WINTER SEVERITY IN EUROPE: THE FOURTEENTH CENTURY

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Abstract. The fourteenth century is known to include a period of winter cooling in Central and Western Europe, but its timing and magnitude are not clearly established. An attempt to obtain a coherent picture from verified documentary evidence yielded 2133 records from a region covering Central Europe and Northem ltaly, mostly originating from the 'Monumenta Germaniae Historica'. Temperatures were assessed using semi-quantitative indices on the basis of proxy information on snow-cover, ice and untimely activity ofvegetation. Results: A run of cold winters from 1303 to 1328 was followed by a run of 'average' winters up to 1354. Then winter temperatures were extremely variable up to 1375. For the rest of the century they fluctuated somewhat be1ow the average of the twentieth century. The pattern in the first five decades is compared to that in the Late Maunder Minimum (1675-1715). The possib1e ro1e offorcing factors (variations in solaroutput, North Atlantic Deep Water formation) is briefly discussed.

1. Introduction

In the framework of global change research decadal to century scale cold relapses have attracted widespread attention, because it is highly probable that they are connected to the thermohaline circulation in the ocean (Stocker, 1995) or with a possible reduction of the solar input (Stuiver, Braziunas, 1992) or with both of these forcing factors. In continental western Europe, the late Maunder Minimu~ period (1675-1704) was such an interval with cold, dry winters and springs which is associated with reduced oceanic circulation (Pfister, 1994; Wanner et al., 1995). The fourteenth century is known to include another period of substantial winter cooling (Lamb, 1977; Alexandre, 1987), but its exact timing and magnitude is not yet clearly established. Hence it seems rewarding to supplement and to reinterpret the known documentation of verified data in order to assess the variations of winter temperatures and the magnitude of warm and cold extremes more accurately.

The widely used term 'Medieval warm epoch' suggests that the Middle Ages were a period of climate during which temperatures were above those of the present century. However, a recent survey of the evidence presented by Hughes and Diaz (1994) indicates that the pattern of regional differences in the character of climatic anomalies during the ninth through fourteenth century, shows spatial and temporal differentiation in much the same way as the Little Ice Age (Bradley and Jones, 1992).

Most climate reconstructions of the Medieval period are based on proxy indica- tors such as tree rings (e.g. Schweingruberet al., 1988; Briffa, 1992), dated glacier moraines (e.g. Zumbühl and Holzhauser, 1988; Nesjeetal., 1991; Matthews, 1991;

Climatic Change 34: 91-108, 1996.

Grove and Switsur, 1994), annua11y layered ice core records (Oeschger and Arquit, 1991; Thompson, 1991) and varves (Leemann et a1., 1991) that are related to tem- peratures in the growing season. However, for assessing annual temperatures it should not been overlooked that in Europe winter temperature variability largely dominates the annual mean (Cecchini et al., 1995).

Documentary data provide possibly the only evidence available for assessing the climatic characteristics of winters that is for disentangling temperature and precipitation patterns. The first collection of medieval texts on climate was compiled by He1lmann (1883). In his classic monograph Lamb (1977) brought together a very wide range of evidence which describes conditions ir. the cold season. It was subsequently shown that some of his material was noncontemporary and was therefore questionable (e.g. Ingram et al., 1981; Alexandre, 1987). The historian Pierre Alexandre made the first major critical compilation of documentary data for the Middle Ages distinguishing between contemporary and noncontemporary sources. Unfortunately, he did not quote his texts at fu1llength and neither did he produce a real substitute for Lamb?s winter severity index. Brazdil (1993, 1994) has published regiona1 indices for the Czech lands.

2. Sources and Data

Meteorological infonnation about winters in the Middle Ages is contained in documentary data. 1Wo main types are distinguished. Narrative sources, annals and chronicles, contain histories of the events memorable for a particular region or town. They were copied from predecessors, supplemented with observations made in the lifetime of the chronicler and handed down to subsequent generations. Public papers were designed to register official transactions of goods such as the payment of taxes in cash or in kind.

Anna1s usua1ly consist of unconnected, short, dry notes in strict annua1 succes- sion. The chronology is believed to be trustworthy. The entries concem politics, the life of the religious communities or meteorological phenomena. But in many cases the infonnation is so laconic that its interpretation is ambiguous (McConnick, 1975).

Chronicles include a variety of narratives in the fonn of extended histories. These rather lengthy descriptions, written mostly in Latin, may include proxy infonnation such as references to the timing ofvegetation, to floods or to low water tables, to the duration of snow-cover and to the freezing of water bodies. Likewise, they provide quite detailed descriptions of hazards and their impacts upon human societies. Chronicles are thereafter more valuable for the reconstruction of past meteorologica1 situations than anna1s, but they are seIdom original throughout. Most chroniclers began their work at the Creation, but many of them hastened through their accounts of the origins of the world in order to concentrate more fully upon the history of their times. Obviously, chroniclers had to copy the histories for periods earlier than their own; sources were not mentioned. The concept of intellectual property was unknown to the Middle Ages (Taylor, 1965; Quirin, 1991).

