VARIABILITY OF CLIMATE IN MERIDIONAL BALKANS DURING THE PERIODS 1675–1715 AND 1780–1830 AND ITS IMPACT ON HUMAN LIFE

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Abstract. The periods from 1675–1715 (Late Maunder Minimum; LMM) and 1780–1830 (Early Instrumental Period; EIP) delineate important parts of the so-called 'Little Ice Age' (LIA), in which Europe experienced predominant cooling. Documentary data, assembled from a number of sources, in the course of the EU funded research project ADVICE (Annual to Decadal Variability of Climate in Europe), has been used to locate and describe events in the southern Balkans and eastern Mediterranean. The resulting data has been used firstly to investigate the incidence of phenomena such as crops sterility, famine and epidemics and their relationships with climate, and secondly to analyse the extent of variability, particularly the occurrence of extreme events, such as severe winters (cold, wet or snowy), long periods of drought and wet periods. During the LMM and EIP, more such extreme situations were apparent compared with the last 50 years of the twentieth century. From the scattered data found for 1675–1715 and 1780–1830, the winter and spring climate in southern Balkans and the eastern Mediterranean, especially during the LMM, can be characterised as cooler and relatively rainier with a higher variability compared with the recent decades.

1. Introduction

One aim of the ADVICE (Annual to Decadal Variability of Climate in Europe) research project, funded by the European Community, was the collection, compilation and quality control of documentary and instrumental data for the Late Maunder Minimum (LMM; 1675–1715) and the Early Instrumental Period (EIP; 1780–1830) for southeastern Europe in order to incorporate these data into reconstructions of monthly atmospheric circulation patterns (Jones et al., 1999; Luterbacher et al., 2000a), as well as monthly precipitation and temperature indices for Greece. The period from 1716 to 1779 was not investigated within ADVICE since it marks a period with a lower number of less reliable instrumental and proxy data. Thus, these years have been discarded from this study. The data are used to investigate the relationship between crop sterility, famine, epidemics, such as plague and climate over the Meridional Balkans. Thus, a brief overview is given referring to the climate conditions during the LMM and EIP periods, the climate impacts on human life, the known relationship (in general and for the Meridional

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Balkans) between climate and crops as well as between climate and epidemics (plague).

1.1. CLIMATIC CONDITIONS DURING THE LMM (1675–1715) AND EIP (1780–1830) PERIODS

Marked climatic variability is characteristic of the periods 1675–1715 and 1780–1830, within the so-called 'Little Ice Age' (LIA; AD 1300–1900, Holzhauser, 1997; Pfister et al., 1998). Surface temperature was at times of the order of 0.7 °C lower than in the 1901–1960 period, especially in Northern Europe (Bradley and Jones, 1993). The long-term reconstructed mean annual and summer Northern Hemisphere (NH) surface temperatures (Jones et al., 1998; Mann et al., 1998) show pronounced cold periods during the Maunder Minimum (MM; 1645–1715), a period with reduced solar activity and low sunspot numbers (Eddy, 1976) and several explosive volcanoes (Briffa et al., 1998). For the whole period the NH temperatures were around 0.1°–0.4 °C lower than in the twentieth century (1902–1980), with a minimum during the LMM, which marks the climax of the 'Little Ice Age' with particularly cold winters, long sequences of winter and spring droughts and rainy summers in western and central Europe (Wanner et al., 1995; Luterbacher et al., 2000b). The post-LMM period up to the end of the eighteenth century can be summarised by a general warming over the whole NH (Jones et al., 1998; Mann et al., 1998) and also over Europe (Pfister, 1999). The turn of the eighteenth century (from around 1780 onwards) where sufficient numbers of European instrumental observations were becoming available (Jones and Bradley, 1992; Jones et al., 1999) until the middle of the nineteenth century the NH including Europe witnessed coldness again (except for the 1820s) (Briffa et al., 1998; Jones et al., 1998; Mann et al., 1998; Pfister, 1999). Recent studies indicate that solar irradiance was the main forcing factor in the NH series during the seventeenth and eighteenth centuries (Lean et al., 1995; Lean and Rind, 1998; Mann et al., 1998), although eruptions from a large number of explosive volcanoes (i.e., Tambora, Indonesia in April 1815) seem also to have been of importance (Briffa et al., 1998; Mann et al., 1998).

1.2. CLIMATE IMPACTS ON HUMAN LIFE

All climate and weather variables have some influence on human life. The effect may be either directly on the human body or indirectly through effects on disease-causing organisms or their vectors. Although the effects of variation of only one weather element may be examined in a particular study, that element does not act independently of other elements, for example, changes in humidity modify the effects of temperature (White and Hertz-Picciotto, 1985).

The most difficult choices of study elements are the choices of impacts and consequences. It is useful to distinguish first-order impacts, usually of a biophysical nature, from higher-order impacts consisting of socio-economic valuation, adjustment responses and long-term 'change'. It is also important to recognise the dual nature of impacts: gains as well as losses are experienced, and growth as well as decline takes place (Kates, 1985).

There are three general, related categories in which climatic factors manifest themselves in human health and well-being: through direct effects on individual health, through population movements and behaviour, and through effects on diet and nutritional level (Escudero, 1985).

Famine is an absolute lack of food affecting a large population for a long time period. Klinterberg (1977) described famine as ‘an event which disrupts the functioning of a community to such an extent that it cannot subsist without outside assistance. According to Wolde-Mariam (1984), famine is a ‘general hunger affecting large numbers of people … as a consequence of non-availability of food for a relatively longer time’. Hunger is not famine. It is similar to undernourishment (chronic food insecurity, in which food intake is insufficient to meet basic energy requirements on a continuing basis (FAO, 1999)) and is related to poverty. When hunger persists for a longer period, covering a large number of the population and resulting in mass migration and death, it then becomes famine (Ayalew, 1997). Malnutrition is an insufficient nutrition, a condition where diet omits some foods necessary for health (FAO, 1999). According to Escudero (1985), malnutrition is the most common biological manifestation of climatic aggression. Hunger and malnutrition are regional and local phenomena that are only incidentally related to agricultural production potential (Reilly, 1999).

1.2.1. *Relationship between Climate and Crops: General*

Seasonal patterns of temperature, air humidity, precipitation, solar radiation and atmospheric CO_2 concentration and soil condition are the main determinants for agriculture (Reilly et al., 1996; Rötter and van de Geijn, 1999) and thus also for controlling the growth and the development of crops, subsequently the size and quality of the harvest, the spreading and aggravation of epidemics and finally they are an indirect influence on the occurrence of hunger and famine.

Plant growth and crop yields depend on mean temperature and temperature extremes. Extreme temperatures are important because many crops have critical thresholds both above and below which crops are damaged (Rosenzweig and Liverman, 1992). In addition, changes in seasonal precipitation distribution and intensities are more important for crops than changes in the annual precipitation and potential evaporation. Drought stress or too much precipitation can quickly lead to crop failure or the inability to timely plant or harvest a crop (Rötter and van de Geijn, 1999). In addition, too much precipitation can cause disease infestation in crops, while too little can be detrimental to crop yields, especially if dry periods occur during critical development stages (Rosenzweig and Liverman, 1992). In addition, the interactions of crop growth and development with local and regional climate and agricultural practice are of great importance (Rötter and van de Geijn, 1999). Climate is a major determinant of what can be grown successfully, non-climate factors related to capital, prices and availability of markets and impacts, land tenure, good seed stock, flood control and irrigation, education levels of farmers, changes in agricultural practices, effective control of pests as well as diseases and the best balance of fertilisers are often the key factors determining high crop yields (Oram, 1985; Rötter and van de Geijn, 1999). It has to be pointed out, that these non-climate factors are not the main subject of this paper.

1.2.2. *Relationship between Climate and Crops: Meridional Balkans*

In dry climates such as the eastern Mediterranean and in the absence of other water resources than precipitation, avoidance of dry periods unfavorable for crop cultivation and associated field operations is of major concern (Rötter and van de Geijn, 1999). Water demand generally exceeds supply and this is the main factor determining agricultural production. For the Mediterranean, a reduction of precipitation leads to lower average yields and higher year-to-year yield fluctuation (Reilly et al., 1996). The impact of climatic variations on Mediterranean crop yield or agriculture in general depends less upon variations in the annual totals or averages of the different parameters (precipitation, temperature, irradiation), than on the distribution of these parameters in the course of the year, and this in turn is controlled by seasonal and irregular changes in the pattern of the general circulation of the atmosphere (Bourke, 1984; Rötter and van de Geijn, 1999). A dry and sunny summer benefit both in winter and spring cereals, particularly if they are backed by adequate reserves of soil moisture (Bourke, 1984). A heat wave can cause summer heat stress, leading to the scorching of the still immature grain and bring on an early and light harvest. Undue cold can also cause damage at different stages of growth; a particularly harsh winter can lead to soil heaving and also cause direct damage to varieties of lesser hardiness, while severe frost can do great harm at the sensitive heading and flowering stages (Bourke, 1984). Abundant and persistent rains at either end of the growing season can be disastrous and heavy rains in autumn and winter can cause water logging of the soil, drown the seeds, retard root development and tillering and weaken the plant structure (Bourke, 1984).

1.2.3. *Relationship between Climatic Variables and Epidemics, Plague: General*

The sensitivity of health-outcome response to climate change depends on population susceptibility. For example, the impact of a climate-related increase in exposure to infectious agents would depend on prior contact (i.e., herd immunity), on general biological resilience (especially nutritional and immune status), and on population density and patterns of interpersonal contact. Social infrastructure and health-care resources also would condition the impact (McMichael et al., 1996). In general, the most vulnerable populations or communities would be those living in poverty, with a high prevalence of undernutrition, chronic exposure to infectious disease agents, and inadequate access to social and physical infrastructure (McMichael et al., 1996).

