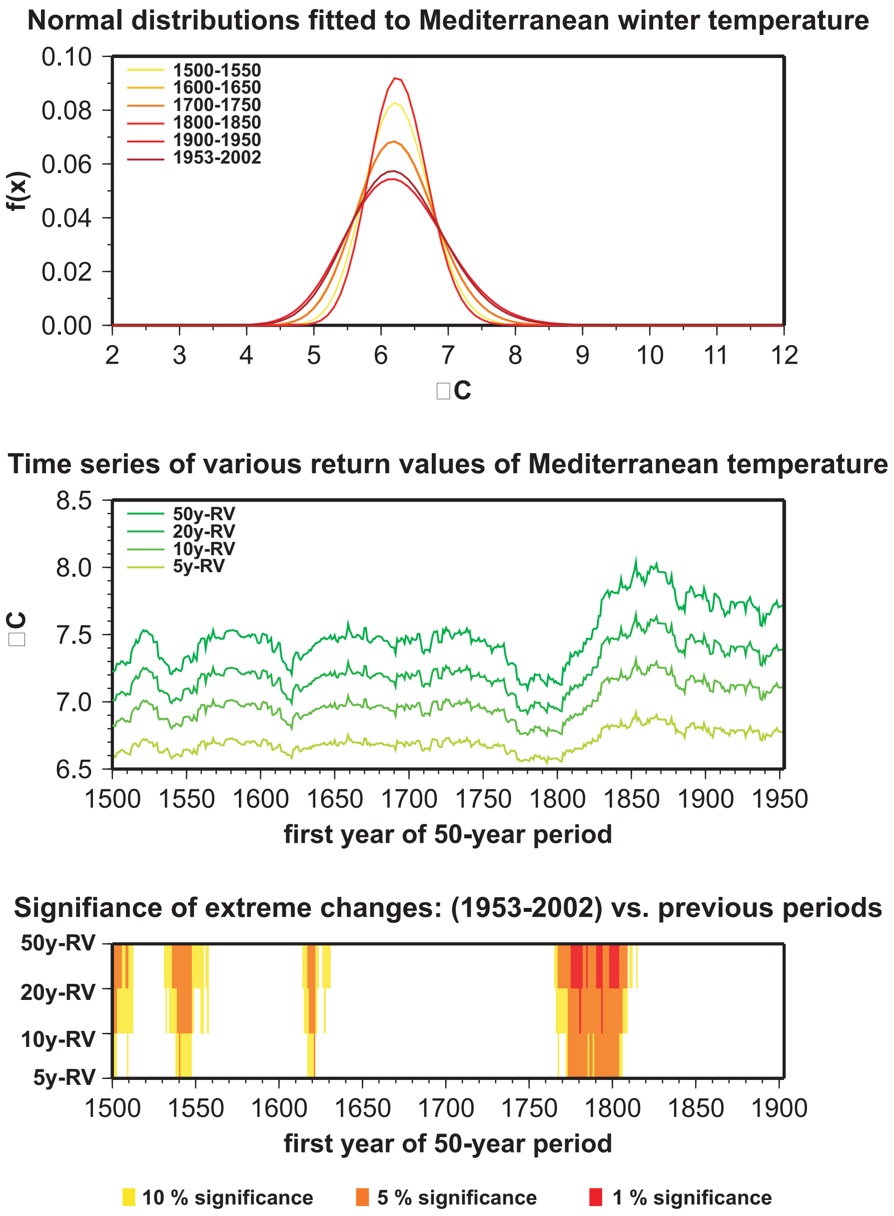

Fig. 29
Luterbacher et al.