Annals and chronicles focus upon extreme or extraordinary weather situations. Sometimes the main characteristics of a winter are described in a few words or a chronicler just refers to a short, cold spell that damaged the vines. Occasionally we even get an idea of the 'normal' climate of the time: For instance, the anonymous writer of the chronicle of Klosterneuburg near Vienna classifies the winter of 1343/44 as mild, because he never saw ice on the Danube. This suggests that the occurrence of (drifting?) ice on this stream was an 'ordinary' feature at that time. A new, valuable type source begins with the weather diary kept by a curate, William Merle, from January, 1337 to January 8 (16th N.S.), 1344. He lived for most of the period in Lincolnshire, but appears to have spent part of the summer in Oxford (Symons, 1891). The information contained in these noninstrumental weather diaries can be quantified by counting the frequencies of events such as rain, snow etc.. Another diary was kept from August, 1399 to the end of 1405 probably in Basel, though the exact location is not known (Thomdike, 1966; Schwarz-Zanetti, in prep.).

Pub1ic papers may contain year by year references to weather which can be arranged to form a calendar of weather conditions for a number of years and used as a check upon, and to fill the gaps in, the accounts of chronic1ers. Titow (1960) certain1y demonstrated the va1ue of extracting c1imatic data from this type of source, but surely he did not show w hat can be achieved because he was curiously unwil1ing to believe in the value of w hat he had done. Refetences to 'hard' (i.e. loI}g) winters involving an exceptionally long duration of snow-cover are usually met with as an explanation of unusually large quantities of grain fed to manorial animals. Reference to fiooding occurs in connexion with the profit of winter pastures. The origin of standing water (long spells of wet weather or abundant snow-melt) is not always specified. Unfortunately, nobody has taken up Titow's work in the recent decades. This paper mainly draws on the important collection of annals, chronicles, letters and public papers edited in the series of the Monumenta Germaniae Historica (MGH) which today comprises more than a hundred volumes. The MGH were the first edition of medieval sources which was critical in method and conceived according to a deliberate and comprehensive plan. It was inspired by the famous Prussian statesman Karl von Stein. By evoking the greatness of German history in a more distant past Stein wanted to fuel the patriotism that had been ignited in the liberation wars in 1813-1815 against Napoleon. After discussions with brilliant scholars like Johann Wolfgang von Goethe, Jacob and Wilhelm Grimm and Wilhelm von Humboldt a learned society was founded in 1819 to prepare and publish a general edition of sources of German medieval history, the 'Gesellschaft für Deutschlands ältere Geschichtskunde'. The geographical framework of MGH was the medieval German Empire including Switzerland, the Netherlands and

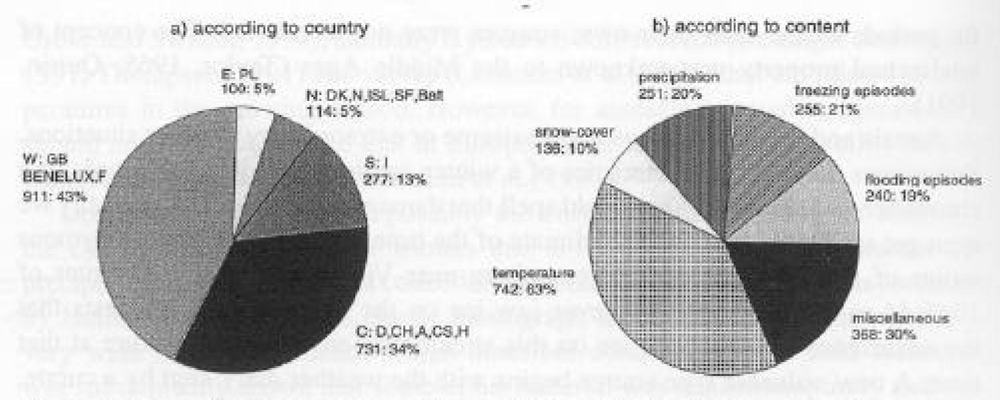

Figure 1. Data on fourteenth-century winters in the Euro-Climhist data-base according to country and to content.

Belgium east of the Scheldt (v. Caenegem, 1978). The first volume was published in 1826. Subsequently, the criticalli1ethod of text edition was adopted by scholars in other European countries.

For the present a11 passages relating to climate in the anna1s and chronicles edited within the series MGH were made machine readable. Most of the evidence for Northem ltaly, France and the Benelux countries is taken from the critica1 compilation of Alexandre (1987). Data from Danish sources were provided by Knud Frydendahl and from the Czech lands by Rudolf Brazdil. A systematica1 analysis of all climatic data contained in the MGH for the Medieval period is being undertaken (Pfister in preparation).

The data are stored in the Euro-Climhist data-base in Bem. This data-base a11ows all sorts of documentary and natura1 data to be integrated into a coherent synthesis at the European level. For the medieval period the entire evidence contained in the work of Alexandre (1987) was made machine readable. All the evidence in the MGH relating to climate were transcribed in full in the original language and translated into English in the form of a short abstract. It is thought that the Euro-Climhist data-base might be useful:

1. As a means of investigating the causes of climatic variations on both decadal and century time scales.
2. As a means of investigating the relationship between climatic variability and changes in the frequency and severity of anomalies.
3. As a tool to assess the impact of climatic changes upon pre- industrial economies and societies both in the short and in the long term (Pfister et al., 1994).