The epidimiology of a communicable disease must be reconciled with the prevailing environmental, ecological and social conditions; that is to say, it should be possible to set forth the functional relationships with the respective independent variables. The execution of the procedure may entail taking account of the weather nutritional status, clothing, housing conditions, personal hygiene, environmental sanitation, behavioural changes, alterations in community spacing arrangements, exposure vectors, and the previous prevalence of an infection (Post, 1985).

In vector-borne and bacterial diseases it is usually climate and weather that influences the vector or the vector's intermediate host, rather than the microorganism, that determine the prevalence of disease (White and Hertz-Picciotto, 1985). In addition, Curson and McCracken (1989) point out that plague, like many northern fevers, is a seasonal ailment.

Plague is a vector-borne or an air-borne disease according to its form. Bubonic plague is a vector-borne, while pneumonic plague is an air-borne disease. The essential vector or medium of transmission of the bacillus of plague to humans is the flea, usually the rodent flea, or in some cases the human flea, which imparts the disease to humans by its bite. The frequency of transmission to humans would seem to be governed by a number of factors concerning the life-cycle and activity-pattern of fleas, rodents and humans. Classically, the flea inoculates the disease by biting its host. It is also possible that plague can be transmitted to humans via lice and certain species of bugs. In order to survive, fleas require fairly specific climatic conditions and do best in a moderately warm and moist climate with a temperature of 15–20 °C and a 90–95% humidity. The temperature range and degree of humidity play a vital role in the life-span and activity pattern of fleas. Seasonal changes in climatic conditions are apt to produce fluctuations in the incidence of the flea population. In addition, in species of fleas such as Xenopsylla cheopis plague bacilli reproduce most rapidly at warm temperatures of up to 27 degrees. To some extent this explains the recline of plague outbreaks with the onset of hot weather.

Plague epidemics have occurred when temperatures have been about 19–26 °C with high relative humidity. When the temperature increases above about 26 °C, the incidence of plague decreases, apparently because fleas are susceptible to desiccation (White and Hertz-Picciotto, 1985).

Bubonic plague, thus, tends to exhibit a marked seasonality, closely related to seasonal changes in flea and rat populations. To this end, it tends to be a disease of late summer/early autumn, although it is possible that the artificially maintained indoor temperature of many houses in winter will allow fleas to survive where otherwise they would not. Whereas the flea is responsible for transmitting bubonic plague, pneumonic plague is communicated directly from person to person via the mechanism of air-borne droplets projected from the lungs during speech, sneezing or coughing. In colder temperatures, these droplets of saliva may remain in suspension for longer periods. Thus, pneumonic plague is essentially associated with winter temperatures or with cooler climates (Curson and McCracken, 1989).

Human infection usually occurs in areas of unsanitary living conditions where humans come into close contact with rats. Rural areas outside of cities, where conditions are poor and access to antibiotics is scarce, usually are the focus of

TABLE I

Periods of the appearance of plague in Greece (from Kostis, 1995)

17th century	18th century
1617	1705
1622–1623	1708–1709
1629–1630	1712–1714
1642	1716–1719
1644–1647	1728–1730
1661–1663	1740–1744
1667	1758–1765
1677–1680	1778
1687–1690	1782–1784
1697–1699	1787–1789
	1791–1793
	1795

plague outbreaks. However, plague cab occurs in areas of increased urbanisation that bring human beings into large rodent habitats. Although large epidemics of plague have not occurred in recent years, it is endemic in many parts of the world.

1.2.4. *Relationship between Climatic Variables and Epidemics, Plague: Meridional Balkans*

According to the climatic conditions, when plague may occur, a sequence of dry years can be an obstruction for the revival of an epidemic, as can particularly cold years.

Plague in the Greek peninsula cannot survive during the summer months. However, even here, climatic fluctuations can be regarded as an additional control of outbursts of plague and they can create conditions required for serious development of an epidemic (Kostis, 1995).

The main periods when plague appeared in Greece during the seventeenth and eighteenth centuries are presented in Table I (Kostis, 1995).

The connection of severe weather and climate anomaly conditions with historical events (floodings, droughts, famines, epidemics, etc.) should be examined carefully in order to avoid errors, including those stemming from uncertainties in the dating methods used or from lags between cause and response. Conclusions concerning the connections between severe weather anomaly conditions and historical events should take into account not only timing but also functional relationships. The scheme of weather hardiness and the related agricultural deficit should be presented with rigorous studies and statistics showing that the bad-harvest years can result from by comparable meteorological conditions that either occurred more frequently during the investigated period or less frequently during the following or preceding periods (Le Roy Ladurie, 1972).

The availability of the data for the periods 1675–1715 and 1780–1830, their verification and the methods used are discussed in Section 2. The sequence of historical events, and corresponding weather conditions are presented in Section 3. Emphasis is placed on the comparison of temperature and precipitation conditions between the LMM and the period 1961–1990 over Greece, which is important for estimation of the reliability of the proxy data used for climatic reconstruction. Synoptic conditions prevailing during extreme temperature and precipitation conditions are investigated in order to increase the understanding of climatic variability. A few representative examples are discussed in an attempt to reveal the connections between severe weather anomaly conditions, their impact on human life and the atmospheric circulation responsible.

2. Data and Methods

Prior to the detailed analysis and elaboration of the available sources and documentary evidence for the LMM and EIP, a short overview of the data availability from the Meridional Balkans for the last two centuries is given in Section 2.1.

2.1. INSTRUMENTAL DATA AVAILABILITY FROM THE MERIDIONAL BALKANS

Many investigators in the past showed a great interest in the nature and the climate of the southern Balkans, mainly Greece, and especially for the Ionian Islands. A good example is the meteorological observations in Corfu. They were first performed at the turn of the eighteenth century by Carlo Botta, Lazzaro de Mordo and Lascaris, but their data were not preserved (Mariolopoulos et al., 1985). In 1805, Emanuel Theotokis started systematic meteorological observations, but also in this case the data are lost (Mariolopoulos et al., 1985). The next meteorological observations, from January 1823 until May 1864, are published in the journal *Gazzetta degli Stati Uniti delle Isole Ionie, Corfu*. Other shorter time series are preserved from the English military Dr. Roe McKenzie (1840–1862) and the English Engineers (1852–1861) (Scott, 1890; Mariolopoulos et al., 1985; Kotini-Zambaka et al., 1996). Instrumental time series from the Meridional Balkans are available since the beginning or mid-nineteenth century and they mainly come from Greece, the former Yugoslavian countries, Albania, Bulgaria, Romania and Turkey. All the time series can be divided in two main categories, according to their length and the time period they cover. The long time series comprise meteorological observations starting in the nineteenth century and coming up to the present (for example, Thessaloniki and Athens); the short time series represent the twentieth century and cover mostly the period 1958–1994. The precipitation and temperature data of the Greek stations stem from the National Meteorological Service, from the Monthly Meteorological Bulletin (1958–1987) and the Statistical Bulletin of Greece (1988–1994). Xoplaki et al. (2000) found that the Greek temperature and precipitation station data can be considered as homogeneous. Parts of these data have been used for the comparison with the climatic conditions during the LMM.

2.2. DATA SOURCES FOR THE LMM AND THE EIP

Annals, chronicles and historiographies, records of public administration and government, travel reports, scientific writings (books and historical climatological papers) and monastery records constitute the body of documentary data used for this study. The sources have been found in several libraries of the study region. All these sources contain direct or indirect information about the course of the weather or meteorological phenomena or they describe natural phenomena and social events related to weather. Information about famine and epidemics, such as plague, are also included. Thus, the different kinds of sources found are similar to those from central and eastern Europe. According to the data terminology of Pfister et al. (1999), most of the data used are descriptive documentary data, while only a few documentary proxy data have been found.

Figure 1 shows the region of the southern Balkans and the eastern Mediterranean with the main locations where data sources have been found for the studied periods, as well as the 23 Greek stations (triangles), which were used for the correlation analysis, in order to select the most representative station for Greece (cf. Section 2.3.2).

The data embody the years of the periods 1675–1715 and 1780–1830, and they can be divided into cold, dry and rainy seasons or years (Figure 2). Figure 2 gives the seasons or years for which there is a clear characterisation of the prevailing weather, according to the abundance and density of the data. The gaps in Figure 2 comprise the turn of the seventeenth century, the turn of the eighteenth century, as well as the years of the 1820s (time of the Greek revolution against the Turkish occupation). No data have been found for the years 1677, 1697, 1703, 1706, 1711, 1786 and 1791. For the remaining years and seasons several data have been found with a daily resolution. However, the incomplete daily series do not allow drawing conclusions about the seasonal or annual character of the year. In some cases, such as the year 1715, there is no information concerning weather but only consequences, such as famine.