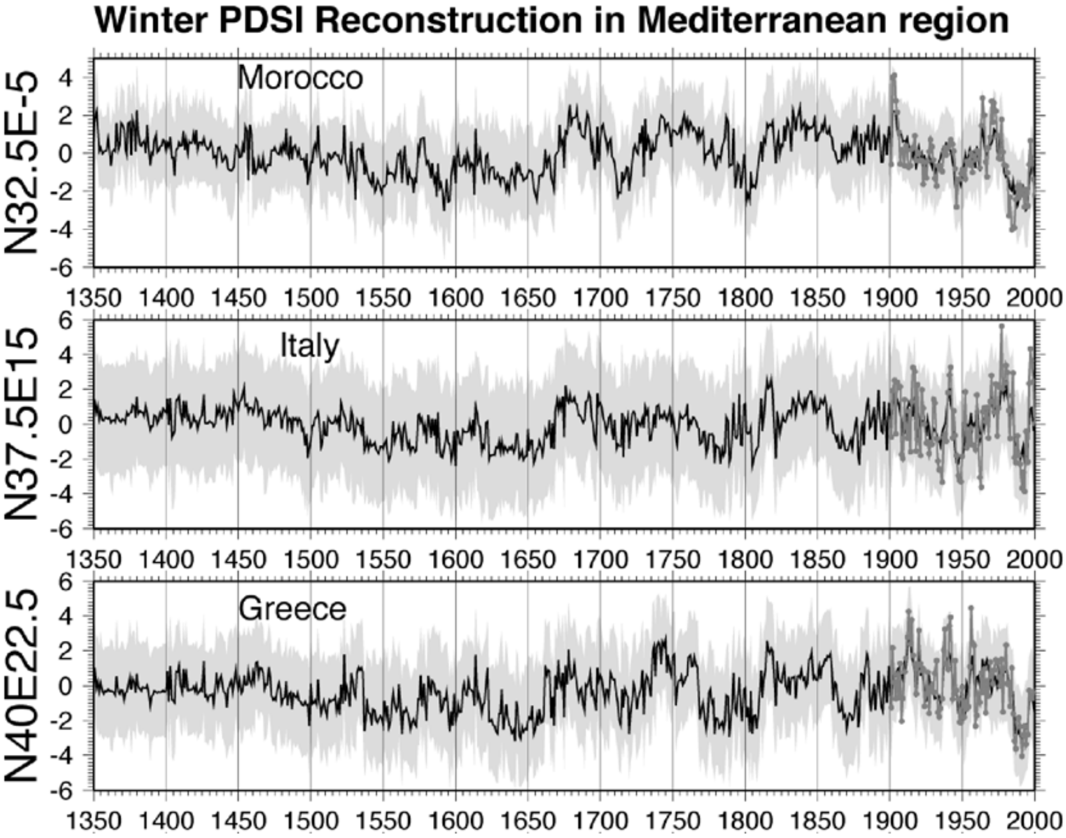

Fig. 30
Luterbacher et al.

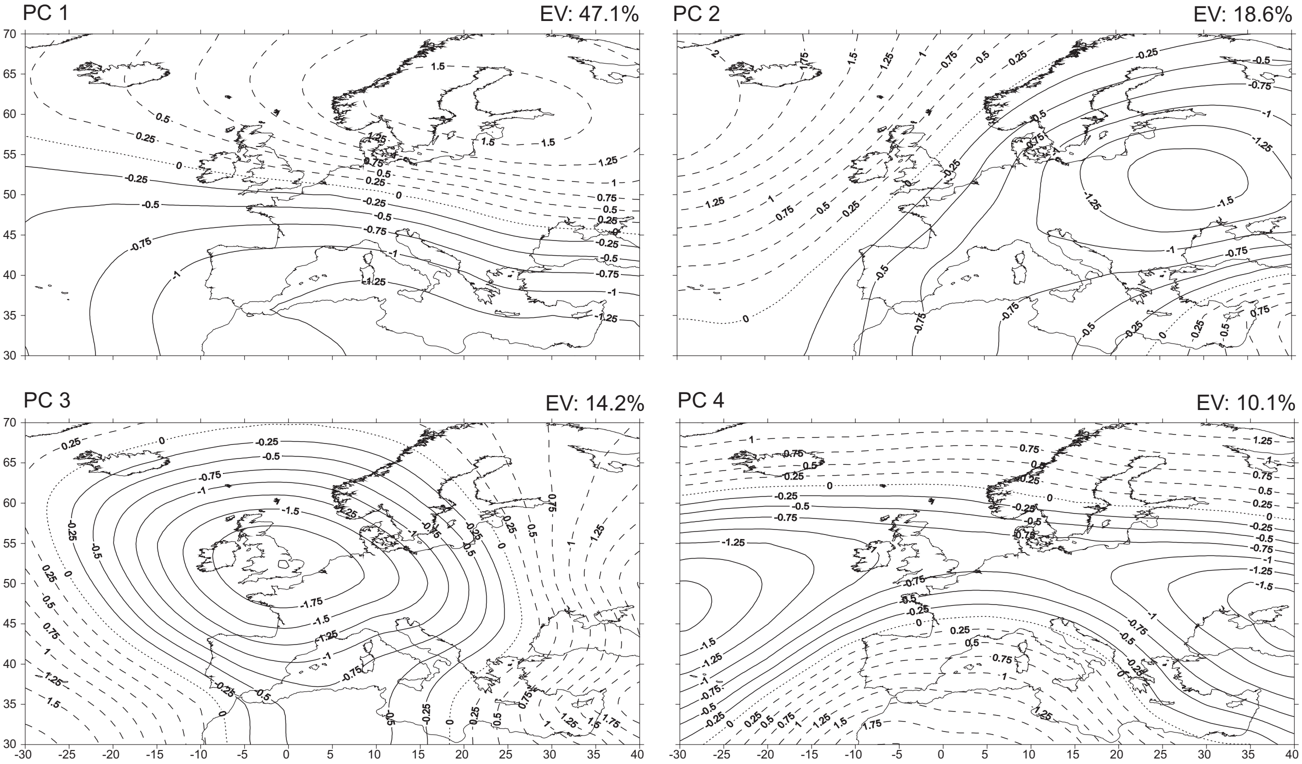

Fig. 31
Luterbacher et al.