2133 mentions of winter weather were extracted for the fourteenth century: 43% of the materia1 refers to Western Europa, 34% to Centra1 Europe, 13% to (Northem) ltaly, 5% to Poland and 5% to Denmark/Norway (Figure la). For two winters (1329/30, 1333/34) there are no records at all. Considering the content of the records 34% refer to temperature, 11% to the freezing of water bodies, 10%

to precipitation, 10% to floods, 5% to the duration of snow-cover and 30% to miscellaneous items (Figure 1 b).

3. Problems of Data Verification and Dating

The researcher attempting to reconstruct climatic situations in the medieval period from chronicles and annals should be familiar with certain properties of this type of sources. It has become commonplace over the last decade or so to emphasize the importance of dealing with observations which were recorderl shortly after the event and precisely dated. Most original merlieval sources are not daterl. The time of composition is derived from the name and the lifetime of the author, if these are known. Sometimes some personal remarks of an author are very helpful in this respect, e.g. if ecclesiastics refer to the time of their ordination or to missions they had to perform for the Church. However, this kind of information is quite often lacking.

Chronicles may survive in a number of copies depositerl in libraries or private collections scattered all over Europe. We cannot just focus on one of these unless its relationship with the others has been established. The mutual relationship of the manuscripts is very difficult to unravel (v. Caenegem, 1978). It is necessary to assess which is the oldest manuscript -the archetype -that serverl as a model for subsequent copies and which of these, in turn, serverl as models for even later copies. Though there may be no autographed copy, textual examination will usually establish the relationship of one manuscript to another. The differences between the existing versions are compared using the philological procerlure of critical text examination. In this way a kind of genealogical tree is established which is called filiation. A good illustration ofthis procedure is given in Quirin (1991: 160-162).

To decide whether a chronicle is, in fact, contemporary with the events which it describes requires a detailerl textual examination. The task oftracing a chronicle's sources may be one of the greatest difficulties. In most cases, the historian cannot get beyond the supposition that a chronicle was written about a certain time, or between two definite dates. Though handwriting may assist in this matter it cannot be more than an approximate guide, and it is rarely that a scholar can, on paleographic grounds, assign a manuscript to a particular year or indeed to a period of less than fifty years (Taylor, 1965: 19). Often, authorship is unkDown or is, at best, a matter of inference. In those cases where the chronicler's name is known, few details concerning his life may be available. Because of imperfect knowledge, error and bias, the chronicler's narrative must, wheneverpossible, be cross-checkerl and supplemented by other sources (Taylor, 1965: 23). These principles of critical text edition were applierl for the MGH.

Style of Dating: In most cases the sources do not specify which style was userl for dating the events describerl (Quirin, 1991: 144). Several styles were in use during this period. The most common was the 'Christmas style', in which the new year began at Christmas. In another style which was also quite frequent the new year began on March 25th (Camuffo and Enzi, 1992). Although through ignorance or carelessness chroniclers might occasionally misrepresent certain incidents, the majority ofwriters struggled for accuracy (Taylor, 1965: 5). By farthemosterrors in copying texts involve misdating. It has been established that the error is frequently one year early or late. In his critical catalogue of climatic events Alexandre (1987: 596-623) lists 300 inconsistencies of this kind. Even events which fall in the lifetime of a chronicler may be misdated one year early or late, if the text was composed a considerable time after an event took place.

For assessing conditions in winter an additional difficulty arises because the change of year falls into this season. Most sources give just one year to date an event. Then it must be decided from the context or from other sources, whether the , old ' or the 'new' year is meant. A cautious interpretation is particularly needed in those cases, where severe winters might have occurred in two consecutive years.

Thus for the Medieval period we have to deal with evidence which is not strictly contemporary in the sense that the events were recorded shortly after their occurrence. Most of the surviving reports may have been copied once or several times, and as a consequence in some cases the year to which an event is attributed may be only approximate. Does it mean that we should refrain from the analysis of documentary data for the Middle Ages altogether? The processes which are available for assessing the validity and reliability of documentary information from this period despite its shortcomings will now be discussed.

Firstly: Reconstructions should be based whenever possible on critical editions of chronicles. Norms for editing and understanding the sources of medieval history became first generally accepted in nineteenth-century Germany.

Secondly: The worst errors which may occur in a reconstruction are related to incorrect dating. If a severe anomaly is reported in two subsequent years in two different sources, just because one of the reports is one year late, the interpretation of the entire record wili be severely biased. As a consequence the interpretation should be always based upon the assumption that severe anoma1ies did not occur in two subsequent years unless this can be proved by the record. For instance if it is explicitly mentioned in a source or if the fact can be established from independent proxy data. Thus, it is specified in a Danish chronicle that the winter 1321/22 and the subsequent winter 1322/23 were so severe that horsemen and coaches could travel on the frozen sea 1.

Thirdly: Reconstructions have to be meteorologically meaningful, i.e. consistent with the physicallaws of the atmosphere. This can be checked from a chart which displays the spatial picture of observations available for a particular month or season.