Data have been collected from many countries in the Balkan Peninsula (Greece, former Yugoslavian countries, Albania, Bulgaria, Romania) and the eastern Mediterranean (Cyprus, Turkey, Israel, Lebanon, Libya, Syria). Most of it refers to Greece (65%) (Figure 3a). In all, 1130 records were extracted for the periods 1675–1715 and 1780–1830, thus much less than for the central and eastern Europe. Figure 3b shows the documentary data classified according to the duration of the

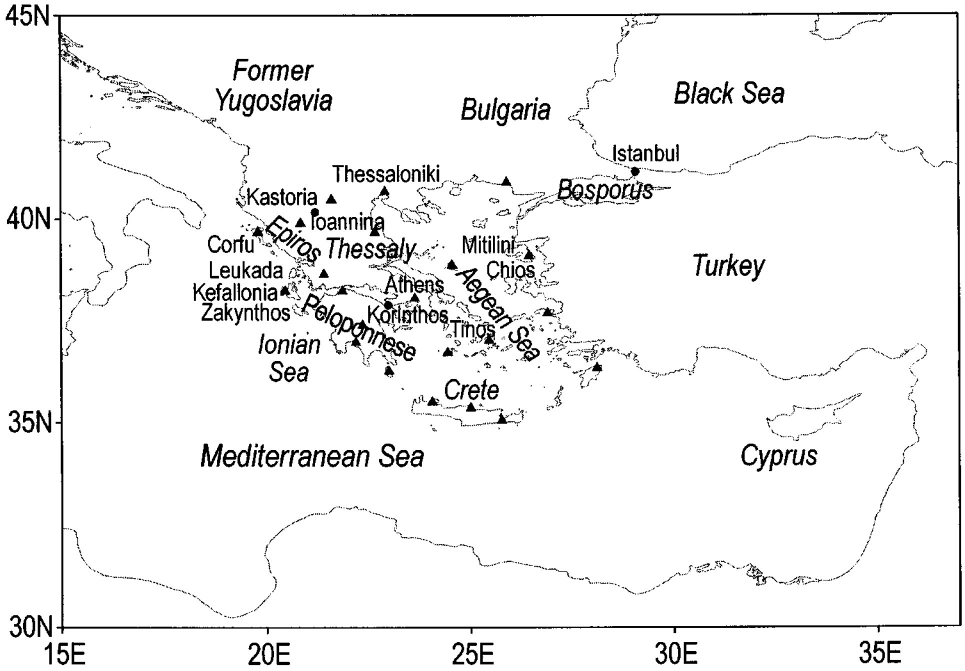


Figure 1. Map of the region of meridional Balkans and eastern Mediterranean showing the main locations mentioned in the text. Triangles present the 23 stations used for the correlation analysis between the Greek stations (cf. Section 2.3.2).

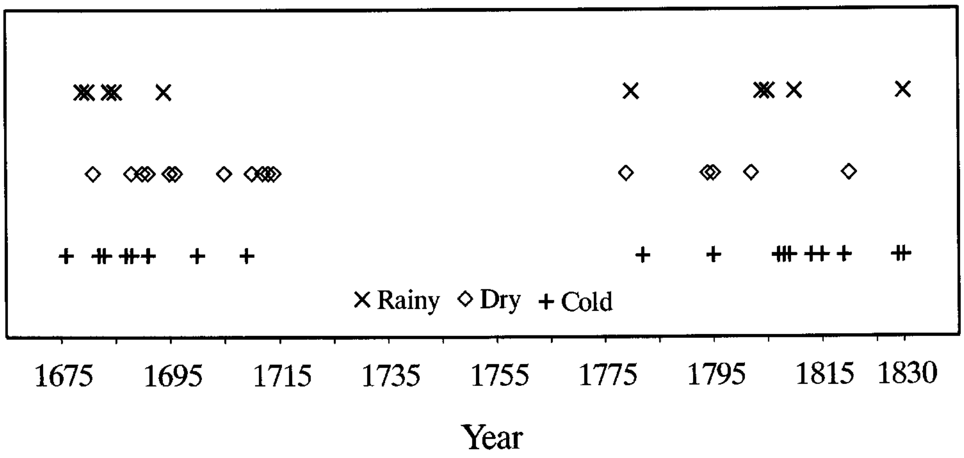


Figure 2. Chronological distribution of the documentary data in connection with cold, dry and rainy conditions over the studied area.

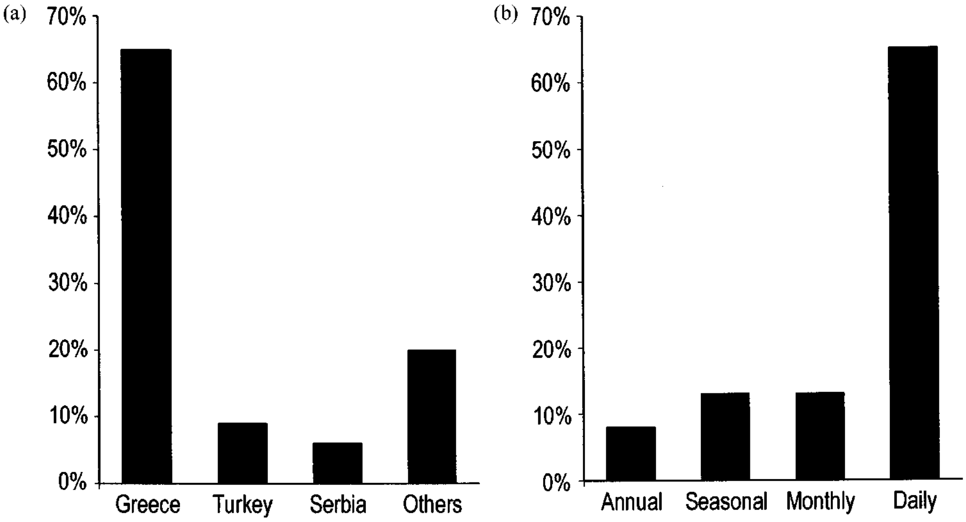


Figure 3. Classification of the documentary data according to their country origin (a) and time resolution (b).

observed phenomena and events related to weather and climate (daily, monthly, seasonal and annual). The figure is based on data from first and second class sources (see Chapter 2.3). Most of the reports found were precise to the day. They comprise the 65% of the total reports. The majority of the daily data comes from the 1800–1830 period (67% out of the 734 daily records). During the studied periods, there are weather observations for 324 months (29%).

2.3. DATA ELABORATION

Several steps are involved in the elaboration of the documentary data. The first concerns the verification of data. The second step constitutes the compilation of the data in order to obtain estimated temperature and precipitation indices for the LMM.

2.3.1. *Data Verification*

The verification of the data includes reliability control of the sources, the determination of the calendar used, as well as a short of 'filtering' of the extraordinary weather descriptions. For instance, the descriptions of catastrophes caused by severe meteorological phenomena are somewhat exaggerated. Descriptions of severe destruction have been filtered by comparing the information with other sources referring to the same period for the same or neighbouring areas. Nevertheless, overlapping of sources is limited and the control of the more farfetched entries has not always been possible. A standardised methodology has been adapted for the evaluation of the sources and the rejection of unreliable information. The basic principles of the tests used are those of contemporaneity, propinquity and faithful transmission (Pfister, 1992). These three principles try to define the distance in time and space between the event and its entry, as well as the accuracy of the transmission.

No detailed information can be given about the location where the manuscript sources were written. Many of the authors were travellers. Thus, they did not always give the location. However, it is believed that the manuscript sources were not only contemporary but also written in the relevant locations. In many records authors give not only the date of the event described, but they also determine this date comparing it with the ‘present day’; they use words such as ‘yesterday’ or ‘last week’, so it is believed that they were, if not at the same location, at least very close to the place of the event.

The nineteenth-century works that were used were published in a period when authors were well known to have paid little attention to the validity of the material they used. That weather conditions or events such as famines or plagues were described does not necessarily mean that the dates given were correct, or that they were based on accurate information and not on inaccurate hearsay. It might be suspected that data drawn from manuscript monastic sources or records of public administration might be much more reliable than that coming from histories and general works.

The body of the documentary data can be divided into three main subgroups. The first group includes data coming from sources characterised as ‘*first class*’, such as manuscripts; the second group of ‘*second class*’ sources comes mainly from collections and the third contains ‘*unreliable*’ sources (Schüle and Pfister, 1994; Pfister et al., 1998). The majority of the data used come from first and second class sources; unreliable sources have been discarded. Not only for the nineteenth century but also for the period 1675–1715 a similar way was followed, as presented in Pfister et al. (1998). It was assumed that the dating of the chroniclers who might have witnessed the event was the most reliable. This step served to prevent a spurious multiplication of extreme events. In addition, reports in non-contemporary sources, which obviously mentioned the same event for a subsequent or preceding season or year, were subsumed to those of the most reliable year. This procedure assumes that it is very unlikely that a specific event occurred in two subsequent seasons or years, unless this would be mentioned in a source (Pfister et al., 1998). According to Pfister (1992), non-contemporary material was not completely rejected. Where a reliable picture of weather patterns had already been obtained from contemporary data, second hand reports, which contributed to the understanding of weather situations, were included. For this reason the ‘second class’ sources were retained in this study.

One of the main problems was the accurate dating. The simultaneous use of two different calendars in the same region was quite common. Time contradictions may arise when two authors using different calendars record the same event. The Greeks changed from the Julian to the Gregorian calendar after 1924, while the Orthodox Slavs retained the Julian calendar up to the present, so identification of the dates used in the documents requires care. Dating problems could also arise when winter season events are described. If only one year is given, then more information is required in order to determine if the ‘old’ or the ‘new’ year is meant (Pfister, 1992).

