Winter air temperature variations in western Europe during the Early and High Middle Ages (AD 750-1300)

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Received 30 August 1996; revised manuscript accepted 27 October 1997

Abstract: In this paper an attempt is made to reconstruct air temperature variations in winter (December, January and February) from 2500 documentary data over the period AD 750-1300 for a region comprising the Benelux countries, eastem France, western Germany, Switzerland and northem Italy. Anomalous (warm and cold) winters were classified on the basis of proxy information on frost, freezing of water bodies, duration of snowcover and untimely activity of vegetation using semiquantitative indices. For the most severe winters during the 'Medieval Warm Period' (MWP) as weil as for the outstanding warm and dry winter AD 1289/90, possible ,analogue cases from the last 300 years are considered, analysed, synoptically interpreted and compared with each other. It is concluded that severe winters were somewhat less frequent and less extreme during the MWP. AD 900-1300, than in the ninth century and from 1300 to 1900. Mean air temperatures for 30 year. periods were estimated from linear regression models including indices and instrumental measurements. From AD 1090 to 1179 winter temperatures were at the level of the .Little Ice Age' (LIA). From AD 1180 tQ 1299 they were at that of the twentieth century .The warm and stable winter climate in the thirteenth century sup- ported subtropical plants such as olive trees in the Po val1ey (northem Italy) and fig trees around Cologne (Germany). The period AD 1300-1329 which marks the transition to the LIA was loC colder. It is concluded that the 1961-90 level of winter temperatures in western central Europe is stil1 within the threshold of natural variability of the last thousand years, albeit at its upper boundary .

Key words: 'Medieval Warm Period', 'Little Ice Age', 'North Atlantic Oscillation' (NAO), winter air tempera- tures, vegetation, western Europe, documentary data.

Introduction

The term 'Medieval Warm Period' (MWP) designates an interval (AD 900-1300) of elevated ternperatures first identified in northern Europe. For this reason the International Geosphere-Biosphere Programme (IGBP) core project, known by the acronyrn PAGES (past Global Changes), identified the MWP as a focus for detailed reconstruction of climatic parameters in comparison with present- day values. A better understanding of past climate regimes frorn the eighth to the fifteenth centuries may be vital if we are to dis- tinguish between natural variability and that resulting frorn an anthropogenic influence on the climate system (Jones et al., 1996). In this sense the regional and seasonal changes during the MWP provide a climate scenario for the twentieth century without anthropogenic perturbations (Jirikowic and Darnon, 1994). The most recent survey of the discussion (Hughes and Diaz, 1994) indicates that the pattern in the character of climatic anomalies during the ninth to the fourteenth centuries shows regional and seasonal differentiation in much the same way as in the .Little Ice Age. (LIA). However, the evidence available .provides at best a rough picture of the c1imate of this epoch and much work remains to be done to portray in greater detail the climatic essence of the MWP'. Yan et al. (1988), and Ogilvie and Farmer (1997), argue strongly for caution in using the traditional term MWP, sug- gesting that this conceptual scenario is.being chal1enged as more detailed data become available.

Most climate reconstructions of the MWP are based on proxy indicators such as tree-rings (e.g., Schweingruber. 1988; Briffa et al., 1992; Serre-Bachet, 1994), dated glacier moraines (e.g., Holzhauser and Zumbühl, 1988; Grove, 1988; Nesje and Kvamme,et al., 1991; Matthews, 1991; and Grove and Switsur, 1994) and lithofacies (Jennings and Weiner, 1996) which are sea- sonally restricted to the summer half year. Guiot et al. (1988) are the on1y scho1ars so far who have attempted a reconstruction of annual temperatures for western Europe.

Few efforts were spent on reconstructing winter temperatures.

The Dutch journalist Cornelis Easton (1928) compiled citations describing extreme conditions in winters from 396 BC to the early twentieth century, and he derived an index as a means of classify- ing winter severity. The pioneering work by Lamb (1977) drew on this idea and he developed a thermal winter index by calculat- ing the ratio of .mild' and .severe' winters per decade. It was subsequently shown that a part of Lamb's material for the early and high Middle Ages was non-contemporary and therefore ques- tionable (e.g., Ingram et al., 1981; Ogilvie, 1991). Alexandre (1987) produced a critical compilation of more than 3500 'cli- matic texts' from AD 1000 to 1425 distinguishing between con- temporary (first class) and non contemporary (unreliable) sources. This was a milestone. However, he did not improve Lamb's meth- odology of data classification and interpretation. Ornato (1988) criticized Alexandre for relying on the impressive descriptions of the chroniclers without considering more objective criteria to determine how warm or cold a month or a season might have been by present-day standards. This implied that the climatic nor- mals of the Middle Ages were the same as today. Another long- term reconstruction of seasonal temperatures from AD 1000 for central Europe (Glaser, 1995) is provided in the form of a sum- mary graph and a short comment. A well-founded critique of these results is not possible, yet.

Following the lead of the Belgium meteorologist, E. Vander- linden (1924), a comprehensive compilation of meteorological texts for the medieval period prior to 1300 was recently presented in Dutch by Buisman and van Engelen (1995). The data were drawn mainly from careful compilations (Britton, 1937; Alexan- dre, 1987) and from Dutch regional sources. Temperatures are expressed in terms of indices on an ordinal scale ranging from 1 (extremely mild) to 9 (extremely severe) with reference to the period 1901-60. In many cases it is not possible to reproduce the derivation of the indices from the data according to the given criteria. Besides these efforts in the larger framework of .Europe' some recent national reconstructions need to be mentioned: Lyons (1989) carefully examined the known annals and chronicles from Ireland. Brazdil and Kotyza (1995) had a fresh look at the Bohem- ian archives and added about a third more cases of extreme sea- sons for the period 1101 to 1425 in the Czech Lands compared to the data compiled by Alexandre (1987). Winter precipitation inMorocco after 1100 was reconstructed from dendrological data (Till and Guiot, 1990). Data on English winter temperature and precipitation are included in a recent reconstruction by Ogilvie and Farmer (1997).

In this paper a 550-year reconstruction of winter temperature is developed for the Early and High Middle Ages over western central Europe from documentary proxy data that relate to observed temperature-dependent processes in the natural environ- ment (ice, snow and plant activity). The onset of the Middle Ages is not universally defined (Faulstich, 1996). The year of AD 750 suggested by Heinzle (1993) was chosen as a starting point, because it coincides with the time from which the first substantial descriptions of anomalies are available. The dates quoted in the text, except the quotation of sources in the footnotes, are accordng to the New Style calendar.

The second section of this paper highlights the creation of med- ieval sources, gives a survey of the evidence and introduces the data base, Euro-Climhist (University of Bern), in which the data are stored. The third section focuses upon dating control which is at the root of the many misinterpretations with which documen- tary data are plagued. The fourth section is devoted to the cali- bration of the evidence and to the setting up of time series. In the fifth section the available information is presented. The last sec- tion includes a consideration of the wider perspective of climatic conditions in medieval times and the question of whether there really was a MWP in western central Europe.

Sources and data

This section provides a survey of the documentary sources avail- able for the Early and High Middle Ages and explores their strengths and weaknesses for the reconstruction of past weather and climate. The bulk of proxy information for the winter half- year is contained in narrative or literary sources. There are enor- mous quantities of data, but not for every period. Before the twelfth century the material is relatively scanty. Almost all of it was included in one or several compilations, but this was some- times undertaken in an uncritical way (van Caenegem, 1978).

This paper mainly draws on the impoftant collection of annals and chronicles edited in the series of the Monumenta Germaniae Historica Scriptores (MGH) which today comprises 33 volumes. The MGH were the first edition of medieval sources which was critical in method and conceived according to a deliberate and comprehensive plan (Pfister et al., 1996). Much of the evidence for France and the Benelux countries is taken from the critical compilation of Alexandre (1987).

All text passages relating to climate were made machine-read- able. The data are stored in the Euro-Climhist data base, which also includes a coherent set of various kinds of proxy data from all parts of Europe for more recent periods -natural and docu- mentary , as weil as a large set of instrumental data comprising the period of network observations. This allows a rapid comparison of data in space and over time. The software allows a ftexible hand- ling of a hierarchical four-level space and time structure and the creation of suitable icons. Examples of the data edition and maps are displayed together with tentative reconstructions of the perti- nent sufface pressure situations. A first focus was put on the LMM (Late Maunder Minimum) which includes the interval from AD 1675 to 1715 (Pfister et al., 1994; Wanner et al., 1995). A recent focus was put on the fourteenth century (Pfister et al., 1996).

Narrative sources are classified by modem historians according to two types, annals and chronicles, depending on the style in which the facts are reported. Attributing a specific source to one of these two types is difficult, because many transitory forms are known. In particular, it must be stressed that the name of a source is not conclusive in this respect (Ondracek, 1992).

The annalistic style consists of a list of unconnected, laconic notes of 'facts' such as biographic episodes of rulers, campaigns, famines, natural hazards or meteorological anomalies which occurred in a given year (McCorrnick, 1975). The narrative scope of this type of report, taken by itself, is rather lirnited: fragments of information such as 'hiems durissima' (very cold winter) or 'hiems longissima' (very long winter) are not sufficient to assess the main meteorological characteristics of a season, but they are often helpful as a complement that improves the spatial recon- struction of an outstanding season. In the earliest narrative sources, weather events are casually mentioned because they were inftuential in a historical event, such as a campaign, an epidernic or a political decision. The style of chronicles is more lengthy, more story-like than that of annals, and this type of source may indeed provide detailed descriptions which are sufficient to ident- ify the basic meteorological traits of a season. In view of climatic information two types of chronicles need be distinguished. Uni- versal chronicles are too general in scope to include references to weather. Most of the 'sources that are attentive to climate' (Alexandre, 1987) focus on the activities in a small region which often coincided with the economic sphere of a convention. Medie- val writers did not reveal their motivation for keeping track of climatic anomalies.

In total, 8850 meteorological texts were extracted for the period from AD 750 to 1300 (Figure 1). The evidence is very unevenly distributed over time. This is explained by the main trends of medieval historiography. The later eighth and the ninth centuries witnessed major developments in th-e secular Frankish historio-

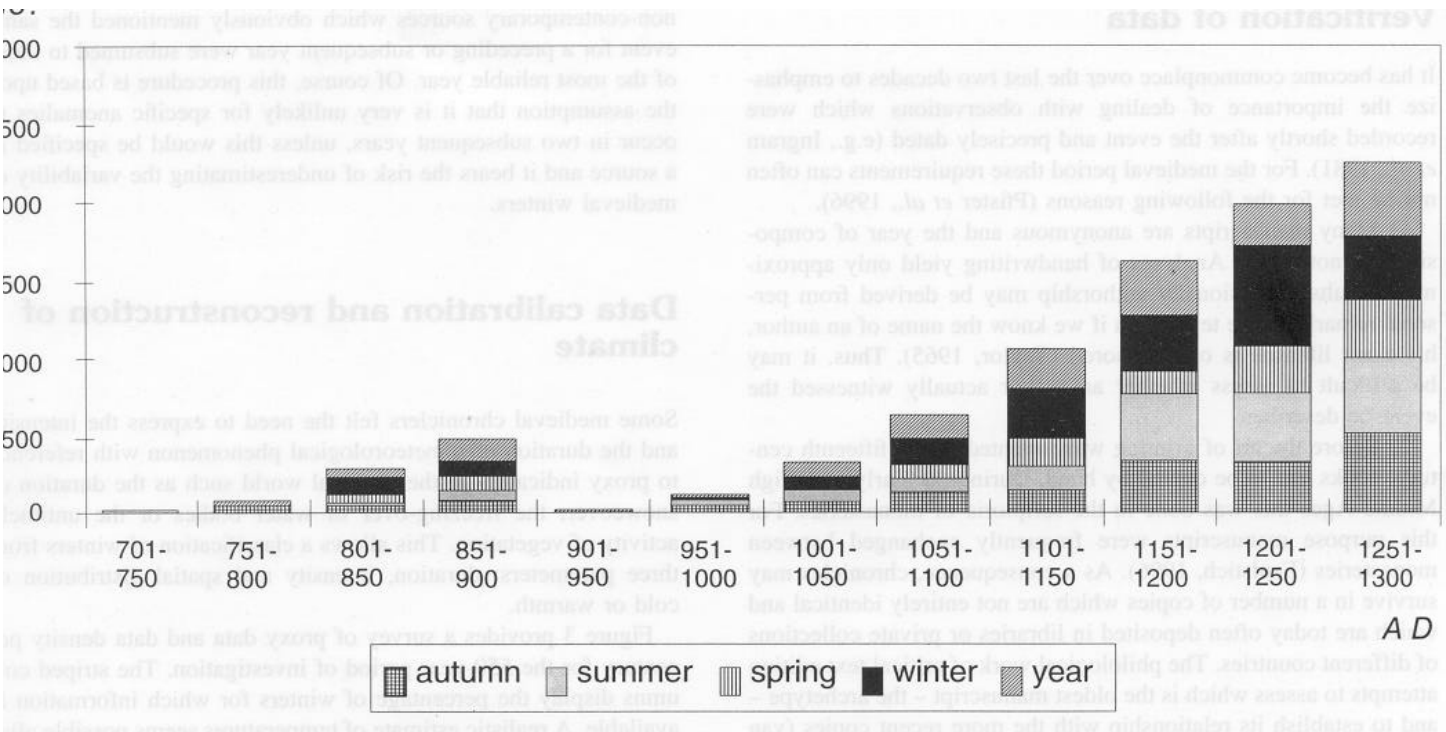

Figure 1 Number of meteorological text passages found in narrative sources for Central Europe (AD 700 to 1300).

graphical tradition with new forrns of historical writing, such as annals, biographies and epic poems. These offer essentially contemporary comrnentary on the events of their own day. The Franks had an especially keen sense both of the past and of the importance of providing a record and interpretation of contempor- ary events for posterity (McKitterick, 1995). The reigns of Charle- magne and Louis the Pious saw a remarkable expansion in the copying of manuscripts throughout the Carolingian empire. Some 500 manuscripts survive from Merovingian Gaul copied before AD 750; and some 7000 manuscripts survive copied in the Caro- lingian empire between AD 750 and 900 (Bischoff, 1990). The blossorning of education and 1iterary culture was promoted by Charlemagne and his sons and grandsons (Contreni, 1995).