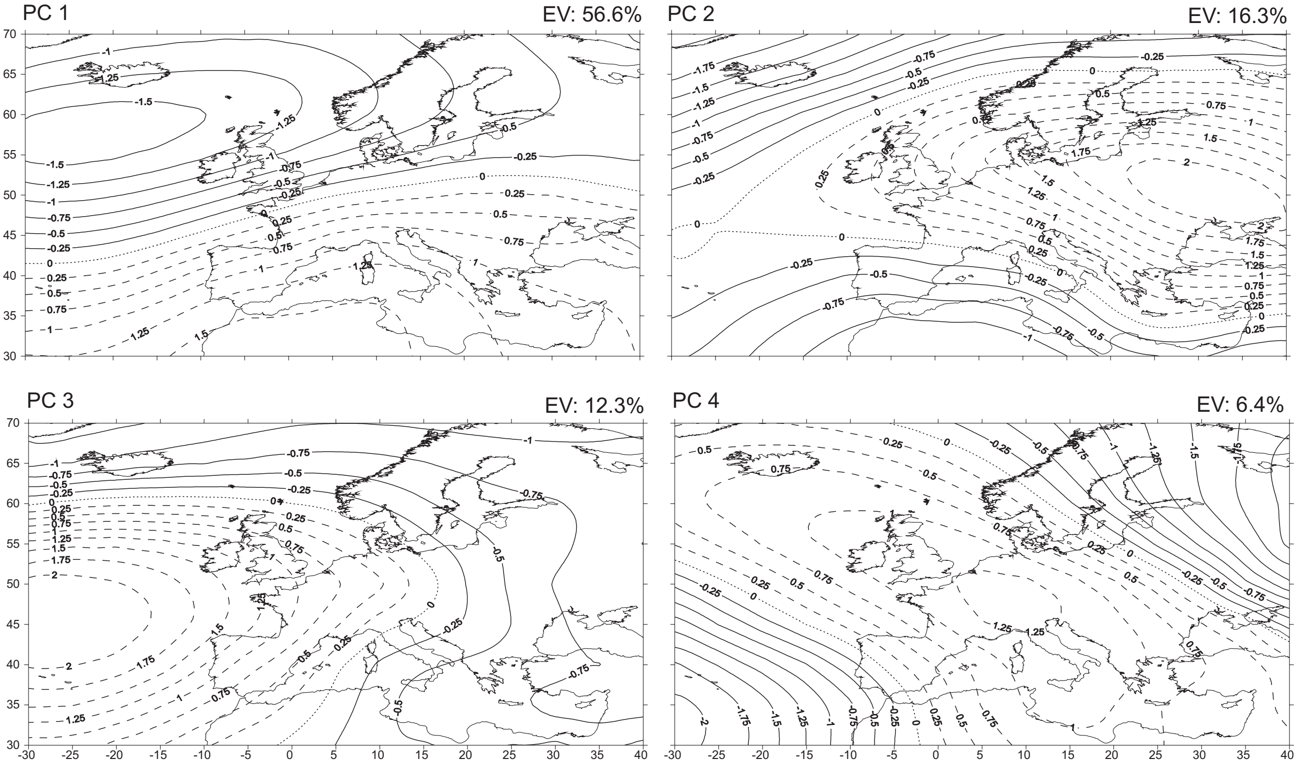

Fig. 32
Luterbacher et al.

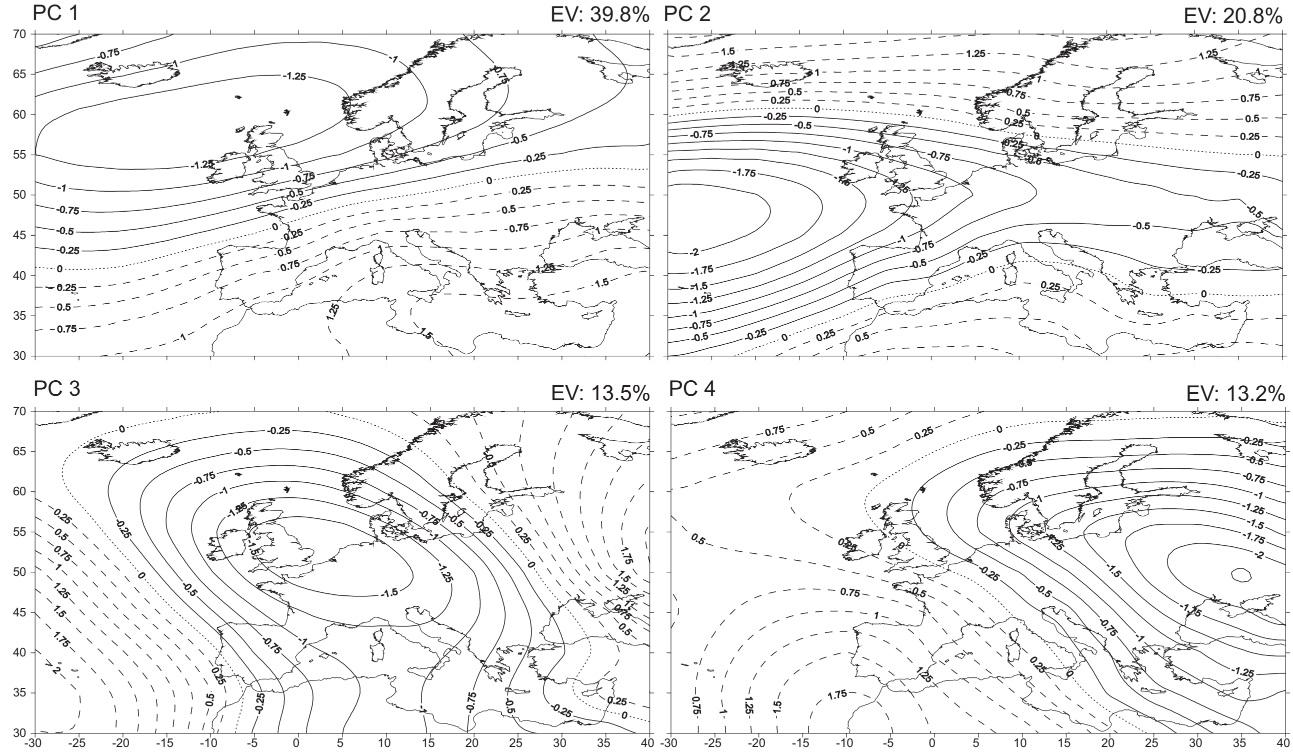

Fig. 33
Luterbacher et al.