4. Calibration and Interpretation

Many observers were well aware that their individual feelings of cold and warrn were subjective. In order to demonstrate the anomalous character of a season, they often referred to observed signs in the physical or biological world. Temperature indicators in severe winters included the observed freezing ofwater bodies and/or an extended duration of snow-cover. For extremely warrn winters signs of vegetational activity and the absence of frost were reported. Freezing is reported mainly for large rivers, such as the Rhine, the Danube or the Po. The Danube in Klosterneuburg (Austria) was ice dammed from the beginning of 1328 for several weeks2.-~ Po was frozen for thirteen days in winter 1305/06. The ice became so thick that people could walk on it and ships hardly passed3. Observations on the freezing of rivers are difficult to calibrate, because most of their channels have been altered or dammed for irrigation, flood control and other reasons in the early nineteenth century or later. In places for which instrumental series are already available in the eighteenth century, these could be used for a calibration, but this would require analysis within the framework of a regional reconstruction for this period. Large water bodies such as lakes or parts of the sea are better suited for calibration. Lengthy freezing of the Ba1tic Sea in the area of the Sound and the Great Belt is used as a yardstick for severe winters in Danish sources: Recent work of the Finnish Institute of Marine research classified the maximum annual extent of the ice cover in the Baltic sea from 1720 according to the severity of winters. The correlation with mean air temperature at Mariehamn (from 1873/4 to 1991/2, 115 winters) is r = 0.96 (Seinä and Palosuo, 1993).

The number of days for which Dutch canals were frozen and closed to traffic is known from the early seventeenth century. Tarand (1992) has coined the term of 'ice phenology' for this type indicator to denote its similarity to plant phenology. Calibration with the De Bilt temperature series has yielded r = -0.92 (van den Dool et al., 1984). Thus similar observations from the Medieval period may be used cautiously as proxy indicators. If bitter cold persisted for a long time, the mills came to a standsti11, and if waterways froze, heavy cargoes had to be moved on land.

An extremely long duration of snow cover or lack of snow is often described to underline the severity or the warrnth of a particular winter. A fresh snow layer is an eye-catching meteorological element which is not easily overlooked. For traditional societies a snow cover of limited duration was a prerequisite for energy saving transport of bulky items such as logs or grain on sledges. Therefore, the absence of snowalso attracted attention. Thus we read in a chronicle from Northern Bavaria for 1361/62: Until the beginning ofFebruary the snow neverremained on the ground for an entire day, as it was always washed away by the rain4. On the other hand, long duration of snow-cover through March and part of April gave rise to widespread fears, because it was often connected with subsequent famines (Pfister, 1978). The term 'winter' was used as a synonym for the existence of snow-cover in Medieval historiography. To take an example: "This year there was no winter", is written in an Augsburg Chronicle for 1381/82 (or 1382/83?). We interpret this as meaning that snow-cover on I y occurred brieflys. Likewise the statement in the Annales Fossenses that in 1362/63 winter lasted for 14 weeks is taken to mean that the snow covered the ground for that period6.

Unfortunately, very few recent long records of snow cover are available (Pfister, 1985). It is therefore not really possible to calibrate the documentary information available from the Middle Ages strictly. Hut in most cases the duration of snow cover reported in severe winters is so long that it clearly points to temperatures far below those of the present century .On the other hand, a very small number of days with snow cover is not conclusive of a warm anomaly, because it could also be the produc t of a cold dry anticyclonic situation. Thus, in Parma the winter 1325/26 was described as "beautiful and without rain or snow until the end of January, but extremely cold"7. Warm winters (e.g. 1303/04) are often described by such terms as: No cold was feIt during the entire winterS .Or an early activity of vegetation is reported. For example: The chronicler Heinrich Truchsess in Diessenhofen (near Constance) observed the appearanceofflowers afterthe New Year 13579, and in the Paris area some fruit trees were seen in bloom around Christmas, 1361.10 Frequent rainfall and floods are considered to be associated with Westerly air flows and to point to temperatures somewhat above normal according to latitude and altitude.

An appropriate statistical tool for quantifying both proxy data and descriptive information is not available. A rather robust solution to this problem consists in rating both types of data available for a specific period with a numerical index. The concept of indices was originally developed by Hrooks (1928) for winter temperature. Lamb and J ohnson (1966) extended it to summer precipitation, Pfister (1984, 1992) to all seasons and months of the year and to both temperature and precipitation. The concept in this latter form had to be adapted to the Medieval period, as the density of verified data is much lower (see table 1).

Indices deviating frorn 0 ('average') were attributed on I y to those winters docu- mented in at least two contemporary sources. Months qualified purely with descrip- tive evidence are scored + 1 or -1 irrespective of the emphasis given by the writer. Theoretically a seasonal score of +3 or -3 might also be obtained from a sum of 'impressionistic' descriptions for every individual winter month. Hut such a case has not been found.

In order to assess whether data originating from distant regions may be combined into the same series, the spatial agreement of temperature anomalies must be known. Regions of similar year-to-year fluctuations of temperatures in Europe were assessed by submitting 27 long instrumental records of seasonal temperatures to cluster analysis (Pfister and Lauterburg, 1992). Clustering was done according to Ward's method (Kalkstein et al., 1987). In a first step similar year-to-year fluctuations were assessed for the period 1901-1960. In order to test the stability of this pattern over time the procedure was applied to earlier sixty-year periods (1841-1900, 1781-1840 and 1701-1780). It turned out that the spatial pattern for