2.3.2. *Data Compilation – Reconstruction of Climatic Indices*

The compilation of the data is based on the method introduced by Pfister (1988) and Pfister et al. (1994). This procedure requires machine-readable data in order to incorporate in the EURO-CLIMHIST database, which is a large body of documentary data on the history of climate in Europe for more than the last 1000 years. Documentary data have a couple of strengths including a high (seasonal to daily) time resolution, a disentanglement of the effects of temperature and precipitation, a coverage of all months of the year and a high sensitivity to anomalies and natural hazards. On the other hand, many types of descriptive documentary proxy data are discontinuous and heterogeneous (Pfister et al., 1994). The derivation of climatic indices (discrete levels from +3 to –3) for temperature and precipitation with a monthly resolution for the LMM period is a first step towards transforming bodies of documentary evidence on climate into time series (Glaser et al., 1999). Within ADVICE it was the aim to derive climatic indices only for Greece since the data density for the other regions of the Meridional Balkans was not sufficient. Such time series allow an estimation of temperature and precipitation anomalies for Greece compared with mean conditions of the same region during the recent/instrumental period. In the case of Greece, Athens has been taken as the reference station for the whole Greek area. The particularities of the data and of the regional climate determined the methodology that has been followed in order to obtain the indexed temperature and precipitation time series. A specific amount of information is coherent for the same weather phenomena in various regions of the country. Contradictory climatic information, for the same period in different regions, is rare. Less than 5% of the data collected, give contradictory climatic information for the same period in different regions. Athens is more representative for the Greek area for both temperature and precipitation than any other station and this for several reasons: the correlation analysis for the period 1958–1994 among 23 stations (Figure 1, marked with triangles), uniformly distributed over Greece, revealed that the correlation coefficients between Athens and the other stations is generally highest and vary between 0.55 and 0.85 (temperature) and from 0.30 to 0.62 (precipitation) (Xoplaki et al., 2000). Lower (higher) correlation coefficients are found between Athens and the stations in western (eastern) Greece (Maheras and Kolyva-Machera, 1990; Xoplaki et al., 2000). In addition, apart from Thessaloniki, Athens is the other Greek station, that can be considered as highly homogeneous because there were no changes in instruments, observing practices, formulae calculating means and in the station environment. Moreover, it functions continuously at the same location since its establishment in the late nineteenth century. The assessing of climate tendencies in terms of indices involves comparing and cross-checking different types of concurrent, high-resolution natural and documentary proxy data. They cannot be directly calibrated with instrumental series, since there is no overlapping period between instrumental measurements and first quality observations for the studied area (cf. Section 2.1). The indices are integer values between +3 and –3, where values of +3 and –3 are applied to anomalies that are unmistakably ‘*extreme*’ by twentieth-century standards, i.e., beyond two standard deviations from the mean of the reference period 1901–1960; values of +2 and –2 are applied to less extreme deviations that are 1.41–2.0 standard deviations from the mean of the reference period; values of +1 and –1 are applied to cases, which deviate between 0.7 and 1.4 standard deviations from the mean of the reference period, or are poorly documented and the value 0 is applied to cases that correspond to the average climate of the reference period or to missing data (Pfister et al., 1994). The estimation of the LMM temperature and precipitation indices is based on a comparison that was made between the documentary evidence (natural archives, description of the underlying weather situations and descriptive proxies) within the LMM and the mean monthly charts, reconstructed for cold, warm, dry and wet conditions for the Mediterranean basin for the period 1860–1990 (Maheras et al., 1999a,b) as well as the station temperature and precipitation conditions for Athens. In each case, where it was not possible to detect any relation between the series of charts and the climatic behaviour during the LMM or where no descriptions have been found we assumed that ‘normal’ temperature and precipitation conditions were prevalent and the table of indices has been completed with zero values.

The whole body of data for the periods 1675–1715 and 1780–1830 can be divided into three groups. Group one consists of cold and rainy or snowy winters (largest group), the second group includes dry conditions and the third group consists of rainy seasons. These groups together with their synoptic conditions will be presented in Section 3. No indications related to temperature have been found in the sources referring to wet and dry seasons. This can be attributed to the personality of the authors and their subjective choices of events considered important or critical and thus worth describing, i.e., in cases of heavy and destructive rainfall or long dry periods, information about the temperature conditions was considered less crucial.

2.3.3. *Reconstructed Monthly Mean Pressure Fields*

For the LMM monthly mean sea level pressure (SLP) fields over the eastern North Atlantic-European area were reconstructed by Luterbacher et al. (2000a). The common way of reconstructing past climate included the quantitative relationship between proxy and if available measured data and the twentieth century instrumental data, which were determined for a calibration period. Apart from the described temperature and precipitation indices for Greece another 20 partly measured and indexed time series from all over Europe were available for the LMM (Luterbacher et al., 1999, 2000a). The period from 1901–1960 was used to calibrate the seasonal statistical models by means of a canonical correlation analysis (CCA). CCA optimally summarises the linear relationship between the large-scale patterns of the atmospheric circulation over the eastern North Atlantic and Europe and the proxy and measured data. The statistical relationships were verified with independent data (1961–1990) to assess the model performance outside the calibration period. The calibrated statistical model for each season was then related to the data during the LMM in order to estimate monthly mean gridded pressure fields (Luterbacher et al., 2000a). Some of these charts were used for the synoptical interpretation in Section 3 (see Figure 5ff). The monthly pressure patterns for the period 1780 to 1995 were reconstructed by Jones et al. (1999) by using a principal component analysis (PCA) – regression technique relating gridded surface air pressure patterns to 51 station pressure series. However, none of these charts is presented in this study.

3. Results

3.1. COMPARISON OF TEMPERATURE AND PRECIPITATION CONDITIONS BETWEEN THE LMM AND THE 1961–1990 PERIOD

The following analysis attempts to explain some special features of the characteristic differences between thermal and moisture regime during the LMM and the period 1961–1990, where the most reliable data are available. The seven-point Pfister index (+3 to –3) is considered suitable as a basis. For a standardised comparison of temperature and precipitation behaviour during LMM and today, only indexed data were used. The scaling period that determines the arithmetic mean and the standard deviation is 1901–1960.

The observed and the expected reference period frequencies (1901–1960) of the Pfister Indices (+3 to –3) for the LMM and 1961–1990 for each season separately are shown in Figure 4. Using a one-sided X^2-test, it was tested to see whether the observed frequencies of the Pfister indices during the LMM and the period 1961–1990 differ from the expected values. All mean frequency distributions that are statistically significant at the 99% level are marked with an asterix. The lack of an asterisk means that the observed frequency is not significantly different from the reference period distribution, which is itself the basis for the Pfister indices. The more pronounced the deviations from the zero-line, the more distinct is the seasonal anomaly of the respective Pfister indices. Comparisons with the seasonal curves during the period 1961–1990 and the LMM show marked differences. A typical feature for Athens, or generally for Greece, is the fact that the frequency of the mean LMM seasonal temperature and rainfall between –0.7 and +0.7 standard deviation (Pfister index 0) is distinctly above the expected value of 52 percent. The distribution of above-average 0 (zero) Pfister values, suggests that over Greece ‘normal conditions’ were more experienced compared to nowadays.

However, cold or severe winters and springs (Pfister indices of –3 and –2) were more frequent than expected by the Gaussian distribution. By contrast, warmer

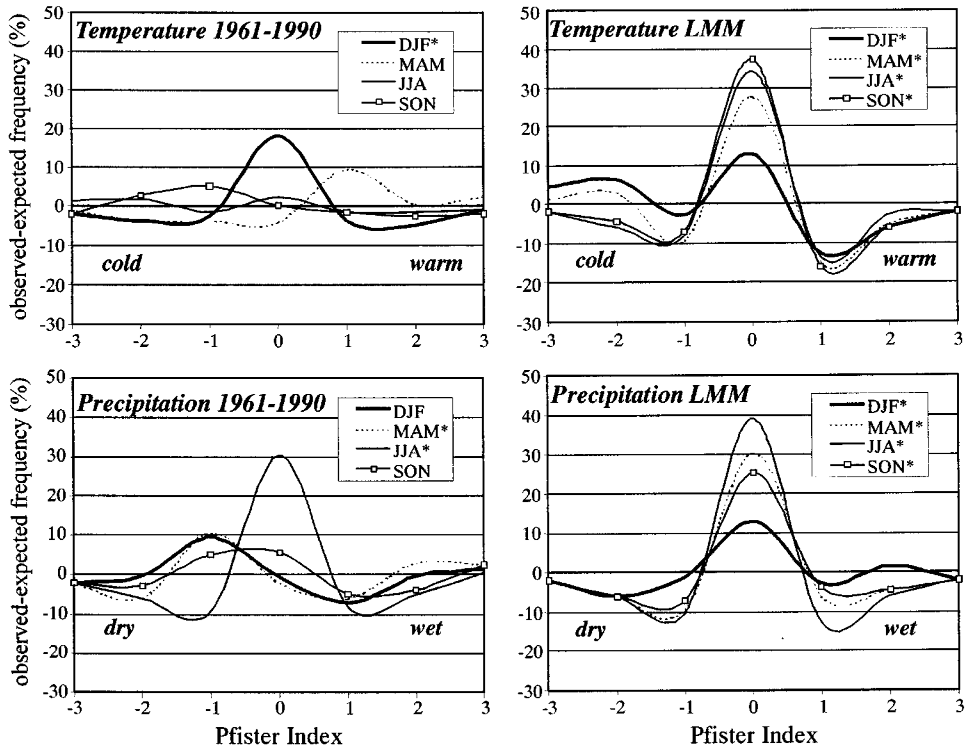


Figure 4. Observed and expected relative frequencies of the Pfister indices (temperature and precipitation), for Athens, for the LMM (right) and 1961–1990 (left) for each season separately. The asterix (*) denotes statistically significant on the 99% level.

situations (Pfister index +1 to +3) were less frequent in Greece during all seasons compared with the reference distribution and during the last 30 years. Seasonal negative bias for drier conditions (Pfister Index –1) over Greece was more frequent during the LMM. On the other hand, there was a significant tendency towards wetter winters (Pfister Index +2) during the LMM.

3.2. SEVERE WEATHER ANOMALY EVENTS IN ACCORDANCE WITH HISTORICAL INFORMATION

In the region of the southern Balkans and the eastern Mediterranean, a few years and seasons within the periods 1675–1715 and 1780–1830 are reported in different sources as exceptional with respect to the incidence of poor harvests, occurrence of famine and plague. In Table II, a few selected cases are presented.