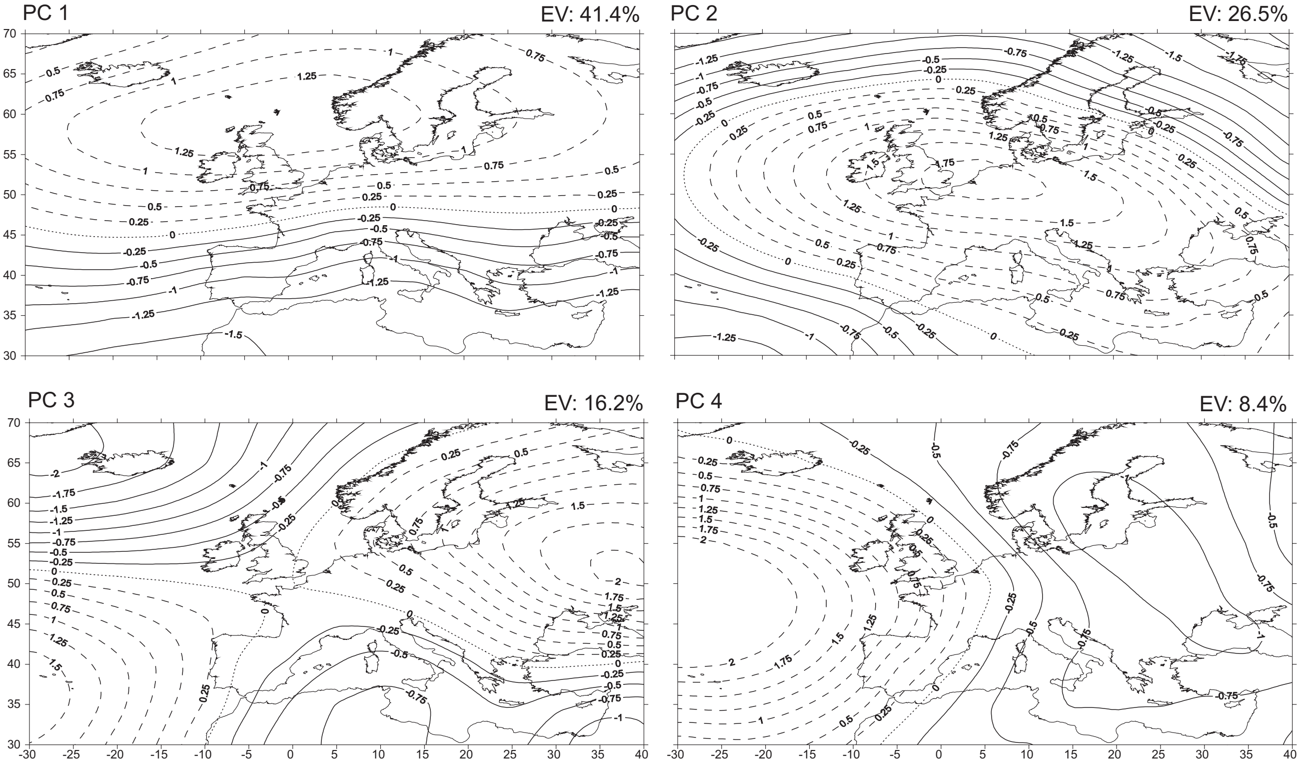

Fig. 34
Luterbacher et al.