Table I
Rating of temperature indices from descriptive and proxy evidence

Index	Type of winter	Descriptive data monthly	Proxy indicators (lowlands)
–3	severe	3 'cold' months and	extreme duration of snow cover water bodies ice covered for several weeks
–2	cold	2 'cold' months or	ground snow covered for several weeks water bodies ice covered for 1–3 weeks
–1	cool	1 'cold' or 2 'cold' and 1 'warm' month	without
0	average	offset of 'cold' and 'warm' months	without
1	mild	1 'warm' or 2 'warm' and 1 'cold' month	without
2	warm	2 'warm' months or	little or no snow and activity of vegetation
3	very warm	3 'warm' months and	little or no snow and activity of vegetation

winter did not change much despite the considerable changes in climate over the last 300 years. Hence it is argued that fundamental changes in this pattern are not likely to have occurred in the fourteenth century. The map of iso-fluctuative areas displays two large clusters in which the individua1 series are correlated at R2 > 0.75 on average. The dividing line between the two clusters runs West to East approxirnately from Birrningham to Ma1mö (Figure 2). This picture suggests that data originating from places South of this line may be ama1gamated into one single series. Of course this does not exclude the existence of substantial regiona1 differences in individual years. There is no independant proxy evidence for the Middle Ages (for instance from tree-rings) to confirm this pattern, because the clusters for spring and for summer were very different from those obtained for winter.

5. Discussion and Conclusions

Lamb (1987) argued that the genera1 results of the early ana1yses of the medieva1 clirnatic pattern (Easton, 1928; Flohn, 1967; Lamb, 1977) "have not been changed very much by later restriction of such studies to refined data" (p. 133). But by closing most of the numerous gaps in his record and by excluding many of his

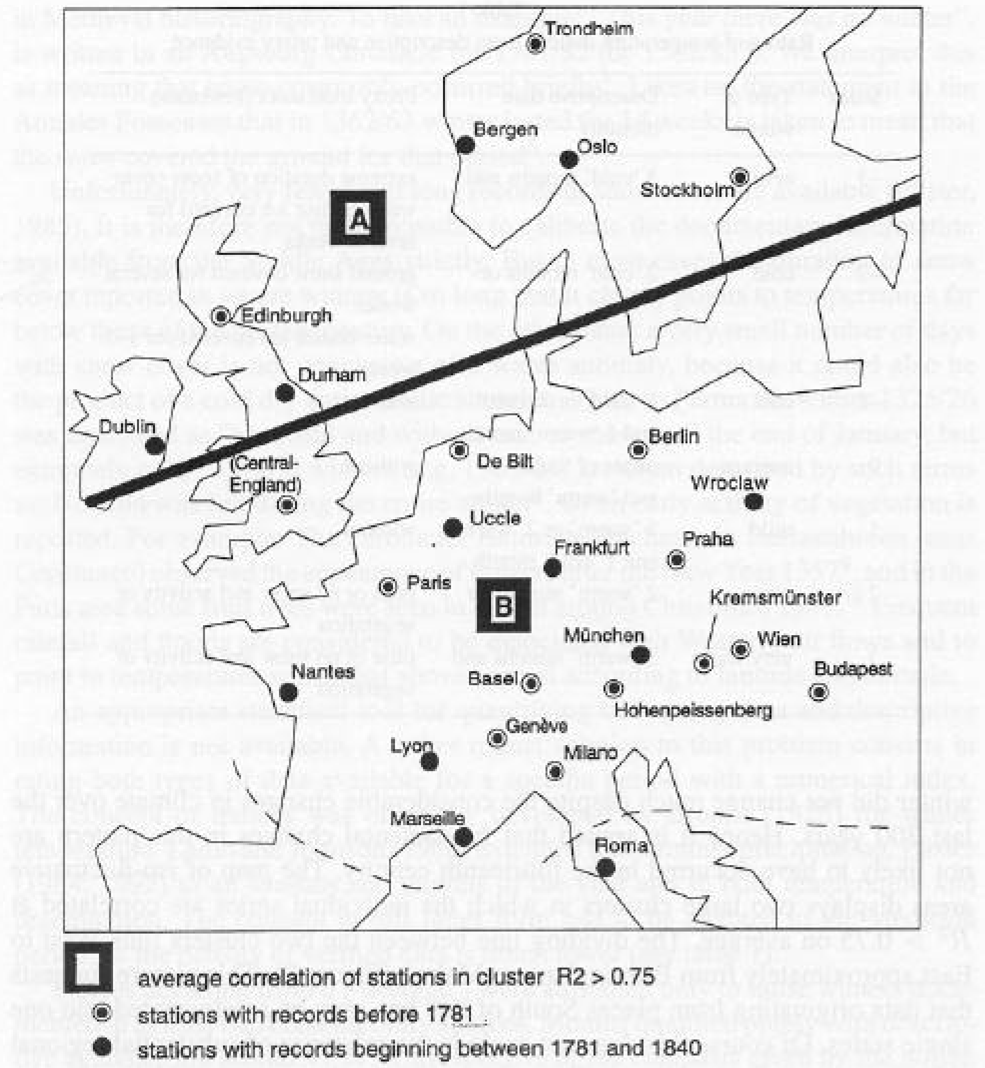

Figure 2. Similo-fluctuative areas for winter temperatures in Europe. The thick boundary line separates the two main clusters 'Northern Europe' and 'Central Europe'. The correlation (R^2) gives the average correlation of all stations within an area. (Pfister and Lauterburg, 1992).

noncontemporary sources from the analysis his picture of an overall period of cold winters between 1310 and 1350 is substantially modified (Figure 3).