From about AD 900, the flourishing Carolingian cu1ture withered away and during the ear1y tenth century the copying and writing of manuscripts nearly ceased (Wattenbach and Holtzmann, 1948). Presumably this was partly as a result of the disruption to econornic and intellectuallife caused by invading Hungarians, Northmen and Slavs.

The gradual rise in meteorological texts over the following three centuries rnirrors the recovery of intellectual life under the Ottos and their successors. New conventions and re1igious orders were founded and the constitution of the first European univer- sities created a comp1ete1y new kipd of cu1tura1 institution (Rüegg, 1992). This included a revival of the Latin classics and Roman law as weil as the rediscovery of Greek science, with its Arabic additions, and of much of Greek philosophy. Up to this time and beyond the perception of nature was based on the fundamental role of God. The theology of Augustine (AD 354-430) reduced nature to the Will of God and denounced any endeavour towards scientific discovery as vain curiosity. Then from the twelfth century the newly discovered classical sources, in particular the natural-philosophical writings of the Greek philosopher and mathematician Plato (c. 428-348 BC), such as Timaeus, and those of his disciple Aristotle (384-322 BC), promoted a turn towards a 'real' world perceptible by the senses, which would be understandable and exp1ainable without any recourse to supernatural agents. The principle of rationality engendered a science of nature which asked about the causes and no longer about the symbolic meaning of natural phenomena (Gregory, 1975). The understanding of nature was now theoretically and practically based on experience.

St. Albertus Magnus (c. AD 1200-1280), who was a follower of Aristotle, made animals and plants, as well as meteorological phenomena, the objects of observation and thereby desacralized them (Dirrigl, 1980). It is hypothesized that these tendencies gave rise to the inclusion of references to plant growth (i.e. phenological observations) in the reports on unusual seasons. Information on winters comprised the lion's share (43%) in the period AD 801- 850. Possibly, the early writers paid most attention to conditions prevailing in the cold seasons. In the High Middle Ages the sea- sonal distribution of the narrative is more balanced.

The regional composition of the data mirrors the economic and cultural centres of gravity of the Old German Empire situated in the regions adjacent to both sides of the Rhine valley: 37% of the meteorological texts refer to events in what is today Germany, 22% to France, 17% to (northern) ltaly, 15% to the Low Countries (today's Benelux) and 7% to Austria. The category .others' con- sists of Switzerland, the UK, Ireland, the Czech Republic, Slo- vakia, Poland, Hungary and Spain (Figure 2).

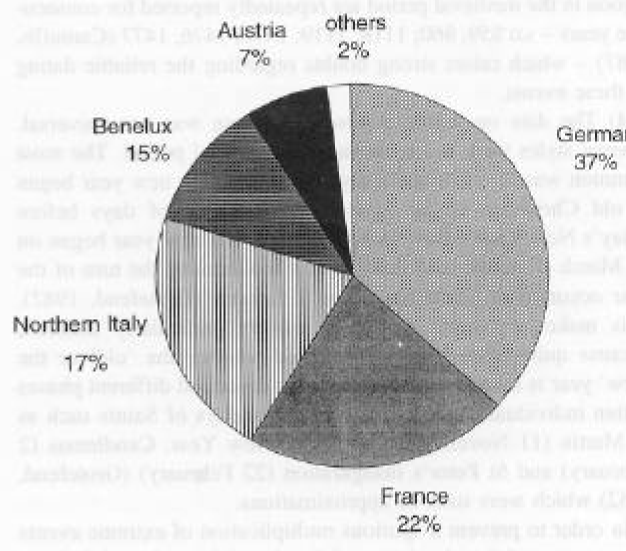

Figure 2 Regional composition of climatic evidence for the period AD 700 to 1300.

Verification of data

It has become commonplace over the last two decades to emphasize the importance of dealing with observations which were recorded shortly after the event and precisely dated (e.g., Ingram et al., 1981). For the medieval period these requirements can often not be met for the following reasons (Pfister et al., 1996).

1) Many manuscripts are anonymous and the year of composition is not given. Analyses of handwriting yield only approximate results. Occasionally authorship may be derived from personal remarks in the text. Even if we know the name of an author, his exact lifetime is often ignored (Taylor, 1965). Thus, it may be difficult to assess whether an author actually witnessed the event he describes.

2) Before the art of printing was invented in the fifteenth century , books had to be copied by hand. During the Early and High Middle Ages this was done in the scriptoria of monasteries. For this purpose manuscripts were frequently exchanged between monasteries (Faulstich, 1996). As a consequence, chronicles may survive in a number of copies which are not entirely identical and which are today often deposited in libraries or private collections of different countries. The philological work of critical text edition attempts to assess which is the oldest manuscript -the archetype - and to establish its relationship with the more recent copies (van Caenegem, 1978). Quite often the autograph is lost or cannot be assessed. The procedure of text edition is discussed together with the issue of authorship in the introduction of critically edited sources -such as the MGH. These comments must be consulted in order to assess the reliability of a source for a given period.

3) Errors occurred frequently in the time-consuming process of transcribing texts from one chronicle to another. Most of them were misdatings, i.e. an event was attributed to a wrong year . The current Roman style of writing numbers was error-prone. For example, Toaldo (1781), through a reading error, changed an X into II, transforrning the year MDXI (1511) into MD111 (1503), and said that the artillery of Pope Julius II crossed the frozen river Po in this year. This statement was then propagated by Easton (1928) as an independent event, in addition to the correctly reported event of AD 1511 (Camuffo and Enzi, 1995). Because the year itself has no logical relation to the event, dating errors are not easily discovered. For medieval sources, it has been established that the error is frequently one year earlier or later. In his critical catalogue of climatic events Alexandre (1987) lists 300 inconsistencies of this kind. These uncertainties in dating have resulted in much confusion, because they often lead to a duplication of extreme events. For example, freezings of the Venetian lagoon in the medieval period are repeatedly reported for consecu- tive years -AD 859,860; 1118, 1119; 1475, 1476, 1477 (Camuffo, 1987) -which raises strong doubts regarding the reliable dating of these events.

4) The date on which a new year began was not universal. Several styles were in use during the medieval period. The most common was the .Christmas style', in which the new year began at old Christmas (Julian style), i.e., a couple of days before today's New Year's Day. In another style the new year began on 25 March (Camuffo and Enzi, 1992). In Germany the turn of the year occurred at Christmas or on 1 January (Grotefend, 1982). This makes a correct dating of winters particularly difficult, because quite often it is not specified whether the .old' or the .new' year is meant. Where chroniclers described different phases within individual winters they referred to days of Saints such as St Martin (11 November), Christmas, New Year, Candlemas (2 February) and St Peter's inauguration (22 February) (Grotefend, 1982) which were used as approximations.

In order to prevent a spurious multiplication of extreme events it was assumed that the dating of the chroniclers who might have witnessed the event was the most reliable. Reports contained in non-contemporary sources which obviously mentioned the same event for a preceding or subsequent year were subsumed to those of the most reliable year .Of course, this procedure is based upon the assumption that it is very unlikely for specific anomalies to occur in two subsequent years, unless this would be specified in a source and it bears the risk of underestimating the variability of medieval winters.

Data calibration and reconstruction of climate

Some medieval chroniclers felt the need to express the intensity and the duration of a meteorological phenomenon with reference to proxy indicators in the physical world such as the duration of snowcover, the freezing-over of water bodies or the untimely activity of vegetation. This allows a classification of winters from three parameters: duration, intensity anq spatial distribution of cold or warmth.

Figure 3 provides a survey of proxy data and data density per century for the 550-year period of investigation. The striped columns display the percentage of winters for which information is available. A realistic estimate of temperatures seems possible after 1040 when data density rises above 25%.

Proxy data are displayed according to type and amount. Most of the 'proxy' characterizations of winters were related to the duration of snowcover. A fresh snow layer is an eye-catching meteorological event which is not easily overlooked. Long periods of cold and snowy weather including March and April were the most serious adverse weather conditions with regard to humans and cattle (Curschmann, 1970) and for this reason they were most often recorded. A few 'proxy' characterizations already appear in the ninth century. The freezing of water bodies occurred less often, but it was more spectacular and therefore it was more often recorded. The bulk of the evidence from AD 1000 relates to the three most outstanding cold anomalies within this interval: 1067/77 , 1149/50 and 1234/35.

Warm anomalies were not consistently recorded before the twelfth century .One major reason for this may be that the impacts of the warm episodes were less obvious and significant for the human ecosystem. Chroniclers, not wrongly, linked these 'unnatu- ral' winters to the outbreak of epidemics and/or epizootic diseases. Most attempts to 'objectively' characterize warm winters related to the lack or to a short duration of frost periods and to the ephem- eral occurrence of snowcover as a consequence of long spells of warm, rainy and stormy weather. Occasional phenological obser- vations, reporting an untimely activity of vegetation during the winter months, appear from the early twelfth century in Europe. The first known observation of this kind is contained in a rhyming chronicle from Liege (Belgium) where it is reported that ripe strawberries were found at Christmas AD 1116, supporting the impression of an exceptionally warm spell (Alexandre, 1987). From the turn of the thirteenth century some chroniclers began to include winters of a mixed character, including warm periods and phases of harsh frost, e.g., AD 1205/06, 1206/07 and 1220/21.

The preferred approach to calibrate the evidence would be setting up long time series of proxy data overlapping the period of instrumental measurements, running regressions and computing transfer functions from the equations. This was done for data on the freezing of some Dutch canals for which continuous administrative data are available from 1634 (van den Dool et al., 1984). Occasional data of this type were also found for the medieval period (van Buisman and van Engelen, 1995). Likewise, continuous time series were set up for the extent of ice cover in the western Baltic (Koslowski and Glaser, 1995).

Unfortunately, this approach could not be applied to the freez-

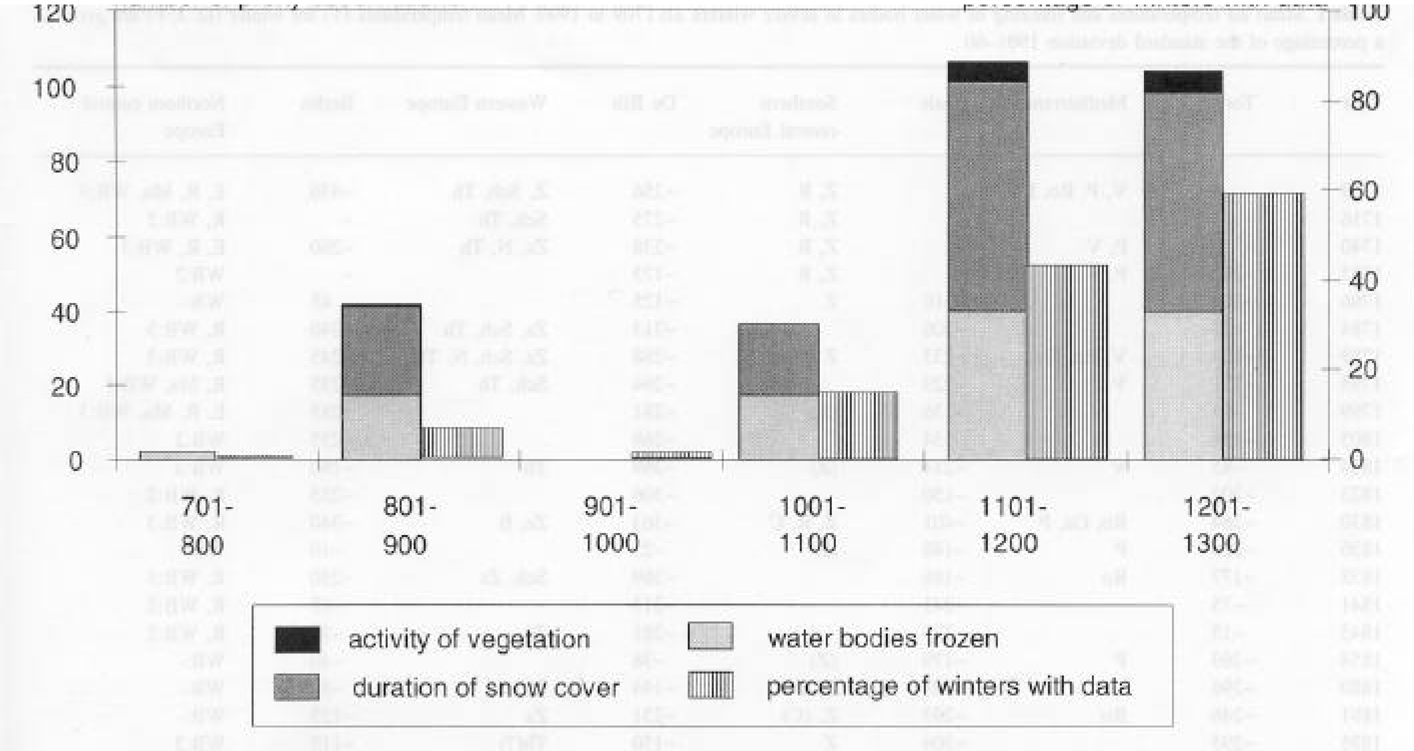

Figure 3 Distribution of proxy data and data density.

ing of rivers, the most frequent and conclusive proxy evidence for medieval winters for the following reasons.