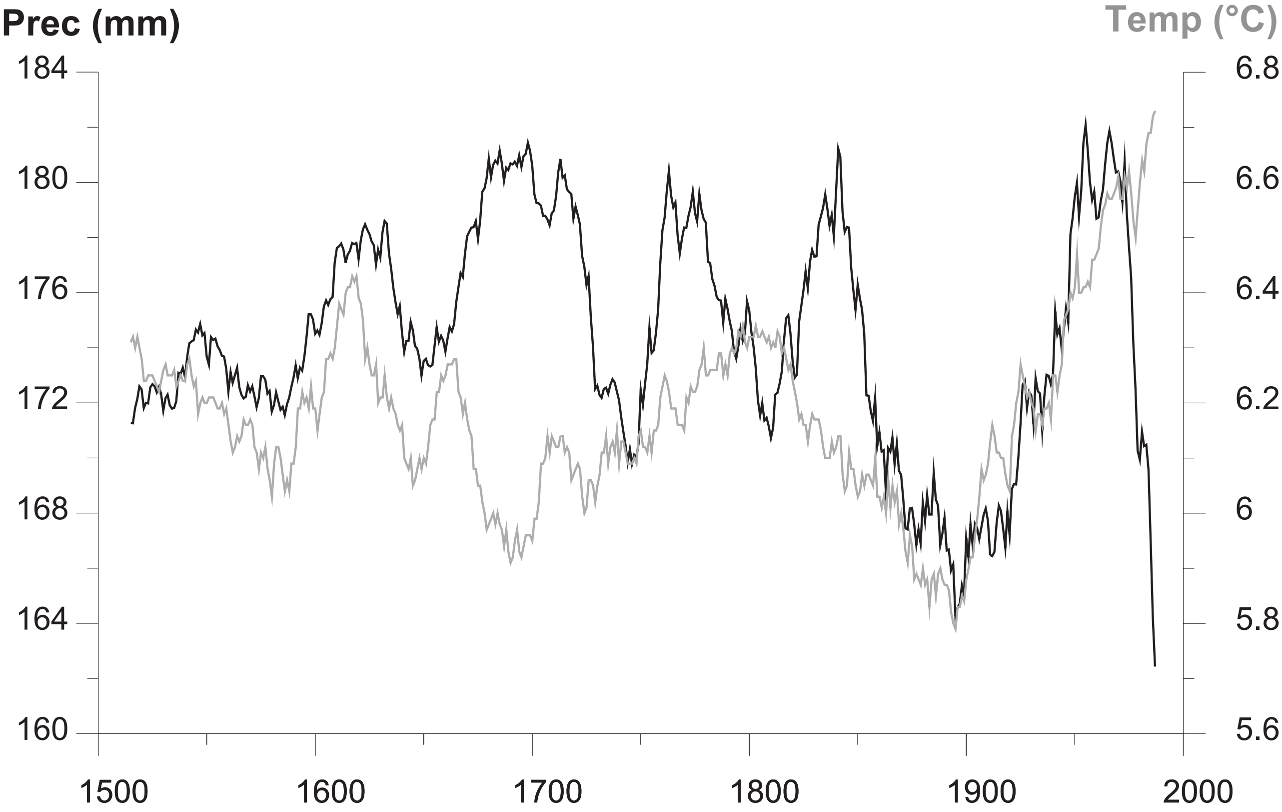

Fig. 35
Luterbacher et al.

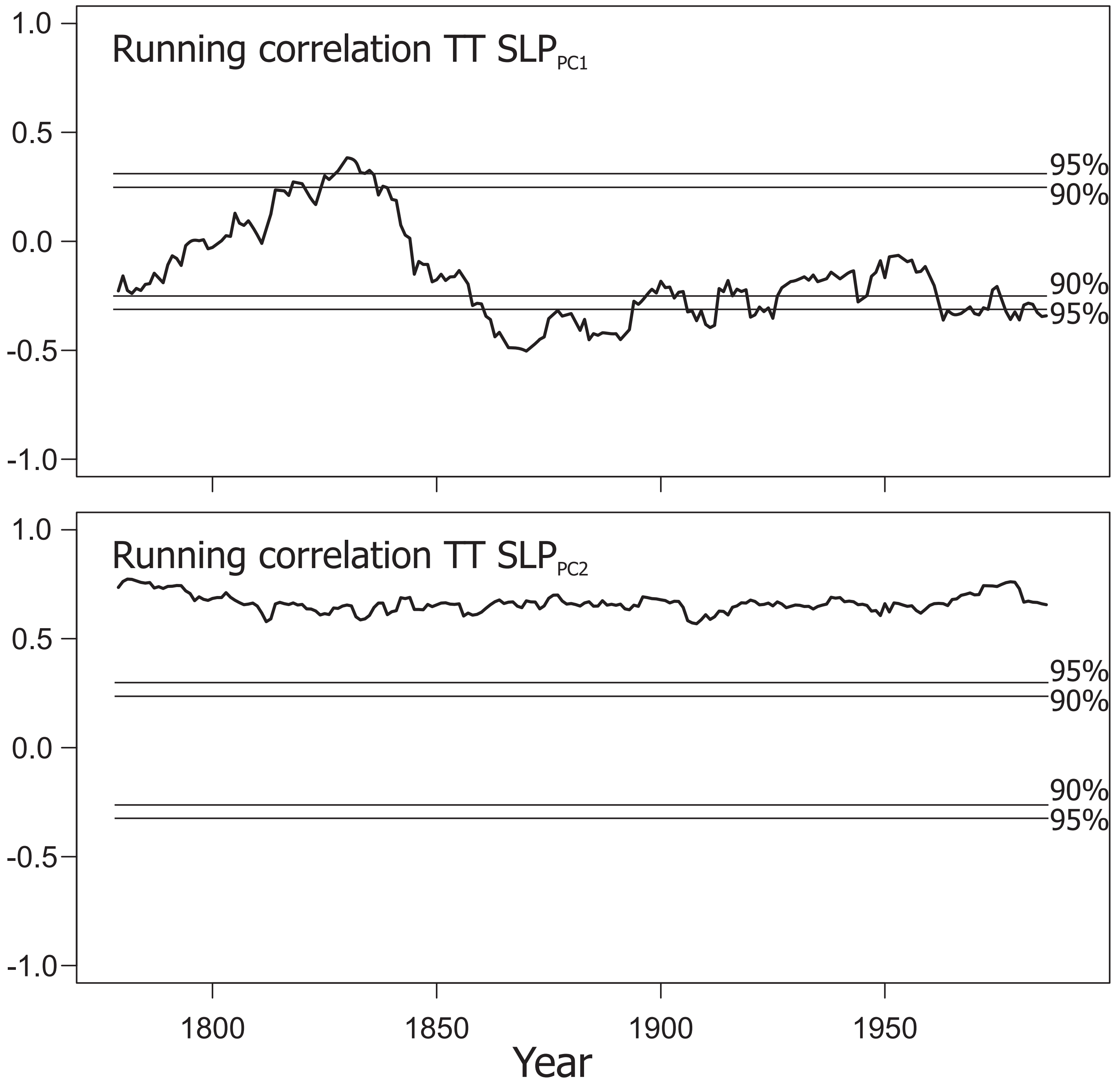

Fig. 36
Luterbacher et al.