Over the entire century average winter temperatures were roughly at a similar level than in the laterperiods ofthe 'Little Ice Age', that is, somewhat below present day values. No trend emerges. Within the century the following four sub-periods can be distinguished:

1. A run of cold winters stands out from 1303-1328. Within these 25 years just a single winter (1303/04) was 'Warnl' according to present day standards. On

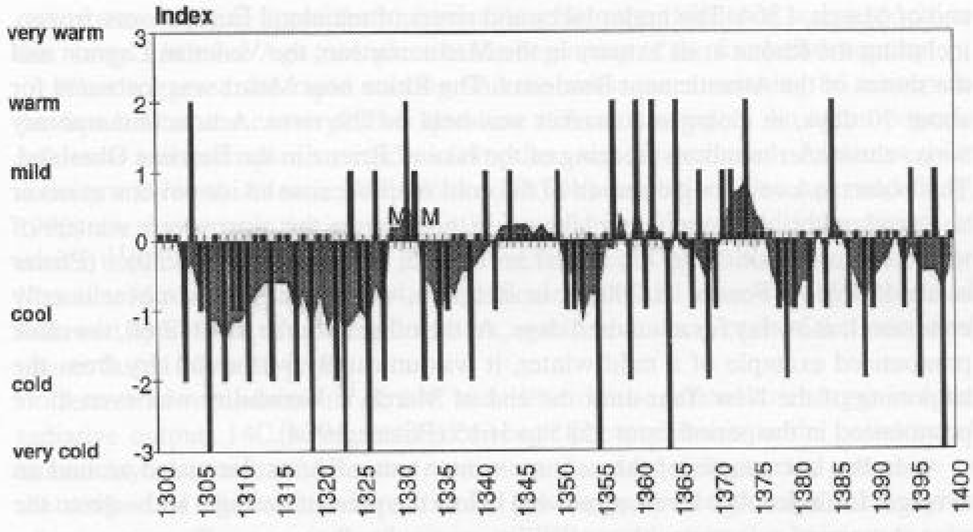

Figure 3. Winter temperature indices (−3, +3) for mainland Europe in the fourteenth century. Values of 0 ('average') are displayed 0,25 in order to distinguish them from missing data. In addition to the individual years a moving average ($x_{t-2} + x_{t-1} + 2x + x_{t+1} + x_{t+2}/6$) was computed. The values of the individual winters are given in the appendix.

the other hand, eleven winters scored 'cold', four of them even 'severe'. In two winters (1305/06, 1322/23) the duration and intensity of the cold were equivalent to the severest winters in the last 300 years (e.g. 1788/89 or 1962/63) (Pfister et al., 1996). Considering subsequent similar runs of cold winters in Central Europe the periods 1561-1575,1677-1697, 1755-1770 and 1880-1895 come to mind. In Switzerland estimated winter temperatures were 1.6 °C below the 1901 to 1960 average in 1561-1575 and 1.7 °C below in 1677-1697, respectively (Pfister, 1984; table 1/27 and 1/30). The departures according to instrumental observations were both 1.6° for 1755-1770 and 1880-1895 (Schüepp, 1961).

2.From the end of the 1320's to the mid 1350's there was a predominance of 'average' winters, for which no clear trend may be obtained from the chronicler's comments. On balance there was still an excess of cold seasons, but no severe winter occurred, and from 1339 to 1354 not a single winter was clearly cold compared with the 1901 to 1960 average. Compared to laterphases ofthe Little Ice Age such a long run of moderate winters is rather unusual. It would be worthwhile to explore, whether the thrust of the Great Plague which decirnated the population of Europe by about a fourth in 1348-1350 was related to this anomaly in some way (Russell, 1985).

3. Over the two decades from 1355 to 1375 winter temperatures were highly variable. In 1354/55 the duration and intensity ofthe cold speIl matched conditions in the most severe winters ofrecent centuries, in 1363/64 it was even more severe: The period of bitter frost began in early December, 1363, and lasted until the

end of March, 1364. The major 1akes and rivers of main1and Europe were frozen, inc1uding the Rhone at its estuary in the Mediterranean, the Venetian Lagoon and the shores of the Atlantic near Bordeaux. The Rhine near Mainz was icebound for about 70 days, in Cologne a market was held on the river. A noncontemporary Swiss chronicler mentions freezing of the lake of Brienz in the Bernese Oberland. This points to a very long duration of the cold spell because an ice cover was never observed on this deep mountain lake again, not even in the most severe winters of recent centuries (i.e. 1476/77, 1572/73,1694/95, 1708/09 and 1829/30)11 (Pfister et al., 1996). At Fosses, at 200 rn, in Belgium, where today snow-cover is only ephemeral, snow lay for a hundred days. At the other extreme in 1359/60, the most pronounced example of a mild winter, it was unusually warm and dry from the beginning of the New Year until the end of March.12 Variability was even more pronounced in the period from 1585 to 1615 (Pfister, 1984).

4. In the last quarter of the century winter temperatures fluctuated around an average 'Little Ice Age level' somewhat below the present average, and- given the near absence of extremes - the variability was rather low.

The circulation patterns underlying severe winters have recent1y regained atten- tion. It is well known that the atmospheric circu1ation over Western Europe is highly influenced by the North At1antic Oscillation (NAO) (Wanner, 1994) which causes a large-sca1e a1ternation of atmospheric mass between the areas of Iceland and the Azores (Lamb and Pepp1er, 1987). Moses et al. (1987) stated that the strong wintery reversals in the month1y pressure field with high pressure over Ice1and represent an extreme mode ofthe NAO. They show that these reversa1s are correlated with low winter temperature over Europe as we11 as over the eastern United States.