Most of these years and seasons belong to the first and second group, cold and wet winters and dry seasons. Most of the reports refer to cold or extremely cold and rainy winters, which caused freezing of lakes, heavy snowfalls and long lasting snow cover. Dry periods were also responsible for destruction of crops and consequently with price rises, famine or increased mortality.

In the next three sections, different groups of extremes are discussed in chronological order. In a few selected cases, presented in Table II, the authors' descriptions of the prevalent climatic conditions are given. The reconstructed mean monthly SLP charts are analysed in order to explain the climatic conditions over the region. The most representative months for the three classes are selected and analysed for the whole period (in *italics* in Table II).

3.3. VERY COLD AND RAINY (SNOWY) WINTERS OVER THE MERIDIONAL BALKANS

The early spring of 1676 was extremely cold for most regions over the Balkans, while snow covered many parts of central Greece (Wheeler, 1682). In Serbia, an unusual heavy snowfall in late April caused snow to cover the central and southern parts of Former Yugoslavia. This situation caused severe problems for the cattle breeders, especially in mountainous areas, and finally provoked *la famine grande* (Vujevic, 1931). During the same year, the southern parts of Serbia experienced a rather cold and rainy summer, which damaged the grain and vine crops. Only small parts of the grain and vine crops reached the mature stage due to the rainy summer, while early snowfall in September destroyed the rest of the harvest completely and caused hunger to the inhabitants (Vujevic, 1931).

Several authors have reported the extreme period from January to April 1683, with heavy snowfalls and continuing frost all over Greece and especially its northern parts (Lampros, 1910, p. 200; Sarros, 1937, p. 109; Politis, 1991, p. 206; Pfister, 1994; Grove and Conterio, 1995). The severe cold and the deep snow cover caused the death of animals and destruction of the crops. On the Ionian Islands, rainfall was continuous during the first two months, while unusually heavy snowfall was reported at the end of March. In Tinos (Aegean Sea) the winter of 1682/83 was hard and windy with continuous rain and heavy snowfalls (Grove and Conterio, 1994). Further south, in Crete, extremely heavy rainfall was reported, while snow covered the mountains (Grove and Conterio, 1994). At the same time, Serbia experienced heavy snow and deep snow cover, which lasted for almost three months (Vujevic, 1931). The consequences of the extreme weather appeared later in the year, in Epiros and Thessaly, as high prices of food and famine (Veis, 1926, p. 55).

Another severe winter was that of 1686/1687. Almost every region of Greece experienced severe cold and heavy snow (Poulitsas, 1928-1929, p. 259). The ice on the lake of Ioannina lasted for more than three months (Aravantinos, 1856). The lake was frozen until April and the grain harvest was very much delayed (Pfister, 1994). Famine occurred in the Peloponnese and in Thessaly (central Greece) lasting for the whole year 1687 (Kostis, 1993).

The winter of 1699/1700 was very cold, with continuous snowfall that lasted more than two months, until the end of March with long lasting snow cover

TABLE II

Exceptional years and seasons with respect to the incidence of poor harvest, occurrence of famine and plague in accordance to weather events (1675–1715 and 1780–1830) (in *italics*, are the historical events of extreme weather, given in more detail in the following section, that are related to the atmospheric circulation)

Spring 1676	Balkans: severe cold
Winter 1679/80–April 1680	Ionian Sea: continuous rainfall, litanies South Aegean: severe cold, snowfalls
Winter-spring 1682	West Greece: drought, lack of grain, famine
Winter 1682/83	Greece: severe cold, frost, death of animals, destruction of crops, high prices, famine
Winter 1684/85	Ionian Sea: continuous rainfall, floods, destruction of buildings, high prices
Winter 1686/87	Greece: harsh cold, freezing of lake of Ioannina for 3 months, famine
1690	Serbia, Bosnia-Herzegovina: high prices, famine Athens: long dry period
1691	Crete: harsh cold, drought, grain did not grow
1691–1694	Crete: bad harvest, famine, high prices olive-oil
Autumn 1695–winter 1696	Aegean Sea: drought, no harvest, church litanies
1699/1700	Greece: very cold and long-lasting snow cover, snow cover over the Cretan mountains the whole 1700; bad harvest Thessaly: death of animals
Winter 1708/09	Serbia: severe cold, famine, plague, death of people
1710	Former Yugoslavia: bad harvest, famine
Autumn 1710–winter 1711	Ionian Sea: warm and dry, drying up of wells Ioannina, Arta: locusts
November 1712–summer 1714	Greece: drought, bad harvest, high prices, famine
	Thessaloniki: plague
Winter 1713/14	North Greece: drought, severe cold, bad grain harvest Serbia: severe cold, death of people
1715	Greece: great famine
1780	West-north Greece: heavy rainfalls, flooding, destruction of buildings (mostly mud constructions), high prices Crete: famine, plague
Winter 1782	Greece: harsh cold, freezing of lake Karla, destruction of olive-trees, fruit trees, death of animals Bosnia-Herzegovina: plague, death of people
Winter 1789/90	Serbia: excessive snow cover, death of people and animals
Winter-spring 1805	North Greece: heavy rainfall, death of cattle, deficient harvest
Winter 1807/08	North-central Greece: severe cold, freezing of lake Kastoria
Winter 1828/29	Greece: severe cold, long-deep snow cover, freezing of lake Kastoria, destruction of trees, death of animals

over the plains of northern Greece (Lampros, 1910, pp. 205–206; Tsopotos, 1912, p. 140; Kordatos, 1960, p. 543). The severe coldness caused the death of animals in Thessaly, while in Crete, during springtime, the snow over the mountains blocked the roads and caused problems to travellers (Tournefort, 1714, pp. 41–42; 1717, p. 228). The snow cover in Crete lasted the whole year, even in August with the mountainous areas full of snow (Tournefort, 1714, pp. 41–42). Not only in Greece but also in other regions in Europe, such as Bohemia, Moravia (Brázdil et al., 1994) and Hungary (Rácz, 1999) a very cold winter was reported for 1700.

The winter of 1708/09 is cited as one of the most severe of the last 500 years for great parts of Europe by many researchers. In central and western Europe (Pfister, 1994, 1999), in central Mediterranean (Grove and Conterio, 1994) the severity was accompanied with freezing of lakes and rivers due to the extremely low temperatures (Glaser et al., 1994), diseases and the death of animals (Russia, Ukraine: Borisenkov, 1994). In the Former Yugoslavia this winter was catastrophic, with severe coldness, heavy snowfalls, long lasting snow cover, famine and plague that caused the death of many people (Vujevic, 1931). Despite the great severity of the winter of 1709, no evidence has been found concerning weather in the eastern Mediterranean and more specifically in Greece. In 1710, very small harvest again caused a rise in foodstuff prices for the countries of Former Yugoslavia and consequently famine (Vujevic, 1931).

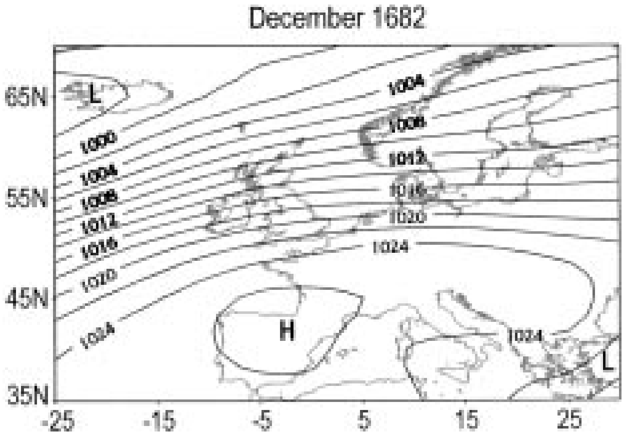
For the western and central part of Greece (Epiros and Thessaly) as well as the northeastern Aegean Sea (island of Mitilini), the winter of 1807/08 is reported as an extremely severe one (Poulitsas, 1928-1929, p. 79; Athinagoras, 1929, p. 33; Sarros, 1937, p. 119; Chatzialexandrou, 1940, pp. 513–514). Excessive snowfall and cold, which lasted for almost two months (February–March), caused the death of people and animals, the freezing of the lake of Kastoria in northern Greece (Golompias, 1985–1986, p. 334) and the destruction of olive trees in Mytilene.

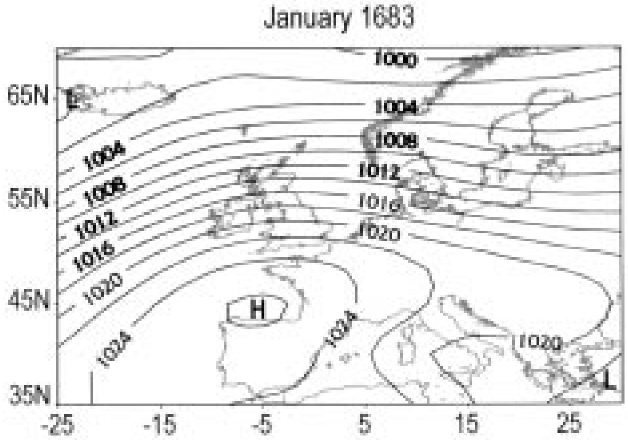
The winter of 1828/1829 was described as severe in the western part of Greece and the Sea of Marmara (Paschalis, 1962). Snow covered the region of Ioannina (Epiros) for 18 days, trees were destroyed and animals died (Soulis, 1994, pp. 115–116), while during February the lake of Kastoria was frozen and passable for 10 days (Golompias, 1985–1986). For the same period, high prices and famine, are mentioned for both western and central Greece (Lampros, 1922, p. 419; Athinagoras, 1929, p. 45; Kalinderis, 1940, pp. 36, 52; Enislidis, 1951, p. 41; Kordatos, 1960, p. 559; Veis, 1962, p. 19; Soulis, 1994, pp. 115–116).