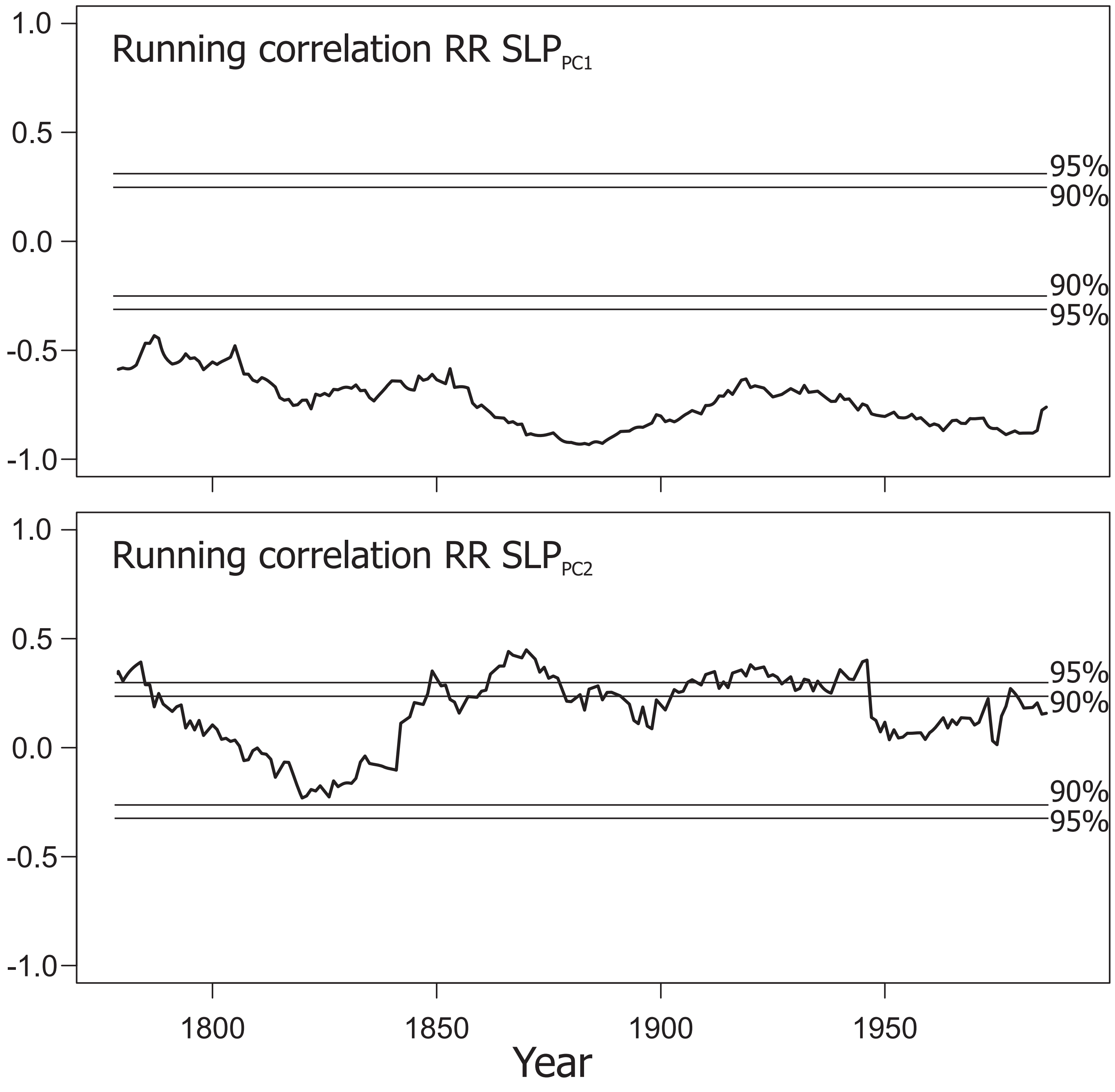

Fig. 37

Luterbacher et al.