I) The events are not annually recurrent, which considerably reduces the number of potential cases.

2) The events were not continuously observOO. We cannot be sure that the event did not occur if it is not mentioned in the sourc- es.

3) The relationship between the freezing of water bodies and air temperature has been changing as a consequence of anthropogenic influence over the last two' centuries. Besides modifications of river channels (Jansen, 1983; Vischer, 1986) this involves Indus- trial pollution. For example, if the Thames was frozen in London, a fair used to be held on the ice-cover. The last episode of this kind occurred in AD 1813/14. Since then, the feeding of warm water into the river from the growing city and its industries, together with the influx of salty water downstream, seem to have impeded further freezing in extremely cold winters, at least near the city (Jansen, 1983; van Buisman, 1984). In February 1895 the river was completely frozen over at Gravesend and Kingston (Currie, 1995). As a consequence a different, somewhat less ideal approach had to be taken. This tactic involved, first, an analysis of the spatial distribution of temperature anomalies that are asso- ciated with the most severe winters of the instrumental period. These results should give an idea of the spatial patterns of extreme anomalies that might plausibly be obtained from documentary data and provide some hints for a synoptic interpretation of these cases. Second, the observed freezings of water bodies were com- pared with the extreme temperature anomalies in order to obtain a yardstick for a classification.

In western and central Europe many air temperature series orig- inate prior to AD 1800; some of them even go back prior to 1750 (Brumme, 1981; Manley, 1974; van den Dool et al., 1984). The cases listed in Table 1 were selected from four long instrumental series -Turin, Basle, De Bilt, Berlin -that are representative for the heartland of medieval Europe. The table includes severe win- ters for which the average air temperature was below 250% of the standard deviation (computed for the period 1901-60) at least at one of the four locations mentioned above. The ice index on the western Baltic (Koslowski and Glaser, 1995) is a good indi- cator for winter air temperatures in the northem part of central Europe. Freezing of the Po and/or the Venetian lagoon occurred in winters in which the mean air temperature was at least two standard deviations below that of the period AD 1901-60. This threshold is also observed for freezings of the other water bodies illustrated: Lake Zürich, Rhine (near Basle and in its middle sec- tion in Germany) as weil as Dutch and Belgian rivers and the former Zuider Zee, which prior to the twentieth century was almost a closed part of the North Sea but has now become the freshwater lake Ijsselmeer.

The reconstruction was based on the classification of documen- tary proxy evidence according to the methodology of developing monthly and seasonal semiquantitative temperature indices (Pfister, 1988) which is now widely accepted (Glaser, 1991; Wang and Zhang, 1988; Wang et al., 1991; Brazdil and Kotyza, 1995; Ogilvie and Farmer, 1997). In view of the medieval period the scheme of classification had to be adapted to the lower density of data compared with the period after AD 1500 (Pfister et al., 1996) (Table 2).

An index of seven discrete levels (-3, -2, -1,0, +1, +2, +3) was attributed to those winters which are documented in more than one contemporary source. Months described with purely descriptive evidence scored + I or -I irrespective of the emphasis given by the chronicler. Winters documented with adequate 'proxy data' scored +2/-2 or +3/-3 according to the duration and severity of the cold speil. 'Norrnal ' winters of a mixed charac- ter scored 0.

The reconstruction involved the long temperature series of De Bilt that originates in AD 1706 (Labrijn, 1945). It was based on a concept that simulated the structure of the temperature indices obtained from the documentary evidence using instrumental data. The series of measured temperatures were downgraded to an ordi- nal scale of seven discrete levels according to the classification of indices (I)0-3 described above (cf. Table 3). Subsequently thirty- year means of indices were computed and compared to the arithmetic averages obtained from the same series in linear regression models.

In a first step the model (regression I) included all seven levels of indices. Regression 2 excludes the indices of level 0, because percentage of the standard deviation 1901–60

'ear	Torino	Mediterranean	Basle	Southern central Europe	De Bilt	Western Europe	Berlin	Northern central Europe
709	–	V, P, Ro, Eb	–	Z, R	–256	Z, Sch, Th	–430	E, R, Ma, WB:3
716	–		–	Z, R	–275	Sch, Th	–	R, WB:2
740	–	P, V	–	Z, R	–238	Zs, N, Th	–260	E, R, WB:3
755	–292	P, V	–	Z, R	–175		–	WB:2
766	–200		–310	Z	–125		45	WB:-
784	–38		–206		–313	Zs, Sch, Th	–240	R, WB:3
789	–108	V, Ro, Ga	–233	Z	–288	Zs, Sch, N, Th	–245	R, WB:3
795	–331	V	–229		–294	Sch, Th	–235	R, Ma, WB:3
799	–95		–136	(Z)	–281		–285	E, R, Ma, WB:3
805	–154		–134		–269		–255	WB:2
814	–85	V	–214	(Z)	–269	Th	–190	WB:3
823	–202		–150		–306		–255	R, WB:2
830	–364	Ro, Ga, P	–401	Z, R, C	–363	Zs, B	–340	R, WB:3
836	–225	P	–148	(Z)	–25		–10	WB:-
838	–177	Ro	–186		–269	Sch, Zs	–250	R, WB:3
841	–75		–241		–213		–65	R, WB:2
845	–15		–223		–281	Zs	–35	R, WB:2
858	–269	P	–179	(Z)	–38		–40	WB:-
880	–298		–324	Z, C	–144	Zs	–80	WB:-
891	–246	Ro	–293	Z, (C)	–231	Zs	–125	WB:-
895	–295		–304	Z	–150	Th(?)	–115	WB:2
929	–259	(P), V	–243	Z	–229	N, Zs	–272	WB:2
940	–59		–192		–267		–320	WB:3
947	–256		–183		–289	N	–279	R, WB:3
963	–159		–324	Z, C	–358	Zs, N	–262	R, WB:3

etters in brackets: water body partly frozen or ice not safe for pedestrians.

	Lake of Constance	Ma	Main	Th	Thames
	Elbe	P	Po	V	Venetian Lagoon
b	Ebro	R	Rhine	WB	Ice Index Western Baltic
ia	Ga Garonne	Ro	Rhone	Z	Lake of Zurich
	shores of North Sea	Sch	Schelde	Zs	Zuidersee

ources: Proxy data: Mediterranean: Venetian Lagoon: Camuffo and Enzi (1992); Po river: Hug (1995); French rivers: Buisman (1984); southern central urope: Pfister (1988); ice index western Baltic (WB): Koslowski and Glaser (1995); northern central Europe: Weikinn (1958–63), Jansen (1983), Buisman 1984); western Europe: Buisman (1984), Currie (1995). Temperatures: DOE, Brumme (1981).

'able 2 Rating of temperature indices from descriptive and proxy evidence

ndex	Type of winter	Descriptive data (monthly)	Proxy indicators (lowlands) (seasonal)	% sigma
3	severe	3 'cold' months and	extreme duration of snow cover; water bodies ice-covered for several weeks	<–250
2	cold	2 'cold' months or	ground snow-covered for several weeks; water bodies ice-covered for 1–3 weeks	.–151 to –250
1	cool	1 'cold' or 2 'cold' and 1 'warm' month	without	.–51 to –150
0	average	offset of 'cold' and 'warm' months	without	0
1	mild	1 'warm' or 2 'warm' and 1 'cold' month	without	.+51 to +150
2	warm	2 'warm' months or	little or no snow and activity of vegetation	.+151 to +250
3	very warm	3 'warm' months and	little or no snow and activity of vegetation	>+250

is assumed that they were rarely recorded before 1300. egression 3 excludes the indices on the level +1 and −1 of hich it assumed that they were not regularly recorded before 300.

Regression 1: $(I)_{0\text{–}3}$ T__e= 2.463 + (1.214 * $(I)_{0\text{–}3}$)
St__E= 0.01°C R2=0.97 Significance >0.0001

Regression 2: $(I)_{1\text{–}3}$ T__e= 2.463 + (0.55 * $(I)_{1\text{–}3}$)
St__E= 0.016°C R2=0.82 Significance <0.001

Regression 3: $(I)_{2\text{–}3}$ T__e= 2.463 + (0.373 * $(I)_{2\text{–}3}$)
St__E= 0.023°C R2=0.73 Significance <0.01

where:

T__e: estimated temperature °C
$(I)_{0\text{–}3}$: indices (−3, −2, −1, 0, 1, 2, 3)
$(I)_{1\text{–}3}$: indices (−3, −2, −1, 1, 2, 3)
$(I)_{2\text{–}3}$: Indices (−3, −2, 2, 3)

In the last step, thirty-year average temperatures for the High

Table 3 Comparison of statistical parameters obtained from ordinal indices and from instrumental data from the temperature series of De Bilt (1706–1990)

					Indic all				Indic without 0				Indic without 1			
Period	T_m	D_m	σ%	N	Ø(I)	T_e	D_e	N	Ø(I)	T_e	D_e	N	Ø(I)	T_e	D_e	N
1706–1720	1.6	−0.7	−68	15	−0.7	1.6	−0.7	14	−2.0	1.3	−1.0	5	−2.7	1.6	−0.8	3
1721–1750	2.5	0.1	−14	30	−0.1	2.3	−0.0	30	−0.2	2.3	−0.0	17	−0.6	2.3	−0.0	7
1751–1780	1.8	−0.5	−54	30	−0.6	1.8	−0.6	30	−0.9	1.9	−0.4	19	−2.3	1.7	−0.7	6
1781–1810	1.3	−1.0	−89	30	−0.9	1.3	−1.0	30	−1.5	1.6	−0.8	19	−2.4	1.6	−0.7	9
1811–1840	1.7	−0.6	−58	30	−0.6	1.8	−0.6	30	−0.9	1.9	−0.4	19	−1.7	1.9	−0.4	9
1841–1870	2.1	−0.2	−22	30	−0.3	2.1	−0.2	30	−0.4	2.2	−0.2	18	−1.0	2.2	−0.2	9
1871–1900	2.1	−0.2	−21	30	−0.2	2.2	−0.1	30	−0.4	2.2	−0.1	17	−0.6	2.3	−0.0	8
1901–1930	2.6	0.2	17	30	0.2	2.7	0.3	30	0.3	2.6	0.2	16	−0.5	2.4	0.0	2
1931–1960	2.2	−0.1	−15	30	−0.2	2.2	−0.1	30	−0.5	2.1	−0.2	13	−1.8	1.9	−0.5	6
1961–1990	2.4	0.1	−4	30	−0.0	2.4	0.0	30	−0.1	2.3	−0.0	16	0.0	2.6	0.2	8

T_m: 30 yr average of measured temperature °C
D_m: measured deviation from the average 1901–1960 °C
σ%: average standard deviation (in % of σ 1901–1960)
Ø(I): 30 yr average of indices
T_e: estimated temperature °C
D_e: estimated deviation from the average 1961–1960 °C
N: number of cases with a minimum of two valid observations

Middle Ages were estimated from the three equations according to the number of cases (N) for which at least two independent observations are available. Table 4 contains the estimates obtained from the regressions 1-3. Considering the number of records available (N) the estimates for the period AD 1090-1149 were derived from regression 3. those for the period 1149-1299 were derived from regression 2. and those for the period 1300-1329 were derived from regression 1.

From Table 4 it is concluded that the winter climate during the 240 years from AD 1090 to 1329 can be divided into three periods. In the first period (1090-1179) mean winter air temperatures were at the level of the period 1706-1900 (1.9°C) which was the last phase of the LIA. In the second period (1180-1299) average win- ters were as warm as those in the twentieth century .In the initial part of this warm period (1180-1209) winter temperatures were somewhat above those in the twentieth century; in the second and third 30-year parts (1210-1299) they were c1ose to those of the 60-year interval from AD 1931 to 1990. Winters in the third inter- val (1300-1329) were l.o°C colder than those in the thirteenth and in the twentieth century .This corresponds roughly to the co1- dest 30-year interva1 (1781-1810) that is documented in the De Bilt temperature record from 1706 (Tab1e 3). The pronounced coo1ing of winters marks the transition between the MWP and the LIA.