3.3.1. *Synoptic Conditions during the Very Cold and Rainy (Snowy) Winters*

The reconstructed synoptic conditions for a few representative seasons during the LMM, which led to severe weather anomaly conditions over most of the Meridional Balkans, are presented below.

The severe conditions during the winter of 1682/1683 (Figure 5) can be attributed to the presence of an extended high pressure system over central and western Europe, with its centre over north Iberia. This pressure distribution led


December 1682


January 1683

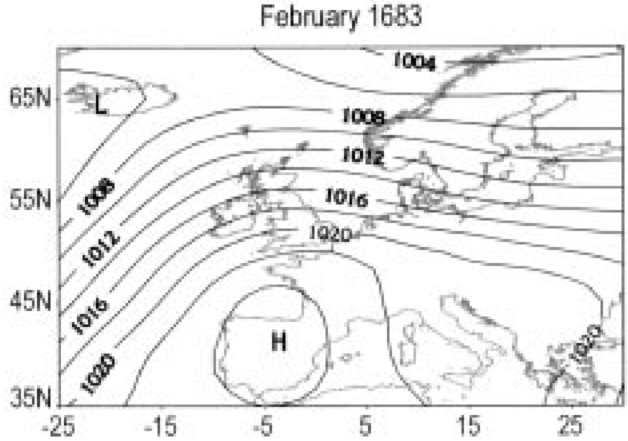

February 1683

Figure 5. Monthly mean reconstructed SLP charts (hPa) over Europe for the winter months 1682/83 (December, January and February) (Luterbacher et al., 2000a).

to persistent northwesterly and/or northeasterly circulation over the Balkans and the eastern Mediterranean. These cold air outbreaks caused the low or extremely low temperature conditions connected with rainfall and/or snowfall.

In the winter of 1686/1687 (Figure 6), which was long and extremely cold, an extended anticyclone stretched over continental Europe and the northern Mediterranean area towards western Russia (January). The influence of the cold outflow at its southern margins and the continuing easterly flow over the whole basin resulted in the very low temperatures. In February, the westward extension of the Siberian and/or Scandinavian anticyclones was of great importance for the climatic conditions of southern Europe. This pressure distribution, in combination with low pressure over the central Mediterranean, which caused persistent cold easterly airflow, prolonged cold and heavy snowfalls over Greece, was supported probably by latent and sensible heat flux due to rather high SSTs (Sea Surface Temperatures) in the eastern part of the Mediterranean.

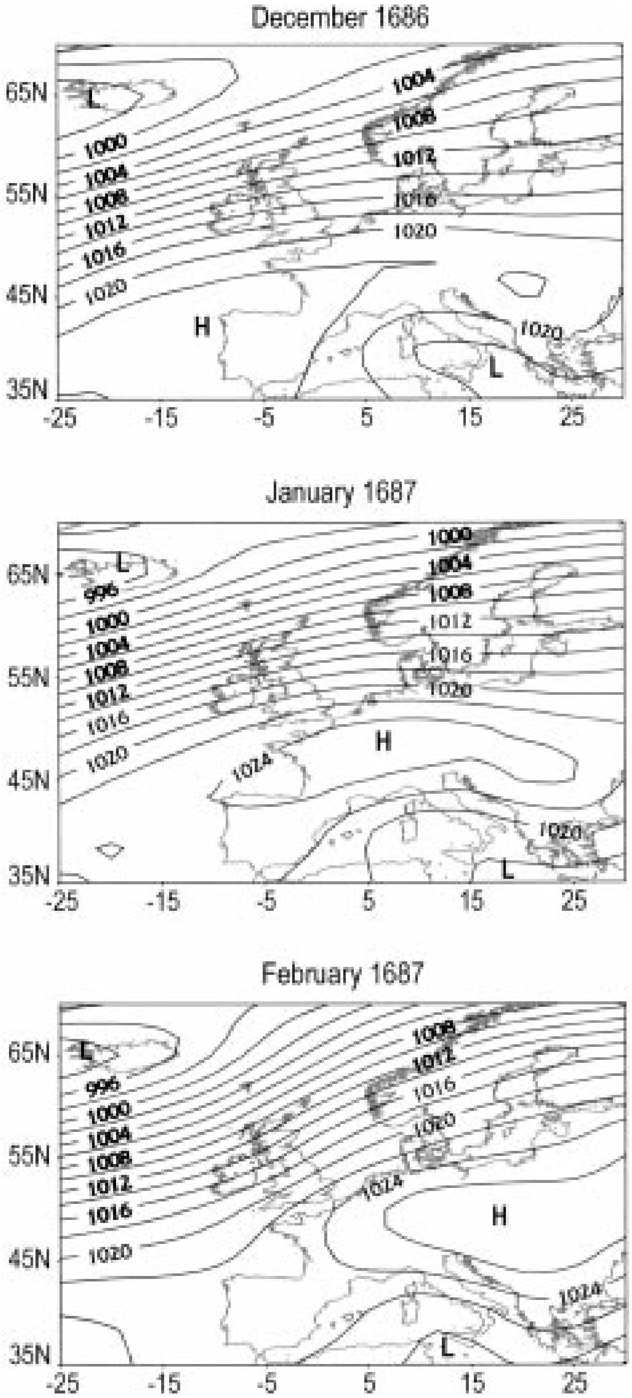
According to the reconstructions of Jones et al. (1999), similar synoptic conditions prevailed also during the winter 1828/1829 (not shown).

3.4. DRY SEASONS OVER THE MERIDIONAL BALKANS

From November 1680 until March 1681, in the western and central Greece, a long dry period with strong winds led to the drying up of the land '*... as if it was summertime ...*' (Veis, 1967, p. 110). The Ionian Islands experienced famine because of lack of wheat, which was insufficient for the nutrition of the inhabitants (Zois, 1893). In the following months, adequate rain in Peloponnese gave an abundant harvest (Politis, 1991, p. 267). The autumn of 1680 was a rather warm and dry season in central and western Europe (Pfister, 1994; Pfister et al., 1994). In Russia, the extreme drought during summer 1680 and during the year 1681 caused the death of animals and famine (Borisenkov, 1994).

During autumn 1695 and the winter of 1695/1696, lack of rain prevented the germination of grain in the Aegean and Ionian Islands (Stoianovich, 1994). The dry weather during the whole year of 1696 forced the desperate inhabitants of the islands in the eastern Aegean to place their trust in God and held litanies for supplication for rain (Kyriakidis-Argentis, 1787). Church litanies are preys developed exclusively inside church to obtain something from God due to environmental problems (i.e., drought, continuous rainfall, coldness, etc.).

The period from November of 1712 to summer 1714 was very dry in almost every region in Greece and caused the destruction of most harvest (Lampros, 1910, p. 209; Kordatos, 1960, p. 543; Iliadou, 1981, p. 25; Stoianovich, 1994). The drought that prevailed for so many months over the Greek area induced long famines in many places. The destruction of crops was total in most Greek areas. Reports about this period have been found for the regions of Epiros, Macedonia, Peloponnese, and central Greece, as well as for the Aegean Islands. The lack of foodstuff caused price rises. The famine of this period has been described as very


December 1686

January 1687

February 1687

Figure 6. Monthly mean reconstructed SLP charts (hPa) over Europe for the winter months 1686/87 (December, January and February) (Luterbacher et al., 2000a).

severe (Stoianovich, 1994). The time span from 1712 to 1714 was also noted as a period of years of plague in northern Greece, especially the Thessaloniki region. The consequences of the extreme weather of 1714 and of the very long dry periods were also pronounced in 1715, which was a year of great famine, especially for the central and southern Greece (Lappas, 1975, p. 29; Mertzios, 1969–1970, pp. 427–429), while in the region of Thessaloniki the food shortage was mainly attributed to the supplies taken for the Ottoman army (Iliadou, 1981, p. 26). For northern Greece and Serbia the winter of 1713/1714 was reported both dry and very cold (Vujevic, 1931). The cold weather also lasted through the spring with a disastrous impact on the grain harvest, leading to price rises. People died, and as it is reported: '*... Les gens erraient sur les routes et y mouraient de faim ...*' in Serbia (Vujevic, 1931). The dry period that lasted almost 14 months in Greece, was a European wide phenomenon, reported also in Bohemia and Moravia (Brázdil et al., 1994) and found to be the driest winter of the last 500 years in Switzerland (Pfister, 1994, 1999), France (Pfister and Bareiss, 1994) and Great Britain (Siegenthaler, 1994).

The lack of rain from May until October of 1802 caused price rises and famine in Serbia. The same phenomena, drought, rises in prices and famine, were also reported for the summer of 1803 in Serbia (Vujevic, 1931).

3.4.1. *Synoptic Conditions during Dry Seasons*

Lack of precipitation over the southern Balkans, in almost every season, is caused by blocking conditions (Maheras and Kolyva-Machera, 1993; Karacostas and Pennas, 1994; Xoplaki, 1998; Xoplaki et al., 2000). The long dry period of the late autumn of November 1695 and of January and February of 1696 (Figure 7) resulted from anticyclonic conditions prevailed over central, eastern and southeastern Europe, respectively which prevented crossing of low-pressure systems towards the Balkans.