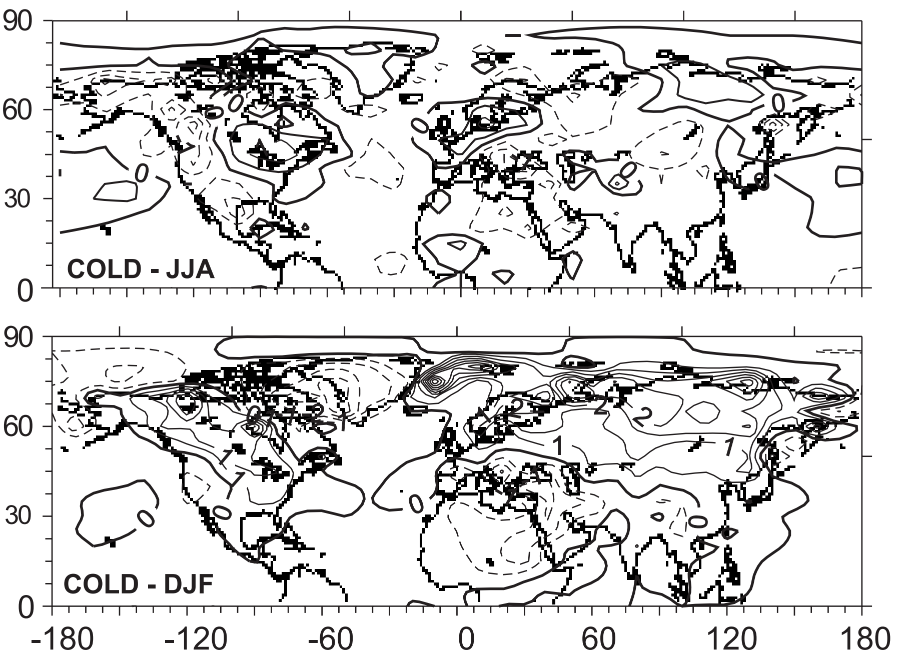

Fig. 38
Luterbacher et al.

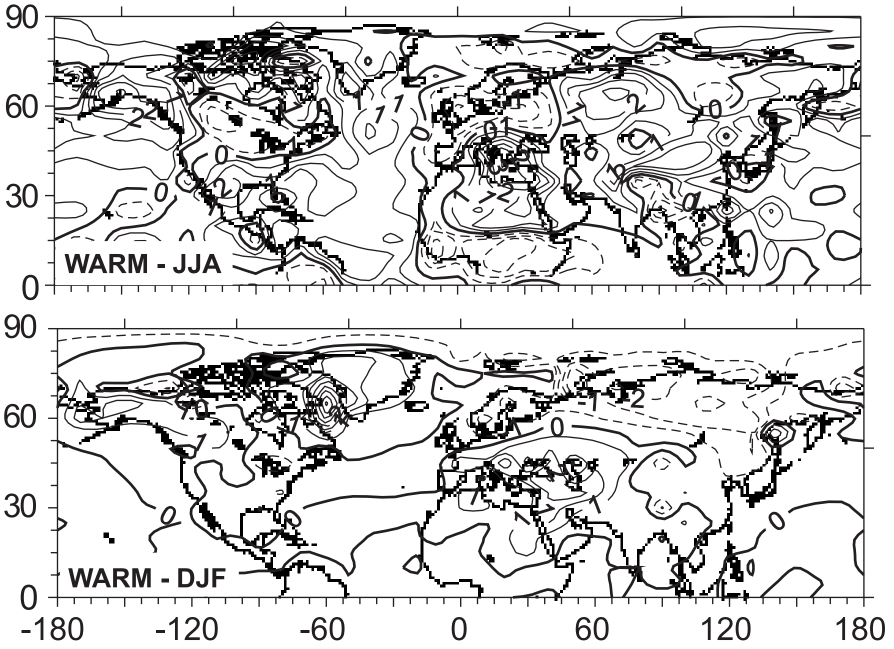

Fig. 39
Luterbacher et al.

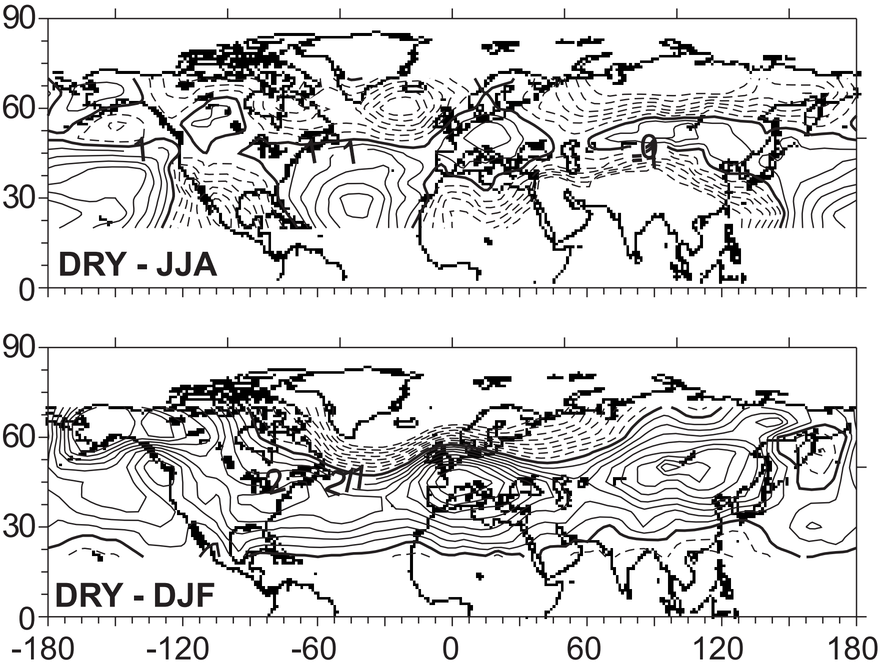

Fig. 40
Luterbacher et al.