Presentation of extreme anomalies

In the following discussion some extreme seasonal anomalies are briefly described in order to provide a realistic impression of the data from which a reconstruction of air temperature is attempted.

Cold anomalies

AD 750 to 1000

The AD 763/64 winter was among the most outstanding cold epi- sodes in the last 2000 years. It is described in a dozen sources of which some are contemporary .According to the Chronicon Moissiacense written in southem France, the extreme cold killed many olive and fig trees in former Yugoslavia and in Thracia (Greece) and grain seeds in France.1 According to the Annales Laurissenses minores written in Lorsch near Worms (Germany), the period of extreme cold lasted from mid December 763 to mid April 764, i.e. about 120 days.2 Extensive contemporary accounts from Byzantine sources mention that the 'bitter' cold in the Black Sea area began in October. During subsequent months the north- ern shores of the Black Sea froze out to 100 miles, and the thick- ness of the ice continually increased from frequent snowfalls. The thawing in February broke this huge ice mass up into pieces which were driven southward by northerly winds. Some of these icebergs

Table 4 Estimates of average winter air temperatures for the late Medieval Warm Period (MWP) and the early Little Ice Age (LIA), AD 1060–1329

	(I)0–3 r_1					(I)1–3 r_2					(I)2–3 r_3				
Period	Ø(I)	T_e	s_e	D_e	N	Ø(I)	T_e	s_e	D_e	N	Ø(I)	T_e	s_e	D_e	N
1090–1119	−1.7	0.3	.01	−2.0	4	−1.8	1.4	.02	−0.9	4	−1.8	1.9	.02	**−0.4**	**3**
1120–1149	−0.9	1.4	.01	−1.0	9	−1.3	1.7	.02	−0.7	6	−2.3	1.7	.02	**−0.7**	**3**
1150–1179	−0.8	1.5	.01	−0.9	12	−0.9	1,9	.02	**−0.4**	**11**	−1.5	2.0	.02	−0.4	6
1180–1209	0.8	3.4	.01	1.1	12	0.8	2.9	.02	**0.5**	**11**	1.3	3.0	.02	0.7	6
1210–1239	−0.6	1.7	.01	−0.6	20	−0.7	2.0	.02	**−0.3**	**17**	−1.3	2.1	.02	−0.3	10
1240–1269	−0.1	2.3	.01	−0.0	13	−0.2	2.3	.02	**−0.0**	**10**	0.0	2.6	.02	0.2	2
1270–1299	−0.2	2.2	.01	−0.1	20	−0.3	2.3	.02	**−0.0**	**16**	−0.2	2.5	.02	0.1	5
1300–1329	−0.9	1.4	.01	**−1.0**	**30**	−1.4	1.6	.02	−0.7	18	−2.1	1.8	.02	−0.6	12

Ø(I): 30 yr average of indices
rg_1: regressions (1,2,3)
T_e: estimated temperature °C
D_e: estimated deviation from the average 1961–1990 °C
s_e: standard error of estimate °C

entered the Bosphorus and crashed against the walls of Constantinople (today Istanbul) which caused serious darnage. One of the chroniclers, Theophanes the Confessor, witnessed this event as a child. He vividly describes how he climbed on top of one of the icebergs and recalls that one could walk on a solid ice-bridge from Europe to Asia (Telelis and Chrysos, 1992).

Four Great Winters are known for the ninth century .For AD 821/22 a source from Aachen (Germany) reports a solid freezing of major rivers such as the Rhine, the Danube and the Seine during a period of more than 30 days. When the ice broke it severely damaged the bridges.3 This passage was later copied (and misdated) by several chroniclers. Prudentius, a bishop of Troyes (Champagne), observed that the seeds around the town suffered from north(east)erly winds during the entire 845/46 winter until the beginning of May, and that people in the villages around the town were attacked by packs of up to 300 hungry wolves.4 Another source reports that the Seine became icebound in AD 849 and people walked on the ice like on a bridge.5 It is assumed that this description is misdated and refers to the same winter, 845/46. For 859/60, Prudentius reported that the snow cover and the frost in the Rhineland lasted from November to early April, i.e. for 120 to 150 days.6 Traders arrived in Venice riding instead of sailing, also transporting merchandise, because the Venetian lagoon was icebound (Camuffo, 1987). Considering the duration of the frost period, this winter is among the longest of the last 1300 years. The 873/74 winter was of a similar duration. A snowcover per- sisted from early November to the end of March, i.e., for about 130 days, and the ice on the Rhine supported riders for a long time! The evidence for the 810/811 winter is less conclusive. It was long and snowy until early April, but a freezing of rivers is not reported.8

The data for the tenth century are fragmentary .A hard winter is noted for 939/40 in sources from Reichenau and from Quedlinburg (Germany) without any reference to its duration or impact. Reports of a long, severe and dry winter in 974/75 are contained in the Annales Hildesheimenses,9 in sources from Bohemia (Brdzdil and Kotyza, 1995) and in Polish chronicles, where a freezing of the (western?) Baltic was observed (Polaczkowna, 1925). The Annales Quedlinburgenses mention a third winter, 992/93, as being extremely long (from early November to early May),IO but this information is not confirmed by any other contemporary source. For Ireland the non-contemporary Gaelic accounts report a freezing of lakes and rivers for the two winters, 916/17 and 944/45 (Lyons, 1989).

AD 1001 to 1100

With the notable exception of AD 1 076m , Great Winters involving a long duration of snowcover far into spring and a week-Iong freezing of major rivers were not known in eleventh-century central Europe. A freezing of rivers and parts of the sea is reported for England in 1046/47 (Britton, 1937), but sources from the continent just highlight the snowiness of this winter. It is true that early eleventh-century chroniclers were concemed with the effects of cold speIls in several winters (1010/11, 1019/20, 1035/36, 1043/44, 1059/60 and 1068/69), but seemingly none of them caused any long-Iasting darnage to the food base. This leads to the conclusion that the long duration and the extreme severity of the Great Winter of 1076m took European societies by surprise. It is described in more than 35 independent sources, which under- lines its outstanding character in the view of contemporaries.

The map (Figure 4) shows the most evident features during the three winter months. On a first glance frozen rivers over northem central Europe indicate recurrent cold air advection and strong radiative energy losses during long winter nights. Recurrent positive pressure anomalies are required to fulfil favourable conditions for such an adequate meteorological development.

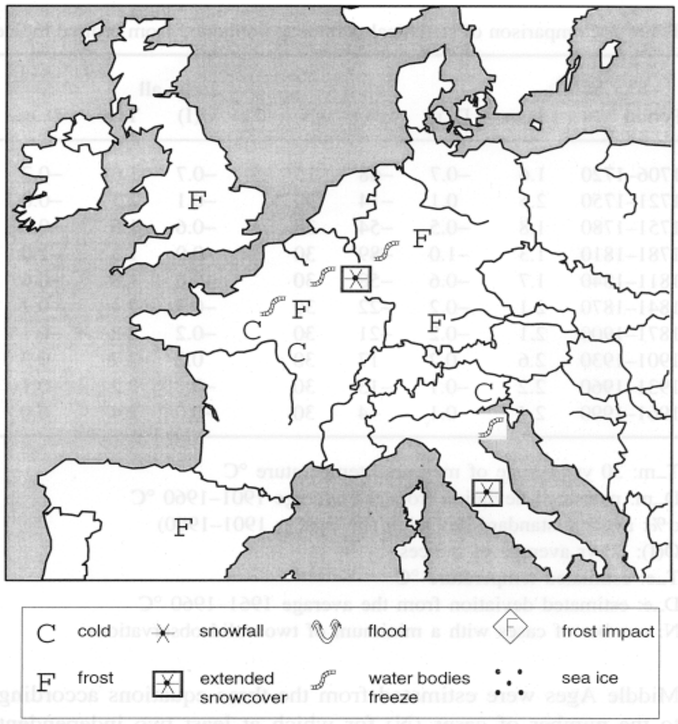

Figure 4 Spatial dimension of the Great Winter 1076/77.

The main weather events are outlined as follows: heavy snow fell in early November and by mid-November major European rivers and water bodies such as the EIbe, the Rhine, the Danube, the Rhone, Lake Constance, the Po and even the Tiber in Rome became icebound. This suggests that temperatures bad already dropped weIl below freezing. In central Europe the severe frost and snowcover persisted untillate March, in some regions even until early April, i.e., for 120 to 140 days. It is weIl known from a memorable episode of European history that the cold extended to central Italy, for, in his struggle for power with the German king, Henry IV, Pope Clement VII bad pronounced a church ban against his opponenLIn order to obtain absolution Henry arrived in January AD 1077 outside the fortress of Canossa in central Italy. By his humiliation and outward penitence -he stood in the deep snow for three days -he was finally able to force the Pope to give hirn absolution (Brooke, 1943).

The evidence suggests that in a first phase the advection of polar maritime air dominated, followed by dry Arctic air in a second phase. These air masses led'to a significant pressure rise north of the Alps and, due to their dryness and the snow-covered landscape, to strong radiative cooling -which itself bad a positive feedback to the anticyclonic development. South of the Alps, the Arctic air was responsible for persistent cyclonic activity with heavy snowfall. With the eastward movement of lows, cold continental air advanced westward, first intruding the Hungarian Basin and later also northern and central Italy. Analogous to today's synoptic development it is assumed that intensive cyclonic activity preceded the cold phase of that winter and led to extended snowc- over north and south of the Alps. The steering w ave pattern in the upper troposphere must have been dominated by planetary waves with a great amplitude over the northeastern Atlantic. Prob- ably, the first half of that winter saw recurrent troughs over central Europe which supported lee cyclogenesis over the Gulf of Genoa. They might, at times, have been followed by cut-off lows which drifted over the Ionian Sea and Greece. Such lows favour severe winter conditions over the Balkans and extended snowfall due to the advection of humid Mediterranean air ahead of the intruding cold air. Today, the relevant weather pattern is weIl known as the cyclonic bora, leading to strong tramontana winds along the west- ern slopes of the Apennine mountains.

The severity of this Great Winter could be interpreted with a reversal in the usual monthly mean sea-Ievel pressure gradient over the North Atlantic -an extreme mode of the North Atlantic Oscillation (NAO) (Moses and Kiladis, 1987), with high pressure over the Icelandic area and low pressure in the vicinity of the Azores, connected with a strong blocking of the westerly zonal flow over the Atlantic. Low temperatures over continental and northwestern Europe, as weil as in the eastern USA are associated with above-normal temperatures in western Greenland (van Loon and Rogers, 1978). The so-calied .Greenland-above (GA)' mode is also associated with below-normal precipitation over northern Europe (including Iceland) and Scandinavia and above-normal precipitation over southern and central Europe as weil as Northw- est Africa. This is a reflection of the southward displacement of storm tracks around blocking high pressure in northern latitudes (Dickson and Narnias, 1976).
Such negative phases of the NAO can be found in both the nineteenth and twentieth centuries with the most outstanding sev- ere winter of 1962/63 (especially January 1963). The monthly mean sea-Ievel pressure maps over Europe for this winter are presented in Figure 5. The blocking high with its centre close to the Icelandic area led to persistent easterly or northerly flows over extensive parts of continental Europe and the British Isles. Well- below-average mean monthly temperatures were widespread in Europe during this winter. Especially severe conditions were con- centrated in Scandinavia, central Europe and eastern Europe, the Low Countries, the British Isles and other areas adjacent to the Baltic Sea. This coincides weil with the statements above about the winter of AD 1076/77 and the evidence in Figure 5. During the winter of 1962/63, cold air also penetrated to southern Europe and brought widespread cold to northern and middle Italy. The cold air advection followed after pronounced cyclonic activity, connected with remarkable amounts of snow. Stations in central and northern Italy reported twice the normal amount of precipi- tation compared with the long-period average. No reports of sev- ere climatic events during the Great Winter of AD 1076/77 are known for Greece, southern Spain and Portugal, which is probably an indication of normal climatic conditions in these areas. This is in agreement with the conditions in these regions during the win- ter of 1962/63 when no temperature or precipitation extremes were reported. Another parallel between the two winters is the markedly lower temperatures during the winter of 1962/63 com- pared with the long-period average in the Aragon (Zaragoza), Cas- tilla-La Mancha (Madrid) and Catalonia (Barcelona) areas and the indication of frost occurrence in these regions. The many sirni- larities in climatic behaviour over Europe between the two severe winters reveal that the winter 1962/63 can be considered as a poss- ible analogous case for the Great Winter of AD 1076/77 .