3.5. RAINY SEASONS OVER THE MERIDIONAL BALKANS

The winter of 1684/1685 brought difficulties to the islands of the Ionian Sea because continuous rain prevented the sowing of the fields and led to increased foodstuff prices (Sathas, 1867, p. 227; Paschalis, 1930, p. 2; 1961, p. 67). The long duration of precipitation, and its extreme intensity, caused an increase in the level of the lake of Ioannina and extensive flooding destroyed many houses located on fairly higher altitudes (Aravantinos, 1856; Athinagoras, 1929). The rise in foodstuff prices in the rest of the year has been reported as a consequence of continuous rainfall (Kostis, 1993).

The year 1780 was rather difficult for the whole of Greece. In Epiros disastrous heavy rainfalls caused flooding and damage to buildings in the Ioannina area (Athinagoras, 1929). The prices of flour, olive oil and cotton kept on rising in western and northern parts of Greece (Scouvaras, 1967), while famine occurred, accompanied with plague, in Crete (Tchihatcheff, 1864, 1866; Kostis, 1995). According to

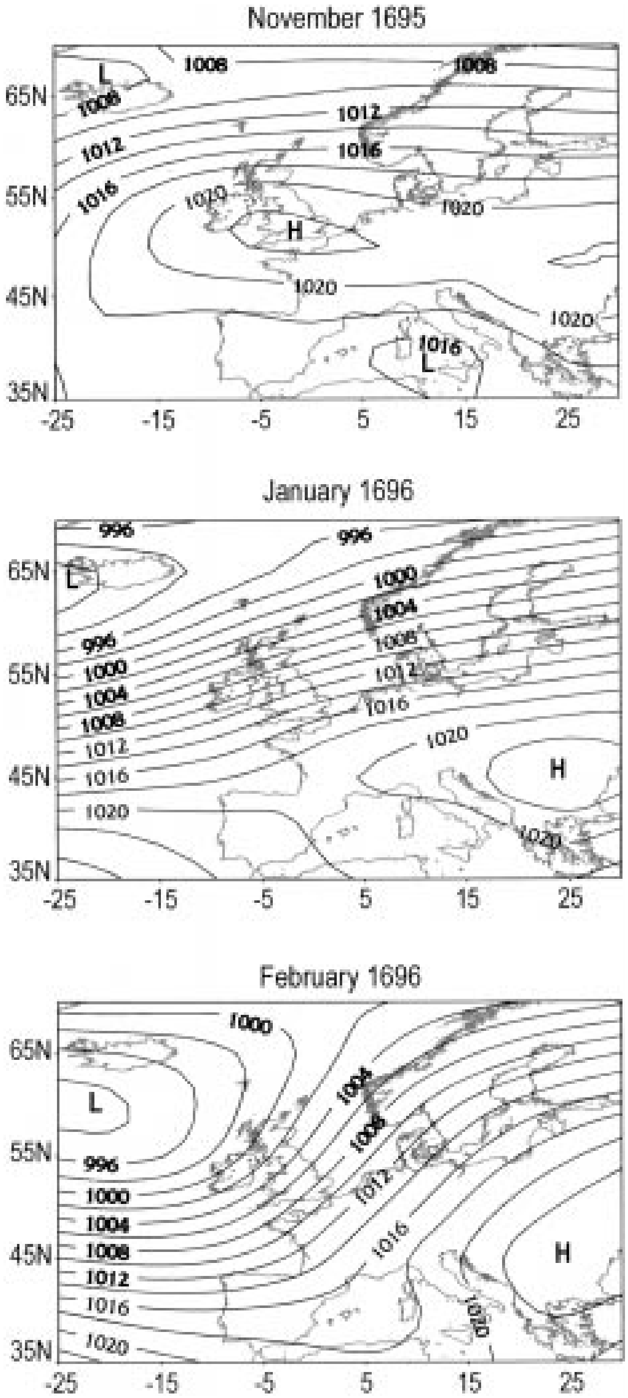


Figure 7. Monthly mean reconstructed SLP charts (hPa) over Europe for November 1695 and the winter months 1696 (January and February) (Luterbacher et al., 2000a).

the traveller Leake (1830), during winter 1804/1805 and spring of 1805 the excess of rain caused the death of cattle and a deficient harvest in western Macedonia.

3.5.1. *Synoptic Conditions during Rainy Seasons*

Anomalously high precipitation during the winter 1684/1685 might be attributed to low pressure over the eastern Mediterranean in combination with an anticyclone to the north or northeast (Figure 8). The combination of the cold air masses from the east, directed at the southern margins of the anticyclone, with the warmer Mediterranean air and sea masses led to distinct cyclogenesis and high precipitation values, especially over western Greece, where the Ioannina lake flooded. Here the effect of orographic lifting by the Pindos chain and the mountains of the Peloponnese played a major role. The SLP reconstructions of Jones et al. (1999) indicated similar synoptic conditions during the year 1780 (not shown).

4. Discussion

The majority of the documentary sources for the LMM and the EIP periods found refers to the winter. Winter is an important season for the eastern Mediterranean because it is normally wet and it is the early growing season. Drought in winters such as presented in Section 3.4, especially if long lasting, must affect the nature of the following harvest. The interaction of autumn rainfall, winter cold and dryness as well as spring rainfall seems to be important in the Mediterranean for the grain harvest volume of the following agricultural year. Winter climatic variability can affect people, their grain crops and their property and for this reason, winter was the most important season for the inhabitants of the studied area. Only limited information has been found about the olive trees, wine or fruit trees. According to Grove and Conterio (1994), no evidence has been found of any winters in the eastern Mediterranean at the turn of the seventeenth century, which were hard enough to cause widespread damage to olive trees and failure of the oil crop. However, the years 1691 and 1692 are mentioned by Lampros (1910) and Stavrinidis (1976) as years of olive oil crops failure. Such winters that caused the failure of the olive oil crop occurred in the twentieth century in the Mediterranean (Crete: 1991/1992; Provence (southern France): February 1956). The consequences of a crop damage may be food shortages or an increase in the cost of food, thus resulting in under- or malnutrition. Only after a particularly bad harvest the prices rise manifest itself immediately; normally a shortage becomes fully effective only in the following year (Bourke, 1984). An important indication of the appearance of food shortage and finally famine is stock prices' fluctuation, since prices are directly connected with the consuming power of the people and so with their welfare. However, the relationship between severe weather anomaly conditions and their consequences on prices includes a time lag. For instance, in the Mediterranean basin, a dry period during the growth stage or immediately after the sowing of the grain can seriously

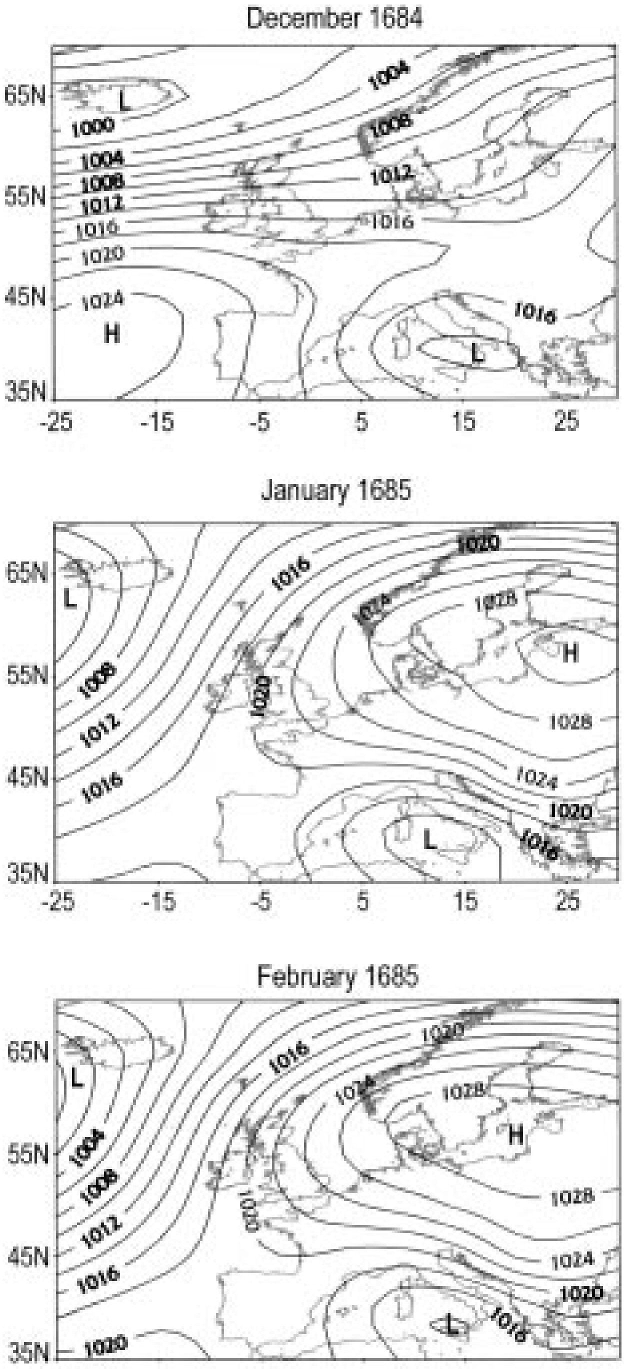


Figure 8. Monthly mean reconstructed SLP charts (hPa) over Europe for the winter months 1684/85 (December, January and February) (Luterbacher et al., 2000a).