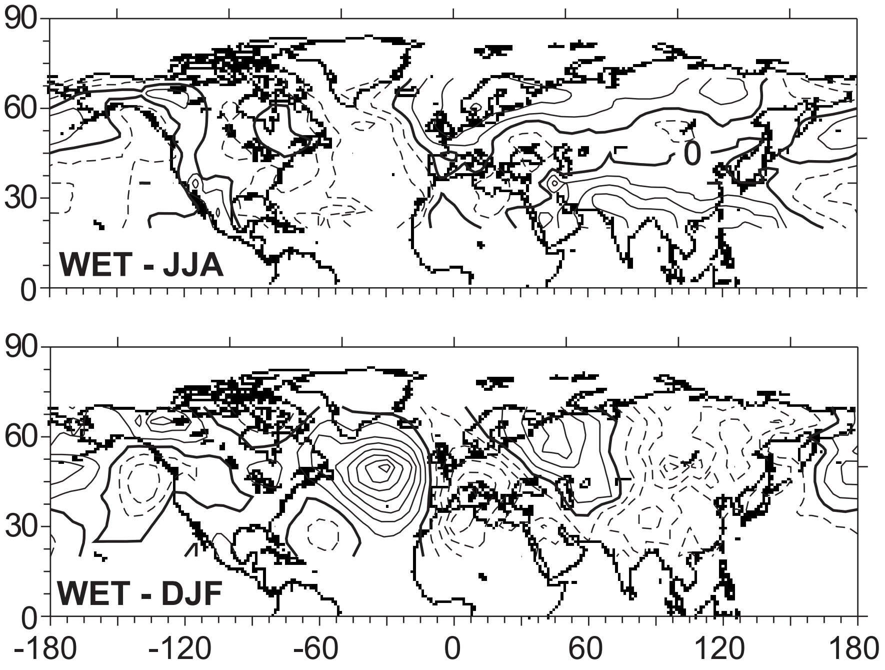

Fig. 41
Luterbacher et al.

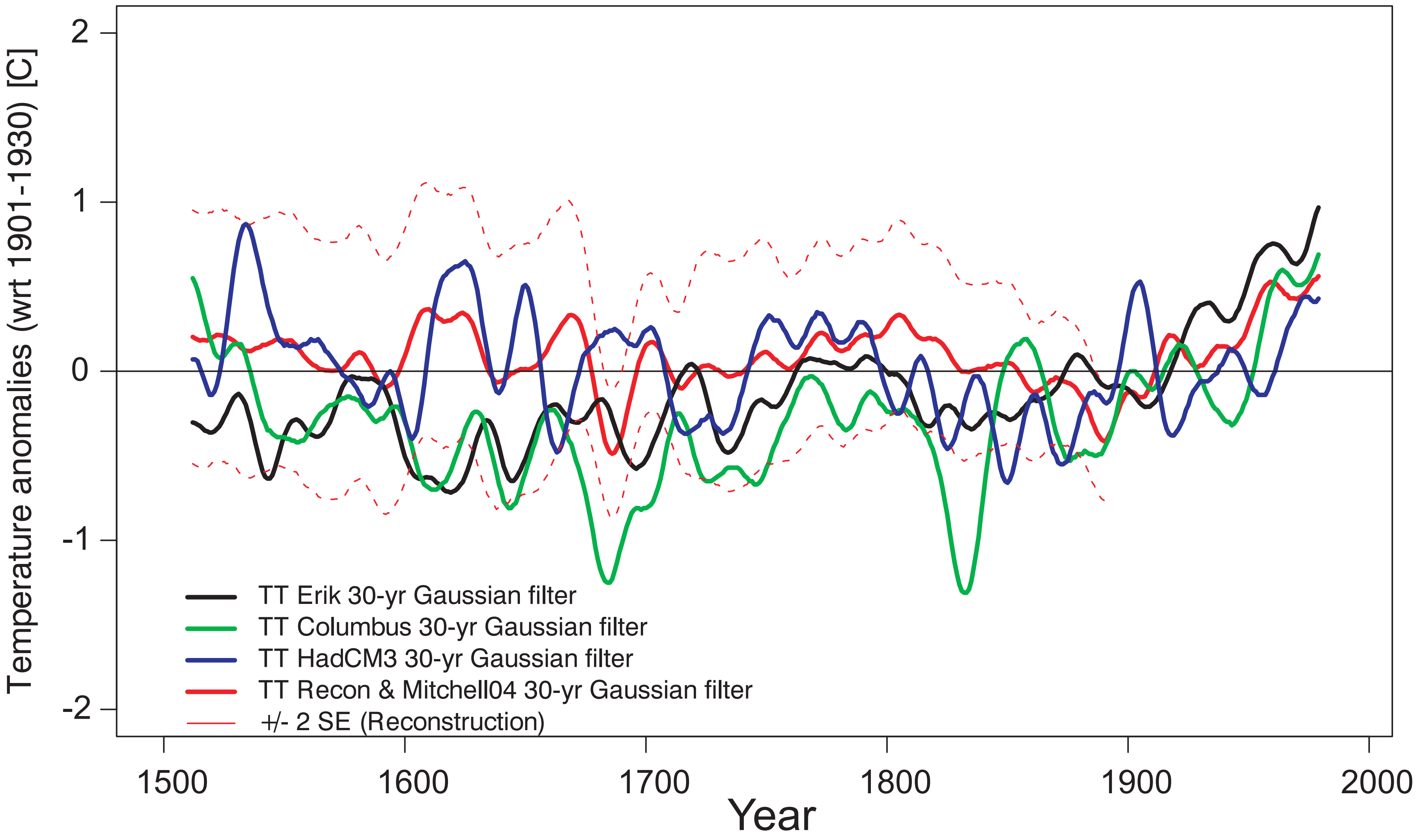

Fig. 42
Luterbacher et al.