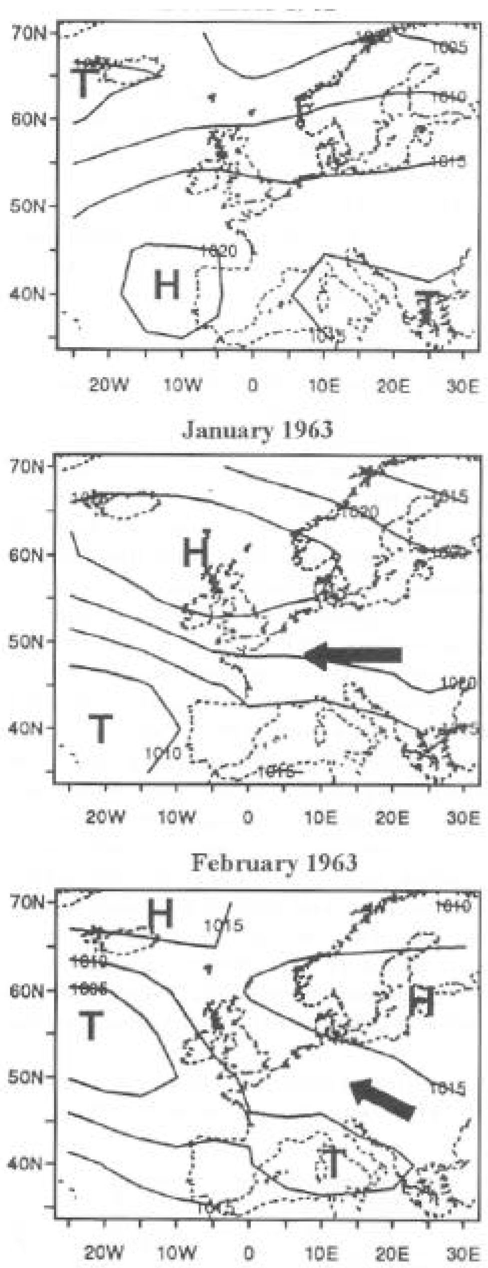

Figure 5 Monthly mean sea-level pressure charts (hPa) over Europe for the winter months of 1962/63 (December, January and February) (data source: NCAR, 1994). Black arrows: cold air advection.

It is weil known that the NAO is strongly related to the North Atlantic Deep Water (NADW) formation, which is a key process for the diagnosis of climatic variability over the European conti- nent (Stocker and Schmittner, 1997). Some of variables mentioned above even persist into spring. With the findings from analogous GA-cases in the instrumental period it is possible, to some extent, to draw conclusions about the prevalent climatic conditions during the MWP in regions where no reports are available.
For the 1099/1100 winter a cold period of eight weeks is described in nine contemporary sources from four countries. These, however, do not contain any references to the freezing of water bodies or to the duration of snowcover.

AD 1101 to 1200
This period included two Great Winters. It is still an open question whether two severe winters immediately succeeded each other in AD 1114/15 and 1115/16 or whether the information for 1114/15 is misdated and relates to 1115/16 (Britton, 1937; Alexandre, 1987; Buisman and van Engelen, 1995). Likewise the duration of the cold in 1115/16 is uncertain. The town chronicle of Liege (Belgium) reports that the cold speil in 1115/16 persisted from early November to the first days of May, but according to the chronicle of the neighbouring town of Ghent it lasted only from Christmas to the end of February (Alexandre, 1987: 345). In Ger- man and French chronicles this winter is not mentioned. but a freezing of the Po reported for AD 1116 (Camuffo. 1987) indicates that the cold air extended south to northem Ita1y. In the next dec- ade a cluster of three severe winters -or at least three more or less pronounced freezing episodes -in AD 1124, 1125 and 1126 is mentioned by the abbot Anseimus de Gembloux who made the entries in his annual chronicle (Alexandre, 1987: 73). In AD 1124 fish bred in ponds perished under the thick ice cover in the Nether- lands, and poor women and children died from the cold.11 In Col- ogne people walked on the frozen Rhine. In Bohemia this winter was severe and snowy (Brlizdil and Kotyza, 1995). In the sub- sequent year the period with below freezing temperatures in Belgium included December and January. A chronicler from St

Omer (Picardy) noted a freezing of water bodies and added the remark .as in the year before' (Alexandre, 1987) which supports the observation by Anselmus de Gembloux. For the third cold winter in the series (1125/26) exact indications of a freezing of large rivers are available for the POl2 and the Weser, and a severe winter is mentioned in Bohernia (Brazdil and Kotyza, 1995) and in Poland (Ma1ewicz, 1980). This situation coincided with a drought in Morocco (Till and Guiot, 1990).
In AD 1142/43 a cold spell in Belgium included December and January and in the latter month the Meuse became icebound, as did possibly rivers in England.13 This situation coincided with a wet winter in Morocco (Till and Guiot, 1990).
The duration of the cold period in the severe winter of 1149/50 varies according the location of the observer (Figure 6). A snowc- over is reported to have persisted for three to four months in France (Bethmann, 1844c) and for six months in Saxony (Pertz, 1859). In England the frost lasted from 4 December to 11 March (Britton, 1937). The North Sea froze out to three miles on the Belgian and Dutch coasts, and the congea1ed waves looked like towers of ice.14 Water bodies such as the Rhine and the Thames became icebound and supported people, horses and heavy car- goeS.15 During the climax of the cold around Epiphany the bark of trees cracked (Pertz, 1861c). These are signs of extremely low temperatures of -25°C to -30°C by inference from well-docu- mented analoguous cases such as January 1709 and December 1788 (Pfister, 1988; Lachiver, 1991). Snow and frozen rivers in northem centra1 Europe indicate the absence of a definite zonal circulation. Probably, during the beginning of the winter a north- westerly airflow dorninated, followed by progressively colder air.
Frozen rivers and sea ice along the Dutch coastline imply reduced cyclonic activity and strong advective and/or radiative frost. These effects are only fulfilled by a more or less persistent anticyclonic situation. The exact pattern of the pressure system cannot be reconstructed. Nevertheless, it seems evident that a bridge of high pressure between the Azores. and a Ba1tic anti- cyclone and/or an extended Baltic anticyclone dorninated the cir- culation.
From the absence of reports, it may be concluded that the cold wave in AD 1149/50 did not extend to northem Italy. This situation
coincided with a wet winter in Morocco (Till and Guiot, 1990) and may be interpreted as follows, Dry and cold continental air extended to the southern edges of the Adriatic, and the western

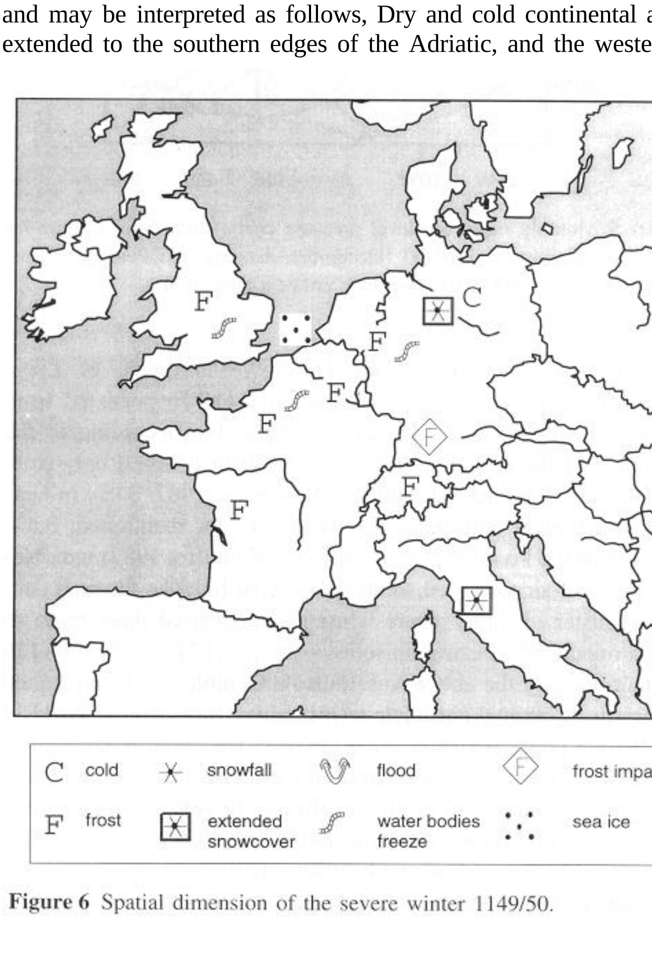

Figure 6 Spatial dimension of the severe winter 1149/50.

and central Mediterraneall Sea. Sharp temperature and humidity contrasts over the open waters engendered recurrent cyclogenesis. Meanwhile, anticyclonic weather over central Europe could on I y persist through a sympathetic upper tropospheric w ave pattern. A half-meridional to slightly zonal ridging promoted such a develop- ment followed by a trough over the central and eastern Mediter- ranean Sea. This trough preserves the advection of relative warm and humid air which undergoes large-scale lifting and leads to rain and snowfall along the adjacent coasts.
A possible analogue case to this outstanding winter could be that of 1694/95 within the Late Maunder Minimum (LMM; AD 1675-1715). This interval is known for its large number of extremely severe and dry winters and springs as weil as a parti- cularly low number of sunspots and reduced solar radiation (Wanner er al., 1995; Camuffo and Enzi, 1992; Glaser and Hage- dorn, 1991). Figure 7 shows the reconstructed monthly mean sea- level pressure charts over Europe for the winter of 1694/95.
These monthly mean grid point pressure charts for the whole LMM are reconstructed for the North Atlantic-European region (25°W to 30°E and 35°N to 70°N) from station records including measured monthly mean air temperature (Kew, Paris), air tem- perature index values (Zürich, Budapest, Lisbon), precipitation index values (Kew, Zürich, Budapest, Lisbon, Madrid, Barcelona), western Baltic winter sea-ice index (Koslowski and Glaser, 1995; Glaser, personal comrnunication, 1997) and station pressure (Paris). For these stations, continuous data are available for the whole LMM. The data were prepared and reconstructed by

different partners of the EU project called ADVICE (Annual to Decadal Variability In Climate in Europe).
The reconstructions are based on a canonical correlation analy- sis (CCA) which effectively and optimally sumrnarizes the relationship between large-scale patterns of the atmospheric circu- lation (predictands) over the North Atlantic-European area and proxy and measured station temperature, precipitation and press- ure data (predictors). The statistical relationship was first estab- lished between the gridded sea-Ievel pressure data (prepared by the National Center for Atmospheric Research NCAR, Boulder, Colorado, USA) over the North Atlantic-European area and the station data in the period 1901-90 (World Weather Disc (NCAR [National Center for Atmospheric Research], 1994) and World Climate Disc (1992», and then used to predict linear I y the simul- taneous responses of the monthly atmospheric circulation from the meteorological station variables during the LMM, under the assumption of climate stationariness.
The January chart in Figure 7 shows another extreme example of low NAO connected by a blocking situation, and low pressure over the Mediterranean. This winter was characterized with strong cold continental air advection and therefore below-average pre- cipitation, especially in Switzerland. Again, the northern part of the continent as weil as the British Isles experienced very low temperatures. This winter was the coldest (with AD 1878/79) in the Central England Temperature (CET) series back to 1659 (Manley, 1974; Kington, 1995). Severe ice conditons for the western Baltic were also pointed out by Koslowski and Glaser (1995). According to Kington (1995) the severe conditions in central parts of England seem to have been fairly general. The Thames was frozen on 23 January, and by the 30th the frost and continual snow had lasted for five weeks in London. These findings are in good agree- ment with the climatic evidence in northwestern Europe during the winter of AD 1149/50 with frost, water bodies frozen and sea ice in the North Sea (Figure 6).
The persistent low pressure over southern Europe together with cold dry air led to marked cyclogenesis with extensive amounts of snow and rain in northern and central Italy as weil as along

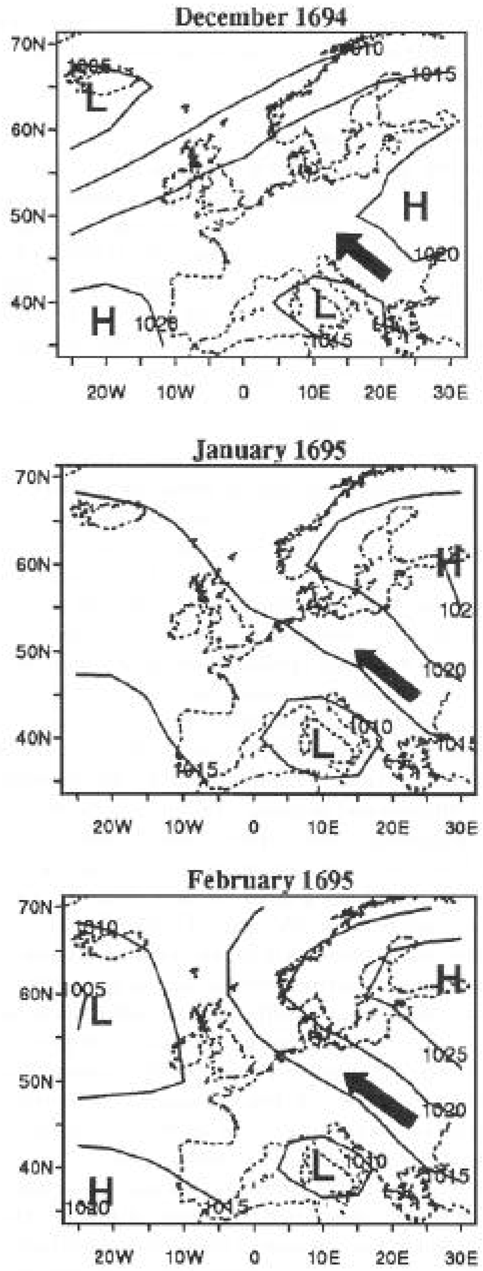

Figure 7 Monthly mean reconstructed sea-level pressure charts (hPa) over Europe for the winter months (December, January and February) of 1694/95.

the Mediterranean coasts, which is in accordance with the reports in Figure 6. The lack of records from the Balkans and the lberian Peninsula show another parallel between these winters and is an indication of normal climatic conditions.