A reconstruction of tentative surface pressure situations in the preinstrumental period was first attempted by Hubert Lamb for some anoma1ous seasons (Lamb, 1977). This approach was readopted in the context of the Euro-C1imhist project. Mean month1y surface pressure patterns were assessed from early instrumental measurements and proxy data for winters and springs in the late Maunder Mini- mum cooling period (1675-1704). A comparison of the winter weather types of these three decades with the recent 30 year period (1961-1990) showed that the Late Maunder Minimum was characterized by strong sea level pressure reversals with high pressure centres over Northern and Northwestern Europe and large out- breaks of northeasterly cold continental air (Wanner et al., 1995). Similar patterns emerged from the mapping of the information for the four most outstanding win- ters in thefourteenth century (1305/06,1322/23,1354/55 and 1363/64) whichwere also dominated by northerly or northeasterly flow and cold air advection (Pfister et al., 1996). 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 the whole Pleistocene (van Loon and Rogers, 1978) and they speak about Litt1e Ice Age type events (Moses et al., 1987). Undoubtedly, severe winters involving NAO reversals became more frequent in the fourteenth and in the fifteenth century (Lamb, 1987). From this shift in winter temperatures it seems reasonable to argue that the transition frofi the 'Medieval warm epoch' to this 'long' Little Ice Age took place at the beginning of the fourteenth century.

What triggered the rapid cooling and the subsequent warming of winters in the first half of the century? This question still remains open. An anthropogenic influence and perhaps also volcanic eroptions can be excluded. As far as solar activity and North Atlantic Deep Water (NADW) formation (Oeschger and Eddy, 1993) are concerned, the answer is still speculative. Undoubtedly the pattern of winter temperatures in the first half of the fourteenth resembles that in the Late Maunder Minimum (Pfister, 1994): In both cases an initial phase of cold winters was followed by a phase of 'average' winters, and in both cases each ofthe individual phases lasted 20 to 25 years.

Terrestrial measurements of 14C and lOBe can be related to changes in solar radiative output. 14C is sequestered through photosynthesis in the cellulose of annual layers in trees; lOBe, the next most abundant, falls in rain and snow to the surrace of the earth, where its rate can be recovered through the anaylsis of ice scores. Three periods of maximum lOBe production (i.e. minimum solar activity) are observed in the Greenland and Antarctic ice records -the Wolf (A.D. 1280-1350), Spoerer (A.D. 1420-1540) and Maunder (A.D. 1645-1715) (Eddy and Oeschger, 1993). The Wolf minimum clearly coincides with the period of pronounced winter cooling in the early fourteenth century. However, the changes of solar irradiance estimated over the last 300 years are small, and it seefis unlikely that these changes alone had a significant impact on the global climate (Bradley & Iones, 1995; Hughes, 1995).

The timescale of these oscillations also suggests variations in the North Atlantic Deep Water (NADW) formation as a possible forcing factor. Over the recent years the subtle interplay between the thermohaline circulation of the ocean and the advection of salt and heat has beeen directly observed (Stocker, 1994). A coupled atmosphere-ocean model, integrated over 600 years, produced irregular, but orga- nized oscillations of 40-60 years in meridional overturning which were related to patterns of sea-surrace temperature (SST) (Delworth, Manabe, Stouffer, 1993). Interdecadal cycles of 24 years were found in the Central England instrumental temperature record covering 318 years (Stocker and Mysak, 1992). Briffa et al. (1992) found significant power in the band of 30-40 years in their 1480-year-long tree ring record of Fennoscandia.

More research is needed in order to obtain a more precise knowledge of fluc- tuations in winter temperatures in the 'Medieval Warm Period' and in the 'long' Little Ice Age. The investigation of administrative sources, such as tax rolls, might make it possible to achieve a clearer picture of regional variations than is possible at present.

6. Appendix: Fourteenth Century Winter Temperature Indices for Central Europe

The indicatian refers ta the year in which J anuary falls.

1300	0						
1301	0	1326	–3	1351	–1	1376	0
1302	0	1327	1	1352	–1	1377	0
1303	–2	1328	–2	1353	–1	1378	–1
1304	2	1329	0	1354	0	1379	–2
1305	–1	1330	miss.	1355	–3	1380	–1
1306	–3	1331	2	1356	0	1381	0
1307	0	1332	1	1357	2	1382	–1
1308	–2	1333	–2	1358	0	1383	0
1309	–1	1334	miss.	1359	–2	1384	–1
1310	–1	1335	–2	1360	2	1385	2
1311	–2	1336	–1	1361	–1	1386	0
1312	0	1337	0	1362	2	1387	–1
1313	0	1338	0	1363	0	1388	0
1314	–2	1339	–2	1364	–3	1389	–2
1315	0	1340	0	1365	2	1390	–1
1316	0	1341	1	1366	0	1391	0
1317	–2	1342	–1	1367	–1	1392	0
1318	0	1343	0	1368	1	1393	0
1319	–3	1344	1	1369	–2	1394	–1
1320	0	1345	0	1370	–1	1395	1
1321	0	1346	0	1371	1	1396	–2
1322	–2	1347	0	1372	1	1397	0
1323	–3	1348	0	1373	0	1398	1
1324	1	1349	0	1374	2	1399	–3
1325	–1	1350	1	1375	0	1400	0