damage the harvest. This damage is only apparent after a few months later and may, if the drought is very long (as from November 1712 to summer 1714; cf. 3.4), affect the harvest of the following year, because lack of grain can lead to price increases the next year, and even affect the next sowing (Le Roy Ladurie, 1972). A study of crops sterility, price-fluctuation and famine conditions in Greece, based on sources referring to meteorological conditions and to the prices of agricultural products has been made by Kostis (1993). He concluded that famines occurred in specific regions of Greece were caused by climatic fluctuations only in certain years, that is 1683, 1700, 1775 and 1779/1783. The period 1780–1783 was also characterised by a sequence of severe winters, except for 1781, and the sources refer to the appearance of famine in the areas where the phenomenon was intense. Thus, a drought or weather catastrophe can push an area into a food crisis but whether such a crisis develop into a famine depends on social and economic institutions (Reilly, 1999). This is in agreement with Bourke (1984) who found, that the pattern of a critical sequence of weather types, none of major significance in itself but cumulative in effects, recurs in many of the historical years of European food shortage. In addition, Gutman (1980) referred to ‘bad’ weather consequences that by itself, might produce a year or two of difficulties, and a few years of recovery, but it could not turn around the generally favourable economic and demographic climate of a region. The dynamic mixed economy of a region probably explains this phenomenon. A bad harvest caused by bad weather might tip the balance in a locale with a poor or single product economy. It is generally accepted that short-term (intra-annual, annual and interannual) variations in climate and weather, having an immediate effect on harvests and other economic activities, are relevant to short-term economic variations (Wigley et al., 1985). However, nutrition crises caused by intense climatic phenomena should be discussed cautiously. Factors that could bring about this kind of crisis include war, robbery, the obligation of the peripheral regions to supply the political centre (Istanbul), as well as the Ottoman army, mostly with grain, high taxes compared with the people’s financial abilities, together with illegal export of grain and the speculative activities of the state officials and/or merchants (the latter very often caused a simulated shortage of food in order to raise the prices!).

Despite the low level of technical development, farmers in the Meridional Balkans were able to develop methods of defence against unexpected climatic fluctuations. One of these was the cultivation of different kinds of crops in the same or different fields, a very common practice at that time. In this way, a farmer could achieve an adequate harvest of one kind of crop, for example maize, a grain sown during spring, while at the same time the wheat harvest could have been deficient because of drought or the excessive rainfall during the autumn-winter season. The importance of multi-cultivation, especially with regard to grain, can be understood from the fact that the ‘common’ people usually ate bread made from barley and wheat or barley and rye, saving the main part of the wheat harvest in order to sell it to the local market, legally or not, in order to fulfil their financial obligations. Therefore, an unexpectedly bad harvest of grain could cause distress in the local population, but not necessarily famine. Besides that, the cultivation of vine, fruit-trees and the possession of certain amount of domestic livestock provided the farmers with additional ways of rescuing themselves from a famine situation (Kostis, 1993).

Of course, there were groups of people, such as the cattle breeders in the mountainous areas, who suffered greater losses from an extremely severe winter or intense climatic fluctuations, since the death of their livestock could result in a very great loss of income. The great number of sources referring to losses of this kind reveal the serious effect of climatic variability on local populations. Intense climatic conditions could also cause great distress in places, such as the islands of the Aegean Sea, were the economic opportunities were limited (Kostis, 1993).

Due to the lack of weather information for some LMM months from Greece and from the neighbouring countries, the temperature and precipitation index 0 was applied (see Section 2.3.2). Existing gaps could mean that the climatic conditions were normal, so there was no motivation for the authors describing them. In addition, during summer, the well-known dry and warm period for the Mediterranean basin, no precipitation index lower than –1 has been reconstructed. The summer dryness is a very common phenomenon in the region, so in many cases precipitation conditions were ‘normal’ and the index 0 was set. Lack of a differentiation between average conditions and missing data can lead to an impression of much greater incidence of average conditions than actually occurred. Thus, the indices should be used with caution, since extreme episodes that are normally extensively described tend to be overestimated as far as the influence on the entire month’s average character is concerned.

Cooler and rainier conditions during the LMM (compared to the period 1961–1990) are in contradiction to central and western Europe, where the LMM was an interval with extremely cold and dry winters and springs (Pfister, 1992, 1999; Wanner et al., 1995; Luterbacher et al., 2000a, b). This estimation is in accordance with similar climatic conditions reconstructed for the western Mediterranean (Barriendos, 1997), but partly in disagreement with the results of Grove and Conterio (1994) for the eastern and central Mediterranean.

The reconstructed mean monthly SLP charts for some severe seasons mentioned in Section 3 showed different atmospheric circulation types leading to very cold and rainy (snowy) winters. The main synoptic situations, responsible for coldness and snowfalls over the region, are generally characterised by north–northwesterly or northeasterly airflow with high pressure over northern Europe and lower pressure over the central or eastern Mediterranean. Additionally, these situations together with the rather warm SSTs of the Aegean Sea and the orography may cause above normal precipitation due to atmospheric instability. Similar conditions from the twentieth century are found for northern Greece. In Thessaloniki, the winter of 1954 was the coldest for the 1901–1998 period. Thessaloniki reported 25 snowy days from December 1953 to February 1954 (mean of the period 1950–

1998 is 8 snowfall events; Mparsakis, 1999) and two times the normal amount of precipitation compared to the long-term average (1901–1998) of 120 mm. In addition, for Athens below normal temperatures and above normal precipitation values were measured. Another example of coldness over Greece was the winter of 1928/1929 with a similar pressure distribution. However, such extreme events were somewhat more apparent during the LMM and the EIP compared to the twentieth century. Situations such as the summer of 1700 with snow cover over the Cretan Mountains is a very rare situation and did not happen the last 50 years where instrumental measurements are available. On the other hand, summer snowfall over the Mount Olympus range (altitude >2500 m) in northern Greece is even nowadays rather common. This occurs about three times every summer (Sahsamanoglou, 1989). However, even in this area the snow normally remains on the ground only for some hours.

Anticyclones over central or western Europe or even over the eastern Mediterranean block low-pressure systems moving from the west. Particularly in winter, but also in spring and autumn, long dry periods over the whole Mediterranean are associated with a positive phase of the North Atlantic Oscillation (NAO). Drought during winter and early springtime can be also attributed to the southward extension of the continental anticyclone over eastern Europe, covering the whole Balkans, connected with subsidence and stability conditions and thus with remarkable dryness. It is interesting to note that the synoptic situation during winter 1695/1696 (cf. Figure 7) was comparable to the winter of 1988/1989, which was responsible for several droughts over Greece (Maheras and Kolyva-Machera, 1993). This winter was the driest in Thessaloniki and the second driest in Athens for the twentieth century.

Above normal precipitation over the eastern Mediterranean can be attributed to the combination of high pressure in the north and low pressure over the Mediterranean basin. In the twentieth century, no similar winter such as 1684/1685 has been found with high precipitation amounts in northern Greece, the Aegean Sea and Athens.

The impact of climatic conditions on human life can also be seen in the outburst of plague, a real menace for pre-industrial societies. Plague rarely occurs during extreme climatic conditions, especially in cold and dry winters. During the period 1712–1714, plague is mentioned in the Thessaloniki region although the climatic conditions were not conducive to the outburst of plague. According to Kostis (1995), the plague was enhanced due to the poor nutritional condition of the people. The meteorological conditions contribute to the development of an epidemic without being capable of inducing its outburst.

5. Conclusions

Compared to the wealth of data found in central and western Europe the data density for the studied periods and areas is rather low and this may be attributed to the Turkish occupation, which lasted from the fifteenth to the nineteenth century. Further detailed data could probably be found in the Turkish archives. Most of the documentary evidence has been found for the winter season. However, based on the documentary evidence monthly temperature and precipitation indices (+3 to –3) have been reconstructed for Greece for the 1675–1715 (LMM) period. The differences between the observed (estimated) and the expected reference period frequencies (1901–1960) of these indices revealed differences between the LMM and the period 1961–1990. The overall balance during the LMM showed more monthly deviations of one Pfister score than expected from the reference period distribution and for temperature (precipitation) more negative (positive) biases. Thus, from the scattered data found for 1675–1715 and 1780–1830, the winter and spring climate in southern Balkans and the eastern Mediterranean, especially during the LMM can be characterised as rather cool and relatively rainy, with a higher variability than during the period 1961–1990.

The higher frequency of colder winters could be due either to the persistence and intensity of the continental anticyclone over the western and central Europe and/or to the persistence and intensity of the extensive high-pressure system over Scandinavia and northeastern Europe. These conditions could explain occasional incursions of cold air towards the southern Balkans and the eastern Mediterranean. Higher pressure to the north in combination with lower pressure over the central and eastern Mediterranean could account for higher frequency and quantity of snow in Greece and in the eastern Mediterranean. The occurrence of some dry periods of long duration during the LMM can perhaps be attributed as well to the presence and persistence of the same anticyclones extended towards the south, covering the whole of the central and eastern Mediterranean.

The most important crops in the southern Balkans during the LMM and EIP periods were grain, olives and grapes. The influence of adverse weather on grain crops, sometimes resulting in their failure, could cause food shortage and famine. In the southern Balkans and the eastern Mediterranean, the meteorological factors that can make the difference between a good and a bad harvest are the amount of rainfall, which is the most important, and the range of temperature at specific times of the year. More specifically, these factors are the amount of precipitation in autumn, the mildness or harshness of winter and the amount of precipitation in spring. However, more complete understanding of the complexity of the relations between climate and harvest failure surely demands detailed knowledge of the basic requirements of different crops in terms of temperature, moisture and wind speed during different seasons. In addition, more research for the period 1716–1779 is necessary in order to study climate variability connected with impacts on human life over the Meridional Balkans for the last centuries.

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Libraries

Gennadios Library, Athens.
Library of the Archaeological Museum of Athens, Athens.
Aristotle's University Library in Thessaloniki, Thessaloniki.
Municipal Library and the Library of the Society for Macedonian Studies in Thessaloniki, Thessaloniki.
University Library of Istanbul.
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