AD 1201 ta 1300

This period included two severe winters: AD 1204/05 and 1233/34. About the 1204/05 winter, 'the cold of this winter was not experi- enced in living memory', w rote an anonymous monk in a monas- tery in Chillons-sur-Marne. This idiomatic expression was fully justilied in this case. lndeed, the last winter of a comparable sever- ity had occurred 55 years before, which was beyond the memory of most people living at that time. Renier (1157-1230), a monk in the abbey of St Jacques in Liege (Belgium), recorded extreme meteorological events almost every day. He distinguished live cold speIls of different intensity between November and April (Alexandre, 1987) including possibly short phases of warming, as are also known to have occurred in the famous winter of AD 1709

(Lachiver, 1991). The period of persistent freezing ended around 20 March 1205. It was possible to walk on the ice across the Danish Sound from Germany to Denmark. Water bodies in the Netherlands and the Thames in England were icebound, but it is not know if the Rhine or the Po were frozen.

The cold spell in AD 1233/34 is described in more than 40 sources (Figure 8). It was the most outstanding meteorologica1 episode in the thirteenth century .Most chroniclers describe the darnage suffered by fruit trees, olive trees, fig trees, nut trees and vineyards. Even a pine forest near Ravenna was damaged (Alexandre, 1987). This winter was relatively dry and cold over northem central Europe where the cold spell was restricted to the month of January. Rivers such as the Rhine and Moselle, how- ever, did not freeze despite widespread frost reports. On the other hand, frozen rivers occurred in northem and central Italy and also in the eastem part of the Alps.

A possible explanation for these reports rnight be the wide- spread formation of fog over continental basins such as the upper Rhine Va11ey, Swiss Plateau and Danube Basin. Supported by a strong inversion, cloud-free hills (Black Forest, Vosges, Jura Mountains, Taunus and others) probably experienced slightly positive temperatures during the daytime and negative values at night. Surface cold air was fed by drainage flow during the night but could not warrn up during the short day because of low-level stratus, or lifted fog, which, however, reduced noctumal radiative losses and inhibited strong radiative frost. As a result, negative temperatures could persist in the lowlands but without the conse- quence of freezing rivers.

Stratus or stratocumulus in a maritime airflow within and at the edge of the continenta1 anticyclone might also have been respon- sible for the lack of sea ice reports along the Frisian coastline.

In southem centra1 Europe the cold spell persisted for a longer time. Rivers in Austria froze down to their beds, and the breaking up of theice in spring caused catastrophic floods.16 Several reports describe a freezing of the Po (Alexandre, 1987) and of the Vene- tian lagoon (Camuffo, 1987). Even the ground around Monte Cas- sino (Apulia) was covered with snow for several weeks in January and February. Local rivers, including the Tiber, became icebound and there was a high mortality among wild animals, birds and

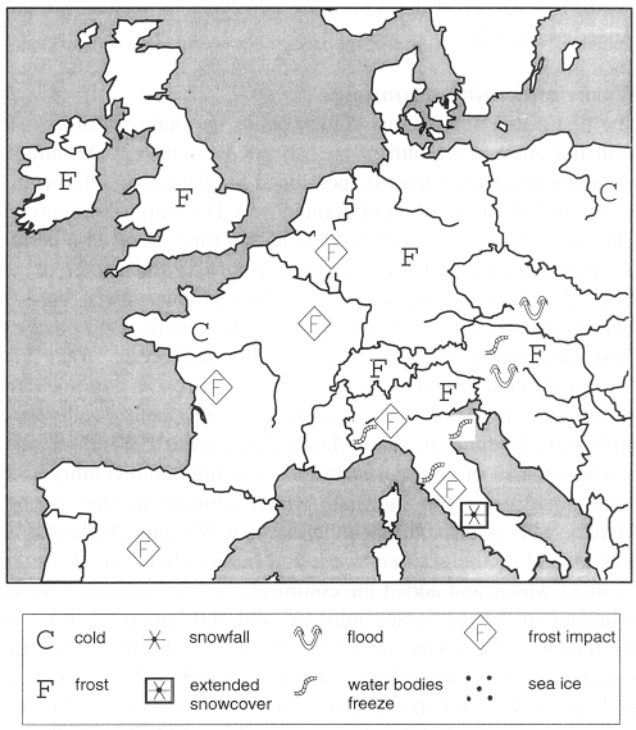

Figure 8 Spatial dimension of the severe winter 1233/34.

sheep.[17] Continuous frosts, killing vineyards and olive trees, were even experienced in Toledo (Spain) (Floriano, 1967). This situ- ation coincided with a dry winter in Morocco (Till and Guiot, 1990) and indicates the combined effect of continental cold air advection and strong radiative frost. Extended snowcover in middle Italy and ftooding rivers in eastem Europe might be explained by the inftuence of recurrent cyclonic activity over the southem Balkans and the Ionian Sea due to similar synoptic weather patterns discussed earlier (AD 1076/77 and 1149/50 winters). In connection with large-scale warm air advection, the edge of a large cold air mass is always a preferred region for enhanced lifting and extended precipitation.

For the southem part of Europe this winter shows some simi- larities to the winters of AD 1962/63 and 1076/77 , although the conditions were more severe. This could be a possible indication that the cold air outbreaks were more directed towards this part of Europe than towards the central and northwestem parts of Europe. Marked cyclonic activity over the central Mediterranean and the Adriatic Sea, with an extension of the low pressure area towards Austria and Hungary , produced more pronounced temperature and humidity contrasts over this region, which could explain the reported climatic evidence. Precipitation over the frozen soil is a possible explanation for the ftoods.

The bulk of the information for the severe winter of AD 1215/16 refers to northem Italy. Several sources describe a freezing of the Po near Cremona and Mantua.[18] The period of below-freezing temperatures lasted two months (Holder-Egger, 1901). Supporting contemporary information for the region north of the Alps is lim- ited to a scanty report from Limoges (France) and from England (Britton, 1937).

Warm anomalies

Two types of warm winters need to be distinguished in centra! Europe. Rainy and windy winters invo!ving ftoods and short epi- sodes of snowcover are associated with the predominance of west erly situations. Large-sca!e associations of high temperature and !ow precipitation are rare. Four cases of warm winters were found for the period AD 1841-1990: 1881/82, 1924/25, 1948/49 and 1988/89. Despite their statistica! simi!arity these winters were determined by quite different synoptic situations (Lauterburg, 1990). In the following section, the two types of winters are dis- cussed separately.

Warm and rainy anomalies

The first description of this kind explains the outbreak of disease with the unusual warmth of the AD 800/01 winter.19 An almost complete absence of frost is mentioned to characterize the winter of AD 862/63 in the town of Xanten near Duisburg (Germany).20 This suggests that 'normal' winters at that time involved a period of several weeks of frost and snow. Likewise the winter of AD 1121/22 was rainy and warm according to chronic1ers from St Evrou1t and Picardy (northem France) (Alexandre, 1987) and no frost was experienced in Prague (Br1izdil and Kotyza, 1995). The 'wester1y' winter of 1171/72 seems to have been an extreme case considering the reports that trees were already leafing and young birds were hatching in ear1y March (A1exandre, 1987).

The remarks of chroniclers in the early thirteenth century shed some light upon the 'normal' winter climate in this period. Menko, who as prior of the monastery in Wierum (Netherlands) was critical of the unusual warm and humid character of the AD 1236/37 winter and added the comment, 'winter according to the characteristic of the season must be cold and humid'.21 In Erfurt (Germany) this winter involved 16 days with frost, but the impression of a chronicler of it being 'rather mild'22 was due, perhaps, to the fact that it fo11owed only a few years after the severe winter of 1233/34. The winter of AD 1248/49 which was rainy and included just a brief two-day speIl of frost was coined 'unnatural' }3 These examples suggest that ' average' winters in the early thirteenth century indeed included a frost period of some duration.

Warm and dry anomalies

Warm and dry winters were not described prior to AD 1100, per- haps because they had litt1e negative consequences for the local economy. A winter of this type seems to have been the origin of the premature appearance of vegetation in 1116/17 (Alexandre, 1987). A more pronounced anomaly of this type is correspond- ingly described in several sources for 1186/87, for example, it was 'summer instead of winter' (Pertz, 1861b). In Marbach near Colmar (Alsace) the flowering of fruit trees and the nesting of wild birds is reported for December and January?4 In AD 1205/06 freezing in Gembloux (Belgium) was restricted to a short spell of two weeks in January. No signs of winter (snow, frost) were observed before, and the following period up to Easter resembled summer more than spring, i.e., it was predominantly warm and dry?5 Likewise the vegetation was extremely early in 1282/83; for example, the first ears of rye appeared in Colmar near Strasbourg (France) around New Year (Alexandre, 1987) but this fact is not reported in another contemporary source. AD 1289/90 was poss- ibly the most outstanding episode of this type within the last mil- lennium; for instance, in Colmar the trees retained their leaves until the appearance of new ones, strawberries were eaten at Christmas and the vine produced leaves, stalks and even blossoms in the middle of January (Jaffe, 1861). In Vienna violets were found at Christrnas and in January fruit trees wereflowering 'like in May' (Wattenbach, 1851). There seems to have been an unin- terrupted transition from autumn into spring. The blossoming of cherry trees begins after a phase of three weeks in which mean temperatures are between 7°C and 8°C (Bider, 1939).

Less pronounced anomalies of this kind are known from the analysis and reconstructed historical data (e.g. ad 1529/30). The most likely analogue case within the last 300 years is the winter of 1833/34. The reconstructed monthly sea-level pressure charts for this winter are given in Figure 9. The synoptic situation is interpretated as follows: A low pressure system extended over northem Europe with a centre over the Norwegian Sea while the Azores high extended to western central Europe. During the win- ter, the low centre shifted furtherwest, while in February the sub- tropical anticyclone dominated large parts of Europe. This winter was the second warmest winter in the CET series (Manley, 1974). The climatic conditions over western Europe and the British Isles were dominated by a southwesterly warm and moist air flow which brought a large amount of rainfall to England and Wales. This agrees with the report of the Oseney Annals that in AD 1289/90 'snow was not once seen to cover the earth' but instead 'rain distilled almost day and night that its heaviness by day dark- ened the earth and the air' (Britton, 1937). Also most parts of France witnessed an outstandingly warm and wet winter. In Switz- erland and Austria mean temperatures were 4-5°C above the long- term mean of 1901-90. In Iceland, the winter of AD 1288/89 was cold (Ogilvie and Farmer, 1997) and probably dominated by east- erly flows. This illustrates the well-known fact that strong anomal- ies often have reversed signs in distant parts of Europe so that descriptions of this kind are not necessarily contradictory .