Acknowledgments

This research was supported by Swiss Nationa1 Science Foundation, Priority Programme Environment (No.5001, 34888). Acknow1edgements are due to Rudo1f Brazdil, Brno (Czech Republic), to Knud Frydendahl and Povl Frich, Danish Meteorological Institute, Copenhagen, to Aryan van Engelen, KNMI, De Bilt, to Erik

Wishman, Archaeological Museum, Stavanger, and to Anita Bokwa, Geographi- cal Institute, University of Krakow (Poland) for providing additional data. Heikki Vesajoki, University of Joensuu (Finland), for providing helpful hints and a trans- lation from Finnish. Daniel Brändli (Institute of History) has drawn the figures and charts. Gudrun Kleinlogel (Research Group for Regional and Environmental History) has done the main programming work. Preliminary versions ofthis paper were read by Thomas Stocker and Heinz Wanner. Jean Grove, Cambridge, acted as a reviewer and took great care to improve the style and the quality of the paper.

Notes

1. Magnus Matthiae, Regum Danice Terra, 2RII, p. 120
2. Zeibig, H. J. (ed.) (1851): Klosterneuburger Chronik. In: Archiv f. Oesterr. Geschichte 7, p. 231- 250, quoted by A1exandre, 1987, p.449.
3. "Item eodem tempore et mense Ianuarii [1306] per 13 djes contjnuos fuit arduum et inmensum frigus, magjs quam a1jqujs recordaretur, jta quod flurnina omnja vales fovee indjferenter et in omnibus partjbus Lombardje congelaverunt, et flumen Paudj [po] in pluribus partjbus congelavjt seu congelatum fujt ta1jter, quod super glacjem mu1te persone transjverunt et naves vjx transire poterant". Jaffe, P. and Pertz, G. H. (eds.) (1863): Annales Parmenses, MGSS 18, Hannover, p.736.
4. "1361. In dje sanctj Mathej aposto1i [Sep. 21] cecjdjt njx in tanta spjssitudine, quod duravjt per triduum, eteodem anno nullanix cecjdjt pertotamhiemem, que duraret permedjam djem, set [sjc] pro nive a1iquando pluvia descendit, qui etjam statjm 1iquefactus fujt; usque ad purificatjonem sanctae Marie [February 2nd] nulla nix cecjdjt, que per integrarn duraret djem". Pertz, G. H., Jaffe, P. (eds.), (1861): Notae A1tahenses MGSS 17, Hannoverp. 423.
5. Frensdorf F. (ed.) (1865): Chronik der Stadt Augsburg. Die Chroniken der Schwäb. Städte. Augsburg 4, pp. 21-113, quoted by A1exandre 1987, p. 521.
6. " 1364 [...] et hoc anno cepjt hyemps ad festurn Njcho1aj, duravjt per quatuordecjm septimanas nive existente semper super terram, fujtque magna caristia pastinarum anima1ium". Pertz, G. H. (ed.) (1844): Annales Fossenses MGSS 4. Hannover, p. 34.
7. "1325. [...] Item eodem anno yems fuit valde pulcrum et sjcum, semper serenum sjne pluvia et sine nive usque ad finem Ianuarij sequentis, set [sic] maximum ge1u et frigus fuit". Jaffe, P. and Pertz, G. H. (eds.) (1863): Annales Parmenses, MGSS 18, Hannover, p. 759.
8. "Item 1304. nu11um frigus compertum est per totam hiemem. Quam hyemem secuta est aestas sjne omni p1uvja et tantae sjccjtatis, quod ad fundum Renus et putej decreverunt [...]". Pertz, G. H. (ed.), (1861): Anna1es Moguntini MGSS 17, Hannover, p. 3.
9. "Et annus LVII [1357] jncepjt cum aura temperantissjma, nam flores jnfra octavam nativitatis domini reperti sunt, nec glacjes apparebat, nec nix terram operuerat usque ad non. febr. Et tunc nix maxima venit Agathe vjrgjnis, et duravjt usque VI kaI. marcij, et inde usque ad jdus marcii est consumpta." Huber, A. (ed.) (1868): Heinricus de Diessenhoven, hrsg. aus dem Nach1ass Joh. Friedr. Boehmers. Fontes rer. Germanicarum, 4, Stuttgart, p. 107 .
10. Le Maresqujer, J. (ed.) (1969): La chronique djte de Jean de Venette [1359-1367], Paris.
11. Johann Gott1ieb Schrämli, Chronik der Naturbegebenheiten, Manuscript, Stadtbibliothek Thun (Swjtzer1and) SBT 3127/II.
12. "Quia annus LX. [1360] a principio erat temperans et calidus usque ad III. ka1. aprilis; et tunc in dje sequenti, que erat djes palmarum, frigus et nix vites, que tunc se ostenderant et nuces pariter destruxerant et erat bisextus. Et tante erat seritatio et temperantie quod corvi in festo nativitatis domini pullos suos produxerunt in castro djcto Merspurg ". Huber, A. (ed.) (1868): Heinricus de Diessenhoven, hrsg. aus dem Nach1ass Joh. Friedr. Boehmers. Fontes rer. Germanicarum, 4, Stuttgart, p. 117.

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