Discussion

The MWP is viewed as an interval of above-average temperatures that lasted from approximately AD 900 to 1300 (Lamb, 1977). With regard to temperatures in the summer half-year this picture was determined by a series of reconstructions from several areas of the globe; for example, in Scandinavia, China, North America and Tasmania summers appear to have been warmer during some

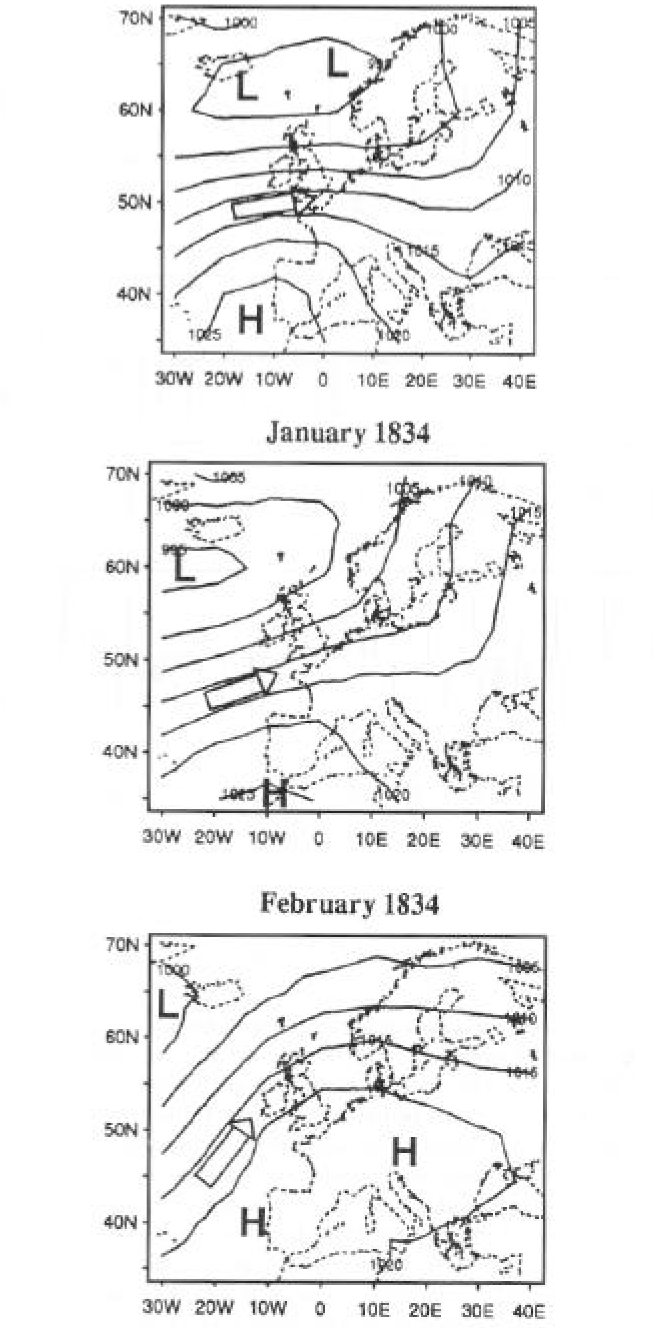

Figure 9 Monthly mean reconstructed sea-level pressure charts (hPa) over Europe for the winter months 1833/34 (December, January and February); white arrows, warm air advection (data source: Jones *et al.*, 1987).

intervals of that period than those that were to prevail until the most recent decades of the twentieth century (Hughes and Diaz, 1994). With regard to Europe, these warm intervals include AD 971 to 1100 in Fennoscandia (Briffa et al., 1992) and -according to Alexandre's (1987) summer dryness-index -the thirteenth cen- tury in central Europe. This latter result agrees with the multi-proxy reconstructions of northwestem European annual tempera- tures by Guiot et al., (1988) which show temperatures colder before AD 1200 and close to modem values between 1200 and 1300.

Evidence on wetness in east China over the last 1033 years based on annual documentary data was recently discussed by Jiang et al., (1997) .Their record includes an oustanding dry per- iod from AD 1120 to 1220 and a wet period from 1280 to 1390 in the coastal region.

W hat about winters? Compared to the known reconstructions of winter climate in central Europe (Lamb, 1977, Alexandre, 1987) which are mainly based on impressionislic statements of the observers, this approach applies an improved method of index classification and draws mainly on proxy information on frost, freezing of water borlies, duralion of snowcover and untimely activity of vegetation.

The main results are summarized in Figure 10 which is the basis for the following discussion. The bars display departures from the twentieth century average (0) in terms of six classes (-3, -2, -I, +1, +2, +3). Broken lines mark those cases which are only supported with one contemporary source or for which the magnitude of the event cannot be fully assessed. The solid curve represents smoothed index numerals obtained by applying a Gaus- sian low pass filter with a Il-year cut-off period.

W hat evidence of an MWP, if any, is offered by this reconstruc- tion? On the century scale a somewhat lower frequency of extreme negative anomalies (-3) compared to the preceding and the following interval is the only feature that is observed over the entire period (Figure 10). Four Great Winters are known from the ninth century which, in the Swiss Alps, was a period of rapid and far-reaching glacier advances (Holzhauser and Zumbühl, 1988). During the MWP the number of these episodes dropped to a level of one to three per century. From AD 1235 to 1303 they were completely absent. In the period from the early fourteenth to the late nineteenth centuries, severe winters were more frequent; the fourteenth century witnessed no less than seven such seasons. In western and central Europe the transition from the winter climate of the MWP to that of the LIA took the form of a rapid shift (Pfister er al., 1996); in England and in Iceland it was more grad- ual (Lamb, 1977; Ogilvie and Farmer, 1997). Regarding the dur- ation, intensity and spatial extent of the cold only the episode of AD 1076/77 and, perhaps, also that of 974/75, were comparable to the Great Winters of the LIA such as 1363/64 (Pfister er al., 1996), 1572/73, 1684/95, 1708/09 or 1829/39 (e.g., Glaser and Hagedorn, 1991; Glaser and Militzer, 1993; Camuffo and Enzi, 1995). The cold in the most severe winters of the twelfth (1149/50) and thirteenth centuries (1233/34) was regionally more restricted and of shorter duration than in 1067/77 (Figures 4-6). The Great Winter of AD 1067/77 was described by more than 35 chronicles. The fact that this occurred at a time when intellectual life had just begun to recover from the dark period in the ninth and early tenth centuries underlines the outstanding character of this event in the view of contemporaries. It is unlikely that an episode of similar magnitude and severity would not have been adequately described later on. It is open how far this argument also relates to the dark period between AD 900 and 1040.

It is weIl known that winter-time atmospheric circulation over western Europe is highly influenced by the North Atlantic Oscil- lation (NAO) (Wanner, 1994) which causes a large-scale alter- nation of atmospheric mass between the areas of Iceland and the Azores (Lamb and PeppIer, 1987). Moses er al. (1987) stated that strong wintery reversals in the monthly pressure field with high pressure over Iceland represent an extreme mode of the NAO. They show that these reversals are correlated with low winter tem- peratures over Europe as weIl as over the eastern USA. Several authors emphasize that these features of meridional cold air out- breaks over western and central Europe are typical elements of climatic fluctuations during the Holocene or even over the whole Pleistocene (van Loon and Rogers, 1978; Wanner er al., 1995) and they refer to 'Little Ice Age' Type Events (Moses er al., 1987). It seems that events of this kind were less frequent and less pro- nounced during the MWP than in the preceding and following per- iods.

These results agree with the chronological boundaries of the MWP proposed by Lamb (1977), but they are seasonally restricted to winter and only refer to western central Europe. This is not

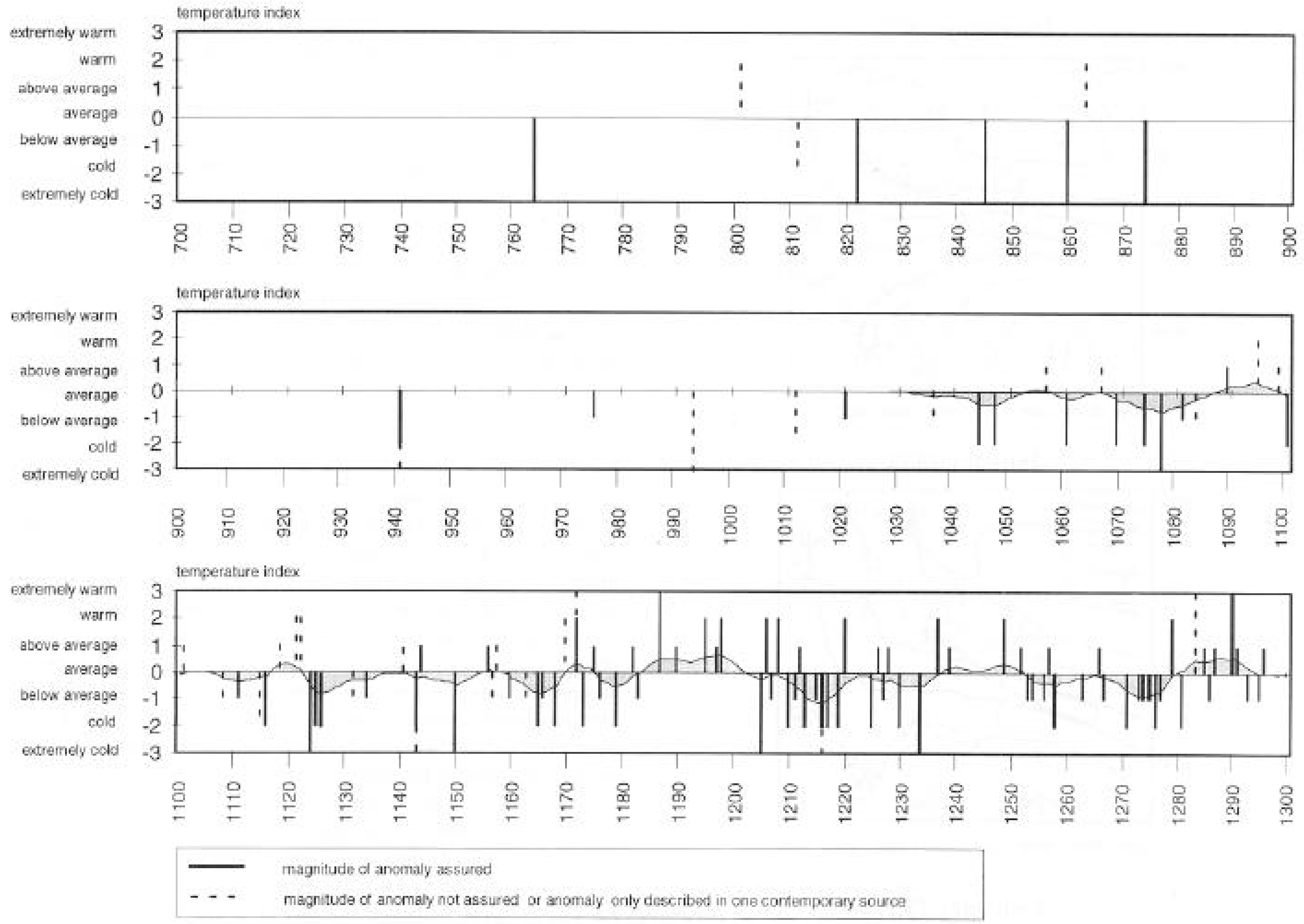

Figure 10 Winter temperature anomalies in western central Europe AD 750 to 1300. Average: Mean temperatures 1901–1960.

sufficient to support the conceptual scenario of a MWP on a Euro- pean level, let alone on a global scale. In a recent study Ogilvie and Farrner (1997) altogether disrniss the concept of an MWP. However, this leaves the question of how this interlude between the ninth and fourteenth centuries is to be labelled. The present authors propose that, as long as no convincing alternative terrn is suggested, the MWP should continue to be recognized.

On a multi-decennial scale two features need to be highlighted. First, it follows from Figure lOthat the MWP included long phases of low variability in which winter climate was rather stable. For the late MWP (e.g., AD 1130 to 1160 and 1240 to 1270) the evidence is sufficient to support this argument. It is open to question whether this also relates to earlier phases such as AD 1000 to 1050.

Second, the MWP included bothcold relapses and warrn phases during which mean winter air temperatures were close to or even above those of the period 1901-1960. The wavelength of those cold and warrn fluctuations varies between 20 and 40 years, which agrees with the known duration of the therrnohaline circulation in the North Atlantic Ocean (Stocker, 1995). An initial cold interval is identified between AD 1060 and 1085 on Figure 10 and Table 4. Another long interval from AD 1115 to 1180 was moderately cool and included a phase of considerable variability (1115- 1126). On the other hand, it follows from Figure 10 and Table 3 that the later phase of the MWP (after 1040) includes four warrn intervals: AD 1086 to 1114, 1180 to 1205, 1236 to 1255 and 1280 to 1302. During the first interval winters were also quite warrn in Japan (Yamamoto, 1967). The second warrn interval (AD 1180 to 1205) was by far the most pronounced. The evidence suggests that mean winter temperatures during these 26 years were above those of the period 1901-1960.

On a broad sca1e these results agree with recent reconstructions attempted for central Europe (Brazdil and Kotyza, 1995; Glaser, 1995). On the other hand, it seems that in England winters were main1y cold over this period (Ogilvie and Farmer, 1997). More coherent results might be obtained from a cooperative effort of reseachers from different countries based upon a rigorous eva1u- ation of sources and a common reconstruction of anomalies, as was attempted for the Late Maunder Minimum (AD 1675-1704) (Wanner et al., 1995). This inc1udes a detailed discussion and a straightforward graphical presentation of data. Alexandre (1987), for example, displayed his results in the form of 50-year moving averages which gives the impression that winter air temperatures in the Middle Ages culminated around AD 1340-60. This contra- dicts the results obtained in the present paper. In an earlier paper (Pfister et al., 1996) it was demonstrated that there was an absence of both severe and warm winters in the mid-fourteenth century.

The rare occurrence of hard winters in the MWP seems to have promoted the cultivation of subtropical trees in the Po valley and even in the Rhine va11ey in Germany, where they are not grown today. This is concluded from several pieces of evidence. The most distinguished witness is St Albertus Magnus who is known as a theologian, philosopher and a natura1 scientist. In his treatise De vegetabilibus ('On plants') he describes the trees that are known in the Rhine va11ey. The list includes pomegranates and fig trees 'whichare abundant in Cologne and in parts of the Rhine valley around the town'. The fig trees bore fruits three times a year, except in cold autumns.Z6 Albertus a1so describes the culti- vation of olive trees (Jessen, 1867). A chronicler from the same town reports a freezing of 'vines, fig and olive trees in Italy, France and Germany' from the bitter frost in January 1234.z7

Another chronicler mentions a widespread killing of fig and olive trees around the town of Parma in the same year (Pertz, 1863).

The northern lirnit of olive cultivation coincides roughly with the 4°C isotherm in January. Olive trees are sensitive to prolonged periods of freezing below -8°C (Hegi, 1927). Today, the mean (1951-80) January air temperature in Parma is 2.1°C (Uni Trier, 1987) which suggests that this month must have been somewhat warmer in the MWP. The fig tree is a Mediterranean plant that is sensitive to prolonged periods of freezing below -10°C. The northernmost zone in which fig trees are cultivated today includes the Po valley, Provence and the western coast of France northwards to Brittany (Hegi, 1927), where mean January temperatures (1951-80) are above 4°C (Uni Trier, 1987). In the warmest areas of Germany, such as the Rhineland Palatinate, trees were grown on espaliers in the early twentieth century; some isolated trees even survived without protection (Hegi, 1927). Winter temperatures which were somewhat above the 1901-1960 means, in connection with the rare occurrence of severe frosts, are consistent with the descripition of St. Albertus who describes the abundant occurrence of fig trees 150 km north of the Palatin~te in the thirteenth century .The winter temperature patterns derived from the northward shift in the occurrence of Mediterranean plants are therefore consistent with those derived from the documentary evidence, indicating a climatic regime where cold extremes were less frequent and less pronounced.

It is hypothesized that Mediterranean plants such as fig trees and olive trees spread northwards during the warm period from AD 1180 to 1299 and that the distribution of these plants was shifted southwards after 1300 when cold winters became, at the same time, more severe and more frequent. These findings agree with those obtained for China where a northward shift in the distribution of subtropical crops such as citrus fruit is demonstrated for the thirteenth century .This indicates a warm stable winter climate with a mean temperature in January being about 0.6°C and a mean extreme rninimum temperature ,about 3.5°C higher than in 1901-1960 (De'er, 1994).

Third, extreme warm and dry anomalies (e.g., AD 1186/87, 1282/83 and 1289/90) were recorded during the warmest phases of the MWP in western and central Europe, to conclude from the observation of ftowering of fruit trees in December and January in the southern Rhine valley. No analogue cases are known for the LIA or the twentieth century .This suggests that the absolute maxima of mean winter temperatures measured in the instrumental period were somewhat exceeded during the warmest phases of the MWP.

As far as forcing factors are concerned, the reader is referred to Jirikowic and Damon (1994) who defined a Medieval Solar Maximum lasting from c. AD 1100 to 1250 which roughly coincides with the MWP .This agrees weIl with recent findings supporting the hypothesis that solar variability represents a significant fraction of the inferred changes during the LIA (Bradley et al., 1995; Crowley and Kim, 1996).

Also Lean and Rind (1996) point out that the connection between solar activity and radiation, coupled with a high abun- dance of isotopes in tree-rings and ice cores, supports the likely case that during the MWP solar activity remained at high levels, especially in the twelfth century. There is stilI an ongoing dis- cussion concerning the sunspot-climate link. The sensitivity of cli- mate to solar radiation changes is not we11 known so far .

Conclusions

Documentary data are the most high-resolution evidence known so far that significantly contribute to our understanding of winter clirnate in the pre-instrumental past. Over the last decade the methodology needed for the valid reconstruction of past climate regimes using documentary evidence has been significantly improved. Several analyses convincingly demonstrate that the cold winter climate of the LIA during the Early Instrumental Period (EIP) did not significantly differ from that in the preceding centuries. Against this multisecular trend the rise in winter temperatures in this century was seen as unprecedented.

Jones etal. (1996) have argued that a better understanding of past climate regimes during the MWP may be vital if natural variability is to be distinguished from that due to anthropogenic influences on the climate system.

For western central Europe it was shown that extremely cold winters were less frequent during the MWP than 1901-1960 and in the LIA (AD 1300 to 1900). On the other hand, it should not be overlooked that winter climate in the MWP -as far as it is adequately documented -was by no means homogeneous. Winters from AD 1090 to 1179 were as cold as those in the LIA. Winters from AD 1180 to 1209 were even warmer than those in 1901-1960. This was a period of purely natural climate variability possjbly with a strong solar forcing. With regard to the present climate, this leads to the conclusion that the level of winter temperatures in western central Europe prior to 190 1 is still within the upper threshold of natural variability of the last thousand years (Pfister, 1998). However, it must be stressed that this finding has a regional and seasonal character. More research is needed to obtain a conclusive picture of winter air temperature variations in the MWP. Future reconstructions should involve a closer cooperation between historical climatologists and meteorologists in Europe as is being attempted for more recent periods of cli- matic history .

Notes

1 ' Anno 762 [763/64] ge1u magnum Galliam, Illyricum et Thraciam deprimit, et multae arbores olivarum et ficulnearum decoctae gelu aruerunt; sed et germen messium aruit; et supervenienti anno praed- ictas regiones gracius depressit farnes, ita ut multi homines penuria panis perirent (Pertz, 1826b).

2 'Facta est hiems va1ida anno 764 (a 19. KaI. Ianuar. usque ad 17. Ka1. April.' (Pertz 1826a).

3 .Auturnna1is satio iugitate pluviarum in quibusdam loci impedita est, cui hiems in tantum prolixa successit et aspera, ut non solum minores rivi ac mediocres fluvii, verum ipsi maximi ac famosissimi amnes, Rhenus videlicet ac Danubius, Albisque ac Sequana [Rhine, Danube, EIbe, Seine], caeteraque per Galliarn atque Germaniarn oceanum pet- entia flumina adeo solida glacie stringerentur, ut tricensis vel eo arnplius diebus plaustra huc atque illuc commeantia velut pontibus iuncta sustinerent, cuius resolutio non modicum villis iuxta Rheni fluenta constitutis darnnum intulit.' (Pertz, 1826b).

4 'Ventus aquilo per totarn hiemem usque ad ipsa fere Maii mensis initia acerrime segetibus et vineis incumbit. Luporum incursio inferiorum Ga11iae partium homines audentissime devorat, sed et in partibus Aqui- taniae in modum exercitus usque ad trecentos ferme conglobati et per viam facto agmine gradientes, volentibusque resistere fortiter unanimi- terque contrastare feruntur' (Pertz, 1829c).

5 'Ipsos diebus gelu magno fluvius Sequana glacierumque densitate superveniente tegebatur, ita ut per eam quasi super pontem populus transiret.' (Pertz, 1829a).

6 .Hiems diutina et continuis nivibus ac gelu dira, a mense videlicet Novembri usque ad Aprilern' (Pertz, 1829c).

7 .Hiems aspera nimis et solito prolixior; nix quoque inmensa a Ka1endis Novembris usque in aequinoctium verna1e sine intermissione decidens, magnum hominibus fecit impedimentum silvas petere lignaque collig- ere. Unde accidit, ut non solum anima1ia, verum etiarn homines plurimi frigore perirent. Sed et Rhenus et Moenus [Main] glacia1i rigore con- stricti, longo tempore se sub vestigiis incedentium ca1cabiles praeb- uerunt' (Pertz, 1826a).

8 'Hiemps fuit durissima, perdurans usque ad finem Martii mensis, [...].' (Wattenbach, 1826).

9 .Hibernus fuit 1ongus, durus, et siccus, et Id. Mai. magna nix cecidit. [...].' (Pertz, 1839b).

10 'Hiems durissima 3. Non. Novembr. (3.11.) exorta, usque 3. Non. Maii (5.5.) stetit, rariss!mis intermissa diebus. Deinde pestiferis et frigidis flantibus ventis. noctibus plurimis pro rore hibernum cecidit frigus.' (Pertz, 1839a).

II 'Hiems solito acerbior, et aggestu nivis sepius decidentis nimis horrida et importuna. Multi enim pauperum infantes et mulieres nimietate frig- oris defecerunt. Mortalitas quoque animalium maxirna. In multis viva- riis pisces absorti sub glacie perierunt. In Bracbanto [Brabant] anguil- lae innumerabiles propter glaciem a paludibus exeuntes, quod dictu mirum est, in foenilibus fugientes latuerunt; sed ibi etiam pre nimietate frigoris deficientes computruerunt' (Bethmann, 1844a).

12 'Eodem quoque anno [1127] gelavit Eridanus [Po] ut super glatiem currus et equi discurrerent' (Holder-Egger, 1903). The source was written around 1201; it is non-contemporary .The correct year could be 1126.

13 Contemporary observers in Belgium date the severe winter to 1142/43 (Alexandre, 1987: 351). For England similar observations are available for both 1141/42 and 1142/43 (Britton, 1937).

14 'Hiemps solito asperior inhorruit, in tantum, ut in mari plus quam tribus littore milibus super glatiem via preberetur, et tumescentes fluctus gelu solidati in similitudinem turrim cernerentur' (Bethmann, 1844b).

15 'Renus calcabilis fuit' (Pertz 1859); 'Tamisia quoquoe ita congelata est, ur bigis, summariis opneratis et equitibus audacter, quasi per stra- tarn Londoniarum publicam transiretur' (quoted in Weikinn, 1958-63).

16 'Tota hyeme illa tanta asperitas frigoris inhorruit, ut multi fluvii qui ante large fluebant, a fundo usque ad summum ita indurescerent pre frigore, ut fluere desinerent. Circa tempus vero vernale cum solveretur glacies, Danubius ex multitudine glaciei et habundantia aquarum excessit terrninos suos, turres muros domos pomaria arboresque sub- vertit, hominesque multos extinxit; vineas et agros a se remotos vasta- vit, replensque ornnia glacie inmensi ponderis, que glacies per mag- num tempus ipsius anni duravit.' (Wattenbach, 1851).

17 'Hoc mense et mense Ianuario preterito tanta fuit habundantia pruine et nivis, quod pre tempestate famis multa millia ovium in Apulia mor- erentur, silvestres etiam bestie et ipse volucres pre farne deficerent, et quo se verterent ignorarent, cum ubique terrarum nix esset, et ipsa etiam flumina fuerint congelata; et etiam quod o}jve et alie arbores fructifere arefacte essent ex gelu nimio, homines desperabiliter mur- murarent' (Pertz, 1866a).

18 '1215. et 1216 dornnus Lambertinus de Bivialdo de Bononia fuit pot- estas Mantue, et in primo anno factum fuit Burgum fortern, et Padus [Po] congelavit' (Pertz, 1866b).

19 'Pestilentia propter mollitiem hiberni temporis facta est' (Waitz, 1881). 20 'Eodem anno hiemps turbulenta mutabilis, et pluvialis valde, ut pene absque gelu omnino, ut in sequentibus patuit in aecclesia sancti Vic- toris [in oppido Xanten].' (Pertz, 1829b).

21 'Precessit hiems humida et calida, et in hoc distemperata; et ideo multe secute fuerunt infirrnitates. Quoniam secundum proprietatem tempo- rum hiems debet esse frigida et humida.' (Weiland, 1874).

22 'Hoc anno adeo calida fuit hiems, ut vix sedecim dies glacieales in ea computari potuerint, in qua et audita sunt tonitrua 6. Idus Martii (10.3.) (Holder-Egger, 1899).

23 'Eodem anno hyems in partibus nostris tota erat corrupta, pluvialis et omnino remissa, ita quod per totalil hyemem duobus diebus et hoc interpolatis modica glacies est visa.' (Pertz, 1872).

24 'Eodem anno hyemps calida ita quod in Decembri et Ianuario multe arbores florerent, in quibus circa Februarium pira, quantitate in modum ave1lane magna conspiciebantur,) corviquoque et pice alieque huius- modi aves in Ianuario fetus produxerant' (Wilmans, 1861).

25 'De qualitate temporis huius anni dicimus, quod usque ad circumci- sionem Domini (1.1.) nu1la fuerunt signa hiemis, nec in gelu, nec in nive, set a circumcisione domini in 15 sequentes dies et non amplius hyemps desevit; reliquum tempus usque in pascha (2.4.), non quasi ver, set quasi estas fuit' (Bethmann, 1844a).

26 'Quaedam enim fructificant semel in anno tantum; et hae sunt notae, sicut pruni et mala punica et hujusmodi. Quaedarn autem pluries, sicut ficus et quaedam piri [...]; quae abundant in Colonia et in partibus Reni circa Coloniarn'. (Jessen, 1867: 98).

27 'Eodem anno [1234] hyems solito asperior inhorruit et multas vineas, ficus et olivas per Italiam, Franciarn et Teutoniam congelavit' (Pertz, 186Ib).

Acknowledgements

This research was supported by the Swiss National Science Foundation, Priority Programme Environment (No.5001, 34888). Thansk are due to; Adrian E. Scheidegger, University of Vienna, for translating part of the second section of this article; Ralph Rickli and Urs Zahnd, University of Beme for reading the manuscript; Marlu Kühn and Stefanie Jacomet, Laboratory for Archeobotany, University of Basle for assistance in the interpretation of botanical data; Daniel Brändli, University of Bem, for drawing the figures; Phil D. Jones, Climatic Research Unit, University of East Anglia, Anita Bokwa, University of Cracow, Mariano Barriendos, University of Barcelona, and Yoshio Tagami, University of Toyama (Japan), for providing data and bibliographical references; and John Kington and Julie Burgess, Climatic Research Unit, University of East Anglia, for reviewing the content and correcting the style of this article.

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